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Research Article

EVALUATION OF THE SOIL CHARACTERISTICS AND LIQUEFACTION RISK IN KAZIMPASA, ADAPAZARI (TURKEY), CASE STUDY

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ABSTRACT
It is necessary to determine the local soil properties in order to safe constructions in settlement areas under the earthquake hazard. In this study, the local soil conditions of Kazimpasa region in Adapazari were investigated by geological, geophysical and geotechnical data in order to evaluate the soil characteristics and liquefaction risk. 19 seismic and 19 drilling studies results have been evaluated to determine the soil characteristics of the study area. The study area is located in the 1st degree earthquake zone. The geology of the study area is generally controlled by Quaternary aged alluvium and Eocene aged claystones. The local soil classes were determined as Z4 in the alluvium and Z2 in some areas controlled by altered claystones in the study area. The P-wave velocities were measured between 333 - 2026 m/s and the S-wave velocities were measured between 118 - 1089 m/s according to the seismic studies. The ground water level in the alluvium is varying between 0 – 3 m. The liquefaction analysis results indicated that some areas covered with alluvium have liquefaction potential considering the soil properties and seismic activities of the study area.

Keywords: *Soil investigation, geotechnics, geophysics, liquefaction, Kazimpasa*

1. INTRODUCTION

17 August 1999 Kocaeli Earthquake has strongly influenced the eastern parts of the Marmara Region. Adapazari city was heavily damaged due to the close to the epicenter of the earthquake, the building quality and the local soil conditions. It has been revealed many times by various researchers that the damages that occurred during the earthquakes were affected by local ground conditions. During the Kocaeli earthquake of 17 August 1999, a large part of the buildings in Adapazari were exposed to the settle, tilt and collapse due to the local soil conditions. Adapazari city is mostly located on thick alluvial deposits near the North Anatolian Fault (Yılmaz et al. 2004). Therefore, it has a strongly liquefaction potential during major earthquakes. There have been carried out many studies related the local soil conditions of Adapazari city, the effects of geotechnical factors on observed damages, liquefaction, loss of bearing capacity and ground deformations by many researchers (Erken et al. 2003; Kaya et al. 2002; Kiku et al. 2001, Kutanis and Bal, 2006, Yılmaz et al. 2011, Sert et al. 2005, Sancio et al. 2002, Bol et al. 2008, Jonathan et al. 2004).

The thickness of the alluvium layer in the Adapazari region is about 1 km (Komazawa et al. 2002). This thick alluvium layer is formed by Holocene aged sediments carried by Sakarya and Cark rivers. The soft and unconsolidated sediment layers have caused ground deformations during major earthquakes in the region. The most important has been the liquefaction. The liquefaction can be explain as the increase of the pore water pressure, the decrease of the effective stress and the behavior of the ground as a liquid due to the disappearance of the sliding resistance especially as a result of cyclic loads on saturated loose soils. Soil liquefaction causes many damages during the earthquake such as settling and tilting in structures with shallow and deep foundations and outcropping in underground transport lines. In addition, flow-type migrations in slopes and lateral spreading types in flat and less inclined lands can occur as a result of liquefaction. The damages due to liquefaction observed in many regions around the world, have been instrumental in the development of sensitivity of the determination of the risk of liquefaction especially in regions with earthquake hazard. For these reasons, determining the liquefaction sensitivity of the ground during earthquakes is a very important issue in terms of geotechnical engineering.

In this study, the soil characteristics of the Kazimpasa region which is located on the western part of Adapazari city were evaluated (Figure 1). In order to evaluate the soil conditions of the study area, totally 19 drilling, 19 seismic studies data and soil - rock samples laboratory tests results have been used. In addition, liquefaction analyzes based on SPT (Standart Penetration Test) method were performed to determine the liquefaction potential of the study area.

2. LIQUEFACTION

The water saturated, loose sand / sandy soils tend to compression and volumetric contraction under the cyclic loads effect. This tendency increases the water pressure in the absence of drainage. When the cyclic loads supports the increase of the water pressure in sand layer the total normal stress can reach equal values with water pressure (Das, 1983). In this case, noncohesive soil loses the shear strength and exposed to large displacement by acting as a liquid. So, the liquefaction phase begins (Das, 1983).

