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Investigation of liquefaction behavior of Geyve county of Sakarya province soils with GIS

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ABSTRACT

The objective of this study is to create a liquefaction map with sample zoning for Sakarya, Geyve. For this purpose, Geyve county was chosen as an example, because it is the largest county of Sakarya in terms of area and also the 3rd largest county in terms of population, and it is possible to have an allivual soil that carries the risk of liquefaction due to its location near the Sakarya River. Analyzes were carried out with the data of 290 drilling points in the ground survey reports obtained from the Geyve Municipality, Directorate of Reconstruction and Urbanization. Liquefaction analyses were made according to the Türkiye Building Earthquake Code 2018 (TBEC). The gathered information is transferred from geographic information system (GIS) mapping to the MapInfo application. Classification of soil in Geyve county, corrected SPTN (SPTN*), water content (W_N), fine grain content (FGC), liquid limit (W_L), plastic limit (W_P), groundwater table (GWT) and soil liquefaction mapping was designed with the transferred data. This study shows that there is no risk of liquefaction in the Geyve county generally but only low risk in some zones.

Keywords: Geyve, GIS, MapInfo, Soil liquefaction map

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Introduction

The North Anatolian Fault Zone (NAFZ) passing through the Marmara Region is divided into three lines in this area. The 1999 Marmara Earthquake, which occurred in this fault zone, significantly damaged the engineering structures as a result of liquefaction.

In the last 1600 years, there have been earthquakes with a magnitude of 6.8 and more in our country. Also in the last century, there have been 10 earthquakes with a magnitude of 6.0 and more [1].

Liquefaction which damages, especially human life and then the economy, can be interpreted that it occurs on the water-logged, dune, low clay content ground under repetitive tensions like earthquakes in parallel with the effective tension decreases on the ground and acts as if it is liquid [2].

One of the significant arguments from the Adapazarı Ground Charette, organized at Sakarya University is that the main problem is the Sakarya River's uncontrolled streaming and this causes liquefaction in some areas of Sakarya [3].

When all these data are taken into account, in this study Geyve county was chosen as the sample area because it is the biggest county of Sakarya in terms of area, it is located in the south part of the North Anatolian Fault and generates a risk of liquefaction.

Within this study, data in every 1.5 m / 3 m / 4.5 m / 6 m / 7.5 m / 9 m / 12 m depth received from Geyve Municipality, Construction and Urbanization Directorate ground reports of 290 drilling points were transferred to the MapInfo program from the GIS programs. Thematic area grade in every 1.5 m / 3 m / 4.5 m / 6 m / 7.5 m / 9 m / 12 m depth related to drills, corrected SPTN, W_N, FGC, W_L, W_P, GWT and soil liquefaction maps were generated. Examining the liquefaction maps, is aimed at identifying the areas at risk of liquefaction. This liquefaction map, which was created by taking into account the seismicity of Sakarya, will be a guide for the construction areas of the Geyve region and will provide prevention for risky areas.

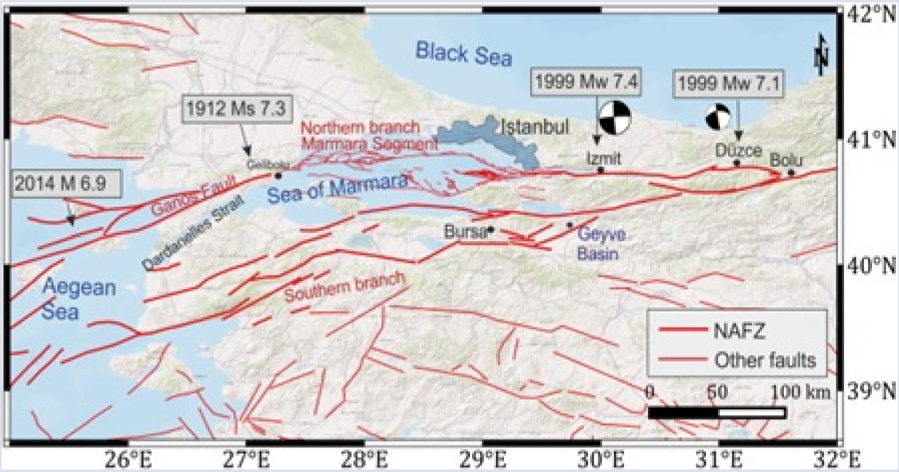

Figure 1. North Anatolian Fault sections [4]

