Cement mix proportion for treated soils recycled from a cement treated soil

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ABSTRACT

Properties of remolded cement treated dredged soil are different from those of its original source soil without cement treatment. In practice, at placing joint between previous and current placements, excavated soils from the previous section are used as a source material for the current section. The objective of this study is to investigate physical and mechanical properties of recycled cement treated soil in association with cement proportion, when the original cement treated soil is remolded and reused as a source soil. Unconfined compressive strengths for both the original cement treated soil and recycled cement treated soil are discussed in association with the water-cement ratio W/C in the mix proportion. The most important governing parameter to control the shear strength is the water-cement ratio calculated for newly added amount of cement.

Keywords: cement treated soil, recycling, marine clay, unconfined compressive strength, liquid limit.

1 INTRODUCTION

Cement treated dredged soils have been developed and applied to large scale reclamation projects in Japan, e.g., at the Central Japan International Airport (Kitazume and Satoh, 2003) and the D-runway of the Tokyo International Airport (Watabe and Noguchi, 2011; Watabe et al., 2012; Watabe and Sassa, 2016). Some of those construction scenes are shown in Figure 1. In these projects, the cement treated dredged soils were used for the purpose of reusing dredged soils from navigation route and anchorage area, saving quarried sands to avoid destruction of the natural environment, and increasing the stability of seawall structure by lightweight filling. These projects are typical case histories in land reclamation using cement treated soils.

Generally, soil properties of remolded cement treated soils are different from those of the original source soils without cement treatment, because of the existence of cement hydrates. At a placing joint of treated soil between previous and current placements (Figure 2), excavation is often required to expose a fresh surface to make good contact. If the excavated treated soil can be reused as a source material for cement treated soils, it is more cost efficient because transportation and disposal of the excavated treated soil would be unnecessary. In addition, because there is a possibility of excavating the treated soil to respond a change of land use in a future phase, it is very important to study how the excavated soil is effectively used at the construction site.

There are many previous studies on cement treated soils, and technical manuals have been published, particularly on the pneumatic flow mixing soil (Coastal Development Institute of Technology, 2008a) and the air-foam treated soil (Coastal Development Institute of Technology, 2008b). However, reuse of those treated soils as a recycling technology has not been studied yet.

The objective of the present study is to investigate physical and mechanical properties of recycled treated soil in association with cement proportion, when the original cement treated soil is remolded and reused as a source soil for the second round cement treatment. An original treated soil is remodeld to be a slurry state, then liquid limit and plastic limit tests are conducted. The test results for the remolded treated soil are compared with those of the original dredged soil without any experience of cement treatment. Then, a certain amount of cement is added to make a soil-cement mixture, and it is placed in a small mold and cured to make specimens for unconfined compression test. Unconfined compressive strengths for both the original cement treated soil and recycled cement treated soil are discussed in association with the water-cement ratio W/C in the mix proportion.

2 METHODOLOGY

2.1 Examined material

The source soil used in this study was named as Hommoku clay dredged in Yokohama Port, Japan. Its
physical properties are tabulated in Table 1. Liquid limit of 108.0% and plasticity index of approximately 60 indicates a typical high-plastic clay. The binder used in this study was a Portland blast-furnace slag cement type B, which is preferably used for treated soils to avoid elution of hexavalent chromium. To make a homogeneous mixture, cement was added as cement milk instead of cement powder. Mixing period was set to 10 minutes, including hand mixing at every 2 minutes (total 4 times) to avoid uneven mixing.

2.2 Test procedure

Unconfined compression test was conducted following JIS A 1216: 2009, and liquid and plastic limit tests were conducted following JIS A 1205: 2009.

2.2.1 Original cement treatment

Test procedure conducted in this study is shown in Figure 3. Mommoku clay was first sieved by 0.425 mm mesh to remove coarse particles and large fragments, and water content was adjusted to be 194% which is equivalent to 1.8 times of liquid limit. Portland blast-furnace slag cement type B was added into the clay slurry in the mix proportion of 100 kg/m³ in outer ratio, and the mixture was placed into a plastic mold with 50-mm diameter and 100-mm height with careful attention not to entrain air bubbles. Then, the molded mixture was cured at 22°C under a wet condition. The sample prepared above is called as “the original treated soil” hereunder.

