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IDENTIFICATION OF CHARACTERISTICS OF SOIL AFFECTED AND NOT AFFECTED LIQUEFACTION AT THE NORTH PART OF PETOBO VILLAGE

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ABSTRACT

On September 28^{th,} 2018, an earthquake measuring 7.4 Mw shook Palu and its surroundings. The effects of this earthquake caused natural disasters, namely liquefaction. One of the areas of Palu City that was affected by liquefaction is located in Petobo Village. With Petobo's position in a relatively sloping area, this situation triggers landslides or landslides along with the liquefaction effect. This study aims to determine the characteristics and bearing capacity of the soil in the affected area and not affected by liquefaction, especially in the central part of the north avalanche. This study consisted of 2 test methods: field testing carried out with the Swedish Weight Sounding at 4 points in the affected area and 2 points in the area unaffected by liquefaction and laboratory testing including sieve analysis, Atterberg limits, direct shear and bulk density. The results of the field research show 3 parameters, namely Nsw, qa and qu. The value of Nsw in the affected area is in the range of 0 n/m-208.33 n/m, the value of qa is in the range of 30 kN/m2-196.67 kN/m2 and the value of qu is in the range of 45 kN/m2-201.25 kN/m2 while the area is not affected, the value of Nsw is in the range of 0 n/m-250 n/m, the value of qa is in the range of 30 kN/m2- 230 kN/m2 and the value of qu is in the range of 45 kN/m2-232.50 kN/m2. Soil classification results from laboratory tests on affected soils are SC (Clayey Sand) and unaffected soil, namely SC (Clayey Sand)and SM (Silty Sand). Based on the SWS parameter, the bearing capacity of the soil in the affected area is 32, 12 t/m2, and the non-affected area is 113, 70 t/m2. Based on the direct shear parameters, the soil bearing capacity in the affected area is 30, 54 t/m2 and the non-affected area is 136, 72 t/m2.

Keywords: petobo village, liquefaction, soil characteristics, soil bearing capacity, swedish weight sounding.

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1. INTRODUCTION

On September 28th, 2018, an earthquake measuring 7.4 Mw rocked the Palu, Sigi and Donggala areas. The effects of this earthquake caused one of the natural disasters that shocked Indonesia at that time, namely the liquefaction event that occurred in Palu City. One of the areas of Palu City that was affected by liquefaction is located in Petobo Village. According to residents' testimonies, the earthquake that occurred in Petobo, followed by mud coming out of the earth, buried parts of the Petobo area, where the asphalt road suddenly bent upwards like sea waves accompanied by a rumbling earthquake, slowly approaching the houses. People's houses, accompanied by loud roars and shaking, the melting of the soil in the form of mud from the bowels of the earth seemed to be under stronger pressure from within, then the vomit formed hills, and slowly hundreds of houses in Petobo collapsed and were drowned by the mud. Otherwise, Petobo's position is located in a relatively sloping area, so this situation triggers ground movements or landslides along with liquefaction effects [1]. The liquefaction potential requires more research in the area.

This research aims to determine the characteristics of soil affected and not affected by liquefaction based on field and laboratory tests. Knowing the comparison of soil bearing capacity in areas affected and not affected by liquefaction based on SWS and direct shear parameters.

