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Araştırma Makalesi / Research Article

Liquefaction Risk Maps Determined By Nonlinear Analysis Method Using Geographical Information Systems: Kütahya Case

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Abstract

Liquefaction risk maps were created in Lala Hüseyin Paşa, Gaybiefendi and Meydan neighborhoods in Kütahya city center. A total of 112 boreholes were investigated by helping the SPT results (Standard Penetration Test) and soil parameters. Matasovic/Vucetic or Dobry/Matasovic model was used in the analyzes according to soil class. For analyzes, 11 earthquake were determined. The determined earthquakes were scaled with the Peak Ground Acceleration (PGA) of the neighborhoods and 44 earthquake data were found. Every borehole was analyzed with these 44 earthquake data in the Deepsoil 6.1 program and liquefaction risk maps were created. The average liquefaction risk data for neighborhoods were created by averaging the results obtained. The liquefaction data found show different results for earthquake levels. Liquefaction analysis results according to Earthquake Level-2 (DD-2), which the regulation accepts as a design earthquake; The average liquefaction risk was calculated as 23% in Lala Hüseyin Paşa neighborhood, 40% in Gaybiefendi neighborhood and 35% in Meydan neighborhood. While the highest risk of liquefaction occurred in the Meydan district with 68% according to DD1, the lowest risk was calculated in Lala Hüseyin Paşa District as 3% according to DD4. The liquefaction maps created can enable the necessary precautions to be taken for the construction in the neighborhoods.

Keywords
Standard penetration test(SPT); Liquefaction; Liquefaction risk map; Deepsoil

Doğrusal Olmayan Analiz Yöntemi ile Belirlenen Sıvılaşma Riskinin Coğrafi Bilgi Sistemleri Kullanılarak Haritalanması: Kütahya Örneği

Öz

Bu çalışmada, Kütahya ili Merkez ilçesine bağlı Gaybiefendi, Meydan ve Lala Hüseyin Paşa Mahallelerinde sıvılaşma risk haritaları oluşturulmuştur. Standart Penetrasyon Deney(SPT) sonuçları ve zemin parametrelerinden yararlanılarak toplam 112 adet sondaj kuyusu incelenmiştir. Analizlerde zemin sınıfına göre Matasovic/Vucetic veya Dobry/Matasovic boşluk suyu basıncı oluşum modeli kullanılmıştır. Analizler için 11 adet deprem seçilmiştir. Mahallelerin PGA(en büyük yer ivmesi) değerleri ile, seçilen depremler ölçeklendirilmiş ve toplamda 44 adet deprem kaydı oluşturulmuştur. Her sondaj kuyusu bu 44 adet deprem ile Deepsoil 6.1 programında analiz edilmiş ve sıvılaşma risk haritaları oluşturulmuştur. Analiz sonuçlarından elde edilen verilerin ortalaması alınarak, mahalleler için ortalama sıvılaşma riskleri bulunmuştur. Elde edilen sıvılaşma riskleri deprem düzeyine göre farklı sonuçlar vermektedir. Yönetmeliğin tasarım depremi olarak kabul ettiği Deprem Düzeyi-2 (DD-2)'ye göre yapılan sıvılaşma analiz sonuçları; Gaybiefendi Mahallesinde ortalama sıvılaşma riski % 40, Meydan Mahallesinde % 35 ve Lala Hüseyin Paşa Mahallesinde % 23 olarak hesaplanmıştır. En yüksek sıvılaşma riski DD1'e göre % 68 ile Meydan mahallesinde oluşurken, en düşük risk DD4'e göre % 3 olarak Lala Hüseyin Paşa mahallesinde hesaplanmıştır. Elde edilen sıvılaşma haritaları, bu bölgelerde yeni yapılacak yapılar için zeminin sıvılaşma durumunu göstererek önceden önlem alınmasına yardımcı olacaktır. Sıvılaşma riskinin yüksek olduğu mevcut yerleşim yerlerinde ise gerekli tedbirlerin alınması önerilmektedir.

Anahtar kelimeler
Standart penetrasyon deneyi(SPT); Sıvılaşma; Sıvılaşma risk haritası; Deepsoil

1. Introduction

An earthquake creates repeated shear stresses in the soil. These stresses raise the groundwater level, increasing the pore water pressure. With the continuation of this event, the effective stress approaches zero over time, resulting in loss soil of strength. Turkey is in a region where earthquakes occur frequently. Even if the reinforced concrete designs of the buildings are suitable, the occurrence of liquefaction causes loss of life and property so soil works should also be taken care of.

1-D ground response analyses are employed to understand the behavioral transmission through the soil column in liquefiable areas. The study here focuses on two main aspects of the liquefaction. Regarding the field response, it was stated that the nonlinear analysis approach is more suitable than other methods in predicting the seismic behavior of the soil column(Afacan, 2019). Liquefaction analysis were created helping from the borehole datas in Lala Hüseyin Paşa, Gaybiefendi and Meydan neighborhoods in the Kütahya City center. Deepsoil 6.1 software was used for analysis. A total of 112 boreholes were investigated. Liquefaction risk maps were created with selected 11 earthquake records.

