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Evaluation of the soil conditions in Alikahya Region (Izmit)

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Abstract

In this study, the soil conditions of Alikahya region (Izmit) were investigated by the results of geological, geophysical and geotechnical survey results. Alikahya region is almost entirely located on sub-mid-upper Eocene aged rocks and Quaternary aged sediments. The alluvium thickness is nearly 300 m. According to seismic studies, P-wave velocities are between 277-2562 m / sec, and S-wave velocities are between 110-1427 m / sec in the study area. The determined local soil classes are Z-3 on the clay stones and Z-4 on the Quaternary aged alluvium, respectively. The ground water level varies between 1-2 m depths in the alluvium. Alikahya region located on first degree earthquake risk zone and liquefaction analysis results indicated that the existence of local liquefiable areas in the study area.

1. Introduction

Since Turkey is located on an active tectonic belt, it has a suitable topography for natural disasters such as earthquakes and landslides. This reveals the necessity of determining safe and risky areas in terms of soil properties in the planning of residential areas. Especially the losses and damages experienced in the Izmit and Düzce earthquakes in 1999 have contributed to the development of earthquake awareness and sensitivity about the precautions to be taken against possible earthquakes in our country.

Local soil conditions also play an important role in the assessment of earthquake risk for residential areas, as well as features such as the probability of an earthquake, its magnitude and distance from the study area. While seismic waves pass through the soil layers, their properties can change according to the local soil conditions and can decrease or increase the earthquake forces acting on the structures located on the ground surface [1]. Likewise, during the propagation of earthquake waves, the properties of the soil layers can also change. Generally, young and thick sedimentary areas deposited on old rock units and creating a significant density difference with the rock units amplify the amplitudes of seismic waves. The amplification effect of such different ground behaviors on seismic waves has been clearly demonstrated by studies on the significant earthquakes in 1985 Mexico City (Mexico), 1989 Loma Prieta (USA) and 1999 Kocaeli (Turkey) earthquakes [2–4]. Based on this, detailed investigation of local soil conditions in areas with high earthquake risk is of great importance in terms of developing earthquake resistant structure design and minimizing the damages that may occur.

During earthquakes, pore water pressure increases that occur under cyclic loading in saturated soil layers can cause liquefaction in the soil, which can be described as the transformation from solid phase to liquid phase. The liquefaction of soils depends on seismic factors such as the size and duration of the earthquake, as well as properties such as grain size and distribution, geological age and precipitation conditions, initial density and water permeability [5]. The looseness of the ground together with the closeness of the groundwater level in the ground to the surface is one of the conditions that are effective for the liquefaction of the ground. Although the liquefaction phenomenon developed in many earthquakes, it started to be taken into consideration with the 1992 Erzincan earthquake in Turkey, and the importance of this phenomenon gained importance by attracting the attention of all segments with the liquefaction events that occurred in the 1999 Marmara earthquake.

Geotechnical studies to be completed prior to any civil engineering design process; it requires an appropriate soil survey program that covers drilling, sampling, laboratory and field tests. Laboratory and field tests are the most important tools that allow the determination of soil properties in geotechnical science. In this study, the soil properties of the Alikahya region of Izmit province were examined with the research results of geological, geophysical and geotechnical methods and the suitability of the region for settlement was investigated. In this direction, field studies such as drilling, seismic refraction, and laboratory results on soil samples were examined in detail. Considering the earthquake hazard of the region, the liquefaction risk of the soils was also investigated.

2. Geological and Tectonical Features

Alikahya Region is located in the eastern part of Izmit province. According to the geological data, the Izmit Basin extending from Izmit Bay to Sapanca consists of Quaternary and Pliocene aged sediments, and a transition towards older and solid soils is observed towards the north and south of the Izmit Basin. In the parts close to Izmit Bay, transitions to Lower-Middle Eocene aged sandstone, conglomerate, shale and mudstone are observed. In the Alikahya Region, Quaternary aged alluvium is generally formed by consecutive clay-sand-silt. The unit observed in the northern parts of the study area has a medium-hard rock quality in terms of engineering. The unit is may described as cracked and fractured. The waters seeping into these cracks and fractures decomposed the rock. Alteration is observed in the surface sections of the unit where it comes into contact with water.

