Geotechnical properties and the liquefaction potential of the soils around Efteni Lake (Düzce-Turkey)

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Abstract: 170 m of boreholes were drilled in 10 different locations, to depths between 10 and 30 m, together with 33 trial pits to depths of 5 m. These were used to identify the geomechanical properties and liquefaction properties of the Efteni Lake area (Düzce-Turkey). There is water flow into the Efteni Lake from the Little Melen Creek, Ugursuyu Creek, Aydinpinar Creek and Aksu Creek. The only discharge is from the Greater Melen River. The groundwater level is at a depth of about 1.0 m. However, it is sometimes at the ground surface. It was found that fine grained soils could be classified in the MH and ML groups while a few of them were classified as CH and CL. On the contrary, coarse grained materials were mainly classified as SM, SC and a few of them in the GM group. According to these classifications based on the numerical geotechnical property values, soils were classified as 67% liquid (based on consistency), 59% viscous (based on liquidity index), 49% low in swelling potential (based on swelling potential), 55% soft (based on SPT N_{30}) and 45% loose. In order to calculate the bearing capacity and permeability of the soils, Standart Penetration Tests (SPT) and unpressured water tests were performed in the boreholes. Based on these studies, safe bearing capacity was calculated between 10 kN/m^2 and 57 kN/m^2 whereas permability was found to be between 10^{-4} cm/s and 10^{-6} cm/s. The study area is located in the highest level earthquake zone. Moreover, the groundwater level is very close to the surface. Therefore it is very important to identify the liquefaction potential. For this reason, data taken from boreholes and laboratory test results, were analysed and the potential liquefaction zones were identified.

Résumé: 170 m de forages ont été forés dedans 10 endroits différents, aux profondeurs entre 10 et 30 m, ainsi que 33 puits de sondage aux profondeurs de 5 m. Ceux-ci ont été employés pour identifier les propriétés geomechanical et des propriétés de liquéfaction de la région de lac Efteni (Düzce-Turquie). Il y a écoulement de l'eau dans le lac Efteni de la petite crique de Melen, de la crique d'Ugursuyu, de la crique d'Aydinpinar et de la crique d'Aksu. La seule décharge est du fleuve plus grand de Melen. Le niveau d'eaux souterraines est à une profondeur d'environ 1.0 m. Cependant, il est parfois sur la surface au sol. On l'a constaté que des sols granuleux fins pourraient être classifiés dans les groupes de MH et de ML tandis que quelques uns d'eux étaient classifiés comme CH et CL. Sur les matériaux granuleux contraires et bruts ont été principalement classifiés comme SM, SC et quelques uns d'eux dans le groupe de GM. Selon ces classifications basées sur les valeurs de propriété géotechniques numériques, des sols ont été classifiés en tant que le liquide de 67% (basé sur l'uniformité), 59% visqueux (basé sur l'index de liquidité), 49% bas dans le potentiel de gonflement (basé sur le potentiel de gonflement), 55% doux (basé sur SPT N30) et 45% lâche. Afin de calculer la portance et la perméabilité des sols, les essais de pénétration de Standart (SPT) et unpressured des essais d'eau ont été exécutés dans les forages. Basé sur ces études, la portance sûre a été calculée entre 10 kN/m^2 et 57 kN/m^2 tandis que la perméabilité s'est avérée entre 10^{-4} cm/s et 10^{-6} cm/s. Le secteur d'étude est situé dans la zone de tremblement de terre du niveau le plus élevé. D'ailleurs, le niveau d'eaux souterraines est très près de la surface. Par conséquent il est très important d'identifier le potentiel de liquéfaction. Pour cette raison, des données prises des forages et des résultats d'essai en laboratoire, ont été analysées et les zones potentielles de liquéfaction ont été identifiées.

Keywords: Bearing capacity, earthquakes, geological hazards, liquefaction

1. INTRODUCTION

The aim of this study is to determine the geomechanical properties and liquefaction potential of the foundation soils under the embankment around Efteni Lake. The study area is located on liquefiable and unsuitable soil conditions for settlement. Besides, there is an significant relation between sedimentation and tectonism affecting the province.

The study area is around Efteni Lake (10 km^2) that is controlled by Aksu, Küçük Melen,Uğursuyu and Aydınpınar creeks, discharging from the Big Melen river at the south of Düzce (Figure 1).

