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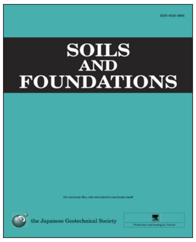

Change in the hydromechanical characteristics of embankment material due to compaction state conditions

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Abstract

In recent years, earthquakes and heavy rains have frequently caused soil embankments to collapse. In order to prevent the collapse of embankments, it is well known that sufficient compaction and drainage control are necessary. Although numerous research findings have described compacted soils, compaction management has been essentially based on simple parameters such as dry density, degree of saturation or air content. It is important for the construction of a stiff embankment that the effect of compaction condition on the mechanical properties and inherent anisotropy of compacted soil should be recognized in detail. In the present study, the relationships between the compaction condition and the mechanical properties obtained from laboratory tests using saturated specimens are presented. Specifically, undrained monotonic and cyclic shear strength, shear modulus, and permeability are reported. The arrangements of soil particles were also observed with a microscope. From the observation of fabric characteristics of soil particles, an inherent anisotropy of compacted soil is discussed. Furthermore, a conceptualization of the relationship between the fabric of soil particles and the mechanical characteristics for each compaction condition is suggested.

Keywords: Compaction; Soil fabric; Embankment; Undrained shear strength; Shear modulus; Permeability coefficient; D06; D09

1. Introduction

In recent years, embankment structures have frequently collapsed due to earthquakes and heavy rains. In order to prevent the collapse of embankments, it is well established that sufficient compaction of soil and drainage control is necessary.

Although all embankments initially satisfy the criterion of compaction, many embankments and structural fill become damaged over time. An example is the significant number of geo-disasters such as river embankment and residential fill collapses that occurred in the 2011 Great East Japan Earthquake (2011 Committee for Geo-hazards during Earthquakes and Mitigation Measures, 2011). Henceforth, a high quality of mechanical performance will be required for the construction of embankments that can endure various natural hazards.

In order to determine the mechanical performance of compacted embankments, basic properties such as the inherent anisotropy of compacted soil must be revealed in detail. The relationship between inherent anisotropy and shear strength

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has been shown to contribute to improved compacted embankment design (for example, Lawton et al., 1991; Delage et al., 1996; Watabe et al., 2000; Jafari and Shafiee, 2004). Knowledge about the microstructure of compacted soil can inform rational embankment design.

A number of researchers (for example, Lambe, 1958a, 1958b; Mitchell, 1960; Seed et al., 1962; Mitchell et al., 1965 and Ahmed et al., 1974) revealed the mechanical properties of compacted clay. These researchers demonstrated that the mechanical properties of clay were significantly affected by compaction condition. In particular, Lambe (1958a, 1958b) described the effects of the differences of compaction conditions on the soil fabric and mechanical properties such as the strength, permeability, and stress–strain modulus of Boston blue clay. These findings have been useful for interpreting the effect of compaction condition on the mechanical properties of clay. For coarse-grained soil, the shear strength and deformation behavior of compacted gravel have been investigated (for example, Modoni et al., 2011). Additionally, the influence of suction on the mechanical behavior of compacted silty clay has been clarified by laboratory tests (for example, Vanapalli et al., 1999; Jotisankasa et al., 2009). Despite the many findings regarding compacted soils, for the design and construction of embankments, compaction management has been essentially based on simple parameters such as dry density, degree of saturation, or air content. In order to upgrade the construction management of embankments, the relationship between mechanical properties and compaction properties of various soils should be leveraged. Specifically, static and cyclic undrained strength, shear modulus and permeability coefficient under various compaction conditions are important for well-designed embankments. The first step of this study involved the observation of soil particles of compacted soil under a microscope. The relationships between soil fabrics and compacted conditions are discussed. Second, mechanical properties such as undrained strength, shear modulus and permeability were measured by a series of laboratory tests. The effect of dry density and water content on the mechanical properties of compacted soil is discussed. Finally, a mechanism of change in mechanical properties due to differences in compaction conditions is described in terms of the fabric characteristics of compacted soil.

