Study on Rheological Constitutive Model of Landslide Loess in Tianshui City under Triaxial Condition with Variable Water Content

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Abstract. This paper analyses the water content of landslide loess in Tianshui City, Gansu Province. Through triaxial cyclic loading and unloading rheological tests, the creep curves and water content forms of landslide loess under different confining pressures are obtained, and their rheological constitutive model for analysis. The rheological constitutive model test under triaxial conditions shows that under low and high stress conditions, the creep strain rate decreases with time, which is manifested as decelerating creep; only under high stress conditions, creep strain The rate undergoes a process of decreasing first, then stabilizing, and finally increasing, corresponding to the three stages of deceleration creep, constant velocity creep and acceleration creep. The specimen will produce a certain instantaneous elastic deformation under different stresses. The rheology of loess has a nonlinear characteristic. The stress-strain iso-curve gradually shifts toward the strain axis as the stress level increases, and the degree of nonlinearity increases as the stress increases.

1. Introduction
With the rapid development of the economy and engineering construction in the western loess area, the practical problems of loess deformation, strength and stability related to time are increasing day by day, such as anti-slide piles, retaining walls, etc. When the change occurs, the unstable water content of the slope appears as an asymptotic water content process with time, and the settlement of the foundation increases with time. This requires the consideration of time effects or rheology to guide engineering practice when studying the physical and mechanical properties and strength and deformation of loess. At the same time, the development of computers has made numerical calculation methods more and more widely used to study stability issues. However, due to the complexity and differences of soils, the constitutive models built in numerical software often cannot fully meet the needs of actual engineering simulations. Based on this, this paper studies the water content of landslide loess in Tianshui City, Gansu Province, and analyzes the rheological constitutive model of loess under triaxial conditions [1].
2. Model description

2.1. Constitutive model

According to the principle of system identification, when the dynamic system model and the observed output information are required to require corresponding input information, this type of problem is commonly referred to as the inverse problem, which is also called parameter inversion in geotechnical engineering. As a method of parameter identification, parameter inversion is very important to determine the cognitive system and further forward analysis. The identification of the model parameters is carried out under the given structural form of the model. The constitutive model is a mathematical expression that can reflect the shape of the rheological curve of the sample. It is directly based on the analysis of the test data. It has the advantages of simple and clear parameters and few parameters. It is convenient and quick to apply in engineering practice. However, the constitutive model also has its shortcomings. For example, it lacks the support of rigorous theoretical basis and is greatly affected by factors such as test conditions. When the soil type and stress state change, the applicability of the constitutive model still needs to be improved. Through the moisture content test of the loess sample, the moisture content of the collapsible loess of Dingyuan tunnel is obtained from 1.6% to 11.7%, from which 1.6%, 5% and 11.7% are selected. The collapsible loess under water content was analysed by constitutive model fitting. The goodness of fit is recorded as R\textsuperscript{2}, which is often used as a characterization index to reflect the fitting effect of the constitutive model, which can well characterize the applicability of the model. The value range of R\textsuperscript{2} is from 0 to 1. The greater the goodness of fit (the closer to 1), the higher the degree of fitting of the model to the test curve, and the better it can describe the actual rheological characteristics of the soil sample. The formula for calculating the goodness of fit is

\[
R^2 = 1 - \frac{SSE}{SST}
\] (1)

In the formula: SSE is the sum of squared residuals; SST is the sum of squared total deviations. The calculation formulas of SSE and SST are as follows.

\[
SSE = \sum_i (y_i - f_i)^2
\] (2)

\[
SST = \sum_i (y_i - \bar{y})^2
\] (3)

Where: \(y_i\) is the measured strain value of the test; \(f_i\) is the model fitted strain value; \(\bar{y}\) is the average measured strain value of the test.

2.2. Rheological model of water content of landslide loess

The Boltzmann superposition principle was used to sort out the axial and lateral deformation test data of the landslide loess obtained by graded unloading confining pressure, so as to comprehensively consider the overall deformation of the sample, and the linear Burgers rheological model was used to fit the test data. The test data and the fitting curve is shown in Figure 1. The data near the curve in the figure is the constant confining pressure at all levels. According to the collated rheological test curve, it can be seen that at all levels of constant confining pressure, the sample has experienced the initial decay rheological stage and the steady-state uniform rheological stage, but under the rupture confining pressure, the sample has a steady-state uniform velocity. The rheological phase transitions into the nonlinear accelerated rheological phase until the moisture content [2].
Figure 1. Rheological model of water content of landslide loess

In view of this, it is assumed that the strain microelement moisture content of the landslide in the accelerated rheological stage follows Weibull distribution, and its distribution function

\[ F(t) = 1 - e^{-\varphi(t)} \]  

(4)

And \( F(t) \) should be an increasing function between 0 and 1. For this purpose, the \( \varphi(t) \) form is introduced as

\[
\varphi(t) = \begin{cases} 
(t - t^*)^n, & t > t^* \\
0, & t \leq t^* 
\end{cases}
\]

(5)

It can be concluded that after the accelerated rheology of the landslide loess, the internal damage variable is

\[
D = F(t) = \begin{cases} 
1 - e^{-(t - t^*)^n}, & t > t^* \\
0, & t \leq t^* 
\end{cases}
\]

(6)

Where: \( D \) is the water content of the landslide loess; \( t \) is the rheological time; \( t^* \) is the starting time of the sample from the steady state uniform rheology to the nonlinear accelerated rheology. When the time \( t \leq t^* \), the landslide loess sample is in a steady-state rheological stage, and a progressive cumulative damage has been generated inside the sample under a constant stress level, but has not yet entered a sudden through rupture damage. Suppose that the water content of the landslide loess \( D \) approaches 0; when the time \( t > t^* \), the sample of the landslide loess enters the stage of nonlinear accelerated rheology through the steady-state rheological stage. It tends to \( \infty \) and gradually approaches 1.

