2118-Evaluating Liquefaction Phenomenon Of Silty Sand Using Piezocone Penetration Test (CPTu

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Evaluating Liquefaction Phenomenon Of Silty Sand Using Piezocone Penetration Test (CPTu)

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ABSTRACT

Most investigations into liquefaction have focused on clean sandy soils, with time, evidence has grown that liquefaction is often associated with silty sand material. Sibalaya Village, which suffered the greatest damage from the Palu-Donggala earthquake, is dominated by silty sand material. Related to this issue, an experimental study is conducted in the laboratory to understand the behavior of excess pore pressure and the strength of the saturated silty sand under dynamic loading. The experimental study uses several sets of testing apparatus such as a shake table, chamber, and CPTu. The shake table provides a dynamic load for the soil sample. The chamber allows the field environment to be duplicated in the laboratory. The CPTu measures excess pore pressure and strength of the soil sample. The test results show that liquefaction can occur in silty sand material. However, the fine-grain particles cannot generate the overall pore water pressure in which the pore water pressure ratio can only reach 93% of the initial effective vertical stress. Liquefaction also generates increased pore water pressure and a decrease in soil strength. The increase of dynamic load will result in a shorter liquefaction starting time, and fine content strongly influences the pore water pressure behavior, especially on the rate of pore water pressure dissipation after liquefaction occurs. Therefore, based on this research, it is known that silty sand material can experience liquefaction and can have a longer liquefaction period due to its lower permeability.

1. Introduction

Liquefaction has become one of the highlights for Indonesia and the world, especially after the phenomenon of liquefaction that occurred in Palu due to the 7.5 Mw Palu-Donggala earthquake on 28 September 2018. The term liquefaction was originally introduced by [1] as a term that indicates the phenomenon of ground movement caused by dynamic loads on coarse-grained soils that are saturated with water and are in undrained conditions. [2] liquefaction is the loss of shear strength of loose sandy soils and can result in flow slide if given external

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disturbances. Most investigations into liquefaction have focused on clean sandy soils and probably due to a natural tendency to work in the simplest materials to avoid complications in testing. With time, evidence has grown that liquefaction is often associated with silty sand and, in some cases, silts [3].

Sibalaya village, located in Palu, is the village that suffered the greatest damage by liquefaction and flow slide initiated by the Palu-Donggala earthquake. Based on observation, the Sibalaya Village area is dominated by silty sand material, which is contained fine-grain particles that have low permeability and is suspected of having a strong influence on the duration of the liquefaction. These aspects are suspected to be the reason for the massive liquefaction and flow slide in Sibalaya Village.

Related to this issue, an experimental study of the liquefaction phenomenon is proposed to see the behavior of excess pore pressure and strength of the silty sand material under dynamic load. An experimental study using a dynamic test, such as the shake table test, which is equipped with chamber and piezocone (CPTu), is conducted to study liquefaction behavior in detail and better understand silty sand material.

2. Literature Review

Liquefaction occurs in loose sand soils saturated with water [4]. Liquefaction occurs when the ratio of pore water pressure (r_u) ≥ 1 [5]. It goes along with [6] and [7] statements that declare liquefaction occurs when excess pore water pressure (ΔU) equals or exceeds initial effective vertical stress (σ_v'). The excess pore pressure criterion, which indicates a soil material has experienced liquefaction plays an important role in studying the mechanism of liquefaction [8]. The pore water pressure ratio in silty sand soils containing fine-grain particles cannot generate the overall pore water pressure. The pore water pressure ratio can only reach 90 - 95% of the initial effective vertical stress (σ_v') [9].

Research on seismic is one of the research that can provide information about ground amplification, change in excess pore water pressure, soil non-linearity, the occurrence of failure, and soil-structure interaction problems. Research on seismic modeling studies can be divided into 2 categories, namely those carried out under conditions of earth gravity (generally referred to as shake table testing or 1-g testing) and those carried out under conditions of higher gravity (centrifuge testing or multi-g testing) [10]. The shake table test has the advantage of well-controlled large-amplitude, multi-axis input motions, and easier experimental measurements [11].

