Experimental Study on Humidity Structure and p-value of Undisturbed Loess in High-risk Slope

Yajun Jia¹*, and Zhihong Tang¹*, and Cunli Chen²,b and Naijun Liu¹,c
¹Gansu Forestry Polytechnic, Tianshui 741020, China
²Civil Engineering and Architecture Institute, Xi’an University of Technology, Xi’an 710048, China

*Corresponding author e-mail: littlemuch722@sina.com, a2051738839@qq.com, b416200570@qq.com, clittlemuch@sina.com

Abstract. A long-term dry-wet cycle will cause changes in the internal structure of the loess, which will affect its permeability coefficient and slope properties. In this paper, through the dry-wet cycle test, the changes of permeability coefficient P value, porosity and dry density of undisturbed loess and remoulded loess under the action of dry-wet cycle are studied. Under the condition of dry-wet cycle, the permeability coefficient of undisturbed loess in high-risk slope decreases, and the permeability coefficient of remoulded loess increases. Remoulding the original loess of high-risk slopes due to soil erosion is more likely to cause gullies and internal erosion, accelerating the occurrence of original loess landslides and collapse of high-risk slopes.

1. Introduction

According to the classification of formation reasons, loess can be divided into primary loess and secondary loess. Loess is a common structural soil with large pores, under-pressure tightness and collapsibility. With the continuous deepening of engineering construction in my country, the engineering problems of loess have also emerged. Due to drought, low rainfall, and periodic climate changes, the loess is always in a state of alternating saturation and non-saturation under the action of dry and wet cycles of rainfall and evaporation, so its physical and mechanical properties are also a dynamic process of change. After repeated drying and wetting cycles, loess generally shows the characteristics of reduced strength and increased deformation. This has an important impact on the long-term stability of building foundations, road slopes and embankment projects in the loess area. The strength and structural changes of loess under the action have important theoretical and practical significance. The factors inducing geological disasters in the loess area are complex and diverse, and the occurrence of disasters is the result of a combination of factors. By investigating the causes of landslides, it is believed that most landslides have a sliding surface that is disturbed and destroyed between the sliding body and the sliding bed, and the sliding surface plays a controlling role in the occurrence of landslides. By studying the main physical property indexes, microstructure characteristics of the loess landslide zone soil and the differences between the landslide body and the sliding bed, a method to identify the sliding surface is proposed [1].

The interaction process of internal elements of loess texture is the main controlling factor of disasters, and the interaction process and mechanism of internal elements of loess soil are the internal main
controlling hazards. Many scholars have a consistent understanding of the structural characteristics of
the sliding surface of the landslide, that is, the structural change of the soil on the sliding surface is the
most fundamental reason for the landslide. Based on the research background, the paper carried out a
triaxial test of normal moisture content of undisturbed unsaturated loess and a triaxial water
humidification test under different partial stress levels, focusing on the analysis of the strength and
deformation characteristics of unsaturated loess under two different humidification conditions. In order
to provide unsaturated strength parameters for slope stability analysis. The second is to provide basic
data for the elastoplastic constitutive model of collapsible loess, thus providing meaningful conclusions
for the basic theory and actual engineering of loess [2].

2. Principle introduction

2.1. Theory of soil shear strength
The shear strength of soil consists of cohesion $c$ and friction resistance $\tau = \sigma \tan \phi$. The theory of shear
strength of soil was proposed by Coulomb in 1776, and the strength index $c$ and $\phi$ of the soil were
assumed to be constant. However, under actual conditions, the cohesive force $c$ and the internal friction
angle $\phi$ are not constant, but vary with the change of stress state. The formula of Coulomb shear strength is

$$\tau = c + \sigma \tan \phi$$

The frictional strength of soil can be divided into two types, namely, bite friction and sliding friction.
Occlusal friction is mainly manifested as the resistance between particles and particles to restrict the
movement of each other. If the occlusion between adjacent particles is destroyed, the soil will appear to
be dilatant, at which point it will reach shear failure. The main factor affecting the size of sliding friction is
related to the nature of the contact surface between particles, mainly the roughness of the contact
surface and the size and shape of the particles. The cohesive strength $c$ of the soil is the result of the
combined effect of the repulsive force and gravity between the soil particles, including van der Waals
force, electrostatic attraction, the valence bond between the particles at the contact point, the bonding
between the particles, the apparent adhesion Cohesion and so on [3].

