Change of mechanical properties of the cement mixed marine clay under seawater

Daisuke Suetsugu i), Hiroyuki Hara ii) and Suman Manandhar iii)

i) Associate Professor, Institute of Lowland and Marine Research, Saga University, 1, Honjo, Saga 840-8502, Japan.
ii) Assistant Professor, Graduate School of Science and Engineering, Yamaguchi University, 2-16-1, Tokiwadai, Ube, 755-0097, Japan.
iii) Guest Associate Professor, Institute of Lowland and Marine Research, Saga University, 1, Honjo, Saga 840-8502, Japan.

ABSTRACT

This paper focuses the mechanical properties of the deteriorated cement mixed marine clay when immersed in seawater. Series of shear box tests were conducted maintaining the constant volume for the deteriorated cement mixed Ariake clay. The deteriorated specimen was prepared immersing into the artificial seawater simulated in the laboratory for 630 days. Authors compared the change in mechanical properties of the deteriorated specimen with the non-deteriorated cement mixed clay together with remolded Ariake clay. The deterioration of specimens with intrusion of simulated seawater increases compressibility which is associated entirely with the presence of cement at the beginning of the experiment. The deterioration decreased the shear strength of the cement mixed marine clay. The strength of deteriorated cement mixed marine clay dissolved by calcium is almost equal to that of the remolded Ariake clay.

Keywords: cement mixed marine clay, deterioration, shear strength, seawater

1. INTRODUCTION

The coastal lowland area with very soft and thickly deposited clay layers have been practiced with ground improvement techniques to prevent the ground failure and extreme subsidence surcharged by structural loads. In recent years, deep mixing has becoming one of the most adopted ground improvement methodology. It has been noticed that layers of tidal river levees treated with quick lime 25 years ago on very soft clay ground has been identified with leakage from lime mixed clay layer which has subjected to muddy environment. These phenomena especially occurred much more near the river mouth. Authors considered that salts which were included in the tidal river water affected the lime mixed clay (Hara, 2008) which seem to cause unfavourable subsidence of upper structures and reduce the stability. Previous researches for these types of seawater influences, deterioration and durability are considered to be very few (Kamon, 1999, Hayashi, 2004). Authors have studied the cause of leaking of the lime mixed clay applied in the coastal area which has altered into muddy environment. Authors have already assessed the cause that the magnesium present in groundwater has accelerated to replace calcium in the form of the calcium leaching from the hydration in the lime mixed marine clay. As a result, the lime mixed clay has become very soft (Hara, 2013).

In near future, the sea level rise can be anticipated with the global warming which may increase not only the sea level but also the groundwater level in the coastal area of lowlands. This will result in increase in salt concentration of groundwater and will be a supplement to the tidal river.

Mechanical characteristics and mechanism of deterioration process need to be clarified for evaluating the stability and long-term durability of the earth structure having improved soil layers and ground. However, there are very few research related to deterioration or durability of the mixed soil. In order to investigate the mechanical properties of the deteriorated cement mixed clay immersed in seawater, Series of shear box tests were conducted for the deteriorated cement mixed marine clay. In this paper, the change of compressibility and shear strength of the mixed clay are demonstrated and discussed the effects of seawater on the cement mixed clay properties with comparison to that of non-deteriorated cement mixed clay and non-treated Ariake clay.

2 EXPERIMENTS

2.1 Samples

In this research, Ariake clay was taken into consideration from the mouth of the tidal river in Saga prefecture (Table 1). Ordinary Portland cement was incorporated as a stabilizer and water content of the Ariake clay was adjusted to be 1.5 times its liquid limit.
Table 1. Physical property of Ariake clay.

| Property          | Value         |
|-------------------|---------------|
| Particle density, \( \rho_s \) (g/cm³) | 2.65          |
| Liquid limit, \( w_L \) (%)          | 158.1         |
| Plastic limit, \( w_P \) (%)          | 51.4          |
| Texture           |               |
| Gravel            | 0.0           |
| Sand              | 0.0           |
| Silt              | 21.9          |
| Clay              | 78.1          |

Table 2. Preparation of the deteriorated specimen

| Property                              | Value         |
|---------------------------------------|---------------|
| Initial water content (%), \( w_{in} \) | 238           |
| Stabilizer                            | Ordinary Portland Cement |
| Additive amount of stabilizer (kg/m³) | 50, 70        |
| Curing period (day)                   | 28            |
| Concentration of seawater (NaCl: g/L)| 0.0           |
| Volume ratio between specimen and seawater | 1:1.5          |
| Immersing period (day)                | 630           |