Standard Penetration data is generally high for Lala Hüseyin Paşa neighborhood so liquefaction potential is low compared to Meydan and Gaybiefendi neighborhoods. The liquefaction maps created can enable the necessary precautions to be taken for the construction in the neighborhoods.

2. Materials and Methods

Liquefaction analysis were created in Lala Hüseyin Paşa, Gaybiefendi and Meydan neighborhoods in the Kütahya City center. The Borehole data required for the analyzes were obtained from the Municipality of Kütahya. The groundwater level location, the rate of soil that passes through the 200 numbered sieve (fine soil ratio), SPT value, plasticity index, unit weight and soil type data were obtained from the soil reports. Dobry/Matasovic and Matasovic/Vucetic pore pressure generation models were applied using Deepsoil 6.1 software to determine liquefaction potentials.

2.1 Introduction of Kütahya Region

Kütahya is located at 38° 70'- 39° 80' north latitudes and 29° 00'-30° 30' east longitudes. The population of Kütahya province is 579 257 as a result of 2019 measurements. The altitude of the city center is 969 m above sea level, and the surface area of the city is 11 977 km^2.

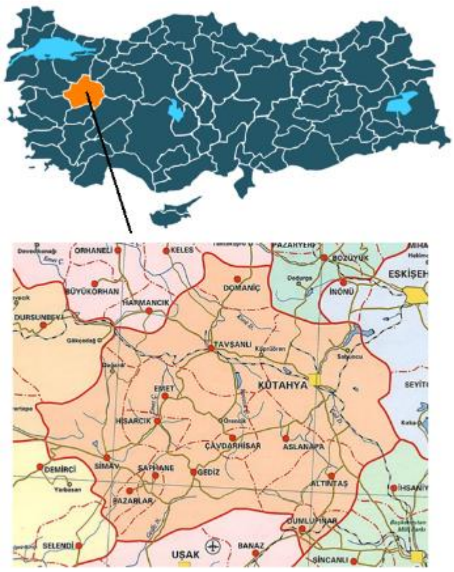

Figure 1. Location of Kütahya.

2.2 Earthquake Characteristics of Kütahya Region

The move of Anatolia in the western direction causes compression in the east-west direction and expansion in the north-south direction. This situation causes the faults in the region to interact and move. The region is located in the Mediterranean Earthquake Belt in terms of earthquakes, and earthquakes with a magnitude of 4 to 8 may occur with active faults on it. There are earthquake places with 1st and 2nd degree risk in the region (Sezer 2010).

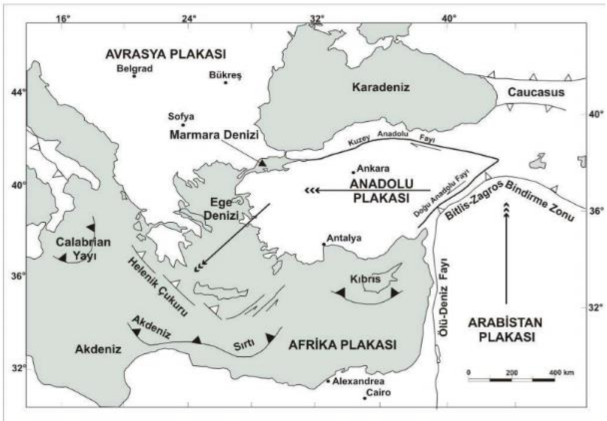

Figure 2. Active tectonic map of Turkey (Okay vd 2000).

2.3 Introduction of Investigated Neighborhoods

Within the scope of the study, liquefaction analyzes were made by examining the soil reports in Lala Hüseyin Paşa, Gaybiefendi and Meydan neighborhood in the Central district of Kütahya. The boundaries of the study area are shown in Figure 3.

Figure 3. The boundaries of the study area (General Directorate of Land Registry and Cadastre).

2.4 Investigation Boreholes

The locations of the examined boreholes are given in the figures below. 33 boreholes in Meydan neighborhood, 44 boreholes in Gaybiefendi neighborhood and 35 boreholes in Lala Hüseyin Paşa neighborhood were investigated.

Figure 4. Locations of Boreholes for Gaybiefendi Neighborhood (General Directorate of Land Registry and Cadastre).

Figure 5. Locations of Boreholes for Meydan Neighborhood (General Directorate of Land Registry and Cadastre).

Figure 6. Locations of Boreholes for Lala Hüseyin Paşa Neighborhood (General Directorate of Land Registry and Cadastre).

2.5 Calculation of Soil Parameters

2.5.1 Shear Velocity (V_S)

Iyisan 1996 equation (1) is used for the shear velocity value.

$$Vs = 51{,}5 \times N^{0{,}516} \quad (1)$$

Vs = Shear Velocity
N = N_{30} value (for SPT)

2.5.2 Unit Weight

There are no unit weight values in the obtained soil reports. The values in Table 1 are taken as a reference for the unit weight data of the soils.

