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Liquefaction assessment based on grain size and CPT analysis in the Birobuli Area, South Palu

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Abstract

Birobuli is located in South Palu, which is highly vulnerable to earthquakes. One of the phenomena that occur after an earthquake is liquefaction, causing significant damage and loss of life. Furthermore, infrastructure needs to be analyzed for the effect of external load and potential hazards. This research aims to investigate the liquefaction potential in Birobuli, South Palu. The method was divided into two categories: grain size distribution analysis and empirical formula based on CPT data. Although the grain size assessments from CPT 1 and CPT 2 at all depths show the liquefaction potential, more liquefaction analysis is required because the groundwater table is less than 4 and 4.4m. Further analyses, such as a liquefaction analysis based on CPT data, are required to obtain more complete results. However, the analysis from CPT 1 and CPT 2 presents a similar trend, resulting in a safety factor lower than 1, Ic less than 2.6, and a fines percentage below 15%, thus indicating the potential for liquefaction hazards. Therefore, this study is expected to provide information for the local government to manage disaster mitigation in the Birobuli area.

Introduction

Indonesia's rapid development of infrastructure leads engineers to ensure structures are safe and stable. If a structure is located in a particular area with high exposure to earthquakes, it ought to accomplish comprehensive initial assessments that set a high value of safety. A feasibility study that includes risk analysis is a necessary process to indicate the performance of a structure against external force, including earthquakes. One of the most significant problems in high susceptibility to earthquakes is liquefaction. Hazards associated with soil liquefaction can cause structural damage or significant loss of life and property. Therefore, it is crucial to consider the stability and safety of a structure against soil liquefaction while designing buildings (Chou et al., 2021).

The City of Palu is highly vulnerable to earthquakes, thus demonstrating that the geological structure and characteristics are at high risk of geological catastrophes. The seismic history has recorded that, following the 7.5 Mw tectonic earthquake that struck Palu on September 28, 2018, a tsunami and liquefaction occurred (Jalil et al., 2021). A previous study of liquefaction in the Palu area suggests designing the architecture, land use, and spatial planning of Palu to reduce the risk of liquefaction. Meanwhile, the valley in Palu City was discovered to have a substantial value of ground shear strain and a low groundwater table, which point to the city's eventual liquefaction (Kuswandi et al., 2020). Therefore, a liquefaction assessment is essential to ensure infrastructure safety.

The Birobuli area is located in South Palu, which is dominated by residential buildings as a government center. Although high-rise infrastructure is rarely constructed in this area, an analysis of liquefaction is required to assess the safety performance of the buildings therein. Therefore, this study aims to evaluate the liquefaction potential in the Birobuli area. The results provide essential information for stakeholders to manage the effect of liquefaction.

Method

The analysis of liquefaction was conducted in two categories consisting of a gradation test and an empirical method by using a cone penetration test (CPT).

Soil Properties

Two points of CPT were determined to identify the soil characteristics in the Birobuli area. The location is described in Figure 1.

Figure 1. Birobuli area

The liquefaction analysis used thickness to generate a safety factor demonstrating the possibility of liquefaction process. The grain size analysis and specific gravity test were conducted through CPT in each layer. Based on this site investigation, the subgrade was dominated by sand with dark color to a depth of 5m.

The results described in Table 1 show that the soil type is dominated by sand. The detail of this analysis is shown in the figure of potential liquefaction based on grain size analysis. Meanwhile, the specific gravity is mostly in the 2.62-2.67 range in CPT 1 and CPT 2.

Grain Size Analysis for Liquefaction Assessment

The potential liquefaction analysis based on a grain size approach was conducted by referring to the range of particle size distribution depicted in Figure 2 (Koester and Tsuchida, 1998). According to Figure 2, the range is divided into two types: most potential liquefaction and potential liquefaction. Therefore, the results of grain size distribution from the site investigation are required to plot in this graph (Idriss and Boulanger, 2008).

