

Characterization of geotechnical properties as affected by sediment environment in Kanto lowland clays in Japan

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Abstract: *The purpose of this study is to investigate effects of sedimentary environment (freshwater and marine deposits) on geotechnical properties for Kanto lowland clays. Freshwater and marine sediments were used to perform standard consolidation tests, undrained triaxial compression tests, and unconfined compression test. Pore-water compositions were also measured for the sediments. As results, higher compression index, higher sensitivity, and lower shear strength ratio were observed for the marine sediments as compared to those for the freshwater sediments. In addition, the measurements of pore-water compositions revealed that the sensitivity values were well related to the proportion of monovalent cations, especially for the sediments with plastic index of less than 30.*

Keywords: *geotechnical properties, sedimentary environment, pore-water composition*

1. INTRODUCTION

It is well known that differences in structure of clays (i.e., fabric and bonding) affect the geotechnical properties such as a compressibility or sensitivity. The structure of natural clays highly depends on the sedimentary environments since the depositional geochemistry and deposition rate contribute to the fabric (arrangement of particles) and interparticle bonding.

In this study, geotechnical properties including Atterberg limits, compression index, undrained shear strength, and sensitivity for alluvial clays in Kanto lowland with different sedimentary environment were measured. In addition, ion compositions in pore water were also measured to characterize the sedimentary environment and the relations between ion compositions and geotechnical properties were also investigated.

2. MATERIALS AND METHODS

2.1. Study Site

The samples used in this study were taken at Kasukabe (Bigohigashi, Kasukabe-city, Saitama) and Kameido (Koto-ku, Tokyo) in Japan. Kasukabe and Kameido sites are located in Nakagawa lowland and Tokyo lowland, respectively. The sample cores of the latest Pleistocene to Holocene sediments up

to 50 m depth were drilled at both sites.

2.2. Measurements of Physical, Chemical, and Mechanical Properties

The core samples were used for the measurements of physical, chemical, and mechanical properties. The particle size distribution was measured by a sieving and hydrometer method. The soil pH and EC (EC, mS m^{-1} : electrical conductivity) were measured in a 1:2.5 and 1:5 (by weight) mixture of soil and distilled water, respectively.

The compressibility (i.e., compression index) of the sediments was investigated by a standard oedometer test. The undisturbed and remoulded shear strengths were determined by the unconfined compression test using the specimen with 5 cm of diameter and 10 cm of height. The sensitivity value of some samples, where remoulded shear strengths could not be measured since the specimen did not stand, were defined as infinity in this study. Undrained triaxial compression test (\overline{CU}) was also performed according to JGS (Japanese Geotechnical Society) 0523 for undisturbed soils using the cylinder specimen (i.d. 5 cm, height 10 cm).

The pore water was extracted by a direct extraction method where the samples of around 300 g were squeezed by centrifugation at different rotation speeds (8000 rpm). The extracts were used for measuring ion concentration. Cations of Na^+ , K^+ , Ca^{2+} , and Mg^{2+} were measured by an atomic absorption spectroscopy and anions of Cl^- and SO_4^{2-} were measured by an ion chromatograph, respectively, following JIS K-0102.

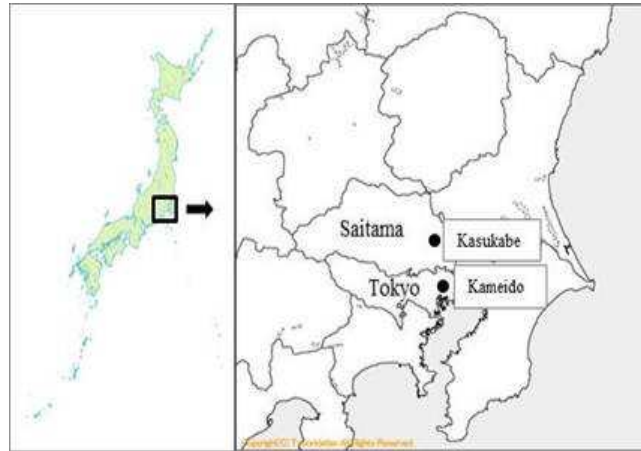


Figure 1 Sampling site

2.3. Monovalent / Divalent Ion Ratio

Gapon's equation was used to investigate the effects of proportion of cations monovalent and divalent in the pore water on mechanical properties. The Gapon's equation can be expressed as below.