Literature

Erken and his colleagues investigated how sand, silt and clay soils behave under the effect of earthquake-like dynamic loads. As a result of the research, they observed that the bearing capacity of water-saturated sand and low plasticity silt soils was destroyed as a result of liquefaction due to earthquakes, while the bearing capacity of soft plastic silt and clay soils decreased significantly [5].

Karavul and his colleagues, in their study on the compactness of Adapazarı soil, made mappings with the GIS mapping method and observed that the soil of the region where the settlement in the center of Adapazarı is high is mostly composed of materials showing loose compactness. In addition, they stated in their study that the groundwater level in this region varies between 0.5 m-4 m [2].

Bayraktar and his colleague prepared an earthquake scenario by using the Gölcük earthquake intensities map in Sakarya province in their study. In their study, they used the geographic information system (ArcGIS) to map the damages to be caused by the earthquake scenario. They stated that the damage that will occur in the event of a possible earthquake in Sakarya province will be serious, especially in Adapazarı county, and stated that a tent city should be established in all counties of Sakarya province to help the disaster victims after the earthquake in public green areas [6].

Material and Method

As liquefaction, a result of repetitive tensions causes much loss of life and property, there may be large settlements on the ground and this can bring about major property damage. In the geological past, it is common to accumulate alluvion in the river bed and the near abroad. Thus Geyve county located near Sakarya river which obtains the liquefaction potential of alluvial soil was chosen as the field.

Method used the analysis

There are several analysis methods using field studies and laboratory experiments for the liquefaction analysis on grounds with the potential of liquefaction. This study applied liquefaction analysis applying the standard penetration test (SPT) results method explained in TBEC 2018 chapter 16B. This approach, known as Simplified Method, was first discovered by Seed and Idriss (1971) and was later gathered by Youd (2001), taking the final form. It is the approach that is most frequently applied in the literature [7,8].

Equation 1 was used to fix the raw SPT data from the soil study report.

$$N_{1,60} = N*C_N*C_R*C_B*C_S*C_E \quad (1)$$

$N_{1,60}$ = The amount of energy corrected SPT stroke
N = SPT impact value measured on the ground
C_N = Cover load correction parameter
C_E = Energy ration correction parameter
C_B = Drilled well correction parameter
C_R = Rod length correction parameter
CS = Sampler method correction parameter

The cover load correction parameter (C_N) in Equation 1 is calculated by Equation 2.

$$C_N = 9,78*\sqrt{\frac{1}{\sigma' v0}} \leq 1.70 \quad (2)$$

The vertical effective stress (σ'_{v0}) in this equation is calculated according to the land conditions when the SPT is taken [9].

Corrected SPT numbers according to the fine grain content ($N_{1,60f}$) are calculated with Equation 3.

$$N_{1,60f} = \alpha + \beta * N_{1,60} \quad (3)$$

Fine grain content correction parameters (α, β) are calculated from the equations below.

$\alpha = 0$; $\beta = 1$ (FGC < %5) (4.1)

$\alpha = \exp [1.76-(190/ \quad FGC^2)$;$\beta = 0.99+FGC^{1.5}/1000$ (%5 < FGC ≤ %35) (4.2)

$\alpha = 5$; $\beta = 1.2$ (FGC ≥ 35) (4.3)

Liquefaction resistance (τ_R) is calculated with Equation 5.

$$\tau_R = CRR_{M7.5} * C_M * \sigma' \quad (5)$$

Cyclic strength ratio ($CRR_{M7.5}$) corresponding to an earthquake with a moment magnitude of 7.5 in Equation 5 is calculated with Equation 6.

