Liquefaction Potential Based on Swedish Weight Sounding Test in Langaleso Village Sigy Regency

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Abstract:- The ground movement caused by the liquefaction phenomenon is one of the disasters that has claimed many lives and material losses in the devastating earthquake that occurred in the cities of Palu, Sigi, and Donggala on September 28, 2018. The village of Langaleso was certainly also affected, resulting in damage to existing facilities and infrastructure. This research investigations the characteristics of the soil and the potential for liquefaction in the soil that is suspected to have occurred. This research was conducted by using the Swedish Weight Sounding test and laboratory testing in the form of particle size analysis and Atterberg boundaries. Data analysis was performed by using the values of Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR), safety factor (FS), Liquefaction Potential Index (LPI), and Probability of Liquefaction (PL) . The study was carried out at 10 test points with a groundwater level of 0.68 meters sourced from JICA in 2020. The results of laboratory testing showed that the soil types range from loamy sand to silty sand with poor grades. While the Swedish Weight Sounding test obtained Nsw values between 0.00 – 454.55 n/m, qa values ranged from 0.00 – 393.64 kN/m^2 and qu values ranged from 2.22 – 385.91 kN/m^2 . It can be concluded that all test points have the potential for liquefaction to occur, where liquefaction occurs at varying depths at a minimum depth of less than 10 meters with an earthquake acceleration limit value (a_{max}) of 0.15 g and an earthquake magnitude of 5 M_w.

Keywords:- *Liquefaction Potential; Swedish Weight Sounding; Langaleso Village.*

I. INTRODUCTION

Indonesia is located between four tectonic plates that are actively moving. This is what causes Indonesia to frequently experience earthquakes. Exactly on Friday, September 28 2018, an earthquake struck several areas in Central Sulawesi, including the cities of Palu, Sigi and Donggala. Which has a magnitude of 7.4 M_w with a shallow depth of 10 km. This earthquake was followed by several other disasters such as the tsunami and the liquefaction phenomenon.

Based on its geographical location, Langaleso Village is a village located just west of Jono Oge Village which experienced liquefaction phenomenon. Based on this, of course, Langaleso Village is also affected, especially for the surrounding population and the impact on various existing building structures. The villagers of Langaleso claim that their area is safe from the liquefaction phenomenon. This is because their village is located in the lower western part of Jono Oge Village, thus making their area a stop for the liquefaction flow. In other words, the liquefaction that occurred in Jono Oge Village moved to an area of lower elevation, in this case Langaleso Village. Of course, this claim must be based on appropriate empirical evidence, so that the residents of Langaleso Village do not simply give up their wary attitude over their area.

This study was conducted to determine the characteristics of the soil under review and the potential for liquefaction based on the Swedish Weight Sounding test, laboratory testing and calculation analysis using various methods of evaluating liquefaction potential.

II. LITERATURE REVIEW

A. Particle Size Analysis

Particle size analysis is a method used to determine the distribution of soil grains that have a size greater than 0.075 mm (resisted by sieve number 200).

$$\%\ \text{weight retained} = \frac{\text{Wretained}}{\text{Wtotal}} \times 100\ \% \qquad (1)$$

$$Cu = \frac{D60}{D10} \qquad (2)$$

$$Cc = \frac{(D30)^2}{D60 \times D10} \qquad (3)$$

According to Tsuchida (1970) cited in Mase (2014), the particle size analysis can be used as an initial parameter to consider the liquefaction potential analysis of a soil. The liquefaction potential analysis is described by means of a particle size analysis curve that has certain criteria for liquefaction potential susceptibility. The particle size analysis chart proposed by Tsuchida can be shown in Fig. 1.

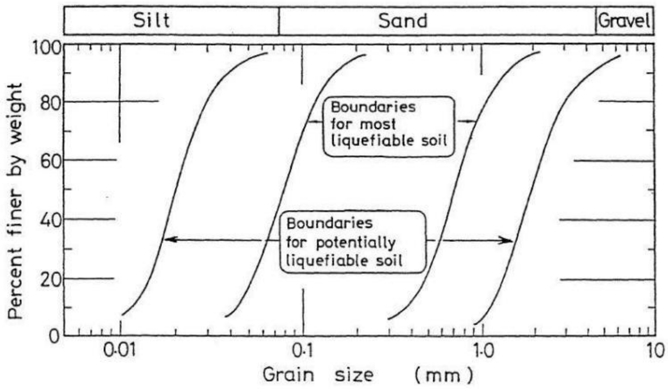

Fig. 1. Particle size analysis curve of soil vulnerable to liquefaction
Source: Tsuchida, 1970

B. Atterberg Limits

The plasticity index is an interval of the value of the water content where the soil is still plastic. To obtain the value of the plasticity index, the Liquid Limit (LL) and Plastic Limit (PL) values are needed.

$$IP = LL - PL \qquad (4)$$

Based on the Modifield Chinese Criteria method, as quoted in Lokananta and Susilo (2018), the criteria for soils that have the potential to liquefy are soils with an LL value of ≤ 35%, and the percent passing filter number 200 is ≤ 15%. Seed et al. (2003), also provides criteria for soils that have the potential to liquefy through three zones. Zone A is soil that has a LL value < 37% and a PI value < 12%, so there is a high potential for liquefaction to occur. Zone B is soil that has a LL value of 37% - 47% and a PI value of 12% - 20%, so liquefaction has the potential to occur. While zone C is soil that has a LL value > 47% and a PI value > 20%, so there is no great potential for liquefaction to occur.