The study area is located on the North Anatolian Fault (NAF). NAF is approximately 1500 km long and is one of the most active faults in Turkey and the world. The NAF splits into two branches from the Mudurnu Stream valley in the west of Izmit Bay. The northern branch forms the Izmit-Sapanca segment, and the southern branch forms the Geyve-Iznik branch (Figure 1). Different structural models have been proposed for this branch of the NAF. The first of these is the right-sided strike-slip system model with a vertical slip component of the NAF in the Gulf of Izmit and the Sea of Marmara [6]. In another model, in which seismological data are also used, it is suggested that the trough areas in the Gulf of Izmit and the Sea of Marmara are grabens developed due to gravitational forces [7]. In the third model, it is assumed that the northern branch of the NAF zone is represented by many fault segments and that there are pull-apart basin structures between these stepped segments [8, 9].

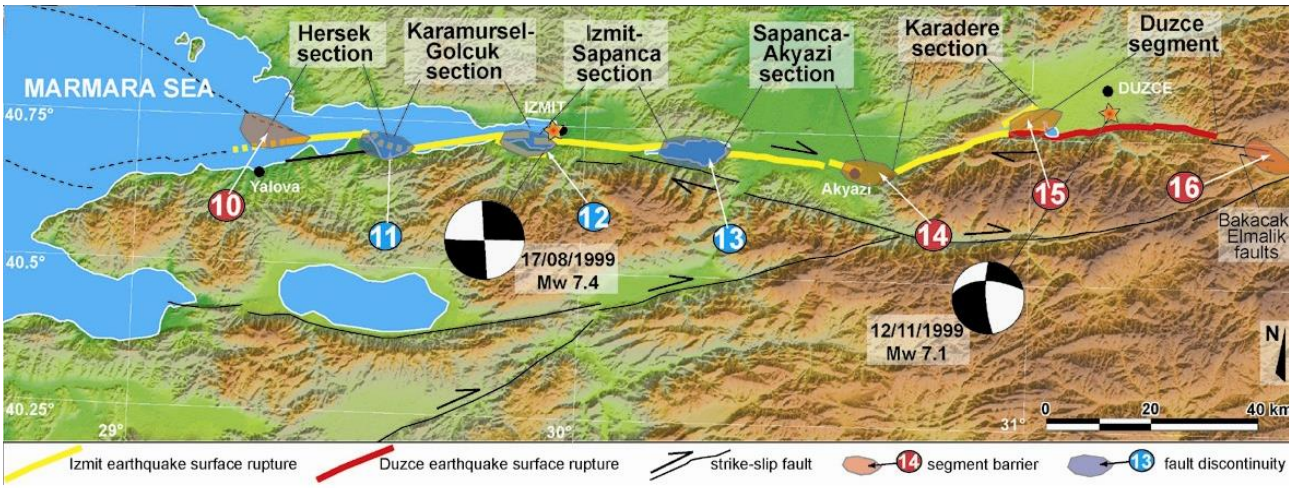

Figure 1. General tectonics map of Eastern Marmara Region [10]

3. Geophysical Research

Field study results of 18 seismic refraction measurements were used to determine the geophysical properties of the soils in the study area. Based on these measurements, layer thicknesses, underground velocity structure, dynamic-elastic engineering parameters of the soils were determined. Table 1 contains the information about the seismic refraction measurement results taken in all profiles. In the seismic refraction measurements performed along 18 profiles, the longitudinal wave velocities of the soils Vp were measured between 277 – 2562 m/sec and shear wave velocities Vs between 110 – 1427 m/sec.