$$CRR_{M7.5} = \frac{1}{34-N1{,}60f} + \frac{N1{,}60f}{135} + \frac{50}{(10*N1{,}60f+45)^{\wedge}2} - \frac{1}{200} \quad (6)$$

The earthquake magnitude correction parameter (C_M) in Equation 6, for design earthquake moment magnitude (Mw) 7.5, is calculated according to the Equation 7.

$$C_M=10^{2.24}/M_W^{2.56} \quad (7)$$

Repetitive shear stress in the ground ($\tau_{earthquake}$) is analyzed with total vertical stress (σ_{v0}) in the liquefaction analyzed soil, stress relief parameter (r_d) and short period spectral acceleration (S_{DS}) as shown in Equation 8.

$$\tau_{earthquake}= 0.65 * \sigma_{v0} * 0.4 * S_{DS} * r_d \quad (8)$$

The stress relief parameter (r_d) is analyzed according to the liquefaction depth (z) as shown in Equation 9.

r_d=1-0.00765z z ≤ 9.15 m (9.1)

r_d=1.174-0.0267z 9.15 < z ≤ 23 m (9.2)

r_d=0.744-0.008z 23m < z ≤ 30 m (9.3)

r_d=0.50 z > 30 m (9.4)

The factor of safety against the liquefaction (FS), is calculated by dividing the liquefaction resistance (τ_R) by repetitive shear stress ($\tau_{earthquake}$) (Equation 10).

$$\tau_R/\tau_{earthquake} \geq 1.10 \quad (10)$$

Mapping Methods

İnterpolation is a method that is used the estimated value at a different point whose value is unknown between to points, starting from the existing value points. Today, interpolation methods are used in the creation of many thematic maps [9].

In this study, using the MapInfo program, one of the GIS programs, the thematic soil class in 1.5 m / 3 m / 4.5 m / 6 m / 7.5 m / 9 m / 12 m depths related to the 290 drills, SPTN*, W_N, FGC, W_L, W_P, GWT and soil liquefaction maps were created. While creating these maps, natural neighbor interpolation (NNI) for soil maps, for SPTN* and liquefaction maps triangular irregular network method (TIN), and inverse distance weighting interpolation method (IDW) for the other maps were used.

Inverse Distance Weighting (IDW) Interpolation

The IDW method, which is frequently used in Geographic Information Systems (GIS), works on the principle of obtaining the values at the unknown point by entering the known points values. Since the value of the point to be estimated is proportional to the distance between to the known point and the points, the value of the point to be estimated varies depending on this distance. When at least two known point values are entered and the radius of the region to be estimated is specified, the unknown point value is estimated using only the points in the circle area covering this region [10].

As in the example in Figure 2, when the red dot value and the radius value to be estimated (the area to be interpolated) are entered to estimate the purple dot, the estimation is only made for the red area and value of the purple dot is estimated. The point to be considered here is that only the points in the area within the specified radius will be used when making the estimation [10,11].

The formula used in the IDW method is as shown in the Equation 11 [12].

The formula used in the IDW method is as shown in the Equation 11 [12].

$$z_p = \sum_{i=1}^{n}(z_i/d_i^p) \,/\, \sum_{i=1}^{n}(1/d_i^p) \quad (11)$$

In this Equation, n is the number of known (baseline) points, z is the property value of known (baseline) points (altitude, temperature, etc.), d is the distance between the point to be interpolated (estimated) and the known (baseline) point, and p is the power parameter, generally accepted as 2 in literature [10].

