Soils and Foundations 2014;54(1):67–80

The Japanese Geotechnical Society

Soils and Foundations

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Medium-size triaxial apparatus for unsaturated granular subbase course materials

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Received 30 November 2012; received in revised form 24 May 2013; accepted 17 June 2013
Available online 24 January 2014

Abstract

This paper proposes a testing method for evaluating the effect of water content on the deformation–strength characteristics of unsaturated subbase course materials. A medium-size triaxial apparatus for unsaturated soils is newly developed in order to examine the mechanical behavior of unsaturated subbase course materials subjected to fluctuations in water content and to shorten the testing time. It adopts the pressure membrane method with hydrophilic microporous membrane filters, instead of the pressure plate method with ceramic disks, and controls both pore air pressure and pore water pressure at the cap and the pedestal separately. The results of the proposed testing method, carried out by this apparatus, are shown to conform well to the results of previous researches. This indicates that the medium-size triaxial apparatus for unsaturated soils is highly useful for triaxial compression tests and water retentivity tests on unsaturated granular base course materials and for shortening the total testing time.

Keywords: Base course; Cyclic load; Pavement; Triaxial test; Water retentivity test; Unsaturated soil; Water content; IGC: D06; E10; H06

1. Introduction

In cold snowy regions, such as Hokkaido, the 0 °C isotherm may penetrate deep into pavements, thereby causing the upheaval of pavement surfaces or the cracking of the asphalt-mixture layer arising mainly from the frost heave of the subgrade. Furthermore, the water content rises in the unsaturated subbase course and the subgrade owing to the infiltration of thaw water and the thawing of ice lenses during the thawing season, resulting in the temporary degradation of the bearing capacity and the stiffness (Ishikawa et al., 2012). Such phenomena specific to cold regions are thought to accelerate the deterioration of pavement structures and the loss of functions. In turn, freeze–thawing greatly affects the decrease in the fatigue life of pavement structures. For example, the mechanistic-empirical pavement design guide (MEPDG; AASHTO, 2008) can evaluate the effects of environmental factors, such as water content, on the fatigue life by using the model proposed by Cary and Zapata (2010). Therefore, to rationalize a design method for transportation infrastructures better suited to the climatic conditions of cold snowy regions, it is of great significance to improve the theoretical design method adopted in Japan (Japan Road Association, 2006), so that it can be applied to evaluate the

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Peer review under responsibility of The Japanese Geotechnical Society.

Production and hosting by Elsevier

0038-0806
http://dx.doi.org/10.1016/j.sandf.2013.12.007

changes in the hydro-mechanical characteristics of unsaturated base course and subgrade materials caused by freeze–thawing. Based on these circumstances, we focus our research on the mechanical behavior of unsaturated granular subbase course materials, which suffer from the seasonal fluctuations in water content due to freeze–thaw as well as rainfall infiltration and variations in groundwater level, in order to propose a mathematical model for predicting the mechanical response of unsaturated subbase course during the thawing season and to incorporate the model into the theoretical design method for asphalt pavements.

The “Method of Test for Modified California Bearing Ratio (E001)” and the “Method of Test for Resilient Modulus of Unbound Granular Base Material and Subgrade Soils (E016)” have been specified by the Japan Road Association (2007) as the testing methods for subbase course materials used in the design calculations of pavement structures. However, these testing methods were generally designed to examine the deformation–strength characteristics of subbase course materials with optimum water contents, and not to evaluate the effects of water content on the mechanical behavior in a detailed manner. Accordingly, the mechanical behavior of unsaturated base course materials has not yet been sufficiently clarified by laboratory element tests here in Japan.

Meanwhile, progress in unsaturated soil testing technology enables the control and the measurement of matric suction in a variety of laboratory element tests for unsaturated soils (Fredlund, 2006). As a laboratory element test on unsaturated base course materials, which have a maximum particle size over 20 mm, various testing methods have been proposed in accordance with the research objectives and the experimental conditions to evaluate the deformation–strength characteristics and the water retention–permeability characteristics (e.g., Kolisoja et al., 2002; Coronado et al., 2005; Ekblad and Isacsson, 2008; Zhang et al., 2009; Yano et al., 2011; Craciun and Lo, 2012). For example, as a water retentivity test for subbase course materials, which have a maximum particle size of almost 40 mm, Yano et al. (2011) employed the suction method (water-head type), while Ishigaki and Nemoto (2005) employed the soil column method. Moreover, Yano et al., 2011 conducted permeability tests on unsaturated subbase course materials using a steady-state method (flux-control type). However, the mechanical behavior of unsaturated subbase course materials has not yet been sufficiently clarified in Japan by laboratory element tests, although shear tests on unsaturated granular subbase course materials have been conducted overseas by measuring the matric suction. Those tests have revealed that the resilient modulus of unsaturated base course materials decreases with the increase in water content (Coronado et al., 2005; Ekblad and Isacsson, 2008). This is because laboratory element tests on unsaturated soils with large-size specimens are quite time-consuming due to the ceramic disk with very low permeability that is usually used in the test apparatus for unsaturated soils. For a detailed examination of the deformation–strength characteristics of unsaturated base course materials, therefore, it is indispensable that a new medium-size triaxial apparatus to be developed for these unsaturated soils, which can reduce the testing time as well as examine the deformation–strength characteristics of granular base course materials under various degrees of compaction and water contents with high precision under sufficiently controlled experimental conditions.

In this study, we newly propose a suction-controlled laboratory element test for the mechanical properties of granular subbase course materials that adopts unsaturated soil testing technology, such as the axis translation technique, in order to quantitatively evaluate the effects of increased water content inside the base course layer during the thawing season on the long-term performance of pavement structures.

2. Test apparatus

2.1. Development plan for test apparatus

Since unsaturated coarse-grained soils, such as subbase course materials, show low suction of 100 kPa or lower (Ekblad and Isacsson, 2008; Zhang et al., 2009), it is assumed that test methods capable of measuring in the low-suction range, such as the soil column method, the suction method, and the pressure method, are appropriate for this type of soil. In particular, the pressure method is suitable as a laboratory element test for evaluating the mechanical properties of unsaturated subbase course materials because it has a wider measuring range than either the soil column method or the suction method. While the pressure method can be classified into a pressure plate method that utilizes a ceramic disc, and a pressure membrane method that utilizes a microporous membrane filter, the former is more widely used. However, ceramic discs are extremely low in water permeability; and thus, the testing time would be extremely long in suction-controlled shear tests for specimens with large diameters, such as the tests for subbase course materials.

To solve this problem, Nishimura et al. (2012) and Ishikawa et al. (2010) recently conducted some laboratory element tests on unsaturated soils with the pressure membrane method, using a microporous membrane filter instead of a ceramic disc, and reported that the pressure membrane method was useful in shortening the testing time. Thus, we developed a medium-size triaxial apparatus for unsaturated soils, which adopts the pressure membrane method, to evaluate the deformation–strength characteristics of base course materials in an unsaturated condition. This study evaluates the applicability and the utility of a testing method using the newly developed medium-size triaxial apparatus to laboratory element tests for the mechanical properties of unsaturated subbase course materials in terms of the validity of the test results and a reduction in the total testing time. For this purpose, a series of water retentivity tests and triaxial compression tests on unsaturated sand and crusher-run was carried out.

2.2. Medium-size triaxial apparatus for unsaturated soils

A schematic diagram of the medium-size triaxial apparatus for unsaturated coarse granular materials is shown in Fig. 1.