CONSOLIDATION CHARACRACTERISTICS FOR SRI LANKAN AND JAPANESE CLAYS: VOID INDEX IN RELATION TO STRESS STATES AND SEDIMENTATION ENVIRONMENT

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Abstract: It is well known that cementation/aging and sedimentation environment affect significantly a compressibility of natural clays. In this study, one-dimensional consolidation curves (e-log p) have been measured using a standard oedometer test for several Sri Lankan and Japanese clays with different sedimentation environment (i.e., freshwater and marine sediments). The void index proposed by Burland (1990) was used to analyze the measured cosnsolidation curves. As a result, void index of marine sediments is higher than that of freshwater sediments and drastically decrease after consolidation yield stress. On the other hand, void index of Sri Lankan clays is quite low and gently narrow as increase consolidation stress. That indicates the Burland's void index well characterized the effects of sedimentation enviroments on the consolidation characteristics of clays.

Keywords: clay, consolidation, sedimentation environment, void index, cementation

1 Introduction

A compressibility of the soils is one of important geotechnical properties which is highly affected by fabric (arrangement of particles) and interparticle bonding. The structure of natural clays (i.e., fabric and bonding) depends on many factors such as depositional conditions, aging, cementation, and leaching. The compressibility of reconstituted clays can be used as a framework for interpreting these structural features for the corresponding properties of natural clays.

In this study, one-dimensional consolidation curves (e-log p) have been measured using a standard oedometer test for several Sri Lankan clays and Japanese clays in Kanto alluvial lowland with different sedimentation environment (freshwater and marine sediments). The void index proposed by Burland [1] was used to characterize the compressibility, stress state, and structure of natural clays.

2 Sample and Method

2.1 Sample

Soil samples were taken from three points in Kanto alluvial lowland, Japan: Kasukabe and Toda in Saitama, and Kameido in Tokyo, Japan (Figure 1). The samples were taken from the depth of 7 m down to 32 m. The sedimentation environments for Japanese clays are tabulated in Table 1. For each site, sediments were deposited under either freshwater or marine sediments. In addition to the measurements for Japanese clays, data for soil samples from various sites in Sri Lanka were used in this study. The Sri Lankan soil samples were mostly taken from relatively shallow layers less than 3 m depth. Basic soil physical properties for Japanese and Sri Lankan were also shown in Table 1 and Table 2. The Japanese marine sediments showed higher water content compared to that for freshwater sediments and Sri Lankan clays. In addition, water content of all marine sediments was higher than liquid limit. On the other hand, the values of liquid limit for the Sri Lankan clays are similar to Japanese clays, but higher than water content.

2.2 Methods

A standard oedometer test was performed according to JIS (Japanese Industrial Standards) A-1217 with a standard cell (6 cm in inner diameter and 2 cm in height) for Japanese undisturbed soils. The load is doubled at each increment until reaching the maximum required load (1256 kPa). The duration of the application of each load was 24 hr. The data for consolidation curves for Sri Lankan soils were also obtained by the oedometer test with maximum load from 314 to 781 kPa.