Table 1. Dynamic parameters determined by the seismic surveys

Profile No/ Layer No	Vp (m/s)	Vs (m/s)	Pre. Period (sec)	Thickness (m)	Bulk M. (kg/cm²)	Density (gr/cm³)	Elasticity M. (kg/cm²)	Poisson Rate	Shear M. (kg/cm²)
P-1/L1	384	129	0.70	2.09	1719	1.37	656	0.43	228
P-1/L2	963	401	"	7.79	12312	1.73	7748	0.73	2776
P-1/L3	1593	782	"		33730	1.96	32127	1.96	11976
P-2/L1	376	150	0.48	2.12	1520	1.37	863	0.40	307
P-2/L2	1323	627	"	9.10	22924	1.87	19920	0.35	7349
P-2/L3	1894	961	"		48179	2.05	50111	0.32	18886
P-3/L1	351	130	0.68	1.92	1350	1.34	644	0.42	226
P-3/L2	873	410	"	8.71	9065	1.69	7696	0.35	2832
P-3/L3	1688	910	"		34677	1.99	42622	0.29	16454
P-4/L1	339	120	0.66	1.81	1273	1.33	547	0.42	191
P-4/L2	956	452	"	7.10	11058	1.72	9551	0.35	3521
P-4/L3	1859	977	"		44439	2.04	50875	0.30	19429
P-5/L1	277	110	0.40	1.99	766	1.26	430	0.40	153
P-5/L2	1274	627	"	4.29	20352	1.85	19515	0.34	7280
P-5/L3	2010	1123	"		48956	2.08	66651	0.27	26177
P-6/L1	385	155	0.43	2.59	1595	1.37	925	0.40	329
P-6/L2	1514	747	"	9.82	29937	1.93	28898	0.33	10790
P-6/L3	2562	1427	"		84883	2.21	114533	0.27	44911
P-7/L1	474	205	0.40	3.42	2478	1.45	1610	0.40	578
P-7/L2	1980	1054	"		50439	2.07	59833	0.30	22972
P-8/L1	424	155	0.44	2.51	2078	1.41	961	0.42	337
P-8/L2	1836	898	"		46584	2.03	43945	0.34	16363
P-9/L1	353	140	0.48	1.65	1323	1.34	740	0.40	263
P-9/L2	1295	622	"	6.00	21593	1.86	19426	0.35	7194
P-9/L3	2487	1310	"		85312	2.19	98279	0.30	37568
P-10/L1	460	200	0.51	1.59	2272	1.44	1588	0.38	574
P-10/L2	923	461	"	5.30	9715	1.71	9687	0.33	3631
P-10/L3	2121	1210	"		53572	2.10	77542	0.25	30801
P-11/L1	414	170	0.47	1.52	1857	1.40	1130	0.39	404
P-11/L2	1372	687	"	5.42	23641	1.89	23734	0.33	8904
P-11/L3	2510	1386	"		82036	2.19	107962	0.28	42150
P-12/L1	369	130	0.51	2.85	1543	1.36	656	0.42	229
P-12/L2	1581	720	"		35349	1.95	27748	0.36	10133
P-13/L1	380	140	0.48	2.55	1618	1.37	762	0.42	268
P-13/L2	1513	750	"		29758	1.93	29083	0.33	10875
P-14/L1	415	180	0.46	1.75	1805	1.40	1254	0.38	453
P-14/L2	1333	642	"	9.80	22989	1.87	20829	0.34	7720
P-14/L3	2247	1210	"		66097	2.13	80984	0.29	31248
P-15/L1	458	185	0.49	1.69	2353	1.43	2353	0.40	490
P-15/L2	1432	714	"		26142	1.91	26141	0.33	9721
P-16/L1	432	170	0.40	1.98	2092	1.41	1150	0.40	408
P-16/L2	2249	1215	"		65959	2.13	81555	0.29	31514
P-17/L1	303	116	0.71	1.49	955	1.29	492	0.41	174
P-17/L2	756	354	"	4.63	6574	1.63	5539	0.36	2037
P-17/L3	1621	854	"		32558	1.97	37525	0.30	14345
P-18/L1	284	110	0.50	2.03	821	1.27	434	0.41	153
P-18/L2	1378	636	"	4.73	25678	1.89	20851	0.36	7639
P-18/L3	2000	1141	"		46938	2.07	67945	0.25	26989