C. Swedish Weight Sounding

Japanese Industrial Standards (1995) cited in Taylor and Cubrinovski (2011), explain that the Swedish Weight Sounding is a simple penetration test which can be operated manually under a dead load of 100 kg (981 N) where the number of half revolutions is required to penetration of 25 cm rod (screw point) was recorded. The measurement results obtained from the Swedish Weight Sounding test are then recorded as Wsw (amount of load) and Nsw (number of half turns per meter of penetration depth). Therefore, if in the recording the higher Nsw value is obtained, then it indicates that the soil is getting harder.

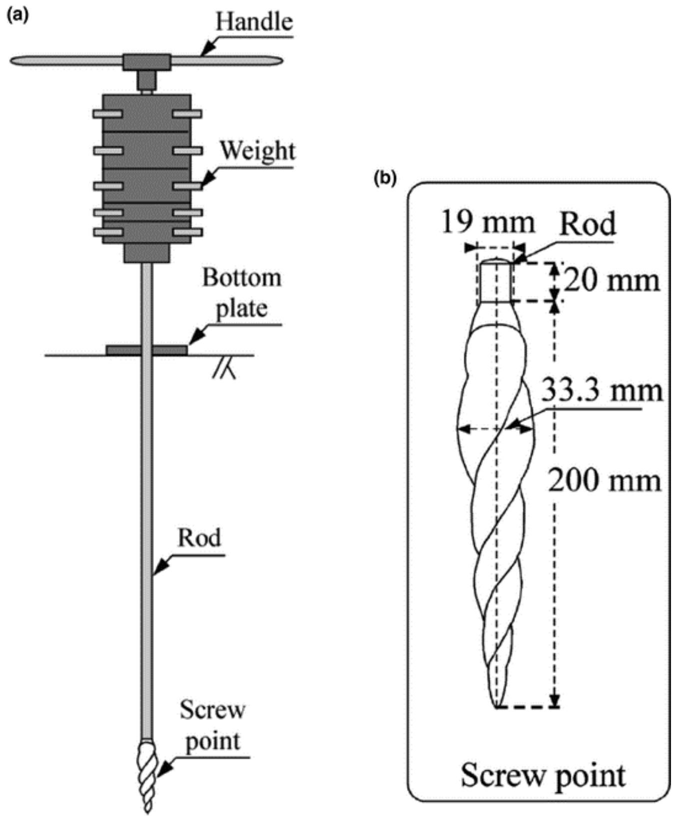

Fig. 2. Swedih Weight Sounding tests equipment

D. Correlation between NSW Value and SPT – N Value

In tests using the Swedish Weight Sounding test, the penetration resistance of the Swedish Weight Sounding test, both Wsw and Nsw were converted to the value of SPT - N. The empirical formula was proposed by Inada (1960) cited in Okada et al. (1996).

For gravel and sandy soil:

$$SPT - N = 2\,Wsw + 0.067 \qquad (5)$$

For cohesive soil:

$$SPT - N = 3\,Wsw + 0.050 \qquad (6)$$

Nomenclature:
Wsw = rated load (kN)
Nsw = number of half turns per meter (ht/m)

E. Methods of Evaluating Liquefaction Potential

To obtain accurate calculation results, three methods are used to evaluate the liquefaction potential of a soil. The method used is to calculate the value of safety factor (FS) based on the value of CSR and CRR, the value of Liquefaction Potential Index (LPI) and the value of Probability of Liquefaction (PL).

- Determination of the Factor of Safety (FS)

In determining the value of factor of safety, Cyclic Stress Ratio (CSR) and Cyclic Resistance Ratio (CRR) values are used. Cyclic Stress Ratio (CSR) is the ratio between the cyclic stress caused by the earthquake and the effective vertical stress of the soil.

ISSN No:-2456-2165

$$CSR = 0.65 \text{ x } (\frac{a_{max}}{g}) \text{ x } \left(\frac{\sigma v}{\sigma' v}\right) \text{ x rd} \quad (7)$$

Nomenclature:
CSR = Cyclic Stress Ratio
a_{max} = horizontal seismic ground surface acceleration (m/s^2)
g = acceleration due to gravity (9.81 m/s^2)
σv = vertical total stress of the soil (kN/m^2)
σ'v= vertical effective stress (kN/m^2)
rd = shear stress reduction factor

The value value of 0.65 is a constant value with the assumption that the average acceleration value due to an earthquake is 0.65 or equivalent to 65% of the maximum earthquake acceleration.

$$\sigma v = \Upsilon \text{ x } z \quad (8)$$

$$\sigma' v = (\Upsilon - \Upsilon_w) \text{ x } z \quad (9)$$

As for if the depth under consideration is below the water table, then:

$$\sigma v = (\Upsilon \text{ x } z_{GWL}) + (\Upsilon_{sat} (z - z_{GWL})) \quad (10)$$

$$\sigma' v = \sigma v - (\Upsilon_w (z - z_{GWL})) \quad (11)$$

Nomenclature:
ϒ = unit weight of density (kN/m^3)
ϒsat = unit weight of saturated density (kN/m^3)
ϒw = unit weight of water (9.81 kN/m^3)
z = depth of soil (m)

