Prediction of Excess Pore Pressure Due to Pile Driving Based on CPTu

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ABSTRACT: Piezocone test (CPTu) is one of the most versatile tools for geotechnical investigation. It is commonly used for soil type identification, soil stratification, and geotechnical parameters determination. In soft soils, the CPTu test is very important because of its capability of pore pressure measurement. This paper presents the result of CPTu test in the soft soil after pile driving works. The dissipation test results are evaluated to distinguish between the excess pore pressure induced by cone penetration and by pile driving works. The results show that the generated excess pore pressure induced by pile driving is up to 1.27 to 1.40 times the effective overburden pressure. In addition, the dissipation of the excess pore water pressure is observed by conducting another CPTu test five months later after the first test. The result shows that the excess pore pressure due to pile driving still exists, with the remaining value of 0.25 times the effective overburden pressure.
KEYWORDS: CPTu, pile driving, soft soil, excess pore water pressure

1. INTRODUCTION

Piezocone test (CPTu) is one of the most versatile tools for geotechnical investigation. It is commonly used for soil type identification, soil stratification, and geotechnical parameters determination. The measured data is generally more reliable because it measured in the in-situ stress condition. Furthermore, the piezocone test gives continuous data and it is fast and economical.

In soft soils, the CPTu test is very important because it is capable to measure the pore water pressure. Various geotechnical parameters and information can be obtained from the pore water pressure measurement, including the value of generated excess pore water pressure due to pile driving. Evaluation and interpretation of the dissipation tests are to be conducted in order to distinguish between excess pore water pressure induced by cone penetration and by pile driving. In addition, the dissipation of the excess pore water pressure is also observed by conducting another CPTu test, five months later after the first test. In this particular case study, the piezocone (CPTu) test is chosen because the cone penetration has the same mechanism as the pile injection process in the field.

2. PROJECT INFORMATION AND PILING WORKS

The case study of the paper is an office and apartment building project located in Surabaya, Indonesia. The foundation type of the building is concrete square piles of 50×50 cm^2, with an embedment depth varies from 20 – 25 m. As for the piling works, the piles are driven by the hydraulic pile driving method. The total number of piles driven is 755 piles.

3. PIEZOCONE AND DISSIPATION TESTS

A number of CPTu and dissipation tests have been conducted to identify the soil condition at the project site. The first series of the test was conducted in October 2012 (one day after pile driving works finished), while the second test was conducted in March 2013. Both tests were conducted after the pile driving works. As for the total number of tests, there are both five CPTu and dissipation tests, with details of test presented in Table 1.

Table 1 Series of CPTu and Dissipation Tests Conducted at Site

CPTu No	Testing Date*	Dissipation Test Depth (m)
PC-01	18 October 2012	8.93
PC-02		14.57
CPTu-01	18 March 2013	8.97
CPTu-02		14.5
CPTu-03		6.84

*conducted after pile driving works

4. SOIL CONDITION

From the CPTu test result, the soil stratification consists of the backfill layer with approximately 2.5 m thick in the upper layer. Underneath this layer, silty clay layer with soft consistency found with a thickness of 17.5 m. At the bottom layer, a sand layer was found and then the test terminated at the depth of 21 m below the existing ground level. The CPTu (PC-01) result is shown in Figure 1.

It has to be highlighted that the pore pressure measurement shows high values, compared to hydrostatic pressure. The difference between the two values is up to 0.3 MPa. This is because the excess pore pressure induced by pile driving still exists. Figure 2 shows the testing location, which is very close to the hydraulic pile driver.

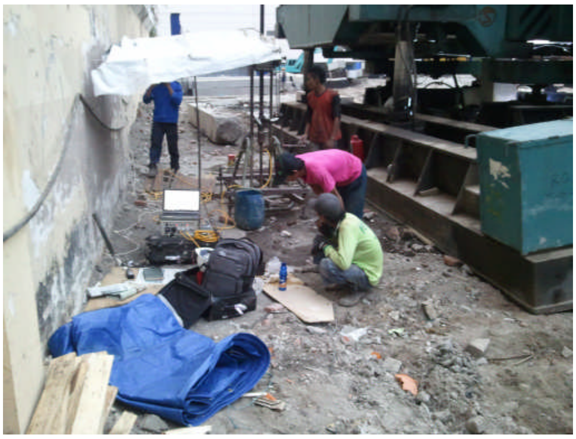

Figure 2 CPTu Testing Near Hydraulic Pile Driver

5. GENERATED EXCESS PORE PRESSURE DUE TO PILE DRIVING

The generated excess pore pressure due to pile driving has been an interest in research for a very long time. A number of excess pore pressure measurements due to pile driving have been made by numerous researcher. Results of the measurement have revealed that the excess pore pressure may become equal to or even greater than the effective overburden stress. A summary of some measurements of the variation with radial distance of excess pore pressures around a single driven pile is shown in Figure 3.