4. Geotechnical Research

14 drilling studies and laboratory test results of the samples obtained from the drillings were used in determining the geotechnical properties of the soils in the study area, Groundwater level in the study area varies between 1 and 3 m according to the drilling data, Average of the number of SPT blows determined during drilling is 16 for the study area. The soil classes are determined as predominantly ML and CH in the region [11]. Statistics of the index properties of soils in the study area are given in the Table 2. According to the classification for local soil classes; in the sections with rock units, the soil class is Z-3 soil group B, and in the alluvial region with low slope, the soil class Z-4 soil group is D [12]. Average cohesion values (c) vary between 0.22 – 0.56 kg/cm^2, and internal friction angle (Ø) vary between 5.20° and 33.4°, according to the results of the triaxial pressure test performed especially for loose soil zones in the study area.

Table 2. Statistics of the index properties

	Minimum	Maximum	Average
Gravel Content %	9.27	36.21	18.25
Sand Content %	11.36	39.52	25.18
Fine Content %	21.52	79.64	56.57
LL	NP	67	21.42
PL	NP	36	9.36
PI	NP	45	12.74
Wn %	16.84	22.30	19.76

5. Liquefaction Risk

The serious decrease in shear strength in parallel with the increase in the pore water pressure of the soil can be accepted as the most general definition of soil liquefaction. Liquefaction occurs in saturated cohesionless soils, when the effective stress is zero, with the increase in pore water pressure during shaking. Thus, the layer behaves like a liquid; cannot support the structure, the structure tilts, sinks, overturns or turns. It is known that liquefaction does not occur in all soil layers in the field. For this reason, in liquefaction hazard analyzes, it is necessary to examine whether the necessary conditions for liquefaction to occur are primarily required. It can be stated that the most important ones among these conditions are the earthquake magnitude and the distance from the center of the earthquake, the composition of the soil layer and its geological history, and the stress and compactness of the soil.

The liquefaction susceptibility of soils is evaluated by the calculated liquefaction safety number using simplified procedures. In this approach, the cyclic shear stresses caused by the earthquake and the cyclic resistance of the soil to liquefaction are compared. The most common field test used to evaluate the resistance of soils to liquefaction is the standard penetration test (SPT). SPT, which is a dynamic penetration test, is one of the most frequently used tests in soil investigations in our country. SPT results are used in liquefaction analysis as well as successfully predicting the firmness and shear resistance properties of especially granular soils. SPT-based liquefaction analysis was first proposed by Seed and Idriss, [13] and has been improved over time. Today, especially with the procedure proposed by Youd [14], it has become a widely used method to determine the liquefaction sensitivity of sands in Turkey as well as in many countries of the world.

In determining the liquefaction potential of the soils in the study area, liquefaction analyzes based on SPT results were carried out in accordance with the purpose of the study with the obtained drilling information. In this context, the simplified procedure proposed by Seed and Idriss [13] was used (Equation 1);

$$FS = \frac{CRR}{CSR} \tag{1}$$

FS is the safety coefficient, CRR is the cyclic rate of resistance and defined on the clean sand curve by Youd et al. [14], CSR is the ratio of cyclic stress generated during earthquakes and calculated as (Equation 2);

$$CSR = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma_v'} \times r_d \tag{2}$$

Here is, g, gravitational acceleration; σ_v and σ_v', total and effective stress; a_{max}, the peak horizontal acceleration; r_d, stress reduction coefficient.

Considering the earthquake hazard of the region and previous studies, the maximum horizontal ground acceleration (a_{max}) was evaluated as 0.40g and the earthquake magnitude (Mw) as 7.5, in the study. The safety coefficients obtained as a result of the calculations were used to determine the levels with and without liquefaction potential. Levels with a factor of safety less than 1 are considered liquefiable, while levels greater than 1 are considered non-liquefiable. The results of the liquefaction analysis of soils in the study area are given in Table 3.

