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Mechanical behavior of artificially cemented clay with open structure: Cell and physical model analyses

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ABSTRACT

In this study, the authors developed an innovative method of artificially preparing cemented clay with relatively large void ratio and explored the properties of the clay through cell and physical model tests. The artificially cemented clay was produced by mixing a defined amount of cement and ice particles with uncemented materials to reproduce interparticle chemical bonds and large pores found in naturally cemented clay. Confined compression and anisotropic compression were performed on the artificially cemented clay specimens, and results showed that the artificially cemented clay does successfully reproduce the primary mechanical properties of naturally cemented clay. Interparticle bonds were primarily responsible for enhanced structural yield stress in compression tests on the clay; the consolidation process damaged the soil structure while simultaneously densifying it. Using specially designed equipment, consolidated-undrained and drained physical loading tests were conducted on a model ground with the artificially cemented clay to measure the footing settlement, specimen surface displacement, and pore water pressure after each step load. A critical load can be identified in the physical model test, near which the pore water pressure increased very quickly during the consolidated-undrained model test.

1. Introduction

Natural soils are characterized by structures ascribed to their unique geotechnical process and local climate. Soil structure is a combination of "fabric" (i.e., particle associations and arrangements) and interparticle cementation (Mitchell, 1976). Cemented clays with large pores are widely distributed at the Yangtze River, Yellow River and Zhujiang River delta areas (Jiang et al., 2009); this cementation enhances material strength, meanwhile, however, facilitates strain-softening and volumetric collapse in the material and induces problems in engineering practice. For example, ground with cemented soil is quickly damaged by vertical loads, showing sudden, large deformation (Bjerrum, 1972). Accordingly, laboratory or in situ tests (Burland, 1990; Leroueil and Vaughan, 1990; Cuccovillo and Coop, 1997; Liu and Carter, 1999; Callisto and Rampello, 2004; Amorosi and Rampello, 2007; Kang et al., 2016) and constitutive modeling (Baudet and Stallebrass, 2004; Yu et al., 2007; Yan and Li, 2011; Yang et al., 2013; Robin et al., 2015; Zhu and Yao, 2015) for cemented soils have been extensively researched in recent years, especially since the 1990s.

Reliable experimental data is necessary for successful constitutive modeling of cemented soil behavior or to verify the effectiveness of finite element simulation. The sampling process may cause excessive sample variability or disturbances related to stress relaxation and sample trimming, however. Sample variability and disturbance may alter the compression and shear behavior of the naturally cemented soil after being retrieved for analysis compared to that of the intact soil (La Rochelle et al., 1981; Clayton et al., 1992; Coop and Willson, 2003). Further, the difference is not easily quantified. The verifications of finite element simulations through in situ tests are difficult because of the complexity of field conditions. On the contrary, physical modeling appears more efficient for this purpose. However, as it is very difficult to employ natural intact soil for physical model test, few physical model tests on natural structured soils have been reported. Researchers have developed new samplers (La Rochelle et al., 1981) designed to collect cemented samples with limited disturbance in effort to solve this problem. Cemented soil samples can also be prepared artificially, which is especially helpful for avoiding sampling disturbance that would otherwise result when taking natural intact soil for physical model tests; the constitutive parameters of the cemented clay in physical model tests can be obtained through laboratory cell tests with approximately the same cemented soil. In addition, mixing soils with cement is also an efficient technique in ground improvement (Consoli et al., 2011).

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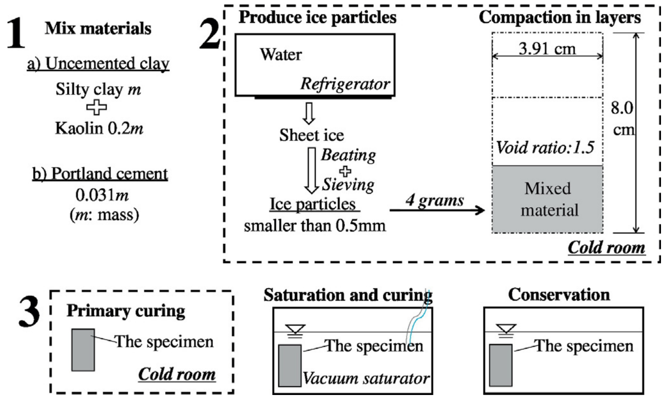

Fig. 1. Preparation of artificially cemented clay specimens for cell tests.

Table 1
Atterberg limits.