As a procedure, the cement was added to the Ariake clay with controlled water content. Then the mixture was stirred vigorously by a hand mixer. The mixture was kept in a plastic mould having dimensions of 100 mm in diameter and 200 mm height with removing air bubble by adding vibration. Afterwards, the mixture was cured for 28 days kept by covering a high polymer sheet on its upper surface in the constant temperature of 20°C and humidity of 80% in the chamber. After curing, specimens were removed from the mould, trimmed to 100 mm diameter and 30 mm height, and covered their sides by rubber sleeve with upper and bottom surfaces left opened as shown in figure 1. Hence prepared specimens were immersed in seawater for 630 days. The artificial seawater was exchanged every week. After immersing, they were further trimmed to 60 mm in diameter and 20 mm in height and, were led for the shear box test. Before the shear box test, X-ray fluorescence spectrometers were used to analyze whether specimens were completely deteriorated. After confirming deterioration by analyzing depth distributions of calcium and magnesium in the specimen for each slices of the specimen which was cut at every 5 mm height. Depth distributions of calcium and magnesium are shown in figure 2. Initially, calcium content of the specimen was 70kg/m³ which was much more than that for 50kg/m³ because a main component of the cement was calcium. After immersing in the seawater, they were almost equal. In the case of magnesium, the difference of magnesium content is very small at the beginning. After immersion into the seawater, magnesium content of the specimen was 70kg/m³ which was much more than that for 50kg/m³. Contents of calcium and magnesium were confirmed to be almost constant in depth. Therefore, all specimens applied for the series of tests were confirmed to be deteriorated completely and homogenously. Table 2 summarizes the preparatory conditions of the deteriorated specimen. Additionally, in order to investigate the change of strength property due to immersion into the seawater, the non-deteriorated cement mixed specimen without seawater immersion and remolded Ariake clay were also applied for the test by applying 50 kPa consolidation pressure.

2.3 Procedure of the shear box test

A series of shear box test was conducted with maintain the constant volume. Consolidation pressures were settled for 50, 100, 150, and 200 kPa before shearing. The consolidation period was determined by 3t method for the deteriorated specimen and the
remolded Ariake clay. In case of the non-deteriorated specimens, the compression settled in the short duration of time due to their stiffed nature. Therefore, the consolidation process has been stopped and shearing tests have been performed with the shear displacement rate of 0.2 mm/min.

3 RESULTS AND DISCUSSIONS

3.1 Compressibility of the deteriorated specimen

Consolidation curves of cement mixed specimens before and after immersing in the seawater at 100 kPa consolidation pressure are shown in Figure 3. In case of the non-deteriorated specimens, settlement of 50 kg/m$^3$ specimen was larger than that for 70 kg/m$^3$ specimen. On the other hand, the deteriorated specimen shows high compressibility compared to the non-deteriorated specimen. Final settlement of 50 kg/m$^3$ specimen was larger than that for 70 kg/m$^3$ one. Figure 2 shows relationships between compressive strain and consolidation pressure for non-deteriorated and deteriorated specimens. Results for Ariake clay were plotted within this figure. Compressive strain of non-deteriorated specimens was very small at this stress level. Meanwhile, the compressive strain of deteriorated specimens increased with increasing consolidation pressure. The compressive strain of 50 kg/m$^3$ specimen was large with compared to that of 70 kg/m$^3$ regardless of stress level. Furthermore, compared to remolded Ariake clay in normally consolidation condition, the compressibility of 70 kg/m$^3$ specimens were smaller than that for the Ariake clay in all cases. In case of 35kg/m$^3$ specimen, when consolidation pressure was more than 100 kPa, the compressive strain was large with compared to the Ariake clay. It was found that the deterioration of the cement mixed clay by immersing in the seawater increases the compressibility. And compressibility of deteriorated specimen depends upon its initially added cement content and its stress level.

3.2 Strength property of the deteriorated specimen

Relationships between shear stress and shear displacement before and after immersing into the seawater at 100 kPa consolidation pressure are shown in
mixed clay is prepared at the slurry condition, it is solidified with high pore volume. When salt components of groundwater intrudes the cement mixed clay without acting the force, calcium present in the clay dissolves gradually in pore water generating high porosity. Consequently, the cement mixed clay turns into the high pore volume condition and bears against the acting force without cementation. When compression pressure and shear force act to this deteriorated cement mixed clay, it shows very high compressibility and very small shear resistance. As shown in figure 7, the reasons for which the strength property of the deteriorated cement mixed clay become similar with that for the Ariake clay due to the intrusion of magnesium salt of the seawater to degenerate the hydrated bearing acting force of the specimen (Hara, 2013). As a result, only Ariake clay remained to be able to resist the shear stress of the specimen.

4 CONCLUSIONS

In this paper, in order to investigate mechanical properties of the deteriorated cement mixed marine clay immersed in the seawater, the shear box test was conducted for the completely deteriorated cement mixed clay. Results of this research are as follows.

1) The compressibility of the deteriorated cement mixed marine clay has increased due to present of the seawater.
2) The compressibility of the deteriorated cement mixed clay is affected by initial amount of cement adjustment.
3) The shear strength of the deteriorated cement mixed clay decreased due to present of seawater.
4) The strength of completely deteriorated cement mixed clay immersed in the seawater is almost equal to that of remolded Ariake clay.

REFERENCES

1) Hara, H., Suetsugu, D., Hayashi, S. and Du, Y. J. (2008): Calcium leaching properties of lime-treated soil by infiltration of tidal river water, Proceedings of International Offshore and Polar Engineering Conference, Canada, 810-813.
2) Kamon, M., Ying, G. and Katsumi, T. (1996): Effect of acid rain on lime and cement stabilized soils, Soils and Foundations, 36(4), 91-99.
3) Hayashi, H., Nishimoto, S., Ohishi, K. and Terashi, M. (2004): Long-term characteristics on strength of cement treated soils (Part 1), Monthly report of civil engineering Research Institute, 11-19 (in Japanese).
4) Hara, H., Suetsugu, D. and S. Hayashi, S. (2013): Deterioration mechanism of cement-treated soil under seawater, Journal of Geotechnical Engineering (C), 69(4), 469-479 (in Japanese).