A total of five embankments with 13 km length around the lake and a discharge control structure have been designed to keep the settlement and agricultural areas safe during floods, and still allow use of the lake for wildlife. For this reason, 10 boreholes have been drilled and 33 trial pits were excavated.

In-situ tests were performed during the field studies, both disturbed and undisturbed soil samples were obtained. The classification, strength and compaction properties of the soils have been determined in the laboratory.

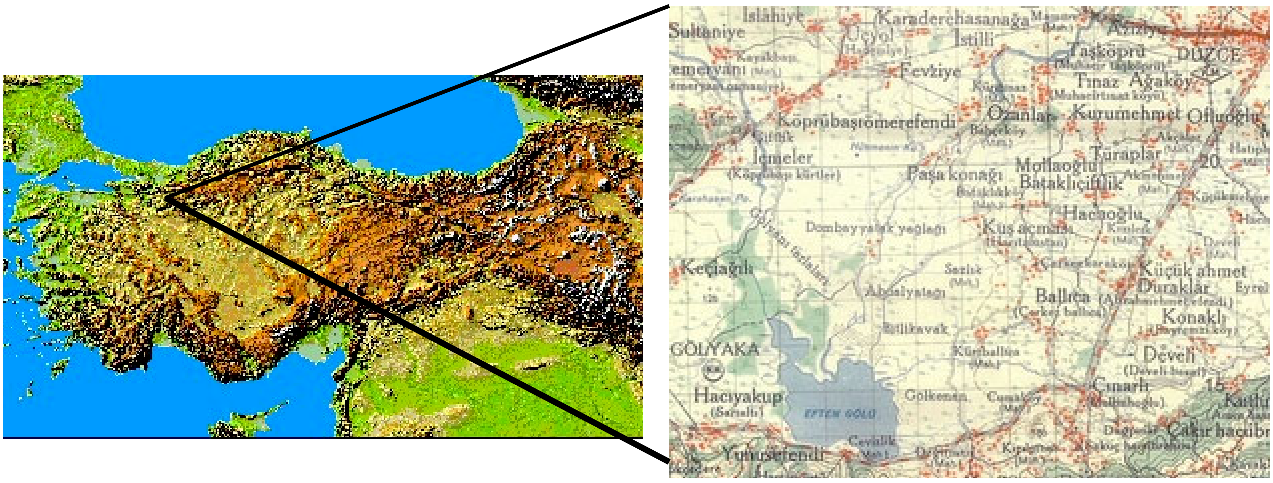

Figure 1. Location map of the study area

2. GEOLOGICAL SETTING

Düzce plain is an active subsidence and deposition area controlled by lateral strike slip faults surrounded by Pre-Quaternary aged rocks. The oldest is the Yığılca Unit of Eocene aged Çaycuma Formation including volcanic sandstone, tuff, andesitic and basaltic lavas and/or volcanic breccia (Emre et al. 1999). Quaternary aged fan, deltaic and marsh type deposits cover this unit consisting of gravel, sand, silt and clay material (Figure 2).

