Experimental Study of Triaxial Creep Characteristics of Q_2 Loess in Yan'an

DUAN Zhao[1,2,a], PENG Jian-bing[1,b]

[1] School of Geology Engineering and Geomatics，Chang′an University，Xi′an710054，Shaanxi，China

[2] College of Geology and Environment, Xi'an University of Science and Technology, Xi'an 710054, Shaanxi, China

[a,b]landsliders@126.com

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Abstract. Triaxial creep test, was conducted on Yan'an Q_2 loess under different moisture contents and confining stresses. The creep strain-time curves were obtained. Based on the test results, the stress levels, confining pressures, and moisture contents were all found to have great impact on the creep properties of Yan'an Q_2 loess, and when the stress level is higher than the yield stress of Q_2 loess, samples show significant creep properties. According to the creep test results and models , a three-dimensional viscous creep model of elasto-plastic stress state was developed based on the use of analogy. On this basis, the transient creep damage constitutive model of loess and the quasi-Newton method were established, where the model parameters were fitted by the theoretical values based on the comparison with the experimental curve, indicted great model applicability.

Introduction

In recent years, with the rapid development of the energy industry in Yan'an, more construction projects are undergoing in this region , all kinds of engineering activities are contributing to the local tremendous economic growth and benefits, however, which also makes the region experiencing a lot of engineering geological problems [1-2]. Practices which based on a large number of test found that the rock mass stress, deformation, strength and construction has a close correlation between the deformation and rock mass destruction which is obvious due to the time effect [3-6], namely the rheological properties. Since the Yan'an loess is very often encountered during construction and engineering works and used as building materials, the experimental study of its rheological properties contributes to better understanding of the region, the variation of strain over time, and the construction area, and also has very important theoretical and practical significances.

Creep characteristics is an important branch of study of the rheological properties, creep characteristics of loess through research can better explain the loess slope, landslides and dam long lasting deformation, or building long lasting foundation subsidence engineering geological problems. In this paper, the triaxial creep creep test instrument, qualitative analysis of the influence of confining pressure, moisture content and stress levels on the Yan'an Q_2 loess creep characteristics, through analysis of test data, the establishment of a three-dimensional stress state sticky elastoplastic model and consider the instantaneous damage viscous elastoplastic model, and according to comparative theoretical curve and experimental curve to show the applicability of the model.

Experimental materials and methods

Test soil samples taken from Yan'an city, soil depth of 18~20m, belongs Q_2 loess, physical and mechanical sample indicators in Table 1. Test temperature is maintained at 20±1℃; trial for Φ39.1 ×80mm with a sample size, by natural air-drying and water membrane migration method to allocate the sample to the required moisture content (5,10,15 and 20%) and conservation (48h or more); test set three levels of confining pressure, including the 100, 200 and 300kPa; Test Methods triaxial consolidated undrained shear creep Variable tested positive stress caused by triaxial consolidated undrained shear test is applied to determine the shear strength rating [7], each grade creep test time is set to 12h.

Table 1 The physical properties of Q_2 loess

density/ (g·cm^{-3})	void ratio	liquid limit /%	plastic limit /%	plasticity index /%	plastic figure	particles		
						>0.05 mm	0.05～0.005mm	<0.005 mm
1.82	0.641	27.6	17.0	10.6	CL	15	67	18

Test results and analysis

Boltzmann superposition principle in accordance with the test data 12 loess samples processed to a water content of 10% and 20%, confining pressure 100kPa and undisturbed loess samples 300kPa example, select the strain-time curves and stress-strain curve analysis.

Strain-time curve analysis: By strain-time curve (Fig.1) analysis can draw the following conclusion: ①From the shape of the curve, the load transient has an instantaneous deformation. At lower stress levels, instantaneous deformation is small, to attenuate the creep-based, and as time increases soon enter the constant creep stage. With the stress level increases, the instantaneous deformation amount increases, when the stress is increased to shear strength, creep into the acceleration phase, a greater deformation of the specimen in a short time, the formation of shear failure; ②Water content Influence of creep more obvious, the same confining pressure, the greater the moisture, creep single stage produces the greater load, which is a high moisture content of soil under low cement related degree; ③The same moisture content, confining The smaller pressure creep phenomenon is more obvious, a single-stage creep produce greater load. When the sample suffered less stress around, the resistance movement to the surrounding soil particles is relatively small, so the amount of axial deformation will increase, of course, sample enters the constant creep stage time required for longer;④ The samples show significant creep properties when the stress level is higher than the yield stress of Q_2 loess,