2.2. Structural overview
A structural parameter $m_p$ is defined according to the pore ratio of the undisturbed loess to the
remoulded saturated loess under the same pressure. It is intended to discuss the structural parameters of
the loess under pressure and water content during the process of pressure and humidified water content.
Influencing, using the structural change characteristics to analyse the mechanism of the original loess
humidification deformation characteristics. Using the sample to measure the depth of the test cone and
the number of vibrations in the dynamic triaxial test, the corresponding structural parameters were
constructed. Next, the mathematical expressions of various structural parameters are introduced:

$$m_p = \frac{m_1}{m_2} = \frac{S_r / S_o}{S_r / S_o} = \frac{S_r / S_o}{S_r / S_o}$$

Where $S_o$ represents the deformation of the original sample under a certain pressure $p$; $S_r$ represents
the deformation of the saturated sample under a certain pressure $p$; $S_r$ represents the deformation of the
reshaped sample under a certain pressure $p$. 
2.3. The slope stability is affected by the dry and wet cycles
The study found that the dry-wet cycle effect leads to a decrease in the shear strength of the slope soil, which is mainly manifested by the reduction of cohesion $c$ and the internal friction angle does not change much. The shallow soil of the slope is affected by the dry-wet cycle, which is mainly manifested by the development of slope cracks, and the structure of the soil is destroyed, which affects the stability of the slope. The stability of the slope decreases with the increase of the number of dry and wet cycles, and the safety factor continues to decrease. The analysis method of expansive soil slope stability considers the dry-wet cycle effect is in line with the actual situation. Appropriate water interception should be taken, and drainage measures can reduce the impact of the dry-wet cycle on the expansive soil slope [4].

3. Research methods

3.1. Nature of soil samples
The test soil sample was taken from a high-risk slope with a depth of 3-4m, belonging to $Q_3$ loess, with a natural water content of 17% (natural saturation of 40.8%) and a natural dry density of 1.28g/cm$^3$, which was compacted by the standard According to the test, the maximum dry density is 1.70g/cm$^3$, and the optimal moisture content is 18.1%. According to the plastic chart, CL and other physical indicators are shown in Table 1.

Table 1. Physical and mechanical properties of soil

| Boring depth/m | Water content $w$/% | Natural density $\rho$/(g·cm$^{-3}$) | Dry density $\rho_d$/(g·cm$^{-3}$) | Porosity ratio $e_0$ | Saturation $S_r$/% | Cohesion $c$/kPa | Internal friction angle $\phi$ (°) |
|---------------|------------------|-----------------------------------|---------------------------------|-------------------|-----------------|-----------------|-------------------------------|
| 1.5           | 6.6              | 1.32                              | 1.24                            | 1.18              | 15.1            | 10              | 26                            |
| 3.0           | 6.1              | 1.35                              | 1.27                            | 1.14              | 14.5            | 12              | 22                            |
| 4.5           | 8.3              | 1.38                              | 1.27                            | 1.14              | 15.9            | 14              | 23                            |
| 6.0           | 8.3              | 1.42                              | 1.31                            | 1.07              | 21.0            | 17              | 24                            |
| 7.5           | 9.0              | 1.42                              | 1.30                            | 1.09              | 22.5            | 18              | 25                            |
| 9.0           | 8.5              | 1.41                              | 1.30                            | 1.09              | 21.2            | 20              | 22                            |
| 10.5          | 8.1              | 1.39                              | 1.29                            | 1.10              | 20.0            | 21              | 23                            |
| 12.0          | 8.4              | 1.44                              | 1.33                            | 1.04              | 21.9            | 20              | 20                            |
| 13.5          | 7.8              | 1.43                              | 1.33                            | 1.04              | 20.3            | 22              | 22                            |
| 15.0          | 9.4              | 1.45                              | 1.33                            | 1.04              | 24.5            | 19              | 24                            |