$$\frac{M_e}{D_e} = k \frac{M_0}{\sqrt{D_0}} \quad (1)$$

where M_0 and D_0 are molar concentration of the monovalent, divalent cations in the free pore water, M_e and D_e are the exchangeable monovalent, divalent cation in meq/100g of air dry soil, k is Gapon's constant (depends on soil type).

Eq. (1) suggests that a plot of $M_e / \sqrt{D_e}$ with depth would indicate a variation of the monovalent / divalent ion ratio in the exchange complex of the pore water provided the soil type is constant with depth (i.e., constant k value with depth). In this study, the monovalent / divalent ion ratio in the soil has been calculated according to Eq. (2).

$$\frac{M_0}{\sqrt{D_0}} = \frac{\text{Na}^+ + \text{K}^+}{\sqrt{\text{Ca}^{2+} + \text{Mg}^{2+}}} \quad (2)$$

where Na^+ , K^+ , Ca^{2+} , and Mg^{2+} were measured monovalent and divalent concentrations.

3. RESULTS AND DISCUSSION

3.1. Physical and Chemical Properties

The sedimentary facies, variation of physical and chemical properties with depth at Kasukabe and Kameido sites are shown in Figures 2 and 3, respectively. For both sites, the sediments were deposited under either freshwater or seawater respectively. Based on the previous studies (Miyachi et al., 2004; Nakanishi et al., 2011) sedimentary facies, the sediments for Kasukabe site at the depth ranging from 7 to 27 m and Kameido site at the depth below 9m were classified as marine sediments.

The marine sediments in Kasukabe showed higher natural water content and void ratio as compared to those for freshwater sediments. The natural water content and void ratio in Kameido increased with depth. The marine sediments at both sites generally showed higher natural water contents than liquid limits, resulting in higher liquidity index more than 1.0. The silt and clay are dominant for the sediments at Kasukabe site, while the shallow samples (less than 18 m) at Kameido site contained more than 15% of sands. The pH values for Kasukabe and Kameido samples varied from 6.5 to 9.4 and 8.2-9.2, respectively. Especially, the marine sediments for both site showed higher pH value. In addition, relatively higher EC values more than 50 (mS m^{-1}) were observed for marine sediments at Kasukabe site as compared to fresh-water sediments below 27 m.