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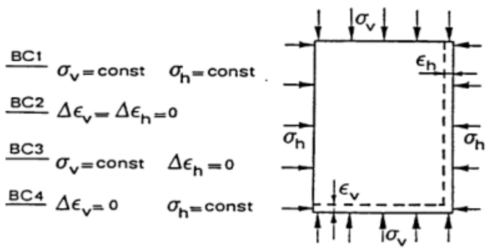
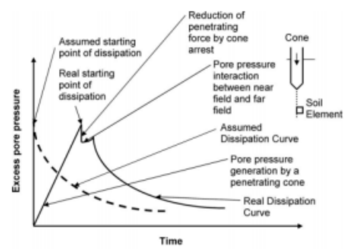
Along with the development of time, various parties have carried out the manufacture and research using calibration chambers and CPTu. A calibration chamber can model field conditions by providing vertical and horizontal stresses on the soil sample. [12] proposed that the limitations in modeling field conditions in the calibration chamber can be carried out in 4 approaches as described in **Figure 1**. [13] stated that BC1 and BC3 limitations are the limitations that are generally used in research using a calibration chamber**.** The use of CPTu as an in-situ testing instrument is widely used to measure pore water pressure. The use of the dissipation feature on the CPTu tool is a feature that is generally used to determine the dissipation curve [14]. The pore water pressure response when CPTu is in dissipation condition can be seen in **Figure 2**.



Source : Jamiolkowski et al. (1985).

Figure 1. Limitations of Calibration Chamber Modeling



Source: Voyiadjis dan Song (2003).

Figure 2. Pore Water Pressure Response in Dissipation Condition

According to the previous investigators, the scale factor of a cone penetration test is an empirical study based on previous research. There are 3 thoughts according to the scale factor of a cone penetration test as described below :

- The first thought is that there is no scale factor effect [15], [16], [17].
- The second thought is a scale factor effect for shallow punctures. [18] [19] and stated that there was no difference in the readings of the cone tip resistance at a certain depth. Based on several studies, it is known that a penetration depth of 20 D in a dense sand layer and 10 D in a loose sand layer is sufficient to eliminate the scale factor effect.
- The third thought is about the existence of a scale factor. [20] conducted a study on a calibration chamber and stated that a scale factor effect would have more impact on dense sand. [21] showed that the effect of sand sample size on the tip resistance value is a function of bulk density, diameter ratio, boundary conditions, stress history, and sand type, as shown in **Figure 3**.

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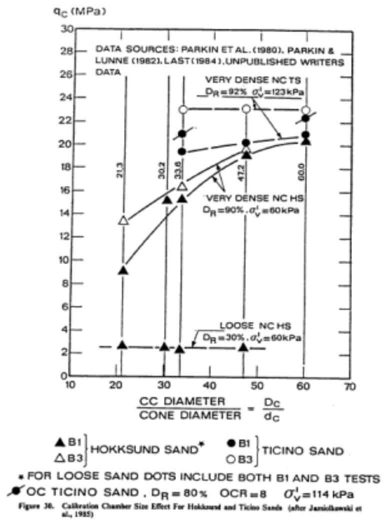
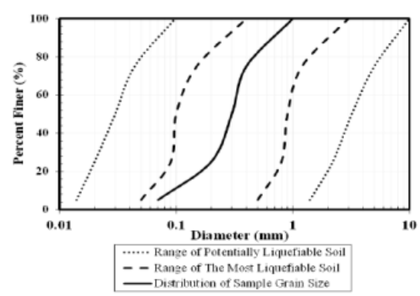


Source : Jamiolkowski (1985) [22].

Figure 3. Effects of Scale Factor Based on Calibration Chamber Test for Hokksund and Ticino Sand.

Conducted research on liquefaction using a shake table in the Cultural Heritage Conservation Center (BPCB) of Prambanan Temple in Yogyakarta (**Figure 4**). The liquefaction research was carried out by applying various dynamic loads (0.3 g, 0.35 g, and 0.4 g) to the Opak River sand sample in Imogiri (South of Yogyakarta). The grain size distribution of the soil sample is shown in **Figure 5**.



