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Effect of the Principal Stress Direction on Cyclic Cumulative Deformation and Pore Pressure of Soft Clay

Maosong Huang[1,*], Zhaoming Yao[2]

[1] *Tongji University, Shanghai, China.*

[2] *Anhui University of Science and Technology, Anhui, China.*

Abstract

Permanent settlement of the subsoil induced by traffic load has been paid more and more attention recently. Predicting the traffic-load-induced permanent settlement correctly especially on saturated soft clay ground has been an important issue for the highway construction. For this propose, simplified methods based on empirical models for predicting the accumulative deformations of soft clays are usually preferred. Numerous experimental studies have been conducted by cyclic triaxial tests. However, little is known concerning the effects of principal stress direction, where the major principal stress direction is rotated away from the vertical by an angle due to undrained embankment loading. In this paper, a series of undrained cyclic tests with the hollow cylinder apparatus have been performed on Shanghai soft clay samples that involved different directions of the principal stress. In order to create explicit (empirical) models for predicting cyclic cumulative strain and pore water pressure, undrained static tests were also conducted under different directions of the principal stress. Test results show that the cumulative plastic strain and pore water pressure depend not only on the effective confining pressure, applied cyclic stress ratio and number of cycles, but also on the direction of principal stress. The improved explicit (empirical) models previously proposed to calculate the cumulative axial plastic strain and pore water pressure of saturated clay from the cyclic triaxial tests are further verified by the cyclic hollow cylinder tests under fixed directions of the principal stress. Such improved explicit (empirical) models will provide an effective approach to calculating the long-term settlement of highway embankment built on the soft ground caused by traffic load.

Keywords: Cyclic cummulative deformation and pore pressure, principal stress direction, soft clay, hollow cylinder apparatus

1 Introduction

The permanent settlement of the subsoil induced by traffic load is one of the key factors which control the design life and the maintenance cost of highway. To propose a cost-effective design, it is desirable to correctly predict the traffic-load-induced permanent settlement especially on saturated soft

* *mshuang@tongji.eud.cn*

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clay ground. Miura et al. (1995) reported that one low embankment highway constructed on Ariake clay in Japan, the settlement of which had been come up to 1~2 m after 5 years operation. Similar situation has been occurred in China, for example, the subsidence, tracking and crack of the asphalt pavement of Shanghai outer ring highway have also been found due to the excessive deformation of the subsoil (Ling et al., 2002). These practices indicate that the deformation and differential settlement of the subsoil caused by traffic load will induce the crack of pavement and excessive deformation of road embankment, which will reduce the travelling comfort and increase the maintenance cost of highway.

Numerous experimental studies have been conducted on conventional triaxial loading tests (Sakai et al., 2003; Huang et al., 2006; Huang & Yao, 2012; Wichtmann et al., 2013; Guo et al., 2013). However, little is known concerning the effect of static embankment loading. Such an effect can be taken into consideration under either drained or undrained condition. Drained condition represents anisotropic "inclined" consolidation, where the major principal stress direction is rotated away from the vertical by an angle during consolidation due to embankment loading. Undrained consideration on the rotation of principal stress direction is supported if the consolidation is very slow or a conservative prediction of traffic-load-induced cumulative deformation is expected.

Setting up a constitutive model for calculating the cumulative plastic strain of saturated clay subjected to cyclic loading is the key work to permanent settlement analysis of soft subsoil induced by traffic load. Constitutive models for describing the accumulative deformation of soils under cyclic load can be divided into two types: implicit models and explicit (empirical) models. Typical implicit models include the bounding surface models, nested yield surface models and so on. Since the implicit model can only simulate the detailed process under each cyclic load, it is difficult to predict the traffic-load-induced permanent settlement by such a model due to a large number of cycles. As a result, the explicit models based on the experimental or measured data can be a more practical method to predict the traffic-load-induced permanent settlement.

The explicit (empirical) models mainly include the exponential model proposed by Monismith et al (1975), Li & Selig (1996) and Chai & Miura (2002). Huang et al (2006) and Huang & Yao (2012) proposed a new explicit (empirical) model different from the conventional explicit (empirical) model whose parameters were difficult to determined and uncertain in physical meaning. Hence, it is suitable for predicting the permanent settlement subjected to large number cyclic loading.

However, these explicit models mentioned above were developed from the results of conventional triaxial tests. It obviously cannot reflect the effect of the principal stress direction in soil due to the embankment loading. If an accumulative strain model for soil which is able to describe the effect of different principal stress directions can be developed from the experimental results under cyclic loading under a fixed principal stress direction, such a model will be more reasonable for predicting the permanent settlement under cyclic loading.

Limitation exists in the experiments with the conventional cyclic triaxial device for simulating the rotation of principal stress direction. Dynamic hollow cylinder apparatus will be an ideal choice to investigate the effect of the principal stress direction in present due to its ability to simulate various loading condition in complex stress paths.

In this paper, a series of tests with the dynamic hollow cylinder apparatus was performed on the saturated Shanghai soft clay and the development of cyclic accumulative deformation in the saturated soft clay is discussed under fixed principal stress directions. Meanwhile, the rationality of the explicit (empirical) model proposed by the authors is verified accounting for the effect of the principal stress direction on the undrained shear strength. It is more effective to predict the permanent settlement with the explicit (empirical) model for saturated soft clay which is capable of simulating the cyclic loading condition under various principal stress directions.