EXPERIMENTAL STUDY OF FINE GRAIN CONTENT OF SOIL ON LIQUEFACTION POTENTIAL

Maulana ARIF[1]*, Ilpandari ILPANDARI[1]

[1]Civil Engineering Department, Faculty of Engineering and Science, Muhammadiyah University of Bangka Belitung, Central Bangka, Indonesia

*Correspondence email: maulana.arif@unmuhbabel.ac.id

[Received: 7 Desember 2022, Accepted: 28 Desember 2022]

ABSTRACT

One of the efforts to realize environmentally sound development is to pay attention to disaster aspects that threaten an area, one of which is the phenomenon of liquefaction. The liquefaction disaster is of particular concern after the 2018 Palu liquefaction, damaging and claiming many victims. Liquefaction is a phenomenon in soils that are initially solid and then turn liquid due to increased pore water pressure due to cyclic loads or earthquakes, which reduce the carrying capacity of the soil. Not all types of soil have the potential to experience liquefaction. In general, soils with a high liquefaction potential are soils with a high content of fine sand grains and fewer clay particles. This study aims to determine the effect of fine grain content (silt and clay) on the magnitude of the liquefaction potential. The study was conducted using experimental modeling with fine sand soil samples (passed sieve number 40 and retained sieve number 100), which varied the content of fine grains (passed sieve number 200) as much as 0%, 5%, 10%, 15%, and 20%. The results of this study indicated that soil with a fines content of 0% liquefied after 5.56 seconds, and soil with a fines content of 20% experienced liquefaction after 23.84 seconds. This condition shows that the higher fine content of soil decreases its liquefaction potential.

Keywords: liquefaction, fines, experimental study

INTRODUCTION

The 2018 Palu liquefaction disaster opened the attention of researchers to developing seismic geotechnical science. Earthquake events with a large enough magnitude can have an impact on liquefaction. Liquefaction can be interpreted as melting soil. At the same time, understanding liquefaction as a whole is a phenomenon in fine sand-sized and water-saturated soils that experience a significant enough cyclic load (earthquake) for a particular time, increasing pore water pressure which makes the effective stress on the soil decrease so that the soil loses its bearing capacity (Das & Ramana, 2011).

The conditions that trigger liquefaction are the type of soil, the depth of the water table, the thickness and depth of the soil layer, and cyclic loads (ex: earthquake). This research will discuss more the type of soil that has more potential to experience liquefaction, primarily related to the content of silt and clay-sized grains (passed sieve number 200).

Several conditions can trigger liquefaction. If one of the conditions is not fulfilled, liquefaction may not occur. The conditions that trigger liquefaction are:

1. The type of soil.
2. The depth of the water table.
3. The thickness and depth of the soil layer.
4. Cyclic loads in the form of earthquakes.

The soil type is essential to determine whether the soil has the liquefaction potential. Not all types of soil can cause liquefaction. Aydan et al. (2008) state that soils with liquefaction potential have grain sizes ranging from sand to silt.

The soil in saturated water conditions is one of the causes of liquefaction. Ramakrishnan et al. (2006) stated that there are three levels of risk of liquefaction, depending on the position of the groundwater table. There are three levels of risk:

1. *Susceptible*, it can occur in alluvium soils with a groundwater depth of <10 m
2. *Marginally susceptible or slightly susceptible*, it can occur in alluvium with a water table depth of 10-15 m
3. Not susceptible or not susceptible, for a depth of groundwater> 15 m

The thickness and depth of the soil layers affect the level of liquefaction susceptibility in the soil. A thick layer of soil has a more significant liquefaction potential and impact. In addition, layers of soil near the surface tend to be more prone to liquefaction than layers of soil far below the surface.

Based on Iwasaki (1982), the soil at a depth of > 20 m does not have the potential to cause liquefaction. It is because the effective stress of the soil close to the surface is smaller than the effective stress of the soil far below the surface, as the vertical stress (σ_v) is a linear function of depth (z).