Table 1. Summary of grain size and specific gravity analysis

No	CPT point	Depth	Gs	Soil type
1	1	0-0.3m	2.63	Sand
2	1	0.3m-0.5m	2.62	Sand
3	1	0.5m-3.5m	2.67	Sand
4	1	3.5m-3.8m	2.66	Sand
5	2	0-0.2m	2.65	Sand
6	2	0.2m-0.4m	2.67	Sand
7	2	0.4m-3.0m	2.63	Sand
8	2	3.0m-3.4m	2.63	Sand
9	2	3.4m-3.8m	2.63	Sand

CPT analysis for susceptibility to liquefaction

The assessment of liquefaction susceptibility was conducted by determining the safety factor calculated according to the following equation:

$$Sf = \frac{CRR}{CSR} \quad (1)$$

where CSR is Cyclic Stress Ratio and CRR is Cyclic Resistance Ratio obtained from the formula:

$$CSR = \frac{\tau_{av}}{\sigma'_{vo}} = 0.65\left(\frac{a_{max}}{g}\right)\left(\frac{\sigma_{vo}}{\sigma'_{vo}}\right) r_d \quad (2)$$

where r_d is the coefficient, and

$$r_d = exp((\alpha(z) + \beta(z))M) \quad (3)$$

$$\alpha(z) = -1.012 - 1.126\,sin\left(\frac{z}{11.73}\right) + 5.133 \quad (4)$$

$$\beta(z) = 0.106 - 0.118\,sin\left(\frac{z}{11.38}\right) + 5.412 \quad (5)$$

where α(z) and β(z) are the coefficients, z is the depth, and M is the magnitude of earthquake.

Meanwhile, CRR is determined with the following steps:

$$q_{c1N} = c_q \frac{qc}{Pa} \quad (6)$$

where q_{c1N} is the tip resistance correction, Cq is the tip resistance in a normal condition, and Pa is the atmosphere pressure (1atm). Because CPT does not represent the soil properties, N is calculated by using the Ic coefficient:

$$I_c = (log(3.47 - log\,Q)^2 + (1.22 + log\,F)^2)^{0.5} \quad (7)$$

where Q is the notation obtained from the equation:

$$Q = \frac{q_{c-\sigma_{vc}}}{Pa}\left(\frac{P_a}{\sigma'_{vc}}\right) n \quad (8)$$

Alternatively, Q can be determined from its correlation with friction ration (Fr) (Iwasaki et al., 1984). This relationship is shown in Figure 3.

$$F = \frac{fs}{qc - \sigma_{vc}}\, x\, 100\% \quad (9)$$

$$F = 2.8\, Ic^{2.6} \quad (10)$$

$$\Delta q_{c1N} = \left(5.4 + \frac{q_{c1N}}{16}\right) .exp\left(1.63 + \frac{9.7}{FC3+0.01} - \left(\frac{15.7}{FC+0.01}\right)^2\right) \quad (11)$$

$$q_{c1Ncs} = q_{c1N} + \Delta q_{c1N} \quad (12)$$

$$CRR_{7.5} = exp\left(\frac{q_{c1Ncs}}{540} + \left(\frac{q_{c1Ncs}}{67}\right)^2 - \left(\frac{q_{c1Ncs}}{80}\right)^3 + \left(\frac{q_{c1Ncs}}{114}\right)^2 - 3\right) \quad (13)$$

If q_{1Ncs} *> 211, then* $CRR_{7.5}$ *= 2*

in which Fc is the finest content with Ic correlation, and qc1Ncs is the CPT coefficient.

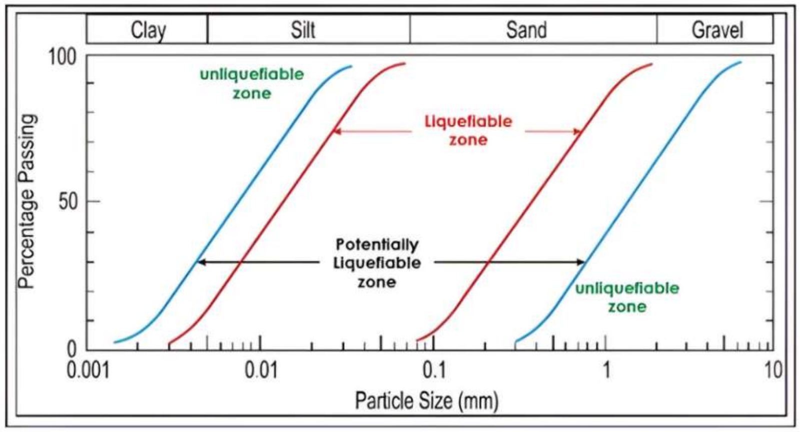


Figure 2. Curve of soil particle size distribution for susceptibility to liquefaction (Suprijanto et al., 2020)