Source: Journal of Civil Engineering - ITB (Mase, 2017).

Figure 4. Shake Table Apparatus in BPCB Prambanan Temple.

Figure 5. Soil Sample Grain Size Distribution.

Based on this research, it is known that the larger dynamic load is applied, excess pore pressure is generated. It passes the effective stress in a short time. In terms of vibration duration, the dynamic load applied in the longer duration will produce a longer dissipated time and vice versa. After the initial liquefaction time, the remained vibration duration continuously triggers the liquefaction until the vibration is stopped. Therefore, the longer vibration can produce a

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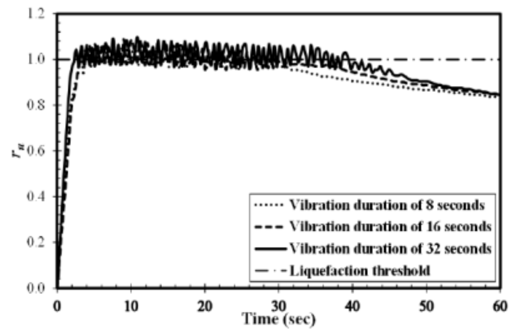
longer dissipated time. Besides that, it is also known that when the dynamic load is stopped, the shake table platform is not directly stopped. There is a free vibration after loading, and the free vibration still releases the remained energy, which contributes to generating a small value of excess pore water pressure. After the free vibration is stopped, the pore water pressure will start to dissipate. **Figure 6** shows the behavior of the ratio of pore water pressure vs. time during dynamic load applied to Opak River soil material.



Source: Journal of Civil Engineering - ITB (Mase, 2017).

Figure 6. The ratio of Pore Water Pressure vs. Time for Dynamic Load.

Based on [22] research, it can be seen that dynamic load has a very crucial role in increasing excess pore water. However, the research has not informed about the strength of the soil after the occurrence of dynamic load. Therefore, this research will discuss the behavior of pore water pressure and soil strength when the soil material is applied with the dynamic load.

3. Research Method

An experimental study is conducted in the laboratory using silty sand material collected from Sibalaya Village and several sets of testing apparatus such as a shake table test, chamber, and CPTu. The silty sand material is given a dynamic load using a shake table. Observation is conducted using CPTu to investigate the behavior of excess pore pressure and the strength of the silty sand material during liquefaction.

3.1 Soil Sample Properties

The soil sample used in this research is silty sand material collected from Sibalaya Village, located in Central Sulawesi. The silty sand material was collected in surface area in disturbed conditions and based on the sieve analysis test. It is known that the grain size distribution of the soil sample is dominated by cohesionless material ± 86.2 % and fine content material ± 13.8 %, as can be seen in **Figure 7**.

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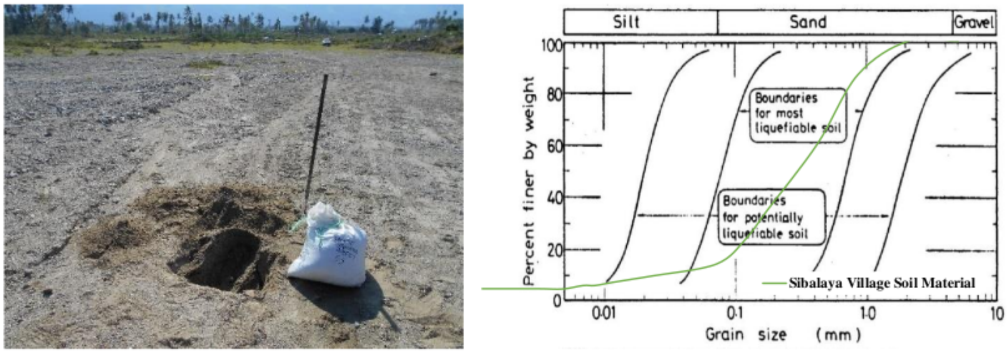

Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 7. Grain Size Distribution of Sibalaya Village Soil Material.