One of the essential factors causing liquefaction is the presence of cyclic loads in the form of earthquake shocks. Generally, liquefaction occurs when an earthquake has a PGA value of > 0.25 g (Toprak and Holzer, 2003).

Research related to liquefaction soil has been carried out quite a lot. However, there are still slight differences regarding the liquefaction criteria for several parameters. Based on computational testing, soils with a fine grain percentage of more than 42% and a PI of more than 10.8% are considered non-liquefied (Ghani & Kumari, 2021).

Based on research on liquefaction in the southern area of Thailand, using drilling data and the percentage of fine grains, it is known that soils that are prone to liquefaction are soils with SPT values <20 and fine grain content ranging from 5-42% (Mase et al., 2015)

Another study approved that poorly graded sandy soils with Cu<6 and Cc<1 values and <33% relative density are examples of soils that have the potential to experience liquefaction based on a study of the sandy soils of Kali Opak Yogyakarta (Mase et al., 2013). The research was conducted using a shaking table with a specific dynamic loading to determine the liquefaction potential of the soil.

The 2018 Palu liquefaction event was one of Indonesia's most significant liquefaction events. Research states that the characteristics of the liquefied soil in Palu, especially in the Balaroa area, are soils in a non-dense condition with known N SPT values of <10 and fine grain content of 20-40% (Jalil et al., 2021).

An analysis of the liquefaction potential was also carried out in the underpass area of Yogyakarta International Airport. The results showed that soils that have the potential to experience liquefaction are sandy soils and sandy loams with N SPT values ranging from 10-17 (Rahman et al., 2020).

Homes, water utilities, and traffic routes have been damaged due to the 7.6 Mw of Padang Earthquake on September 30, 2009, which caused soil liquefaction. The soil grain size distributions revealed that more than 65% of the soil samples' grains are fine sand. (Hakam and Suhelmidawati, 2013). The Quarternary alluvial deposit at shallow depth appears to have been the primary location of liquefaction in Padang City. The main areas of ground deformation and liquefaction are primarily along the shoreline and connected to alluvial sand. For Padang City, a micro-zonation map showing liquefaction susceptibility was created. The susceptibility map and the field data made following the earthquake occurrence in 2009 are in good agreement. Due to the existence of dense sand to gravelly sand or thick layers of fine-grained soils serving as cap soils, the susceptibility of the soil layers to liquefaction decreases dramatically toward the northeastern area of the city (Tohari et al., 2011).

Based on the latest research conducted above, it can be seen that liquefaction soils have quite varied fine grain sizes. Therefore this study was conducted to see how the effect of differences in fine grain content in soils with poor gradations on liquefaction potential based on simple experimental tests.

The relationship between the two variables can be known using the regression method. Several regression methods are linear regression, non-linear regression exponential model, and non-linear regression power model.

Regression modeling, also referred to as linear regression analysis, was the precursor to the later development of artificial neural networks and is covered in-depth in this study. Techniques for linear regression are frequently utilized in the field of building (Thomas and Sakarcan, 1994). Linear regression is an analytical method to see/predict a variable based on the relationship of a variable with other variables with a linear equation. The form of the linear regression equation is stated in Equation 1 (Yulistyanto, 2019).

$$y = a + bx \tag{1}$$

While non-linear regression is an analytical method to see/predict a variable based on the relationship of a variable with other variables with a non-linear equation. There are two types of non-linear regression, namely non-linear regression exponential model, which is expressed in the form of Equation 2. and non-linear regression power model, which is described in the form of Equation 3 (Yulistyanto, 2019).

$$y = ae^{bx} \tag{2}$$

$$y = ax^{b} \tag{3}$$

The level of correlation of a regression equation is determined based on the value of *r* for each method. Equation 4 describe the general formula for *r* value (Yulistyanto, 2019).

$$r = \sqrt{\frac{Dt^2 - D^2}{Dt^2}} \tag{4}$$

$$Dt^2 = \sum_{i=1}^{n} (y_i - \bar{y})^2 \tag{5}$$

$$D^2 = \sum_{i=1}^{n} (y_i - a - bx_i)^2 \tag{6}$$

$$D^2 = \sum_{i=1}^{n} (y_i - ae^{bx_i})^2 \tag{7}$$

$$D^2 = \sum_{i=1}^{n} (y_i - a{x_i}^{b})^2 \tag{8}$$

The formula for calculate the Dt^2 is described from Equation 5, and the formula for calculate the D^2 is described from Equation 6-8. Equation 6 for the linear regression method, Equation 7 (exponential model) and Equation 8 (power model) for the non-linear method (Yulistyanto, 2019).

