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RESEARCH ARTICLE

Liquefaction Analysis for Aziziye District (Erzurum, NE Turkey) Soils According to Turkey Building Earthquake Regulations 2018 (TBER-2018)

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ABSTRACT

Erzurum, like many provinces of Turkey, which is located in the earthquake zone, faces the danger of a major earthquake at any moment. There are many active fault lines especially in the eastern, southern and central districts of Erzurum (NE Turkey). Especially the central districts will be highly affected by a possible earthquake due to their proximity to active fault lines. In this study, the liquefaction potential of Aziziye District (Erzurum, NE Turkey), which is considered to have a high liquefaction risk due to the high groundwater level in the central districts of Erzurum province, was investigated according to the Turkish Building Earthquake Regulations (TBER). Since Aziziye District is a district with a large construction and population density, the results of the study are important. The drilling data belonging to the ground investigation reports (made by the Municipality, Public Institutions and Organizations and individuals) and the master's thesis on this subject were used for Aziziye District. Within the scope of the study, local soil classes were determined according to TBER-2018 and liquefaction potentials were calculated according to earthquake magnitude Mw=6.0, Mw=6.5, Mw=7.0, Mw=7.5 and earthquake ground motion level DD-2. As a result, it was determined that a large part of Aziziye District is under liquefaction risk.

Contents

1. Introduction

Turkey, which is located at the junction of the Eurasian and Arabian plates, faces many destructive earthquakes due to its geological structure and topographical features. Many lives and property have been lost in the earthquakes that occurred in the past, and earthquakes with a magnitude of Mw = 6.0 and above are expected to occur in many cities at any time in the future. In order to take measures against the disasters

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experienced in our country (the most prominent of these disasters was the earthquake), studies were initiated after 1940. In this context, a total of 10 disaster/earthquake regulations, the first of which was published in 1940, have been enacted and implemented in order to minimize earthquake damages. These regulations listed below have been renewed according to current information.

- 1940 - Italian Building Instructions for the Construction to be Built in Earthquake Areas
- 1944 - Regulations on Temporary Construction in Earthquake Areas
- 1949 - Turkey Earthquake Zones Building Regulations
- 1953 - Regulation on Structures to be Built in Earthquake Zones
- 1962 - Regulation on Structures to be Built in Disaster Areas
- 1968 - Regulation on Structures to be Built in Disaster Areas
- 1975 - Regulation on Structures to be Built in Disaster Areas
- 1998 - Regulation on Structures to be Built in Disaster Areas
- 2007 - Regulation on Buildings to be constructed in Earthquake Zones
- 2018 - Turkey Building Earthquake Regulations (TBER-2018).

The TBER-2018 regulation, which was published in 2018 and entered into force on 1 January 2019, shows major differences in terms of calculation methods and scope compared to the previous regulation in 2007. In 1998 and 2007 regulations, Turkey was divided into 5 earthquake zones.

In TBER-2018, the concept of earthquake zone has been abolished by emphasizing site-specific research, and analysis and design. In TBER-2018, a separate soil investigation report is provided for each site/parcel and with the web application of Turkey Earthquake Hazard Map published by Disaster and Emergency Management Presidency (AFAD), it is possible to determine separate spectral properties for each site/parcel.

In this respect, TBER-2018 emphasized the soil-structure interaction and enabled the design of buildings in a healthier and more reliable manner. In addition, TBER-2018 is the first earthquake code to introduce the liquefaction potential/risk analysis and calculation method.

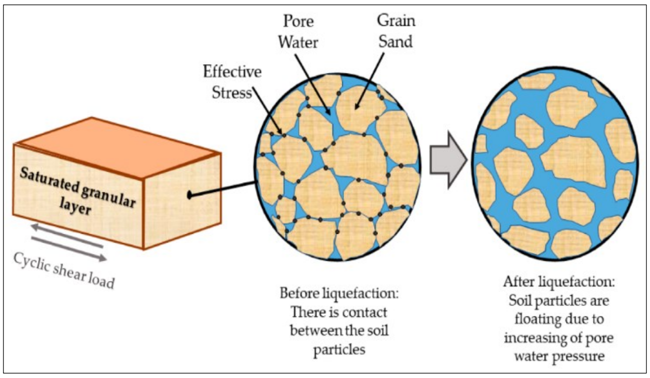

Figure 1 Liquefaction mechanism: soil particles floating due to the increment of pore water pressure [1]

The word liquefaction first used after the 1964 Niigata Mw7.6 earthquakes is defined as a change of the soil phase from a solid to a liquid state due to pore water pressure increment, and the corresponding loss of effective stress, during an earthquake. In other words, liquefaction is defined as the tendency of water-saturated loose soils to compress under seismic loads and the decrease in shear strength due to increased pore water pressure (Figure 1). As a result, large deformation, settlement and slippage occur [1, 2].

