One-Dimensional Consolidation Model Based on Sub-Superloading Surface Theory and its Applicability to Consolidation Behavior of Pleistocene Clays under Kansai International Airport

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ABSTRACT

The upper Pleistocene clays under Kansai International Airport are typical “quasi-overconsolidated clay”, of which mechanical characteristics are quite distinctive from those of mechanically overconsolidated clays. An elasto-viscoplastic one-dimensional consolidation model is proposed in order to express time-dependent consolidation behavior for quasi-overconsolidated clays. The numerical simulation of a series of long-term consolidation tests for Ma10, upper Pleistocene clays under Kansai International Airport, is carried out in which the model proposed is applied. The applicability of proposed model is confirmed through a comparison between the experimental and analytical results.

KEY WORDS: Consolidation, Numerical analysis, Upper Pleistocene clay, Osaka Bay, Elasto-viscoplastic model, Subloading surface theory

INTRODUCTION

The seabed ground in Osaka Bay is composed of the sand or sandy gravel layers and thick clay layers which are cumulated alternately. 15 thick marine clay layers (Ma-1~Ma13) are established through recent geological research works. Ma13 is situated near the seabed and Holocene origin whereas the other clay layers are Pleistocene origin. It has been elucidated that the consolidation yield stress, $p_c$, of these Pleistocene clays are higher than the current overburden pressures, $p_0$, although the clays have not been applied higher pressure than $p_0$, judging from the geological findings. In that sense, these clays have been called “quasi-overconsolidated clay”. It has been known that the mechanical characteristics of quasi-overconsolidated clays are quite distinctive from those of mechanically overconsolidated clays due to loading/unloading history. That is, remarkable compression occurs just after the yielding. Also, a significant secondary consolidation occurs even in the range of stress lower than $p_c$. Their secondary consolidation behaviors are distinctive from those of reconstitutive clays. Especially, the slope of curve between the creep strain and the logarithm of time becomes gentle with the elapsed time in the long-term consolidation tests (Tanaka 2005). Furthermore, based on the field measurements, significant residual settlements of reclaimed lands and man-made islands, such as Kansai International Airport, have occurred, although the applied pressure due to reclamation is lower than $p_c$ (Matsui et al, 2001).

The authors have developed a mechanical model which can express such distinctive consolidation characteristics of quasi-overconsolidated clays as mentioned (Oda and Matsui, 2004 and 2005a; Oda et al, 2005b). It has been found that the linear relationship between void ratio and logarithm of vertical effective stress is not available in order to express time-dependent compression behavior of quasi-overconsolidated clays through their works. Also, they pointed out that the secondary consolidation behavior plays a key role in long-term consolidation behavior of the upper Pleistocene clay layers. In this paper, firstly, an elasto-viscoplastic one-dimensional consolidation model for expressing the time-dependent secondary consolidation behavior of the quasi-overconsolidated clays is proposed. The proposed one-dimensional consolidation model is based on both the sub-superloading yield surface concept and the flow surface theory. Secondly, the numerical simulation of long-term consolidation tests of Ma10, the upper Pleistocene clays under Kansai International Airport, is carried out in order to confirm the applicability of the proposed model to the time-dependent compression characteristics of quasi-overconsolidated clays.

COMPRESSION CURVE BASED ON SUPERLOADING YEILD SRUFACE CONCEPT

Asaoka et al (2000) proposed the superloading yield surface concept in order to express the mechanical behaviors of highly structured soils, such as heavily over-consolidated clays. This concept is based on subloading surface theory, which has been proposed by Hashiguchi (1989) in order to express the loading/unloading behavior of elasto-plastic material. Based on this concept, not only a smooth transition from elastic state to plastic state but also a remarkable compression just after the yielding can be expressed. Applying this theory to one-dimensional consolidation behavior of clays, the superloading yield stress, $p_c^*$, and the normal yield stress, $p_c^*$, are defined as the following equation, respectively.

$$p_c^* = rac{p_c}{R}$$

$$p_c^* = R \times p_c$$

where $R$ is the normal stress.