2.2.2 Unconfined compression test for the original treated soil

After 14 days curing, unconfined compression test was conducted. Half of the unconfined compressive strength obtained here is considered as the standard shear strength representing the shear strength of the
Source soil for the recycled cement treatment was prepared by remolding the original cement treated soil after 14 days curing. The original cement treated soil was crashed and sieved by 0.425 mm mesh, and aggregations were grinded by stainless pallet on a glass plate. This work is like grating a Japanese radish.

To the remolded sample in slurry state, a certain amount of cement was added. Because soil properties of the remolded cement treated soil is different from those of the original source soil without cement treatment, liquid limit test was conducted for the remolded one and the water content of the remolded slurry was adjusted to 1.8 times of the updated liquid limit. The sample prepared above is called as “the recycled cement treated soil” hereunder. The mix proportion in a ratio of cement weight to unit volume of slurry was set to 50, 100, 200 and 400 kg/m$^3$ in outer ratio. These conditions are called as Case 1, Case 2, Case 3 and Case 4, respectively. After sufficiently mixing, the mixture was molded in dimensions of 50-mm diameter and 100-mm height not to entrain air bubbles, and cured at 22°C under wet condition. Test conditions are shown in Table 2.

### Table 2. Test conditions (newly added amount of cement).  
| Sample | Original cement treatment (kg/m$^3$) | Curing period | Recycled cement treatment (kg/m$^3$) | Curing period |
|--------|------------------------------------|---------------|--------------------------------------|---------------|
| Case 1 | 100                                 | 14 days       | 50                                   | 14 days       |
| Case 2 | 100                                 | 14 days       | 100                                  | 14 days       |
| Case 3 | 200                                 | 14 days       | 200                                  | 14 days       |
| Case 4 | 400                                 | 14 days       | 400                                  | 14 days       |

2.2.3 **Recycled cement treatment**

Source soil for the recycled cement treatment was prepared by remolding the original cement treated soil after 14 days curing. The original cement treated soil was crashed and sieved by 0.425 mm mesh, and aggregations were grinded by stainless pallet on a glass plate. This work is like grating a Japanese radish.

To the remolded sample in slurry state, a certain amount of cement was added. Because soil properties of the remolded cement treated soil is different from those of the original source soil without cement treatment, the liquid limit test was conducted for the remolded one and the water content of the remolded slurry was adjusted to 1.8 times of the updated liquid limit. The sample prepared above is called as “the recycled cement treated soil” hereunder. The mix proportion in a ratio of cement weight to unit volume of slurry was set to 50, 100, 200 and 400 kg/m$^3$ in outer ratio. These conditions are called as Case 1, Case 2, Case 3 and Case 4, respectively. After sufficiently mixing, the mixture was molded in dimensions of 50-mm diameter and 100-mm height not to entrain air bubbles, and cured at 22°C under wet condition. Test conditions are shown in Table 2.

### Table 2. Test conditions (newly added amount of cement).

**2.2.4 Unconfined compression test for recycled treated soils**

After 14 days curing, unconfined compression tests were conducted. Half of the unconfined compressive strength obtained here represents the shear strength of the recycled cement treated soil.

### 3 TEST RESULTS AND DISCUSSION

#### 3.1 Physical properties

Unconfined compressive strength $q_u$, liquid limit $w_L$, plastic limit $w_p$, and plasticity index $I_p$ are summarized in Table 3. In addition, relationships between consistencies ($w_L$, $w_p$, and $I_p$) and newly added amount of cement are shown in Figure 4. Here, consistencies are normalized by those for the original source soil (Hommoku clay).

The liquid limit $w_L$ of the original treated soil increased to approximately 1.2 times from that of the source soil, and that of the recycled treated soil increased to 1.3–1.4 times from that of the original source soil. The plastic limit $w_p$ of the original treated soil increased to approximately 1.7 times from that of the source soil, and that of the recycled treated soil increased to approximately 2.1 times from that of the source soil. The plasticity index $I_p$ of the original treated soil decreased to 0.7 times from that of the source soil, and that of the recycled treated soil was almost the same as that of the original treated soil.

