P-ISSN: 2776-7329, E-ISSN: 2776-7310
Proceedings
5th Vocational Education International Conference
Semarang, 13 July 2023

Analysis of Potential Liquifaction Risk Using the Simple Procedure Method Based on Standard Penetration Test (SPT) Data

Case Study Of Medan Tuntungan SubDistrict, North Sumatera

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ABSTRACT
The direct result of an earthquake can be in the form of damage to the soil structure by reducing the carrying capacity of the soil resulting in a decrease in the shear strength of the soil due to an increase in pore water and a reduction in the effective stress (liquefaction). The source of the earthquake around the Medan Tuntungan sub-district is predicted to originate from a fault that has not been identified properly but earthquakes have been recorded and the cause of an active or inactive fault is unknown. The aim of this research is to determine the liquefaction potential index regionally using a simple procedure method. The research was conducted in the Medan Tuntungan sub-district. The results showed that the potential for liquefaction is high to very high. The high liquefaction potential index values are 5.95 to 14.72 and the very high liquefaction potential index values are 16.59 to 17.60.

Keywords*: Risk, Liquefaction, Earthquake, Region, SPT data.*

1. INTRODUCTION

Earthquake events that occurred and were felt in Medan City included the earthquake on November 15, 1996 with a magnitude of 4.1M at a depth of 100 km with the epicenter of the earthquake 1.2 km from Kutalimbaru sub-district; the earthquake that occurred on October 24, 1999 with a magnitude of 4.4M at a depth of 150.7km with the epicenter of the earthquake 4.82km from the Merdeka sub-district; the earthquake that occurred on December 20, 2005 at a depth of 30km with a magnitude of 4.4M at a distance of 3.81km from Pancur Batu sub-district; the earthquake that occurred on January 16, 2017 at a depth of 6 km with an epicenter 24 km from Kabanjahe sub-District, Karo Regency and with the closest distance to the city of Medan and its surroundings is 8.91 km from Sibolangit sub-district; the earthquake that occurred on February 9, 2017 at a depth of 42.47 km and a magnitude of 4.4M with an epicenter 5.15km from Sibolangit sub-district.

According to [9] [10] damage caused by earthquakes can be divided into two types, namely: indirect damage to the soil which causes liquefaction, cyclic mobility, lateral spreading, to slope failures, soil cracks, subsidence and excessive deformation, as well as damage structure as a direct result of the inertial forces that the building receives during shaking.

Liquefaction is defined as the transformation of solid materials consisting of loose granules (granular) from a solid to a liquid state as a result of an increase in pore water pressure and a reduction in effective stress. [5]. Liquefaction is the effect of shaking resulting in a sudden decrease in the shear strength of the soil due to excess pore and pressure reduction. [8]. Liquefaction is a serious natural disaster in an area prone to earthquakes. [11].

The principle in liquefaction analysis is to compare the value of the Factor of Safety (FS) to liquefaction by comparing the Cyclic Resistance Ratio (CRR) and Cyclic Stress Ratio (CSR) values. [5]. CSR is the cyclic stress that causes liquefaction and CRR is the ability of the soil to withstand liquefaction obtained from the SPT field test. Liquefaction occurs if the FS value is less than 1 and liquefaction does not occur if the FS value is greater than 1.

Parameters for evaluating the level of liquefaction potential regionally using the Liquefaction Potential Index (LPI) method [4]. The liquefaction potential index (LPI) is a single value parameter to evaluate the liquefaction potential of the entire soil column. It combines depth, thickness and an indicator of the occurrence of liquefaction (safety factor or probability of liquefaction). Soil effects of liquefaction were limited to a depth of 20 m as no liquefaction damage was reported for the greater depths. [12], [8], [4], [5], [3].