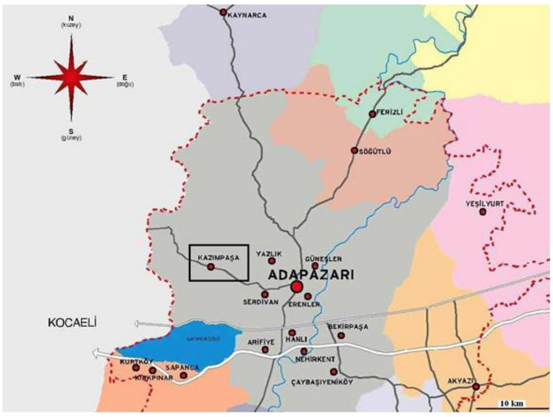

Fig. 1. The location of the study area

Simplified procedure development studies to assess the liquefaction sensitivity of the soils were first performed by Seed and Idriss (1971). This study, which is the basis for liquefaction analysis has updated, improved over time and begun to be discussed in detail especially in the early 2000s (Youd et al. 2001; Cetin et al. 2004; Idriss ve Boulanger, 2008, Idriss ve Boulanger, 2010, Boulanger ve Idriss, 2014). The procedure recommended by especially Youd et al. (2001) is a widely used method to determine the liquefaction sensitivity of soils in Turkey as in many countries of the world. In this method, the safety of the soil against liquefaction during an earthquake expressed in the form of comparison of the rate of cyclic resistance of the soil with the rate of cyclic stresses due to earthquakes. The ratio of cyclic stress generated during earthquakes (CSR) is defined by Seed and Idriss (1971) as in Equation 1.

$$CSR = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma_v'} \times r_d \tag{1}$$

Here is, a_{max}, the peak horizontal acceleration at the ground surface during the earthquake; g, gravitational acceleration; σ_v and σ_v', total and effective stress; r_d, stress reduction coefficient. The average values are used for the r_d depending on the depth in the Equation 2 in engineering applications.

$$r_d = \begin{cases} 1.0 - 0.00765z, & z \leq 9.15 \text{ m} \\ 1.174 - 0.0267z, & 9.15 < z \leq 23 \text{ m} \end{cases} \tag{2}$$

The most plausible way to determine the rate of cyclic resistance of soils is to conduct laboratory tests on undisturbed samples taken from the field. However, due to the disturbeds, during the sampling and factors such as cost the cyclic rate of resistance (CRR) is attempted to be estimated based on the standard penetration test (SPT), cone penetration test (CPT) and shear wave velocity (Vs) measurements for constructions except in very special engineering structures. It is seen that liquefaction analysis based on SPT is more preferred method in Turkey.

For sands with a fine grain content, FC ≤ 5% and for Mw = 7.5 magnitude earthquakes, the curve that separates the regions where the liquefaction occurs and is not observed is defined as a clean sand curve by Youd et al. (2001) and the cyclic rate of resistance ($CRR_{7.5}$) is expressed for this situation (Figure 2). The safety factor (FS) against the liquefaction is calculated from Equation 3. The safety factor below 1.0 indicates the presence of liquefaction sensitivity on the soil.