The value of rd is a value that can reduce stress in the soil, where the value of rd also depends on the depth of the soil (z). The further the depth of the soil, the smaller the value of the reduction factor will be. The equation regarding the stress reduction factor cited in Youd and Idriss (1997) is:

$$rd = 1 - (0.00765 \text{ x } z) \;;\; \text{for } z \leq 9.15 \text{ m} \quad (12)$$

$$rd = 1.174 - (0.0267 \text{ x } z) \;;\; \text{for } 9.15 \text{ m} < z \leq 23 \text{ m} \quad (13)$$

$$rd = 0.744 - (0.008 \text{ x } z) \;;\; \text{for } 23 \text{ m} < z \leq 30 \text{ m} \quad (14)$$

$$rd = 0.5 \;;\; \text{for } z > 30 \text{ m} \quad (15)$$

Cyclic Resistance Ratio (CRR) is the amount of soil resistance to liquefaction hazards caused by cyclic stresses. Some correlations use the number of corrected SPT strokes which is denoted as $(N_1)_{60}$, where the value of 60 is the percentage of hammer energy falling freely. However, considering that the correction factors (C_N, C_E, C_B, C_R, C_S) are only intended for the use of the SPT tool and in this study the SWS tool is used, then the correction factor cannot be used because the SPT tool and SWS tool have different tool specifications.

$$(N_1)_{60} = Nm \quad (16)$$

The meaning of Nm is the value of SPT – N.

Idriss, assisted by Seed, developed the equation $(N_1)_{60}$ which was given a correction factor based on the value of fines (Fines Content = FC) which is equivalent to the value of clean – sand (cs). The equation is expressed in $(N_1)_{60}cs$ as written by Youd and Idriss (2001).

$$(N_1)_{60}cs = \alpha + \beta (N_1)_{60} \quad (17)$$

Where the value of α and β can be obtained based on the value of FC.

$$\alpha = 0 \;;\; \beta = 1 \;;\; \text{for FC} \leq 15\% \quad (18)$$

$$\alpha = \exp[1.76 - (\frac{190}{FC^2})] \;;\; \beta = [0.99 + (\frac{FC^{1.5}}{1000})] \;;\; \text{for } 5\% < FC < 35\% \quad (19)$$

$$\alpha = 5 \;;\; \beta = 1.2 \;;\; \text{for FC} \geq 35\% \quad (20)$$

Idriss and Boulanger (2006) cited in Tsai et al. (2009), provides an equation in determining the CRR value on the earthquake scale (M_w) which has been corrected based on the $(N_1)_{60}cs$ value.

$$CRR_{7.5} = \exp\left(\frac{(N1)_{60}cs}{14.1}\right) + \left(\frac{(N1)_{60}cs}{126}\right)^2 - \left(\frac{(N1)_{60}cs}{23.6}\right)^3 + \left(\frac{(N1)_{60}cs}{25.4}\right)^4 - 2.8 \quad (21)$$

The value of Magnitude Scaling Factors (MSF) is used to equalize the CRR value to the general value of Moment Magnitude (M_w) = 7.5. Seed and Idriss (1982) cited in Youd and Idriss (2001), provide an equation regarding the MSF value.

$$M_w < 7.5 \;;\; MSF = \frac{10^{2.24}}{Mw^{2.56}} \quad (22)$$

$$M_w > 7.5 \;;\; MSF = \left(\frac{Mw}{7.5}\right)^{-2.56} \quad (23)$$

As quoted in Youd and Idriss (2001), Seed (1983) introduced the overburden stress correction factor (Kσ).

$$K\sigma = \left(\frac{\sigma' vo}{Pa}\right)^{(f-1)} \quad (24)$$

Pa is the pressure at 1 atm (101 kN/m^2) and the value f is the relative density of the soil:

$$f = 0.831 - \frac{(N1)_{60}cs}{160} \quad (25)$$

So that,

$$CRR_{Mw} = CRR_{7,5} \text{ x MSF x } K\sigma \quad (26)$$

$$FS = \frac{CRR_{Mw}}{CSR} \quad (27)$$

Provided that:
If FS < 1 (liquefaction occurs)
If FS = 1 (critica condition)
If FS > 1 (no liquefaction occurs)

- Determination of the Liquefaction Potential Index (LPI) value

According to Muley et al. (2018), LPI was first proposed by Iwasaki et al. (1982). LPI is proportional to the thickness of the liquefied soil layer, the non-liquefied soil layer and the factor of safety against soil liquefaction. Table 2 describes the liquefaction severity categories as described by Hannich et al. (2007).

$$LPI = \int_0^{20} F(z) \text{ x } w(z) \text{ x } dz = 0.65 \text{ x } (\frac{a_{max}}{g}) \text{ x } \left(\frac{\sigma v}{\sigma' v}\right) \text{ x rd} \quad (28)$$

For soil profiles with a depth of less than 20 m, the LPI equation proposed by Luna and Frost (1998) should be used.

$$LPI = \sum_{i=1}^{n} Fi \ \text{x} \ wi \ \text{x} \ hi \qquad (29)$$

Provided that:
If FS < 1 ; then F(i) = 1 - FS
If FS ≥ 1 ; then F(i) = 0
z < 20 m ; then w(i) = 10 – 0.5(zi)
z > 20 m ; then w(z) = 0

Nomenclature:
Fi = severity factor for layer i
wi = weight factor into the i-th layer
zi = i-th layer depth (m)
Hi = thickness of the soil layer (m)

TABLE I. LIQUEFACTION POTENTIAL CLASSIFICATION

LPI value	Liquefaction Potential Rate
LPI = 0	Non - Liquefiable
0 < LPI ≤ 2	Low
2 < LPI ≤ 5	Moderate
5 < LPI ≤ 15	High
LPI > 15	Very high