The purpose of this research is to assess the Liquefaction Potential Index (LPI) for the Medan Tuntungan sub-district based on an earthquake with a magnitude of 5.5

2. METHOD

The method in this research is case study research of an area with components that affect liquefaction and provides a description of the liquefaction potential index (LPI) based on the Standard Penetration Test (SPT) field test around the study area. The LPI value is calculated using a simple procedure (simplified procedure) and the potential impact of liquefaction is measured based on the equation presented by [5] and [6] where the Safety Factor (FS) for liquefaction is by comparing the Cyclic Resistance Ratio (CRR) and Cyclic Stress Ratio (CSR) values.). Liquefaction occurs if the FS value is less than 1 and liquefaction does not occur if the FS value is greater than 1. The form of the safety factor equation is as follows:

$$\mathrm{FS} = \frac{\mathrm{CRR}_{7.5}}{\mathrm{CSR}} \qquad (1)$$

Cyclic Stress Ratio (CSR) is the ratio of cyclic stress which is affected by the maximum acceleration of the earthquake on the ground surface, total vertical stress, effective vertical stress and stress reduction in the soil.

$$\mathrm{CSR} = 0{,}65 \left(\frac{\mathrm{a_{mak}}}{\mathrm{g}}\right)\left(\frac{\sigma_{vo}}{\sigma_{vo'}}\right)\mathrm{r_d} \qquad (2)$$

Where :

CSR	:	Cyclic Stress Ratio
amax	:	maximum acceleration at ground level g the acceleration due to gravity
g	:	the acceleration due to gravity
σ_{vo}	:	total vertical stress
$\sigma_{vo'}$	:	effective vertical stress
rd :	:	coefficient of reduction factor, which is a value that can affect stress in the soil and calculated by the equation:

$$\mathrm{r_d} = \frac{(1.000-0.4113\mathrm{z}^{0.5}+0.04052\mathrm{z}+0.001753\mathrm{z}^{1.5})}{(1.000-0.4177\mathrm{z}^{0.5}+0.05729\mathrm{z}-0.006205\mathrm{z}^{1.5}+0.001210\mathrm{z}^{2})} \quad (3)$$

z is the depth in meters

Cyclic Resistance Ratio (CRR) is the ability of the soil to withstand liquefaction. The CRR value can be calculated based on field test data such as the Standard Penetration Test (SPT) on an earthquake scale of Magnitude 7.5 which is described in the following equation:

$$\mathrm{CRR}_{7.5} = \frac{1}{34-(\mathrm{N1})_{60cs}} + \frac{(\mathrm{N1})_{60cs}}{135} + \frac{50}{[10\ (\mathrm{N1})_{60cs}=45]^2} - \frac{1}{200} \qquad (4)$$

Where (N1)60cs is a correction factor which is equivalent to clean sand with a Fines Content (FC) limit of <5%. [10]. The equation for the value of (N1)60cs is as follows:

$$(\mathrm{N1})_{60cs} = \alpha + \beta(\mathrm{N1})_{60} \qquad (5)$$

value $\alpha = 0$ and $\beta = 1$ for FC value < 5%. (N1) 60 is the normalized N-SPT penetration resistance value at 1 atm overburden pressure due to a free-fall hammer with 60% energy efficiency which has undergone many corrections from the N-SPT results obtained directly in the field. [10]. The correction for the value (N1)60 is shown in the following equation:

$$(\mathrm{N1})_{60} = \mathrm{N_M}\ \mathrm{C_N}\ \mathrm{C_E}\ \mathrm{C_B}\ \mathrm{C_R}\ \mathrm{C_S} \qquad (6)$$

Where:

N_M	:	N-SPT value obtained from field tests
CN	:	correction factor for effective normalization of overburden pressure and calculated by the equation: $C_N = \frac{2,2}{\left(1,2+\left(\frac{\alpha_{vo'}}{Pa}\right)\right)} \leq 1,7$ (7)
Pa	:	atmospheric pressure (100 Kpa)
CE	:	correction factor for the energy ratio
CB	:	correction factor for borehole diameter
CR	:	correction factor for stem length
CS	:	correction factor for the sample

