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Material properties of solidified soil grains produced from dredged marine clay

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Abstract

Solidified soil grains are produced by crushing a solidified soil mass which is made of dredged soil mixed with cement. It would be beneficial if these solidified soil grains could be used as fill material instead of sand/gravel. However, the strength property of solidified soil grains has not yet been thoroughly studied. In addition, as it is well known that solidified soil tends to deteriorate in seawater due to the leaching of calcium, it is necessary to make a complete study of the deterioration properties of solidified soil grains. In the current study, the material properties of solidified soil grains have been investigated. The test results revealed that (1) the strength of normal single solidified soil grains is smaller than that of natural rock grains, (2) the internal friction angle of solidified soil grains is greater than 30°, and (3) the internal friction angle of solidified soil grains tends to decrease along with the progress of deterioration; however, deterioration will not be experienced by solidified soil grains which have unconfined compressive strength larger than approximately 14 MN/m^2.

Keywords: Solidified soil grains; Dredged marine clay; Deterioration; Seawater; Internal friction angle

1. Introduction

To maintain the required water depth of fairways and basins etc., about 20 million m^3 of sediment soil are dredged every year in Japan despite the low availability of dumping areas. The way with which this dredged soft soil should be dealt has become a serious problem that must be resolved. In order to utilize the dredged soil effectively, a lot of solidification methods (Coastal Institute, 2002; Kitazume, 2017; Tsuchida et al., 2004) for mixing dredged soil with cement have already been developed. The required shear strength can be achieved in a short period by these methods. In fact, a very soft dredged soil with negligible strength can be changed to a stiff soil with an unconfined compressive strength of 100–500 kN/m^2 by the application of the above solidification methods. As the volume of dredged soil is huge, there is always a demand for the development of more effective solutions for dredged soil.

In addition, from the viewpoint of the protection of the natural environment, it is strongly advised here in Japan that stones be acquired from excavations in mountains and that sand/gravel be acquired from the dredging of rivers. There is a chronic deficiency of these materials in construction work. Therefore, to simultaneously resolve the problem of the disposal of dredged soil and to counteract the shortage of sand/gravel, the use of solidified soil grains as an alternative material to sand/gravel is proposed. Solidified soil grains are produced by crushing a solidified soil mass which is made of dredged soil mixed with cement (Shinsha and Tsutsumi, 2016a). On the other hand,

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solidified soil grains can also be produced by mixing together dredged soil, cement and a polymer using a special mixing device (Dong et al., 2011; Hayano et al., 2014). The addition of a polymer is advantageous in that the polymer can absorb the superfluous pore water contained in clay that has a very high water content so that solidified soil grains can be easily produced. However, there are also disadvantages to this method, namely, that the production costs tend to increase with the addition of a polymer and that large volumes of solidified soil grains cannot be produced in a short period due to the small mixing device. On the other hand, the method whereby solidified soil grains are produced by crushing a solidified soil mass is advantageous in that large volumes of solidified soil grains can be produced in a short period using such mixing methods as the premixing method, the pneumatic flow mixing method etc.

It is desirable for solidified soil grains to possess the following features:

(1) The general strength is similar to that of sand/gravel.
(2) The permeability is higher than 1×10^{-5} m/s.
(3) The internal friction angle is higher than 30°.
(4) The unit weight is less than that of normal soil for reducing the earth pressure.
(5) The material properties continue to be stable for a long period.

In order to examine the material properties for the above items (1) to (4) for solidified soil grains, two kinds of strength tests were carried out. One is the compression test for single grains and the other is the consolidated-drained tri-axial compression test for aggregated grains. In addition, in order to examine the properties for item (5), two kinds of strength tests for solidified soil exposed to seawater were carried out. One is the needle penetration test for the solidified soil mass and the other is the consolidated-drained tri-axial compression test for the grains.

Based on the results of these tests, the performances of the proposed solidified soil grains are clarified. In particular, with the desirable features for permeability, the internal friction angle and the unit weight for items (2) to (4), the applicability of the proposed material as quasi-alternative material for natural sand/gravel is revealed in this study.

2. Production of solidified soil grains

Marine clay dredged from Nagoya Port in Japan was used in this study. The physical properties of the marine clay are summarized in Table 1. The liquid limit is 84.3%, the fine fraction content is 82% and the ignition loss is 9.3%.

The mix proportions of the solidified soil are summarized in Table 2. Portland blast-furnace slag cement B was used. The cement, in a slurry condition with the mass ratio of 1:1 of cement and water, was mixed with 1 m^3 of clay, as seen in Table 2. The water content of the marine clay was 101% and the cement content was in the range of 100–400 kg/m^3. After curing the sample for 28 days, the results showed that the unconfined compressive strength (UCS) of the sample was from 1.205 MN/m^2 to 7.400 MN/m^2 (Table 2).

The solidified soil grains were produced according to the following simple steps: (1) The cement was mixed with the marine clay. (2) The mixture was poured into a plastic bag with a diameter of 5 cm and a length of 40 cm. (3) The mixture was cured in a homeothermal room, at a temperature of 20 °C and humidity of 60%, for 28 days and, as a result, the solidified soil mass was produced. (4) The solidified soil mass was crushed into coarse grains less than 50 mm in size, and then the grains were further crushed into smaller ones less than 10 mm in size. (5) The grains were then filtered through sieves having several different mesh sizes. Finally, grains with the size of 0.85 mm to 2 mm (Grain-A), 2 mm to 4.75 mm (Grain-B) and 4.75 mm to 9.5 mm (Grain-C) were prepared for the soil tests.

3. Material properties of single solidified soil grains

3.1. Densities of solidified soil

The densities of the solidified soil are shown in Table 2. When the solidified soil mass is crushed, the density of the grains does not change from that of the solidified soil mass, and the densities fall in the range of 1.471 g/cm^3 to 1.510 g/cm^3. Therefore, the density of the solidified soil mass is considerably less than that of the dredged soil particles, namely, 2.668 g/cm^3. This is because the solidified soil grains of the solidified soil contain a great deal of water and the water contains liquid water and a hydrate compound, which is transformed from liquid water by a chemical reaction. The theoretical amount of water transformed for the complete hydration of the cement is 42.4 ml per 100 g of cement (Fujii, 1986; Japan Cement Association, 2012) (see Fig. 6).

3.2. Strength of single solidified soil grains

Strength tests on single solidified soil grains were carried out, as seen below: (1) 30 grains (Grain-C) were used. It is

Table 1
Physical properties of marine clay.

Specific gravity ρ_s (g/cm^3)	Grain size distribution (%)			Liquid limit w_L (%)	Plastic limit w_P (%)	Ignition loss L_i (%)
	Clay	Silt	Sand			
2.668	38	44	18	84.3	24.4	9.3

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