Chart 1. Typical density values of some soils (Hansbo 1975).

Soil Type	Density (Mg/m^3)		
	ρ_{sat}	ρ_d	ρ'
Sands and Gravels	1,9-2,4	1,5-2,3	0,9-1,4
Silts and Clays	1,4-2,1	0,6-1,8	0,4-1,1
Organic silts and clays	1,3-1,8	0,5-1,5	0,3-0,8

* ρ_{sat} = saturated density, ρ_d = dry density,
ρ' = density under water

2.5.3 N_{60} Value

Many factor affect the result while performing the SPT (Standard Penetration) test. The SPT test is used in many parts of the world and the results obtained need to be corrected to be global. Various parameters have been created for this. Equation (2) was used for the N_{60} value in this study.

$$N_{60} = (SPT - N) \times C_E \times C_R \qquad (2)$$

SPT-N = N_{30} value
N_{60} = SPT N value corrected to 60% of the theoretical free fall hammer energy
C_E = Energy correction factor
C_R = Drill Length correction factor

C_E value constant is 0.75 and C_R values are given in Table 2.

Chart 2. C_R correction factors used in the study.

Depth (m)	Drill Length correction factor (C_R)
≤ 3	0,75
4,5	0,85
6	0,95
7,5	0,95
9	0,95
10-30	1,00

2.5.4 Overburden Correction Factor (C_N)

Liao and Whitman (1986) equation (3) is applied for the C_N value.

$$C_N = \sqrt{\frac{1}{0{,}01 \times \sigma_V'}} \quad \leq 1{,}70 \qquad (3)$$

σ_v' = Effective stress
C_N = Overburden correction factor

2.5.5 Angle of Internal Friction (ϕ)

Hatanaka and Uchida 1996 equation (4) was used to find the internal friction angle (ϕ) value of gravel, sand and silt type soils.

$$\phi = \sqrt{20 \times (N_1)_{60}} + 20 \qquad (4)$$

ϕ = Angle of Internal Friction
$(N_1)_{60}$ = When calculating $(N1)_{60}$, C_N is multiplied by N_{60}.
Angle of internal friction (ϕ) was calculated from the expression corresponding to the PI (Plasticity index) value shown in Figure 7 for clay soils.

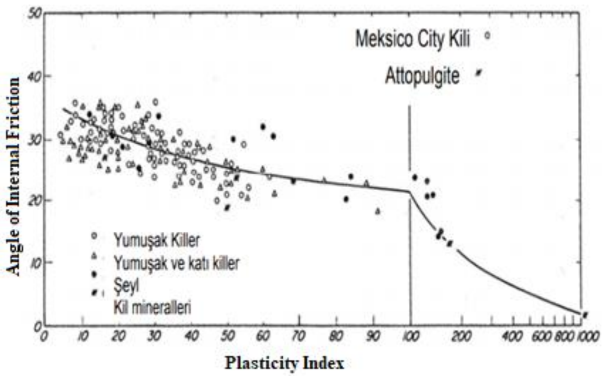

Figure 7. Relationship between the plasticity index and the angle of internal friction (Terzaghi vd. 1996).

2.5.6 Coefficient of Earth Pressure At Rest (K_0)

Jacky 1944 equation (5) was applied to find the K_0 value on gravel, sand and silt soils. K_0 constant 0.5 was used for clays.

$$K_0 = 1 - Sin\phi \quad (5)$$

ϕ = Angle of Internal Friction
K_0 = Coefficient of Earth Pressure At Rest

2.5.7 Undrained Shear Strength (C_u)

Equation (6) was used for the undrained shear strength.

$$C_u = \sigma' \times tan\varphi \quad (6)$$

C_u = Undrained Shear Strength
ϕ = Angle of Internal Friction
σ' = Effective Stress

2.5.8 Overconsolidation Ratio (OCR)

The over-consolidation ratio (OCR) was determined using equation (7).

$$OCR = 0,193 \times \left(\frac{N_{60}}{\sigma'/1000}\right)^{0,689} \quad (7)$$

OCR = Overconsolidation Ratio
σ' = Effective Stress
N_{60} = SPT N value corrected to 60% of the theoretical free fall hammer energy

2.6 Pore water Pressure Models

The pore pressure generation models are given in Table 3.

Chart 3. Pore water pressure models and parameters (Hashash vd. 2016).

Model	Soil Type	Abbrev.	Model No	Parameters						
				1	2	3	4	5	6	7
Dobry& Matasovic	Sand	S-M /D	1	F	p	F	s	γ_{tvp}	v	-
Matasovic & Vucetic	Clay	C-M	2	S	r	A	B	C	D	γ_{tvp}
GMP	Cohesioneless	GMP	3	A	Dr (%)	FC (%)	-	-	v	-
Park& Ahn	Sand	P/A	4	A	β	D_{ru}=1	CSR_t	-	v	-
Generalized	Any	G	5	A	β	-	-	-	v	-

2.6.1 Dobry / Matasovic Model

Matasovic and Vucetic (1993,1995) suggested equation (8) for sand soils.

$$u_N = \frac{p*f*N_C*F*(\gamma_C-\gamma_{tvp})^S}{1+f*N_C*F*(\gamma_C-\gamma_{tvp})^S} \quad (8)$$

The definitions of the parameters in Equation (8) are given in Table 4.

