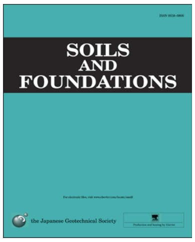
Soils and Foundations 2015;55(1):192–200

HOSTED BY

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf



Alternative methods for assessing particle breakage in weathered soil

Younghwan Son[a], Taeho Bong[a,*], Sookack Noh[b]

[a]*Department of Rural Systems Engineering, and Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea*
[b]*Department of Rural Systems Engineering, Seoul National University, Seoul, Republic of Korea*

Received 28 February 2014; received in revised form 29 September 2014; accepted 21 October 2014
Available online 3 January 2015

Abstract

Particle size distribution (PSD), fractal dimension (FD), electrical resistivity, and penetration using the fall cone test were evaluated as alternative measures for assessing particle breakage in weathered soil. The percentage of particles passing through a 0.075 mm sieve (% fines) was used as the standard value to represent the estimated particle breakage, and then, the FD was estimated using a particle size analysis. The % fines and the FD of compacted specimens with the optimum moisture content (OMC) were found to increase for the original specimens, but the electrical resistivity was found to decrease. In particular, electrical resistivity, measured at 5, 10, and 20 MHz, was applied to minimize the error at each measurement frequency. At higher volumetric water contents (above 0.35), the values of electrical resistivity become similar and are difficult to differentiate. Therefore, to estimate the particle breakage at high water contents, an alternative method to the fall cone test was used. The fall cone penetrations were measured in the water content range of 35–55%. The water contents of the compacted specimens were lower than the values of the original specimens at the same penetration. This result signifies that the penetration increased at the same water content. Furthermore, the variation in % fines could be evaluated by measuring the variation in water contents at the same penetration.

Keywords: Particle breakage; Fractal dimension; Electrical resistivity; Fall cone test; Weathered soil

1. Introduction

As weathered soil is generally classified as SM or SC by the Unified Soil Classification System, it is regarded as a stable soil. Although it seemingly has good strength, it is in a state of instability, because the particles can easily be separated by impact or disturbance (Brand and Phillipson, 1985). The particles of weathered soil are easily broken by stress, which is significantly influenced by the environment and field conditions. Furthermore, particle breakage leads to changes in the particle size distribution and the strength parameters. Researchers who study particle breakage claim that the particle breakage in soil is attributed to stress and that it can occur under a relatively low stress level. Studies have been conducted to examine the breakage depending on the particle strength, shape, and size (Hagerty et al., 1993; Lade et al., 1996; Yamamuro et al., 1996). Knowledge of microscopic particle crushing is important for understanding the mechanism of particle breakage (Nakata et al., 2001a) and visualization helps in the understanding of the size distribution of broken particles as a result of crushing. Many tests have been carried out on various granular materials to examine the visualization of the evolution of crushing in materials subjected to different stress levels, compression methods, and computer simulations using the Discrete Element Method (DEM) (Nakata et al., 2001a, 2001b; Lobo-Guerrero and Vallejo, 2005, 2006). The

---

[*] Corresponding author. Tel.: +82 28804593; fax: +82 28732087.
E-mail address: bth21@snu.ac.kr (T. Bong).
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2014.12.015

existing studies on particle breakage have mainly used the results of particle size analyses. The level of particle breakage has been evaluated using the specific area or the percent passing through a 0.075 mm sieve (Jeong and Yang, 2000; Kim et al., 2001). Particle breakage has been represented by the breakage index, the breakage ratio, and the breakage potential, which were defined using the results of particle size analyses (Lee and Farhoomand, 1967; Marsal, 1967; Hardin, 1985). Therefore, a particle size analysis is performed as a standard method to represent the estimated particle breakage of the soil. Meanwhile, many researchers have studied the use of fractals in particle size analyses. The fragmentation fractal of the particle size distribution curve was proposed by equations and models (Tyler and Wheatcraft, 1992; Hyslip and Vallejo, 1997; Bittelli et al., 1999; Min and Lee, 2003). A fractal is generally defined as a fragmented geometric shape that can be split into parts, each of which is a reduced-size copy of the entire shape. Hence, the fractal dimension is estimated using the results of a particle size analysis.