Around the pile surface, very high excess pore pressures are generated, in some cases approaching 1.5 to 2.0 times the effective overburden pressure. However, the generated excess pore pressure decreases rapidly with radial distance from the pile and generally dissipate rapidly.

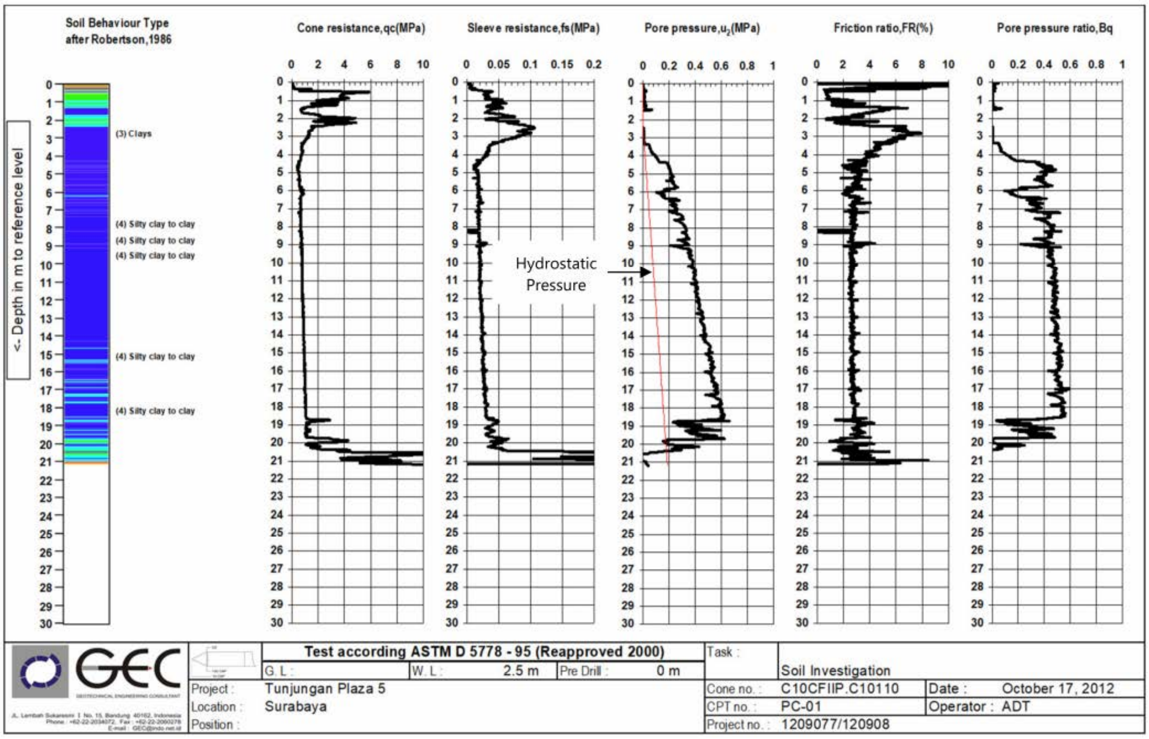

Figure 1 CPTu (PC-01) Test Result (October 2012)