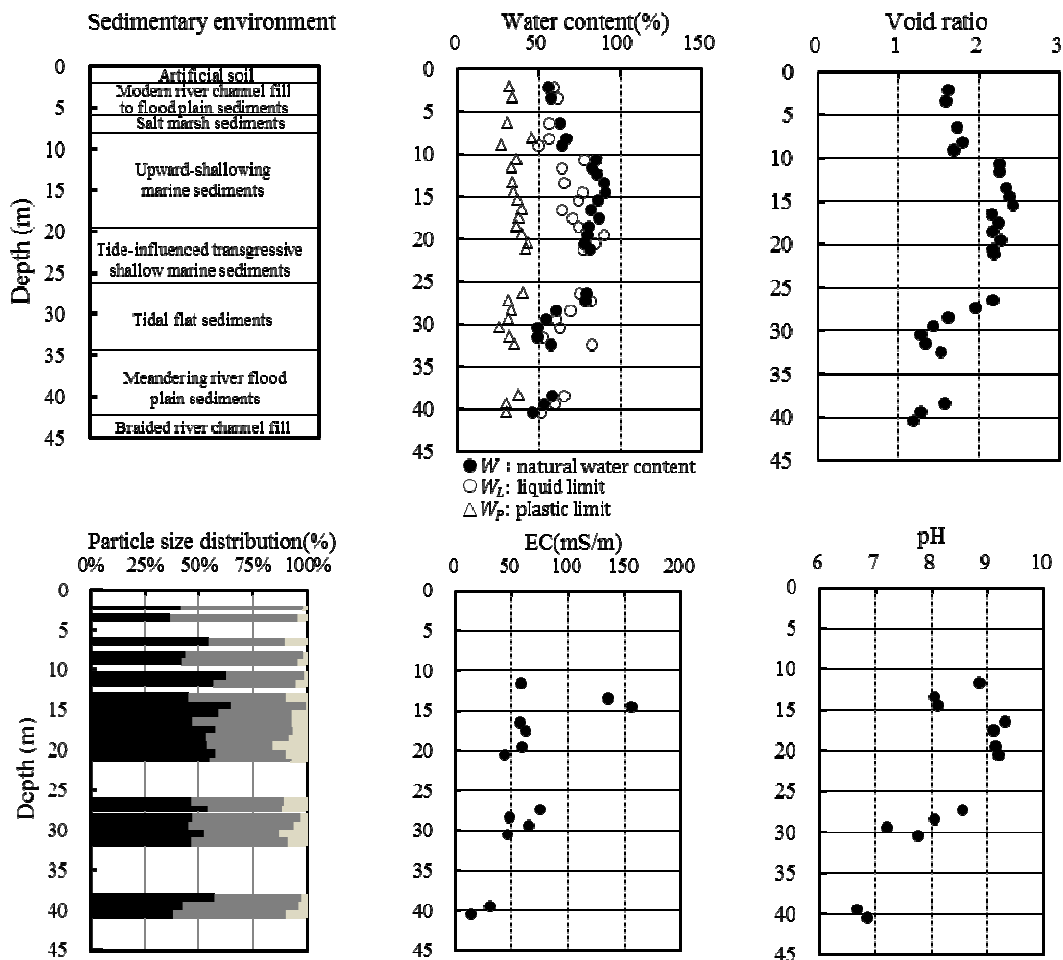


Figure 2 Sedimentary facies, variation of physical and chemical properties with depth at Kasukabe.