Liquefaction is a phenomenon when the strength and stiffness of the soil decrease due to an earthquake or ground movement. This is a process or event that changes the properties of the soil from a solid state to a liquid state, this occurs when water-saturated non-cohesive soil that loses its shear strength is shaken by cyclic (regularly repeated) loads caused by earthquakes so that the pore water pressure will increase to near or exceeds the effective stress. Kertapati (1998) [2], states that soil that experiences liquefaction can endanger the buildings above it or is often referred to as soil structural failure. Kramer (1996) [3], stated that soil deposits that have the potential to experience liquefaction when subjected to cyclic loading are fine sand, silty sand, and loose sand. Muntohar (2010) [4], stated that as water pressure increases due to earthquake shocks, the effective stress decreases. The sand modulus decreases as the effective stress decreases. This causes the sand soil to become soft (melt). As a result, the soil is unable to support the load on it and causes buildings to collapse, tilt, or landslide. Tohari *et al.* (2011) [5], show that this liquefaction phenomenon occurs due to the presence of a layer of water-saturated sand with density varying from loose to medium to a depth of 10 m. Jefferies & Been (2015) [6], stated that liquefaction is a phenomenon of losing the shear strength of the soil in the water-saturated layer due to an earthquake so that the soil collapses and behaves like a liquid. Liquefaction events generally occur in loose to medium saturated granular soil consistencies.

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2. METHODOLOGY

2.1 The Research Location

The research and sampling location is in Petobo Village, South Palu District, Palu City, Central Sulawesi Province. The research location can be seen in Figures 1 and 2.

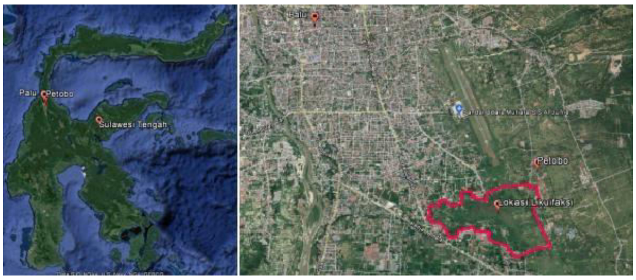

Figure-1. Sulawesi Island, Palu Area and Petobo Village Source: (https://earth.google.com).

2.2 Sampling

Researchers began by conducting a survey of the research location to determine soil sampling points that were considered to represent the soil classification at the research location. Soil sampling was carried out at locations indicated to be affected by liquefaction and not affected by liquefaction. Soil samples were taken at points where 6 SWS tests had been completed, of which 4 soil points were from locations affected by liquefaction and 2 were from locations unaffected by liquefaction. The samples used were disturbed and undisturbed soil samples. The map of the Petobo area before and after the liquefaction occurred can be seen in Figure-2. Field data collection using the Swedish Weight Sounding (SWS) tool was carried out at 6 (six) points, namely 4 (four) points were in areas affected by liquefaction and 2 (two) points were in areas not affected by liquefaction. Sampling for laboratory testing follows the SWS point. The map of the SWS testing location and soil sampling can be seen in the Figure-3.

Location details

a. Affected areas

- **P1:** Latitude: 0°56'15.00"S; Longitude 119°54'40.90"E (Elv. 53 MDPL)
- **P2:** Latitude: 0°56'15.53"S; Longitude 119°54'47.10"E (Elv. 55 MDPL)
- **P3:** Latitude: 0°56'10.05"S; Longitude 119°54'47.61"E (Elv. 56 MDPL)
- **P4:** Latitude: 0°56'9.52"S ; Longitude 119°54'40.90"E (Elv. 54 MDPL)

b. Not Affected areas

- **P5:** Latitude: 0°55'59.48"S; Longitude 119°54'41.02"E (Elv. 56 MDPL)
- **P6:** Latitude: 0°56'0.38"S; Longitude 119°54'48.70"E (Elv. 60 MDPL)