The soil properties of silty sand material collected in Sibalaya Village are summarized in **Table 1**. Furthermore, it is known that Sibalaya Village soil material was categorized as well-graded sand, which can be detected from the uniformity coefficient, Cu = 14.2 (Cu > 6), and the curvature coefficient, Cc = 2.01 (1 < Cc < 3).

Table 1. Soil Properties of Sibalaya Village Soil Material.

Soil Properties	Symbol	Value	Unit
Water content	w	1.17	%
Bulk density	γ_b	1.59	t/m^3
Dry density	γ_d	1.57	t/m^3
Specific gravity	G_s	2.67	-
Maximum void ratio	e_{max}	0.75	-
Minimum void ratio	e_{min}	0.46	-
Uniformity coefficient	C_u	14.2	-
Curvature coefficient	C_c	2.01	-

Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

3.2 Set of Test Apparatus

To support this research, several sets of testing apparatus are used, as shown in **Figure 8**. Those apparatus are described below.

- **Shake Table**

  A shake table is used to model the dynamic load for the soil sample. The input of dynamic load is determined using the vibration of the shake table by modeling the movement in the horizontal axis. The dimension of the shake is 0.8 m x 0.8 m. The shake table is equipped with a 1 HP 3 phase motor, 380 VAC, so that various speed controls can be done.
- **Chamber**

  The soil sample was placed in a rigid cylindrical chamber made of 3 cm thick acrylic, so the horizontal deformation was not allowed in the soil sample (BC 3 condition). The dimension

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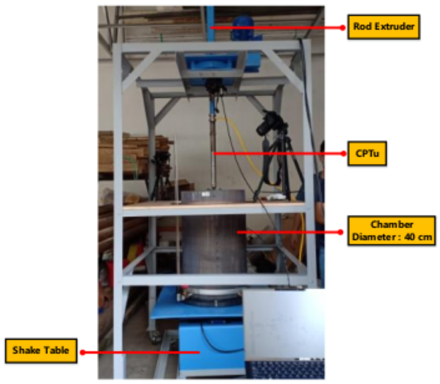
of the chamber is 0.4 m in diameter and 0.7 m in height to avoid the scale factor effect for loose silty sand material. The chamber is equipped with 2 holes at the bottom of the chamber, which function as a burette installation location and as a drain.

- **CPTu**

CPTu test is gaining popularity because of the addition of a pore water pressure sensor and the capability to provide a continuous soil profile [23]. This research determines soil strength and pore pressure measurements before and after liquefaction using the CPTu apparatus. CPTu is used to obtain the tip resistance (q_c) and pore water pressure (u) value before, during, and after the dynamic load.



Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 8. Set of Liquefaction Research Apparatus.

3.3 Test Procedure

The following presents stages of the test procedure conducted in this research.

1. Preparation of soil sample

The preparation method on a sample of coarse-grained soil material greatly affects the shear strength of the coarse-grained material [24], [7]. Since the soil sample in Sibalaya Village is dominated by silty sand material, the soil sample preparation in the chamber is determined using the slurry method by consolidating the silty sand from a slurry [3]. In nature, alluvial soil areas are deposited and consolidated over the years [3]. This natural process can be simulated in the laboratory by consolidating the silty sand from a slurry. Such a consolidation process is suitable for liquefaction studies since many reports have presented evidence that the area of the liquefiable soil recently deposited alluvial materials [3]. Samples can be fabricated very close to full saturation with this method. Disadvantages of the process derive from the fact that it cannot be automated like a pluviator, and time is required for the consolidation process.

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In this research, the slurry is planned to be in a saturated condition with a relative density of 50%. The slurry is made outside the chamber and poured gradually into the chamber every 2.5 cm until the slurry reaches the peak elevation, as shown in **Figure 9**. In this research, the slurry is planned to have a diameter of 40 cm and a height of 57 cm. Slurry sample properties can be seen in **Table 2**.

Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 9. Slurry Material in The Chamber.

Table 2. Slurry Sample Properties.