An earthquake with a magnitude M = 7.5 is a reference earthquake, if an earthquake occurs with a magnitude M < 7.5 then the effect will be smaller for an earthquake with M = 7.5 assuming the soil layer has greater resistance. [5], [10]. To calculate the CRR with an earthquake magnitude greater or less than M = 7.5, a Magnitude Scale Factor (MSF) correction factor is needed which can be calculated with the following equation:

$$\mathrm{CRR}_{\mathrm{M_w}} = \mathrm{CRR}_{7.5} \times \mathrm{MSF} \times \mathrm{K\sigma} \times \mathrm{K\alpha} \qquad (8)$$

Where:
the value of the Kσ variable depends on the analysis of liquefaction potential in soils with a depth of > 15 meters, the Kσ value needs to be corrected and the Kα variable value needs to be corrected if there is a clay layer that has a certain plasticity index, so that in this study the Kσ and Kα variables have values 1.

$$\boldsymbol{MSF} = \frac{\mathbf{10^{2.24}}}{\boldsymbol{M_w}^{\mathbf{2.56}}} \quad \text{for magnitude earthquakes Mw < 7,5} \quad (9)$$

$$\boldsymbol{MSF} = \left(\frac{\boldsymbol{M_w}}{\mathbf{7{,}5}}\right)^{\mathbf{-2.56}} \quad \text{for magnitude earthquakes Mw>7,5} \quad (10)$$

The magnitude values to be analyzed are those around the study area for magnitudes with Mw < 7.5, namely M=5.5 and magnitudes with Mw = 7.5. The parameters for evaluating the level of liquefaction potential regionally are using the Liquefaction Potential Index (LPI) method which refers to [13], with the following equation:

$$\boldsymbol{LPI} = \int_{\mathbf{0}}^{\mathbf{20}} \boldsymbol{F(z)}\ \boldsymbol{w(z)dz} \qquad (11)$$

Where:

LPI	:	Liquefaction Potential Index
z	:	the depth of the midpoint of the soil layer (0 to 20 meters). [4], [8], [14].
H	:	thickness of soil layer (m)
F(z)	:	liquefaction safety factor for each layer of soil
	:	$F(z) = 1 - FS$ for FS < 1
	:	$F(z) = 0$ for FS ≥ 1
w(z)	:	$w(z) = 10 - 0{,}5z$ for z < 20 m
		$w(z) = 0$ for z > 20 m

The level of liquefaction safety is shown in the following table:

Table 1. Liquidation potential safety level

LPI	Information
LPI = 0	Very low
0 < LPI < 5	Low
5 < LPI < 15	High
15 < LPI	Very high

Source: [4], [8], [14]

3. RESULT AND DISCUSSIONS

Based on the Standard Penetration Test (SPT) data in Medan Tuntungan sub-district, there are types of silty clay, coarse sand, silty sandy clay and silty sandy clay at a depth of 0m – 2.5m. Coarse sand is also found at depths of 4.5m – 8.5m. Types of silt sandy soil with pumice rock are found at a depth of 4.5m – 10.5m. Coarse sandy pumice soil types are at a depth of 4.5m – 14.5m. At a depth of 4.5m -6.5m there is a type of silty sand soil mixed with gravel and silty sand, silt sand is also found at 10.5m – 12.5m. The type of soil at a depth of 8.5m – 14.5m is coarse sand with pumice and at a depth of 14.5m – 22.5m there is a type of fine sand with silt. For this type of fine sand soil, it is generally located at a depth of 8.5m – 24.5m. The depth of the groundwater level is between 0.4m – 1.5m. The following table displays data on soil types and soil parameters based on SPT points:

Table 2. soil type data on SPT points

<table>
<tr><th>Depth</th><th colspan="5">POINT SPT</th></tr>
<tr><th>m</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>0</td><td colspan="5">top soil</td></tr>
<tr><td>2.5</td><td>silty clay</td><td>rough sands</td><td>sandy loamy clay</td><td>sandy loamy clay</td><td>silty sandy loam</td></tr>
<tr><td>4.5</td><td rowspan="4">pumice silty sand</td><td rowspan="6">coarse pumice sand</td><td rowspan="3">rough sands</td><td rowspan="2">silty sand mixed with</td><td rowspan="2">silty sand</td></tr>
<tr><td>6.5</td></tr>
<tr><td>8.5</td><td rowspan="7">fine sand</td><td rowspan="4">coarse pumice sand</td></tr>
<tr><td>10.5</td><td rowspan="2">silty sand</td></tr>
<tr><td>12.5</td><td rowspan="5">fine sand</td></tr>
<tr><td>14.5</td><td rowspan="2">fine sand</td></tr>
<tr><td>16.5</td><td rowspan="5">fine sand</td><td rowspan="4">fine silty sand</td></tr>
<tr><td>18.5</td><td></td></tr>
<tr><td>20.5</td><td>-</td></tr>
<tr><td>22.5</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>24.5</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Table 3. soil parameters based on SPT points

Depth	Point SPT - M=5,5									
m	1		2		3		4		5	
	γd g/cm3	γsat g/cm3	γd g/cm3	γsat g/cm3	γd g/cm3	γsat g/cm3	γd g/cm3	γsat g/cm3	γd g/cm3	γsat g/cm3
top soil	0.930	1.580	1.220	1.770	1.220	1.770	1.220	1.770	1.220	1.770
2.50	-	1.580	1.220	2.160	1.220	1.770	1.220	1.770	1.220	1.770
4.50	-	1.990	-	1.990	-	2.160	-	2.160	1.220	1.990
6.50	-	1.990	-	1.990	-	2.160	-	2.160	-	1.990
8.50	-	1.990	-	1.990	-	2.160	-	1.890	-	1.990
10.50	-	1.990	-	1.990	-	1.990	-	1.890	-	1.990
12.50	-	1.890	-	1.990	-	1.990	-	1.890	-	1.990
14.50	-	1.890	-	1.990	-	2.090	-	1.890	-	1.990
16.50	-	1.890	-	2.090	-	2.090	-	1.890	-	1.990
18.50	-	1.890	-	2.090	-	2.090	-	1.890	-	1.990
20.50	-	1.890	-	2.090	-	-	-	1.890	-	1.990
22.50	-		-	2.090	-	-	-	-	-	1.990
24.50	-		-	2.090	-	-	-	-	-	-

From a comparison of the Cyclic Resistance Ratio (CRR) and Cyclic Stress Ratio (CSR) values for an earthquake with a magnitude of 5.5 at SPT point number 1 liquefaction occurred at a depth of 2.5m with an FS value of 0.698. SPT point number 2, SPT number 3 and SPT number 4 liquefaction occurs to a depth of 4.5m with the value of FS SPT number 1 is 0.731, FS SPT number 3 is 0.587 and FS SPT number 4 is 0.567. At SPT number 5 liquefaction occurred at a depth of 2.5m with an FS value of 0.746. Liquefaction also occurred at a depth of 12.5m with an FS value of 0.975 at SPT point number 3. The following table shows the FS values and liquefaction events:

Table 4. Safety Factor values and liquefaction events:

Depth	SPT Point - M=5,5									
m	1		2		3		4		5	
	FS	L/NL	FS	L/NL	FS	L/NL	FS	L/NL	FS	L/NL
-	-		-		-		-		-	
2.50	0.698	L	0.561	L	0.592	L	0.554	L	0.746	L
4.50	14.114	NL	0.731	L	0.587	L	0.567	L	4.926	NL
6.50	14.315	NL	15.317	NL	16.770	NL	16.348	NL	19.549	NL
8.50	14.650	NL	15.436	NL	16.814	NL	16.053	NL	18.519	NL
10.50	15.232	NL	15.894	NL	1.217	NL	16.251	NL	18.374	NL
12.50	1.455	NL	3.675	NL	0.975	L	2.140	NL	3.976	NL
14.50	2.092	NL	3.154	NL	19.128	NL	18.085	NL	3.012	NL
16.50	18.751	NL	3.533	NL	20.790	NL	19.549	NL	21.494	NL
18.50	20.332	NL	3.692	NL	22.539	NL	21.101	NL	23.087	NL
20.50	21.802	NL	23.212	NL	-		22.541	NL	24.569	NL
22.50	-		24.642	NL	-		-		25.829	NL
24.50	-		5.683	NL	-		-		-	