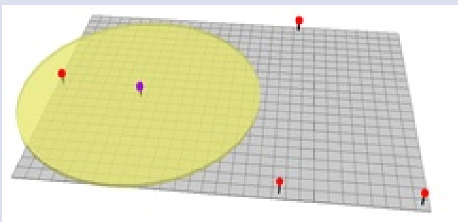

Figure 2. An example of finding an unknown point with the IDW method [12]

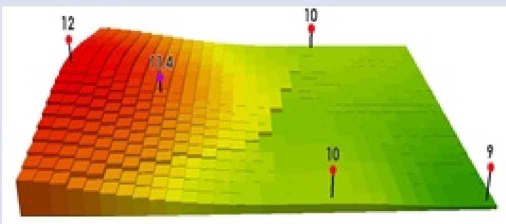

Figure 3. Example created by using Equation 11[12]

Triangular Irregular Network (TIN) Interpolation

The TIN forms circles around each of the nearest neighboring points, and the intersections of these circles form the triangles so that their intersections do not overlap. It estimates the values inside these triangles and thus creating a triangular surface and map [11].

As seen in Figure 4 triangular regions are created by creating circles around the red points so that the intersections of these circles do not overlap. The inner parts of these triangular regions are interpolated, the calculation is made and the surface is created [11].

Looking at the methods described so far, while no interpole is made outside the triangle boundaries created in the TIN method (Figure 4), it is understood that in the IDW method, interpole is made from the point found in a circular way as the radius of the region where interpole is required (Figure 3).

Natural Neighbor Interpolation (NNI)

The NNI is a method based on quickly and reliably determining a weighted average surface from available data points [13].

In the NNI, Voronoi polygons are formed with the available data. A subset is determined by interpolating in line the weighted average of the distance between two points forming these polygrams, and a Voronoi polygram (white space) is created as in Figure 5 for this subset. The new polygrams formed in this way separate the transition boundaries better and allow the detailing of the transition boundaries [13,14].

The reason why we used the natural neighbor interpolation method (NNI) for the soil class in this study is that it is the best method to show heteregeneous transitions in soil types [13]. This method developed by Robin Sibson and based on the bond polygon system, calculates the weighted average for the Voronoi polygrams for every point given x,y coordinates of subset. Sibson represented every contribution to the calculation of the formed Voronoi polygram with λ (lambda). The Equation created by Sibson is seen in the Equation 12 [15].

$$\lambda_i (x) = (A(x_i))/(A(x)) \tag{12}$$

λ_i : Polygon values from 1 to N

$A(x_i)$: The intersection between the new polygon to be created and the the known polygon

$A(x)$: Total area of new polygon to be created

The new Voronoi polygon created by taking the interpolation weights of polygons is seen in Figure 5. Here, the areas of the polygons indicated by each number are their interpolation areas. The white colored polygon in the middle is the new Voronoi polygon created by taking the weight average (Equation 12) of these interpolated areas.

Results

In this study, the soil class at 1.5 m / 3 m / 4.5 m / 6 m / 7.5 m / 9 m / 12 m depths of each soil survey report, received from the Geyve county Directorate of Reconstruction and Urbanization corrected SPTN, W_N, FGC, W_L, W_P, GWT etc. were obtained and liquefaction calculations were made according to the TBEC 2018 with the same soil types that are under the risk of liquefaction. In accordance with these calculations, with the MapInfo program, soil classifications for each depth in Sakarya province Geyve county at 1.5 m / 3 m / 4.5 m / 6 m / 7.5 m / 9 m / 12 m, corrected SPTN, W_N, FGC, W_L, W_P, GWT, and soil liquefaction mapping were created.

Example Liquefaction Analysis

In this section, the liquefaction analysis will be explained step by step which is carried out in Alifuatpaşa Town 157 Block 1 Parcel obtained from Geyve Dictorate of Reconstruction and Urbanization. Table 1 shows some information of borehole number 2 in the soil survey report. In addition to this information, the unit volume weight of the water was considered as (γ_w) 9,81 kN/m^3.

When liquefaction analysis is made with SPT values, first of all the soil parameters are determined and then SPT value correction is made, afterwards the liquefaction resistance (τ_R) is analyzed and finally the shear stress in the ground ($\tau_{earthquake}$) is analyzed, it is checked whether there is a risk of liquefaction on the ground according to the safety numbers.

Soil Parameters and SPTN Values

In accordance with the collective test report, the total vertical stress value calculated from Equation 10 is 114 kN/m^2, the total vertical effective stress value calculated from Equation 11 is 84.57 kN/m^2 and pore pressure value calculated from Equation 12 is 29.43 kN/m^2.

