The Effect of Hydrophilic Coating on Concrete Pile Surface in Pile Driving: Field Test

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Abstract. At laboratory scale, hydrophilic coating on the surface of precast concrete piles is capable of affecting the piles to be installed into a certain depth level with less number of hammer strokes than piles without coating. In this work, a preliminary study of pile driving tests in the field, the origin of the soil at laboratory scale, has been carried out. Based on our analysis result of the measurement data, it is found that the hydrophilic coating has different effects on pile driving at laboratory and field scales.

1. Introduction
Significant generation of pore water pressure during the installations of precast concrete pile foundations into fine-grained soils has been reported in many scientific papers. Field measurements by Seed and Reese in [1] suggested that pressures created during the pile installation were transferred to the soil mainly as an increase in pore water pressure, generated large excess pore water pressure at the pile surface. Negligible excessive pore pressure that increased beyond eight pile diameters from the pile wall was disclosed by Roy et al. [2]. Field observations by Chandra and Hossain in [3], concerned with soft clay layer of Bangkok subsoil, recorded that excess pore pressure from eighteen piezometers surrounding the pile from the time of pile installation continued for three months until most of the excess pore pressure dissipated, as the dissipation of pore pressure was very slow. Hwang, Liang and Chen in [4] reported that dissipation of excess pore water pressure induced by a driven pile was fast in a sandy layer and very slow in a clayey layer. In agreement with mentioned studies, significant excess pore pressure was generated as a result of pile driving of a closed-ended pipe pile into a uniform deposit of Young Bay Mud [5].

2. Pore Water Pressure
Every soil particle in nature is surrounded by water. The water in the pore spaces of soil is called pore water. The pressure within this pore water is called pore water pressure. Pore pressure itself is a function of permeability of the soil and penetration rate of an object when subjected into the soil. Meanwhile, permeability is the ability of water to flow through the soil. The more permeable the soil is, the greater
is the seepage of water through it. Several factors that influence the permeability of soil are water viscosity (affected by temperature), particle size and shape, the degree of saturation, and void ratio.

In general, materials of larger particle size will be more permeable. However, a soil can have a high porosity, but low permeability if the open spaces are not well connected. The sandy soils are often quite porous since there is a relatively high percentage of void spaces between the sand grains. The soils are also very permeable, because the pore spaces are usually large and interconnected, allowing water to flow through them more readily. Clay particles are very small, and as a result, the pores are also small. Since the centers of positive and negative charges of water molecules do not coincide, water molecules act like dipoles. The negative charge accordingly attracts hydrogen on the surface of the soil particles, as the positive end of the water molecules. More than one layer of water molecules stick on the surface with considerable forces. The attractive forces decrease with the increase in the distance of the water molecule from the surface.

Figure 1. Pore water is attracted to the soil particles by physical and chemical forces: (a) adsorptive forces between soil particles and water molecules, and (b) intermolecular forces between water molecules [7].

Figure 1 illustrates how water molecules are held in the soil pores by physical and chemical/electrical forces. The forces between soil particles and water molecules, Coulombic forces, are on the order of 4-20 times larger than the intermolecular forces, or van der Waals forces [7]. Surface-related forces are inversely proportional to the particle size. With very small particles, water can be adsorbed very strongly between clay particles. The clay particle needs to be heated to more than 200°C, to drive off the adsorbed water, which indicates that the bond between the water molecules [7] and the surfaces is considerably greater than between normal water molecules [6].

Pile driving process is rather a severe process by loading the pile with a mass that larger than itself continuously, imparts force onto the soil, and generates significant pore water pressure. Clay with very small particle size and water absorbed on the surfaces makes it almost impermeable. Since pore water in clay has different characteristics with bulk water, an external force is needed to suppress the excess pore water pressure. In this case, modifying pile surface by coating the pile with hydrophilic materials is hypothetically able to attract pore water molecules into the surface hence an excess pore water pressure during pile driving process can be evaded.

3. Pile Driving Test at Laboratory
Titanium dioxide (TiO₂, titania) photocatalyst has an outstanding hydrophilicity and durability [8], making it exceptionally well-suited as the material for applying hydrophilic treatment to precast concrete pile surface. Under UV-irradiation, titania-coating becomes hydrophilic. According to various experiments, hydrophilicity appears to be related to the density in surface OH groups. This density increases under UV-irradiation. Water molecules behave like dipoles since the centers of positive and negative charges of the molecules do not coincide. Therefore, water molecules are prone to be hydrogen-bound to the OH groups [9,10]. If the hydrogen as the positive end of the water molecules could be attracted to the titania, the excess pore water pressure could be diminished during pile driving process.