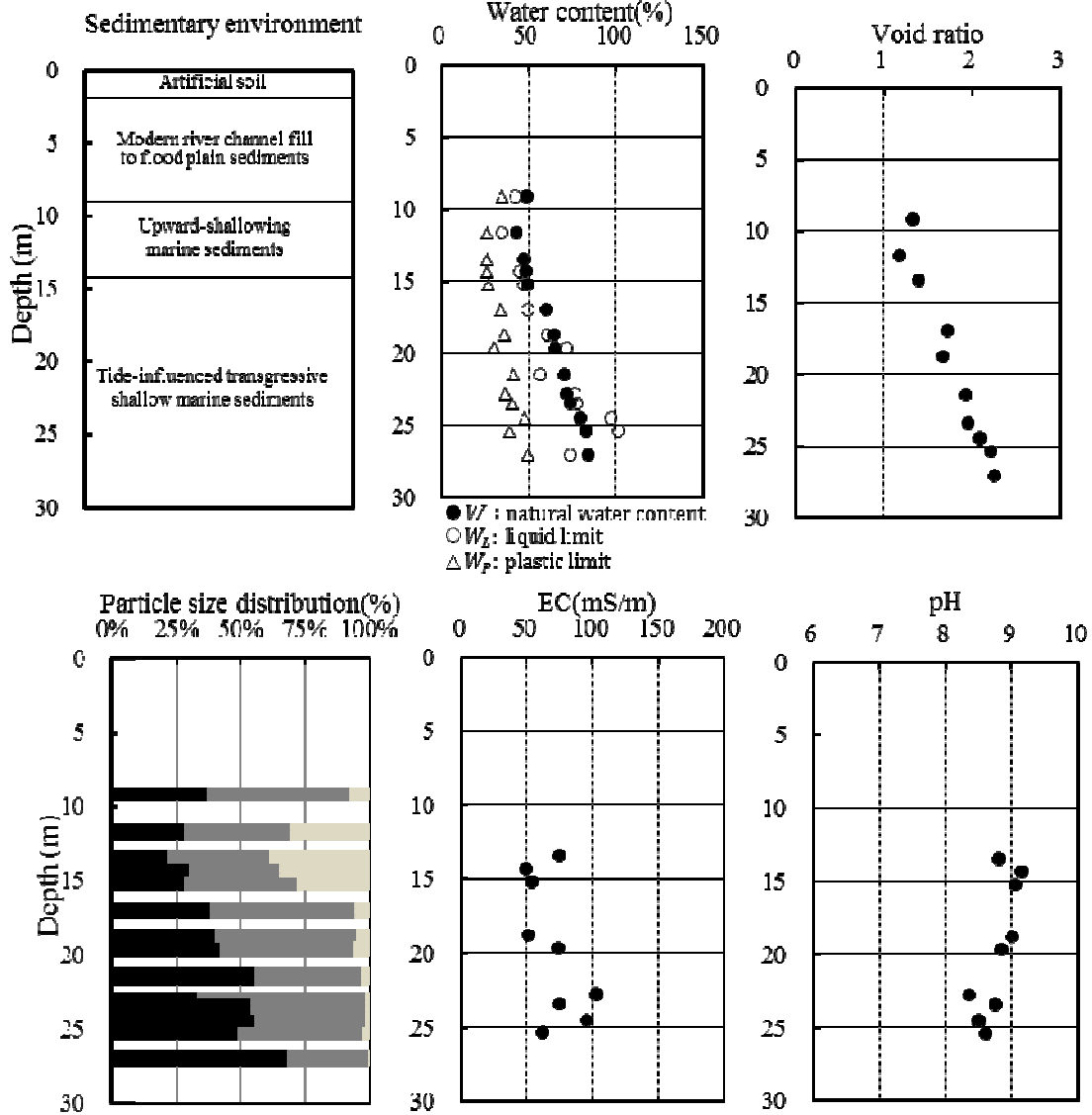


Figure 3 Sedimentary facies, variation of physical and chemical properties with depth at Kameido.

Figure 4 shows pore-water chemistry in the Kasukabe and Kameido sediments. For cation concentration profiles at both sites, Na^+ showed highest percentage in the pore water, followed by Ca^{2+} , K^+ , and Mg^{2+} . The ion concentrations, especially Na^+ concentration, in marine sediments were higher than those for freshwater sediments, supporting higher EC values for the marine sediments. For anion concentration profiles, higher SO_4^{2-} values than Cl^- were observed for the sediments at both sites, suggesting that the oxidation of the pyrites (FeS_2) which are generally contained in the marine sediments caused the formation of sulphuric acid. To support this, a clear relation between SO_4^{2-} and pH was observed for the marine sediments. In addition, the average Cl^- concentration (0.01 N) at both sites were around 1/50 of the one for the sea water, indicating the marine sediments were affected by the leaching of the pore water.