Chart 4. Dobry / Matasovic Model Parameters.

PARAMETERS	DESCRIPTION
u_N	Normalized excess pore pressure ($r_u = u'/\sigma_v'$).
N_{eq}	Equivalent number of cycles.
γ_c	The current reversal shear strain
γ_{tvp}	Threshold shear strain value.
P	Curve fitting parameter. It takes a value between 1±% 7,1 for sands of different types and relative densities. In the absence of laboratory data, p = 1 is usually assumed.
S	Curve fitting parameter. $s = (FC + 1)^{0,1252}$ (FC, fine soil ratio %.) (Carlton, 2014)
F	Curve fitting parameter. $F = 3810 * V_S^{-1,55}$ (V_s , Shear Velocity m/s.) (Carlton, 2014)
F	Dimensionality factor. For 1D motion f=1, For 2D motion f=2.
V	Degradation parameter.

2.6.2 Matasovic / Vucetic Model

Matasovic and Vucetic, (1995) suggested equation (9) for clay soils in this model.

$$u_N = AN_C^{-3s(\gamma_c-\gamma_{tvp})^r} + BN_C^{-2s(\gamma_c-\gamma_{tvp})^r} + CN_C^{-s(\gamma_c-\gamma_{tvp})^r} + D \qquad (9)$$

The explanations of the parameters in equation (9) are given in table 5.

Chart 5. Matasovic / Vucetic Model Parameters.

PARAMETERS	DESCRIPTION
u_N	Normalized excess pore pressure ($r_u = u'/\sigma_v'$).
N_{eq}	Equivalent number of cycles
γ_c	The most recent reversal shear strain.
γ_{tvp}	Threshold shear strain value.
r	Curve fitting parameter. $r = 0,7911 \times PI^{-0,113} \times OCR^{-0,147}$ (Carlton, 2014).
s	Curve fitting parameter. $s = 1,6374 \times PI^{-0,802} \times OCR^{-0,417}$ (Carlton, 2014).
A	Curve fitting coefficients. $A = \begin{cases} OCR < 1,1 \ for \ 7,6451 \\ OCR \geq 1,1 \ for \ 15,641 \times OCR^{-0,242} \end{cases}$ (Carlton, 2014).
B	Curve fitting coefficients. $B = \begin{cases} OCR < 1,1 \ for \ -14,714 \\ OCR \geq 1,1 \ for \ -33,691 \times OCR^{-0,33} \end{cases}$ (Carlton, 2014).
C	Curve fitting coefficients. $C = \begin{cases} OCR < 1,1 \ for \ 6,38 \\ OCR \geq 1,1 \ for \ 21,45 \times OCR^{-0,468} \end{cases}$ (Carlton, 2014).
D	Curve fitting coefficients. $D = \begin{cases} OCR < 1,1 \ for \ 0,6922 \\ OCR \geq 1,1 \ for \ -3,4708 \times OCR^{-0,857} \end{cases}$ (Carlton, 2014).

* PI : Plasticity Index, OCR : Overconsolidation Ratio

2.7 Pore Pressure Generation Models Used in The Study

Matasovic/Vucetic and Dobry/Matasovic models were used in the study. Which soil type they are used in are given in Table 6.

Table 6. The pore water pressure models used in the study.

Soil Type	Used Model
Clay	Matasovic & Vucetic
Silt **Silt (NP)**	Matasovic & Vucetic Dobry & Matasovic
Gravel	Dobry & Matasovic
-Sand (fine soil ratio less than 30%) **-Sand (fine soil ratio greater than 30%)** **-Sand (fine soil ratio greater than 30% and NP)**	-Dobry & Matasovic -Matasovic & Vucetic -Dobry & Matasovic

* NP : non-plastic

2.8 Determination of Earthquake Records

Chart 7. Earthquakes used in the analysis (AFAD).

Earthquake	Magnitude (M_w)	Depth (km)
Adana (Ceyhan) 27.06.1998	6.2	23
Bingöl 01.05.2003	6.1	6
Chi Chi (Taiwan) 21.09.1999	7.3	8
Denizli 20.03.2019	5.5	10.76
Dinar (Afyon) 01.10.1995	6.1	5
Düzce 12.11.1999	7.2	11
Elazığ 24.01.2020	6.8	8.06
Erzincan 13.03.1992	6.6	23
Kobe 17.01.1995	6.9	17.6
Kocaeli 17.08.1999	7.4	15.9
Van 23.10.2011	6.7	19.02

* Mw : Moment magnitude

Earthquakes were scaled with the earthquake ground motion level (DD) data of the neighborhoods. The term DD is specified in the Turkish Building Earthquake Code (TBDY 2018) as follows.