Analysis of The $N_{1,60f}$

The value of the cover load correction coefficient using Equation 2 is calculated as C_N = 1.06. Here when $C_N > 1.7$, C_N =1.7 should be accepted [9].

In line with the information in the ground survey report, when the SPTN correction coefficients taken from Table 1 C_R = 0.85, C_S = 1, C_B = 1, C_E = 1 values are placed in Equation 1, $N_{1,60}$ is calculated as 7.21.

According to the Equation 4.2, α is analyzed as 2.91 and β is analyzed as 1.06. When α and β values are placed in the Equation 3, $N_{1,60f}$ is analyzed as 10.55.

Analysis of The T_r

When the $N_{1,60f}$ value found as 10.55 is placed in Equation 6, $CRR_{M\,7.5}$ is analyzed as 0.14. When M_w is selected as 7.5, C_M is obtained as 0.99 according to the Equation 7. In liquefaction analyses, the M_w is always chosen as 7.5 [15]. These obtained data from Equation 5 are placed, τ_R is analyzed as 11.72.

Analysis of The $T_{earthquake}$

σ_{v0} at the liquefaction analyzed depth is placed according to the Equation 9.1, if the r_d and S_{DS} are substituted in Equation 8, $\tau_{earthquake}$ is analyzed as 31.81.

Analysis of The FS

According to the TBEC 2018, safety number must be at least 1.1 so that there is no risk of liquefaction (Equation 10). According to the Equation 10, there is a risk liquefaction since the safety number is analyzed as 0.37 when the τ_R value for the relevant depth is divided by the $\tau_{earthquake}$ value.

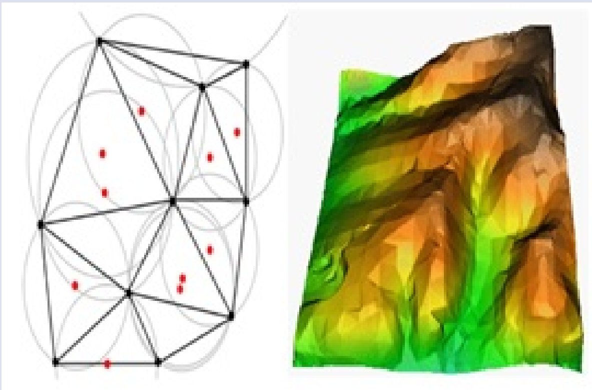

Figure 4. Example of creating a surface with the TIN method [12]

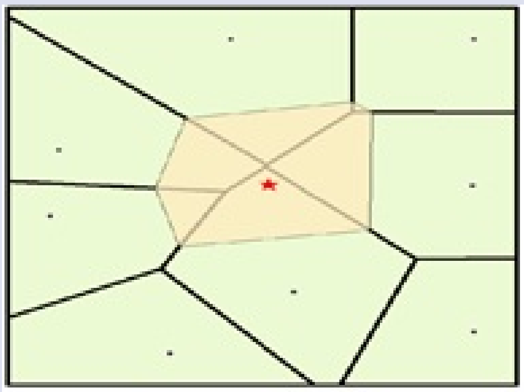

Figure 5. New polyram created by the weighted average of neighboring polygons [14]

Table 1. Drilling log information

İnformation	Value
Soil Class	SM
Depth (m)	6
FGC (%)	16.58
GWT (m)	3
$\gamma_{natural}$ (kN/m^3)	18
$\gamma_{saturated}$ (kN/m^3)	20
S_{DS}	1.125

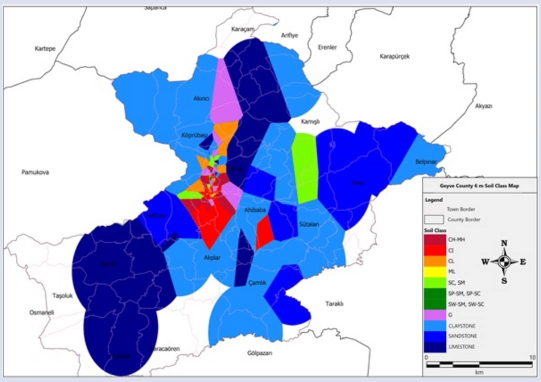

Figure 6. 6 m soil class map

Assumption Made in the Analysis

While the liquefaction analysis is made, in soil investigation report where γ_n ve $\gamma_{saturated}$ values are not given, these values are accepted according to the TS 498 standard [16].