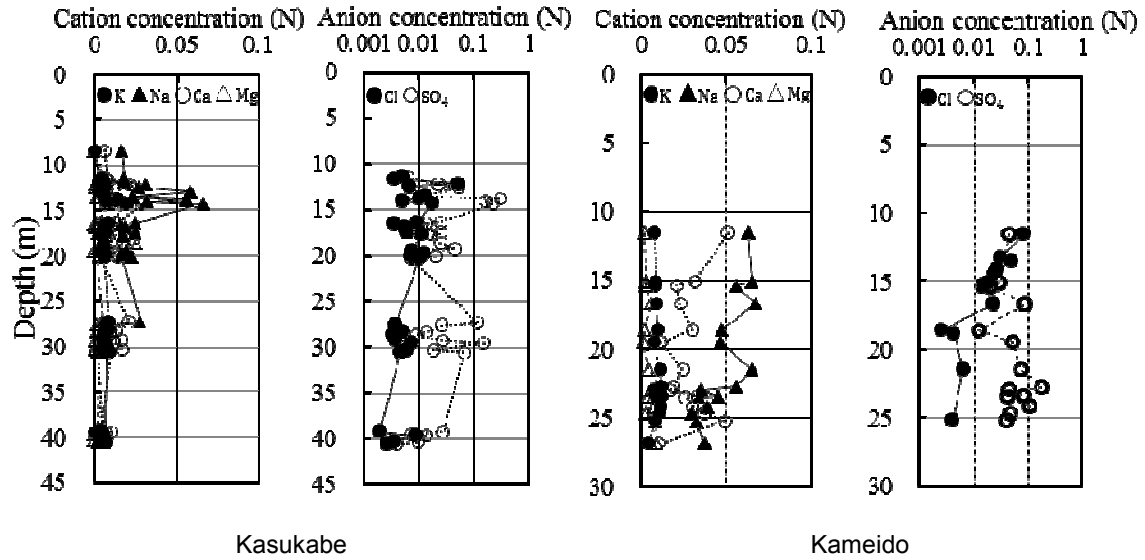


Figure 4 Pore-water chemistry in the Kasukabe and Kameido sediments.

3.2. Consolidation Properties

Figure 5 shows measured consolidation index (C_c) with depths for the sediments at both sites. As a literature data (Yamamoto, 2000), the C_c data at Oshima (a site around 2 km far from Kameido) was also added into Figure 5. The C_c at freshwater sediments was around 0.5, while the marine sediments exhibited significant higher C_c values of around 1.0. The results indicate that well-developed fabric likely represented by edge-to-face orientation of clay particles is formed for marine sediments due to the sedimentation under high salinity.

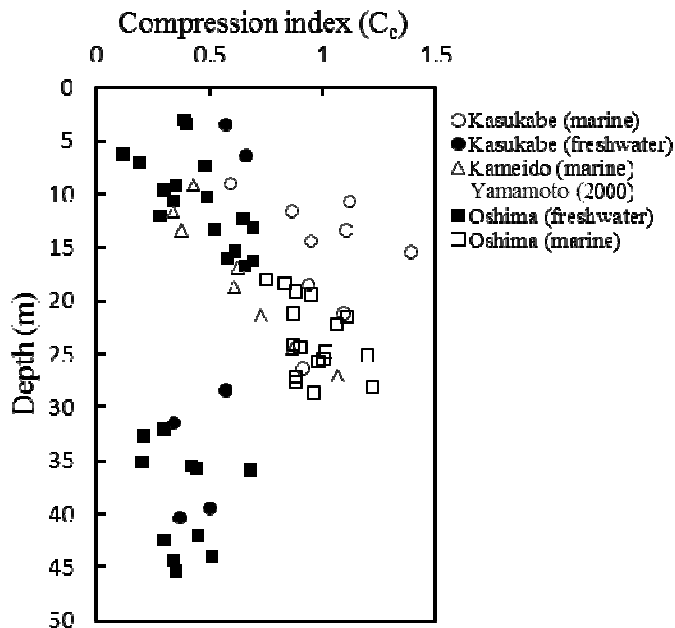


Figure 5 Consolidation index (C_c) with depth.

3.3. Shear Strength Properties

3.3.1. Undrained triaxial compression test ($\bar{C}U$)

Figure 6(a) shows the deviator stress and excess pore-water pressure against an axial strain for the marine (20 m depth) and freshwater (28 m depth) sediments at Kasukabe site. As examples shown in Figure 6(a), the excess pore-water pressure relative to the maximum deviator stress more significantly increased for the marine sediments as compared to one for the fresh water sediments. To support this, Skempton's pore water pressure coefficient (A_f) was generally higher for the marine sediments, showing A_f values more than 0.70. On the other hand, the A_f values for the freshwater sediments were less than 0.65. Figure 6(b) shows relation between undrained shear strength and consolidation pressure for the sediments at Kasukabe site. Undrained shear strength was increased with increasing consolidation pressure. The shear strength ratio was higher for the freshwater sediment than marine sediment, exhibiting the ratio of 0.56 and 0.36 for the freshwater and marine sediments, respectively. Again, this difference in shear strength characteristics in freshwater and marine sediments is probably attributed to the difference in the soil structure for each sediment where the marine sediments have well-developed more porous soil structure.