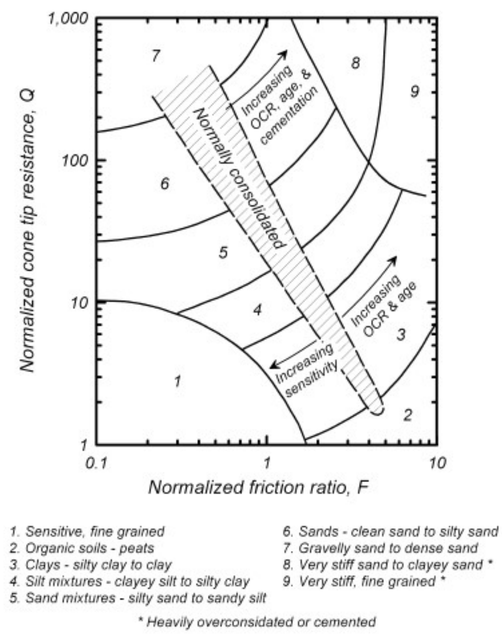


Figure 3. Correlation between Fr and Q (Idriss and Boulanger, 2008)

RESULT AND DISCUSSION

The assessment of liquefaction potential is divided into a grain size analysis and empirical formulation based on area CPT.

Grain size analysis

The results of sieve analysis for CPT 1 and CPT 2 are plotted in Figure 4 and Figure 5 presenting the range of particle size distribution. The depth varies from 0 to 3.8m for CPT 1 and between 0 and 3.4m for CPT 2.