In Türkiye Building Earthquake Regulation, soils with the potential of liquefaction are described as gravelly sand non-plastic silt and silt-sand mixture below ground water [9].

According to Karl von Terzaghi (1925), who is regarded as the father of soil mechanics, "liquefaction can occur when the weight of the solid particles forming the soil is transferred to the surrounding water during the subsidence of the saturated soil. As a result of this, the hydrostatic pressure of the soil with increasing hydrostatic water pressure at the relevant depth becomes close to the unit weight of the soil submerged in water [17].

In another definition, liquefaction is the rapid loss of strength that occurs in cohesionless (permeable) soils subject to cyclic shear stresses caused by earthquakes. Sometimes the shear strength drops below normal, and sometimes it disappears completely. In both cases, it can cause different damages" [18].

Considering all these definitions, since there will be no liquefaction in claystone, sandstone, limestone soil units, the safety number values for liquefaction in mapping for these research pit reports are taken as 2. Since the soils are above the groundwater level, liquefaction calculation was not made in the drillings where the groundwater level is not encountered [9].

In most of the ground survey reports received from the Geyve Directorate of Reconstruction and Urbanization, it was observed that this area was crossed with a research pit, since drilling could not be done due to the hardness of the ground. Considering the hardness of the ground in the reports passed with the research pit, the SPTN values were taken as 100.

Liquid limit values for non-plastic soil types were taken as 10 in reports of hard soils such as sandstone, claystone and limestone, which were observed to be passed by the survey pit during mapping [19].

Mapping Studies

In most of the ground survey reports received from the Geyve Directorate of Reconstruction and Urbanization, it was observed that these areas were crossed with a research pit, since drilling could not be done due to the hardness of the ground. Therefore, the sample for SPTN*, W_N, FGC, W_L, W_P and GWT maps was limited in a very small area. These mappings were made to cover the limited area that includes Gazi Süleymanpaşa, Alifuatpaşa, Orhaniye, Epceler, Camikebir, Tepecikler, Eşme and Sarıgazi towns, where construction is more intense.

Looking at the ground map in Figure 6, coarse-grained gravel units are observed in the county center at a depth of 6 m, while silty clayey sand units are observed in the east of the center.

When looking at the county center, a very variable soil profile, such as coarse-grained gravel and fine grained clay units, is seen in Figure 7.

Looking at the map in Figure 8, it is seen that the SPTN* number is generally 30 hits or more throughout the study area at a depth of 6 m 30.