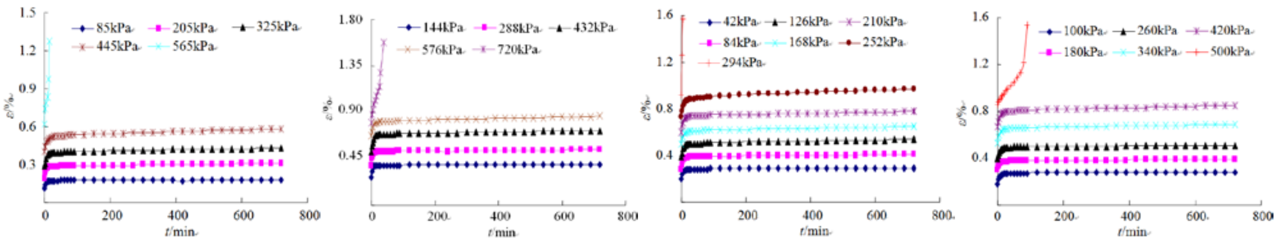


Fig.1 strain-time curves

Instantaneous injury loess stick plastic creep model

Sticky establish elasto-plastic model: Through the front strain-time curves and stress-strain analysis tautochrone point of view, can be divided into loess creep visco-elastic and visco-plastic two stages, it had a total creep deformation based on the principle of the sum of the various stages of deformation, The linear visco-elastic model and linear visco-plastic model in series combined model consisting of loess creep [8]. On this basis, according to the Sun are presented herein analogy [9], the one-dimensional stick plastic creep model rewritten to give the creep constitutive model three-dimensional stress conditions, below the equations:

$$\{\varepsilon\}=\frac{1}{2G_{\mathrm{H}}}\{\sigma\}+\frac{1}{2G_{\mathrm{K1}}}\{\sigma\}[1-\exp(-\frac{G_{\mathrm{K1}}}{H_{\mathrm{K1}}}\cdot t)]+\frac{1}{2G_{\mathrm{K2}}}\{\sigma\}[1-\exp(-\frac{G_{\mathrm{K2}}}{H_{\mathrm{K2}}}\cdot t)]+(\frac{1}{2G_{\mathrm{M}}}+\frac{t}{2H_{\mathrm{M}}})\left\langle\left(\frac{F}{F_0}\right)\right\rangle\frac{\partial Q}{\partial\{\sigma\}} \tag{1}$$

Where, $\{\varepsilon\}=\{\varepsilon_x,\varepsilon_y,\varepsilon_z,\gamma_{xy},\gamma_{yz},\gamma_{zx}\}^T$, $\{\sigma\}=\{\sigma_x,\sigma_y,\sigma_z,\tau_{xy},\tau_{yz},\tau_{zx}\}^T$,G, H, respectively, under three conditions shear modulus and viscosity coefficient, where $G_i = E_i / 2(1+\mu)$; $\langle (F/F_0) \rangle$ switching function, when $F \le 0$, a value of 0, when $F > 0$, the value of for the F/F_0; *F* is the yield function, is a function of three stress invariants, namely $F(\sigma) = F(\sigma_m, J_2, J_3)$, select the D-P yield criterion, Eq.3; F_0 to make coefficient immeasurable and the use of constant, usually taken 1; when *Q* is the plastic potential function, when using the related flow rule, $Q = F$, uses not related flow method, the $Q \ne F$. SUN, ZHENG and NAN et al. research indicates that, D-P yield criteria on π plane into a circle, can be seen as Mohr-Coulomb criterion in order to avoid singularities and make a smooth approximation, you can adjust the cone size to accommodate the Mohr-Coulomb criterion, this paper selection of D-P yield criterion to determine the loess yield function, yield function equations is [10-11]:

$$F = \alpha I_1 + \left(J_2\right)^{1/2} = k \tag{2}$$

Where, $\alpha = \mathrm{tg}\varphi \ / \left(9 + 12\mathrm{tg}^2\varphi\right)^{1/2}$, $k = 3c / \left(9 + 12\mathrm{tg}^2\varphi\right)^{1/2}$, $J_2 = [(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_2)^2 + (\sigma_3 - \sigma_1)^2]/6$, $I_1 = 3\sigma_m$, c、φ are the cohesion and internal friction angle.

