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Study on Physical and Mechanical Properties of Soil in a Loess Landslide

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Abstract. This article takes a landslide in Zhidan County as the research object. Based on the field survey before and after the landslide occurred, the engineering geological conditions of the landslide were obtained, the landslide deformation characteristics were mastered, and then the landslide development process was divided into the early stable stage, the creeping deformation stage. the severe sliding stage and the stage after violent sliding. Soil samples of the landslide were taken before and after the landslide occurred, and the physical parameters were measured to analyze the physical properties of the slide zone soil. At the same time, direct shear, triaxial, and ring shear tests were used to obtain the mechanical properties of the landslide soil under different test conditions, and the shear strength index value of the slide zone soil was analyzed. The main conclusions are as follows: After the landslide slides fiercely, the water content increases, the plasticity and compressibility increase, the properties of the slip zone soil deteriorate, and the relevant physical parameters such as the porosity ratio of the slip zone soil at the front edge change little; Moreover, the C and ψ values of the landslide soils decreased significantly, indicating that landslide sliding caused a large degree of shear damage to the landslide soils.

Keywords. Loess Landslide; Physical and Mechanical Properties; Shear Test; Slip Zone Soil; Shear Strength Index

1. Introduction

Landslide is a geological phenomenon in which the local or overall stability of the slope is damaged under the action of gravity, and the rock and soil mass or other debris slide along one or more fracture faces [1-2]. China's mountainous area reaches more than 2/3 of the total land area, and most of these areas have concentrated rainfall, and most of them are located between the Pacific Rim and the Mediterranean-Himalayan seismic zone, which has become a strong favorable condition for landslides [3].

Loess landslides were often developed in hilly ravines, the edges of loess plateau or the edges of terraced edges [4]. With the gradual strengthening of human attention to landslide geological disasters, scholars at home and abroad have made relevant studies on the physical and mechanical properties, formation and development of the slip belt/slip soil of loess landslide[5]. In foreign related studies, Terzaghi believes that the change of pore water pressure in soil is the most fundamental cause of landslides caused by the weakening of the strength of the Landslide soil, followed by regional geological conditions [6]. Stefano has proved that the decrease of soil mechanical properties and the increase of pore pressure were the most direct causes of slope failure through in situ test, laboratory triaxial test and numerical simulation [7]. Langejan, WU, Lumb, etc. all studied the shear strength parameters of soil from the perspective of mathematical statistics, so as to obtain their distribution models [8,9,10]. In relevant domestic studies, Long Jianhui, Li Tonglu et al. have compared and analyzed the values of physical index such as moisture content and liquid limit, plastic limit of slip zone soil and slip solid soil by studying multiple loess landslides in Jingyang County, Shaanxi Province [11]. Zhu Yanpeng et al. combined the two methods of strength reduction and displacement optimization inverse analysis to obtain the mechanical parameters of slope rock and soil [12]. Wang Lunan studied the material structure change characteristics of the process of interlayer evolution into slip zone soil in the Badong Formation through the results of repeated direct shear tests, and obtained the rate effect of the residual strength parameter at this place through the results of ring shear tests [13]. Liu Shenwei et al. analyzed the rheological characteristics of the slip zone soil through the landslide slip zone soil creep and the stress relaxation test [14]. You Huijie et al. obtained the peak strength and residual strength of the Liu Jiaao landslide through repeated direct shear tests [15]. Wang Lei, Zhao Fasuo et al. obtained the correlation function between the shear strength parameters and its moisture content and dry density of landslide soil on the loess-bedrock contact surface through shear test [16]. Wang Xiaoya et al. used the consolidation and non-drainage experiment to confirm that the starting moisture content of the Zhengcheng landslide was the limit value of soil plastic [17]. Liu Jizhixian analyzed the correlation between the basic physical and mechanical parameters of landslides and the shear strength parameters of slip zone soil by performing mathematical statistics on the collected landslide cases [18].

Based on the on-site investigation of different time periods before and after the occurrence of landslide, this article analyzes and studies the physical and mechanical properties of the slip zone soil, summarizes the differences in the mechanical parameters of the slip zone soil under different test conditions. It provides strong theoretical support and reference significance for the follow-up research on the physical and mechanical properties of landslide soils and the design of landslide control engineering.