- Determination of the Probability of Liquefaction (PL) value

The value of the liquefaction probability (PL) obtained is later expected to provide an overview of the liquefaction potential analysis function in the form of the probability value of the occurrence of the uncertainty of a factor of safety (FS) result obtained. In modeling the calculation of this liquefaction probability value, the researcher uses the equation proposed by Juang et al. (2008) as a cited in Ansori (2020). The use of the equation proposed by Juang et al. (2008), this was chosen because it is an equation that is considered more renewable.

$$PL = \frac{1}{(1+\frac{FS}{1,905})^{3.8}} \qquad (30)$$

Hannich et al. (2007), explained that previously Chen and Juang (2000) had also provided a grouping of probabilities or the possibility of liquefaction.

TABLE II. THE CLASSIFICATION OF PROBABILITY OF LIQUEFACTION

Probability	Description (likelihood of liquefaction)
0.85 ≤ PL < 1.00	Almost certain that it will liquefy
0.65 ≤ PL < 0.85	Very likely
0.35 ≤ PL < 0.65	Liquefaction/non-liquefaction is equally likely
0.15 ≤ PL < 0.35	Unlikely
0.00 ≤ PL < 0.15	Almost certain that it will not liquefy

Source: Hannich et al., 2007

III. RESEARCH METHODS

The research location is located in the segment one of Langaleso Village, Dolo District, Sigi Regency, Central Sulawesi Province. At the location of this study, there are many sources of water in the form of irrigation canals that irrigate the residents' plantations. Thus, research on the potential for liquefaction at the research location is very necessary, given that liquefaction can occur in areas close to water sources.

Based on the report of the JICA (Japan International Cooperation Agency) Survey for Disaster Information Collection in Indonesia in 2020, the location of the groundwater level close to the research site is located at a depth of 0.68 meters from below the ground surface. The groundwater level data used is assumed to be the same for each test point.

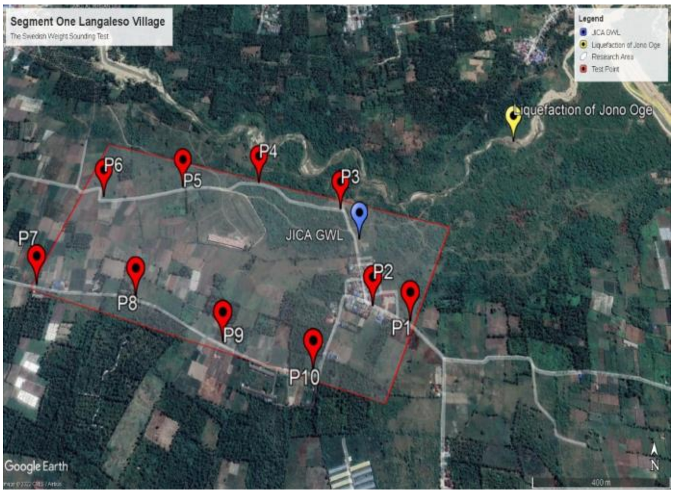

Fig. 3. Research site

IV. RESULTS AND DISCUSSION

A. Laboratory Testing

The form of the graph of the results of the particle size analysis test that is correlated with the Tsuchida graph (1970) can be seen in Fig. 5. The form of the graph of the results of the particle size analysis test that is correlated with the Tsuchida graph (1970) can be seen in Fig. 4. As for the type of soil with liquefaction potential obtained from laboratory tests, it can be seen in Table 3.

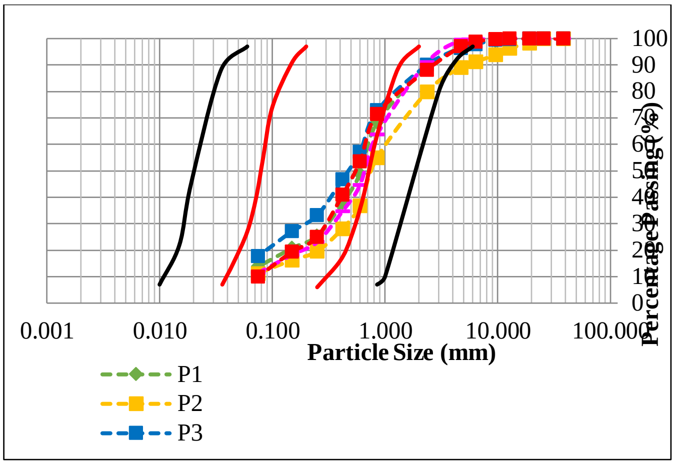

Fig. 4. Curve of test results for particle size analysis according to Tsuchida (1970)

TABLE III. RESULTS OF THE ANALYSIS OF PARTICLE SIZE ANALYSIS AND ATTERBERG LIMITS

Point	Tsuchida (1970)	*Modifield Chinese Criteria*	Seed dkk. (2003)	USCS
P1	Most liquefiable	Potentially liquefiable	Potentially susceptible	Loamy sand
P2	Most liquefiable	Potentially liquefiable	Potentially susceptible	Poorly graded loamy sand
P3	Most liquefiable	Potentially liquefiable	Potentially susceptible	Silty sand
P4	Most liquefiable	Potentially liquefiable	Potentially susceptible	Loamy sand
P5	Most liquefiable	Potentially liquefiable	Potentially susceptible	Loamy sand
P6	Most liquefiable	Potentially liquefiable	Potentially susceptible	Poorly graded loamy sand
P7	Most liquefiable	Potentially liquefiable	Potentially susceptible	Poorly graded loamy sand
P8	Most liquefiable	Potentially liquefiable	Potentially susceptible	Well graded loamy sand
P9	Most liquefiable	Potentially liquefiable	Potentially susceptible	Poorly graded silty sand
P10	Potentially liquefiable	Potentially liquefiable	Potentially susceptible	Well graded loamy sand

