Soils and Foundations 2015;55(2):242–257

HOSTED BY

ELSEVIER

CrossMark

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Influence of moving wheel loads on mechanical behavior of submerged granular roadbed

Tatsuya Ishikawa*, Seiichi Miura[1]

Laboratory of Analytical Geomechanics, Faculty of Engineering, Hokkaido University, Kita 13, Nishi 8, Kita-ku, Sapporo, 060-8628, Japan

Received 27 March 2013; received in revised form 5 October 2014; accepted 19 November 2014
Available online 18 March 2015

Abstract

This paper presents an experimental study to evaluate the synergistic effects of principal stress axis rotation and change in water content on the mechanical behavior of granular roadbed subjected to cyclic moving wheel loads. Two types of small scale model tests and laboratory element tests, in which a single-point loading method and a moving-wheel loading method were adopted, were mainly performed with a base course material under air-dried condition and saturated condition. Based on the test results, the applicability of a multi-ring shear test, which is a torsional simple shear test, to an element test of granular base course materials subjected to moving wheel loads, and the influence of water content and moving-wheel loads on the deformation–strength characteristics of granular roadbed were examined. The results indicate that the multi-ring shear test has excellent applicability to the estimation of deformation behavior of granular base course materials subjected to repeated moving-wheel loads. Besides, it was revealed that residual settlement of submerged granular roadbed is more likely to increase with the repetition of moving-wheel loads than that of air-dried one and under single-point loading, showing that the difference in the loading method and water content has a considerable influence on the cyclic plastic deformation of granular roadbed. These lead to the conclusion that for the precise prediction of the long-term performance of granular roadbed under cyclic moving-wheel loads, it is important to take into account the synergistic effects of principal stress axis rotation and change in water content on the cyclic plastic deformation characteristics of granular base course materials.

Keywords: Base course; Cyclic load; Gravel; Moving wheel load; Special shear test; Water content (IGC: D6/E11/H6)

1. Introduction

In general, granular roadbed at road and railway subjected to traffic loads gradually loses functions as a structural component of transportation facility, which should be normally maintained in service, with repeated vehicle passages. Therefore, the periodic maintenance activities of roads and railways is required to ensure riding quality and safety. Faced with dwindling public works expenditure and a serious reduction in the Japanese workforce in recent years, besides an urgent need for the development of maintenance-free public transportation infrastructure, efficient maintenance methods for transportation networks need to be established. Hence, the importance of researching the cumulative irreversible (plastic) deformation characteristics of granular roadbed under a moving wheel load, has been growing.

There are two main research and development tasks in terms of geotechnical engineering: to determine the effect of principal stress axis rotation, and to determine the effect of

*Corresponding author. Tel./fax: +81 11 706 6202.
E-mail addresses: t-ishika@eng.hokudai.ac.jp (T. Ishikawa), s-miura@eng.hokudai.ac.jp (S. Miura).
[1]Tel./fax: +81 11 706 6201.
Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2015.02.002

the water content. Many researchers have revealed the importance of principal stress axis rotation caused by moving-wheel loading on the performance of pavement and railway track (Chan and Brown, 1994; Brown, 1996; Lekarp et al., 2000a, 2000b; Burrow et al., 2005; Momoya et al., 2005, 2007; Kim and Tutumluer, 2005; Powrie et al., 2008; Gräbe and Clayton, 2009; Maheshwari and Khatri, 2012). Accordingly, a testing device has been developed for measuring the moving-wheel loading, which involves a wheel with a constant vertical load traveling on a granular roadbed like actual traffic loading. A multi-ring shear apparatus was developed to evaluate the effects of moving wheel loads on the cyclic plastic deformation of granular materials (Ishikawa et al., 2007). It has been shown that moving-wheel loading results in more cumulative residual settlement of granular roadbed than single-point loading, which applies pulsating compression vertical loads to a cross section of model roadbed, and other major effects of moving wheel loads on the cyclic plastic deformation have also been understood (Ishikawa et al., 2011). However, since the two studies which came to these conclusions (Ishikawa et al., 2007, 2011) were based on test results obtained under a limited experimental condition, namely the air-dried condition only, the effects of moving wheel loads on the mechanical behavior of actual granular roadbed subjected to rain, freeze-thaw, rising underground water levels and other changes in water content need to be investigated.