Earthquake Ground Motion Level-1, (DD-1): The probability of exceeding its magnitude is 2% (in 50 years) and its equivalent is the ground motion corresponding to 2475 years of recurrence time (TBDY 2018).

Earthquake Ground Motion Level-2, (DD-2): The probability of exceeding its magnitude is 10% (in 50 years) and its equivalent is the ground motion corresponding to 475 years of recurrence time. DD-2 is also referred to as design ground motion (TBDY 2018).

Earthquake Ground Motion Level-3, (DD-3): The probability of exceeding its magnitude is 50% (in 50 years) and its equivalent is the ground motion corresponding to 72 years of recurrence time (TBDY 2018).

Earthquake Ground Motion Level-4, (DD-4): The probability of exceeding its magnitude is 68% (in 50 years), it is 50% for 30 years and its equivalent is the ground motion corresponding to 43 years of recurrence time (TBDY 2018).

As stated in TBDY, the peak ground acceleration (PGA) data were determined with the help of Turkey Earthquake Hazard Maps (AFAD) for DD-1, DD-2, DD-3, DD-4 in Lala Hüseyin Paşa, Gaybiefendi and Meydan neighborhoods. In line with the determined data, 11 earthquakes in Table 7 were scaled for each earthquake ground motion level. As a result, 44 earthquake records were obtained. The PGA values found for the neighborhoods are shown in Table 8.

Chart 8. Acceleration values used in scaling earthquake records.

Earthquake Ground Motion Levels	PGA (g)
DD-1	0,78
DD-2	0,37
DD-3	0,10
DD-4	0,07

* PGA : Peak Ground Acceleration

3. Results

Matasovic&Vucetic or Dobry&Matasovic model was applied according to the soil type in the examined boreholes. The specified parameters were calculated at every 1,5 meters of depth in the boreholes. Soil profiles were created by entering the calculated pore pressure generation model data and soil parameters into the Deepsoil 6.1 software. Analyzes were made for the boreholes with the determined earthquake records and liquefaction maps were created according to the earthquake ground motion levels (DD) specified in TBDY (2018).

3.1 Determination of Liquefaction Potentials

In order to show the sequence of operations required to perform the liquefaction analysis, the borehole located at Plot 232/5 and 39.4286 latitude 29.9864 longitude coordinates in Gaybiefendi neighborhood is shown as an example The described steps were applied to all boreholes and in line with the results, liquefaction maps were created in the neighborhoods.

Soil type, groundwater level, SPT number, plasticity index and fine soil ratio values were taken from the boreholes report. Using these values, the necessary soil parameters were calculated (Table 9). Table 10 was created by calculating the necessary data for the pore pressure generation models used according to the soil type. First the pore water pressure analysis was defined in the Deepsoil software (Figure 8).

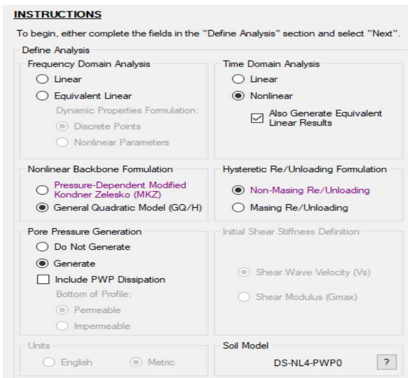

Figure 8. Definition of pore water pressure analysis in Deepsoil 6.1 software.

Chart 9. Soil parameter values of the borehole with 39.4286 / 29.9864 coordinates.

Depth (m)	N_{30}	Vs (m/s)	Soil Type	Fine Soil Ratio (under sieve 200 numbered) (%)	Density (gr/cm^3)	Effective Stress (kN/m^2)	$(N_1)_{60}$	Plasticity Index	N_{60}	OCR	Ko	C_N	Angle of Internal Friction ° (ϕ)
1,50	11	177,49	SM	31,40	1,89	13,9057	10,52	NP	6,19	1,00	0,43	1,700	34,50
3,00	11	177,49	SM	38,60	1,89	41,717	9,58	NP	6,19	1,00	0,44	1,548	33,84
4,50	9	160,03	SM	38,60	1,94	62,5377	7,26	17,4	5,74	1,00	0,47	1,265	32,05
6,00	7	140,57	SC	41,50	1,94	76,3677	5,71	17,4	4,99	1,00	0,49	1,144	30,68
7,50	8	150,59	SC	29,30	1,94	90,1977	6,00	18	5,70	1,00	0,49	1,053	30,96
9,00	5	118,16	SC	43,20	1,94	104,028	3,49	20,2	3,56	1,00	0,53	0,980	28,36
10,50	12	185,64	SM	43,20	1,94	117,858	8,29	20,2	9,00	1,00	0,46	0,921	32,88
12,00	16	215,34	SM	23,70	1,94	131,688	10,46	NP	12,00	1,00	0,43	0,871	34,46
13,50	8	150,59	SM	23,70	1,94	145,518	4,97	NP	6,00	1,00	0,50	0,829	29,97
15,00	19	235,31	SM	49,20	1,94	159,348	11,29	NP	14,25	1,00	0,43	0,792	35,03
16,50	10	168,97	SM	49,20	1,94	173,178	5,70	NP	7,50	1,00	0,49	0,760	30,68
18,00	13	193,46	SC	44,60	1,94	187,008	7,13	23,4	9,75	1,00	0,47	0,731	31,94
19,50	7	140,57	SC	44,60	1,94	200,838	3,70	23,4	5,25	1,00	0,52	0,706	28,61

* The groundwater level is at 3 meters.