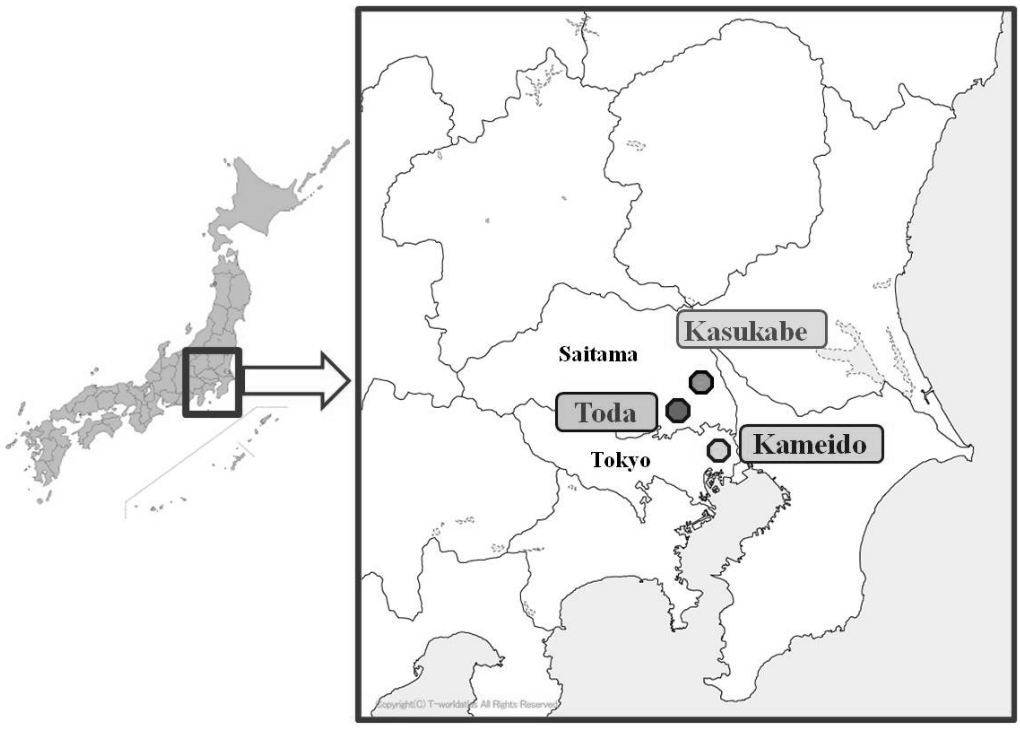

Figure 1: *Sampling site of Japanese soil [2]*

Table 1: *Sedimentation environments and basic soil physical properties (Japanese)*

depth(m)	sedimentation environment	w_n(%)	w_L(%)	G_s(g/cm^3)	e_L	e_{100}^*	C_c	C_c^*
KASUKABE								
7	Freshwater	61.4	56.2	2.63	1.480	0.971	0.49	0.34
9	Freshwater	64.9	50.1	2.68	1.341	0.898	0.59	0.30
11	Marine	90.6	78.3	2.67	2.092	1.286	1.12	0.50
15	Marine	94.6	76.8	2.64	2.027	1.253	1.39	0.48
21	Marine	82.4	75.8	2.57	1.949	1.213	1.09	0.46
27	Marine	88.6	75.3	2.64	1.986	1.232	0.91	0.47
31	Freshwater	46.1	48.1	2.61	1.254	0.852	0.82	0.28
TODA								
9	Freshwater	41.5	42.3	2.70	1.141	0.792	0.34	0.25
12	Marine	49.2	39.5	2.69	1.064	0.750	0.42	0.23
16	Marine	81.0	69.5	2.73	1.889	1.783	0.82	0.45
19	Marine	47.1	43.2	2.68	1.158	0.801	0.47	0.26
22	Freshwater	37.4	37.4	2.74	1.026	0.729	0.36	0.22
KAMEIDO								
9	Freshwater	48.9	42.3	2.71	1.144	0.793	0.43	0.25
12	Freshwater	41.9	34.7	2.71	0.938	0.681	0.34	0.20
17	Marine	62.3	49.6	2.69	1.336	0.895	0.63	0.30
21	Marine	67.5	56.4	2.65	1.495	0.978	0.73	0.34
27	Marine	81.8	73.4	2.65	1.945	1.211	1.07	0.46

w_n is a natural water content, w_L is a liquid limit, G_s is a specific gravity, e_L is a void ratio at liquid limit, C_c is a consolidation index, respectively.

Table 2: *Basic soil physical properties (Sri Lanka)*

Sampling Place	depth(m)	w_n(%)	w_L(%)	G_s(g/cm^3)	e_L	e_{100}^*	C_c	C_c^*
Court Complex (Nawalapitiya) 1	1.1	23.7	55.0	2.60	1.430	0.945	0.30	0.33
Court Complex (Nawalapitiya) 2	1.0	33.6	65.0	2.60	1.690	1.080	0.21	0.39
Court Complex (Nawalapitiya) 3	1.0	33.9	66.0	2.60	1.716	1.093	0.20	0.40
University of Peradeniya 1	3.4	25.0	57.0	2.60	1.428	0.972	0.28	0.34
University of Peradeniya 2	2.4	22.3	49.0	2.60	1.274	0.863	0.22	0.29
Ulapane 1	2.0	31.6	65.0	2.60	1.690	1.080	0.18	0.39
Ulapane 2	2.0	17.5	57.0	2.60	1.482	0.972	0.17	0.34
Ulapane 3	2.5	20.9	52.0	2.60	1.352	0.904	0.17	0.31
Katugastota	1.3	18.9	36.0	2.60	0.936	0.680	0.15	0.20
Nawalapitiya	2.0	43.6	69.0	2.60	1.794	1.133	0.33	0.42

