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Characterisation of subsurface spatial variability using a cone resistivity penetrometer

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ABSTRACT

The subsurface spatial variation in clay soils, such as thin-layered sand seams, affects the mechanical strength and electrical resistivity. The objective of this study is the development and application of cone resistivity penetrometer (CRP), which measures the cone tip resistance, sleeve friction, and electrical resistivity to evaluate the subsurface spatial variability. The electrical resistivity is measured at the cone tip to increase its resolution. Two outer diameters of the cone resistivity penetrometers (CRPs) are developed: $D=10$ mm CRP with a projected area of 0.78 cm^2 and $D=15$ mm CRP with a projected area of 1.76 cm^2. The cone tip resistance is effectively separated using a friction sleeve. Strain gauges are used to measure the mechanical strength, and coaxial type electrodes monitor the electrical resistivity. The application tests in the laboratory are conducted using layered soils and saturated sands. In addition, the penetration tests in the field are carried out and compared with the standard piezocone test. The penetration tests show that the soil layers and the density changes are clearly detected by the electrical resistivity and mechanical strength. Field tests show that CRP clearly evaluates the subsurface profile. This study suggests that CRP may be a useful technique for the evaluation of subsurface spatial variability during penetration testing.

1. Introduction

The behaviours of soils are dependant on their spatial variability [1–7]. The spatial variability in uniform soft soils is related to thin sand or silt layers. The thin layers result from soil formation processes like erosion, weathering, transportation, and sedimentation and may affect the hydraulic conductivities in both the vertical and horizontal directions [8]. Thus, the spatial variability should be determined during site characterisation.

Liquefaction and post-liquefaction phenomena are related to the spatial variability of soils. It has been shown that monotonic, cyclic, and dynamic loadings cause saturated sand or silt soils to liquefy [9,10]. When the soils are liquefied, the pore water pressure increases, the effective stress becomes zero, and the soil particles start to settle [11]. As the soil particles settle, the soils become denser and the strength increases. Thus, the increase in density and strength should be investigated to determine the design parameters under dynamic loading.

Cone penetration testing (CPT), which has been commonly used for the subsurface characterisation of soils, measures the cone tip resistance, sleeve friction, and pore pressure [12]. Therefore, CPT can render information related to a geological formation (spatial variability) and geotechnical parameters without boring and sampling [13,14]. The typical dimensions of the standard cone penetrometer are 10 cm^2 in the projected cross-sectional area, which implies a diameter of 35.7 mm, and an area of 150 cm^2 at the friction sleeve.

Cones with diameters as large as 35.7 mm may deteriorate the resolution in the cone tip resistance because the size of disturbed area during the penetration of the CPT is dependant on the probe size. Thus, smaller diameter cones have been developed to obtain higher resolution. Tumay et al. [15] developed a miniature cone with a diameter of 12.7 mm (projected area$=$1.26 cm^2). Hird et al. [16] developed a miniature piezocone with a diameter of 11.3 mm (projected area$=$1 cm^2) and another with a diameter of 25.2 mm (projected area$=$5 cm^2) to compare the resolutions of the two cones for thin layer detection. Hird et al. [16] showed that the smaller cone produced higher resolution in thin layer detection. Similar results were also reported by Hird and Springman [8]. A micro-cone penetrometer with a diameter of 5.0 mm (projected area$=$0.196 cm^2) was introduced by Lee et al. [17]. Lee et al. [17] used strain gauges to measure the cone tip strength. Recently, ultra small cone penetrometers with diameters of 1.0 and 3.0 mm were developed by Kim et al. [18], which used the fibre Bragg grating (FBG) optical sensors to detect the cone tip resistance and the sleeve friction.

The electrical resistivity is the reciprocal value of the electrical conductivity, which is related to the charge mobility in response to an electrical field [19]. Because the electrical resistivity of soil

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