Chart 10. The pore pressure generation model parameters of the borehole with 39.4286 / 29.9864 coordinates.

Depth (m)	Vs (m/s)	Soil Type	Fine Soil Ratio (under sieve 200 numbred) (%)	PI	OCR	Model Dobry & Matasovic: 1 Matasovic & Vucetic: 2	f: 2 s	p: 1 r	F A	s B	ɣ: 0,06 C	v: 1 D	_ ɣ: 0,1
1,5													
3,0													
4,5	160,0281	SM	38,6	17,4	1	2	0,1657	0,5729	7,6451	-14,714	6,38	0,6922	0,1
6,0	140,5652	SC	41,5	17,4	1	2	0,1657	0,5729	7,6451	-14,714	6,38	0,6922	0,1
7,5	150,5919	SC	29,3	18	1	1	2	1	1,6045	1,5328	0,06	1	_
9,0	118,1614	SC	43,2	20,2	1	2	0,1470	0,5633	7,6451	-14,714	6,38	0,6922	0,1
10,5	185,6371	SM	43,2	20,2	1	2	0,1470	0,5633	7,6451	-14,714	6,38	0,6922	0,1
12,0	215,3442	SM	23,7	NP	1	1	2	1	0,9217	1,4941	0,06	1	_
13,5	150,5919	SM	23,7	NP	1	1	2	1	1,6045	1,4941	0,06	1	_
15,0	235,312	SM	49,2	NP	1	1	2	1	0,8033	1,6328	0,06	1	_
16,5	168,9691	SM	49,2	NP	1	1	2	1	1,3422	1,6328	0,06	1	_
18,0	193,4648	SC	44,6	23,4	1	2	0,1306	0,5540	7,6451	-14,714	6,38	0,6922	0,1
19,5	140,5652	SC	44,6	23,4	1	2	0,1306	0,5540	7,6451	-14,714	6,38	0,6922	0,1

* The groundwater level is at 3 meters.

After the definition phase of the analysis, soil parameter data (Table 9) and pore pressure generation model data (Table 10) were entered into the software for each 1,5 meters section of the borehole and the soil profile was obtained. Darendeli 2001 was used for reference curves in the software.

11 earthquakes were selected for earthquake records (Table 7). Peak ground acceleration (PGA) data (Table 8) for neighborhoods were obtained from the Turkey Earthquake Map (AFAD) for ground motion levels defined in TBDY (2018). Selected earthquakes were scaled with PGA data and a total of 44 earthquake records were created. Each borehole was analyzed with these 44 earthquake records

As a result of DD-1, DD-2, DD-3 and DD-4 earthquake analysis of the borehole with 39.4286 / 29.9864 coordinates, the pore water pressure ratios obtained from the Deepsoil software are given in Figures 9, 10, 11, 12, respectively. The pore water pressure ratio values vary between 0-1 and the closer it is to 1, the higher the risk of liquefaction.

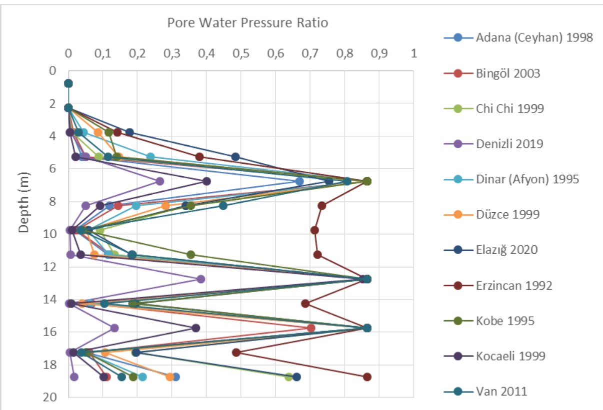

Figure 9. Pore water pressure ratios as a result of the DD-1 analysis of the borehole with 39.4286 / 29.9864 coordinates.

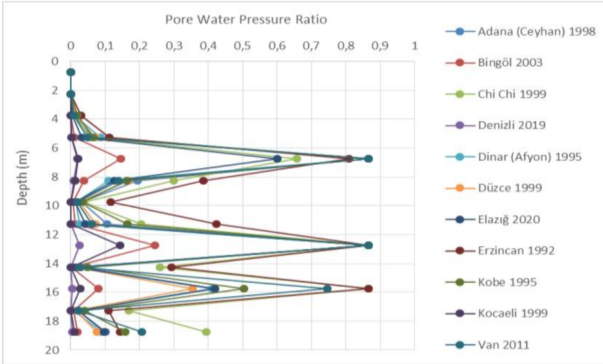

Figure 10. Pore water pressure ratios as a result of the DD-2 analysis of the borehole with 39.4286 / 29.9864 coordinates.