RESEARCH METHOD

The research was carried out by conducting laboratory experiments. The research limitation determined that the soil samples were restricted to poor gradation conditions, and fine grain content varied from 0%, 5%, 10%, 15%, and 20%. Soil samples consist of coarse-grained soil and fine-grained soil. Coarse-grained soils are fine sand with the criteria of soil passing sieve number 40 and retained by sieve number 100, while fine-grained soils are silt and clay with criteria of passing sieve number 200.

The container is a 3mm thick clear acrylic box with dimensions of 14 cm x 14 cm x 18 cm. The acrylic box serves as a container for water and soil before the modeling experiment is carried out. The level of soil density is regulated according to the criteria for liquefaction soil when N SPT <10 so that the unit weight of the soil is determined based on the value of N SPT <10, which is 17.3 kN/m3 (Bowles, 1977). Table 1 shows the experimental scenarios carried out. Where W_S is weight of soil, W_W is weight of water, W_C is the weight of coarse grain (soil passing sieve number 40 and retained by sieve number 100), and W_F is the weight of fine grain.

The step of laboratory tests carried out is as follows.

1. *Soil sample preparation*. The soil for the liquefaction test is determined as fine sand with the criteria of soil passing sieve number 40 and retained by sieve number 100, while fine-grained soils are silt and clay with standards of passing sieve number 200 (Figure 1a).
2. *Model preparation*. Soil and water were put into the acrylic box according to the test on Table 1 (Figure 1b).
3. *Running model.* The model (acrylic box with the soil) were placed on the sieve shaker. The simulation is run until the soil experiences total liquefaction. Then record the time it takes for the soil to liquefy (Figure 1c).

The relationship between the fines content and time to liquefaction is also observed in this research using regression methods. Linear regression and non-linear regression were conducted.

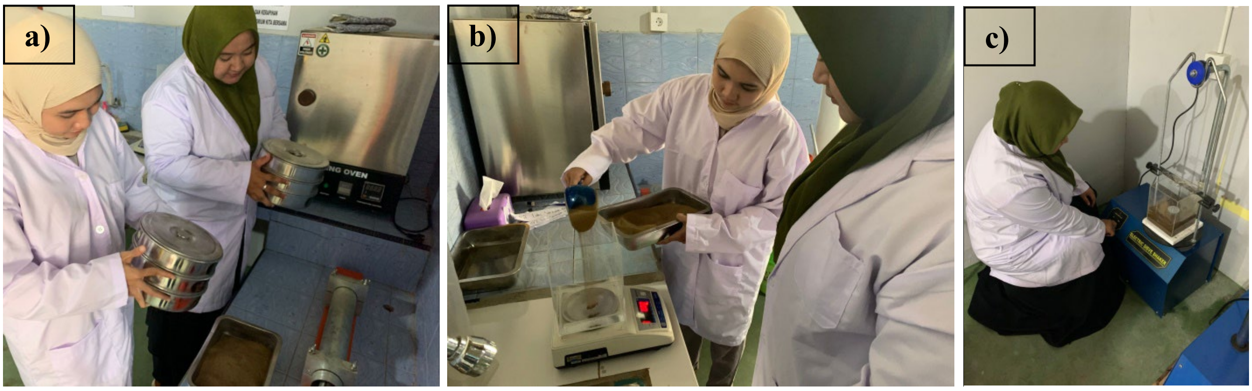


Figure 1. The step of laboratory tests a) Soil sample preparation; b) Model preparation; and c) Running model with sieve shaker