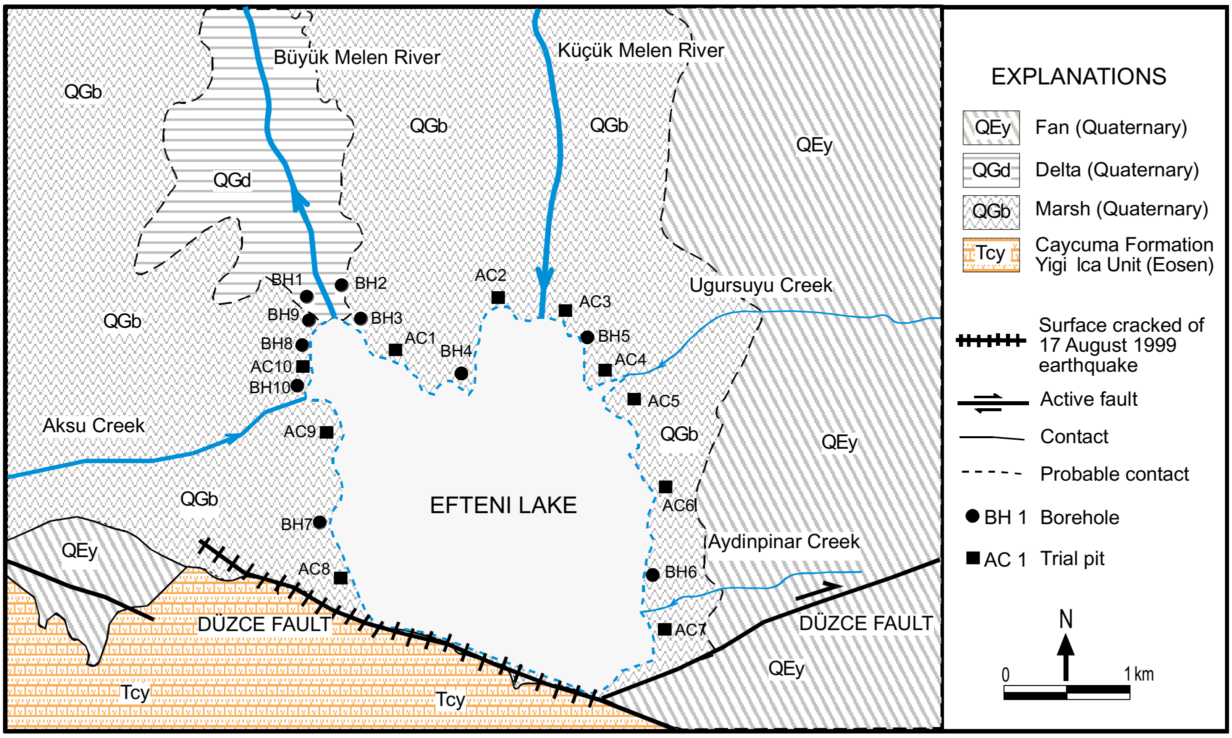

Figure 2. Geological map of the study area

Due to the elevation of the surrounding rocks and as a result of the basin drainage system, deposition is mostly in the Efteni Lake (Figure 3). Little Melen creek discharges into the lake and continues flowing towards the only discharge from the lake named as Big Melen. In addition; Aksu, Uğursuyu and Aydınpınar creeks deposit the alluvial fans that prograde and join in the lake basin. The surounding rock are extremely altered allowing the increase in the sedimentation. The thickness of the sedimentation reaches up to 260 m. The deposition areas have displaced laterally and the horizontal stratigraphy have been differed (TÜBİTAK-AÜ-MTA 1999).

Figure 3. Deposits of near the Efteni lake

2.1. Active faults and seismicity

The study area takes place in North Anatolian Fault Zone (NAFZ) and first degree earthquake zone (GDDA 1996). Düzce has been affected by the active faults (Figure 4). The 1957 Bolu (M=7) and 1967 Adapazarı (M=7.1) earthquakes have occured on the Bolu-Abant and Dokurcun segments of NAFZ. The active and probably active faults are Düzce, Hendek and Çilimli in the close proximity of the study area.

Figure 4. Efteni lake and Düzce fault

The 30 km east segment of the 130 km fault rupture has occured on the west part of Düzce fault reaching to Efteni lake during the 1999 M=7.4 earthquake (TÜBİTAK-AÜ-MTA 1999).

3. FIELD STUDIES

The 1/25.000 scaled geological and the 1/10.000 scaled engineering geological map of the study area have been drafted. Besides; 10 boreholes with depths ranging between 10-30 m (totally 170 m) have been drilled by the General Directorate of State Hydraulic Works (DSİ) and 33 trial pits with maximum 5 m depth have been excavated (Sel &Kutlu 2002) (Figure 2, Table 1).

Table 1. Boreholes, trial pits number and depth

Borehole no	BH 1	BH 2	BH 3	BH 4	BH 5	BH 6	BH 7	BH 8	BH 9	BH 10
Depth (m)	30.00	20.00	20.00	20.00	20.00	20.00	10.00	10.00	10.00	10.00
Trial pits no	AC 1	AC 2	AC 3	AC 4	AC 5	AC 6	AC 7	AC 8	AC 9	AC 10
Depth (m)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Standart Penetration Tests (SPT) and Lugeon tests have been carried out during the drillings. In-situ unit weight and moisture content values have been tested in the trial pits. Representative soil samples have been obtained in order to determine the geomechanial properties of the soils.

The 260 m thick alluvium is so heterogeneous including unconfined and confined aquifers. Groundwater level is mostly at the surface ranging between 0.5 m – 3.70 m.

