III-261 A Constitutive Model for Rock Discontinuity with Strain Softening

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Introduction

In order to explain the mechanical behavior of joint in geomaterials, research usually assumed that the joint itself is discontinuous and its mechanical behavior is related to frictional angle, roughness of the joint and joint orientation and spacing. The thickness of joint in geomaterial usual is considered as zero. In present study, we assumed that the joint in geomaterial is continuous medium and its mechanical behavior can still be explained by continuous medium theories. Based on the Adachi-Oka' model with strain hardening and softening, a new constitutive model is proposed to describe the mechanical behavior of the joint. As a special case, the direct shear test is considered. In order to explain the physical meaning of the variables involved in the constitutive equation, we introduce a new concept of so-called equivalent displacement. Some components are real displacements which we are interested in. The equivalent displacement is related to plastic strain tensor by introducing parameter D which stand for the thickness of joint or the shearing zone of samples undergoing direct shear test.

Description of the model

Adachi Oka's model with strain-softening is considered within stress-strain space. Therefore it cannot be directly applied to direct shear test or joint problem in which displacement instead of strain is considered. As a matter of fact, the thickness of shear zone in which large shear strain may occur is not equal to zero and the distribution of shear deformation along the direction normal to the shear direction is continuous. The problem left now is that the depth D cannot be determined because not only it is related to material properties but also to boundary condition. We here introduce the parameter D only try to establish the relation between shear displacement and strain in shear zone. The magnitude of D is not interested to us because by some calculation we can substitute it by other variable which can be measured by experiment.

In the present model, the non-associated flow law, plastic yield function, the plastic potemtial function the boundary surface which define the boundary between normally consolidated region($f_b \geq 0$) and overconsolidated region($f_b<0$) take the same forms as the ones of Adachi-Oka's model and and are given in Eq.(1) (2) (3) (4) respectively,

$$d\varepsilon^p_{ij}=A\cdot\frac{\partial f_p}{\partial\sigma_{ij}}\cdot\frac{\partial\eta^*}{\partial\sigma^*_{mn}}d\sigma^*_{mn} \qquad (1) \qquad\qquad f=\eta^*=k_s \qquad (2)$$

$$f_b=\eta+M_m\ln\left(\frac{\sigma_m+b}{\sigma_{mb}+b}\right)=0 \qquad (3) \qquad\qquad f_p=\eta+\tilde{M}\ln\left(\frac{\sigma_m+b}{\sigma_{mb}+b}\right)=0 \qquad (4)$$

here

$$\eta^*=(s^*_{ij}\ s^*_{ij}/\sigma^{*2}_m)^{1/2} \qquad (4) \qquad\qquad \sigma^*_{ij}=\frac{1}{\tau}\int_0^z \exp\left(-\frac{z-z'}{\tau}\right)\sigma_{ij}(z')dz' \qquad (6)$$

is stress history invariant and stress history.

The strain hardening and softening parameter κ_s is different from the one in Adachi-Oka's model. In present case, we introduced a new concept of so-called equivalent displacement as follow,

$$\overline{e^p_{ij}}=\overline{\varepsilon^p_{ij}}-\overline{\varepsilon^p_m}\cdot\delta_{ij}/3 \qquad (7) \qquad\qquad \overline{\varepsilon^p_{ij}}=\int_0^{\varepsilon^p_{ij}} D(e^p_{mn})d\varepsilon^p_{ij} \qquad (8) \qquad\qquad \overline{\gamma^p}=\sqrt{\overline{e^p_{ij}}\cdot\overline{e^p_{ij}}} \qquad (9)$$