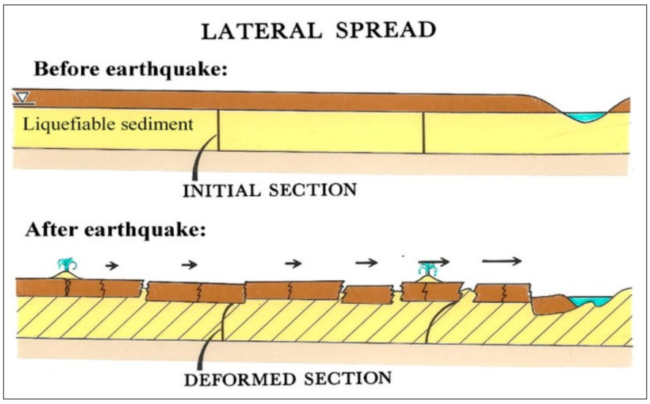

Figure 2 Schematic representation of lateral spreading [1, 3]

Liquefaction is a relevant soil phenomenon for geotechnical design as it may cause local or global failures of foundations and even the collapse of complete structures. Among the potential consequences of soil liquefaction, one of the most dangerous ones is lateral spreading. This phenomenon as the horizontal displacement of a soil layer riding on liquefied soil either down a gentle slope or toward a free face like a river channel [1, 3–5] (Figure 2).

Liquefaction, which was first mentioned by Mogami and Kubo [6], started to be investigated and analyzed by many researchers due to the damages caused by the Niagata-Japan (Mw=9.2) and Great Alaska (Mw=7.5) earthquakes that occurred in 1964. Seed and Idriss [7], Iwasaki et al. [8], Tokımatsu and Yoshımı [9], Seed et al. [10] and Youd and Idriss [11] are important studies on this subject. In our country, many damages occurred due to liquefaction after the 17 August 1999 Kocaeli earthquake. After 1999, many researchers have conducted studies on liquefaction and measures to be taken against liquefaction [12–16].

In liquefaction analyses performed before TBER-2018, mostly Seed and Idriss [7], Iwasaki et al. [8], Tokımatsu and Yoshımı [9] methods were used. TBER-2018 is based on the determination of liquefaction potential with a single procedure.

Erzurum province is among the provinces with high earthquake risk in our country. Especially in and around the city center, there are many live faults and many earthquakes have occurred on these faults in the past. The 1983 Horasan earthquake with a magnitude of Mw=6.9 caused many losses of life and property. In all three central districts of Erzurum city center (Aziziye District, Palandöken District and Yakutiye District) there is a dense construction. Especially in Aziziye District, loss of life and property is likely to occur after an earthquake due to the high groundwater level and soil structure. For this reason, it is important to investigate the liquefaction potential of Aziziye District of Erzurum Province and to identify liquefiable areas. In this context, the drilling data of the soil investigation reports (Municipality, Public Institutions and Organizations and individuals) for Aziziye District were used.

Within the scope of the study, local soil classes were determined according to TBER-2018 and liquefaction potentials were calculated and mapped according to different earthquake magnitudes (Mw=6.5, Mw=7.0 and Mw=7.5) and earthquake levels (DD1, DD2 and DD3). As a result, it was determined that a large part of Aziziye District is under liquefaction risk.

1.1. Geology of the Study Area

The surface geology of the study area is largely covered by the Oligocene-Quaternary aged volcano-sedimentary series (Figure 3). The crystalline basement in the central part of the study area consists of complex, high-grade metamorphic rocks. Quaternary alluvial deposits unconformably cover all units. The thickness of the sediment, which is the sum of six stratigraphic units, is about 6.5 km in the region [17–21].