Instantaneous damage constitutive model of visco-elasto plastic: Loess during creep damage include instantaneous damage when loaded with the creep deformation and creep damage arising from the development, further explore the transient creep damage on the basis of the loess section built on sticky plastic rheological model deformation of the case. Because the plastic deformation of loess structural damage occurs, the parameters of the mechanical properties of loess with plastic deformation accumulation continued deterioration, and therefore, to reflect the creep characteristics of loess by considering coupling damage and plastic strain. YU[12] proposed a full decoupling method to consider coupling damage and creep, the method that: without considering the material injury cases solved loess creep deformation of expression, coupled with damage of loess deterioration of the elastic modulus and the effect of increasing the effective stress injury containing the equivalent deformation modulus or effective stress were replaced corresponding equivalent deformation modulus or creep stress to the mathematical equations as follows:

$$E_t^* = \left(1 - D\right) \quad \text{or} \quad \sigma^* = \sigma / \left(1 - D\right) \tag{3}$$

Where, E_t* is equivalent deformation modulus, σ* is the effective stress, *D* is the damage variable. In this paper, according to the method described above on the basis of the one-dimensional model of the state, according to the analogy derived directly creep model three-dimensional stress state:

$$\begin{aligned} \{\varepsilon\} &= \frac{1}{2G_{\mathrm{H}}}\{\sigma\} + \frac{1}{2G_{\mathrm{K1}}}\{\sigma\}[1 - \exp(-\frac{G_{\mathrm{K1}}}{H_{\mathrm{K1}}}\cdot t)] + \frac{1}{2G_{\mathrm{K2}}}\{\sigma\}[1 - \exp(-\frac{G_{\mathrm{K2}}}{H_{\mathrm{K2}}}\cdot t)] \quad F < 0 \\ \{\varepsilon\} &= \frac{1}{2G_{\mathrm{H}}}\{\sigma^*\} + \frac{1}{2G_{\mathrm{K1}}}\{\sigma^*\}[1 - \exp(-\frac{G_{\mathrm{K1}}}{H_{\mathrm{K1}}}\cdot t)] + \frac{1}{2G_{\mathrm{K2}}}\{\sigma^*\}[1 - \exp(-\frac{G_{\mathrm{K2}}}{H_{\mathrm{K2}}}\cdot t)] + (\frac{1}{2G_{\mathrm{M}}} + \frac{t}{2H_{\mathrm{M}}})\left\langle \left(\frac{F^*}{F_0}\right) \right\rangle \frac{\partial Q^*}{\partial\{\sigma^*\}} \quad F \ge 0 \end{aligned} \tag{4}$$

Where σ* is the effective stress, F_0 taken as 1, the relevant flow rule, yield function and plastic potential function *F* and *Q* are same with Eq.2, the same as the other variables in the equations.

Viscous-elasto-plastic damage variables determine: It is assumed that when damage loess obey D-P yield criterion, loess completely destroyed before the infinitesimal intensity obey Weibull distribution, taking into account the damage threshold, damage evolution equation is:

$$D = \begin{cases} 0 & G < 0 \\ 1 - \exp\left[-\left(\dfrac{F^* - F_{\mathrm{G}}^*}{F_0} \right)^m \right] & G \ge 0 \end{cases} \tag{5}$$

Where, F_G^* is the damage stress threshold corresponding differential element intensity value. From conventional triaxial test results can be obtained fitting:

$$F_G^* = (\alpha + 0.2557e^{-0.0425\omega})I_{1\mathrm{G}}^* + 630.7\omega^{-0.59}\ \frac{\mathrm{Pa}}{1 - D} \tag{6}$$

Thus, three-dimensional damage evolution equation is:

$$D=\begin{cases}0 & G<0\\ 1-\exp\left[-\left(\dfrac{\alpha I_1+\sqrt{J_2}-(\alpha+0.2557e^{-0.0425\omega})I_{1G}-630.7\omega^{-0.59}\mathrm{Pa}}{F_0(1-D)}\right)^m\right] & G\geq 0\end{cases} \quad (7)$$

Where, ω is moisture, Pa is unit of stress.

