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Soil Stiffness Gauge (SSG) and Dynamic Cone Penetrometer (DCP) tests for estimating engineering properties of weathered sandy soils in Korea

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ABSTRACT

Laboratory tests are conducted using nondestructive and penetration methods for in-situ estimation of the engineering properties of weathered sandy soils in Korea. Soil Stiffness Gauge (SSG), Dynamic Cone Penetrometer (DCP), Plate Load Test (PLT), and California Bearing Ratio (CBR) are performed with three uncemented soil groups: poorly graded sand (SP), silty sand (SM), and well-graded sand with silt (SW-SM) that were compacted in a large container. The SSG and DCP results show acceptable repeatability. Dynamic Penetration Index (DPI) and the modulus of elasticity obtained from the SSG test (E_{SSG}) are significantly affected by the water content of SM and SW-SM soils, whereas the SP sample showed no clear effect of water content in either the DPI or E_{SSG} test. Compared with previous reports in the literature, the relationship obtained between CBR and DPI shows a similar trend although at a given DPI it produces significantly larger CBR values. For elastic moduli E_{SSG} is linearly proportional to E_{PLT} and is 1.7 times larger than E_{PLT}. For all three soils considered, the void ratio (e) is linearly proportional to the DPI divided by the median particle size (DPI / D_{50}) while the angle of internal friction is inversely proportional to DPI / D_{50}. The dry density of compacted soil appears to increase nonlinearly with increase in $E_{SSG} \cdot D_{50}/e$. It is, therefore, concluded that E_{SSG}, DPI, and D_{50} can provide complementary information for the estimation of void ratio and dry density.

1. Introduction

Soil stiffness and strength are widely recognized as essential and relevant engineering properties in the design and construction of earthworks, while soil density and water content are essential measurements during the construction process. However, soils prepared at the same density and water content show differing stiffness and strength, which are dependent on several factors including the state of stress, strain level, boundary condition, and fabric of the soil (Duffy and Mindlin, 1957; Terzaghi et al., 1996; Cho and Santamarina, 2001; Holtz et al., 2011).

The use of alternative methods, which directly measure the mechanical properties of soils, has been proposed to assess soil stiffness and strength using instruments such as Soil Stiffness Gauge (SSG), Light Falling Weight Deflectometer (LFWD), Falling Weight Deflectometer (FWD), and Dynamic Cone Penetrometer (DCP). Several studies have used these devices to monitor the engineering properties of soils and assess compaction quality during earthwork construction (Ayers et al., 1989; Livneh et al., 1995; Fiedler et al., 1998; Siekmeier et al., 1999; Sawangsuriya et al., 2003; Alshibli et al., 2005; Chen et al., 2005; Mohammadi et al., 2008; Rahman et al., 2008). These alternative methods have advantages of greater testing speed and quantitative evaluation for quality assurance and control during the compaction process. However, their use requires the development of reliable correlations with conventional evaluation methods because the developed correlations are dependent on the tested materials in addition to the inherent and stress-induced engineering properties of specific soils.

In this study, comprehensive laboratory experiments were performed to assess the engineering properties of Korean weathered sandy soils using nondestructive and penetration tests. The tested materials, which are classified as poorly graded sand (SP), silty sand (SM), and well-graded sand with silt (SW-SM), were collected from three different locations in Korea. The SSG and DCP tests were conducted on compacted soil specimens prepared in a large container. The applicability of the SSG and DCP tests was evaluated, and the results were correlated with those from conventional test methods such as Plate Load Test (PLT) and California Bearing Ratio (CBR) test. In addition, new empirical equations are suggested for estimating the physical and

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mechanical properties of compacted soils through laboratory tests using SSG and DCP.

2. Materials and methods

2.1. Geological description and test materials

Precambrian granite gneisses and crystalline schists occurring with granites occupy more than half of the Korea peninsula, although Paleozoic, Mesozoic, and Cenozoic rocks are also found in isolated and narrow areas (Tateiwa, 1960). Denudation remnants of base rocks and sedimentary successions are found with granitic intrusions (Chough et al., 2000). Fig. 1 shows generalized soil maps for the locations at which test materials were collected in this study. The soil samples were found to be composed of quartz, plagioclase, K-feldspar, and biotite with muscovite and chlorite (Lee et al., 2001). The soil samples were oven-dried, and then the index properties were measured (Table 1). The specific gravity ranges from 2.63 to 2.71. Sieve and/or hydrometer analysis were conducted to determine the particle size distribution (Figure 2). The soils are classified as SP, SM, and SW-SM, respectively, according to the Unified Soil Classification System (USCS).

2.2. Test devices

The SSG, which was originally developed to detect land mines, is a portable and nondestructive device used to measure in situ soil stiffness. The SSG used in this study is manufactured by the Humboldt Manufacturing Company. As shown in Fig. 3(a), its weight is approximately 98.1 N (22 lbs.), with dimensions of 280 mm (11 in.) diameter and 254 mm (10 in.) height. A ring-shaped foot, which has an outer diameter of 114.3 mm (4.5 in.) and a thickness of 12.7 mm (0.5 in.), supports the weight of the SSG on the soil surface (Fiedler et al., 1998). The SSG measures physical impedance by generating a small displacement in the soil. Approximately 10.0–17.3 N of dynamic force is applied by an internal mechanical shaker, with 25 different frequencies (ranging from 100 Hz to 196 Hz) at increments of 4 Hz. Velocity sensors installed inside of the SSG measure the force and displacement of the foot (Alshibli et al., 2005; Sawangsuriya et al., 2006). To analyze the measured results, the stiffness (k) of the ground is evaluated via the static–elastic equation proposed by Poulos and Davis (1974) for the circular ring load on the semi-infinite plane:

$$k = \frac{r \cdot E_{SSG}}{(1-\nu^2) \cdot \omega(n)} \quad (1)$$

where r is the radius of the ring (57.15 mm), E_{SSG} is the modulus of elasticity from the SSG test [MPa], ν is the Poisson's ratio of the elastic medium, and $\omega(n)$ is 0.565 for the SSG geometry ($n = r_i / r_0$: the radius ratio of the ring (44.5 mm/57.15 mm $\approx$ 0.78)). Previous studies, based on both finite-element analyses and experimental studies, reported that the SSG has as influence radius of up to 300 mm (Sawangsuriya et al., 2002).

The DCP is a simple, portable device used to measure in-situ soil resistance. Scala (1956) introduced the DCP to access the shear strength of compacted soils in Australia. Since being used for in situ evaluation of pavement structures in South Africa (Kleyn, 1975), the DCP has widely been adopted to measure the penetration resistance of compacted soils. As shown in Fig. 3(b), the DCP consists of three parts: an upper part, a lower part, and a vertical scale (optional). The upper part comprises the following subparts: a handle to keep the DCP vertical, an upper stopper indicating the maximum height, a falling hammer of 78.5 N (17.6 lbs.), and an upper rod (16 mm (5/8 in.) in diameter and 575 mm (22.6 in.) in length). The lower part consists of the following: a lower rod (16 mm in diameter and 1000 mm (39.4 in.) in length),

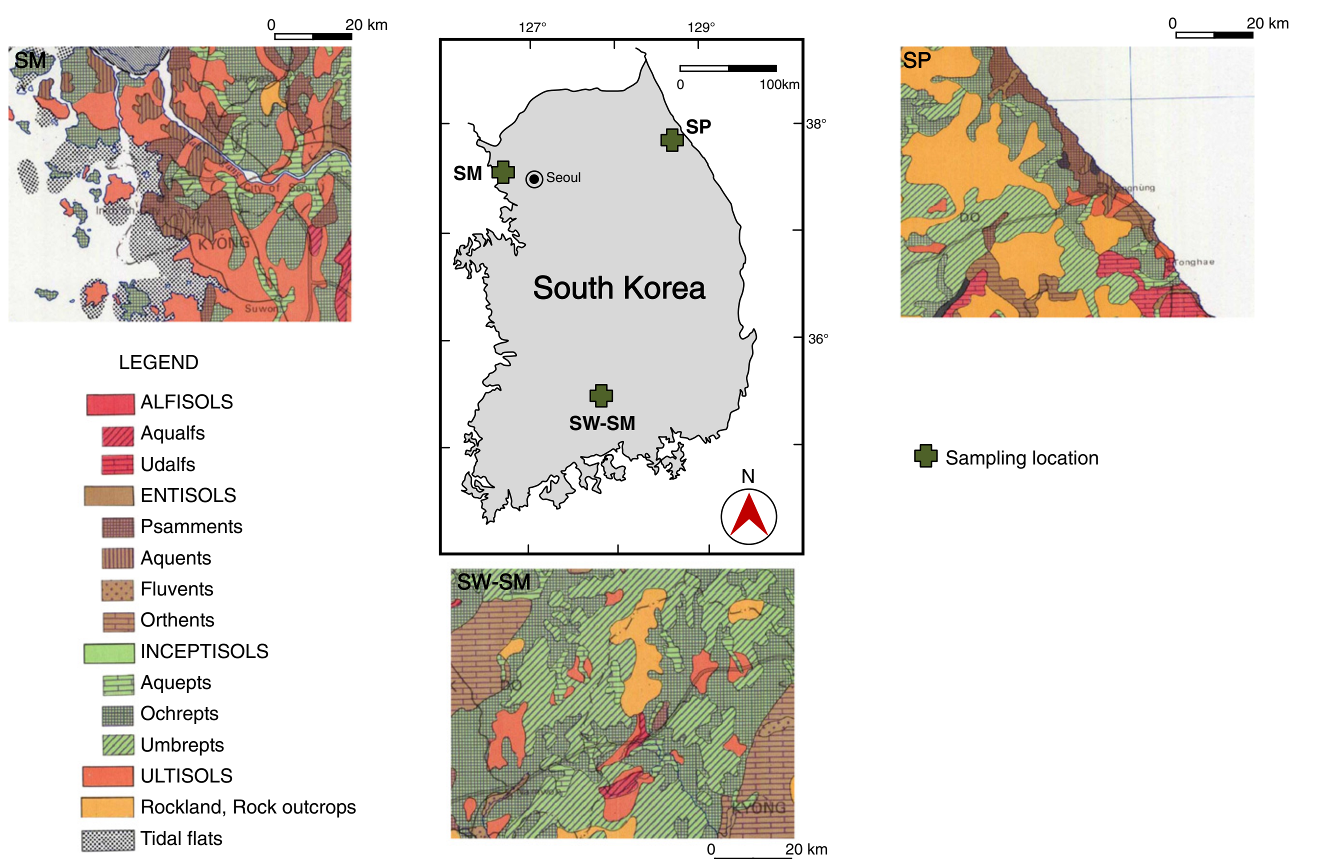

Fig. 1. Generalized soil map of Korea with sampling location (modified from Geological Society of Korea, 1956).