4. LABORATORY STUDIES

The soil samples (totally 50) have been tested at the DSI laboratories according to the related ASTM and TS standarts.

The natural moisture content (ω_n), natural unit weight (γ_n), saturated unit weight (γ_{sat}) and specific gravity of the soils have been determined. Wet sieve, hydrometer, LL, PL, PI and the classification of the soils have been done according to the USCS.

Oedometer tests have been conducted in order to determine the swelling ratio, swelling potential, coefficient of consolidation (C_v) and volume compressibility modulus (m_v).

Unconsolidated-undrained triaxial and unconfined tests have been performed to determine strength criteria of the soil samples.

5. GEOTECHNICAL EVALUATION

5.1. Geotechnical properties of the soils

According to the geotechnical studies around Efteni Lake, the soils are light brown in color, sometimes silty and sandy clay occurs 0.0 m - 3.0 m beneath the surface. Grey-blue clay, silt, sandy clay, clayey and silty soils underly this. Grey-blue unit sometimes contain peat and wood fragments (Figure 5). Fine grained soils are mostly MH, ML, sometimes CH-CL, other soils are in SC, SM and GM groups.

Figure 5. Peat, wood fragment and silt

Mean natural moisture content is 67 %, PI is 32 %, specific gravity is 2.68, natural unit weight is 15.8 kN/m^3, unconfined compressive strength is 127 kPa, cohesion is 11 kPa, internal friction angle is 2.67°, activity is 0.34, liquidity index is 1.18 and consistency value is – 0.18. The statistical values of the laboratory results are given in Table 2.

Table 2. The statistical values of the laboratory results

	Moisture content(%)	Atterberg Limits (%)			Specific gravity	Wet sieve (%)		Natural unit weight kN/m^2	Unconfined compresive strength (kN/m^2)	Triaxial compresive strength		Activity	Liquidity index	Consistency
		LL	PL	PI		+4	-200			ϕ^0	c (kN/m^2)			
Samples piece	50	50	50	50	50	50	50	40	15	7	7	50	50	50
Min.	21	30	22	7	2.50	0	48	13.5	18	1	5	0.07	-0.02	-1.96
Max.	138	93	48	54	2.75	90	10	19.3	337	10.5	18	0.56	-2.96	1.02
Mean	67	66	35	32	2.68	22	74	15.8	127	2.67	11	0.34	1.18	-0.18

The soils of the study area have been classified as plastic, viscous, non-active, with low swelling potential, very soft-soft and cohesive according to different classifications.

5.2. Bearing capacity

According to the triaxial test results; cohesion (c) ranges between 5 kN/m^2 - 18 kN/m^2 , friction angle (ϕ) is 1^0 - $10.5\ ^0$ in the first 10 meters. At this level, SPTN blow count is between 0-27, sometimes penetrating directly in to the soil with its own weight. If the static stress is 46 kPa, foundation depth is 2.0 m, basement width is 15.0 m and the foundation length is 50 m, bearing capacity (q_{ult}) of the soil is 48-170 kPa, safe bearing capacity (q_{safe}) is between 16-57 kPa according to Terzaghi and Peck (1948). Bearing capacity (q_{ult}) of the gücü soil is 22-159 kPa, safe bearing capacity (q_{safe}) is between 7-53 kPa according to Meyerhof (1951). The critical height of the slope has been calculated by Fellenius (1936) and Taylor (1948) graphs. This height is 0.50 m, the corresponding slope value is 1/3 (H/V). The swelling percent of the units is 0.28-1.81 and the swelling pressure value is 6-16 kPa. Probable settlement value calculated by Meyerhof (1951) is 2.1 mm

5.3. Liquefaction potential

During the earthquakes, there is not enough time for water to discharge, therefore the pore water pressure increases. Confining stresses at the grain contacts can approach zero, and concurrently the pore-water pressure alone supports the weight of the overburden. The first time this occurs is often referred to as "initial liquefaction" (Obermeier 1996, Committee in Earthquake Engineering 1985). A large loss of strength can take place once this condition is reached. The combination of elevated pore pressure with large loss of strength is sometimes referred to as "complete liquefaction" (Obermeier 1996, Youd 1984). The liquefaction potential of the soils has been evaluated by Seed & De Alba (1986) and factor ıf safety against liquefaction has been calculated by Tokimatsu & Yoshimi (1983) methods. The results are given in Table 3 and 4. In addition; LiquefyPro v2.1 software has been used and the liquefiable layers have been detected (Figure 6).