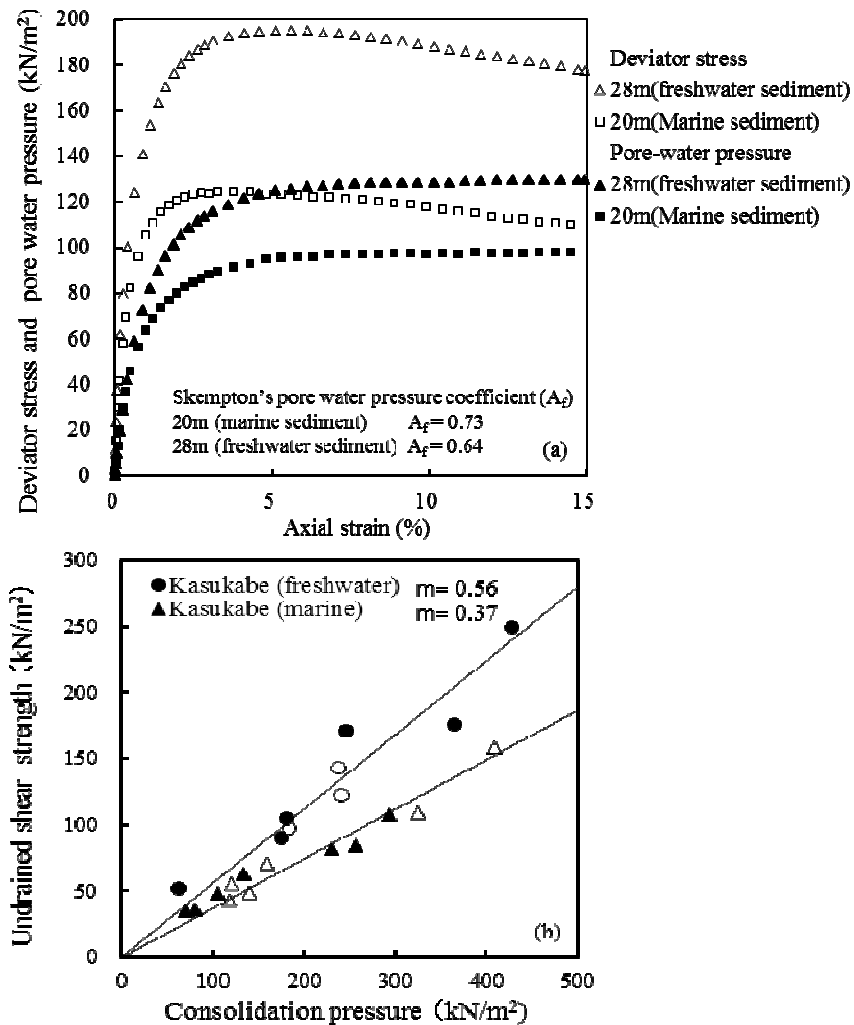


Figure 6 (a) Deviator stress and excess pore-water pressure against an axial strain and (b) Shear strength ratio for Kasukabe sediments. Open plots in Fig. 6(b) represent the samples which were consolidated at 1.5 to 3.0 times of in-situ effective stress.

3.3.2. Unconfined compression test

Measured unconfined compression strength for the undisturbed sediments and calculated sensitivity, which is the ratio of undisturbed to remoulded strength at the same water content, for the sediments at both sites with different depths are shown in Figures 7(a) and 7(b), respectively. Unconfined compression strength increased with depth. Hence, the effects of sedimentary environment on the unconfined compression strength was not clearly observed. However, higher sensitivity values were observed for the marine sediments. Especially, the marine sediments at Kasukabe site with higher silt and clay contents than those at Kameido site showed significantly higher sensitivity values.

Figure 8 shows the relation between sensitivity and proportion of cations in the pore water. The sensitivity of the sediments with plastic index of less than 30 at both Kasukabe and Kameido sites increased with increasing the proportion of monovalent cations. Higher sensitivity for the sediments with higher proportion of monovalent cations suggests that degree of repulsion between clay particles, highly affected by pore-water composition, contributed to the compression strength for the remoulded specimens.