Since the elastic modulus of loess creep test and triaxial tests have obvious differences, this difference may be related to load when grading loess deformation hardening, and therefore, damage evolution equation parameters m, F_0 needs to be based loess creep test results recalculated on the Eq.7, $G \geqslant 0$ finishing on both sides to take part on the number, then:

$$-\ln(1-D)=\left(\frac{\alpha I_1+\sqrt{J_2}-(\alpha+0.2557e^{-0.0425\omega})I_{1G}-630.7\omega^{-0.59}\mathrm{Pa}}{F_0(1-D)}\right)=AB^m \quad (8)$$

In the Eq.8:

$$A=\left(\frac{1}{F_0}\right)^m \quad (9)$$

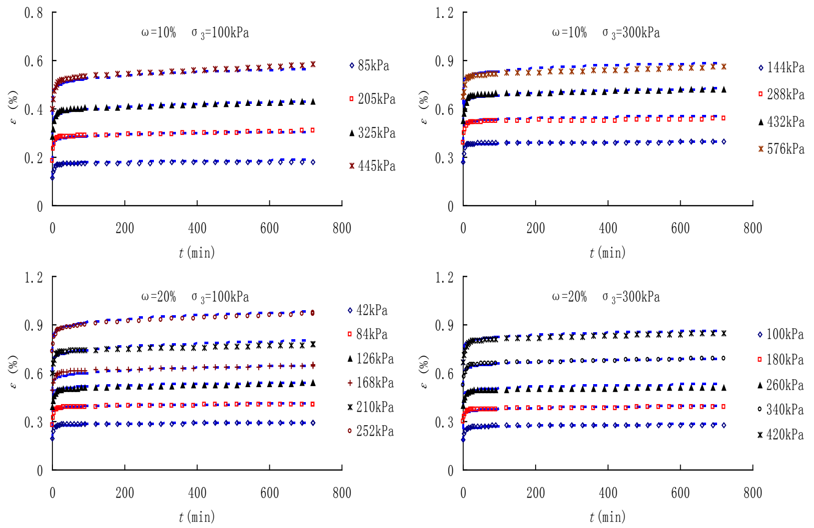
$$B=\frac{\alpha I_1+\sqrt{J_2}-(\alpha+0.2557e^{-0.0425\omega})I_{1G}-630.7\omega^{-0.59}\mathrm{Pa}}{1-D} \quad (10)$$

Then take the logarithm of both sides, the

$$\ln(-\ln(1-D))=\ln A+m\ln B \quad (11)$$

Therefore, as long as that damage variable D under different stress levels, you can use the equations linear fitting parameters F_0, m.

Application of elastoplastic damage model loess stick: To determine the damage variable creep under conventional triaxial condition by Eq.7, the water content depending on the linear fit obtained under different confining pressures Q_2 loess triaxial creep damage parameters. This article assumes that loess yield function and plastic potential function Q are same, that the use of the associated flow rule, but that the loess creep deformation process Poisson's ratio μ constant, loess triaxial creep constitutive model parameters G_H, G_{K1} , H_{K1}, G_{K2}, H_{K2}, G_M, H_M fitting by quasi-Newton method to determine. Each model parameters have substituted into the Eq. 7 and 4 calculate the water content of loess triaxial creep different theoretical curves under different confining pressure conditions, as shown in Fig.2. Compare triaxial creep theoretical curve and experimental curve, we can see the loess transient model and experimental results agree damage asked to establish good condition, it can be used to describe the rheological properties of Yan'an Q_2 loess.



(The dot line is test curve is, the dashed line is theoretical curve)

Fig.2 Theory curves with instantaneous damage and triaxial creep curves of Q_2 loess

Conclusion

⑴ Water content and confining pressure on the creep of the more obvious manifestations: the same confining pressure, the greater the moisture content, or the same moisture content, the smaller the confining pressure, single-stage creep produce greater load.

⑵ Through the stress-strain curve analysis found that under different conditions the curve have a significant inflection point, the inflection point corresponding to the stress can be considered as the yield stress of the sample, when the stress level is lower than this value, the sample visualization visco-elastic body, and when the stress is higher than this value, loess showed significant nonlinear visco-plastic characteristics.

⑶ Coupled creep test results according to Yan'an Q_2 loess and model principle, the use of analogy to establish a three-dimensional viscous creep model of elastoplastic stress state, on this basis, through the whole decoupling method, consider damage and creep effect, and apply strain equivalence principle is established considering the instantaneous three-dimensional stress state creep damage constitutive model of loess. By comparing the theoretical curve with the experimental curve, indicating that the creep model can better describe Yan'an Q_2 loess creep properties.

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