Elasto-viscoplastic model for expressing strain rate dependency of creep behavior and its applicability to one-dimensional consolidation behavior of Pleistocene clays in Osaka Bay

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ABSTRACT
The Pleistocene clays in Osaka Bay are typical “quasi-overconsolidated clay”. Their mechanical characteristics are quite distinctive from those of mechanically overconsolidated clays. That is, their consolidation yield stresses, p_c, are higher than the current overburden pressure, p_0, although they have never been applied higher pressure than p_0. Also, a significant secondary consolidation, which is different from that of re-constituted clay, occurs even in the range of stress lower than p_c.

In this paper, an elasto-viscoplastic one-dimensional consolidation model is proposed in order to express time-dependent consolidation behavior for quasi-overconsolidated clays in the range of stress from p_0 to slightly over p_c. The numerical simulation of a series of long-term consolidation tests for Ma3 clay, one of Pleistocene clays in Osaka Bay, is carried out in which the proposed model is applied. The applicability of the proposed model is confirmed through a comparison between the experimental and analytical results. Also, another series of numerical simulations is carried out to investigate the effect of drainage path length on the consolidation behavior of quasi-overconsolidated clays in the range of stress lower than p_c. As the results, it is concluded that the proposed model can reasonably express the compression behavior of Pleistocene clays in Osaka Bay.

1 INTRODUCTION

The seabed deposits in Osaka Bay are composed of the sand or sandy gravel layers and thick clay layers which are cumulated alternately. The formation of 14 thick marine clay layers (Ma0 ~ Ma13) was established through geological research works. Ma13 is the uppermost layer near the seabed and Holocene origin, whereas the other clay layers are Pleistocene origin. It has been elucidated that the consolidation yield stresses, p_c, of these Pleistocene clays are higher than the current overburden pressures, p_0, although the clays have never been applied higher pressure than p_0, judging from the geological findings. In that sense, these clays have been called "quasi-overconsolidated clay" (Akai and Sano, 1981). 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, a 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 re-constituted clays. Especially, the slope of curve between creep strain and logarithmic time becomes gentle with the elapsed time in the long-term consolidation tests (Rito et al 2004, Tanaka et al 2004, Tanaka 2005). Furthermore, based on the field measurements, significant residual settlements of reclaimed lands and man-made islands have occurred, although the applied pressure due to reclamation is lower than p_c (Matsui et al, 2001). It is very difficult to express such distinctive consolidation behaviors through the conventional mechanical models already proposed.

The authors have developed a mechanical model which can express such distinctive consolidation characteristics of quasi-overconsolidated clays as above-mentioned (Oda and Matsui, 2004, 2005, Oda et al, 2005). It has been found that the linear relationship between void ratio and logarithmic vertical effective stress is not valid in order to express time-dependent compression behavior of quasi-overconsolidated clays in the range of stress from p_0 to slightly over p_c through their works. Also, they pointed out that the secondary consolidation behavior plays a key role in long-term consolidation behavior of the Pleistocene clay layers.

In this paper, firstly, an elasto-viscoplastic one-dimensional consolidation model is proposed for expressing the time-dependent secondary consolidation behavior of the quasi-overconsolidated clays in the range of stress from p_0 to slightly over p_c. The proposed one-dimensional consolidation model is based on both the subloading surface theory and the flow surface theory. Secondly, the numerical simulation of long-term consolidation tests of Ma3 clay, one of Pleistocene clays in Osaka Bay, is carried out in order to confirm the applicability of the proposed model to the time-dependent compression characteristics of quasi-overconsolidated clays. Then, the effect of drainage path length on the long-term consolidation behavior of quasi-overconsolidated clays in the range of stress lower than p_c is investigated through another series of numerical simulations. Finally, the availability of the model proposed for predicting the consolidation behavior of the Pleistocene clay layers is discussed.

2 COMPRESSION CURVE BASED ON SUBLOADING SRUFACE THEORY

The subloading surface theory has been proposed, in order to express the loading/unloading behavior of elasto-plastic material (Hasiguchi, 1989). Based on this theory, a smooth transition from elastic state to plastic state can be expressed. Applying this theory to one-dimensional consolidation behavior of clays, the normal yield stress, p'^*, is defined as the following equation:

$$p'^* = \frac{p'}{R} \tag{1}$$

where p' is the vertical effective stress at current state. R is called the “normal-yield subloading surface size ratio”. As shown in Figure 1, it is assumed that p'^* moves on the linear