	Plastic limits/%	Liquid limits/%	Plasticity index
Silty clay	22.8	39.0	16.2
Uncemented clay	23.8	39.5	15.7
Cemented clay	24.5	39.8	15.3

Various techniques have been proposed to produce artificially cemented soils. Saxena and Lastrico (1978) and Clough et al. (1981) prepared artificially cemented sand by mixing it with cement, for example. Maccarini (1987) mixed clay with sand and burned the mixture at 500 °C for 5 h to obtain weakly bonded sand for triaxial tests (Malandraki and Toll, 2001). Sudhakar et al. (1995) used wetting-drying cycles to prepare collapsible soils with large pores, and Medero et al. (2003) created artificially collapsible soil with large voids and metastable structure by mixing soil, cement, water, and expanded polystyrene particles. Jiang et al. (2012) produced artificially collapsible loess by cementing loess particles with calcite, and Horpibulsuk et al. (2004a, b, 2012) created cement-admixed clays to investigate the influence of cement and water content on the material's mechanical performance. Rios et al. (2012) investigated the effects of porosity/cement ratio on the compression of an artificially cemented soil. Rotta et al. (2003) formed cemented sand using Portland cement under different confining pressures to reproduce the deposition condition, and Du et al. (2014) studied the compression behavior of cement-treated soil with various cement contents and zinc concentrations.

In this study, laboratory cell and physical model tests were conducted to characterize the mechanical behavior of an artificially cemented clay. To fabricate the clay, appropriate amounts of cement and ice particles were mixed with uncemented materials to reproduce the interparticle chemical bonds and large pores found in naturally cemented clay. To reproduce shallow deposited cemented clay, the bonds were formed at a large void ratio (which is equivalent to a low-stress state.) The compression behavior, consolidated-undrained, and drained behavior of the artificially cemented clay were then tested at length; a new piece of laboratory equipment was also developed to perform physical model tests on the artificially cemented clay.

2. Preparation and physical properties of artificially cemented clay

2.1. Preparation of the artificially cemented clay

Dry silty clay (which mass is m), taken from 20 m depth at a site in Nanjing, China and then was air dried and passed through the 0.5 mm sieve, was mixed with 0.2 m granular kaolin to prepare the uncemented clay (UC). In order to create a cemented clay with large void ratio (not the natural silty clay at 20 m depth), interparticle bonds were produced by mixing cement with the UC, then large pores were formed by adding small ice particles.

The artificially porous cemented clay (CC) was prepared in three steps, as shown in Fig. 1. Mixed material was obtained first by mixing the UC with 0.031 m of 525# Portland cement; the amount of Portland cement was determined according to the cohesion properties of typical naturally cemented soils. Next, the specimen with 1.5 void ratio was prepared by compacting a specified amount of mixed material in a cylindrical container in three layers with 4 g ice particles added into each layer. The proportion of ice particles, which were prepared by

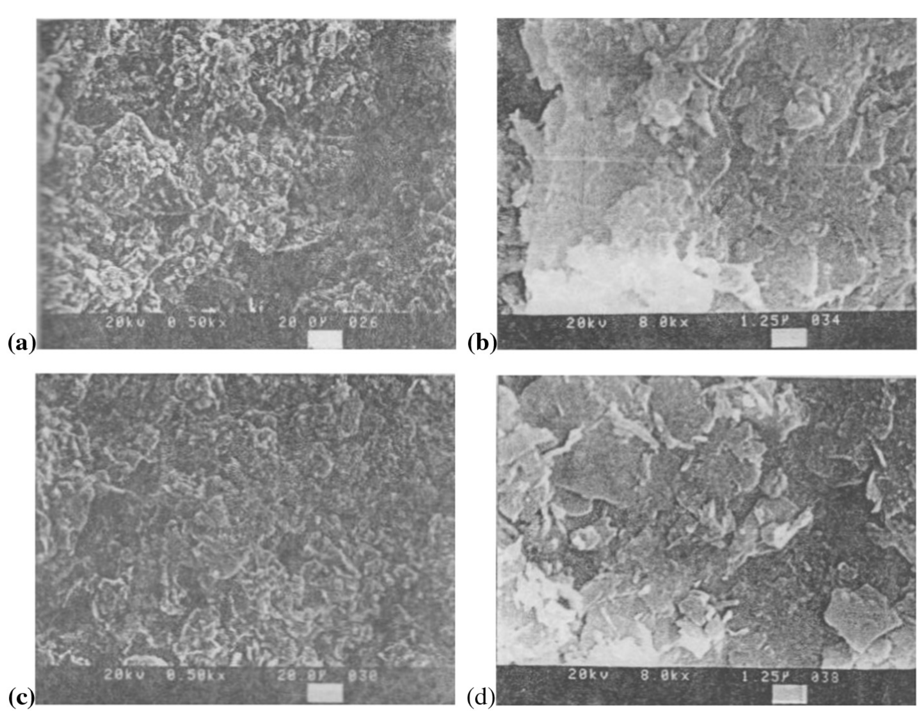

Fig. 2. SEM micrographs: (a–b) artificially cemented clay, (c–d) uncemented clay.