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Dynamic Behavior Characteristics of Clay in Wide Strain Range Based on Viscoelastic-viscoplastic Constitutive Model

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In this study, a cyclic viscoelastic-viscoplastic constitutive model based on the kinematic hardening rule was proposed. The proposed model, based on the generalized nonassociated flow rule, and the concept of the overconsolidated boundary surface as well as the nonlinear kinematic hardening rule within the context of infinitesimal strain, was calibrated and verified using cyclic triaxial tests. In order to examine the properties of the proposed model, the element simulations considering viscoelastic effects and also viscoplastic effects were studied by both an elastic-viscoplastic model and the viscoelastic-viscoplastic model based on the kinematic hardening rule. From the simulation of cyclic triaxial tests, it was found that viscoelastic behavior of clay in the small strain range is an important characteristic during motion. Both the shear modulus and the hysteretic damping ratio are strain level dependent, and these can only be explained within the framework of the viscoelastic-viscoplastic constitutive model. This study reveals that the viscoelastic-viscoplastic model can describe the damping characteristics of clay accurately at small strain levels, namely cyclic softening, while the elastic-viscoplastic model cannot do so.

INTRODUCTION

The well-known phenomenon of soil liquefaction is caused by both negative dilatancy under cyclic undrained loading conditions and upward flow of water after earthquake motion. As is well known, natural ground has a layered structure composed of sand and clay layers. Until now, many constitutive models for sand have been proposed and ground liquefaction has been studied, but most of them have been focused only on the liquefaction of the sand layer. But when we consider the response of ground composed of sand and clay layers, it can be expected that the behavior of the clay layer affects the ground motion.

Up to now, elastic or elastoplastic models have been often used for clay behavior in the dynamic analysis. It is, however, preferable to use viscoelastic-viscoplastic model for clay because of the rate sensitivity of clayey materials. Accordingly, in order to accurately predict the dynamic behavior of ground with liquefaction phenomena, the behavior of both sands and clays have to be taken into consideration. In this study, a viscoelastic-viscoplastic approach was adopted, since the behavior of soil materials is both viscoelastic and viscoplastic.

The linear viscoelastic approach is valid for behavior in the range of small strain, while the viscoplastic modelling of soils is useful in the range of large strain. In this study, the viscoelastic-viscoplastic constitutive model is proposed based on the concept of the nonlinear kinematic hardening rule; it incorporates 3 parameters for the viscoelastic model, which is composed of the Maxwell model and Voigt model. However, in the proposed model, a 3-parameter model is adopted based on the results from other research (Murayama and Shibata, 1964; Kondner and Ho, 1965; Hori, 1974; Murayama, 1983; Di Benedetto and Tatsuoka, 1997).

Perzyna (1963) developed an elasto-viscoplastic continuum for analyzing clay behavior at large-strain field and creep failure. Oka (1982) and Adachi and Oka (1982) developed an elasto-viscoplastic constitutive model for clay based on the overstress-type viscoplastic theory. More recently, Oka (1992) proposed a cyclic elasto-viscoplastic model for clay using the nonlinear kinematic and isotropic hardening rules, initially advocated by Armstrong and Frederick (1966) and developed by Chaboche and Rousselier (1983). The formulation of the model was done with 2 yield surfaces for shear and compressional viscoplastic components in a general form. However, the validity of the model was evaluated for shear plasticity based on experimental results of cyclic undrained triaxial compression tests for natural clay.

As mentioned above, the main objective of this study can be divided into 2 parts. First, a viscoelastic-viscoplastic constitutive model for clay based on the nonlinear kinematic hardening rule is proposed. Second, in order to examine the strength and deformation characteristics of natural clay, laboratory tests such as cyclic triaxial tests, and a cyclic triaxial test to determine clay's deformation properties, are carried out. Then the viscoelastic-viscoplastic characteristics of clay are studied with a comparison between the simulation results by the proposed model and the experiment results.

CYCLIC VISCOELASTIC-VISCOPLASTIC CONSTITUTIVE MODEL FOR CLAY

Many constitutive models for clay have been proposed and studied based on elastoplastic or elasto-viscoplastic theory, and it has been recognized that the effect of loading time is a salient feature. Since clay behavior is viscoelastic in the small strain, a viscoelastic-viscoplastic model for clay is necessary to explain the actual deformation characteristics of clay in both small and large strain levels.

The linear viscoelastic approach is valid for behavior in the small strain range, while viscoplastic modeling of soils is useful in the large strain range, including failure. In this study, a cyclic viscoelastic-viscoplastic model for clay based on the nonlinear kinematic hardening rule and 3-parameter viscoelastic theory is proposed.

Chaboche and Rousselier (1983) proposed a constitutive model for metal using the concept of the nonlinear kinematic hardening

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