Table 3. Liquefaction analysis according to Seed ve De Alba (1986) methods (M=7.4 a= 0.4)

Borehole no	**z m**	**γ_n kN/m^3**	**γ_d kN/m^3**	**GWL m**	**σ_o kN/m^2**	**σ_o' kN/m^2**	**N**	**$N_{(60)}$**	**D_{50} mm**	**CSR**
SK1	1,50	18.3	18.5	0,5	28	18	16	12,00	0,04	0,73
SK1	3,50	17.6	17.8	0,5	62	32	13	9,75	0,12	0,49
SK1	5,50	16.2	16.6	0,5	91	41	8	6,00	0,16	0,30
SK2	3,50	17.5	18.0	0,5	63	33	4	3,00	0,05	0,22
SK2	5,50	15.3	15.9	0,5	87	37	4	3,00	0,02	0,79
SK2	8,50	17.5	18.0	0,5	53	73	8	6,00	0,8	0,29
SK2	10,50	17.8	18.2	0,5	191	91	9	6,75	1,25	0,13
SK3	5,50	17.4	18.0	0,5	99	49	6	4,50	1,09	0,26
SK3	7,50	17.5	18.2	0,5	136	66	10	7,50	1,11	0,34
SK3	9,50	18.0	18.5	0,5	176	86	13	9,75	1,4	0,39
SK4	3,50	16.8	17.3	1,0	60	35	9	6,75	0,9	0,43
SK4	4,50	17.0	17.7	1,0	79	44	7	5,25	1	0,33
SK5	5,50	17.9	18.6	0,5	102	52	10	7,50	1,15	0,37
SK5	7,50	17.7	18.2	0,5	136	66	8	6,00	1,22	0,3
SK5	9,50	17.7	18.2	0,5	173	83	10	7,50	1,25	0,32
SK6	3,50	17.9	18.5	2,0	64	49	10	7,50	1,08	0,55
SK6	5,50	17.1	17.7	2,0	96	61	8	6,00	1,09	0,38
SK6	7,50	17.4	17.7	2,0	132	77	8	6,00	1,19	0,34
SK7	5,50	16.1	16.8	2,0	91	56	8	6,00	1,15	0,38
SK7	7,50	17.4	18.0	2,0	134	79	11	8,25	1,22	0,42
SK8	3,00	16.4	16.9	0,5	50	25	3	2,25	0,17	0,18
SK8	4,50	17.8	18.2	0,5	82	42	19	14,25	1,22	0,58
SK8	6,00	17.6	18.1	0,5	108	53	13	9,75	1,21	0,43
SK9	3,00	16.8	17.3	1,5	51	36	5	3,75	0,6	0,34
SK9	4,50	17.1	17.6	1,5	78	48	8	6,00	0,9	0,39
SK9	6,00	17.3	17.9	1,5	107	62	11	8,25	1,29	0,43
SK10	3,00	16.4	17.0	1,5	50	35	5	3,75	0,76	0,34
SK10	4,50	16.7	17.3	1,5	77	47	7	5,25	0,8	0,36

Table 4. Liquefaction analysis according to Tokimatsu ve Yoshimi (1983) methods (M=7.4 a= 0.4)