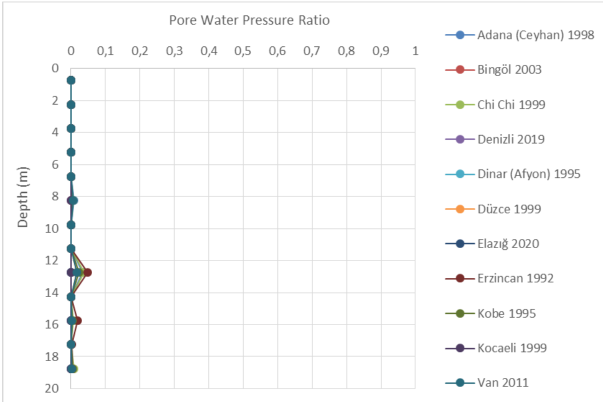

Figure 11. Pore water pressure ratios as a result of the DD-3 analysis of the borehole with 39.4286 / 29.9864 coordinates.

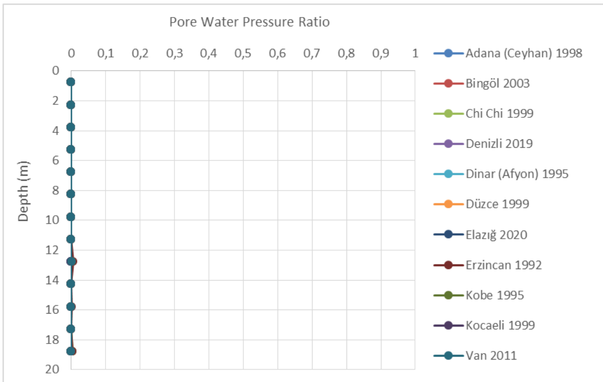

Figure 12. Pore water pressure ratios as a result of the DD-4 analysis of the borehole with 39.4286 / 29.9864 coordinates.

Upon completion of the analysis of the borehole, the graphs of the pore water pressure ratios were created for DD-1, DD-2, DD-3 and DD-4. The maximum pore water pressure ratio value was taken for each DD. İn this borehole, values of 0,865 for DD-1, 0,865 for DD-2, 0,049 for DD-3 and 0,005 for DD-4 were found and these analysis steps were performed for each boreholes and liquefaction maps of the neighborhoods were created.

3.2 Creation of Liquefaction Map

As a result of the analysis, the maximum pore water pressure ratio value at each ground motion level (DD) was taken for the boreholes. Liquefaction maps were obtained for the neighborhoods by using geographic information systems (The boundaries of the neighborhoods were obtained from the General Directorate of Land Registry and Cadastre).

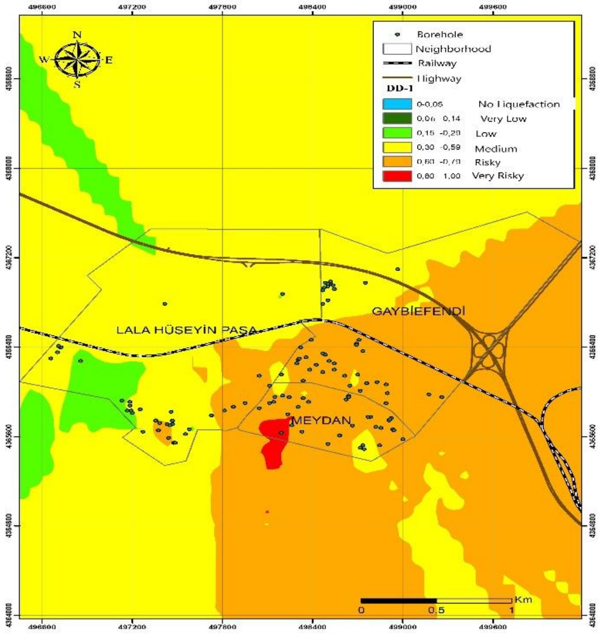

Figure 13. Liquefaction map for DD-1.

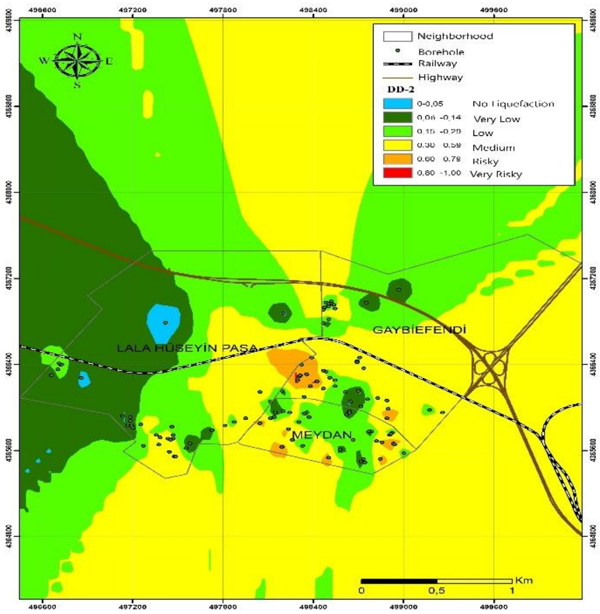

Figure 14. Liquefaction map for DD-2.