3.2. Test plan and method
In order to study the effect of pore ratio, isotropic stress, saturation and suction on the seepage characteristics of undisturbed loess, and to explore the influence of hydraulic action path at the same pore ratio, the natural humidity state (water content $w_r=15.2$%, initial suction $S_0=175$kPa) samples were tested without Stress-water seepage (NSW) test and isotropic stress-water seepage (ICW) test. Water infiltration will cause the horizontal displacement of the original high-risk slope. In order to facilitate the observation of the flooding effect of the high-risk slope and the relationship between the flooding time and the displacement of the high-risk slope, the free surface of the vertical high-risk slope is provided with a horizontal displacement observation of the surface of the high-risk slope. Point (see Figure 1). After the preparation work is completed, the flood test is started until the high-risk slope produces a landslide. The test layout is shown in Figure 2.
3.3. Calculation of related parameters

After injecting a certain amount of water $Q_i$, under the action of force-water coupling, the water gradually penetrates from top to bottom, and the humidification causes the sample to change in volume. The axial deformation and pore water pressure $u_w$ gradually increase, and the suction force $C_s$ ($s = u_s - u_w$) gradually decreases, and both gradually stabilize. When all three reach the stability standard, the seepage water is considered to be stable, that is, the water stops moving. Since the body deformation and axial deformation are easier to stabilize than the pore water pressure (suction) during the seepage process, the duration from the beginning of water immersion to the stability of the suction force (stop of the seepage motion) is taken as the infiltration duration $t$. With the increase of the immersion level, the water content $w$, saturation $s$, and pore water pressure $u_w$ of the sample gradually increase, and the suction force $s$ gradually decreases. When immersed in water to saturation step by step, $u_s \approx u_w, s \approx 0$. Although the suction is not a constant value during the seepage process, but gradually decreases and tends to be stable, the average seepage coefficient $kL$ of the soil sample after deformation and stable suction under the coupling of force and water can be determined according to the normal head method.
L. Calculate the hydraulic gradient \( i_w \) according to the difference between the suction \( s_1 \) and \( s_2 \) of the sample before each stage of immersion and when the penetration is stable, the expression is

\[
i_w = \frac{(s_1 - s_2)}{\rho_w g L}
\]  

(3)

Where \( L \) is the height of the sample (cm); \( \rho_w \) is the density of water (g/cm\(^3\)); \( g \) is the acceleration of gravity (take 10m/s\(^2\)). According to Darcy’s law, \( A \) is the area of the sample (cm\(^2\)). The expression of the average seepage coefficient \( Q_L \) under a certain amount of water immersion of \( Q_L \) (cm\(^3\)) is:

\[
k_L = \frac{Q_L}{i_w t A} = \frac{Q_L \rho_w g L}{(s_1 - s_2) t A}
\]  

(4)

4. Results

4.1. Analysis of the influence of dry-wet cycle on the structure of loess

As shown in Figure 3. (1) When the moisture content of the test is 5%, the structural parameters of the undisturbed loess without dry-wet cycle change most obviously with the consolidation confining pressure. Among them, the structural parameter is the largest when the confining pressure is 100kPa. With the increase of the confining pressure, the structural parameters decrease obviously. When the confining pressure is reduced from 100kPa to 200kPa, the structural parameter is the smallest when the confining pressure is 400kPa. (2) As the consolidation confining pressure increases, the structural parameters do not decrease to the same extent. The structural parameters are relatively close when the consolidation confining pressures are 300 kPa and 400 kPa. It can be inferred that when the consolidation confining pressure increases by 300kPa, the structure of the loess has been damaged to a large extent. When the confining pressure is increased to 400kPa, the structural decrease is not obvious. (3) Under the same confining pressure, with the progress of the shearing process, the size of structural parameters generally shows a decay trend. This is because as the shearing process progresses, the original structure of the loess is gradually destroyed and the structure is weakened. By the end of the shearing process, the structural parameters tended to be stable. This is because the structure of the loess has been completely destroyed and the properties are close to remoulded soil. The slippage between the particles is the main reason for deformation. The effect of confining pressure can be ignored. (4) With the increase of the test water content, the effect of consolidating confining pressure gradually weakens. When the test water content increases to 20%, the effect of consolidating confining pressure is no longer significant. The structure under the four confining pressures the parameters are relatively close, and as the shearing process progresses, the structural parameter curves under different confining pressures quickly get closer. This is because the loess is structurally damaged after being immersed in water, replacing part of the confining pressure [5].
Figure 3. Structural parameter change curve

4.2. Stability calculation of high-risk slope
Through direct quick shear test, the shear strength parameters of loess under different dry and wet cycle amplitudes and times are obtained, on this basis, analyse the influence of the dry-wet cycle on the stability of loess high-risk slopes. As shown in Figure 4.