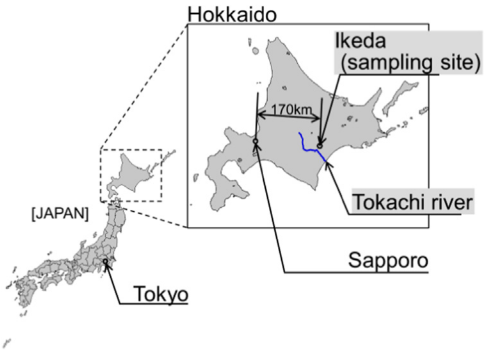

Fig. 1. Sampling location of I soil.

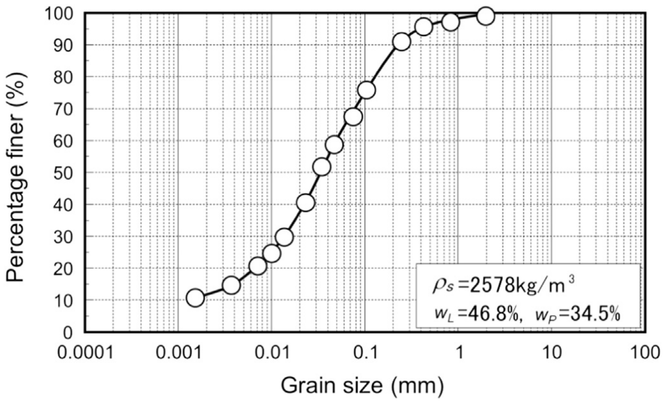

Fig. 2. Grain size distribution of I soil.

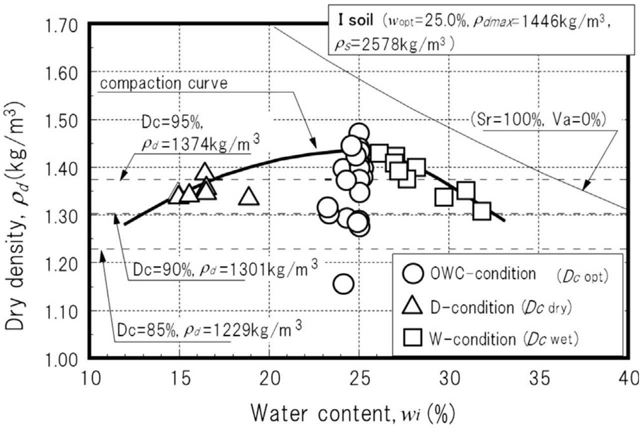

Fig. 3. Compaction curve of I soil and initial state condition of specimens.

2. Specimen preparation and compaction property

The tested soil was sampled in the Ikeda region, which is located in the eastern part of Hokkaido in Japan (the sampling site is shown in Fig. 1). This soil was used as a material in the construction of a river embankment. In this paper, the soil is referred to as I soil. Fig. 2 shows the grain distribution of I soil. In this figure, the density of soil particles, liquid limit, and plastic limit are also denoted. The maximum diameter is 2.0 mm. The fines content of this soil is 68.1%. The liquid limit w_L, and plastic limit w_P, are 46.8% and 34.5%, respectively. The density of soil particle ρ_s equals 2578 kg/m^3. From these data, it is recognized that I soil is categorized as sandy-silt. Fig. 3 shows the compaction curve of I soil. This compaction curve was obtained from a compaction test with a mold that was made specifically for preparing the specimen for laboratory testing. The diameter and height of the mold were 100 mm and 150 mm, respectively. If a specimen height of over 150 mm was required for a laboratory test, compaction was performed by setting a collar on top of the mold in order to make up for the deficiency in the height of the mold. The size of the constructed mold was different from the test method defined in the ASTM standards (ASTM International, 2011). Therefore, the compaction curve for this study was derived