Borehole No	Z m	γ_n kN/m^3	γ_d kN/m^3	GWL m	σ_o kN/m^2	σ_o' kN/m^2	FC	ΔN_f	N	N_1	$N_{1(80)}$	N_a	CSR	τ_l/σ_o'	FS
SK1	1,50	18.3	18.5	0,5	28	18	70	11,0	16	31	22	33	0,39	2,16	> 3.0
SK1	3,50	17.6	17.8	0,5	62	32	44	8,4	13	22	16	24	0,47	0,39	0,84
SK1	5,50	16.2	16.6	0,5	91	41	40	8,0	8	12	9	17	0,52	0,18	0,35
SK2	3,50	17.5	18.0	0,5	63	33	83	12,3	4	7	5	17	0,46	0,19	0,40
SK2	5,50	15.3	15.9	0,5	87	37	93	13,3	4	6	5	18	0,55	0,20	0,36
SK2	8,50	17.5	18.0	0,5	153	73	40	8,0	8	10	7	15	0,47	0,16	0,35
SK2	10,50	17.8	18.2	0,5	191	91	38	7,8	9	10	7	15	0,45	0,16	0,36
SK3	5,50	17.4	18.0	0,5	99	49	41	8,1	6	9	6	14	0,48	0,16	0,34
SK3	7,50	17.5	18.2	0,5	136	66	35	7,5	10	12	9	16	0,47	0,18	0,39
SK3	9,50	18.0	18.5	0,5	176	86	39	7,9	13	14	10	18	0,45	0,20	0,45
SK4	3,50	16.8	17.3	1,0	60	35	44	8,4	9	15	10	19	0,42	0,21	0,52
SK4	4,50	17.0	17.7	1,0	79	44	48	8,8	7	10	8	16	0,43	0,18	0,42
SK5	5,50	17.9	18.6	0,5	102	52	37	7,7	10	14	10	18	0,46	0,20	0,43
SK5	7,50	17.7	18.2	0,5	136	66	30	7,0	8	10	7	14	0,47	0,16	0,34
SK5	9,50	17.7	18.2	0,5	173	83	40	8,0	10	11	8	16	0,46	0,18	0,38
SK6	3,50	17.9	18.5	2,0	64	49	45	8,5	10	14	10	19	0,32	0,21	0,67
SK6	5,50	17.1	17.7	2,0	96	61	40	8,0	8	10	7	15	0,37	0,17	0,46
SK6	7,50	17.4	17.7	2,0	132	77	42	8,2	8	9	7	15	0,39	0,16	0,42
SK7	5,50	16.1	16.8	2,0	91	56	45	8,5	8	11	8	16	0,38	0,18	0,47
SK7	7,50	17.4	18.0	2,0	134	79	40	8,0	11	13	9	17	0,39	0,19	0,48
SK8	3,00	16.4	16.9	0,5	50	25	62	10,2	3	5	4	14	0,48	0,16	0,33
SK8	4,50	17.8	18.2	0,5	82	42	40	8,0	19	29	21	29	0,47	0,91	1,95
SK8	6,00	17.6	18.1	0,5	108	53	44	8,4	13	18	13	21	0,47	0,27	0,58
SK9	3,00	16.8	17.3	1,5	51	36	75	11,5	5	8	6	17	0,35	0,19	0,55
SK9	4,50	17.1	17.6	1,5	78	48	45	8,5	8	11	8	17	0,39	0,18	0,48
SK9	6,00	17.3	17.9	1,5	107	62	38	7,8	11	14	10	18	0,40	0,20	0,50
SK10	3,00	16.4	17.0	1,5	50	35	41	8,1	5	8	6	14	0,35	0,16	0,45
SK10	4,50	16.7	17.3	1,5	77	47	40	8,0	7	10	7	15	0,39	0,17	0,43

[z (m): depth, γ_n (kN/m^3): natural unit weight, γ_d (kN/m^3): saturated unit weight, GWL(m): groundwater level, σ_o (kN/m^2): normal stres, σ_o'(kN/m^2): effective stres, N: SPTN blow count, $N_{(60)}$: corrected blow count, D_{50} (mm): mean diameter, CSR=τ_l/σ_o': cyclic stress ratio, FC: fines content, FS: safety factor]

The depth (z) of the sand in the study area was taken as the mid-level. The scenario for the earthquake magnitude 7.4 (M) and horizontal acceleration as 0.40g (a_{max}) were accepted.

All of the methods and the computer program results have been tested and compared. Especially, the silty sandy and sandy silt levels seem to have a liquefaction potential 2-10 m beneath the surface sometimes down to 16 m.

6. RESULTS AND RECOMMENDATIONS

The soils of the study area are classified as; plastic, viscous, non-active, with low swell potential, very soft-soft and cohesive.

The liquefaction potential of the study area has been evaluated by different methods. The sandy, silty sand, sandy silt soil types are at risk to liquefaction between 2 m and 10 m depths. This composition can sometimes be seen down to 16 m.

Cohesion ranges between 5-18 kPa in the 0 m to 10m interval while the friction angle ranges between 1.0-10.5^0 and the SPT N values are between 0-27. The foundation soil is soft and unconsolidated and this level is saturated, thus further reducung the bearing capacity. As the result; the embankments should be projected on the basis of this composition and the basement width should be 15 m.