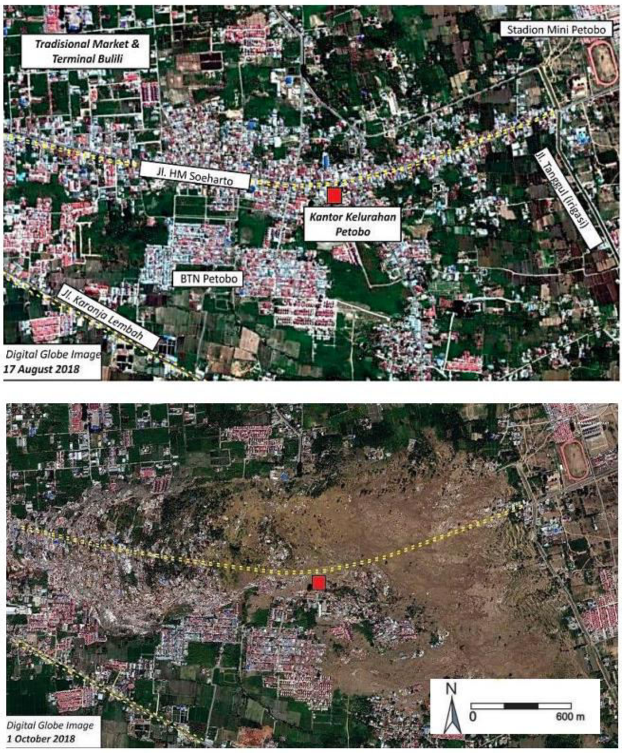

Figure-2. The map of the Petobo area before and after the liquefaction. Source : (https://geologi.co.id).

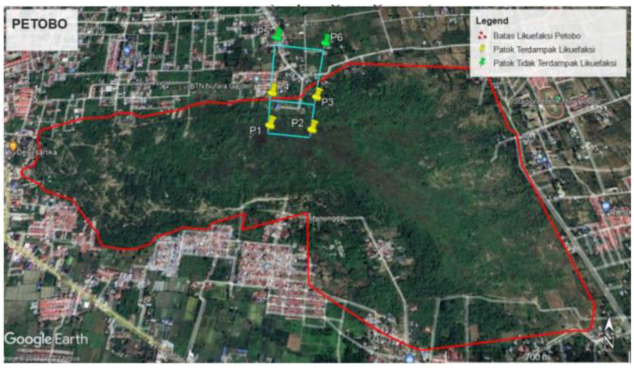

Figure-3. The location of SWS testing and soil sampling source: (https://earth.google.com).

3. RESULT AND DISCUSSIONS

This study consisted of field and laboratory tests. The field testing was carried out with the Swedish Weight Sounding at 4 points in the affected area and 2 points in the area not affected by liquefaction. The results of the field research show 3 parameters, namely Nsw, qa, and qu. The laboratory testing included sieve analysis, Atterberg limits, direct shear, and bulk density.

3.1 The Laboratory Test Results

The Laboratory testing was carried out at the Soil Mechanics Laboratory, Faculty of Engineering, Tadulako University

ARPN Journal of Engineering and Applied Sciences

3.1.1 Sieve analysis

The sieve analysis test was carried out using disturbed soil which was carried out on 6 soil samples located at different points with a depth of 0.5 m from the ground surface. Each sample was dried in an oven for 24 hours at a temperature of 80°C-100°C. Then the soil samples were weighed 1000 grams for each sample. Then the sample is put into sieve no. 3/4, ½, 3/8, ¼, 8, 10, 16, 20, 40, 60, 80, 100, 200 using ASTM D422 [7]. The following is data from the sieve analysis test.

From the results of sieve analysis tests in areas affected by liquefaction, the following data were obtained:

Table-1. Sieve Analysis Result.

Examination Description		P1	P2	P3	P4
Not Pass #4	%	4.5	8.0	66.0	5.5
Not Pass #40	%	37.8	38.2	36.0	38.0
Not Pass #200	%	70.2	69.0	73.5	67.9
Pass #200	%	29.8	31.0	26.5	32.1

Table-1 shows the distribution of soil types in the Unified Soil Classification System (USCS) classification system, showing that of the 4 (four) soil samples in the area affected by liquefaction, they are categorized as coarse-grained soil because less than 50% of the total weight of the soil samples passed the sieve number 200.

Table-2. Granule size D_{10}, D_{30}, D_{50} and D_{60}.