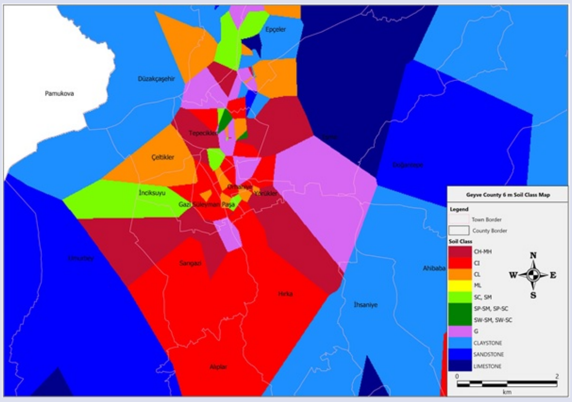

Figure 7. 6 m close-up soil class map

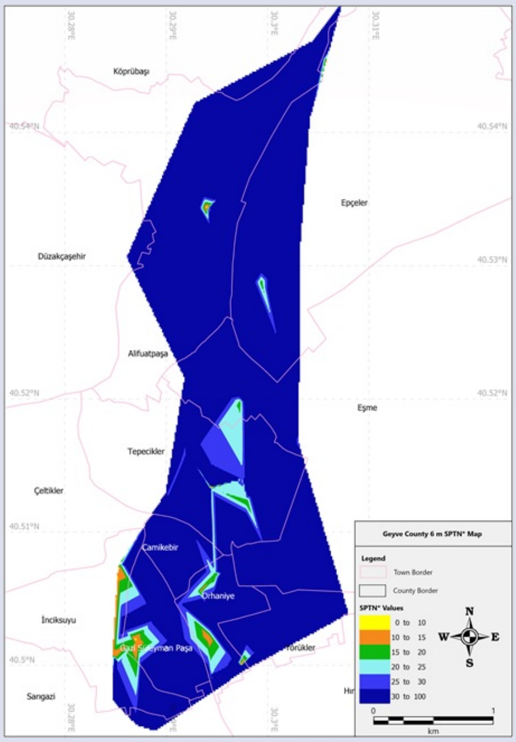

Figure 8. 6 m SPTN* map

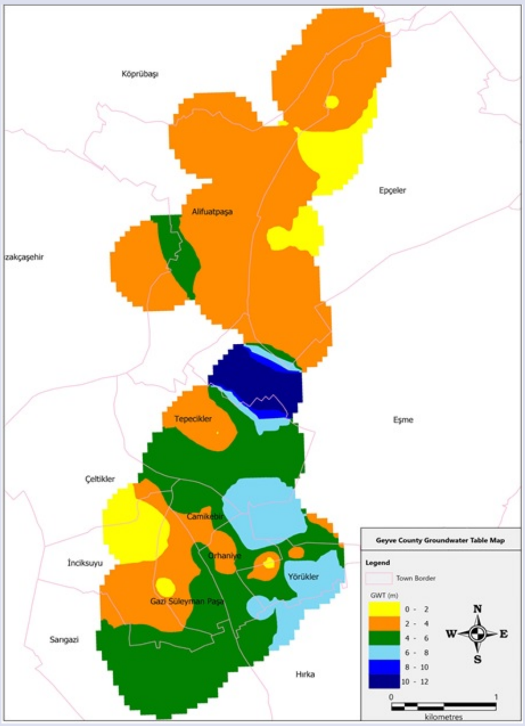

Figure 9. Geyve county groundwater table map

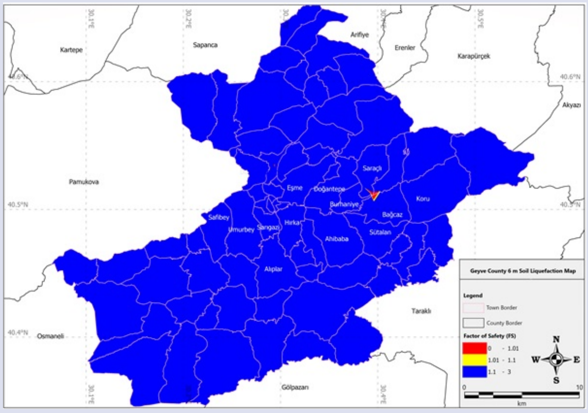

Figure 10. 6 m soil liquefaction map

In Figure 9, looking at the GWT map created with the available data, it is seen that the groundwater table is generally between 2-4 m in the south of the towns covering the sample area, and it is generally between 4-6 m in the north of the towns covering the sample area. The increase in groundwater table in the north-east of the region is thought to be related to the presence of mountainous areas

Figure 10 shows the soil liquefaction map for 6 m depth. On the map, the parts with a safety factor of less than one and a high risk of liquefaction are shown in red, and the parts with a safety coefficient between 1-1,1 and a low risk of liquefaction are shown in yellow. According to the map, it can be said that there is generally no risk of liquefaction at 6 m depth

Discussion and Conclusion

Within the scope of the study, the Geyve county of Sakarya province was selected. In order to make a thematic mapping in the selected region, the drilling data in the reports obtained from the previous ground survey studies in the region were used.