Soil Sample Properties	Symbol	Value	Unit
Water content	w_{slurry}	20.37	%
Relative density	Dr	50	%
Void ratio	e_{50}	0.59	-
Degree of saturation	Sr	92	%

Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

2. Consolidation stage due to load of the soil sample

After the soil sample has reached the peak elevation, the soil sample is given 21 days lag time. The purpose of the lag time is to make the soil sample experience consolidation due to its weight.

3. CPTu Penetration

After the consolidation stage due to the load of the soil sample has been completed, the CPTu penetration is carried out as deep as 34 cm, then the surcharge load is given to the soil sample. The initial pore pressure and the excess pore pressure induced by surcharge load were recorded using a data acquisition system, which was connected to the pore water pressure sensor located on the tip of the cone.

4. Consolidation stage due to load of surcharge

A surcharge load was given to the soil sample to model the soil sample's initial condition in the field. Surcharge load was given on the surface of the soil sample with a 30 kg ring-shaped iron plate with a cumulative weight equivalent to 3.8 kPa. The pore pressure measurement

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was recorded to find out the consolidation process. Documentation of the surcharge load application can be seen in **Figure 10**.

5. Dynamic load input

After the surcharge load has been input, the next step is to provide dynamic load in the form of horizontal vibrations through the shake table until liquefaction occurs, as shown in **Figure 11**. The dynamic load approach in this research is a constant sinusoidal waveform that different from the original earthquake waveform [25], as can be seen in **Figure 12**. In this condition, CPTu is used to measure the increase of excess pore water pressure and the change of strength in the soil sample.

3.4 Test Performance

In this research, the analogy is applied to saturated sand by assuming the earthquake wave propagating from the bottom of the soil deposit. The test was performed to see the behavior of silty sand material when receiving a dynamic load. Dynamic load application refers to the acceleration that occurred in the Palu-Donggala earthquake. Then the acceleration is increased to determine the behavior of soil material when given a higher magnitude of the dynamic load. Recapitulation of the acceleration generated by the shake table can be seen in **Table 3**.

Source: Thesis on Civil Engineering Department – Parahyangan University (Johan, 2021).

Figure 10. Application of Surcharge Load on Soil Sample.

Figure 11. Liquefaction on Soil Sample.

Table 3. Dynamic Load Input.

Acceleration	Symbol	Value	Unit
Initial x-axis acceleration	a_{x1}	0.22	g
Enhancement of x-axis acceleration	a_{x2}	0.65	g
Initial y-axis acceleration	a_{y1}	0.27	g
Enhancement of y-axis acceleration	a_{y2}	0.84	g

Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 12. shows the input of the initial and the enhancement of the sinusoidal waveform for the x-axis and y-axis acceleration x-axis and y-axis acceleration.

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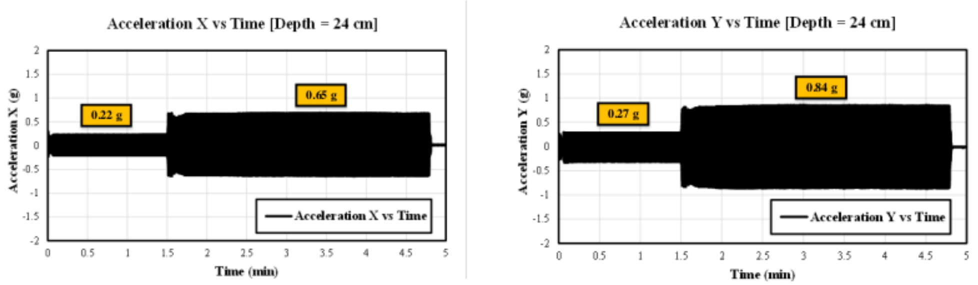


Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 12. Dynamic Load Input in X-Axis, Y-Axis Direction vs. Time.

4. Results

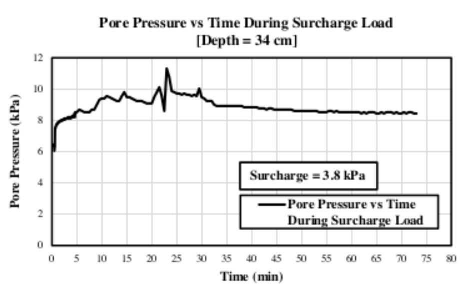
The result of the research that has been carried out are listed as follows :

4.1 Influence of Surcharge Load

The below describes the influence of surcharge load on excess pore pressure and tip resistance.

