Evaluation of Deformation Modulus of Cemented Sands using Cone Tip Resistance
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ABSTRACT
This study evaluates the constrained modulus (M) and the small strain shear modulus (Gmax) of cemented sand from cone tip resistance (qc). For this, a series of piezocone and bender element tests are performed in a large calibration chamber, and one-dimensional compression tests are also carried out in an oedometer cell. From the experimental results, the effects of gypsum content, relative density and vertical confining stress on cone tip resistance are investigated. After comparison of the sensitivity of cementation to the deformation moduli and cone tip resistance, the relations between cone tip resistance and the two deformation moduli are interpreted.

KEY WORDS: Cemented sand; calibration chamber, cone tip resistance; small strain shear modulus; constrained modulus

INTRODUCTION
Geotechnical engineers are often confronted with cemented or structured materials. The cementation increases the peak strength and the brittle and dilative behavior of sand (Abdulla and Kiousis, 1997; Asghari et al., 2003; Clough et al., 1981; Huang and Airey, 1993; Ismail et al., 2002; Schnaid et al., 2001). Therefore, the cementation of soils has a significant effect on the settlement and bearing capacity of the foundation. However, the effect of cementation on soil is often neglected in the design process since it is difficult to quantify the effect of cementation.

A few studies have been performed to evaluate the cementation effect on sand by cone penetration test (CPT). Akili and Torrance (1981), Akili and Al-Joulani (1988), Rad and Tumay (1986), Joshi et al. (1995) and Puppala et al. (1995) estimated the cementation effect on CPT results using artificially cemented specimen prepared in a calibration chamber. Beringen et al. (1982), Schnaid et al. (1998), Puppala et al. (1998), and Dauziger et al. (1998) conducted cone penetration tests on natural cemented sediments. Their results showed that the cone tip resistance and sleeve friction increase with the increase of the cementation level. However, since the penetration of in-situ equipment breaks down all cementation bonds adjacent to penetration probe, it is difficult to interpret the properties of cemented sand from the result of CPT. As a result, the relationship between cone tip resistance and deformation modulus still remains unexplored, although studies have indicated the change of deformation modulus of sand by cementation effect. Therefore, this study analyzes the relationships between the cone tip resistance and two deformation moduli such as the constrained modulus and the small strain shear modulus, respectively. For measuring the cone tip resistance and the small strain shear modulus of cemented sand, a series of miniature cone penetration tests and bender element tests were carried out in artificially gypsum-cemented specimens in a large calibration chamber. And then, the constrained modulus of cemented sand was measured in a one-dimensional compression test using an oedometer cell.

EXPERIMENTAL PROGRAM
Materials
K-7 sand, an artificially crushed sand from a parent rock, was used. Particle size distribution and basic properties of this sand are presented in Figure 1 and Table 1. This sand is classified as SP in the unified soil classification system (USCS) and the mean particle size (D_{50}) is 0.17 mm. From X-ray fluorescence analyses, SiO2 was identified as the dominant particle mineral. The roundness of the particle was identified as sub-angular by scanning electron microscopy analysis. Gypsum, generally used for manufacturing ceramics, was used as the cementing agent in this study because the behavior of gypsum-cemented sand is similar to that of naturally cemented sand (Ismail et al., 2002). The compressive strength of gypsum cured at a water content of 40% is about 20 MPa. Gypsum starts to cure approximately 16 minutes after it is mixed with water, and the curing continues about 40 minutes after the initial mixing. The expansion rate of gypsum during curing is about 0.03%, which is relatively small compared that of ordinary gypsiums.

Table 1. Engineering properties of K-7 sand

<table>
<thead>
<tr>
<th>Gs</th>
<th>D_{50} (mm)</th>
<th>D_{10} (mm)</th>
<th>Cu</th>
<th>Cc</th>
<th>ε_{max}</th>
<th>ε_{min}</th>
<th>USCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.647</td>
<td>0.09</td>
<td>0.17</td>
<td>2.111</td>
<td>0.988</td>
<td>1.054</td>
<td>0.719</td>
<td>SP</td>
</tr>
</tbody>
</table>