Sample Number	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)
P1	-	0.075	0.22	0.38
P2	-	-	0.23	0.38
P3	-	0.095	0.22	0.33
P4	-	-	0.20	0.35

Hakam (2020) [8], formulated the liquefaction potential based on the D50 soil grain size, where the D50 grain size is: 0.1 mm < D50 < 0.3 mm, this range is the largest range for liquefaction events. The D50 soil grain size in the area affected by liquefaction is in the range of 0.1 mm - 0.3 mm, so it can be concluded that the soil in the area affected by liquefaction is a soil grain that has the liquefaction potential.

Figure-4 shows that most of the soil in the areas affected by liquefaction (P1-P4) falls within the red curve, which means there is a high potential for liquefaction and some of the curve falls within the black curve, which means there is a potential for liquefaction

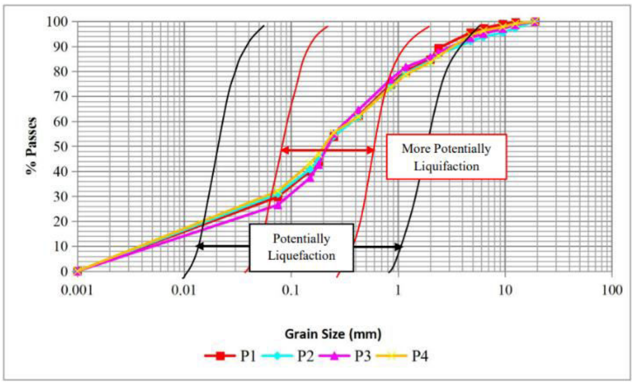

Figure-4. Tsuchida (1970) liquefaction potential graph based on grain size in areas affected by liquefaction.

Figure-4 shows that most of the soil in the areas affected by liquefaction (P1-P4) falls within the red curve, which means there is a high liquefaction potential and some of the curve falls within the black curve, which means there is a liquefaction potential.

From the results of the sieve analysis test in areas not affected by liquefaction, the following data were obtained:

Table-3. Sieve analysis result.

Examination Description		P5	P6
Not Pass #4	%	1.3	10.4
Not Pass #40	%	32.9	51.7
Not Pass #200	%	76.4	83.7
Pass #200	%	23.6	16.3

Table-3 shows the distribution of soil types, the USCS classification system shows that of the 2 (two) soil samples in areas not affected by liquefaction, they were categorized as coarse-grained soil because less than 50% of the total weight of the soil samples passed sieve number 200.

Table-4. Granule size D10, D30, D50 and D60.

Nomor Sampel	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)
P5	-	0.12	0.23	0.32
P6	-	0.18	0.48	0.9

Table-4 shows that the D50 soil grain sizes in areas not affected by liquefaction are P5: 0.23 mm and P6: 0.48 mm. Where the D50 grain size range in the P5 area is 0.1 mm < D50 < 0.3 mm. So it can be concluded that the soil in area P5 is soil granules that have the liquefaction potential. Meanwhile, the soil in area P6 is soil that does not have the liquefaction potential.

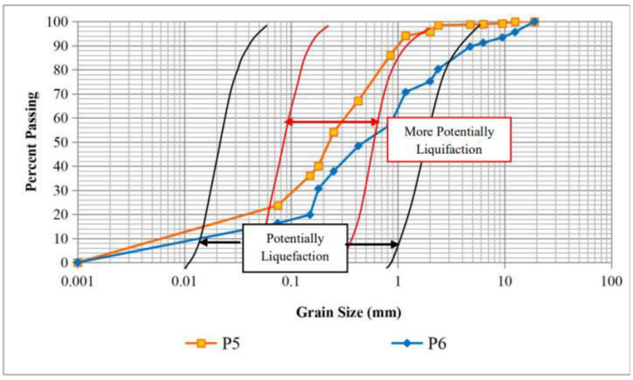

Figure-5. Tsuchida, Liquefaction potential graph based on grain size in areas not affected by liquefaction.

