A Modified ALPHA Model Based on Subloading Surface Theory

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ABSTRACT

ALPHA model is modified by adopting subloading surface theory, and the initial anisotropy is taken into account. Yield functions for the modified model in true stress space and dissipative stress space are deduced, and the loading/unloading criterion is developed. Considering the characteristic of the modified model, an elastoplastic finite element code is programmed by using semi-implicit constitutive integration algorithm. Finite element simulations for triaxial tests are performed with varied model parameters, and the numerical results are compared with that of modified Cam clay model. The comparison shows that the modified ALPHA model, integrating the merits of ALPHA model and subloading surface model, can describe more complicated deformation behaviors by changing model parameters.

KEY WORDS: ALPHA model; modified Cam clay model; subloading surface theory

INTRODUCTION

To predict the deformation behavior of geomaterial is necessary for estimating the safety and strength in geotechnical engineering. Nevertheless, the geomaterial exhibits more complicate deformation behaviors such as nonlinearity, dilatancy, and anisotropy. Until now none of general constitutive models can cover all the deformation characteristic of geomaterial, and of the constitutive models address to describe one or more aspects of deformation behavior. Recently, based on the thermodynamic rule, Collins and his co-workers (Collins and Kelly, 2002; Collins and Hilder, 2002) present an ALPHA (α τ) model, a hierarchic model, which combines the volumetric hardening behavior of modified Cam-clay model, the 'coulomb frictional' shearing of the linear frictional and original Cam-clay models. Yield surface of the model is defined in dissipative stress space and true stress space, and it can be transformed between the two stress spaces. The plastic flow is associated in dissipative stress space but non-associated in true stress space. Through varying model parameters, the ALPHA model changes its yield surface shape, and can reduce to the modified Cam-clay model or linear frictional model. Accordingly, the model can predict deformation behavior for a large scope of geomaterials. However, the hierarchic ALPHA model falls into the scope of conventional elastoplastic constitutive model, which premises the interior of the initial yield surface is a purely elastic domain and the yield surface remains stationary during elastic stress changing. Thus, it is incapable of predicting a plastic deformation within the initial yield surface, which can often be observed in geomaterial model tests. Subloading surface model (Hashiguchi and Ueno, 1977; Hashiguchi, 1989) has been proposed to improve on the limitation of conventional elastoplastic model. This model defines two yield surfaces named normal yield surface and subloading surface, which keep geometric similarity in their shapes. The normal yield surface is the same as the yield surface defined in conventional elastoplastic theory, and the subloading surface always expands or contracts such that the current stress point lies on it but can never go beyond the normal yield surface. It is assumed that the plastic strain rate progresses as the ratio of the size of the subloading surface to that of the normal yield surface increases. A conventional elastoplastic response is obtained due to loading when the subloading surface coincides with the normal yield surface. The subloading surface model always fulfills the smoothness condition and exhibits a smooth elastic-plastic transition. This unconventional method to depict elastoplastic deformation is also referred to as subloading surface theory. Another limitation of ALPHA model is that it takes the hydrostatic axis as the central axis of isotropic hardening; thereby the ALPHA model cannot reflect the deformation characteristics of initially anisotropic soil. Approximately at the time of Cam-clay model was developed, Ohta-Sekiguchi model (Shibata, 1963; Ohta and Hata, 1971; Sekiguchi and Ohta, 1977) was presented and developed to take into account the initial anisotropy of soil, in which the isotropic hardening centers on the K0 axis.

This study improves the ALPHA model in terms of subloading surface theory, and takes into account the initial anisotropy for K0 condition following Ohta-Sekiguchi model. Yield function for the modified model in true stress space and dissipative stress space is deduced, and the loading/unloading criterion is developed. Considering the characteristic of the modified model, a finite element code is programmed by using semi-implicit constitutive integration algorithm. Finite element simulations for triaxial tests are executed to validate the developed model and illustrate the performance of the model.