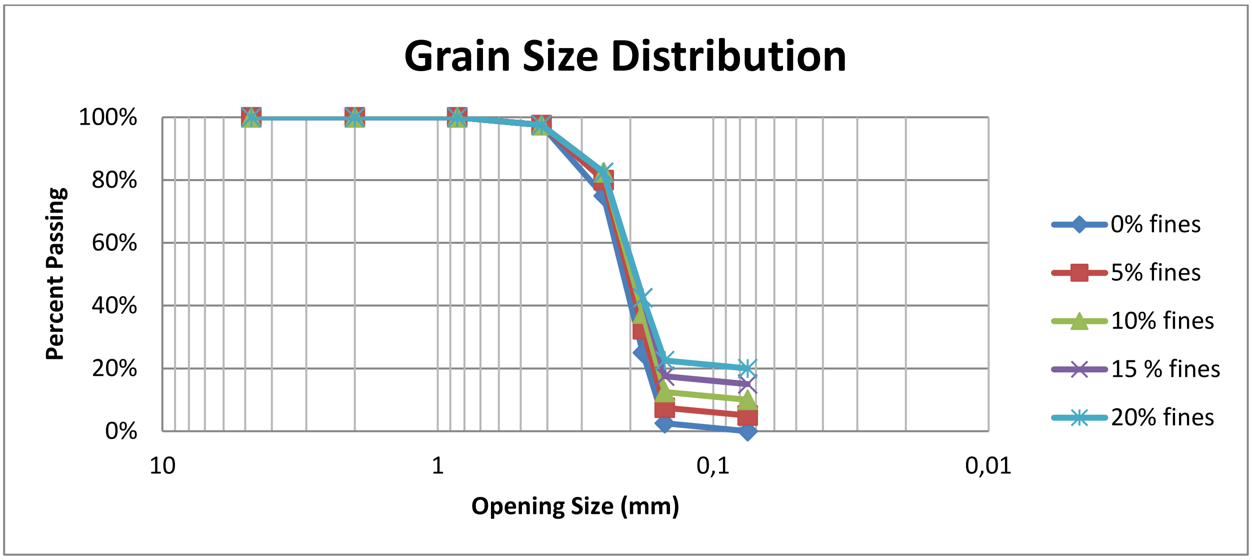


Figure 2. Soil grain size distribution of model

Table 1. Scenario test with different silt-clay percentage

Test Number	W_S(gr)	W_W(gr)	W_C(gr)	W_F(gr)	%FINES
1	1250	537.5	1250	0	0
2	1250	537.5	1187.5	62.5	5
3	1250	537.5	1125	125	10
4	1250	537.5	1062.5	187.5	15
5	1250	537.5	1000	250	20

RESULT AND DISCUSSION

The grain size distribution of the soil model can be seen in Figure 2. The curve shows that the soil of each model has poorly graded grain distribution characterized by the steep curve angle, which means it has a relatively uniform grain size. The fine grain varied from 0%, 5%, 10%, 15%, and 20%. The soil model's uniform coefficient (Cu) ranges from 1-3, and the gradation coefficient (Cc) ranges from 0.01-0.03.

The result of the running model is shown in Table 2. It can be seen that the increase in fines content affects the time of the soil liquefaction. Figure 3 shows the result of the running model test number 1. The iron plate above the soil layer (Figure 3a) has sink during the running model until the liquefaction of soil (Figure 3b). From the test number 1, when the soil did not contain fine grain, it needed 5.56 seconds to liquefy after the shaker started. Along with the addition of fine grain content, liquefaction potential is lower. It can be seen from the long time it takes for the soil to liquefy.

Table 2. Test results

Test Number	Fines content (%)	Time of liquefaction (s)
1	0	5.56
2	5	10.54
3	10	12.59
4	15	20.94
5	20	23.84

From test number 2 (5% fines content), the soil experienced liquefaction after 10.54 seconds of the running test. The liquefaction occurs 5.58 seconds slower than test number 1 (0% fines grain). Test number 3 (10% fines content) also generates slower liquefaction occurrence. It takes almost 12.59 seconds to liquefy after the running test. The liquefaction occurs 7.03 seconds slower than the test without fines content (test number 1).