$$FS = \frac{CRR}{CSR} \tag{3}$$

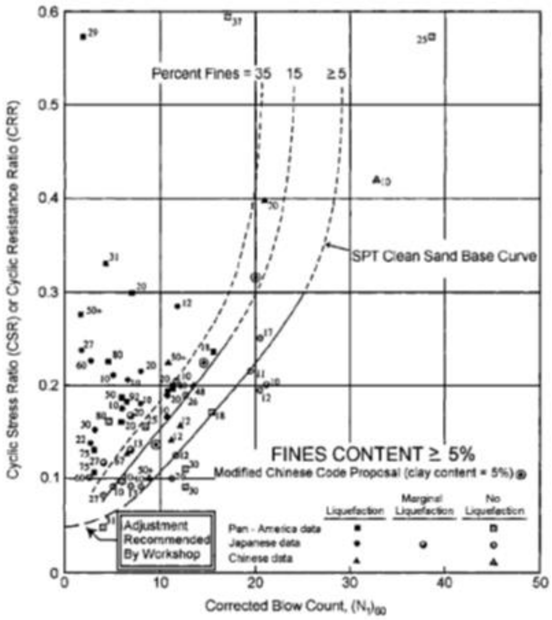

Fig. 2. SPT Clean-Sand Base Curve and Curves for Fines Content = 15% and 35% for Magnitude 7.5 Earthquakes with Data from Liquefaction Case Histories (from Youd et al. 2001)

3. GEOLOGICAL SETTINGS AND SEISMICITY

Geological settings in Adapazari plain and its surroundings suggest that downtown Adapazari is developed by fluvial sediments during the past thousands of years. The Sakarya River is a main river in this area runs in the east of the downtown area to Black Sea flowing from south to north. The Cark River one of the rivers branches of the Sakarya River runs to the north passing the south west of the downtown. A large part of the Adapazari plain is consist of deposits of Quaternary aged alluvium containing gravelly and silty sand brought by the rivers (Figure 3). Generally, silt and clay series exist on the ground and gravel, sand, silt series continuously follow the surface series. Dominant ground consists of gravelly and silty sand having different densities and contains low plasticity silty and clay bandage at some places (Onalp et al. 2000). The depth of the bedrock is approximately 1100 m in the center of the city (Komazawa et al. 2002; Hitoshi et al. 2002). The groundwater level is usually 1 to 2 m below the surface of the ground and shows seasonal variations. The ground stratum is usually randomly formed. The thickness of many layers is rarely several meters. Top 5 meters is dominated by silty units. Clays and sands are seen in the form of band. High-plastic clays are seen in old marsh or shallow lakes while sands and silty sands are seen in the old stream beds.

The geology of Kazimpasa region is generally controlled by Quaternary aged alluvium and Eocene aged claystones. The alluvium units are consist of silt, clay, gravel, sand bands, organic matter-rich mud, lake shaft and mud.

The seismotectonic structure threatening Adapazari and its vicinity is the North Anatolian Fault system. The North Anatolian Fault (NAF) which is a right lateral strike fault with a length of 1200 km is located approximately 8 km south of the Adapazari basin. Adapazari has been exposed to several major earthquakes over the last 100 years. In 1943, 1967 and 1999 are the most catastrophic ones occured in the region. The earthquake of Marmara on August 17th 1999 was the most destructive one. Its magnitude was 7.4 (Mw) and associated with faulting over length of 100 -120 km. It was resulted in 17.479 death and 43.953 injured. The government data indicated that %27 of the buildings were either damaged or destroyed, %20 of buildings medium damaged and %53 of building less damaged or undamaged.

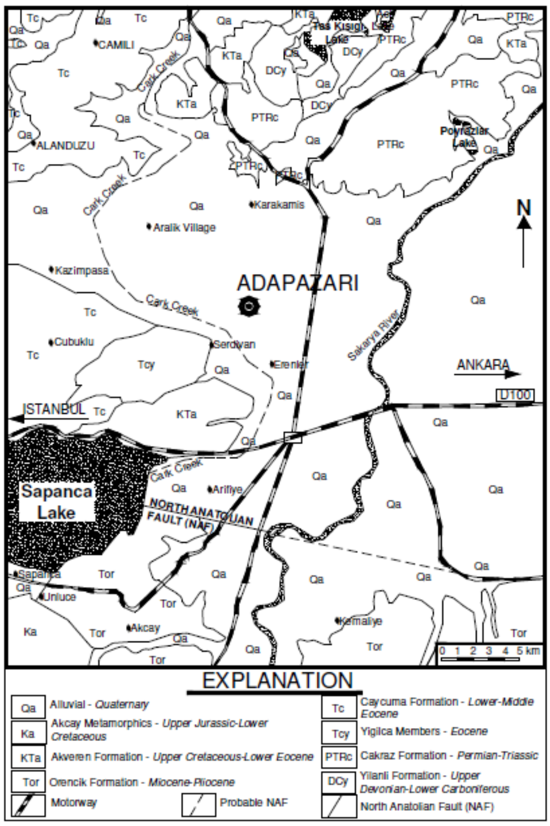

Fig. 3. The geology map of the region.

