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Explanation of Dry Density Distribution Induced by Compaction through Soil/Water/Air Coupled Simulation

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Abstract

Most onshore earth structures, such as earthen dams, embankment, and river levees, are constructed by compaction. Transportation geotechnics also includes construction of compacted earth structures, such as road and railway embankment. Optimum compaction can increase shear strength, while decreasing compressibility and permeability of earth structures. For this reason, compaction has been used for earthworks since the dawn of times. Generally, a series of lab compaction tests is conducted to obtain a compaction curve before constructing these structures. The shape of the compaction curve, which determines the maximum dry density at the optimum water content, is very important in the design and construction of structures. However, it is difficult to control compaction quality on the basis of lab tests alone, as soil materials are inhomogeneous. Furthermore, there are differences in the compaction methods used in lab tests and at construction sites. Therefore, it is necessary to explain the mechanisms of compaction in the framework of soil mechanics. In this study, compaction of earthworks is simulated in a similar way. The effect of compaction layer thickness and the number of compaction layers on the distribution of dry densities in an earth structure was investigated through soil/water/air coupled simulation. Consequently, it was found that multi-layered compaction can create a gap in the dry density between two layers and that this gap can be reduced by thinner layer compaction. On the other hand, though the average dry density in a compacted earth structure can be increased by increasing the number of compacted layers, some gap between compaction layers was inevitable. Through these findings, this study contributes to the performance design of compacted earth structures.

Keywords: Compaction; Soil/water/air coupled simulation; Soil water retention characteristics

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1 Introduction

When constructing embankment and base course for highways and railways, the application of an external force to increase soil density is necessary. This is called 'compaction'. Increasing density means to decrease the voids between soil particles. This leads to decreasing permeability and compressibility, while increasing strength. Optimum compaction contributes to the stability of an earth structure. The effects of compaction are known to strongly depend on material properties, moisture content, and the compaction procedure. Furthermore, the underlying mechanics of compaction are fairly complicated. Proctor [1] first standardized the lab-compaction test for geotechnical engineering sites and linked compaction curves, namely the relationship between water content and dry density, to the needle penetration test (shown in Fig. 1). Dry density has long served as the index for compaction effects, since Proctor's concept was developed (shown in Fig .2). However, the mechanisms of compaction are still not fully understood.

Kawai et al. [2] conducted static compaction tests on silty clays (Figs. 3 and 4). They found that compaction of specimens with higher moisture contents caused a greater change in suction. Furthermore, materials with higher moisture contents required a smaller load in order to reach the same dry density level as specimens with lower moisture contents. They suggested that unsaturated soil mechanics could explain this behavior, and accordingly, that compaction curves exhibit a maximum dry density at optimum moisture content. Kawai et al. [3] assumed 'compaction' to be loading and subsequent unloading of an unsaturated specimen under water undrained and air drained conditions and simulated the static compaction tests using the soil/water/air coupled finite element analysis code, DACSAR-MP (Figs. 5 and 6). By this method, they succeeded in defining compaction curves and compaction-induced

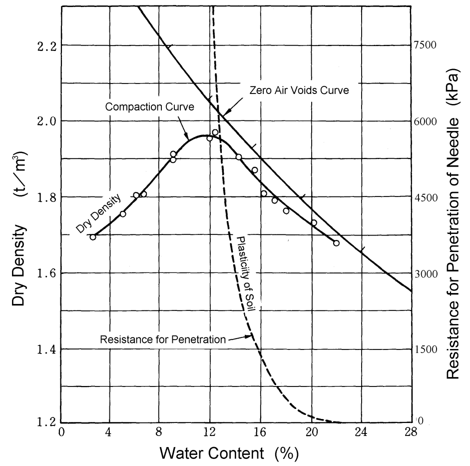


Fig. 1 Procter's Concept

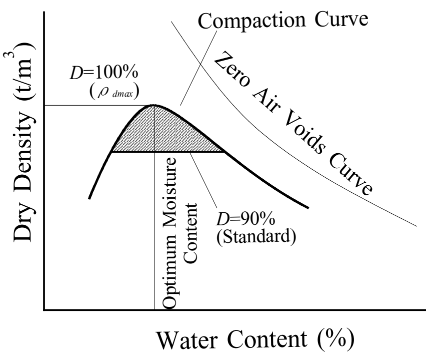
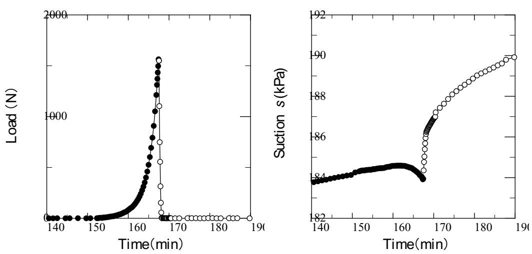
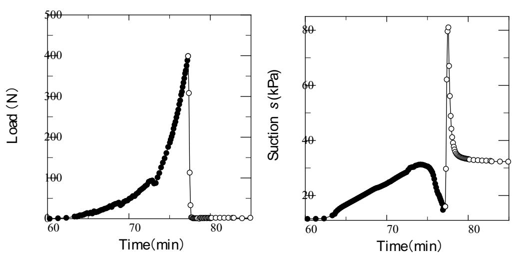


Fig. 2 Compaction curve with dry density



(a) Load change (b) Suction change

Fig. 3 Compaction on a lower moisture-specimen



(a) Load change (c) Suction change

Fig. 4 Compaction on a higher moisture-specimen