- **Excess Pore Pressure**

This part will discuss the behavior of excess pore pressure due to surcharge load. Based on **Figure 13**, the initial pore pressure represents the cumulative hydrostatic pore pressure and excess pore pressure in the depth of 34 cm, indicating that the soil material is saturated. Furthermore, due to surcharge load, the pore pressure measurement shows an increase in excess pore pressure of 3.8 kPa, which is equivalent to surcharge load. An increase in pore water pressure was seen to occur slowly, and the peak was identified at 23 minutes, then the pore pressure began to dissipate. However, after 73 minutes of measurement, the excess pore pressure has not returned to the hydrostatic pore water pressure, which indicates that the consolidation stage has not finished. This mechanism is generally caused by the fine grain material that tends to be undrained and results in a long time dissipating due to its low permeability.



Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 13. Pore Pressure vs. Time During Surcharge Load.

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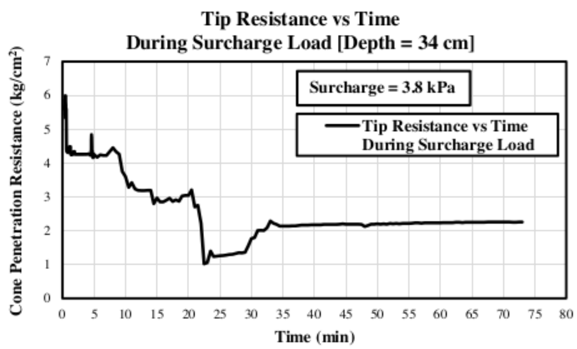
- **Tip Resistance**

This part will discuss the behavior of tip resistance due to surcharge load. Based on **Figure 14**, the tip resistance appears to strongly correlate with excess pore water pressure induced by surcharge load. When the pore water pressure starts to increase, the tip resistance behaves the other way, and vice versa when the pore water pressure decreases. This mechanism is by the statement that an increase in pore water pressure will decrease the soil shear strength, and a decrease in pore water pressure due to dissipation of excess pore water pressure will increase the soil shear strength.



Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 14. Tip Resistance vs. Time During Surcharge Load.

4.2 Influence of Dynamic Load

The below describes the influence of dynamic load on excess pore pressure and tip resistance.

- **Excess Pore Pressure**

This part will discuss the behavior of excess pore pressure due to dynamic load. Based on **Figure 15.** the initial pore pressure is the excess pore pressure generated by the surcharge load, and the excess pore pressure has continued to increase because of the dynamic load from the shake table. The value of excess pore water pressure increased until the ratio reached the average value of 0.93, as shown in **Figure 16.** When the ratio reaches the average value of 0.93, the excess pore pressure value has almost the same value as the cumulative value of effective stress + surcharge load ($\sigma v' + \Delta\sigma v'$). Generally, the soil material due to dynamic load has started to liquefy in 2.5 minutes, and it started to dissipate to the initial condition. However, based on pore pressure measurement after 15 minutes, the excess pore water pressure dissipation has not reached the initial condition yet. It shows that the ratio only reached the value of 0.89, as can

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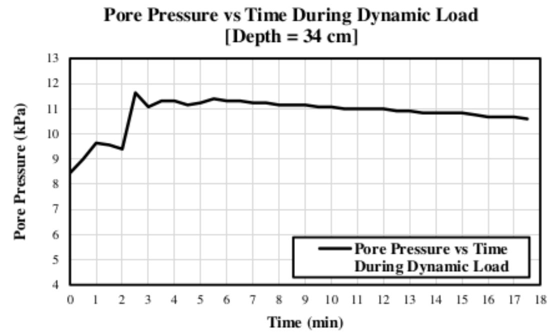
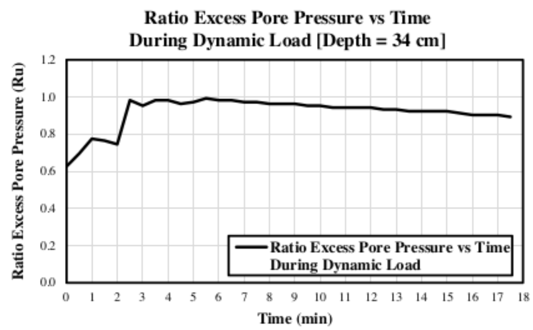
be seen in **Figure 16.** This indicates that the dissipation rate has a strong influence due to soil type material, especially for the permeability aspect, which is closely related to the percentage of the fine content.



Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 15. Pore Pressure vs. Time During Dynamic Load.



Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 16. Ratio Excess Pore Pressure vs. Time During Dynamic Load.

- **Tip Resistance**

This part will discuss the behavior of tip resistance due to dynamic load. Based on **Figure 17**, the initial tip resistance before being given the dynamic load shows the initial condition of soil material is a very loose silty sand which is by the criteria of liquefaction. Furthermore, after the soil material had started to liquefy in 2.5 minutes, when the pore pressure ratio reached an average value of 0.93, the tip resistance decreased until approximately 0 kPa. It proves the statement that soil material will lose its shear strength when it is liquefied. Based on tip resistance measurement after 15 minutes, when the pore pressure ratio reached the value of 0.89, the tip resistance has not gained the initial condition yet. This indicates that the soil material probably takes time to regain its strength after the liquefaction occurs.

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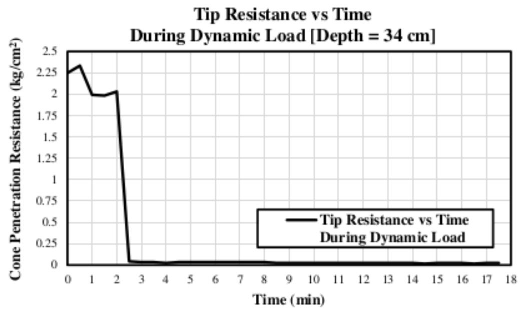

Source: Thesis on Civil Engineering Department - Parahyangan University (Johan, 2021).

Figure 17. Tip Resistance vs. Time During Dynamic Load.

5. Conclusions

The liquefaction phenomenon of silty sand was evaluated in the laboratory using several sets of testing apparatus such as a shake table, chamber, and CPTu. The test results show that liquefaction can occur in silty sand material, which is concluded based on the ratio of pore water pressure obtained from the test. Based on observation, liquefaction occurred when the pore water pressure ratio reached the average value of 0.93, which verifies Ishihara's (1993) statement that silty sand material that contains fine particles cannot generate overall pore water pressure (the pore water pressure ratio can only reach 90% to 95% of the overburden stress).

When liquefaction occurs, it increases pore water pressure and decreases soil strength, which is concluded based on the pore water measurement dan tip resistance measurement during and after liquefaction occurs. The increase of dynamic load will result in a shorter liquefaction starting time, and fine content strongly influences the pore water pressure behavior, especially on the rate of pore water pressure dissipation after liquefaction occurs longer liquefaction period.

6. Acknowledgements

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Bibliography

[1] K. K. T. Mogami, "The behavior of soil during vibration," in *Proceedings of 3rd International Conference on Soil Mechanics and Foundation Engineering*, 1953, pp. 152–155.

[2] K. Terzaghi, R. B. Peck, and G. Mesr, *Soil mechanics in engineering practice*, 1st ed. New York: Wiley, 1996.

[3] P. P. Rahardjo, "Evaluation of liquefaction potential of silty sands based on cone penetration resistance.," *Natl. Sci. Found. Virginia Tech Blackbg.*, 1990.

[4] I. Towhata, *Geotechnical earthquake engineering*. Heidelberg: Springer, 2008.

[5] L. Studer, J. and Kok, "Blast-induced excess pore water pressure and liquefaction experience and application," in *International Symposium on Soils under Cyclic and Transient Loading*, 1980, pp. 581–593.