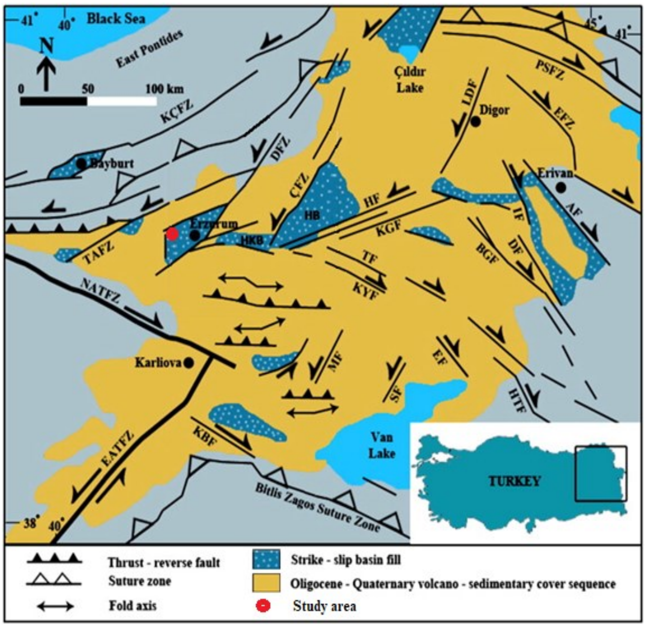

Figure 3Simplified geological map showing major compressional and extensional structures (modified from Oruç et al., Koçyiğit et al. [21, 22] and location map of the study area. KÇFZ, Kelkit-Çoruh fault zone; TAFZ, Tercan-Aşkale fault zone; KBF, Kavakbaşı fault; HKB, Hasankale basin; HB, Horasan basin; ÇFZ, Çobandede fault zone; DFZ, Dumlu fault zone; MF, Malazgirt fault; KYF, Karayazı fault; TF, Tutak fault; KGF, Kağızman fault; HF, Horasan fault; LDF, Leninakan-Digor fault; SF, Süphan fault; EF, Erciş fault; HTF, Hasantimur Lake fault; BGF, Balık Lake fault; DF, Doğubeyazıt fault; IF, Iğdır fault; AF, Aras fault; EFZ, Erevan fault zone; PSFZ, Pambak-Seven fault zone.

There is slope rubble along the areas where the Erzurum plain meets the Palandöken Mountains, old alluvium at the edges, and new alluvium units that continue to form in the river valleys and plains in the central parts. According to the results of the drilling study, the underlying older geological units are generally composed of water-saturated fine-grained sand, silt and clay-sized grains, and the current thick alluvial deposits have a wide distribution, and the groundwater level is also at very high levels [23].

1.2. Tectonics of the Study Area

There are many active faults in and around Erzurum in the Eastern Anatolia Region. According to the Turkey Fault Map, there are many active faults passing through and south of Erzurum city center. Palandöken Fault Zone in the south is a left laterally thrust fault and extends along Palandöken Mountain. Erzurum Fault Zone located in the north consists of many parallel faults. Passing through Börekli and Tuzcu neighborhoods in the southeast of Erzurum city center, the fault extends east to the city center and the zone then continues towards the northeast [24]. These faults near Erzurum city center are capable of producing earthquakes with magnitude greater than 7. Therefore, Erzurum and its vicinity should be considered as one of the regions with high earthquake hazard in the country [25–29]. Many large and small earthquakes occurred in Erzurum and its surroundings, which has high tectonic activity, between 1901 and 2011 (Figure 4).

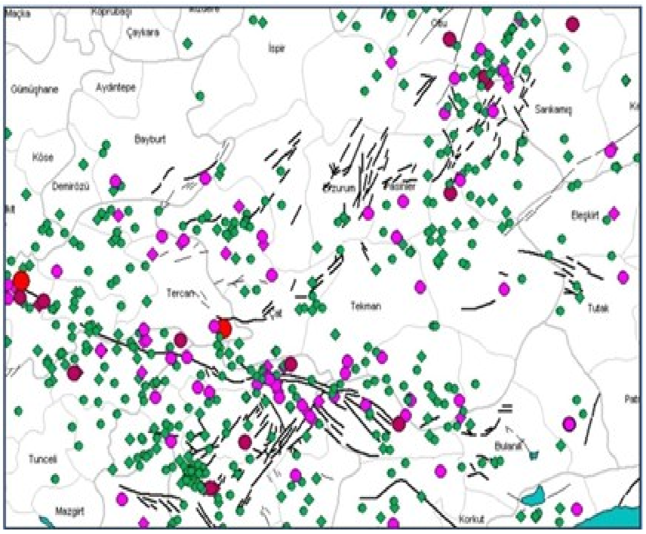

Figure 4 Epicenter distribution of earthquakes that occurred in the region between 1901-2011 and active fault map prepared by MTA [23]