There have been a number of studies on the effect of water content on the mechanical behavior of granular roadbed in the field of highway engineering and railway engineering (e.g. Coronado et al., 2005; Ekblad and Isacsson, 2008; Inam et al., 2012; Trinh et al., 2012; Duong et al., 2013). For example, Coronado et al. (2005) and Ekblad and Isacsson (2008) reported that the amount of deformation modulus decreases with the increment of water content. However, since most of these tests employ cyclic triaxial compression tests under constant confining pressure in which the principal stress axes never rotate throughout the test, the above-mentioned conventional laboratory element tests are not appropriate for simulating the actual stress states inside substructures under moving wheel loads. Recently, Inam et al. (2012) revealed that the principal stress axis rotation has a significant influence on the cyclic plastic deformation of unsaturated granular base course material by performing multi-ring shear tests under various water content conditions. Unfortunately, however, they failed to grasp the relationship between results of the laboratory element tests and the real phenomena, and to clarify the role of pore water in the cyclic plastic deformation of gravel subjected to moving loads. Thus, we can suggest that the mechanical behavior of wet granular materials subjected to moving wheel loads has yet to be sufficiently elucidated.

This paper presents an experimental study designed to evaluate the mechanical behavior of submerged and air-dried granular roadbed subjected to moving wheel loads. By taking the synergistic effects of principal stress axis rotation and change in water content into account, a more realistic approach to the experimental conditions has been taken than those featured in past investigations. In this study, a series of small scale model tests and laboratory element tests were performed with coarse granular materials under air-dried and submerged conditions. First, to understand the mechanical behavior of wet granular roadbed under moving wheel loads, four types of small scale model tests with differerent loading methods were performed. Next, to examine the deformation–strength characteristics of wet granular material subjected to the rotation of principal stress axes, five types of multi-ring shear tests which correspond to the loading method in the small scale model tests were performed. Based on these test results, the effects of water content on the cyclic plastic deformation of granular roadbed were evaluated by comparing the test results under the air-dried and submerged conditions, and then, a method was developed for evaluating the mechanical properties of granular roadbed under traffic loads.

2. Soil samples

2.1. Material property

Test materials are natural crusher-run made from the andesite used in Japanese roads as a base course material. Two types of test samples with different mean grain sizes were employed in this study. The physical properties and gradation curves for the test samples are shown in Table 1 and Fig. 1, respectively. The grading of actual crusher-run has a grain size distribution between approximately 40 mm and 0 mm. Accordingly, one test sample is actual crusher-run, and the other is a similar grading gravel with approximately one-fourth the mean grain size of the original crusher-run. Gravel is produced by screening out particles larger than 9.5 mm and finer than 0.075 mm in grain size from original crusher-run. Here, the term "C-40" and "C-9.5" are used to refer to natural crusher-run and natural gravel, respectively. Crusher-run (C-40) was employed in the small scale model tests, while the gravel

Table 1
Physical properties of test materials.

Name	Maximum dry density ρ_{dmax}[a] (g/cm^3)	Optimum water content w_{opt}[a] (%)	Fine fraction content F_c (%)	Plasticity Index *PI*	Soil particle density ρ_s (g/cm^3)	Maximum dry density ρ_{dmax} (g/cm^3)	Minimum dry density ρ_{dmin} (g/cm^3)
C-40	2.070	8.2	5.20	NP	2.720	2.270[b]	1.680[b]
C-9.5	1.775	9.5	0.00	NP	2.675	1.730[c]	1.480[c]

[a]Results determined by the E-b method for C-40 and A-b method for C-9.5 of JIS A 1210: 2009.
[b]Results determined by JGS 0162-2009.
[c]Results determined by JIS A 1224: 2009.