4. GEOPHYSICAL CHARACTERISTICS OF THE STUDY AREA

The geophysical properties of the soils in the study area were evaluated by using 19 seismic fracture measurements. The layer thicknesses, underground velocity structure, dynamic-elastic engineering parameters of the soils were determined depending on these measurements. The geophone ranges were changed between 2 - 5 m in straight and reverse shots. The device used for seismic refraction application is 12 channels and has a high-mid-low pass filter with a sampling interval of 0.5 ms. Seismic profile lines were chosen to match soil drillings and to best represent the study area. The P-wave velocities were measured between 333 - 2026 m/s and the S-wave velocities were measured between 118 - 1089 m/s in the seismic studies. It was understood that the ground was divided into two or three layers in the study area according to the seismic velocities. The dynamic characteristics of the soils obtained from seismic refraction results are given in Table 1.

5. GEOTECHNICAL CHARACTERISTICS OF THE STUDY AREA

In order to determine the geotechnical characteristics of the study area, 19 drilling study results and laboratory samples test results obtained from these drillings have been used. The units cut in drilling wells whose depths are changing between 5 and 15 m are generally alluvium materials and Eocene aged claystones. The drilling locations and distributions were identified considering the geology of the area, covered sections according to field observations. The SPT blow count values determined during the drillings are less than 10 in the near surface alluvium units and changed between 5 and 65 in the study area.

5.1. Laboratory Results

The grain size distributions of soils, water content, natural unit weight, atterberg limits and strength properties were determined with laboratory experiments on the 109 disturbed and 17 undisturbed samples taken from the drilling. The laboratory test results related to the disturbed samples are given in Table 2. Sieve analysis and atterberg limits test results were used to classify the soil samples for 109 samples according to the USCS. The soil classes were determined as 75.222% ML, 10.10% SM, 8.26% CL, 5.50% SC and 0.92% GM in the study area. The strength parameters of the alluvial soils in the study area were determined with triaxial compression tests and the results are given in in Table 3

In addition, the soils in the study area were classified according to the regulation on buildings to be made in disaster areas, which was issued in 1998 by the General Directorate of Disaster Affairs. The local soil classes were determined as Z4 in the alluvium and determined as Z2 in altered Eocene aged units.

The superficial appearance of the Eocene aged claystones in the study area is yellow-green brown colored and thin-medium layered. The RQD values are ranged from 0 to 52 and the rock qualities are defined as very poor - poor. The results of uniaxial compression tests on samples of claystones are given in Table 4. The strength values are range from 117.65 to 148.50 kg/cm^2 (ASTM 2008) and these are defined as very low strength according to Deere and Miller, (1966).

Table 2. Descriptive statistics of parameters

	Least	Most	Mean
Gravel %	12.39	44.36	21.42
Sand %	17.56	56.78	29.64
Clay-Silt %	19.82	70.36	48.94
LL %	NP	42	24.36
PL %	NP	30	16.56
PI %	NP	18	8.78
Wn %	19.32	42.36	23.48
γ_n (gr/cm^3)	1.72	20.42	1.86

Table 3. Triaxial Compression Tests results of the undisturbed samples

Drilling Number	Depth (m)	c (kPa)	(Φ^0)
D-1	2.50	74.85	7.85
D-2	2.50	77.08	8.04
D-3	2.50	44.64	12.77
D-4	2.50	82.20	7.69
D-5	2.50	72.26	8.36
D-6	2.50	94.41	8.03
D-7	2.50	82.59	7.13
D-9	2.50	51.81	8.84
D-10	2.50	65.53	8.05
D-11	2.50	75.75	7.12
D-12	2.50	65.53	8.05
D-14	2.50	75.31	7.12
D-15	2.50	70.10	7.50
D-16	2.50	55.76	8.14
D-17	2.50	45.80	7.12
D-18	2.50	74.32	7.79
D-19	2.50	83.53	6.12