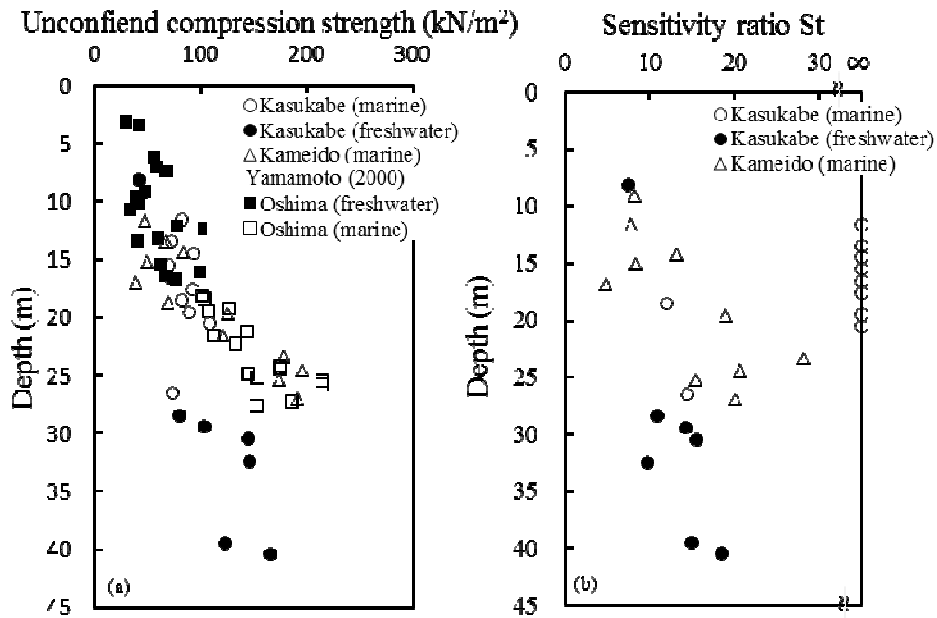


Figure 7 (a) Unconfined compression strength and (b) sensitivity with depth.

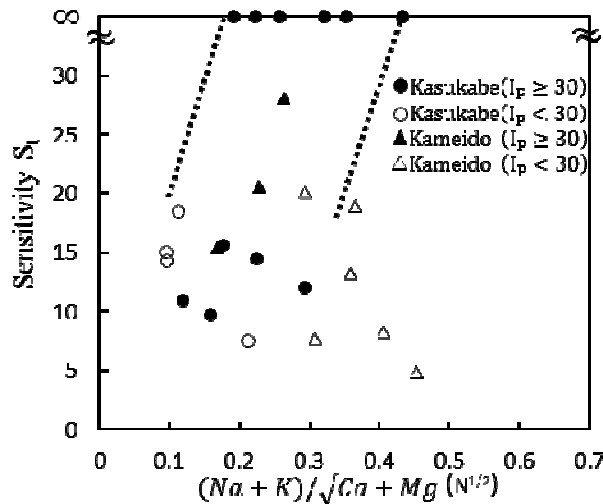


Figure 8 Sensitivity as a function of $M_0/\sqrt{D_0}$

4. CONCLUSIONS

In this paper, geotechnical properties of alluvial clays affected by sedimentary environment are characterized with geochemical investigations of pore-water compositions. The findings are as follows;

- (i) Higher C_c values were observed for the marine sediments than those for fresh-water sediments at Kasukabe and Kameido sites.
- (ii) Shear strength ratio was higher for the freshwater sediment. The difference in the fabric of the marine and freshwater sediments might affect the compressibility and shear characteristics.
- (iii) Unconfined compression strength for the undisturbed samples increased with depth and the effects of sedimentary environment on the compression strength were not clearly observed.
- (iv) Sensitivity for the marine sediments was higher than freshwater sediments. In addition, the sediments with higher proportion of monovalent cations and plastic index of less than 30 showed higher sensitivity values for both Kasukabe and Kameido sites.

5. ACKNOWLEDGMENTS

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