In the liquid limit and plastic limit tests, the soils were remolded and mixed as much as possible corresponding to the testing method (JIS A 1205: 2009); however, the influence of mixing period has to be considered (Ogawa and Kobayashi, 1995).

#### 3.2 Mechanical properties

Relationship between unconfined compressive strength and water-cement ratio W/C is shown in Figure 5. The water-cement ratio for the recycled treated soils is calculated using the amount of cement added for the recycled treatment, not to consider the amount of cement added for the original treatment. In the cases of the recycled treated soils, compressive strength decreased with increase of water-cement ratio, i.e. compressive strength increased with the amount cement. Both the original treated soil and the recycled treated soil Case 2 with cement amount of 100 kg/m$^3$ show almost the same unconfined compressive strength. This fact indicates that the cement amount of 100 kg/m$^3$ in the original treatment did not contribute to strength development in the recycled cement treatment. To examine a mix-proportion for the cement treated soils, including the recycled cement treated soils, it is just required to consider the properties of the source soil remolded at that stage. The most important governing parameter to control the shear strength is the water-cement ratio W/C calculated for newly added amount of cement.

#### 3.3 Microfabric

Soil skeletal structure, i.e. microfabric, of the cement treated soil was observed by scanning electron microscope (SEM). Figure 6 shows SEM images for (a)
Table 3. Test results.

| Sample condition     | Newly added cement (kg/m³) | Water-cement ratio W/C | Unconfined compressive strength $q_u$ (kN/m²) | Liquid limit $w_L$ (%) | Plastic limit $w_p$ (%) | Plasticity index $I_p$ |
|----------------------|---------------------------|------------------------|-----------------------------------------------|------------------------|-------------------------|------------------------|
| Original treatment   | 100                       | 8.2                    | 620                                           | 124.0                  | 80.6                    | 43.4                   |
| Recycled Case 1      | 50                        | 16.2'                  | 92.6                                          | 145.2                  | 100.6                   | 44.6                   |
| Recycled Case 2      | 100                       | 8.1'                   | 576                                           | 146.4                  | 101.3                   | 45.1                   |
| Recycled Case 3      | 200                       | 4.1'                   | 2250                                          | 147.1                  | 101.2                   | 45.9                   |
| Recycled Case 4      | 400                       | 2.0'                   | 5935                                          | 146.4                  | 100.9                   | 45.5                   |

* Calculated for newly added amount of cement

Figure 4. Relationships between consistencies ($w_L, w_p, I_p$) and newly added amount of cement.

Figure 5. Relationship between unconfined compressive strength and water-cement ratio W/C.

Figure 6a. SEM image for the original treated soil.

Figure 6b. SEM image for the recycled treated soil (Case 2).

the original cement treated soil and (b) Case 2 of the recycled cement treated soil. In both samples, the amount of cement added to the unit volume of slurry was 100 kg/m³. Magnification in the SEM observation was 2500 times and the length of the scale bar shown in the image is 10 µm. Both images are very similar and there are some numbers of needle shape cement hydrates; ettringite. There is no significant difference in microfabric between the original cement treated soil and the recycled cement treated soil.

4 SUMMARY

A series of unconfined compression tests and consistency tests were conducted for the original cement treated soil and recycled cement treated soils. The new knowledges obtained in the present study are
summarized hereunder.

1) The liquid limit and the plastic limit of the original cement treated soil significantly increased from those of the source soil (dredged soil). Those of the recycled treated soil additionally increased from the original treated soil. It is notable that the plasticity index of the cement treated soils decreased from the source soil because the increase of the plastic limit was larger than the increase of the liquid limit.

2) The original cement treated soil with cement amount of 100 kg/m$^3$ and its recycled cement treated soil with cement amount of 100 kg/m$^3$ showed almost the same unconfined compressive strength. In these tests, water-cement ratios $W/C$ calculated for newly added amount of cement was almost the same (8.2 and 8.1, respectively), indicating that the cement amount of 100 kg/m$^3$ in the original treatment did not contribute to strength development in the recycled cement treatment. The most important governing parameter controlling the shear strength is the water-cement ratio $W/C$ calculated for newly added amount of cement.

3) There is no significant difference in microfabric observed by SEM between the original cement treated soil and the recycled cement treated soil.

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