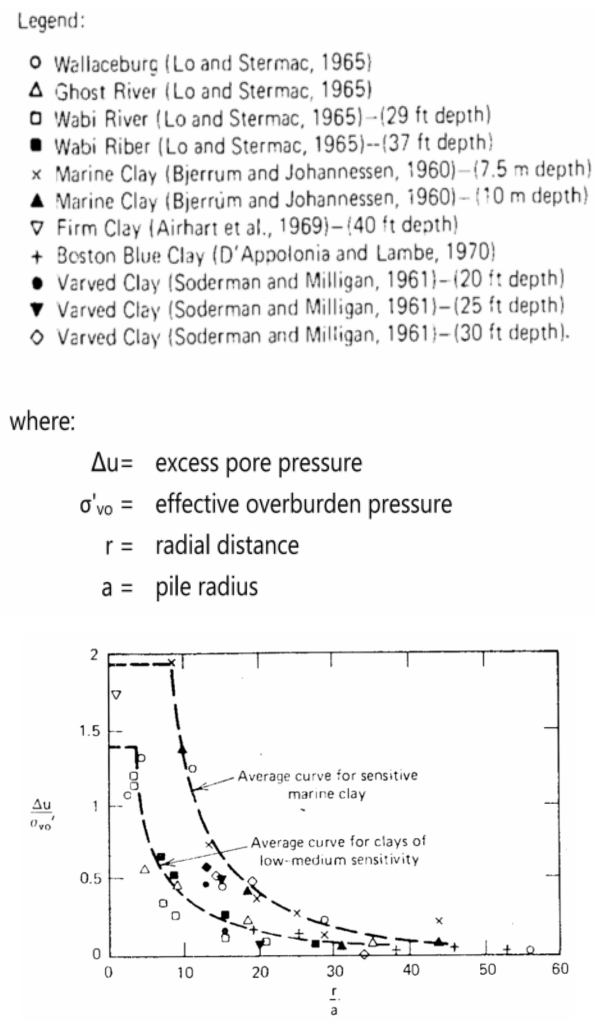

Figure 3 Summary of Measured Pore Pressure (Poulos and Davis, 1980)

6. PREDICTION OF EXCESS PORE PRESSURE USING DISSIPATION TEST

The dissipation test can be used for estimating the excess pore water pressure induced by pile driving. The interpretation method is suggested by Rahardjo et al (2008), which can be done by extrapolating the dissipation test curve. This method assumes that when the dissipation test carried out ultimately, the curve follows the hyperbolic function.

When the pile driving works conducted in saturated clays, excess pore pressure will be generated due to the pile is driven into the soil mass. Therefore, when conducting a dissipation test ultimately in such condition, the dissipation curve will not reach the value of the hydrostatic pressure but the value of final pore pressure (u_f). The difference between u_f and u_o called the residual excess pore pressure. Figure 4 shows the scheme of the method.

6.1 Dissipation Test Results

Five dissipation tests have been conducted at a certain depth, as tabulated in Table 1. These dissipation curves are then extrapolated using the suggested method above to obtain the final excess pore pressure (u_f). Figure 5 shows the dissipation test curves.

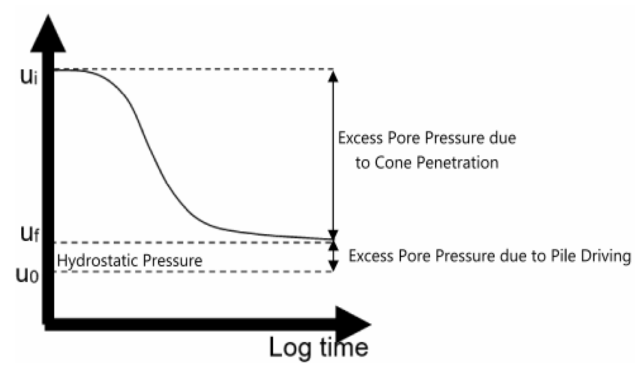

Figure 4 Extrapolation of Dissipation Test Curve (Rahardjo et al., 2008)

