Journal of Zhejiang University-SCIENCE A

Cite this as: Ting-chun LI, Lian-xun LYU, Shi-lin ZHANG, Jie-cheng SUN, 2015. Development and application of a statistical constitutive model of damaged rock affected by the load-bearing capacity of damaged elements. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 16(8):644-655. [doi:10.1631/jzus.A1500034]

Development and application of a statistical constitutive model of damaged rock affected by the load-bearing capacity of damaged elements

Key words:

Rock materials, Damaged elements, Statistical theory, Load-bearing capacity, Constitutive model

Rock damage mechanism

◎ Introduction

To investigate the damage and deterioration mechanism of rock under the effect of the external environment, a model of a rock specimen with an initial defect element can be established (Fig. 1).

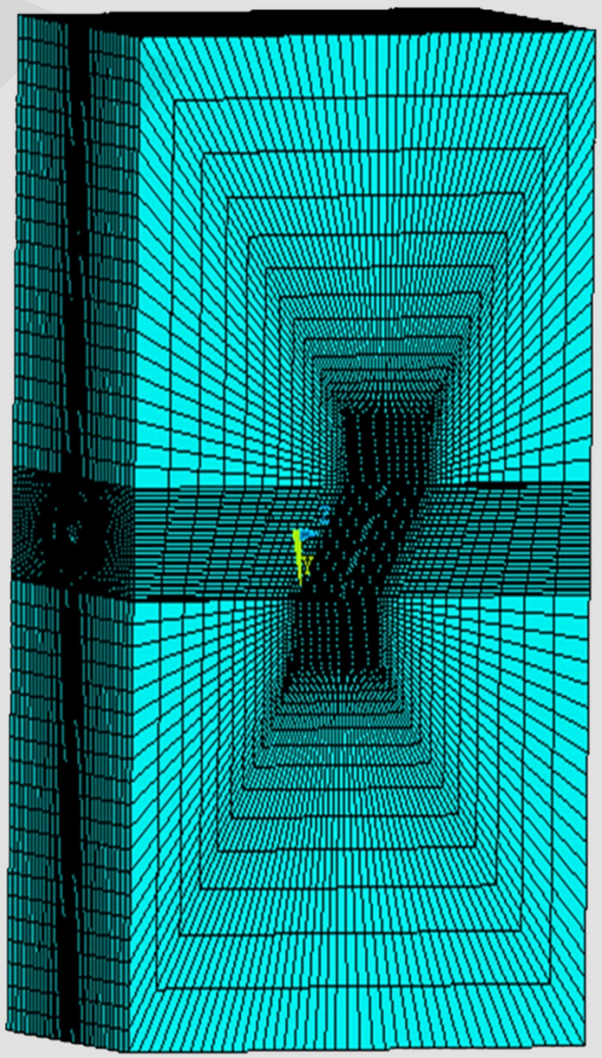


Fig. 1 Calculation model of a rock specimen

◎ Conlusions

➢ Deformation submitting to linear elasticity explains the effect of threshold in the damage process of rock materials.

➢ The stress near the damaged elements does not match the strength of the microelements when the stress and strain are at a lower level.

➢ In view of the deformation curve of rock and the characteristic of material residual strength, the damaged elements have a certain stress bearing capacity.

Statistical constitutive model of damage

➢ The damage to the rock elements can be defined as the result of reduced stiffness caused by the change in the physical properties of undamaged elements, we conclude that:

$$\sigma_f = \eta\sigma_w$$

➢ Assuming that the initial damage variable of rock D_0=0, then the damage model can be simplified as:

$$\sigma_{w0} = \sigma \qquad \sigma_w = \frac{1}{1-D+\eta D}\sigma$$

➢ The strength of the rock elements F complies with the Weibull distribution, then the distribution of the density function can be expressed as follows:

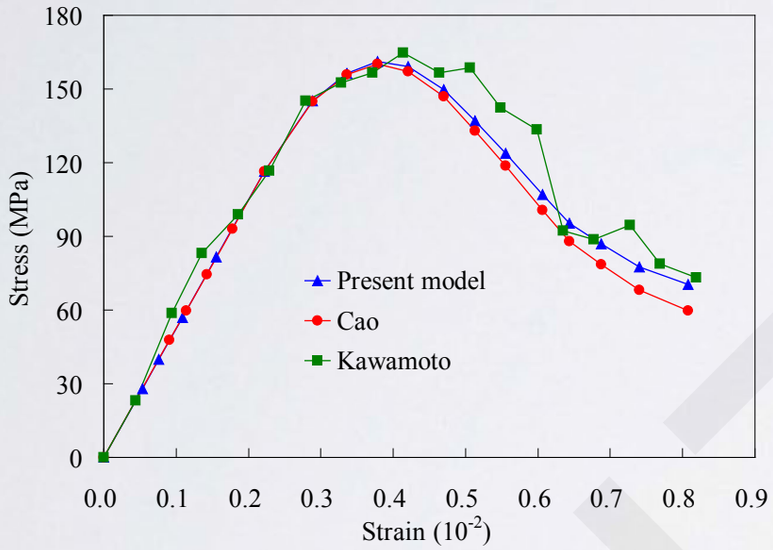
$$P(F) = \frac{m}{F_0}\left(\frac{F}{F_0}\right)^{m-1}\exp\left[-\left(\frac{F}{F_0}\right)^m\right]$$

➢ Mohr-Coulomb yield criterion can be taken as the strength criterion, the statistical constitutive model of damage in the whole process of rock deformation can be described as follows:

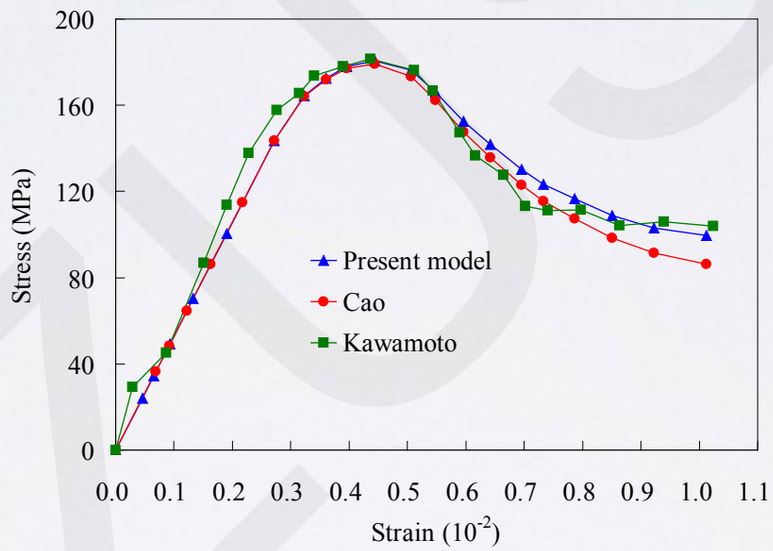
$$\sigma_1 = \begin{cases} E\varepsilon_1(1-D+\eta D)+\upsilon(\sigma_2+\sigma_3) & (F \geq 0) \\ E\varepsilon_1+\upsilon(\sigma_2+\sigma_3) & (F<0) \end{cases}$$

Verification and analysis of the model

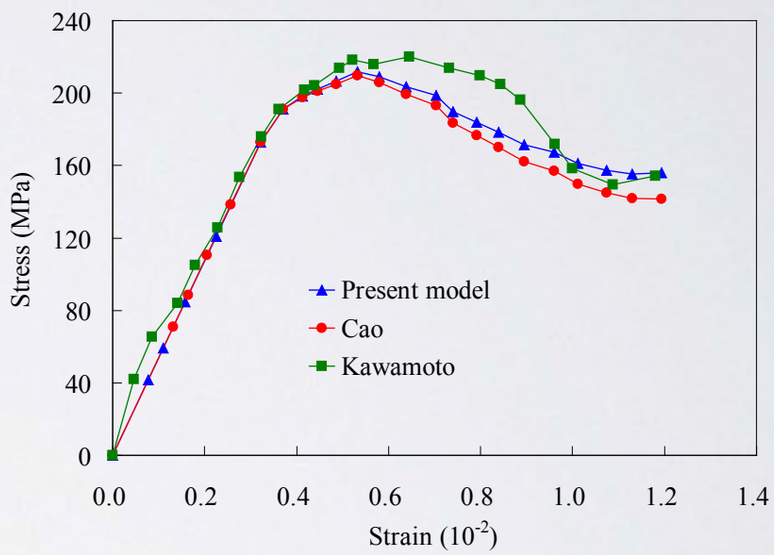
The theoretical curves in this paper are consistent with the test data, and they reflect the stress-strain relationship of rock under different confining pressures.



(a) confining pressure 3.5 MPa



(b) confining pressure 7.0 MPa



(c) confining pressure 14.0 MPa

Fig. 2 Comparison of present model under specific confining pressure with test curves of Kawamoto et al. (1988) and theoretical curves of Cao et al.