Figure-5 shows the soil in areas not affected by liquefaction P5, almost all of the curves fall within the red curve limits, which means there is a high liquefaction potential and some curves fall within the black curve limits, which means there is a liquefaction potential. Meanwhile, in area P6, some of the curves fall within the red and black curve boundaries, which means that this area has liquefaction potential.

3.1.2 Atterberg limit

From the results of the sieve analysis test, the D10 value was not available for all samples, both in areas affected and not affected by liquefaction, meaning that the D10 value did not meet the requirements for calculating Cu and Cc, so the soil classification was carried out based on the Atterberg limits. The Atterberg Limits test is carried out for disturbed soil samples that more than 50% pass sieve number 40, using ASTM 4318[9]. The following test results can be seen in Table-5.

Table-5. Result of Atterberg limit test.

Area	Point		(LL)	(PL)	(PI)	Soil Classification (USCS)
Affected	P1	%	21.6	10.10	11.50	SC
	P2	%	24.7	12.92	11.78	SC
	P3	%	26.0	18.63	7.37	SC
	P4	%	26.5	17.90	8.60	SC
Not affected	P5	%	24.8	13.17	11.63	SC
	P6	%	41.5	37.63	3.87	SM

Table-5 shows the soil classification system according to USCS, showing that soil samples in areas affected by liquefaction (P1-P4) consist of clayey sand (SC), while soil samples in areas not affected by liquefaction, namely P5, consist of clayey sand (SC) and P6. consists of silty sand (SM). According to Seed *et al.* (1982) [10], soil that has great potential to experience liquefaction with LL < 37% and PI < 12%. All soil samples in areas affected by liquefaction have LL values < 30% and PI < 12%. Meanwhile, the area not affected by liquefaction (P5) has LL: 24.8% PI: 11.63%, and P6 has LL: 41.5% PI: 3.87%, so it can be concluded that the area is affected (P1-P4) and one of the not affected areas (P5) has a high liquefaction potential.

Table-6. Conclusion soil grain size D50, Seed et al and USCS.

Sample	Method		
	Soil grain size D_{50}	Seed et.al. (1982)	USCS
Affected			
P1	Very potential	Very potential	clayey sand
P2	Very potential	Very potential	clayey sand
P3	Very potential	Very potential	clayey sand
P4	Very potential	Very potential	clayey sand
Not affected			
P5	Very potential	Very potential	clayey sand
P6	Not potential	Small potential	silty sand

Table-6 shows the liquefaction potential method based on the D50 soil grain size and the method of Seed *et al* (1982) [10], it can be concluded that the area affected by liquefaction (P1-P4) is an area with high liquefaction potential. Meanwhile, the area not affected by liquefaction (P5) is an area with a high liquefaction potential, and area P6 according to the soil grain size D50, the soil has no potential for liquefaction, whereas according to Seed *et al* (1982) [10] this area has a low potential for liquefaction.

3.1.3 Direct shear

Direct shear testing was carried out using undisturbed soil samples at a depth of 0.5 m from the ground surface, using one soil sample as a representative sample in the affected and unaffected areas, the test used ASTM D3080[11]. The test results can be seen in Table-7.

Table-7. Direct shear test result.

Area	Depth (m)	Cohesion (c) kg/cm²	Angle of Friction (Ø) °
Affected (P2)	0.5	0.304	33.87
Not affected (P6)	0.5	0.547	46.43

Table-7 shows that areas not affected by liquefaction show higher values of soil cohesion and angle of friction compared to areas affected by liquefaction.

3.2 The Field SWEDISH Weight Sounding (SWS) Test Results

Field testing was carried out at 4 (four) points in the affected area and 2 (two) points in the area not affected by liquefaction, using 1 set of SWS tools. This test aims to determine the values of Nsw, qa, and qu on soil in Petobo village.

