Journal of Applied Geophysics 108 (2014) 167–175

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Slime thickness evaluation of bored piles by electrical resistivity probe

Ok-Hyun Chun [a], Hyung-Koo Yoon [b], Min-Chul Park [a], Jong-Sub Lee [a,*]

[a] School of Civil, Environmental and Architectural Engineering, Korea University, Seoul 136-701, Republic of Korea
[b] Department of Geotechnical Disaster Protection Engineering, Daejeon University, Daejeon 300-716, Republic of Korea

ARTICLE INFO

Article history:
Received 18 April 2014
Accepted 3 July 2014
Available online 11 July 2014

Keywords:
Bored pile
Electrical resistivity probe
Field test
Layer detection
Slime
TDR

ABSTRACT

The bottoms of bored piles are generally stacked with soil particles, both while boreholes are being drilled, and afterward. The stacked soils are called slime, and when loads are applied on the pile, increase the pile settlement. Thus to guarantee the end bearing capacity of bored piles, the slime thickness should be precisely detected. The objective of this study is to suggest a new method for evaluating the slime thickness, using temperature compensated electrical resistivity. Laboratory studies are performed in advance, to estimate and compare the resolution of the electrical resistivity probe (ERP) and time domain reflectometry (TDR). The electrical properties of the ERP and TDR are measured using coaxial type electrodes and parallel type two-wire electrodes, respectively. Penetration tests, conducted in the fully saturated sand–clay mixtures, demonstrate that the ERP produces a better resolution of layer detection than TDR. Thus, field application tests using the ERP with a diameter of 35.7 mm are conducted for the investigation of slime thickness in large diameter bored piles. Field tests show that the slime layers are clearly identified by the ERP: the electrical resistivity dramatically increases at the interface between the slurry and slime layer. The electrical resistivity in the slurry layer inversely correlates with the amount of circulated water. This study suggests that the new electrical resistivity method may be a useful method for the investigation of the slime thickness in bored piles.

1. Introduction

Driven piles have been widely applied due to their cost-effectiveness and high bearing capacity (Meyerhof, 1983). However, the application of driven piles is limited, due to the vibration and noise generated during construction (Attewell et al., 1992; Thandavamoorthy, 2004). Because severe noise and vibration can be effectively removed for bored piles, they have been used as an alternative method for installing piles in most soils, including boulder and granular layers, as well as sand, silt, and clay layers. During excavation of the soil layer, the soil particles settle, and deposit on the bottom of the hole. The deposited soil layer is known as slime. The slime layer may yield extra settlement, and thus decrease the ultimate bearing capacity (Poulos, 2005; Sew et al., 2003). Schmertmann et al. (1998) reported a large pile tip settlement (see Fig. 1) due to poor pile tip cleaning in the drilled hole. Thus, the amount of slime should be accurately detected and properly removed. For the estimation of slime thickness, a weighted pendulum that is connected to a rope has been used. The weighted pendulum method subjectively detects the slime via the change in rope tension at the interface between the suspension and the slime. The results depend on the experience, because the rope tension is measured by hand. A new method, which can objectively evaluate the slime thickness with high resolution and accuracy, is required, to increase the ultimate bearing capacity of piles.

Geophysical methods, which are categorized as the gravity method, magnetic method, electric method, and elastic wave method, have been widely used for subsurface characterization (Lee et al., 2009; Yoon and Lee, 2012). In addition, the in situ penetration tests utilized for the electric and elastic wave methods were also performed to obtain complementary information about soils, including their strength, density, and stiffness, with high resolution (Campanella and Weemees, 1990; Cho et al., 2004; Kwon and Cho, 2005; Yoon and Lee, 2010). Electrical resistivity is commonly used for the evaluation of soil properties in the laboratory and field (Lee and Santamarina, 2007; Lee et al., 2008, 2011, 2013; Yun et al., 2011). Thus, application of the electrical resistivity method has continuously increased in geotechnical engineering. Shin et al. (2009) adopted the electrical resistivity probe for the evaluation of the size of the smear zone, which is induced by the installation of a prefabricated vertical drain. Truong et al. (2010) detected the soil layers by using a mini-sized penetration type electrical resistivity probe. Kim et al. (2011a) developed a cone type electrical resistivity probe for the evaluation of the void ratio in soft soils. Kim et al. (2011b) suggested the Wenner arrayed resistivity probe for penetration tests in the field, as well as for installation in soil cells, such as oedometer cells. Yoon et al. (2011) measured the electrical resistivity at the cone tip and the mechanical cone tip resistance, by using a mini-sized cone resistivity probe, whose diameter was 15 mm. However, Jung et al. (2014)

* Corresponding author.
E-mail address: jongsub@korea.ac.kr (J.S. Lee).

http://dx.doi.org/10.1016/j.jappgeo.2014.07.004
0926-9851/

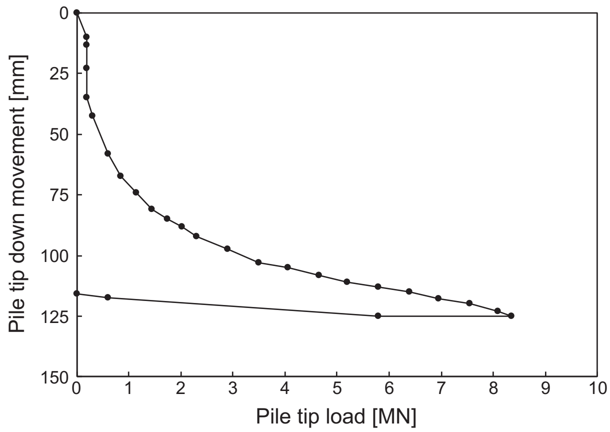

Fig. 1. Excessive pile tip movement, due to loose material in pile tip (Schmertmann et al., 1998).

mentioned that the temperature should compensate for the electrical resistivity, because the electrical resistivity depends on the temperature.