Figure 3 shows the fault lines in Erzurum and its surroundings. Erzurum is located close to the North Anatolian Earthquake Fault zone and the East Anatolian Fault zone, which are the most dangerous fault zones in Turkey. In addition, there are many direct fault lines such as Palandöken and Kandilli Fault and Erzurum Fault zone in and around the city center. Many earthquakes have occurred in Erzurum throughout history [24]. It is very close to the active faults especially in Palandöken District (Erzurum, NE Turkey). According to Turkey Earthquake Hazard Maps Interactive Web Application, the distance of the closest direct fault to Dadaşkent neighborhood of Aziziye District (Erzurum, NE Turkey), where the highest population density and construction is the highest, is 4 km [30].

2. Material and Method

Within the scope of the study, ground investigation and zoning plan survey reports made within the borders of Aziziye District (Erzurum, NE Turkey) were obtained from the relevant municipalities and institutions.

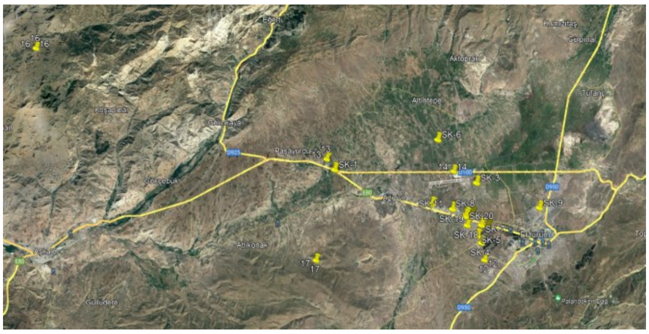

Figure 5 Drilling points

The obtained reports were carefully examined and the boreholes to be used in liquefaction analysis were determined. Geotechnical parameters (groundwater level, SPT N values, unit volume weights, consistency limits, soil classes, fine grain percentages, etc.) of 20 boreholes were determined. The view of the 20 boreholes used in the analyses within the scope of the study on the map is given in Figure 5. In addition, the coordinate-borehole depth-groundwater level (groundwater level) information of the boreholes are given in Table 1.

Table 1 Information about the drillings used in the study

Drilling	Coordinate X	Coordinate Y	Depth (m)	Groundwater level (m)	V_s (m/sn)	Local Ground Class
SK1	4426192	673823	20	2	220-310	ZD
SK2	4420147	688823	20	3	130-190	ZE
SK3	4424314	687887	15	5	250-270	ZD
SK4	4418571	688111	15	NO	230-260	ZD
SK5	4419255	687740	15	NO	250-350	ZD
SK6	4428603	684215	20	1	110-160	ZE
SK7	4420267	688188	20	1	190-330	ZD
SK8	4421362	686731	20	3	150-230	ZD
SK9	4421655	694044	15	NO	240-355	ZD
SK10	4422616	4421655	15	0.6	150-250	ZD
SK11	4422481	683364	15	1.2	150-250	ZD
SK12	4416727	431820	10	NO	773-805	ZB
SK13	4427547	416903	20	5	246-343	ZD
SK14	4425409	429407	15	1.3	170-220	ZD
SK15	4421265	430944	15	8	270-290	ZD
SK16	4440357	388810	15	5.5	212-387	ZD
SK17	4418003	415074	20	5.3	195-380	ZD
SK18	4420313	686777	20	3	142-176	ZE
SK19	4421916	685388	15	2	140-212	ZE
SK20	4421159	686637	15	2	123-129	ZE

In the TBER-2018, liquefaction potential analyses, which were previously performed according to different methods of different researchers, have been reduced to a single method and a special section has been reserved for this purpose. In this section of the regulation, there are some prerequisites for liquefaction analyses of soils. These conditions are;

- The most important parameter for liquefaction is groundwater level. The most important condition for liquefaction is the presence of earthquake load and groundwater level above 20 m in the ground environment.

- The presence of groundwater is not sufficient. It is also necessary that the soil layers consist of liquefiable soil formations. Unplastic silt (silts with ML-plasticity index less than 12%), silty sand (SM), sand (SP), sand with little gravel and mixtures of these soils are liquefiable soils.