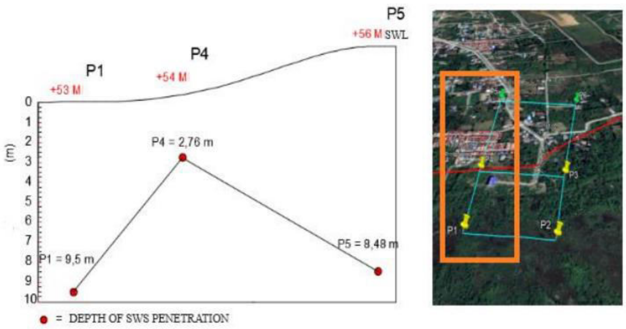

Figure-6. Depth of SWS penetration at point P1, P4 and P5.

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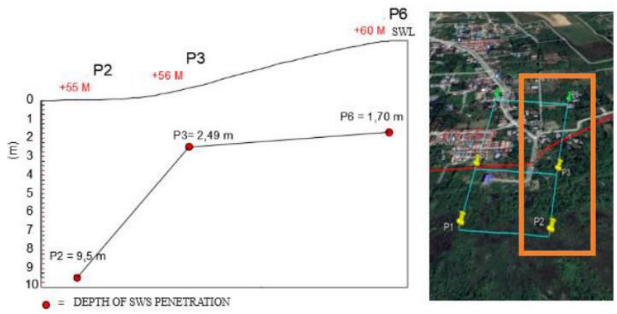

Figure-7. Depth of SWS Penetration at Point P2, P3, and P6.

3.2.1 Nsw value

Table-8. Nsw value from SWS Test.

Affected								Not Affected			
P1		P2		P3		P4		P5		P6	
z (m)	Nsw (n/m)	z (m)	Nsw (n/m)	z (m)	Nsw (n/m)	z (m)	Nsw (n/m)	z (m)	Nsw (n/m)	z (m)	Nsw (n/m)
0.06		0.07		0.04		0.06		0.05		0.06	
0.07		0.08		0.06		0.07		0.08		0.07	
0.07		0.09		0.08		0.08		0.10		0.09	
0.11		0.11		0.12		0.09		0.13		0.11	
0.19		0.13		0.14		0.13		0.20		0.20	
0.22		0.25		0.14		0.16		0.28		0.25	
0.25	85.71	0.50	12.00	0.25	72.73	0.25	22.22	0.50	45.45	0.50	44.00
0.50	80.00	0.75	0.00	0.50	104.00	0.50	20.00	0.75	88.00	0.75	28.00
0.75	68.00	1.00	0.00	0.75	72.00	0.75	48.00	1.00	176.00	1.00	116.00
1.00	56.00	1.25	20.00	1.00	116.00	1.00	60.00	1.25	72.00	1.25	132.00
1.25	48.00	1.50	28.00	1.25	132.00	1.25	84.00	1.50	60.00	1.50	156.00
1.50	64.00	1.75	8.00	1.50	100.00	1.50	68.00	1.75	64.00	1.70	250.00
1.75	48.00	2.00	0.00	1.75	156.00	1.75	48.00	2.00	60.00		
2.00	52.00	2.25	0.00	2.00	124.00	2.00	44.00	2.25	144.00		
2.25	52.00	2.50	0.00	2.25	168.00	2.25	34.00	2.50	28.00		
2.50	64.00	2.75	0.00	2.49	208.33	2.50	64.00	2.75	24.00		
2.75	80.00	3.00	0.00			2.76	192.31	3.00	40.00		
3.00	28.00	3.25	8.00					3.25	28.00		
3.25	8.00	3.50	0.00					3.50	0.00		
3.50	28.00	3.75	28.00					3.75	52.00		
3.75	40.00	4.00	40.00					4.00	52.00		
4.00	64.00	4.25	8.00					4.25	28.00		
4.25	0.00	4.50	24.00					4.50	0.00		
4.50	0.00	4.75	28.00					4.75	28.00		
4.75	0.00	5.00	20.00					5.00	40.00		
5.00	0.00	5.25	0.00					5.25	16.00		
5.25	16.00	5.50	0.00					5.50	72.00		
5.50	36.00	5.75	4.00					5.75	128.00		
5.75	56.00	6.00	0.00					6.00	64.00		
6.00	64.00	6.25	0.00					6.25	20.00		
6.25	68.00	6.50	0.00					6.50	0.00		
6.50	68.00	6.75	0.00					6.75	32.00		
6.75	60.00	7.00	32.00					7.00	40.00		
7.00	36.00	7.25	20.00					7.25	40.00		
7.25	32.00	7.50	96.00					7.50	16.00		
7.50	48.00	7.75	40.00					7.75	100.00		
7.75	52.00	8.00	96.00					8.00	24.00		
8.00	32.00	8.25	80.00					8.25	80.00		
8.25	16.00	8.50	56.00					8.48	217.39		
8.50	40.00	8.75	68.00								
8.75	28.00	9.00	64.00								
9.00	40.00	9.25	76.00								
9.25	88.00	9.50	80.00								
9.50	132.00										