B. Swedish Weight Sounding

In the Swedish Weight Sounding test, the Nsw value ranges from 0.00 - 454.55 ht/m, the qa value ranges from 0.00 - 393.64 kN/m^2, and the qu value ranges from 2.22 - 385.91 kN/m^2. While the average value of Nsw for each test point is 67.34 ht/m, the average value of qa is 53.07 kN/m^2, and the average value of qu is 67.60 kN/m^2. This average value indicates that if a soil layer obtains a parameter value of Nsw, qa and qu below the average value, then the liquefaction potential will be greater than the soil layer that has a value of Nsw, qa and qu above average value.

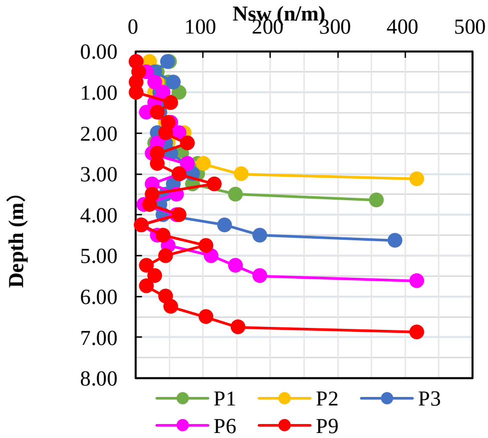

Fig. 5. Graph of relationship between Nsw value to depth

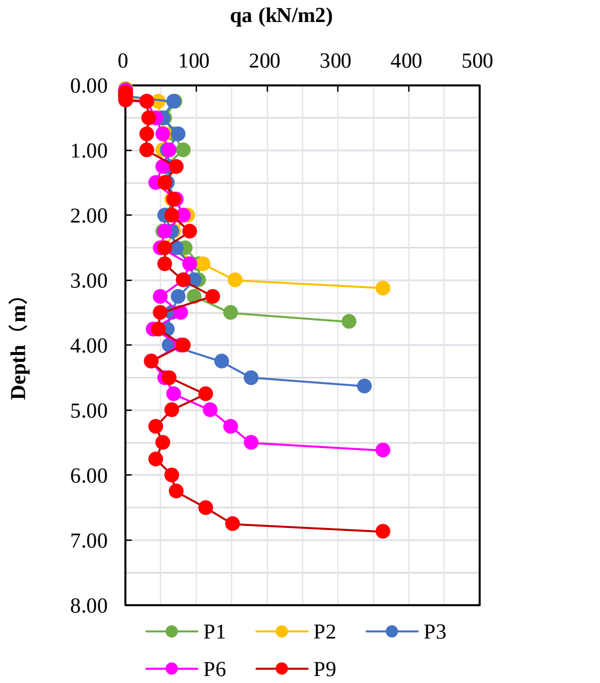

Fig. 6. Graph of the relationship between the value of qa to depth

ISSN No:-2456-2165

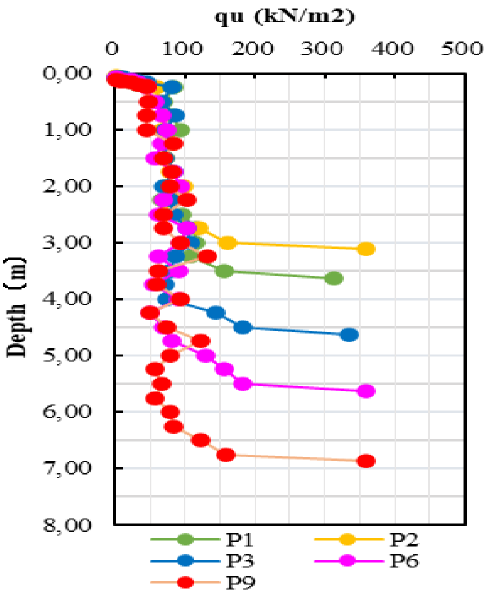

Fig. 7. Graph of the relationship between the value of qu to depth

TABLE IV. CALCULATION RESULTS OF FS VALUE AT POIN P1 WITH A_{MAX} VALUE OF 0.34 G AND EARTHQUAKE MAGNITUDE OF 7.4 M_W

Depth (m)	Unit weight of density (kN/m³)	σv (kN/m²)	σ'v (kN/m²)	rd	Pa (kN/m²)	amax (g)	g (m/s²)	CSR	SPT - N	$(N1)_{60}$	FC (%)	α	β	$(N1)_{60\,CS}$	$CRR_{7.5}$	MSF	f	Kσ	CRR_{Mw}	FS	Keterangan
0,09	16,22	1,46	1,46	1,00	101	0,34	9,81	0,22	0	0	13,76	2,13	1,04	2,24	0,07	1,03	0,82	2,17	0,16	0,73	Liquefiable Potentially
0,10	16,22	1,62	1,62	1,00	101	0,34	9,81	0,22	0	0	13,76	2,13	1,04	2,44	0,07	1,03	0,82	2,14	0,16	0,73	Liquefiable Potentially
0,12	16,22	1,95	1,95	1,00	101	0,34	9,81	0,22	1	1	13,76	2,13	1,04	2,65	0,07	1,03	0,81	2,08	0,16	0,72	Liquefiable Potentially
0,17	16,22	2,76	2,76	1,00	101	0,34	9,81	0,22	1	1	13,76	2,13	1,04	3,17	0,08	1,03	0,81	1,97	0,16	0,70	Liquefiable Potentially
0,20	16,22	3,24	3,24	1,00	101	0,34	9,81	0,22	2	2	13,76	2,13	1,04	3,69	0,08	1,03	0,81	1,94	0,16	0,72	Liquefiable Potentially
0,23	16,22	3,73	3,73	1,00	101	0,34	9,81	0,22	2	2	13,76	2,13	1,04	4,21	0,08	1,03	0,80	1,90	0,16	0,73	Liquefiable Potentially
