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Importance of sedimentation process for formation of microfabric in clay deposit

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Abstract

When a clay sample is reconstituted from a slurry state to a normally consolidated state, a higher initial water content generally derives a higher void ratio in *e*–log*p* relationship. However, in undisturbed Holocene clay samples collected from a soil layer under the seabed, void ratio is much higher than that for the reconstituted, even though the reconstituted sample was consolidated from a sample slurry state with a very high initial water content. Therefore, the higher void ratio for undisturbed Holocene clay cannot be explained by the initial water content. There must be another key factor to explain the higher void ratio for undisturbed Holocene clay. In this study, the difference between the microfabric of deposited clay from suspension state and reconstituted clay from a slurry state is investigated to clarify the key factors contributing to the higher void ratio. The clay in this study is Osaka Bay Holocene clay sampled from GL −15 to −19 m below the seabed. Sedimentation tests from the suspension state were carried out in various conditions of initial water content, salt concentration, and pH. A series of sedimentation tests was carried out with two types of hollow cylinders: an observation glass cylinder with an inner diameter of 60 mm and a height of 400 mm (specimen height of 350 mm), and a cylindrical acrylic container with an inner diameter of 100 mm and a height of 1800 mm (specimen height of 1500 mm). In the 100-mm diameter cylinder, the deposited sample was consolidated by a pressure of 19.6 kPa, then mounted in an oedometer ring with an inner diameter of 60 mm and a height of 20 mm. An incremental loading oedometer test was then carried out up to 39.2 kPa. The microfabric of the consolidated specimen was observed by scanning electron microscope (SEM) and quantitatively investigated by mercury intrusion porosimeter (MIP). It was shown that the high void ratio of natural clay deposit is not only due to the high initial water content but also to the sedimentation process with flocculation. This plays an important role in the formation of the microfabric of natural clay deposits characterized by a significantly higher void ratio than reconstituted samples.
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Keywords: Microfabric; Clay deposit; Sedimentation; Flocculation; Void ratio; Consolidation

1. Introduction

Clay particles transported with a river flow flocculate and precipitate when they meet seawater in a bay. The accumulation of such sediments forms a natural clay deposit through a process of long-term self-weight consolidation. Although Holocene clays are younger deposits, they were deposited several hundred or several thousand years ago, and the behavior of these soils shows aging effects. Thus, the mechanical properties of a natural intact sample of the Holocene clays differ significantly from those of its reconstituted clay, which has been completely remolded and undergone preliminary consolidation from a slurry

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state in the laboratory. Normally consolidated clays, which show mechanical behaviors similar to slightly overconsolidated clays, are often referred to as quasi-overconsolidated clays. Quasi-overconsolidation occurs due to microstructures derived from the inter-particle bonding that takes place due to the aging effect.

Reconstituted clay sample is generally consolidated from a slurry state in a water content of $1.5w_L$ to $2.0w_L$, and its void ratio increases with the initial water content. This phenomenon can be expressed using the concept of the void index and the intrinsic compression curve proposed by Burland (1990), in which the compression curve of natural clay deposit is above the intrinsic compression curve and converges when the consolidation pressure is sufficiently high. In many cases, the water content of natural intact clay is much higher than that of its reconstituted clay, even when preliminary consolidation begins in the slurry in $2w_L$, as described later. Because of long-term secondary consolidation, or "delayed consolidation" (Bjerrum, 1973), the void ratio of the natural intact clay is expected to be smaller than that of its reconstituted clay. In contrast, if cementation due to the aging effect is dominant over the delayed consolidation, the void ratio of the natural clay deposit can be higher than its reconstituted clay under the same overburden effective stress. This concept, however, makes less sense when considering the monotonically increasing overburden effective stress of a typical natural sedimentation ratio of about 1 mm/year in a bay. Because the void ratio of a natural marine clay is generally higher than that of its reconstituted normally consolidated clay under the same overburden effective stress (e.g., Watabe et al., 2003), the formation process of the clay deposit has to be examined more closely, and from various perspectives above and beyond the initial void ratio and aging effect.

While the evaluation of the consecutive process from sedimentation to consolidation is considered important in soil formation (Imai, 1980, 1981), the majority of research relating to this has been focused on the process of reclamation with dredged soil in predicting consolidation settlement. In those studies, the key factor has been the initial void ratio for use in a conventional approach to calculate the amount of consolidation after the sedimentation process (e.g. Egashira et al., 2003). The process from sedimentation to consolidation has been reported for dredged clays (Imai, 1980, 1981; Tong et al., 2012; Xu et al., 2012; Zhang et al., 2013) and kaolin clay (Ma and Pierre, 1999). The influence of segregation in the sedimentation process on mechanical properties has been reported (Sridharan and Prakash, 2001, 2003). In addition, a practical testing method using seepage force to examine the process from sedimentation to consolidation has been developed and proposed (Imai, 1979; Sridharan and Prakash, 1999). The focus of these investigations was to explain the formation process of manmade island reclaimed by dredged soil. The formation process of natural soft clay deposit, however, has yet to be explained.

In this study, the reason for the higher void ratio of the natural clay deposit than that of its reconstituted clay is examined and discussed through a series of experiments focused on the sedimentation process (Imai, 1980, 1981). The sedimentation processes are the key difference in the formation processes of the natural clay deposit in the field and the reconstituted clay sample in the laboratory. To clarify the differences between these clays, their microfabrics are observed microscopically by SEM (scanning electron microscope) and pore-size distribution by MIP (mercury intrusion porosimeter).

2. Laboratory experiments

The clay samples examined in this study are Osaka Bay Holocene clay, collected from 15 to 19 m depths below the seabed at the construction site of the Kansai International Airport (Watabe et al., 2002), sieved by a 75 μm mesh to remove the sand fraction. The clay (0–5 μm) and silt (5–75 μm) fractions are 43.6% and 56.4%, respectively, with a plastic limit w_L of 75.1%, plasticity index I_p of 43.1, and soil particle density ρ_s of 2.68 g/cm^3. The results of a series of sedimentation tests are listed in Table 1. A basic test case is in the condition with an initial water content of 3000% (adjusted by water), a salinity concentration of 3.3% (adjusted by salt) and a pH of 7 (adjusted by sulfuric acid).

Table 1
Test conditions.

Code	Initial water content w_0 (%)	Salt concentration (%)	pH	Observation glass cylinder	Cylindrical acrylic container	Consolidation
Case1	1000	3.30	7.93	No	Yes	Yes
Case1′	1000	3.30	7.93	Yes	No	No
Case2	2000	3.30	7.93	No	Yes	Yes
Case2′	2000	3.30	7.93	Yes	No	No
Case3	3000	3.30	7.93	No	Yes	Yes
Case3′	3000	3.30	7.93	Yes	No	No
Case4	3000	3.30	5.59	No	Yes	No
Case5	3000	3.30	4.50	No	Yes	No
Case6	3000	3.30	3.42	No	Yes	No
Case7′	3000	1.65	7.93	Yes	No	No
Case8′	3000	0.83	7.93	Yes	No	No
Case9′	3000	0.00	7.93	Yes	No	No

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