According to the TBER-2018, SPT N30, ɣn (kN/m^3), ɣd (kN/m^3), plasticity index (%), USCS Soil Class and fine grain percentage FC (%) are used as soil parameters for liquefaction analysis. In addition, earthquake magnitude (Mw) and spectral acceleration coefficient (SDS) are used. To calculate SDS, the local soil class of the drilling location should be determined according to TBER-2018. Earthquake ground motion level (DD) is used to determine the spectral acceleration coefficient. In this study, earthquake ground motion level DD-2 (earthquake ground motion level with 10% probability of exceedance in 50 years (recurrence period 475 years)) and earthquake magnitude Mw=7.5 were selected.

Shear wave velocity (Vs) is the most important parameter when determining the local soil class. The local soil classes of the boreholes were determined by using the Vs velocities obtained as a result of the seismic refraction tests (MASW-Multichannel Surface Wave Analysis Method) performed in the survey reports and presented in Table 1.

According to TBER-2018, Turkey Earthquake Hazard Maps Interactive Web Application (Emergency Management Presidency-AFAD) is used to determine parcel-based soil spectral properties (such as SS, S1, SDS, SD1). After the parcel/site is marked on the map on the web application (or after the coordinates are entered); earthquake ground motion level and soil class are entered and the values are calculated in the reporting process. As a result of the calculation, site-specific spectral properties are determined. While SDS is used in liquefaction analysis, all spectral values together with SDS are used in building design.

Since the soils of Erzurum Aziziye District consist of alluvial units with high groundwater level, they are generally classified as ZD and ZE local soils. When the earthquake ground motion level is selected as DD-2, SDS≥0.75. In case of SDS≥0.75, the Earthquake Design Class is DTS=1a or 1 according to the Building Use Class (BKS1 or 2 or 3).

2.1. Liquefaction Analysis According to TBER-2018

According to the TBER-2018, the following calculations are made respectively during liquefaction analysis:

SPT values are corrected:

In the analysis, correction coefficients are used for automatic SPT and impact ramming in TBER-2018. After the correction coefficients are determined, the correction coefficients are multiplied by the SPT-N numbers obtained from the SPT experiments performed in the field, and the corrected SPT-N number, i.e. (N1)60 is obtained. (N1)60 (corrected SPT-N) number is calculated by the following formula:

$$(N_1)_{60}=N^*\ C_E{*}C_N{*}C_S{*}C_B{*}C_R$$

Correction coefficients used in this formula;

CN (for depth) = $\sqrt{95.76*1/\sigma'v} \leq 1.7$

In order to calculate CN, the effective stress is calculated.

CB (for borehole diameter) = 1

CE (for energy rate) = 0,90

CS (for sampler) = 1

CR (for rod length) = 0,75

The corrected SPT-N number obtained with the correction coefficients given above should be corrected again according to the fine grain ratio (IO or FC). The corrected SPT-N number obtained as a result of this correction is expressed by $(N1)_{60,f.}$

$$(N_1)_{60,f}= \alpha+\beta*(N_1)_{60}$$

The liquefaction resistance is calculated by using (N1)60,f obtained after all corrections are made.

τR (liquefaction resistance) is obtained by multiplying the cyclic resistance ratio (CRRM7.5) corresponding to the earthquake with moment magnitude Mw=7.5 by the design earthquake moment magnitude correction coefficient (CM) and the effective vertical stress ($\sigma'v$).

$$\tau_R=CRR_{M7,5}*C_M*\sigma'_V$$

$$C_M=10^{2,24}/M_W{}^{2,56}$$

$$CRR_{7.5}=[1/(34-(N_1)_{60,f})]+[(N_1)_{60,}f/135]+[50/(10.(N_1)_{60,f}+45)^2]-[1/200]$$

Calculate the Shear Resistance of the Ground:

The shear resistance of the ground is calculated by the following formula:

$$\tau_{erathquake}=0,65*\sigma_{V0}*0,4*S_{DS}*r_d$$

In this formula, σV0 is the vertical stress (at the level of calculation). rd is the depth factor and represents the stress reduction coefficient at the analyzed level (z-analyzed depth). SDS is the short period design spectral acceleration coefficient obtained from AFAD-Turkey Earthquake Hazard Maps Interactive Web Application.