3 Void Index

The void index proposed by Burland [1] was used to analyze the measured cosolidation curves. Void Index (I_v) can be defined as following equation (Eq. (1)).

$$I_V = \frac{e - e_{100}^*}{C_C^*} \quad (1)$$

where e is the void ratio for the undisturbed samples, e_{100}^* and C_c^* are the void ratio and consolidation index for the corresponding reconstituted samples at 100 kPa, respectively. In this study, due to lack of data for consolidation curves for reconstituted samples, the following relations (Eq. (2) and Eq. (3)) proposed by Burland [1] were used.

$$e_{100}^* = 0.109 + 0.679e_L - 0.089e_L^2 + 0.016e_L^3 \quad (2)$$

$$C_C^* = 0.256e_L - 0.04 \quad (3)$$

where e_L is the void ratio at the liquid limit.

As shown in Figure 2., Burland [1] have found consistent relations between I_v and effective stress for the clay that have been reconstituted at a water content of between w_L and 1.5 w_L (preferably 1.25 w_L), called intrinsic compression line (ICL). Consistent relation between I_v and effective stress have been also reported for several marine clays (the data from Skenmpton [3]), called sedimentation compression line (SCL) [1].

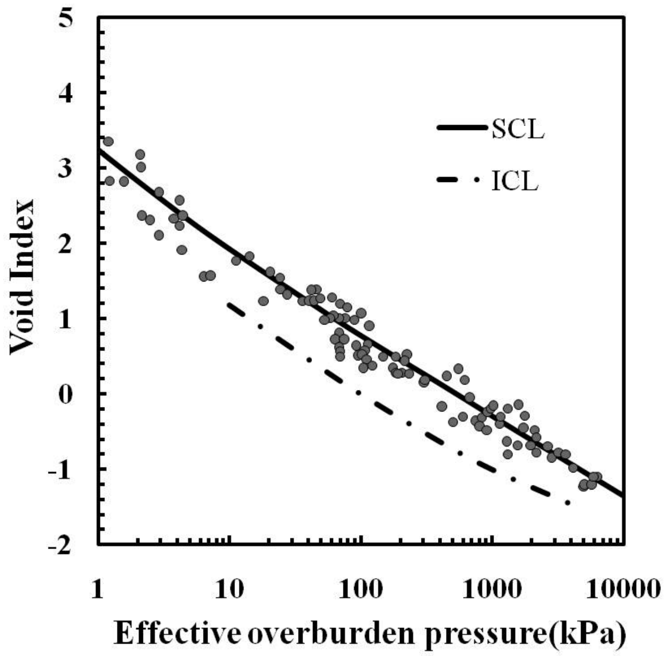

Figure 2: *Normalized compression curves for several clays (from Skempton [3]) in showing the intrinsic compression line (ICL) and sedimentation compression line (SCL) (from Burland [1])*

4 Results and Discussion

4.1 C_c and liquid limit

Figure 3 shows relation between consolidation index (C_c) and liquid limit for marine clay sediments of Tokyo bay and Osaka bay, Japan, reported by Tsuchida [4]. The measured data of this study and relation between C_c and liquid limit proposed by Terzaghi and Peck [5] (Eq. (4)) and Ogawa and Matsumoto [6] (Eq. (5)) are also plotted in the Figure 3.

$$C_C = 0.009(w_L - 10) \tag{4}$$

$$C_C = 0.015(w_L - 15) \tag{5}$$

For both literature and measured data for Japanese clays, the C_c values linearly increased with increasing the liquid limit. However, the measured data showed relatively higher C_c values especially for marine sediments at the same liquid limit as compared to the literature data. It suggests higher compressibility of marine sediments used in this study (taken from three alluvium lowland sites located at 10 km~40 km far from Tokyo bay) possibly due to a salt leaching. In contrast, Sri Lankan clays showed much lower C_c values than Japanese soils and Eq. (4). Furthermore the value of C_c of all Sri Lankan clays is lower than C_c^*.