[6] H. B. Seed and K. L. Lee, "Liquefaction of saturated sands during cyclic loading," *J. Soil Mech. Found. Div.*, vol. 92, no. 6, pp. 105–134, Nov. 1966, doi: 10.1061/JSFEAQ.0000913.

[7] K. M. Larson-Robl, "Pore pressure measurement instrumentation response to blasting," *UKnowledge*, 2016, doi: http://dx.doi.org/10.13023/ETD.2016.271.

[8] J. Wu, A. M. Kammerer, M. F. Riemer, R. B. Seed, and J. M. Pestana, "Laboratory study of liquefaction triggering criteria," *13th World Conf. Earthq. Eng.*, no. November 2014, 2004.

[9] K. Ishihara, "Liquefaction and flow failure during earthquakes," *Geotechnique*, vol. 43, no. 3, pp. 351–451, 1993, doi: 10.1680/geot.1993.43.3.351.

[10] V. E. K. Bojadjieva, J. Sesov, "Experimental setup for sand liquefaction studies on shaking table," 2015.

[11] F. Jafarzadeh, "Design and evaluation concepts of laminar shear box for 1G shaking table tests," 2004.

[12] M. Jamiolkowski, C. C. Ladd, J. T. Germaine, and R. Lancellotta, "New developments in field and laboratory testing of soils," in *Proceedings of the 11th International Conference of Soil Mechanics and Foundation Engineering*, 1985, pp. 57–153.

[13] A. K. Parkin, "The calibration of cone penetrometers," 1988.

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ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

[14] G. Z. Voyiadjis and C. R. Song, "Determination of hydraulic conductivity using piezocone penetration test," *Int. J. Geomech.*, vol. 3, no. 2, pp. 217–224, Dec. 2003, doi: 10.1061/(ASCE)1532-3641(2003)3:2(217).

[15] J. H. Schmertmann, *Guidelines for cone penetration tests, performance, and design*. Federal Highway Administration, FHWA-ts-78-209, 1978.

[16] D. H. Shields, "Should ASTM adopt the European standard?," *ASCE Spec. Conf.*, pp. 383–393, 1981.

[17] L. Van der Veen, C. and Boersma, "The bearing capacity of a pile predetermined by a cone penetration test," *Proc. 4th Int. Conf. Soil Mech. Found. Eng.*, vol. 2, pp. 76–68, 1957.

[18] E. E. De Beer, "The Scale Effect in the Transposition of the Results of Deep-sounding Tests on the Ultimate Bearing Capacity of Piles and Caisson Foundations," *Géotechnique*, vol. 13, no. 1, pp. 39–75, May 1963, doi: https://doi.org/10.1680/geot.1963.13.1.39.

[19] A. Vesić, *Ultimate loads and settlements of deep foundations in sand*. Durham N.C.: Duke University, 1967.

[20] N. Last, "Seminar on cone penetration testing in the laboratory," *Univ. Southampt.*, 1984.

[21] E. Bellotti, R., Crippa, V., Pedroni, S., Baldi, G., Fretti, C., Ostricati, D., Ghionna, V., Jamiolkowski, M., and Pasqualini, "Laboratory validation of in situ tests," *Geotech. Eng. Italy, an overview, A.G.I., ISSMFE Golden Jubil.*, 1985.

[22] L. Z. Mase, "Experimental Liquefaction Study of Southern Yogyakarta Using Shaking Table," *J. Tek. Sipil ITB*, vol. 24, no. 1, pp. 11–18, 2017, doi: 10.5614/jts.2017.24.1.2.

[23] Y. Sulastri and P. P. Rahardjo, "Study of anisotropy characteristics of Bogor volcanic soil," *UKaRsT*, vol. 5, no. 1, p. 95, 2021, doi: 10.30737/ukarst.v5i1.1137.

[24] R. S. Ladd, "Specimen preparation and liquefaction of sands," *J. Geotech. Eng. Div. ASCE*, vol. 100, no. 10, pp. 1180–1184, Oct. 1974, doi: 10.1061/AJGEB6.0000117.

[25] A. Johan, "Evaluation of behaviour and viscosity of silty sand material in liquefied condition based on piezocone test," Parahyangan Catholic University, 2021.

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