Table 3. Liquefaction analysis results in the study area

Drilling No	Z (m)	Water Level (m)	FC (%)	Unit Weight kN/m^3	N1$_{60}$	CSR	CRR	FS
D1	3.00	2.44	45.08	19.57	16.50	0.281	0.176	0.63
D1	6.00	2.44	43.27	19.59	34.10	0.354	0.425	1.20
D1	7.50	2.44	40.29	19.61	45.20	0.370	0.489	1.32
D1	9.00	2.44	32.22	19.81	48.00	0.378	0.453	1.20
D3	3.00	1.9	35.18	19.75	36.00	0.311	0.374	1.20
D3	4.50	1.9	24.15	19.99	19.50	0.353	0.209	0.59
D4	3.00	2.2	46.36	19.56	18.50	0.294	0.197	0.67
D4	4.50	2.2	41.44	19.59	24.30	0.339	0.278	0.82
D4	9.00	2.2	48.67	19.53	37.10	0.386	0.464	1.20
D7	7.50	2	46	19.56	43.60	0.388	0.465	1.20
D7	12.00	2.1	7	20.41	21.70	0.369	0.238	0.64
D7	14.50	2.1	5	20.43	24.20	0.343	0.277	0.80
D8	3.00	2.8	45	20.10	32.20	0.265	0.318	1.20
D8	14.50	2.8	8	20.39	39.00	0.338	0.405	1.19
D9	6.00	2.5	15.5	20.26	24.00	0.347	0.274	0.79
D9	9.00	2.5	17.3	20.23	41.10	0.369	0.443	1.20
D9	12.00	2.5	14.8	20.26	45.20	0.361	0.455	1.26
D10	1.50	1.2	10	20.50	14.80	0.285	0.158	0.55
D10	3.00	1.2	11	20.34	16.80	0.358	0.178	0.50
D10	4.50	1.2	7	20.41	21.00	0.389	0.229	0.59
D10	6.00	1.2	10	20.36	26.80	0.405	0.332	0.82
D10	9.00	2	44.2	29.30	5.00	0.393	0.426	1.08
D11	3.00	2.1	3	20.46	13.80	0.297	0.148	0.50
D11	4.50	2.1	2.3	20.47	15.70	0.339	0.167	0.49
D11	6.00	2.1	3.1	20.45	17.40	0.362	0.185	0.51
D11	9.00	2.1	3	20.46	25.00	0.379	0.292	0.77
D11	12.00	2.1	2.9	20.46	20.50	0.368	0.222	0.60
D11	14.50	2.1	3.5	20.45	24.20	0.343	0.277	0.80
D13	3.00	2.1	47	19.56	42.50	0.304	0.395	1.30
D13	4.50	2.1	48	19.55	45.40	0.351	0.421	1.20
D13	6.00	2.2	8	20.39	27.70	0.358	0.361	1.01

6. Discussion and Conclusions

In building design, the behavior of the ground in response to the general characteristics of the ground and the loads acting on it is of great importance. As a result of the seismic loads that the ground is exposed to, the parameters based on the building safety should be determined correctly. Considering the fact that our country is located in an earthquake zone, the importance of the situation increases even more. The liquefaction in the soil layers can cause significant damage to the surface and buried structures during the earthquakes. Therefore, it is very important to determine the factors that cause liquefaction in soils and the liquefaction hazard and to predict their possible harmful effects in geotechnical earthquake engineering.

In this study multiple research data were used together to determine the soil properties and liquefaction potential of Alikahya region (Izmit). Despite the presence of sandstone, conglomerate, shale and mudstone units in the north of the study area, the remaining areas are represented by Quaternary aged alluvium. Seismic velocities and SPT blow numbers were found to be low, especially at near-surface depths throughout the study area. According to the liquefaction analyzes performed considering the earthquake hazard and loose soil structure of the region, it has been determined that some local areas in the study area are at risk of liquefaction (Table 3). It will be beneficial to use the necessary soil improvement methods for new constructions to be made in areas with liquefaction risk in the region.

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Conflicts of interest

The authors declare no conflicts of interest.

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