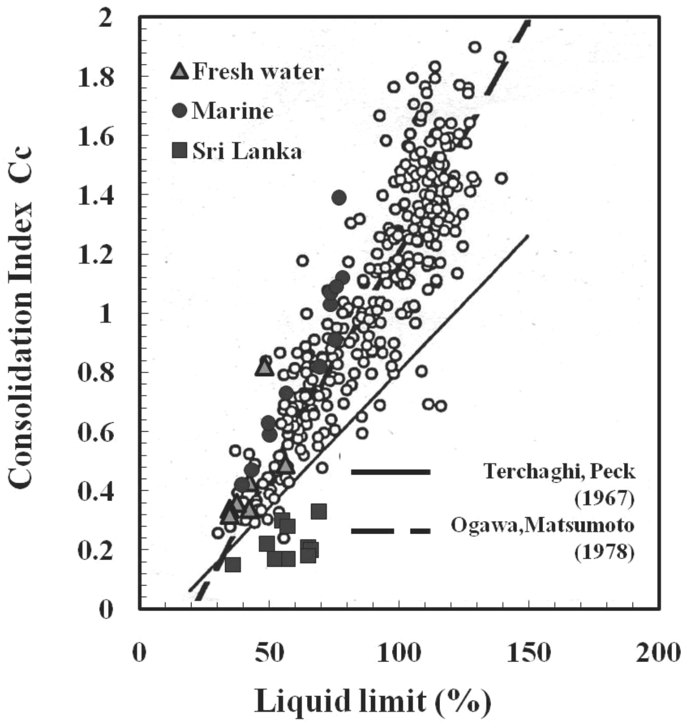

Figure 3: *Relation between consolidation index and liquid limit data in present study is added to data from Tsuchida [4]*

4.2 e-log p and Iv-log p curve

The e-log p (p: pressure, kPa) and I_v-log p curves for Japanese clays (Kasukabe) and Sri Lankan clays are shown in Figure 4 and Figure 5, respectively. Figure 4 (a) shows that marine sediments for Japanese clays showed higher e values than those for freshwater sediments, and the e values drastically decreased after consolidation yield stress (i.e., higher C_c). I_v-log p curves for both marine and freshwater sediments approached SCL after the consolidation yield stress. However, generally higher I_V values for the marine sediments were observed under variable pressure conditions, indicating the well-developed fabric likely represented by edge-to-face orientation of clay particle.

In Figure 5 (a), the e values of almost Sri Lankan clays and I_v-log p curves were quite lower than those of Japanese clays. In addition, some samples indicated different trend between e-log p curve and I_v-log p curve. For example, e-log p curve of Nawalapitiya is similar to that of other sample but I_v-log p curve of it is much higher than that of other Sri Lankan clays. This result suggests I_v can describe consolidation characteristics clearly.

I_v-log p curves of many Sri Lankan clays show similar trend as the ICL (Figure 5 (b)). It suggests poor fabric for Sri Lankan clays expected by some reasons. For example, Sri Lankan soil was deposited at inland area (i.e., under freshwater environment), Sri Lankan clays were taken from shallow sediments, so their samples indicated high over consolidation ratio. Furthermore, Sri Lankan clays have low water content indicating higher sand content than Japanese clays.