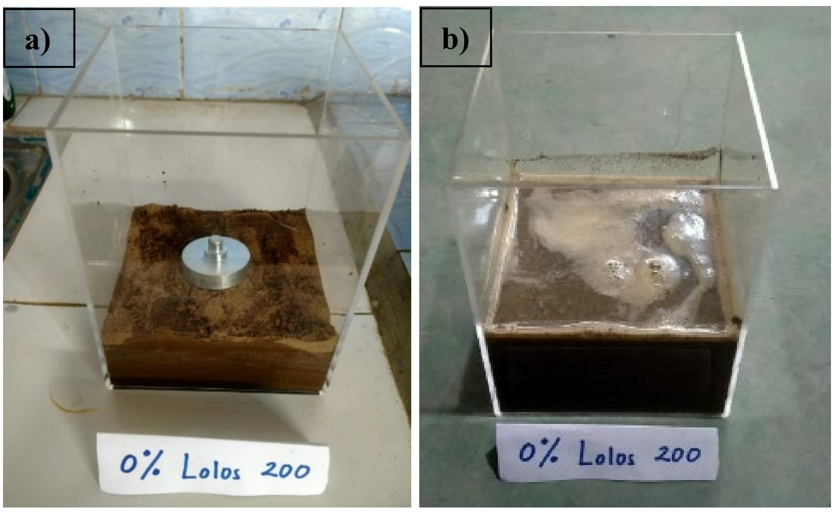
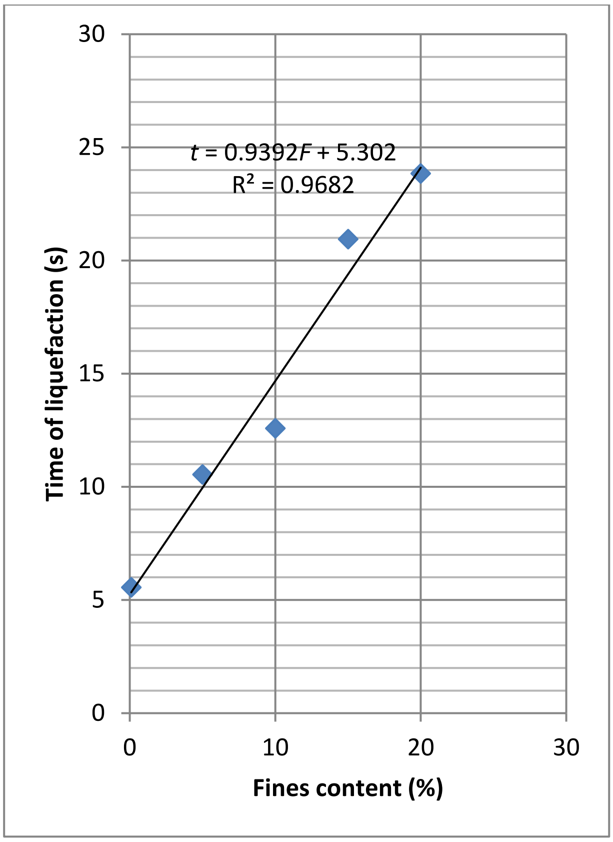