0,25	16,22	4,06	4,06	1,00	101	0,34	9,81	0,22	5	5	13,76	2,13	1,04	7,70	0,10	1,03	0,78	2,01	0,21	0,97	Liquefiable Potentially
0,50	16,22	8,11	8,11	1,00	101	0,34	9,81	0,22	4	4	13,76	2,13	1,04	6,45	0,09	1,03	0,79	1,70	0,17	0,76	Liquefiable Potentially
0,75	17,43	12,25	11,56	0,99	101	0,34	9,81	0,23	5	5	13,76	2,13	1,04	7,56	0,10	1,03	0,78	1,58	0,17	0,71	Liquefiable Potentially
1,00	17,43	16,61	13,47	0,99	101	0,34	9,81	0,27	6	6	13,76	2,13	1,04	8,68	0,11	1,03	0,78	1,50	0,17	0,63	Liquefiable Potentially
1,25	17,43	20,97	15,37	0,99	101	0,34	9,81	0,30	4	4	13,76	2,13	1,04	6,45	0,09	1,03	0,79	1,39	0,14	0,46	Liquefiable Potentially
1,50	17,43	25,32	17,28	0,99	101	0,34	9,81	0,32	4	4	13,76	2,13	1,04	6,72	0,10	1,03	0,79	1,34	0,13	0,42	Liquefiable Potentially
1,75	17,43	29,68	19,19	0,99	101	0,34	9,81	0,34	5	5	13,76	2,13	1,04	7,56	0,10	1,03	0,78	1,30	0,14	0,41	Liquefiable Potentially
2,00	17,43	34,04	21,09	0,98	101	0,34	9,81	0,35	4	4	13,76	2,13	1,04	6,72	0,10	1,03	0,79	1,26	0,13	0,36	Liquefiable Potentially
2,25	17,43	38,40	23,00	0,98	101	0,34	9,81	0,36	4	4	13,76	2,13	1,04	6,17	0,09	1,03	0,79	1,22	0,12	0,32	Liquefiable Potentially
2,50	17,43	42,76	24,90	0,98	101	0,34	9,81	0,37	7	7	13,76	2,13	1,04	8,96	0,11	1,03	0,78	1,21	0,14	0,37	Liquefiable Potentially
2,75	17,43	47,11	26,81	0,98	101	0,34	9,81	0,38	8	8	13,76	2,13	1,04	10,63	0,12	1,03	0,76	1,20	0,15	0,40	Liquefiable Potentially
3,00	17,43	51,47	28,71	0,98	101	0,34	9,81	0,39	8	8	13,76	2,13	1,04	10,63	0,12	1,03	0,76	1,17	0,15	0,38	Liquefiable Potentially
3,25	17,43	55,83	30,62	0,98	101	0,34	9,81	0,39	8	8	13,76	2,13	1,04	10,07	0,12	1,03	0,77	1,15	0,14	0,36	Liquefiable Potentially
3,50	17,43	60,19	32,52	0,97	101	0,34	9,81	0,40	12	12	13,76	2,13	1,04	14,54	0,15	1,03	0,74	1,14	0,18	0,45	Liquefiable Potentially
3,64	17,43	62,63	33,59	0,97	101	0,34	9,81	0,40	26	26	13,76	2,13	1,04	29,12	0,44	1,03	0,65	1,18	0,53	1,33	No Liquefiable Potentially