Table 4. Uniaxial Compression Tests results of the claystones

Drilling Number	Depth (m)	σ_c (kg/cm^2)
D-2	7.5	120.35
D-4	3.0	138.20
D-5	4.5	117.65
D-6	6.5	145.45
D-9	6.3	115.20
D-11	7.4	127.80
D-14	8.9	119.70
D-16	4.7	148.50
D-17	7.5	114.84

Table 1. Dynamic Elastic Properties Obtained from Seismic Measurements

Profile No / Layer No	Vp (m/sn)	Vs (m/s)	V. Period sn	Thickness (m)	B. Module (kg/cm^2)	Density (gr/cm^3)	E. Module (kg/cm^2)	Poisson Ratio	S. Module (kg/cm^2)
S-1/T1	387	140	0,45	3,90	1699	1.37	767	0,42	269
S-1/T2	1152	548	"		16736	1,81	14684	0,35	5423
S-2/T1	392	136	0,65	6,85	1779	1,38	730	0,43	255
S-2/T2	847	385	"	10,17	8692	1,67	6791	0,37	2478
S-2/T3	1778	883	"		42709	2,01	41947	0,33	15695
S-3/T1	411	174	0,40	3,04	1794	1,40	1175	0,39	422
S-3/T2	1278	569	"	9,69	22271	1,85	16519	0,37	6000
S-3/T3	1865	923	"		47717	2,04	46436	0,33	17355
S-4/T1	402	167	0,51	2,67	1727	1,39	1080	0,39	387
S-4/T2	939	428	"	5,62	10939	1,72	8606	0,36	3143
S-4/T3	1625	784	"		35843	1,97	32623	0,34	12097
S-5/T1	365	120	0,50	2,36	1545	1,35	561	0,43	195
S-5/T2	987	451	"	7,59	12214	1,74	9670	0,36	3534
S-5/T3	1488	744	"		28420	1,93	28420	0,33	10657
S-6/T1	362	120	0,43	2,28	1512	1,35	560	0,43	194
S-6/T2	1179	540			18187	1,82	14484	0,36	5296
S-7/T1	358	120	0,68	3,02	1469	1,35	557	0,43	194
S-7/T2	785	322	"	8,05	7843	1,64	4759	0,39	1701
S-7/T3	1420	748	"		24175	1,90	27852	0,30	10647
S-8/T1	339	118	0,64	1,92	1281	1,33	530	0,43	185
S-8/T2	721	334	"	5,56	5961	1,61	4886	0,36	1792
S-9/T1	388	132	0,60	3,24	1751	1,38	687	0,43	239
S-9/T2	712	320	"	9,86	5931	1,60	4504	0,37	1639
S-9/T3	1652	885	"		33297	1,98	40207	0,29	15479
S-10/T1	333	124	0.57	1,98	1196	1,32	578	0,42	203
S-10/T2	880	380	"	6,19	9824	1,69	6755	0,38	2438
S-11/T1	421	176	0,30	2,38	1908	1,40	1212	0,39	434
S-11/T2	1788	898	"		42770	2,02	43283	0,33	16255
S-12/T1	389	140	0,32	2,40	1723	1,38	769	0,42	269
S-12/T2	1659	769	"		38852	1,98	31897	0,36	11699
S-13/T1	413	156	0,37	2,60	1930	1,40	963	0,41	340
S-13/T2	1374	622	"		25895	1,89	20023	0,37	7301
S-14/T1	380	140	0.48	3,07	1618	1,67	762	0,42	268
S-14/T2	1020	480	"	8,88	12845	1,75	10961	0,35	4036
S-15/T1	425	175	0,35	2,69	1967	1,41	1205	0,39	431
S-15/T2	1335	658	"	8,57	22578	1,87	21735	0,34	8113
S-16/T1	359	130	0,4	2,60	1435	1,35	649	0,42	228
S-16/T2	1426	623	"		28879	1,90	20437	0,38	7393
S-17/T1	378	160	0,51	2,50	1486	1,37	973	0,39	349
S-17/T2	898	420	"	8,25	9693	1,70	8142	0,36	2993
S-17/T3	1485	770	"		27224	1,92	30033	0,31	11409
S-18/T1	354	133	0,56	2,14	1367	1,34	674	0,41	237
S-18/T2	862	384	"	7,06	9178	1,68	6817	0,37	2476
S-19/T1	364	124	0,56	4,11	1516	1,35	597	0,43	208
S-19/T2	781	340	"	12,19	7470	1,64	5240	0,38	1894