Looking at the soil maps prepared for the Geyve county of Sakarya province, it has been observed that hard soil units in the form of sandstone, claystone and limestone are dominant throughout the county. When we look at the central towns (Alifuatpaşa, Gazi Süleymanpaşa, Orhaniye, Camikebir, Eşme, Sarıgazi) where the settlement is the largest in the county, a complex soil profile is observed, mostly dominated by fine-grained clay, as well as coarse-grained sand and gravel units up to 6 m deep. After 6 m of depth, it was observed that there was an increase in coarse grained (gravel) soil units in the counties.

Based on the soil maps prepared for Geyve, it can be said that the fine-grained soil unit (silt) which has high liquefaction potential is very few in the region. Therefore, the liquefaction analysis made with TBEC 2018 was considered sufficient.

When the corrected SPTN maps prepared for Geyve county covering the most populated central counties are examined, it is seen that the majority of the study area at 1.5 m depth is below 20 impact numbers. It was observed that the number of impacts increased at 3 m of depth. After 3 m depth, it was found that almost all of the study area had 30 or more impacts. When the corrected SPTN maps are compared with the ground maps, it can be said that the fine-grained soils up to 6 m depth are hard and compact soils. In addition since it is known that there is an increase in coarse-grained soil (gravel) units in the ground maps after the 6 m depth, it has been observed that the ground mapsand the corrected SPTN maps are compitable with each other.

When the W_N maps prepared for Geyve county are examined, it is seen that the water content value, which changes 25% and above until 6 m depth, gradually decreases after 6 m depth and remains below 20%. In addition, since the number of available data decreased, it was observed that the white colored parts in the sample area increased as the depth increased.

When the prepared FGC maps were examined, it was seen that the fine grain ratio was 76% and above up to 4.5 m depth. It is seen that after 4.5 m depth in the sample area, this value drops below 76% and decreases as the depth increases. When the prepared FGC maps were examined, it was seen that the fine grain ratio was 76% and above up to 4.5 m depth. It is seen that after 4.5 m depth in the sample area, this value drops below 76% and decreases as the depth increases. The first is that the soil profile of the town is composed of coarse-grained soils such as gravel and sand and hard claystone units. The second is that the Sakarya river passes over this town and coarse-grained soils dominate at the base levels along the river line.

When the consistency limit maps prepared for Geyve county are examined, it is observed that there is an increase in coarse grained soils due to the increase in depth, although not regularly, there is a decrease in W_L values with depth. The same is true for W_P maps.

When we look at the prepared GWT map, it is seen that the GWT is shallower than 6 m (usually 2-4 m) in most of the county. In regions with mountainous areas, the groundwater table is encountered after 6-10 m.

When the liquefaction maps prepared for Sakarya province Geyve county are examined, it is observed that there is no liquefaction risk in the county except for some small areas. Looking at the close-up maps, areas with a high risk of liquefaction up to 7.5 m depth have been identified in Alifuatpaşa, Gazisüleymanpaşa and Orhaniye towns, where the settlement is dense. Since there are dense zoning areas in these regions that make up the county center, it is thought that necessary ground and structure improvements should be made despite the risk of liquefaction.

Since the area between Burhaniye-Bağcaz to the east of these maps and where there is a risk of liquefaction is mountainous and there is no settlement, it is thought that even if liquefaction occurs in this region, it will not pose a danger to human life. However, in case of zoning, it is foreseen that detailed ground examinations and ground improvement processes will be carried out in this region. In addition, since there are mountainous lands outside the county center, it is predicted that there will be no risk of liquefaction in these areas based on the data available.

Although this study, which was prepared on the basis of the available data, is in accordance with the general literature, since the existing data are thought to be insufficient, a more detailed liquefaction analysis should be done on the basis of parcels in order to obtain more consistent data and not be considered as an inclusive study in the whole of Geyve county.

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