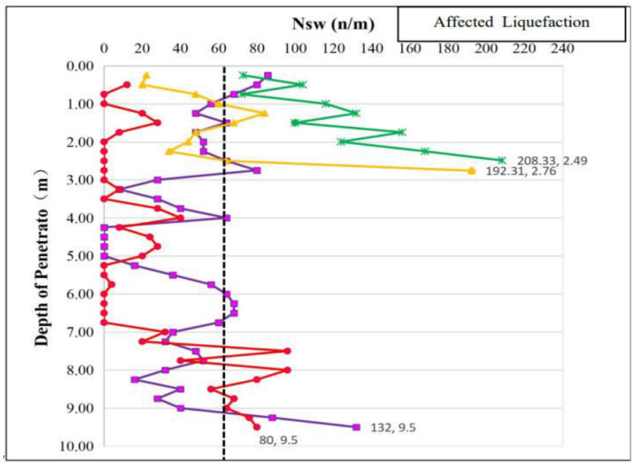

Figure-8. Relation between Nsw value to depth in affected area

Figure-8 shows the average Nsw value in the liquefaction-affected area is 64.90 n/m. If divided into 2 zones in areas P1 and P2 where the SWS point is far from the boundary of the area not affected by liquefaction with a penetration depth of 9.5 m, the Nsw value is in the range 0 n/m-132 n/m, the highest Nsw is in the depth of 9.5 m, in this case, the SWS rod has reached its maximum limit of 10 meters. So in this case it is still possible to test the soil because maximum penetration has not yet been obtained, but due to the limitations of the rods, the data presented is up to the maximum depth that can be reached by the SWS tool. Meanwhile, in areas P3 and P4, where the SWS point is near the boundary of the area not affected by liquefaction with an average penetration depth of the non-liquefaction area, namely P3 and P4.

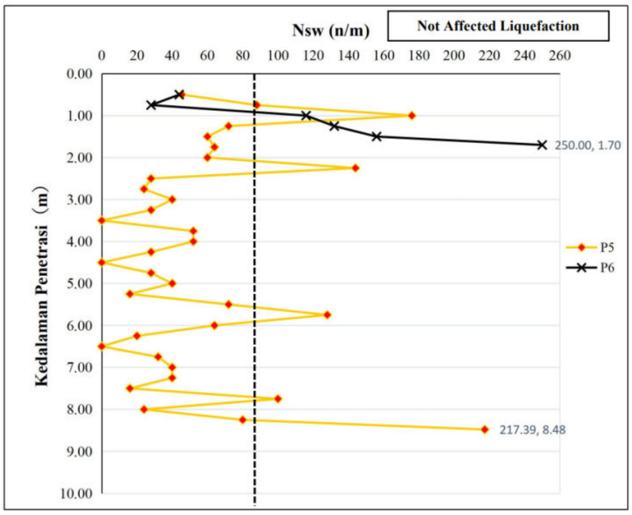

Figure-9. Relation between Nsw value to depth in not affected area.