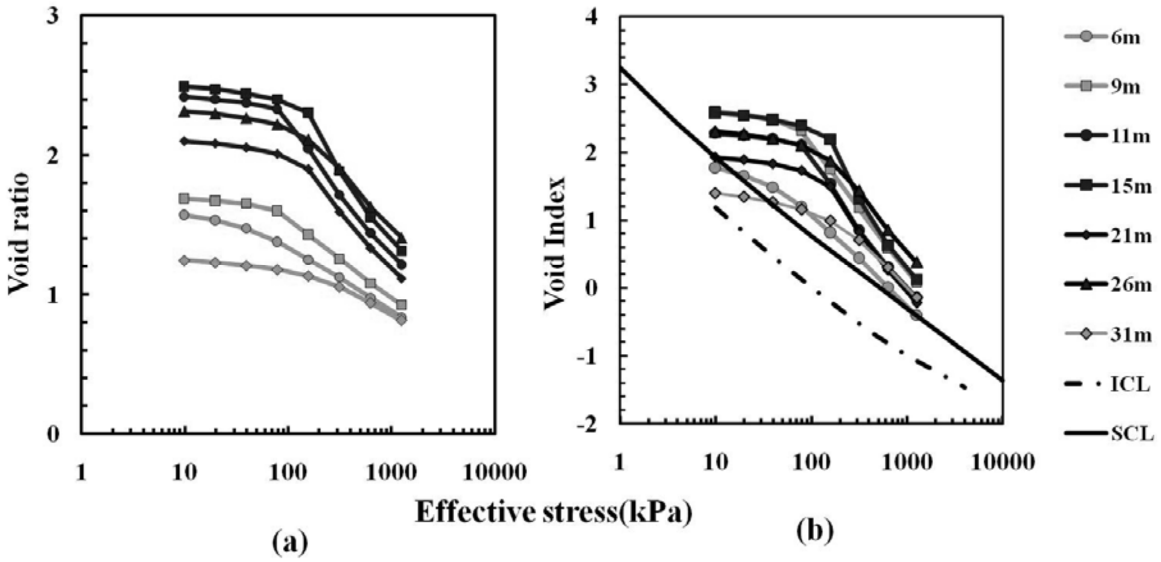

Figure 4: *(a) e-log p curve. (b) I_v-log p curve in Japanese clays (Kasukabe)*

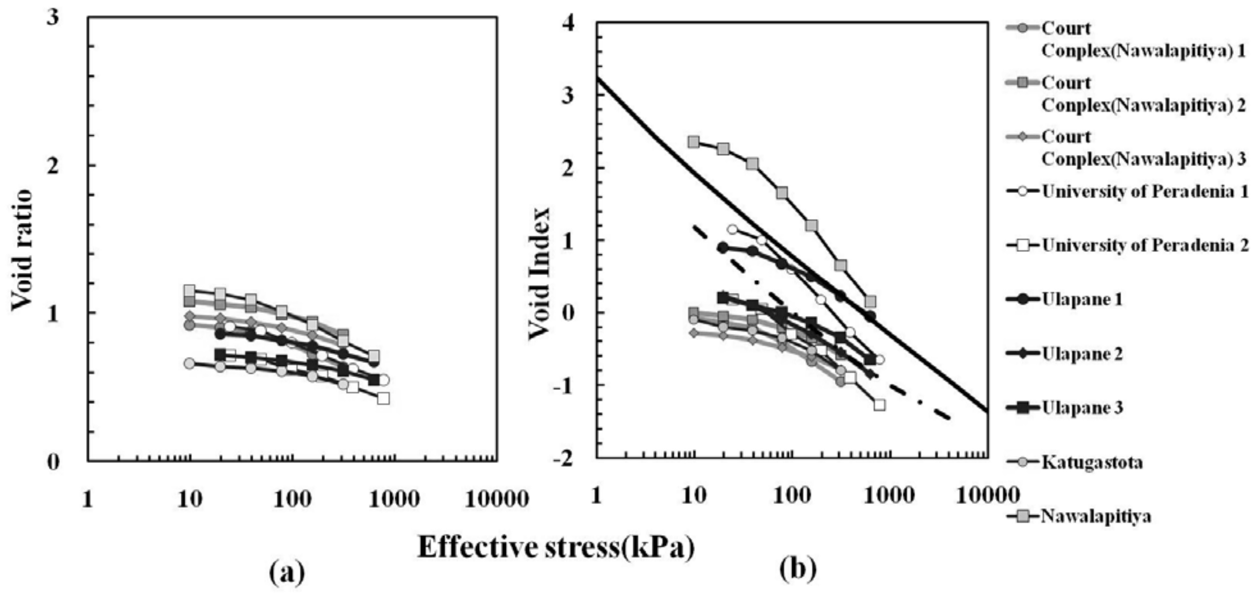

Figure 5: *(a) e-log p curve. (b) I_v-log p curve in Sri Lankan clays*

5 Conclusions and Future work

In this paper, the effect of sedimentation environment on consolidation characteristics is described by using void index (I_v). Then, some findings are shown as follows.

1. Cc values linearly increased with increasing the liquid limit, especially compressibility of marine sediments are higher than freshwater sediments. It suggests higher compressibility of marine sediments used in this study possibly due to salt leaching.
2. Marine sediments for Japanese clays showed higher I_v values than freshwater sediments for Japanese clays. In contrast, I_v values of most of Sri Lankan clays were quite lower than those of Japanese clays. It can be considered that the difference of sedimentation environment and soil

characteristics (liquid limit, water content, over consolidation ratio, sand content) which make difference of degree of fabric, has caused the difference of consolidation characteristics.

In this study, to compute void index for each samples, e_{100}^* and C_c^* are calculated by equation (Eq. (2) and Eq. (3)). To show relation "intrinsic" and "sedimentation" in consolidation characteristic explicitly, it is necessary to obtain consolidation curve of reconstituted samples, and determine e_{100}^* and C_c^* experimentaly.

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