2. Features of Landslides

2.1 Basic Features of Landslides

The landslide area is located in the hilly gully area of the Loess Plateau in northern Shaanxi, and the original geomorphological unit belongs to the slope part of the loess residual beam-gully area. Loess beam and hill are mostly covered by loess layers, the river bed is deeply cut into bedrock, and the loess overlaid with tens of meters forms a broken loess beam and hill landform. The strata are distributed from new to old, including Upper Pleistocene silty soil (Q_3), loess (Q^{eol}), Middle Pleistocene loess (Q^{eol}) and Cretaceous system lower Zhidan Qunluohe Formation sandstone ($K_1 1$). No groundwater was revealed during the investigation before the violent sliding of the landslide, but the soil mass at the top surface of the interface between argillaceous sandstone and loess was in a saturated state.

The landslide terrain is generally high in the north and low in the south, and the plane form is "dustpan" shaped. The trailing edge of the landslide is 1465m above sea level, the leading edge is 1392m above sea level, the width of the leading edge is about 100m, the height difference between the front and rear edges is about 73m, the longitudinal shape of the slope is linear, the upper and lower is steep, and the overall slope is about 50°. The main slip direction of the landslide is 176°, the maximum longitudinal length is about 140m along the main slip direction, the maximum thickness of the slip body is about 38m, and the volume is about 24×10^4m^3, which is a medium-sized deep soil landslide.

The on-site investigation showed that the trailing edge of the landslide was steep, the tension cracks were clear, the scratches and the marks of dislocation were visible, the perimeter of the landslide was obvious, the leading edge exposed the slip surface, and the sliding belt with a certain thickness was presented, the feather cracks were dislocated, the extrusion and crumpling were obvious, there were obvious mirror scratches, and the position of the shear outlet was determined. The full view before and after the violent sliding of the landslide can be seen in figure 1 and figure 2.

Figure 1. Landslide panorama

2.2 Deformation Features of Landslides

The occurrence of landslide is a long-term and gradual process, which is the result of the combined action of various internal and external factors, and its development is divided into four processes according to the features of this landslide: early stabilization stage, the creeping deformation stage, vigorous sliding phase, and post-slide stop stage (next sliding stage).

(i) The early stabilization stage. The landslide is originally an old landslide that has been in a stable state for a long time, but the stratum structure in the area is the upper loess and the lower bedrock layer. The loess layer has great water permeability and great water insulation of the bedrock layer, which is easy to form a saturated weak zone, which providing a material foundation and geological conditions for the occurrence of landslides, and once it has sufficient external force and rainfall and other inducing factors, it can promote the revival of old landslides.

(ii)The creeping deformation stage. The excavation of the proposed road subgrade on the leading edge of the landslide causes the slope foot to be free, the stress is gradually concentrated at the foot of the slope, and the shear force is greater than the strength of the rock and soil when the stress gradually increases to a certain extent. At this time, the upper soil began to deform, and after heavy rainfall, the slope developed many cracks and misalignments, and the landslide entered the creeping deformation stage.

(iii) The vigorous sliding phase. The trailing edge of the slope is completely penetrated with the cracks in the side wall, and the whole movement occurs, the roadbed cracks, and the mountain collapses in a large area (figure 2). After on-site investigation, the trailing edge of the landslide sits downward, forming a steep ridge 2~8m high, the back wall is dry and smooth, and multiple longitudinal cracks are formed on the side wall. The upper part of the slope is wavy from top to bottom, the structure is loose, forming a number of step-like arrangement of through cracks, the original roadbed of the leading edge is arched 4.5-7.0m, the slip zone soil layer is obvious, the moisture content is high, and it is present a blocky structure. The upper part of the slope is wavy from top to bottom, the structure is loose, forming a number of terrace arrangement of through cracks, the original roadbed of the leading edge is arched 4.5-7.0m, the landslide soil layer is obvious, the moisture content is high, and it is present a blocky structure. In addition, the leading edge slides of the landslide forward into the stream channel, causing serious blockage of the stream channel.

(iv)The post-slide stop stage. After the vigorous sliding stage, the landslide mass is concentrated at the foot of the leading edge slope, the center of gravity is reduced, the anti-slip force of the slope is increased, the sliding force is reduced, and the deformation stops. However, at this time, the soil structure is extremely loose, and the slope has developed many en Echelon transverse cracks, all of which have a certain depth, forming a great path for rainfall infiltration. Once conditions are in place, the landslide will continue to develop, so this stage is also the preparation stage for the landslide to occur again.

3. Study on the Physical Properties of Slip Zone Soil

In this paper, the soil samples of the slip zone soil in the creeping deformation stage of the landslide and the post-slide stop stage were compared by conventional physical property index tests, and the moisture content ω, density ρ, void ratio e, liquid limit ω_L and plastic limit ω_P, compressibility coefficient a_{1-2}, compression modulus E_{s1-2} and other parameters were obtained (table 1).