TABLE V. CALCULATION RESULTS OF LPI VALUE AT POIN P1 WITH A_{MAX} VALUE OF 0.34 G AND EARTHQUAKE MAGNITUDE OF 7.4 M_W

Depth (m)	FS	zi (m)	Hi (m)	w (zi)	Fi	LPI	Description
0,09	0,73	0,05	0,09	9,98	0,27	0,25	Low
0,10	0,73	0,10	0,01	9,95	0,27	0,03	Low
0,12	0,72	0,11	0,02	9,95	0,28	0,06	Low
0,17	0,70	0,15	0,05	9,93	0,30	0,15	Low
0,20	0,72	0,19	0,03	9,91	0,28	0,08	Low
0,23	0,73	0,22	0,03	9,89	0,27	0,08	Low
0,25	0,97	0,24	0,02	9,88	0,03	0,01	Low
0,50	0,76	0,38	0,25	9,81	0,24	0,60	Low
0,75	0,71	0,63	0,25	9,69	0,29	0,69	Low
1,00	0,63	0,88	0,25	9,56	0,37	0,90	Low
1,25	0,46	1,13	0,25	9,44	0,54	1,28	Low
1,50	0,42	1,38	0,25	9,31	0,58	1,35	Low
1,75	0,41	1,63	0,25	9,19	0,59	1,36	Low
2,00	0,36	1,88	0,25	9,06	0,64	1,45	Low
2,25	0,32	2,13	0,25	8,94	0,68	1,51	Low
2,50	0,37	2,38	0,25	8,81	0,63	1,38	Low
2,75	0,40	2,63	0,25	8,69	0,60	1,30	Low
3,00	0,38	2,88	0,25	8,56	0,62	1,32	Low
3,25	0,36	3,13	0,25	8,44	0,64	1,35	Low
3,50	0,45	3,38	0,25	8,31	0,55	1,14	Low
3,64	1,33	3,57	0,14	8,22	0,00	0,00	Non Liquefiable
LPI = ΣF . W(z) . Hi						16,28	Very High

TABLE VI. PL VALUE AT POIN P1 WITH A_{MAX} VALUE OF 0.34 G AND EARTHQUAKE MAGNITUDE OF 7.4 M_W

Depth (m)	Nsw	7,4 M_w 0,34 g FS	PL (%)	Description
0,09	0,00	0,73	29,34	Unlikely
0,10	0,00	0,73	29,31	Unlikely
0,12	0,00	0,72	29,74	Unlikely
0,17	0,00	0,70	30,24	Unlikely
0,20	0,00	0,72	29,73	Unlikely
0,23	0,00	0,73	29,12	Unlikely
0,25	50,00	0,97	20,95	Unlikely
0,50	32,00	0,76	28,08	Unlikely
0,75	48,00	0,71	29,79	Unlikely
1,00	64,00	0,63	34,01	Unlikely
1,25	32,00	0,46	44,16	Liquefaction
1,50	36,00	0,42	47,05	Liquefaction
1,75	48,00	0,41	47,88	Liquefaction
2,00	36,00	0,36	51,97	Liquefaction
2,25	28,00	0,32	54,96	Liquefaction
2,50	68,00	0,37	50,54	Liquefaction
2,75	92,00	0,40	48,51	Liquefaction
3,00	92,00	0,38	49,74	Liquefaction
3,25	84,00	0,36	51,91	Liquefaction
3,50	148,00	0,45	44,42	Liquefaction
3,64	357,14	1,33	13,34	Almost Certain that it will not Liquefy

The liquefaction zone that occurs at points P1 to P10 includes a depth below the ground water level of 0.68 m until the soil depth reaches a safety factor (FS) value equal to one. As for the calculation of the FS value, LPI value and PL value at all test points using an earthquake acceleration value (a_{max}) of more than 0.15 g and an earthquake magnitude of more than 5 M_w, liquefaction has the potential to occur. Assuming the liquefaction zone can occur in shallow soil depths of less than 10 m, it can be concluded that the area has the potential for liquefaction to occur with an earthquake acceleration value limit (a_{max}) of 0.15 g and an earthquake magnitude of 5 M_w.