The following formula is used for the calculation of rd (stress reduction coefficient):

$$r_d=1-0,00765*z \quad z\leq 9,15m$$

According to the TBER-2018, the safety against liquefaction is made with the comparison given below:

$$(FS);\ \tau_R/\tau_{erathquake} \geq 1,10$$

3. Results and Discussion

A total of 20 borings and seismic refraction (MASW) results obtained from ground investigation and zoning reports prepared within the borders of Erzurum Aziziye District were used [31]. According to the drilling and seismic refraction data used, local soil classes and spectral coefficients were determined using Turkey Earthquake Hazard Maps Interactive Web Application in accordance with TBER-2018 (Table 1).

All these data were used in liquefaction analyses as defined in TBER-2018 and liquefaction analyses were performed separately for the boreholes used in the study. The liquefaction analyses were repeated for four different earthquake magnitudes (Mw=6.0, Mw=6.5, Mw=7.0 and Mw7.5). The liquefaction conditions obtained as a result of liquefaction analyses are given in Table 2.

Table 2 Liquefaction analyses results

Drilling	Liquefaction Condition (Mw=6.0)	Liquefaction Condition (Mw=6.5)	Liquefaction Condition (Mw=7.0)	Liquefaction Condition (Mw=7.5)
SK1	NO	NO	NO	NO
SK2	YES	YES	YES	YES
SK3	NO	NO	NO	NO
SK4	NO	NO	NO	NO
SK5	NO	NO	NO	NO
SK6	NO	YES	YES	YES
SK7	YES	YES	YES	YES
SK8	YES	YES	YES	YES
SK9	NO	NO	NO	NO
SK10	YES	YES	YES	YES
SK11	YES	YES	YES	YES
SK12	NO	NO	NO	NO
SK13	NO	NO	NO	NO
SK14	NO	NO	NO	NO
SK15	NO	NO	NO	NO
SK16	YES	YES	YES	YES
SK17	YES	YES	YES	YES
SK18	NO	NO	NO	NO
SK19	YES	YES	YES	YES
SK20	YES	YES	YES	YES

In the studies carried out in Aziziye District, it was determined that the soils in the boreholes generally have a sandy and silty structure. In the liquefaction analyses of Aziziye District according to TBER-2018, as a result of the analyses using earthquake magnitude Mw=6.0; there is no liquefaction risk in boreholes SK-1, SK-3, SK-4, SK-5, SK-6, SK-9, SK-12, SK-13, SK-14, SK-15 and SK-18. Liquefaction will occur in other boreholes.

In order to investigate the effect of earthquake magnitude, liquefaction analyses were repeated for Mw=6.5, Mw=7.0 and Mw=7.5 for the same boreholes. As a result of the analyses, all boreholes except borehole SK-6 gave the same results with Mw=6.0 earthquake magnitude. While SK-6 borehole does not carry liquefaction risk at Mw=6.0 earthquake magnitude, it carries liquefaction risk in all analyses performed for all earthquake magnitude values larger than Mw=6.0. The liquefaction risk for Aziziye District (Erzurum, NE Turkey) is independent of earthquake magnitude and depends on soil properties and Groundwater level.

Although there are no live faults within the borders of Aziziye District (Erzurum, NE Turkey), there are many active live faults in the neighboring districts of the district.

There is a high probability of an earthquake of 6.0 and greater at any time in the district, which is located approximately 1-15 km close to live faults. When the liquefaction analyses and earthquake risk are considered together, it can be said that Aziziye District (Erzurum, NE Turkey) faces liquefaction risk in the event of an earthquake.

4. Conclusions

Erzurum, like many provinces of Turkey, which is located in the earthquake zone, faces the danger of a major earthquake at any moment. There are many live fault lines especially in the eastern, southern and central districts of Erzurum. Especially the central districts will be highly affected by a possible earthquake due to their proximity to live fault lines. In this study, the liquefaction potential of Aziziye District (Erzurum, NE Turkey), which is considered to have a high liquefaction risk due to the high groundwater level in the central districts of Erzurum province, was investigated according to the TBER. Since Aziziye District (Erzurum, NE Turkey) is a district with a large construction and population density, the results of the study are important. In the study, local soil classes were determined according to TBER-2018 and liquefaction potentials were calculated according to earthquake magnitude Mw=6.0, Mw=6.5, Mw=7.0, Mw=7.5 and earthquake ground motion level DD-2. As a result, it was determined that a large part of Aziziye District (Erzurum, NE Turkey) is under liquefaction risk.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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