3. Experimental research

3.1. Experimental materials

The landslide loess used in this experiment was selected on a landslide loess roadway in a mine and processed into 50 mm × 100 mm international standard landslide loess specimens. In order to ensure the comparability of the analysis of the experimental results, the same large landslide loess is tried Intensive
drilling. The water content of the drilled landslide loess sample was measured according to the method of measuring the natural water content of landslide loess. In order to study the rheological disturbance effect of landslide loess with different water content, the test sample must be prepared with at least three water content rates. Therefore, some test pieces were immersed in the water tank, and through different water absorption times, test pieces with water contents of 12% and 24% were prepared [3].

3.2. Related experiments

3.2.1. Instantaneous triaxial compression test. The instantaneous triaxial test landslide loess is off-white feldspar quartz fine landslide loess, which is more complete and mostly columnar, with more developed joint layers and clear joint surfaces. The angle between the joint surface and the horizontal direction is about 25°-30°, of which the landslide loess of some samples developed obviously. Axial partial stress and axial strain curve are shown in Figure 2.

![Figure 2. Axial partial stress and axial strain curve](image)

3.2.2. Triaxial rheological test. The samples used for the triaxial rheological test of the landslide loess and the samples used for the instantaneous triaxial compression test were taken from the same borehole and had the same characteristics.

4. Analysis of experimental results

4.1. Analysis of creep characteristics of compacted loess under immersion load test

Figure 3 shows the settling-time curves of different levels of immersion load test. It can be seen from Figure 3: 1) Under the first few levels of load, due to the small load, the settlement rate of the soil on the saturated foundation is small and does not change much. The time required to stabilize the standard is long; 2) As the load increases, there is a rapid settlement process at the front of each level of load, the duration lasts for a short time, and then enters the settlement at a constant rate until it stabilizes, this is because after adding a new level of load, At the moment of loading, the pore water pressure in the soil body is less than the load, the soil body quickly settles, the pores are compacted, and the pore water pressure increases accordingly. With the continuation of time, when the pore water pressure approaches the load, the soil settlement rate Slowing down, the settlement time curve becomes gentler; 3) When the external load is close to or reaches the saturated soil ultimate strength, the settlement rate increases rapidly, shear damage occurs inside the soil, and the soil enters the stage of accelerated creep [4].
Figure 3. Settlement-time curve of landslide loess in water load test

Figure 4 shows the settlement-time curve clusters of the field load test of the loess in the immersed condition, as can be seen from Figure 4: 1) When the applied load is small (<100 kPa), the settlement rate of the foundation soil is small and basically constant, and the settlement amount varies. The time increases and slowly increases; 2) With the increase of the applied load, at the beginning of each newly added first-level load, due to the stress difference between the pore water pressure and the applied load, a rapid settlement process will occur in a short time. At equilibrium, the settlement rate slows down and the settlement continues to increase steadily with time; 3) when the load is applied near the yield strength of the soil structure, the settlement rate of the foundation soil is significantly accelerated. A stable or increasing trend [5].

Figure 4. Settlement-time curve clusters of landslide loess in water load test

4.2. Loess water creep test analysis
In this triaxial creep test, the water content is controlled at 20%, and 20% is greater than the plastic limit water content, and the soil creep is obvious; in order to completely dissipate the excess pore water pressure, the consolidation time is selected to be 24h; the grading cycle loading and unloading method is used. In the creep test, when the loading creep variable or unloading spring back of each load level is less than 0.05mm within 24h, the deformation is considered to be basically stable, which is used as the loading and unloading standard; 9 samples under three confining pressures were selected for creep test.
The three-axis creep cycle loading and unloading test data is processed by the "coordinate translation method", and the loading and unloading creep curves of nine samples under three different confining pressures are obtained, as shown in Figure 5.

![Figure 5. Creep curve of sample with confining pressure of 50kpa](image)

(1) The sample will produce a certain instantaneous elastic deformation under different stresses, and the amount of deformation increases with the increase of stress, and the elastic deformation fully rebounds instantly when unloaded. (2) Under the low stress level and the high stress level, the creep curve only undergoes deceleration creep. The creep deformation increases with time, and eventually tends to be stable and will not reach destruction; under high stress, the creep curve shows three creep stages: deceleration creep stage, constant velocity creep stage and accelerated creep stage. Once constant velocity creep occurs, accelerated creep will inevitably occur until the specimen is destroyed. (3) In the stage of decelerating creep, the time required for creep to stabilize increases with increasing stress. (4) Under low stress, the creep deformation will fully rebound when unloading. Under higher stress, the creep deformation will not fully recover when unloading, and part of it will rebound. (5) Under the same confining pressure, the time to enter the acceleration section shortens with the increase of stress when the specimen fails. (6) The stress at the time of sample failure increases with the increase of confining pressure [6].

5. Conclusion
In this paper, through the analysis of the water content of the landslide loess in Tianshui City, Gansu Province, the following conclusions are obtained for the mechanical parameters of the loess rheological model: (1) Based on the rheological constitutive mechanical parameters derived from the viscoelastic rheological model of the loess derived from previous studies Theoretical analysis was carried out so that it could be fitted with the test data better; (2) The instantaneous triaxial compression test and triaxial rheological compression test under different confining pressures were carried out on the loess, and the loess-related test data were obtained. Data analysis shows that the instantaneous triaxial compression test and triaxial rheological compression test under different confining pressures can better reflect the instantaneous mechanical properties and rheological mechanical properties of loess.

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