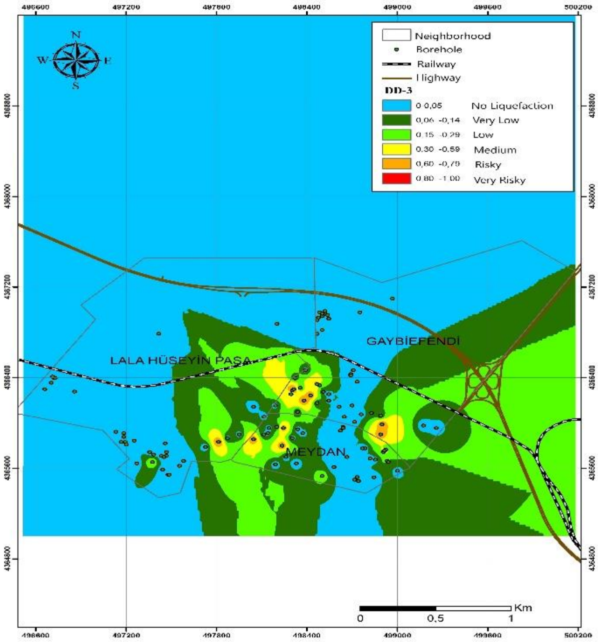

Figure 15. Liquefaction map for DD-3.

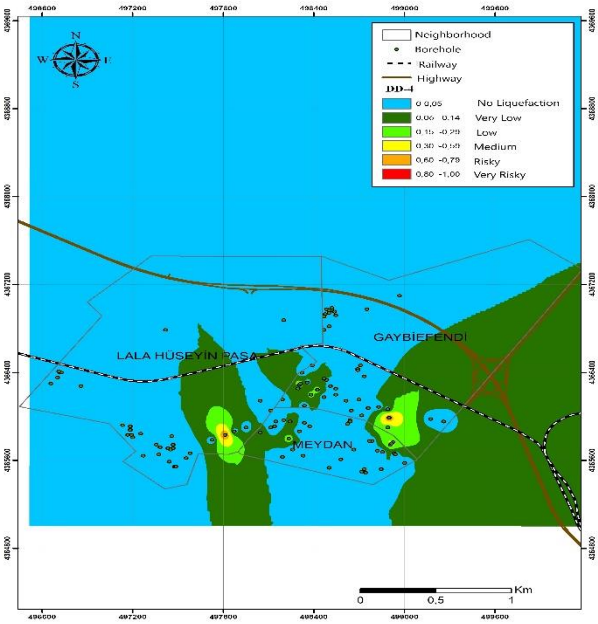

Figure 16. Liquefaction map for DD-4.

The blue parts on the maps represent the regions between 0 - 5% of the liquefaction risk.

4. Discussion and Conclusion

By calculating the average of the analysis results, average liquefaction risks were created for the neighborhoods.

- According to DD-1 analysis liquefaction results; The average liquefaction risk is 48% in Lala Hüseyin Paşa neighborhood, 63% in Gaybiefendi neighborhood and 68% in Meydan neighborhood. There are regions with a liquefaction risk of more than 80% in the Meydan neighborhood (Figure 13).

- According to DD-2 analysis liquefaction results; The average liquefaction risk is 23% in Lala Hüseyin Paşa Neighborhood, 40% in Gaybiefendi neighborhood and 35% in Meydan neighborhood. There are regions with the liquefaction risk is less than 5% in Lala Hüseyin Paşa neighborhood (Figure 14).

- According to DD-3 analysis liquefaction results; The average liquefaction risk is 4% in Lala Hüseyin Paşa neighborhood, 15% in Gaybiefendi neighborhood and 12% in Meydan neighborhood (Figure 15).

- According to DD-4 analysis liquefaction results; The average liquefaction risk is 3% in Lala Hüseyin Paşa neighborhood, 5% in Gaybiefendi neighborhood and 5% in Meydan neighborhood (Figure 16).

- The average groundwater level is at 4 m in Lala Hüseyin Paşa neighborhood, at 3 m in Gaybiefendi neighborhood and at 4,5 m in Meydan neighborhood. The fact that the groundwater level is so close to the surface increases the risk of liquefaction of the neighborhoods. SPT data is generally high in Lala Hüseyin Paşa neighborhood so liquefaction potential is low compared to Meydan and Gaybiefendi neighborhoods.

- The liquefaction maps created will help to take the necessary precautions in the neighborhoods. It is recommended to take measure in settlements where the risk of liquefaction is high.

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