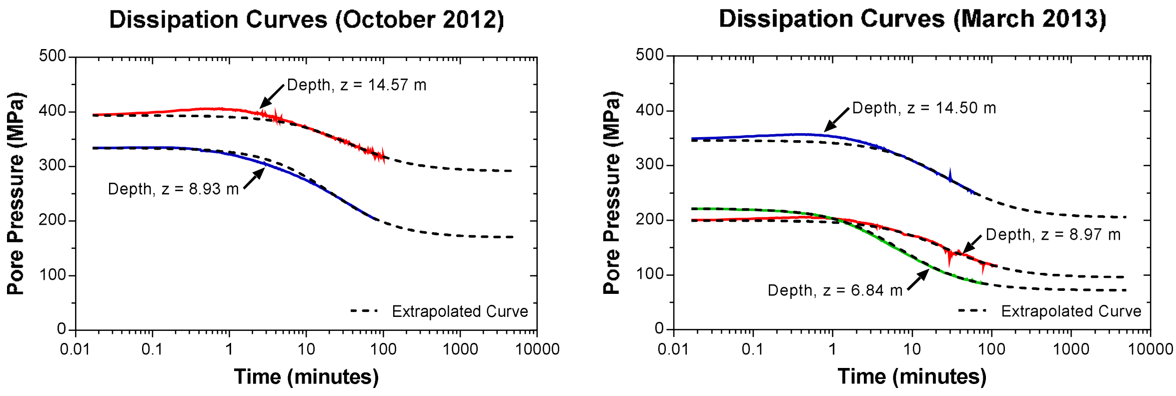

Figure 5 Dissipation Test Results

Table 2 Estimation of Excess Pore Pressure Ratio After Pile Driving

CPTu No	Dissipation Test Depth (m)	Hydrostatic Pressure, u_o (kPa)	Calculated Residual Excess Pore Pressure, u_f (kPa)	Effective Overburden Pressure, σ_v' (kPa)*	Normalized Excess Pore Pressure, $(u_f-u_o)/\sigma_v$'
PC-01	8.93	64.3	172	85.01	1.27
PC-02	14.57	130.7	293	115.5	1.40
CPTu-01	8.97	79.7	97	71.8	0.24
CPTu-02	14.5	115	207	128.5	0.71
CPTu-03	6.84	58.4	73	56.9	0.25

*assuming the soil unit weight, γ = 16 kN/m^3, and γ_{sat}= 17 kN/m^3

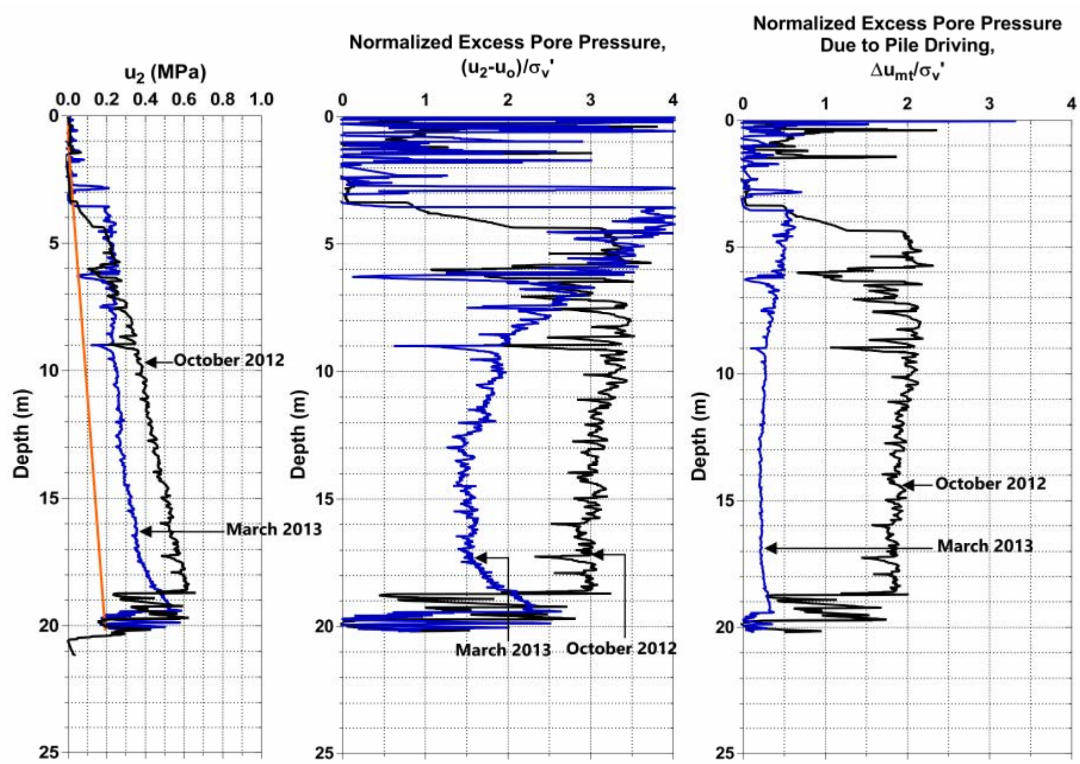

Figure 6 Comparison of Pore Pressure Measurement and Normalized Excess Pore Pressure (Recalculated from Rahardjo et al, 2014)

The value of excess pore pressure due to pile driving then can be calculated by subtracting with the value of hydrostatic pressure. Furthermore, the ratio between existing pore pressure and effective overburden pressure is also calculated. Table 2 summarizes the calculated value of excess pore pressure ratio after pile driving.