The objective of this study was to introduce an evaluation method of slime thickness, by using electrical resistivity. First, this paper describes an electrical resistivity probe that can compensate for the temperature, including the design concept and calibration. The slime thickness detected by the electrical resistivity probe and time domain reflectometry is compared. The field application tests, and summary and conclusions are subsequently reported.

2. Laboratory tests

Laboratory tests were performed in advance, to compare the resolution between the electrical resistivity probe (ERP) and time domain reflectometry (TDR). The ERP and TDR probe were designed in consideration of the sizes and shapes for the laboratory tests. The two probes are described in detail in the following.

2.1. Electrical resistivity probe for laboratory tests (ERPL)

The electrical resistivity method, which generally applies two pairs of current and potential electrodes, is commonly divided into two categories: the invasive method, and the non-invasive method. In this study, the invasive method was adopted for the evaluation of the electrical resistivity profile in bored piles. The electrical resistivity probe for laboratory (ERPL) was manufactured for the measurement of the electrical resistance and temperature at the coaxial type probe tip, with minimized soil disturbance. Thus, the ERPL consists of an outer electrode, insulator, and inner electrode, as shown in Fig. 2. The outer diameter of the outer electrode is designed to be 4.4 mm. The diameter of the inner electrode is 2.2 mm. A wedge with an angle of 60° was chosen as the tip shape. The total length of the tip part is approximately 10.5 mm. Note that temperature change affects the electrical conductivity within the material. Thus, the electrical resistance should be compensated for, by using the measured temperature. The thermocouple was attached 10.5 mm behind the probe tip, to obtain the temperature compensation for the electrical resistivity, as shown in Fig. 2. A four-terminal pair configuration was used for the cable connection, which minimizes the oxidation–reduction reaction among electrodes. Thus, the inner electrode was connected to the high current (Hc) and high potential (Hp) parts, and the outer electrode was connected to the low current (Lc) and low potential (Lp) parts, as shown in Fig. 3.

2.1.1. Temperature effect

The Faraday coefficient, ion mobility, concentration, and valence of the electrolyte affect the electrical conductivity (Keller and Frischknecht, 1966). In particular, the ion mobility, which strongly influences the electrical conductivity, depends on the temperature (Abu-Hassanein et al., 1996; Light, 1984). The reciprocal value of the electrical conductivity is the electrical resistivity. Thus, the electrical resistivity is also affected by temperature change. The temperature effect on the electrical resistivity was investigated by using salt water in an insulation box, whose dimensions were 250 mm × 250 mm × 300 mm (width × length × height). As the temperature of salt water gradually increased from 18 °C to 38 °C, the electrical resistance was measured, using the ERPL. The measured electrical resistance and the temperature are plotted in Fig. 4(a). Fig. 4(a) shows that the electrical resistance decreases as the temperature increases, because the ion mobility depends on the temperature. Finally, the temperature compensated for electrical resistance, R_C [Ω], and the temperature change, T, can be expressed as follows:

$$R_c = \frac{R_{20}}{[1 + \alpha(T - 20)]} \quad (1)$$

where R_{20} [Ω] is the electrical resistance measured at a temperature of 20 °C, T indicates the temperature in degrees Celsius, and α [°C^{-1}] is the temperature factor. The temperature factor, α, for the ERPL was determined to be 0.02 [°C^{-1}].

2.1.2. Shape effect

The electrical resistance is not only affected by the ground properties, but also by the geometric properties of the probe, in particular, the size and shape. Thus, the electrical resistance measured by the ERPL was converted into the electrical resistivity, which is an intrinsic property. The shape effect was investigated using NaCl solutions with

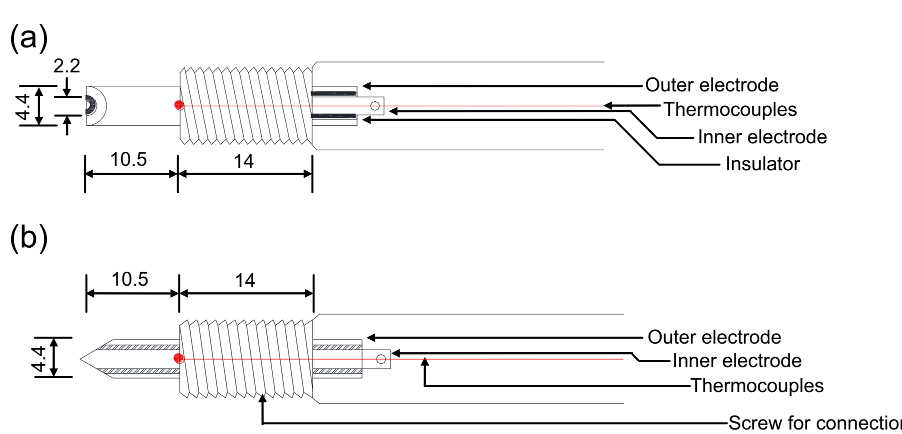

Fig. 2. Schematic drawing of the electrical resistivity probe for laboratory (ERPL): (a) Plan view (0°); and (b) side view (90°). The units are millimeters.