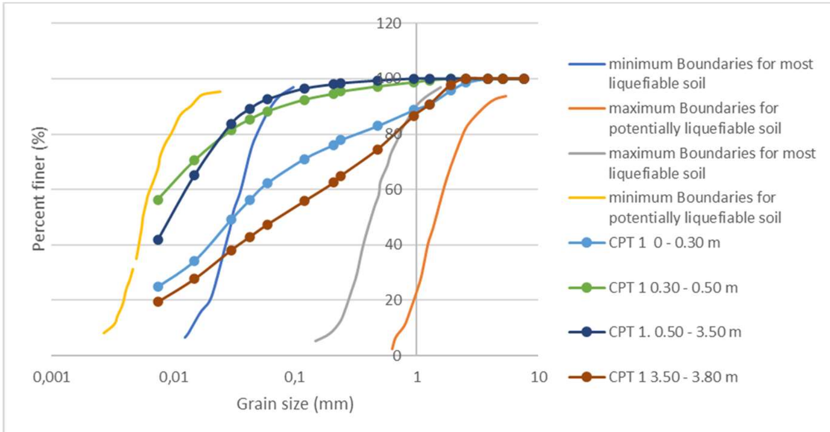


Figure 4. Liquefaction analysis in CPT 1 based on grain size analysis

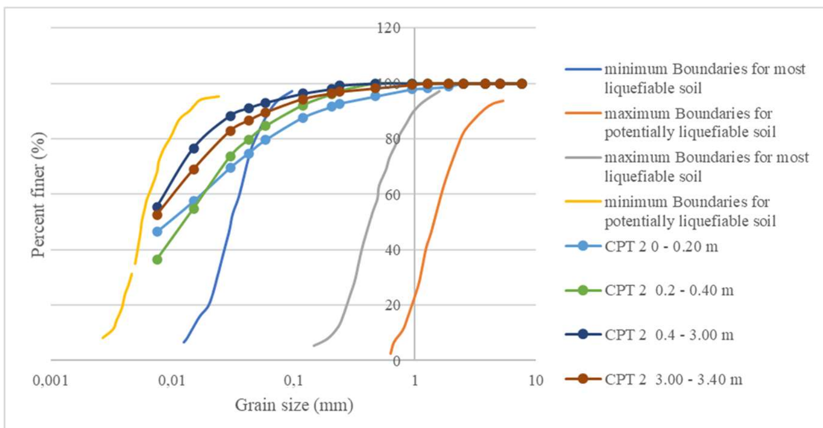


Figure 5. Liquefaction analysis in CPT 2 based on grain size analysis

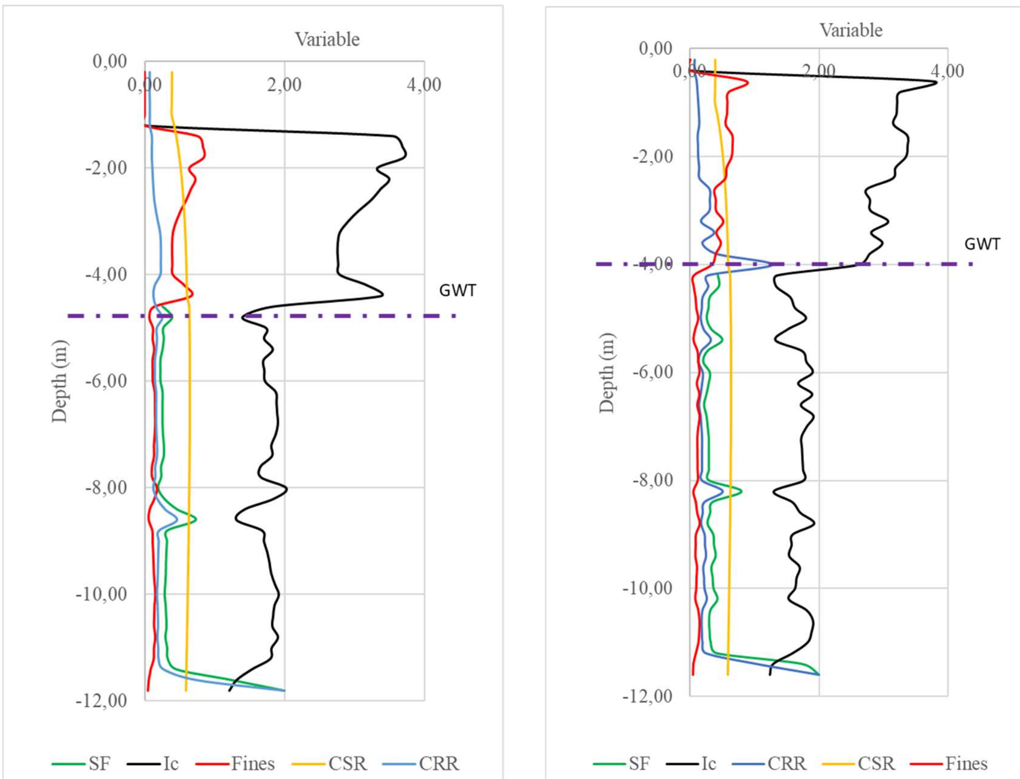
According to Figure 4, the results of grain size analysis show liquefaction potential. Although the curve is not precisely in the range of the most potential liquefaction, it is located in the field of potential liquefaction hazards. According to the survey of the nearest areas (Balaroa and Petobo) for peak ground acceleration (PGA) values, it is liquefiable in the near-surface soil layers. Although deeper soil layers can also liquefy, there has been no liquefaction in non-Nalodo locations because of the thick medium layer of the soil nearby (Tohari et al., 2022).

Meanwhile, Figure 5 represents the liquefaction analysis result of CPT 2. A similar trend with that of CPT 1 is obtained, in which the sieve analysis depicts the potential of liquefaction. All the soil properties in CPT 1 and CPT 2 are dominated by sand. According to Markus (Anda et al., 2021), liquefaction increases the number of weatherable minerals in the sand fraction. Consequently, further research is required to understand different behavior of soil consistency.

On the other hand, the liquefaction analysis includes such variables as fines percentage and location of the groundwater table. In this area, the size of the groundwater table is varied between 4 and 4.4m (discussed in the CPT analysis). A soil layer of above 4 and 4.4m is hard to liquefy because the soil is unsaturated. Since all the grain size analysis is located at a depth of 0-4m, it indicates the possibility of liquefaction. However, assessment of the actual condition shows no liquifying because of the unsaturated soil. The next evaluation of the soil below the groundwater table is shown in the CPT analysis.

CPT analysis

The liquefaction analysis is calculated by using an empirical formula based on CPT 1 and CPT 2. The outcome is a value of safety factor for each thickness of the soil layer. All the results are shown in Figures 6(a) and 6(b).



(a) (b)

Figure 6(a). Liquefaction analysis based on CPT 1 Figure 6(b). Liquefaction analysis based on CPT 2

Figure 6(a) describes several variables, including Ic, fines percentage, CSR, CRR, and safety factor (SF). The value of SF ranges between 0.18 and 2.00. A safety factor (SF) for liquefaction vulnerability shows the correlation between soil strength and load stress, in which SF <1 indicates soil that is susceptible to liquefaction (Idriss, et.al, 2008). This analysis was conducted at the thickness below the groundwater table because a liquefaction phenomenon occurs in saturated conditions. In addition, the Ic criterion shows a smaller value than 2.6, thus indicating a high possibility of liquefaction. The figure also shows that the fines percentage of the soil layer at 4.4-12m is less than 15%, indicating that it is vulnerable to liquefy. In a liquefaction analysis, CSR and CRR results are used to examine the safety factor.