From the results, it can be concluded that the excess pore pressure ratio in October 2012 (CPTu PC-01 and PC-02) is as high as 1.40 σ'_v, while in March 2013 (CPTu-01 – CPTu-03) is much less, with the value of 0.25 σ'_v. These obtained values agree well with the previous publication from Poulos and Davis (1980), where the generated excess pore pressure due to pile driving can be as high as 2.0 σ'_v.

6.2 Observation of Excess Pore Pressure Dissipation

As mentioned before in the previous section, another CPTu test is conducted five months later after the first test. The purpose of the second test is to observe the dissipation of the excess pore pressure. In addition, the normalized excess pore pressure distribution along depth is also plotted.

The normalized excess pore pressure distribution ($\Delta u_2/\sigma_v$') can be calculated by subtracting the measured pore pressure (u_2) with the hydrostatic value (u_o). The purpose of the calculation is to investigate how high the total excess pore pressure (due to cone penetration and pile driving) generated along the depth.

It has been observed that when the pile is long compared to its diameter, the excess pore pressure generated due to pile driving are essentially constant with depth (Reese and Seed, 1955 and Soderberg, 1962). By multiplying the proportion with the normalized excess pore pressure, the excess pore pressure due to pile driving (Δu_{mt}) can be calculated by the following equation:

$$\Delta u_{mt} = \left(\frac{u_f - u_o}{u_2 - u_o}\right) \times \left(\frac{\Delta u_2}{\sigma_v'}\right) \quad (1)$$

where:

u_f = residual excess pore pressure (obtained from extrapolation dissipation test)

u_o = hydrostatic pressure

$\Delta u_2/\sigma'_v$ = normalized excess pore pressure

Figure 6 shows the pore pressure measurement of CPTu test in October 2012 and in March 2013, along with the calculated normalized excess pore pressure.

From the results, it can be seen that one day after the pile driving works finished (October 2012), the value of the excess pore pressure due to pile driving is as high as 2.0 times the effective overburden pressure. While from the CPTu test conducted five months later (March 2013), it can be seen that the excess pore pressure due to pile driving is not fully dissipated. The remaining excess pore pressure due to pile driving is relatively low, with the value of 0.20 – 0.25 σ_v'.

6.3 Degree of Dissipation

The degree of excess pore pressure dissipation (U) can be estimated using the dissipation test results, following the equation as follows:

$$U = 1 - \frac{\Delta u_t}{\Delta u_i} \quad (2)$$

where: Δu_t = excess pore pressure due to pile driving at time *t*

Δu_i = excess pore pressure due to pile driving at the initial time after pile driving finished

In this particular study, the CPTu test is not conducted directly after the pile driving works finished, but conducted one day after. Therefore, the calculated degree of dissipation will be based on this available data, which will produce an overestimated value. Figure 7 shows the calculation steps to determine the degree of dissipation, obtaining 80.6% dissipation degree in October 2013.

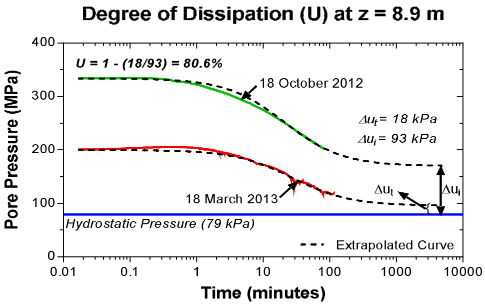

Figure 7 Determining the Degree of Dissipation

7. DISCUSSION

The generated excess pore pressure due to pile driving can be estimated by dissipation test of the CPTu test. In order to increase the confidence and the reliability of this method, it is interesting to compare the obtained results both with piezometer measurements and numerical simulations. Furthermore, the dissipation degree value towards the time is also interesting to be investigated.

8. CONCLUSIONS

CPTu test has proven its ability to measure the pore pressure in the soil strata, as well as the generated excess pore pressure due to pile driving by conducting the dissipation test. The dissipation test during CPTu can be conducted easily and generally fast. In addition, the dissipation test is so flexible that can be conducted at several depths during a test.

Furthermore, the extrapolation of the dissipation curve can be done easily to calculate the proportion of the excess pore pressure due to cone penetration and due to pile driving.

9. REFERENCES

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