Previously, pile driving tests have been conducted at laboratory scale using models of a precast concrete pile, in reference to Indonesian National Standard (SNI) number 03-2834-2000 which is equivalent to ASTM in the US, with shaft length of 30 cm and diameter of 3.175 cm. The tip of the pile...
was closed-ended and conical in shape. Surface treatment by coating the pile with titanium dioxide was based on a hypothesis that if the pile surface exhibits hydrophilicity, hence pore water in the clay could be attracted to the pile surface during the pile driving process and excess pore water pressure could be suppressed. The titania was obtained from Bratachem, Indonesia which previously reported as anatase with an average particle size of 160 nm by Sutisna et al. in [11]. The mass of the hammer was 3.2 kg, and it was dropped at 30 cm above the pile's head continuously until the piles reached the desired depth.

![Figure 2](image2.png)

**Figure 2.** The result of pile driving tests at laboratory scale.

The result of penetration tests at laboratory scale can be seen in figure 2, the penetration depths of piles as the function of the number of hammer strokes. Clay used as the driving media, Plered clay, was obtained from Balai Besar Keramik Bandung. It was originated from Citeko, Purwakarta and has been previously processed and remolded. The tests were carried three times for piles without coating and piles with titania-coating in Plered clay deposited within containers. The average result of pile driving tests in clay at laboratory scale showed that coating precast concrete piles with titania able to make the piles reached certain depth level with less number of hammer strokes than piles without titania-coating.

![Figure 3](image3.png)

**Figure 3.** SEM result of Plered clay.

The structure of Plered clay is shown in figure 3. The planar structure of clay minerals can be observed from Scanning Electron Microscope (SEM) image of the soil. Before the analysis, the soil sample was prepared by heating the sample to make sure no water content was contained. Based on the accompanying EDS characterization results, the constituent clay minerals were C, MgO, Al₂O₃, SiO₂, K₂O, and FeO. The characteristics of these minerals supported the results why titania-coating affected the pile driving tests at the laboratory. Further, field tests with components that were the same as the previous laboratory scale tests were conducted in Citeko, Purwakarta.
4. Results and Discussion

Evaluations at laboratory scale are needed to be conducted before field tests. Thus, hypotheses can be approved or declined from the beginning. Since at the laboratory scale, the experiment results showed an agreement with the hypotheses, field tests could be considered. Based on the result of pile driving in the field, which can be viewed in figure 4, we can find that pile with titania-coating (washed) was able to be installed deepest at initial driving, followed by pile without coating and pile with titania-coating (unwashed). However, after several blow counts or hammer strokes, it did not apply the same. Unfortunately, the result of field tests was far from similar with the result of laboratory tests, unlike the predictions. This needs careful attention. The model piles used were the same, also the pile driving apparatus. Hypothetically, the results should be not much different, but in fact, they were eminently different. Factors like soil layers which could be different at the point of pile driving and the possibility of coarse-grained soil under the soil’s surface at the penetration point could be a noise.

![Figure 4. The result of pile driving tests at the field.](image)

We can discuss about boundary conditions first in both systems. The size of piles used at laboratory and field scales were the same. Pile driving at laboratory scale used containers with a height of 40 cm and diameter of 40 cm to hold the clay inside. The size of piles used might influence the mass and resulted compression experienced by clay during the driving process. Perhaps, the size of the containers at laboratory test was too small; hence pore water which might be still able to dissipate was contained in the container. Therefore, an extra pore water pressure occurred compared to the field tests. Possibly the piles for field tests should have been much more massive than piles used at laboratory scale because the boundary conditions have become much larger. Determining dimensions of models for laboratory tests, which has reduced size, need to consider the maximum grain size of the soil particles to the minimum dimension of the models. ASTM suggests that the ratio of mold diameter to the maximum size of the particles should be more than or equal to 5. Otherwise, the surrounding will take place and interfere with our results. It has been fulfilled, but surely there must be many other assumptions and conditions need to be considered.