Figure 3. a) initial condition, and b) soil liquefaction after running model

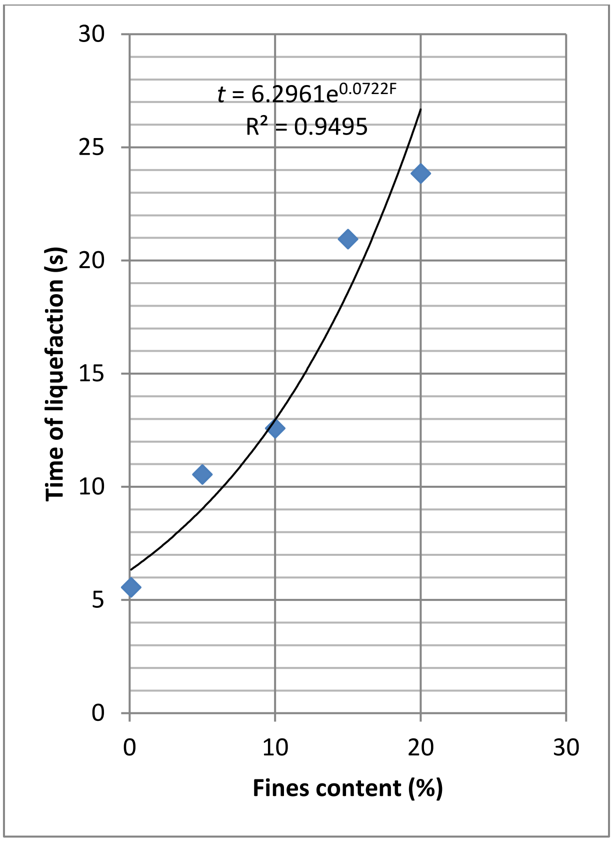
Furthermore, test number 4 (15% fines content), the soil experienced liquefaction after 20.94 seconds of the running test. The liquefaction occurs 15.38 seconds slower than test number 1 (0% fines grain). Test number 5 (20% fines content) generates slower liquefaction occurrence. It takes almost 23.84 seconds to liquefy after the running test. The liquefaction occurs 18.28 seconds slower than the test number 1.

Based on the results of the five tests number, we can conclude that the higher the content of fine grains contained in the soil, the smaller the liquefaction potential. The fine grain presence impacts the soil permeability to become lower. It makes the water in the soil harder to drain during the earthquake. This condition affects the generation of liquefaction becomes slower.

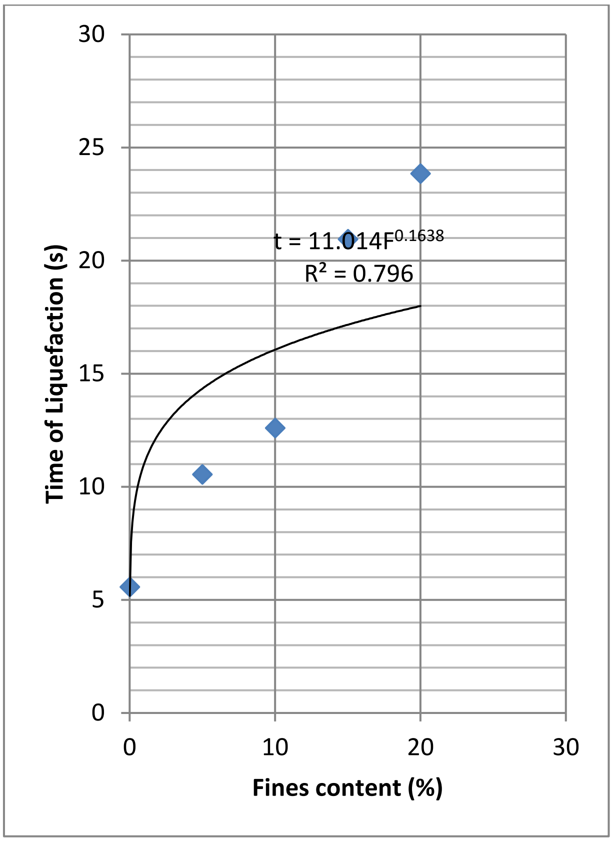
The relationship of fines content (F) and the time of liquefaction occurrence (t) can be seen on the Figure 4. It shows the result of linear regression and non-linear regression analysis.



(a)



(b)



(c)

Figure 4. a) Linear regression result; b) non-linear regression (exponential model) result; and c) non-linear regression (power model) result

According to the linear regression analysis result, the relationship of those variables relatively strong where the coefficient of correlation is 0.9682. Furthermore, based on the non-linear regression analysis result, the relationship of those variables relatively strong where the coefficient of correlation is 0.9495 for exponential model and 0.796 for power model.

