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Implementation of an Elastoplastic–Viscoplastic Constitutive Model of Soil in ABAQUS Code and Its Validation on Laboratory Paths

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ABSTRACT: Many attempts have been made to model the mechanical behavior of soil materials. The assumption that predicting soil plastic behavior in some engineering problems doesn't present a significant relation with construction time has led to the neglect of the time effect in many constitutive models in geotechnical engineering. However, damage due to settlement or instability of excavations and many other such problems are caused by the time-dependent plasticity behavior of soil. Also, in some phenomena such as explosions, earthquakes, or consolidation, the issue of time is inherently raised. Therefore, it is important to install a time-dependent constitutive model in finite element codes that can properly predict the time-dependent behavior of structures in geotechnical engineering. In this study, an elastoplastic-viscoplastic constitutive model via UMAT subroutine was implemented in the ABAQUS finite element code. By considering the nonlinear elastoplastic-viscoplastic behavior with mixed (kinematic and isotropic) hardening mechanisms, this model removes most of the limitations of the constitutive models already installed in the ABAQUS code. The results of validation under laboratory paths such as creep, relaxation and rate effect indicate the high capacity and capability of the model in predicting the time-dependent behavior of soil

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1- Introduction

In a large number of geotechnical problems, the strain rate effect on the behavior of soil materials is significant. Several researches have been done so far to investigate the strain rate effect on the mechanical properties of soil materials [1, 2]. One of the most important issues is the increase in strength and stiffness modulus due to the increase in strain rate [3]. Moreover, as the initial strain rate increases, the creep or the stress relaxation leads to more crushed soil particles [4]. Studies show that volumetric strains during the creep are both dilatancy and contractancy while the axial strain is always in the same direction with the applied stress [5]. This topic can be considered to define the direction of viscoplastic strains in constitutive models.

Along with doing experimental studies on the time-dependent behavior of soils, some new constitutive models have been developed and presented in order to describe these aspects of soils behavior. One of the recommended methods for modeling the time-dependent behavior of materials is the Perynza theory of overstress [6]. Many elasto-viscoplastic constitutive models have been developed to model the time-dependent behavior of material based on this theory [7-10].

In the constitutive models based on Perzyna overstress, it is possible to exceed the stress point in the stress space by the yield surface, which contradicts the principles of thermodynamics. On the other hand, the principle of compatibility is not satisfied [11, 12]. In addition, the instantaneous behavior in soils is predominantly elastoplastic rather than elastic. Thus, the development of time-dependent modeling of soil has been inevitable. The elastoplastic-viscoplastic model based on boundary surface theory developed by Dafalias and Kaliakin [11] is important progress in comparison with elasto-viscoplastic models. In the other model, a viscoplastic mechanism based on a new concept called viscous kinematic hardening has been added to the CJS elastoplastic model. Base model CJS was presented firstly by Cambou and Jafari [12]for granular soils. This model was then developed to better describe the behavior of soils [13, 14]. The elastoplastic-viscoplastic version of this model [15] has some advantages, including considering the instantaneous elastoplastic behavior, plastic rupture, and modeling the second stage of creep. In addition, this model is able to explain the behavior of the time function during the cyclic loading path due to its kinematic hardening mechanism.

For this purpose, in the present study, the elastoplastic-viscoplastic model of CJS was implemented in the ABAQUS code via VUMAT subroutine and validated under laboratory paths.

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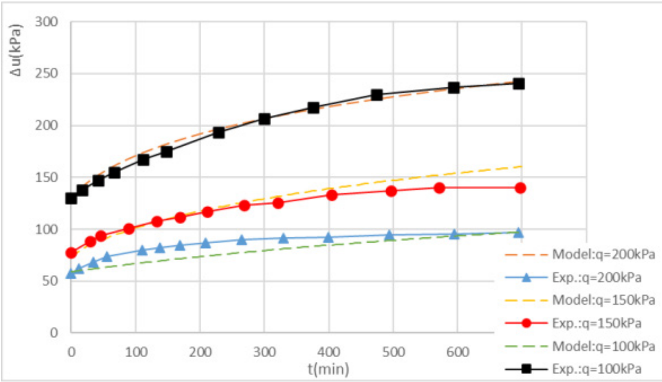

Fig. 1. Excess of pore water pressure in undrained creep tests.

2- Methodology

The basic CJS model is an elastoplastic model and, besides the nonlinear elastic mechanism, includes two plastic mechanisms; isotropic and deviatoric. The yield surface in the first mechanism is perpendicular to the hydrostatic axis in the stress space and an isotropic hardening rule pilots its evolution. For the second mechanism, the yield surface has asymmetric in the deviatoric plane and piloted by a mixed (isotropic and kinematic) hardening rule. For added viscoplastic part, similar to the elastoplastic part, there are two mechanisms; deviatoric and isotropic. The intensity of viscoplastic strain rate depends on the distance between the plastic yield surface and the viscous surface (delayed surface). The evolution of the viscous surface is done based on the concept of viscous kinematic hardening. The movement of the viscous surface is always toward the plastic yield surface and when these two surfaces reach each other, viscoplastic evolution will be stopped. The secondary stage of creep is modeled by defining a limiting surface called the secondary creep surface. Because of the interesting options of the model in describing the time-depending behavior of soils, it was implemented in the ABAQUS code via VUMAT subroutine in the present work. After implementation, for elaborating viscoplastic mechanism response, a modification was applied to the direction of viscoplastic strain rate.

3- Results and Discussion

In order to validate the model, results from the experiments on the clay soil sampled from the depth of 5 to 8 m of a clay core of an earth dam were used [16].

According to the results of undrained axisymmetric triaxial tests with measuring pore water pressure under monotonic loading paths and considering confining pressure of 400 kPa, the effective internal friction angle and the effective cohesion are φ=27° and c=0, respectively. Then various time-dependent tests such as creep and stress relaxation were performed under monotonic and periodic loading conditions [16].

In order to determine the parameters of the model, results of axisymmetric triaxial tests with the strain rate of 1% were used. Based on the obtained values of parameters and without change in them, different tests including creep, stress relaxation in monotonic and non-monotonic paths, were simulated and compared with the results of experimentation. An example of model validation is presented in Figure 1. This is related to the undrained creep test with different applied constant deviatoric stress and generation of excess pore water pressure during the time. As seen from this Figure, the results of the simulation are in agreement with those of experimentation.

4- Conclusion

An elastoplastic-viscoplastic model was implemented successfully through the UMAT subroutine in ABAQUS/Explicit code. This model presented a new solution to resolve the existing limitations in many elasto-viscoplastic models based on Perynza overstress with introducing a viscous hardening mechanism with the kinematic nature. By installing this model, many time-dependent problems in geotechnical engineering can be modeled in the ABAQUS code. The results of model validation on laboratory paths indicate a very good capacity of the model in describing the time-depending behavior of soils.

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