ISSN No:-2456-2165

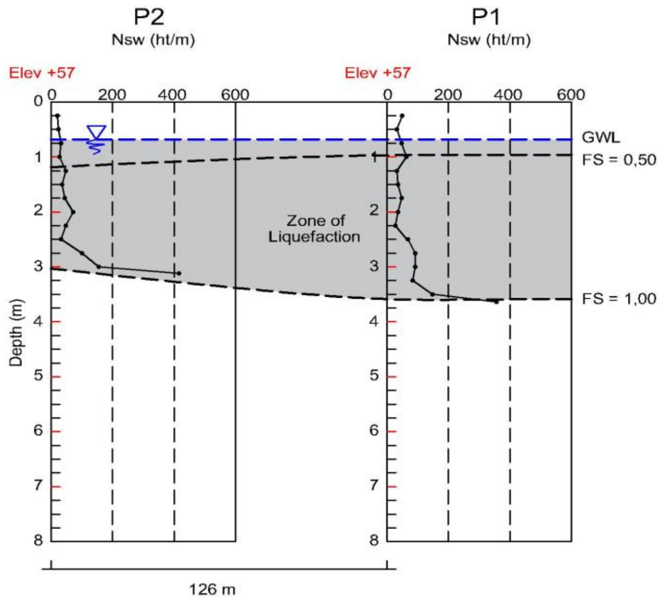

Fig. 8. Liquefaction zone at points P2 and P1

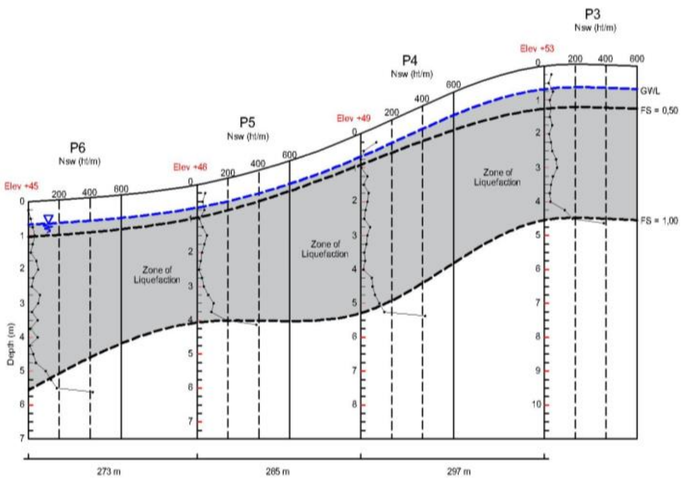

Fig. 9. Liquefaction zone at points P3, P4, P5 and P6

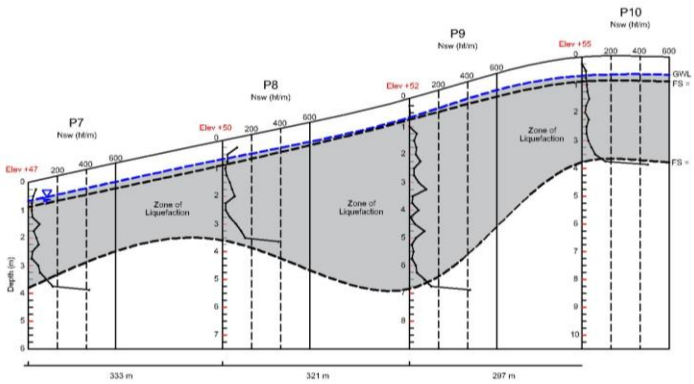

Fig. 10. Liquefaction zone at points P7, P8, P9 and P10

V. CONCLUSION

Based on the results of field testing and laboratory testing of all test points in the segment one of Langaleso Village, Sigi Regency, it can be concluded that the soil characteristics obtained through the Swedish Weight Sounding test with ten test points resulted in Nsw values ranging from 0.00 – 454.55 ht/m, qa values ranging from 0.00 – 393.64 kN/m^2 and qu values ranging from 2.22 – 385.91 kN/m^2. In the particle size and Atterberg boundary analysis, it was found that all tested samples were categorized as coarse-grained soils. With the soil classification system using the Unified Soil Classification System (USCS), the type of soil obtained at points P1, P4 and P5 is loamy sand (SC). At points P2, P6 and P7 are poorly graded loamy sands (SP – SC). At point P3 the soil type is silty sand (SM). At points P8 and P10, the type of soil is well graded loamy sand (SW – SC). While at point P9, the type of soil is poorly graded silty sand (SP – SM).

In addition, in laboratory testing in the form of particle size analysis, when connected to the liquefaction potential curve according to Tsuchida, all test points have a high potential for liquefaction to occur. In laboratory testing in the form of the Atterberg limit, according to the Modifield Chinese Criteria, all test points have the potential for liquefaction. Meanwhile, according to the method of Seed et al. (2003), then all test points fall into the category of high liquefaction potential. Meanwhile, based on the results of calculations using the factor of safety (FS), the value of the Potential Liquefaction Index (LPI) and the value of the Probability of Liquefaction (PL) with the potential for liquefaction. the researchers concluded that at all points reviewed the potential for liquefaction with a depth of less than 10 meters with an earthquake acceleration limit (a_{max}) of 0.15 g and an earthquake magnitude of 5 M_w.

REFERENCES

[1]. Ansori A.L., “Analysis of Liquefaction Potential Due to Earthquake Based on Insitu Test Using Probability Method (Indonesia: Islamic University of Indonesia)”, 2020, p 33.

[2]. Hannich D., Hoetzl H., Ehret D., Huber G., Danchiv A. and Bretotean M., “Liquefaction Probability in Bucharest and Influencing Factor. Int. Symp. on Strong Vrancea Earthquakes and Risk Mitigation” Germany and Romania: University of Karisruhe/National Institute of Hydrology and Water Management, 2007, pp 206 – 21.

[3]. Japan International Cooperation Agency, “Boring Survey for Basic Response for Central Sulawesi Earthquake (Phase 1) Under The JICA Survey for Disaster Information Collection in Indonesia*”,* 2020, p 79.

[4]. Lokananta R. D., and Susilo A. J., “*Analysis of Axial Pile Bearing Capacity Considering Liquefaction Potential.*”, 2018, **1** 281 – 89.

[5]. Mase L. Z., “Preliminary Analysis of Liquefaction Potential in Kali Opak Imogiri Special Region of Yogyakarta*”*, 2014, 145 – 49.

[6]. Muley P., Maheshwari B. K., and Paul D. K., “Assessment of Liquefaction Potential Index for Roorkee Region. Symp. on Earthquake Engineering 257” (Indian: Indian Institute of Technology Roorkee), Correlations between Soil Strength of Embankment Surface Using Different Sounding Tests. 2018.

[7]. Okada K., Sugiyama T., Muraishi H., Noguchi T., and Samizo M., 1996, **36** 43 – 50.

ISSN No:-2456-2165

[8]. Taylor M., and Cubrinovski M., “Preliminary Assessment of Liquefaction in Urban Areas Following the 2010 Darfield Earthquake*”,* 2011, 056.
[9]. Tsai P. H., Lee D. H., Kung G. TC and Juang C. H., “Simplified DMT-based Methods for Evaluating Liquefaction Resistance of Soils” **103** 13 – 22.
[10]. Tsukamoto Y., Hyodo T., and Hashimoto K., “Evaluation of Liquefaction Resistance of Soils from Swedish Weight Sounding Tests”, 2016, **56** 104 – 14.
[11]. Youd T. L., and Idriss I., M., “Proceeding of The NCEER Workshop on Evaluation of Liquefaction Resistance of Soils” (New York: Bringham Young University/University of California) p 3. 1997
[12]. Youd T. L., and Idriss I. M., “Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils”, 2001, **127** 297 – 313.