Figure 4. Calculation results of high-risk slope stability
(1) The high-risk slope has a high safety factor in the initial state, and there will be no instability problem, and as the slope of the high-risk slope increases, the safety factor gradually decreases. (2) After 1-2 wet and dry cycles, as the slope increases, the safety factor decreases, but the decrease is smaller than the initial state, and the rate of decrease is slow. (3) After three dry and wet cycles, the safety factor first decreases with the increase of the slope of the high-risk slope, and increases slightly after 50°.

The reason for the increase in analysis is that the thickness of the slope becomes smaller due to the dry-wet cycle. It can be seen from the analysis that the slope of the high-risk slope affects the stability of the high-risk slope. As the slope of the high-risk slope increases, the safety factor of the high-risk slope becomes smaller. From the experimental results, considering the influence of the dry-wet cycle on the stability of the high-risk slope, the slope of the high-risk slope should not exceed 50°. If it exceeds 50°, waterproof measures must be taken. As the number of wet and dry cycle’s increases, the safety factor of high-risk slopes decreases. This shows that with the continuous circulation of rainfall evaporation over time, the stability of high-risk slopes will continue to decrease, which may cause instability, which is also related to the slope of high-risk slopes. According to the calculation results, it is found that after 5 cycles, instability will occur when the slope of the high-risk slope increases to 50°. Therefore, necessary waterproof, water interception and drainage measures must be taken to ensure the stability of high-risk slopes. The percentage of decrease in the safety factor after the dry-wet cycle is shown in Table 2 compared with the initial one [6].

| Slope/° | 30   | 40   | 50   | 60   | 70   | 80   |
|---------|------|------|------|------|------|------|
| Percentage drop/% | 36.9 | 36.2 | 35.8 | 32.2 | 30.5 | 26.7 |

5. Conclusion
Combined with the on-site water content observation data of the loess high-risk slope and the depth of rainfall influence, the dry and wet cycle amplitude of the loess laboratory test was determined; through the direct quick shear test, the shear resistance of the loess under different dry and wet cycle amplitude and times Based on the strength parameter values, the SLOPE/W module in Geo Studio software is used to analyse the effect of the dry-wet cycle on the stability of loess high-risk slopes. The following conclusions are drawn: (1) the slope of the high-risk slope affects the stability of the high-risk slope. As the slope of the high-risk slope increases, the safety factor of the high-risk slope becomes smaller. (2) Consider the influence of dry and wet cycles on the stability of high-risk slopes. The slope of high-risk slopes should not exceed 50°. If it exceeds 50°, waterproof measures must be taken. (3) As the number of dry and wet cycle’s increases, the safety factor of high-risk slopes decreases. The effect of dry and wet cycles on the gentle slope is more severe, so the safety of the gentle slope cannot be ignored.

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References
[1] Zhang, X. Lu, Y. Li, X., Lu, Y., & Pan, W. Microscopic structure changes of malan loess after humidification in south jingyang plateau, china. Environmental Geology, 78 (10) (2019) 281 - 287.
[2] Wang, J. Li, P., Gu, Q., Xu, Y., & Gu, T. Changes in tensile strength and microstructure of loess due to vibration. Journal of Asian earth ences, 169 (1) (2019) 298 - 307.
[3] Gurda, D. Handschuh, L., Kotkowiak, W., & Jakubowski, H. Homocysteine thiolactone and n-homocysteinylated protein induce pro-atherogenic changes in gene expression in human vascular endothelial cells. Amino Acids, 47 (7) (2015) 1319 - 1339.
[4] Flowers, J. M. Hazzouri, K. M., Pham, G. M., Rosas, U., & Purugganan, M. D. Whole-genome resequencing reveals extensive natural variation in the model green alga chlamydomonas
[5] Jia, F., Shi, Y., Han, Y., Wang, H., & Zhang, Q. Improving milling quality of brown rice with compound enzyme solution humidification. Nongye Gongcheng Xuebao/transactions of the Chinese Society of Agricultural Engineering, 31 (16) (2015) 264 - 271.

[6] Dante René Bosch, & Rubén Rafael Sotelo. Determination of stratigraphy—soil types—using cone penetration test in sedimentary deposits in north-east of argentina. Journal of geoscience & environment protection, 03 (6) (2015) 134 - 139.