From the liquefaction analysis in CPT 2, Figure 6(b) shows that the SF value and depth have a similar trend with those in CPT 1. The safety factor analysis was performed at the thickness of below 4m. The groundwater table in CPT 2 is located closer to the surface than that in CPT 1. The calculation shows that the Ic, fines percentage, CSR, and CRR are less than the maximum requirement to not liquefy. The Ic is varied between 1.34 and 1.9 while the percentage of the fines is 5-15%. Therefore, the outcome shows that the area between 4-12m deep has liquefaction potential.

According to another investigation (Rahayu et al., 2021), the findings from eight CPTs in the Village of Lolu indicate that soil with varied end resistance and friction ratio values has liquefaction potential at a depth of 5 to 10 m. Studies of grain size distribution also show that sandy soils are prone to liquefaction and predominate among soil types. In addition, Rahmawati shows that the potential liquefaction indicated by the safety factor (0.6 to 0.9) obtained from both methods is consistent with the depths from 2.0m to 5.0m in the Palu area (Rahmawati et al., 2020).

Conclusion

Overall, the liquefaction analysis using both methods has shown similar results. Even though the curve does not plot in the range of the most potential area, it is located in the range of potential liquefaction. Nevertheless, although the grain size assessments from CPT 1 and CPT 2 at all depths show the liquefaction potential, they are insufficient for a liquefaction analysis since the ground water table is less than 4 and 4.4m. Further analysis such as liquefaction analysis based on CPT data is required to obtain better results. In addition, both CPT 1 and CPT 2 analyses result in a similar trend with a safety factor less than one, Ic below 2.6, and fines percentage smaller than 15%, thus indicating the potential for liquefaction hazards.

References

Chou, J., Yang, H., & Lin, D. (2021). *Calibration of Finn Model and UBCSAND Model for Simplified Liquefaction Analysis Procedures*. Applied Sciences. 11. 5283. 10.3390/app11115283.

Idriss, I. & Boulanger, R. (2008). *Soil Liquefaction During Earthquakes*. MNO. 12.

Jalil, A., Fathani, T.F., Satyarno, I and Wilopo, W. (2020). *Liquefaction in Palu: The Cause of Massive Mudflows*. 10.21203/rs.3.rs-137316/v1.

Kuswandi, Y., Erwindi, J., Hadian, M., & Muslim, D. (2020). *Disaster Mitigation for Palu City Residents in Dealing with Liquefaction Disasters in Accordance of Spatial Patterns of Palu City, Central Sulawesi Province, Indonesia*. Journal of Geoscience, Engineering, Environment, and Technology. 5. 219-226. 10.25299/jgeet.2020.5.4.5653.

Koester, J.P and Tsuchida, T. (1988). *Earthquake-Induced Liquefaction of Fine-Grained Soils-Considerations from Japanese Research*. Final Report.

Markus, A., Setiyo, P., Erna, S., Husnain, H., & Muchtar, M. (2021). *Pristine soil property and mineralogy as the strategic rehabilitation basis in post-earthquake-induced liquefaction, tsunami and landslide in Palu, Indonesia*. Catena, 203, 105345. doi: 10.1016/j.catena.2021.105345.

Rahayu, W., Yuliyanti, I., & Bahsan, E. (2021). *Analysis of potential liquefaction using cone penetration test data and grain size distribution test with case study of liquefaction in Lolu Village*. IOP Conference Series: Earth and Environmental Science. 622. 012015. 10.1088/1755-1315/622/1/012015.

Rahmawati, H., Prakoso, W., Rahayu, A. (2020). *V_s and CPT based evaluation of location with high liquefaction damage during 2018 Palu earthquake*. IOP Conference Series: Materials Science and Engineering. 930. 012034. 10.1088/1757-899X/930/1/012034.

Suprijanto, H., Hendrawan, A., & Nugraha, A. (2020). *Potential study of the liquefaction hazard at the reclamation* *development site of I Gusti Ngurah Rai airport, Nusa Dua region, province of Bali*. IOP Conference Series: Earth and Environmental Science. 437. 012058. 10.1088/1755-1315/437/1/012058.

Tohari, A., Muttaqien, I., & Syifa, R. (2022). *Understanding of flow liquefaction phenomena in Palu City from shear wave velocity profiles*. E3S Web of Conferences. 340. 01011. 10.1051/e3sconf/202234001011.

Toshio I., Tadashi A., & Ken-Ichi, T. (1984). *Simplified procedures for assessing soil liquefaction during earthquakes*, International Journal of Soil Dynamics, and Earthquake Engineering.