L : Likuifaksi
NL : Non Likuifaksi

The level of regional liquefaction potential (LPI) in the Medan Tuntungan sub-district area with a high level is at point SPT number 1, SPT number 2 and SPT number 3, the LPI value is 7.08 for SPT number 1, the LPI value is 14.72 for SPT number 2 and LPI value of 5.95 for SPT number 5. The level of liquefaction potential with a very high level is at SPT number 3 and SPT number 4, with an LPI value of 16.59 on SPT number 3 and LPI of 17.60 on SPT number 4. The potential for liquefaction occurs up to a depth of 4.5 meters. The following table displays the Potential Liquefaction Index (LPI):

Table 5. Level of Potential Liquefaction Index (LPI):

Depth m	H	SPT POINT														
		1			2			3			4			5		
		w(z)	F(z)	LPI	w(z)	F(z)	LPI	w(z)	F(z)	LPI	w(z)	F(z)	LPI	w(z)	F(z)	LPI
-																
2.50	2.50	9.38	0.30	7.08	9.38	0.44	10.28	9.38	0.41	9.56	9.38	0.45	10.46	9.38	0.25	5.95
4.50	2.00	8.25	0	-	8.25	0.27	4.44	8.25	0.41	6.82	8.25	0.43	7.14	8.25	0	-
6.50	2.00	7.25	0	-	7.25	0	-	7.25	0	-	7.25	0	-	7.25	0	-
8.50	2.00	6.25	0	-	6.25	0	-	6.25	0	-	6.25	0	-	6.25	0	-
10.50	2.00	5.25	0	-	5.25	0	-	5.25	0	-	5.25	0	-	5.25	0	-
12.50	2.00	4.25	0	-	4.25	0	-	4.25	0.03	0.21	4.25	0	-	4.25	0	-
14.50	2.00	3.25	0	-	3.25	0	-	3.25	0	-	3.25	0	-	3.25	0	-
16.50	2.00	2.25	0	-	2.25	0	-	2.25	0	-	2.25	0	-	2.25	0	-
18.50	2.00	1.25	0	-	1.25	0	-	1.25	0	-	1.25	0	-	1.25	0	-
20.50	2.00	0.25	0	-	0.25	0	-	-		-	0.25	0	-	0.25	0	-
22.50	2.00	-		-	0	0	-	-		-	-		-	0	0	-
24.50	2.00	-		-	0	0	-	-	-	-	-		-	-		-
LPI				7.08			14.72			16.59			17.60			5.95
Level: Iwasaki et al, 1982				High			High			Very high			Very high			High

4. CONCLUSION

The results showed that the potential for liquefaction in the Medan Tuntungan sub-district is high to very high. With a liquefaction potential index value of 7.08 at SPT point number 1 with a high level. The liquefaction potential index at SPT point number 2 is high with a value of 14.72. The liquefaction potential index at SPT point number 3 is very high with a value of 16.59. The liquefaction potential index at SPT point number 4 is very high with a value of 17.60 and the liquefaction potential index at SPT point number 5 is high with a value of 5.95.

AUTHORS' CONTRIBUTIONS

The title of the research is: Analysis Of Potential Liquifaction Risk Using The Simple Procedure Method Based On Standard Penetration Test (SPT) Data. Case Study of Medan Tuntungan Sub-District, North Sumatra

Edo Barlian (EB), Bambang Hadibroto (BH), Kemala Jeumpa (KJ), Wisnu Prayogo (WP) and Rumila Harahap (RH) understood the ideas presented, designed the concepts and verified the methods in this study. EB, BH and WP develop theory, conduct surveys and collect data. EB, KJ and RH designed the model and analyzed the data and performed calculations. All contributing authors provided critical feedback and helped shape the research, discussed results and drafted the manuscript.

ACKNOWLEDGMENTS

First of all, the researcher would like to thank LPPM Medan State University for funding this research. The researcher would also like to thank all parties involved in carrying out this research, both those who helped directly or indirectly.

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