CONCLUSION

An experimental study of the effect of fine-grain soil was conducted. The presence of fine grain on the soil affects the liquefaction potential marked by increasing the soil's time to liquefy from 5.56 seconds to 23.84 seconds. On the other hand, the relationship between those two variables (fine content and time to liquefy) was observed to be strong, where the coefficient of correlation of 0.9682 from linear regression analysis, 0.9495 from non-linear regression analysis for exponential model and 0.796 from non-linear regression analysis for power model.

ACKNOWLEDGMENTS

I appreciate having the opportunity to work on this and other relevant projects with everyone. I also like to express my gratitude to the University of Muhammadiyah Bangka Belitung, the funding source for this study project.

REFERENCES

Aydan, O., Ulusay, R., Atak, V.O. 2008. *Evaluation of Ground Deformations Induced by the 1999 Kocaeli Earthquake (Turkey) at Selected Sites on Shorelines.*

Bowles, J.E. 1977. *Foundation Analysis and Design.* New york: McGraw-Hill Inc.

Das, B. M., & Ramana, G. V. 2011. Principles of Soil Dynamics. In T. Altieri (Ed.), *Cengage Learning* (second edi). Cengage Learning.

Ghani, S., & Kumari, S. 2021. Liquefaction study of fine-grained soil using computational model. *Innovative Infrastructure Solutions*, *6*(2). https://doi.org/10.1007/s41062-020-00426-4

Hakam, A., Suhelmidawati, E. 2013. *Liquefaction Due to September 30th 2009 Earthquake in Padang*. Elsevier

Iwasaki, T., Tatsuoka, F., Tokida, K., & Yasuda, S. 1978. A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan. *Proc., 2nd Int. Conf. on Microzonation*, pp. 885-896, San Francisco.

Jalil, A., Fathani, T. F., Satyarno, I., & Wilopo, W. 2021. Liquefaction in Palu: the cause of massive mudflows. *Geoenvironmental Disasters*, *8*(1). https://doi.org/10.1186/s40677-021-00194-y

Mase, L. Z., Fathani, T. F., & Adi, A. D. 2013. Studi Eksperimental Potensi Likuifaksi di Kali Opak Imogiri Provinsi Daerah Istimewa Yogyakarta. *17th Annual Scientific Meeting*, *April*. https://doi.org/10.13140/RG.2.1.2802.1284

Mase, L. Z., Likitlersuang, S., Soralump, S., & Tobita, T. 2015. Empirical Study of Liquefaction Potential in Chiang Rai Province in North of. *Proceeding of the 28th KKHTCNN Symposium on Civil Engineering*, *November*. https://doi.org/10.13140/RG.2.1.1706.1840

Rahman, M. A., Fathani, T. F., Rifa'i, A., & Hidayat, M. S. 2020. Analisis Tingkat Potensi Likuefaksi di Kawasan Underpass Yogyakarta International Airport.

JURNAL REKAYASA SIPIL (JRS-UNAND), *16*(2), 91–104. https://doi.org/https://doi.org/10.25077/jrs.16.2.91-104.2020

Ramakhrisnan, D., Mohanty, K.K., Nayak, S., Chandran, V. 2006. *Mapping the Liquefaction Induced Soil Moisture Changes using Remote Sensing Technique: An Attempt to Map the Earthquake Induced Liquefaction Around Bhuj, Gujarat, India*. Springer

Thomas, R. and Sakarcan, A. 1994. Forecasting Labor Productivity Using FactorModel. *Journal of Construction Engineering and Management*, 120(1), 228–239.

Tohari, A., Suganti, K., Subowo, E. 2011. Liquefaction Potential at Padang City: A Comparison of Predicted and Observed Liquefactions during the 2009 Padang Earthquake. *Riset Geologi dan Pertambangan, 21(1)*.

Toprak, S., Holzer, T.L. 2003. *Liquefaction Potential Index: Field Assessment.* California: ASCE

Yulistyanto, B. 2019. *Metode Numerik Aplikasi untuk Teknik Sipil*. Yogyakarta: Gadjah Mada University Press