5.2. Liquefaction Evaluation of the Study Area

In this study, liquefaction analyzes have been performed for sandy soils based on the procedure recommended by Youd et al. (2001). Different blow counts measured in the field (SPT-N) during the standard penetration tests, fine grain ratios (FC) and depths of groundwater level (hw) as summarized in Chapter 2 were used in the analyzes. In this context, the analyzes were carried out for Mw = 7.5 magnitude earthquake and a_{max} = 0.4g (1st degree earthquake zone) peak ground acceleration and the safety factors (FS) were calculated. It was paid attention the location, soil class and SPT blow count of the soil samples during the decision making of the depths to be analyzed. The analyzes were made for the first 10 m depth and the SPT blow counts for points not exceeding 30 as possible. It has already known that if the safety factor is below 1, it indicates a risk of liquefaction. Situations where the safety factor is between 1 and 1.2 were considered as low risk or possible liquefaction for the study area. A liquefaction hazard map was created for the study area by using the analysis results (Figure 4). There are some local areas especially in the eastern parts of the study area have liquefaction risk as seen in the hazard map.

6. CONCLUSIONS

In this study, the geological, geophysical and geotechnical data were used together to determine the soil characteristics and liquefaction potential of Kazimpasa region in Adapazari city. According to the findings obtained, two different geological units are observed in the study area. These are the Quaternary aged alluvium and Eocene aged claytones. Seismic velocities and the SPT blow counts were identified to be low especially in the depths close to the surface in most of the study area. The strength of the Eocene aged claystones was determined as very low seen in some local sides. The liquefaction analyzes showed that some local areas are at risk of liquefaction considering the earthquake hazard and the soft soil characteristics of the study area. It should be useful to take the necessary soil improvement precautions for new constructions to be built in areas of risk of liquefaction in the region.

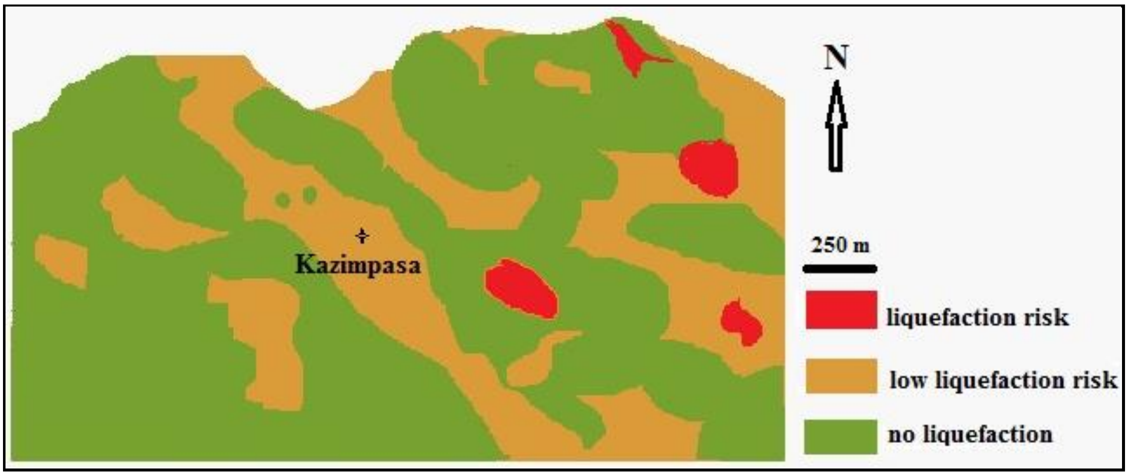

Fig. 4. The liquefaction hazard map of the study area

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