The critical slope height of the excavation has been calculated as 0.50 m. The slopes should be 1/3 (H/V).

The swelling of the soils is between 0.28-1.81 % and the swelling pressure value ranges between 6-16 kPa and the probable settlement is 2.1 mm. The embankments bring out extra load minimizing this settlement.

The study area is in the first degree earthquake zone according to the “Earthquake Zoning Map of Turkey”. For this reason, the procedures given by the related orders for the hazard-prone areas must be taken into account.

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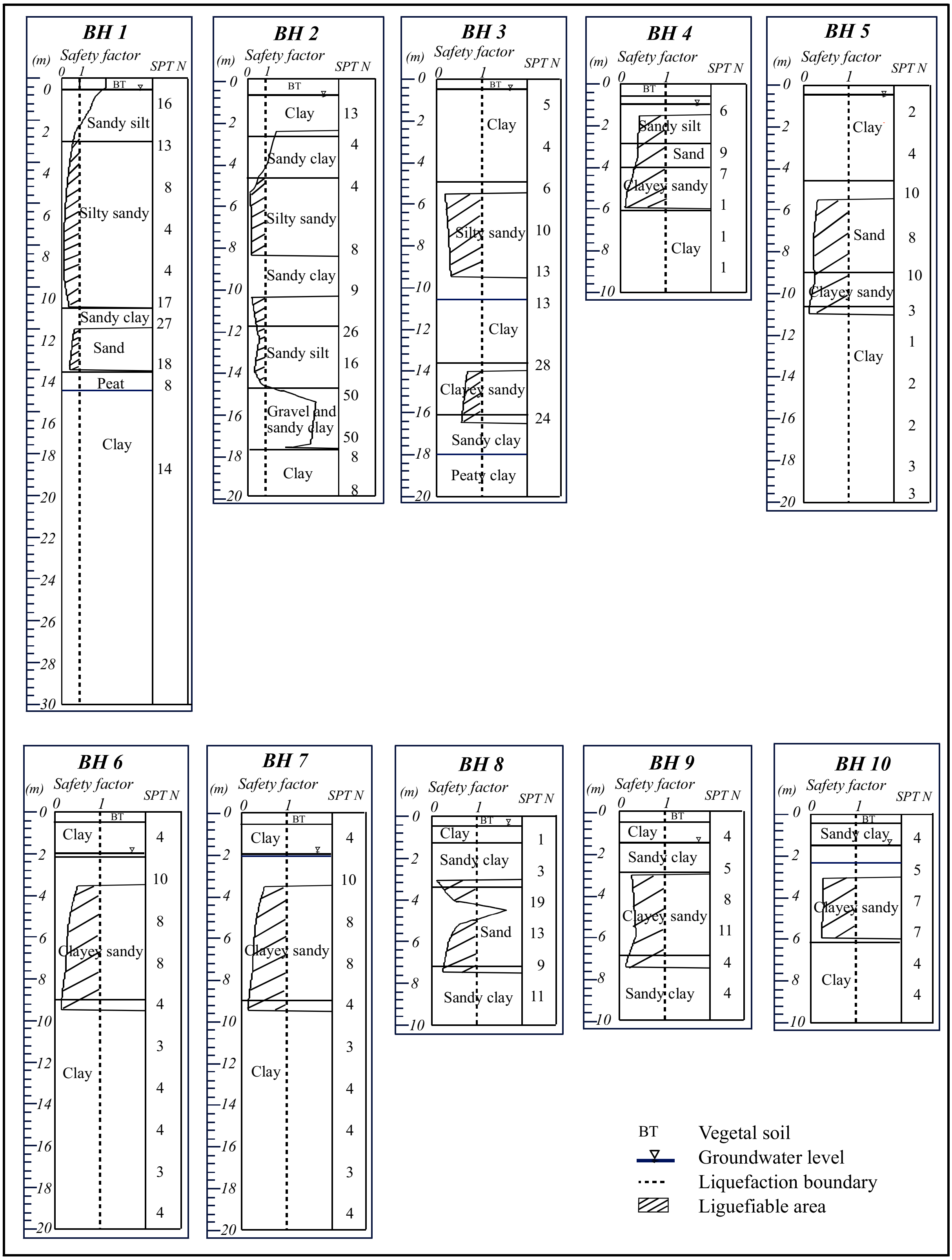

Figure 6. Logs, SPT N value and liquefiable area

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