Here D is the depth of joint and is the function of plastic strain. $\overline{\varepsilon^p_{ij}}$ is equivalent displacement and its physical meaning is explained in Fig.1. The equations relating the equivalent displacement to plastic strain are given as follow,

$$dw_s^p=D(e^p_{mn})\cdot\gamma^p_{xy} \qquad (10)$$

$$w_s^p=\int_0^{\gamma^p_{xy}} D(e^p_{mn})d\gamma^p_{xy} \qquad (11)$$

$$dw_n^p=D(e^p_{mn})\cdot\varepsilon^p_{yy} \qquad (12)$$

$$w_n^p=\int_0^{\varepsilon^p_{yy}} D(e^p_{mn})d\varepsilon^p_{yy} \qquad (13)$$

$$w^p_{xx}=\int_0^{\varepsilon^p_{xx}} D(e^p_{mn})d\varepsilon^p_{xx} \qquad (14)$$

$$w^p_{zz}=\int_0^{\varepsilon^p_{zz}} D(e^p_{mn})d\varepsilon^p_{zz} \qquad (15)$$

By introducing these parameters, we assumed that the strain hardening and softening parameter κ_s takes the form as Eq.(16)

$$k_s=\frac{M_f^*\,\overline{G'\gamma^p}}{M_f^*+\overline{G'\gamma^p}} \qquad (16)$$

It should be pointed out that the equation is similar to Adachi-Oka's model only in the form. Its physical meaning is different. Eq.(16) assumed that the strain hardening and softening parameter is dependent on the equivalent displacement $\overline{\gamma^p}$. Parameter $\overline{G'}$ has the dimension of 1/Length and is the initial tangential modules between the stress historical parameter η^* and equivalent displacement $\overline{\gamma^p}$. By above mentioned assumption we can easily obtain the constitutive equation related to displacement.

Application to direct shear test for jointed concrete sample

In order to examine the validity of the model proposed in this paper, a series of direct shear tests are carried out for jointed speciments. The joint in the sample here is carefully cast from natural joint surface of rock. Fig 2 is the Comparison between experimental results and theoretical computed results. It is evident that the peak strength and residual strength can be well simulated while for the after-peak stress the theoretic results decrease very rapidly which is not coincide with the experiment ones. The dilatancy can be well simulated by the present constitutive model.

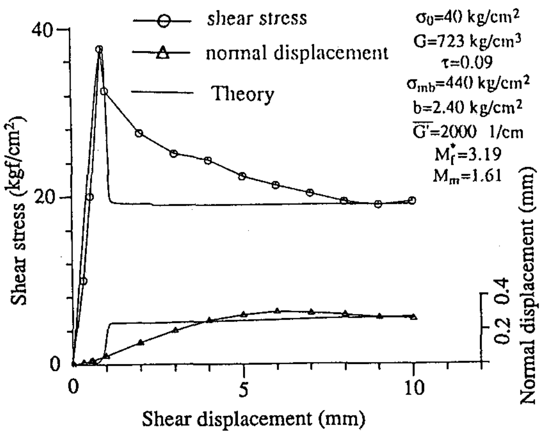

Fig.(1) Geometry of the shear zone in sample undergoing direct shear

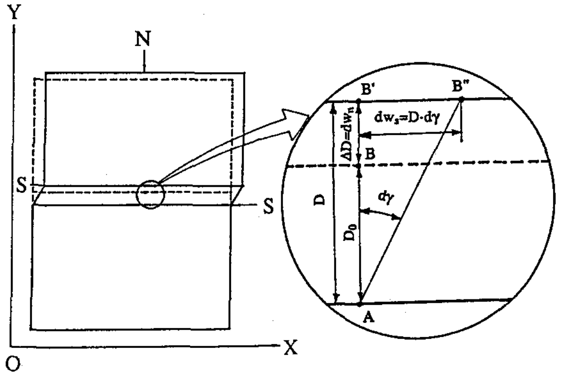

Fig (2) Comparison between experimental results and theoretical computed results.for the relation of shear stress -displacement and shear displacement-normal displacement for jointed cement sample undergoing direct shear test at constant normal stress.

Conclusion

Present constitutive model is based on the Adachi-Oka's model with strain-hardening and strain-softening. By introducing a new strain-hardening and softening parameter to which we endow a new physical meaning, we can use continuous theory to describe the discontinuous behavior of joint materials. Comparison shows good agreement between experiment results and computed results based on the model.

Reference

Oka, F. and Adachi, T. : "A constitutive equation of geologic materials with memory." Proc. 5th Int. conf. on Numerical Method in Geomechanics,1,pp.293-300, 1985