Illustrative examples

◎ Introduction

Taking the Jiangxi Road station of the Qingdao Metro as engineering background, a stability analysis of station excavation can be conducted by obtaining parameters of the physical and mechanical properties of the engineering rock mass from field investigation and laboratory tests.

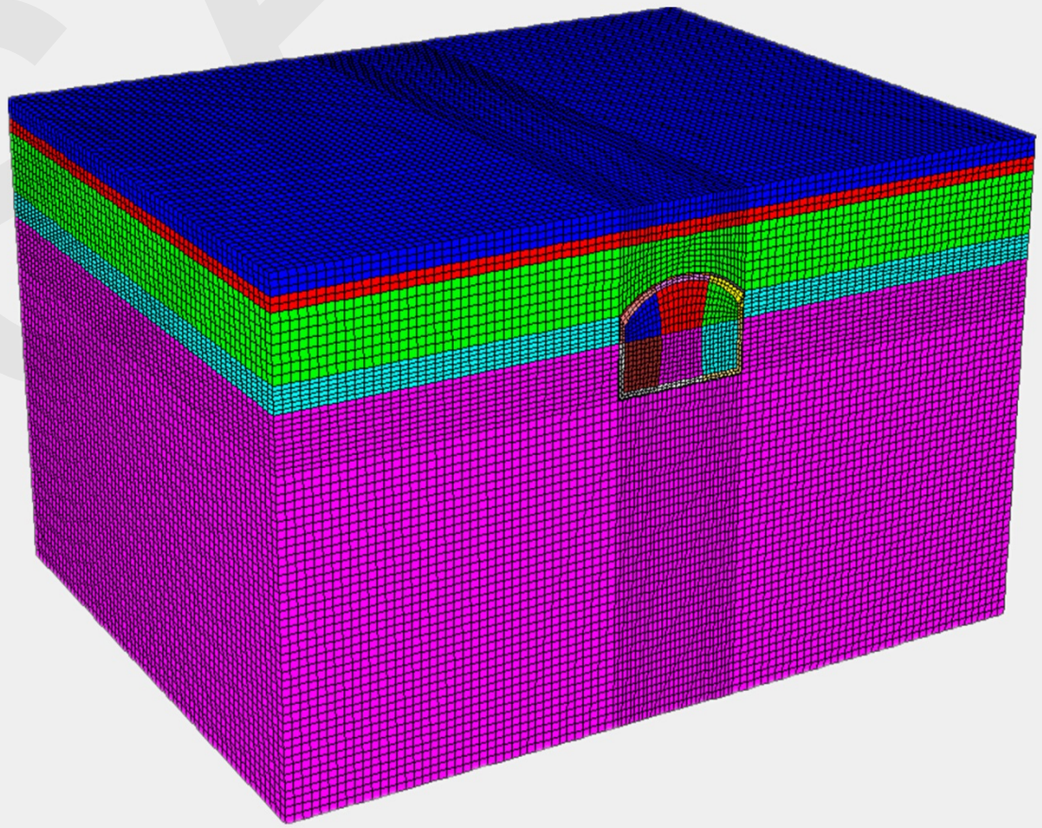


Fig. 3 Calculation model of the Jiangxi Road station of the Qingdao metro

◎ Conlusions

➢ Plastic zone area considering damage effect was twice size of that without considering damage effect.

➢ Settlements of the crown and the surface by considering damage effect were larger than those without considering damage effect.

➢ Constitutive model can reflect deterioration effect of soft rock mass, and the computation results are reasonable and reliable.

Results and conlusions

- Damage can be defined as the result of lower stiffness due to a change in the physical properties of undamaged elements. A correction coefficient of damage is introduced to correct the stress borne by damaged elements.

- The stress concentration near initial defects is the main cause of rock deterioration, along with material damage. Rock of different initial conditions can be regarded as materials with different properties, and the initial damage variable can be assumed to be zero, then the problem of the solution of undamaged conditions can be avoided and the damage model can be simplified reasonably.

- A statistical constitutive model of rock damage, whose reasonability has been discussed and analyzed, was established on the basis of a triaxial compression test and the use of theories of continuum damage and statistical mechanics. The model and test curves have high fitting precision, which can reflect the stress-strain relationship of the whole process of rock failure. In particular, the description of the rock strain softening stage is more reasonable.

- Taking the Jiangxi Road station of the Qingdao Metro Line 3 as engineering background, a stability analysis of station excavation was conducted using the established constitutive model. The computation results indicate that the model can reflect the deterioration effect of the soft rock mass at the site and that the results from the model coincide well with field monitoring deformation curves.