In the laboratory tests, the clay was homogenous. Meanwhile in the field tests, even within 1 m² the soil might have different layers. The information of geotechnical analysis results from soil samples can be viewed in table 1. All these certainly affect the pore water dissipation. Based on Unified Soil Classified System (USCS), the soils are clay of low plasticity (CL) for Plered clay and clay of high plasticity (CH) for clay from the field. However, soil samples from the field have a larger value of void ratio and porosity. These are probably caused by the grain size of particles of the soil. Soil samples from field tests contain gravels 5.50% and 14.73%, while Plered clay does not even contain gravels. The percentages of sand are also higher than in Plered clay.
Table 1. Index properties and Atterberg limit of soil samples used as the pile driving media.

| Index Properties | Plered       | Bore hole A | Bore hole B |
|------------------|--------------|-------------|-------------|
| Average unit weight (gr/cm³) | 1.79         | 1.86        | 1.81        |
| Specific gravity (Gs)          | 2.60         | 2.62        | 2.65        |
| Void ratio (e)                | 0.45         | 0.84        | 0.95        |
| Porosity (n)                  | 0.31         | 0.46        | 0.49        |
| Water content (%)             | 31.70        | 30.57       | 33.42       |
| Atterberg limit               |             |             |             |
| Liquid limit                  | 45.67        | 50.59       | 64.50       |
| Plastic limit                 | 18.76        | 24.69       | 30.48       |
| Plasticity index              | 26.90        | 25.89       | 34.02       |
| Soil type (USCS)              | CL           | CH          | CH          |
| Grain size analysis           |             |             |             |
| Gravel (%)                    | 0.00         | 5.50        | 14.73       |
| Sand (%)                      | 8.30         | 8.79        | 9.32        |
| Silt (%)                      | 60.72        | 64.39       | 59.00       |
| Clay (%)                      | 30.98        | 21.32       | 16.95       |

Since the soil samples from field tests contained coarse, the pores might be bigger, even though generally the soil is still categorized as clay of high elasticity. The adsorbed film of water on coarse particles is thin in comparison with the diameter of the particles. Based on Murthy in [6], this layer of adsorbed water is relatively much thicker and even exceed the size of the grain in fine-grained soils. The force associated with the adsorbed layers, therefore, play an essential part in determining the physical properties of the very fine-grained soils but have little effect on the coarser soils. Small particles have more surface per weight or per volume than do large particles. In addition to this surface area effect, smaller particles arrange themselves in such a way that soil pores are smaller. Both surface and pore size phenomena are important because water adheres to mineral surfaces and has an affinity for small pores as described in the previous section. Therefore, clay with small pores and large surface area compared to sand with large pores and small surface area is different distinctly in water-holding properties.

Amalia et al. in [12] analyzed the relationship between the number of hammer strokes to the penetration depth of driven pile from the ground surface, achieved as $F \propto y^\alpha$, with $\alpha$ being the parameter showing the soil characteristics of the pile driving media. For non-cohesive soils, $\alpha = 0$, so $F$ which is the upward force experienced by the pile of each hammer stroke on non-cohesive soil is constant to depth. Equation (1) denotes penetration depth as the function of the number of hammer strokes and the soil engineering parameters of the pile driving media $\alpha, k = c_2 / c_1$ and $c = c_1$.

$$f(n) = \left[ (\alpha + 1) \left( \frac{n}{c} + k \right) \right]^{\frac{1}{\alpha + 1}}$$

(1)

Fitting experimental data at the laboratory scale with equation (1) shows excellent property using $\alpha = 0.9$ for Plered clay. Furthermore, in order to investigate the parameters of soil engineering in the field, fittings using equation (1) has also been implemented for the data of either without coating, with coating (unwashed), and with coating (washed).
Washing the pile surface after successfully coated with the titania was intended to see the effect of coating thickness on the pile driving process. But based on the result of the field tests in figure 4, it can be concluded that the coating did not give any significant effect. The values for the fitting results that best match the experimental data are 0.3 as can be observed in figure 5. In table 1, it can be seen that the moisture contents of soil samples from the laboratory and field tests were not much different. And this implies that for the characteristics of the field is different according to different values of $\alpha$, not 0.9 but rather 0.3, closer to $\alpha = 0$, which means tend to be like non-cohesive soils. This is, again, related to the soil layers in the field that might differ even within 1 m$^2$. Tang and Chen in [13] explained that the pore pressure response to additional pore pressures is strongly dependent on the permeability, seepage path and boundary conditions. Thus, further strengthens the explanations that have been put forward.
5. Conclusions
Previously, pile driving tests at laboratory scale successfully show that coating piles with titanium dioxide (TiO2, titania) could make driven piles to be installed into certain depth level in clay with less number of hammer strokes than piles without titania-coating. Further study in the field, unfortunately, gave different results. Although the clay used at laboratory tests was originated from Citeko, where field-tests took place, the results of geotechnical analysis of the soil samples were distinctive. Coarser grains in the soil at field tests might affect pore arrangement of the soil and result in the difference in soil permeability compared to the soil at laboratory tests. Accordingly, more massive piles are required for field-tests, and further investigation of titania-coating is still needed.

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