Figure-9 shows the average Nsw value in areas not affected by liquefaction of 88.97 n/m. The combined Nsw value is in the range 0 n/m-250 n/m. If divided into 2 points, namely P5 and P6 with very different depth ranges, then we get the P5 area where the SWS point has a penetration depth of 8.48 m and has an Nsw value in the range 0 n/m - 217.39 n/m. The highest Nsw value is at a depth of 8.48 m. In area P6 where the SWS point has a penetration depth of 1.7 m, it has an Nsw value in the range of 28 n/m-250 n/m, the highest Nsw is at a depth of 1.7 m.

The high Nsw value obtained from the SWS test can be predicted that the soil has high soil density. So it can be concluded that the soil density in P5 is lower than the soil density in P6.

If the range of Nsw values from the two areas is compared, namely the area affected by liquefaction and the area not affected by liquefaction, it shows that the Nsw value in the area not affected by liquefaction has a higher range of Nsw values and tends to show an increase with increasing depth.

Table-9. The conclusion of Nsw, qa, and qu range values in affected areas and not affected by liquefaction.

Area	Nsw n/m	qa kN/m²	qu kN/m²
Affected	0 - 208.33	30 - 196.67	45 - 201.25
Not affected	0 - 250	30 - 230	45 - 232.50

Table-9 shows that the Nsw, qa, and qu values in unaffected areas are higher compared to the Nsw, qa, and qu values in areas not affected by liquefaction.

3.3 Ground Water Level (GWL) of the Petobo Community

In areas not affected by liquefaction, researchers conducted interviews with Village residents regarding the depth of the Ground Water Level (GWL) in their respective homes. From the interview results, it was found that the GWL in area P5 reached 5 m below the ground surface and area P6 had a GWL of 10 m below the ground surface. Meanwhile, in the area affected by liquefaction in areas P1 and P2, from the SWS test results, when the penetration rod was removed, it looked wet at a depth of 4 m. It can be concluded that the GWL in areas P1 and P2 was 4 m below the ground surface.

4. CONCLUSIONS

Based on the results of research conducted in the Central part of North Landslide, Petobo Village, it can be concluded as follows:

a) Soil characteristics obtained from field and laboratory test results are as follows:

a. The characteristics of the soil obtained in areas affected and not affected by liquefaction are categorized as coarse-grained soil; the classification of soil obtained is based on the USCS method in areas affected by liquefaction, namely clayey sand (SC). In areas not affected by liquefaction, namely clayey sand (SC) and silty sand (SM).

b. The soil characteristics of the SWS test results in the affected areas showed that the Nsw value was in the range of 0 n/m-208.33 n/m, the qa value was in the range of 30 kN/m2-196.67 kN/m2 and the qu value was in the range 45 kN/m2-201.25 kN/m2, while for areas not affected the Nsw value is in the range 0 n/m-250 n/m, the qa value is in the range 30 kN/m2-230 kN/m2 and the qu value is in the range of 45 kN/m2-232.50 kN/m2. The test results with SWS show that the soil strength parameters (Nsw, qa, and qu) in areas not affected by liquefaction are higher than in areas affected by liquefaction. This can happen because the condition of the soil in the affected area, such as the midsize, is a pile of soil on the upside that has been eroded.

b) The bearing capacity of the soil on a shallow foundation at a depth of 0.5 m with foundation dimensions of 1 m x 1 m based on the SWS parameters in the affected area has a qall value of 32.12 t/m2, in an unaffected area the qall value is 113.70 t/m2 while the bearing capacity of the soil on a shallow foundation based on direct shear parameters in the affected area the qall value is 30.54 t/m2, in the unaffected area the qall value is 136.72 t/m2.

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