Water has a large effect on particle crushing because of its high polarity, low viscosity, and small molar volume (Miura and Yamanouchi, 1975). Also, particle breakage in rockfill depends on the strength of the individual particles, the grain size distribution, the stress level, and the relative humidity prevailing in the rockfill voids (Chavez and Alonso, 2003). Electrical resistivity and the fall cone test are used as alternative methods for measuring particle breakage. There are three routes through which electrical currents flow in soil: they pass through both solid and pore fluids, they pass through soil particles alone, and they pass through pore fluid alone (Smith and Arulanandan, 1981; Mitchell, 1993). It is also known that the electrical resistivity in soil is subject to the influence of factors such as porosity, the electrical resistivity of the pore fluid, the characteristics of the solids, the degree of saturation, the particle shape and orientation, and the pore structure (Keller and Frischknecht, 1966; Parkhomenko, 1967; Arulanandan and Muraleetharan, 1988; Ward, 1990; Thevanayagam, 1993; Yoon and Park, 2001). In soil under wet conditions, electric currents are conducted through the connected pore fluid, which has high conductivity and is a main route for electrical currents generated in the soil (Yoon et al., 2002). This is because the electrical resistivity becomes rapidly lower under wet conditions and its value is not sufficient to evaluate at higher water contents. That is, it is not clearly distinguishable at high water contents. Therefore, the upper limit of the water content, measurable using electrical resistivity, was estimated in this research, and the fall cone test was used when specimens had higher water contents than this upper limit water content.

Researchers have attempted to resolve the drawbacks of the Casagrande method, and the fall cone test was developed as an alternative method (Houlsby, 1982; Wood, 1982, 1985; Koumoto and Houlsby, 2001). In England, Sweden, and Canada, determining the liquid limit using the fall cone test is listed in the relevant specifications; the fall cone test is considered to be more reliable than the Casagrande method (Koumoto and Houlsby, 2001). Researchers have suggested that the liquid limit is the water content at which clay has a certain un-drained shear strength (Wroth and Wood, 1978). This relationship between water content and shear strength can be applied to the results of the fall cone test. With this background in mind, the present research attempted to identify particle breakage by observing the changes in penetration at the same water content. To date, there have been no studies that have estimated the relationship between particle breakage and penetration using the fall cone test.

In this study, the fractal dimension was estimated using a particle size analysis. The electrical resistivity was measured at different volumetric water contents by varying the frequency from 100 Hz to 30 MHz, and then, the applicable ranges in volumetric water content, used to estimate the electrical resistivity, were proposed. The fall cone test was used at high water contents when the electrical resistivity could not be used to estimate particle breakage. Based on the results, the ranges in effective water content for using electrical resistivity and the fall cone test, to estimate particle breakage in weathered soil, were proposed. Furthermore, the fractal dimension, the electrical resistivity, and the penetration by the fall cone test were verified as alternatives for measuring the particle breakage in weathered soil.

2. Materials and methods

2.1. Materials

The four different soils used in this study were collected in Hwaseong, Gyeonggi, South Korea and were labeled as A–D according to the sampling location. All the soils in this area originated mostly from the in situ weathering of granite and were classified as silty sand by the Unified Soil Classification System. Their physical properties are summarized in Table 1.

To analyze the chemical composition and mineralogy of the soil particles, oven-dried soils were pulverized and an X-ray fluorescence (XRF) analysis (XRF-1700, Shimadzu, Japan) was run. The results of the XRF analysis for all the soils are shown in Table 2.

2.2. Methods

The four different disturbed samples were collected in situ and compacted using standard A compaction, according to ASTM D 698-07. As the particle breakage of the specimens

Table 1
Physical Properties of Soils

Soils	Sampling Depth (m)	Specific Gravity (G_s)	Liquid Limit (%)	Plasticity Index (%)	% Fines	USCS[a]	γ_{dmax} (kN/m^3)	OMC (%)
A	1.0	2.75	–	NP	12.90	SM	16.21	16.0
B	2.0	2.73	–	NP	24.03	SM	17.02	19.2
C	3.0	2.72	–	NP	17.60	SM	16.49	20.3
D	1.0	2.68	–	NP	20.38	SM	16.01	20.0

[a] Unified Soil Classification System.