Through comparative analysis, it can be seen that after the landslide slides, the natural density ρ_0, the nature moisture content ω, liquid limit ω_L, plastic limit ω_P, liquid index I_L and plasticity index I_P all increase, dry density ρ_d, the saturated moisture content ω_{sat}, void ratio e, specific gravity d_s, etc. are basically unchanged, the compressibility coefficient increases and the compression modulus decreases. The above results further show that after the occurrence of landslide, the moisture content increases, the plasticity and compressibility increase, and the physical properties of the slip zone soil deteriorate. On the other hand, the sliding of the landslide will inevitably lead to loose soil structure, but the leading edge slip zone soil is squeezed by the slippery body, so the relevant physical parameters such as the void ratio of the soil body do not change much.

Table 1. Comparative analysis of General physical indexes of slip zoon soil

Research phase of landslides	ρ_0 (g/cm^3)	ρ_d(g/cm^3)	ω_0 (%)	ω_{sat} (%)	e	d_s
The creeping deformation stage	1.79	1.57	17.3	25.7	0.69	2.69
The post-slide stop stage	1.95	1.57	23.1	25.7	0.70	2.69
Research phase of landslides	ω_L (%)	ω_P (%)	I_L	I_P	a_{1-2} Mpa^{-1}	E_{s1-2} MPa
The creeping deformation stage	26.3	17.5	<0	8.8	0.21	9.48
The post-slide stop stage	38.56	23.44	0.06	15.12	0.26	7.02

4.Study on the Mechanical Properties of Slip Zone Soil

From the coulombic shear strength formula $\tau = C + \sigma \tan\varphi$, it can be seen that the shear strength of soil is composed of $\sigma \tan\varphi$ (friction strength) and C (cohesive strength), and the two shear strength parameters affecting the mechanical properties of soil are the cohesion C and internal friction angle of soil φ [19-20]. Therefore, the object of this study is mainly the C and φ values of the soil zone soil. The direct shear fast shear test (comparing the creeping deformation stage of landslide with the parameter value after violent sliding), the triaxial consolidation without drainage (CU) test and the ring shear test of reshaped soil were carried out on different soil samples (to obtain the peak strength and residual strength parameters of slip zone soil).

4.1 Direct Shear Test

The strain-controlled straight shear instrument was used to carry out the slip zone soil direct shear and saturation residual shear test in the creeping deformation stage and the straight shear test in the post-slide stop stage, and the shear strength parameter values were obtained, and the test results are shown in table 2.

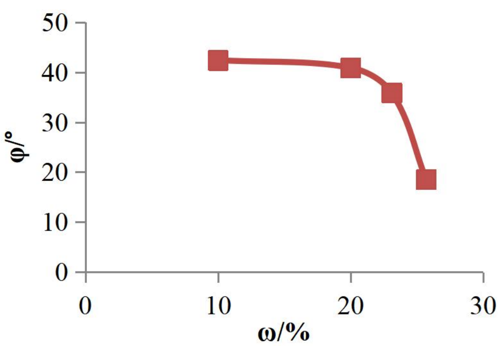
Comparing and analyzing the results of the direct shear test in the creeping deformation stage of landslide and the post-slide stop stage, it can be concluded that the C and φ values of the slip belt soil after violent sliding are greatly reduced. It shows that the slip zone slide has caused a large degree of shear damage to the landslide soil, and it is easy to slide again in bad weather such as heavy rainfall, which further confirms that the treatment of the landslide is imminent.

Table 2. Statistics of direct shear test results

Research phase of landslides	Experimental method	Statistical parameters	Maximum	Minimum	Average value
The creeping deformation stage	The direct shear test	C(kPa)	53.2	26.3	38.45
		φ(°)	34	10	23
	The saturation residual shear test	C(kPa)	47.4	32.5	37.35
		φ(°)	25	16	19
The creeping deformation stage	The direct shear test	C(kPa)	19.497	13.533	16.515
		φ(°)	9.247	8.682	8.965

4.2 Triaxial Test

The SLB-1 stress-strain controlled triaxial shear permeameter was used to test the mechanical properties of the slip zone soil. In the test, a set of undisturbed soil samples (ω_0=23.1%) was taken, and the reshaped soil samples were made to do triaxial consolidation without drainage (CU) tests under three different moisture content conditions of ω=10%, 20% and 25.7% (saturation), respectively, and the standard at the end of the test was that the axial strain reached 12%. The stress Mohr circle is drawn by Excel software, and the intensity parameters are obtained by fitting the common tangent of the stress Mohr circle, and the results are shown (figure 2).



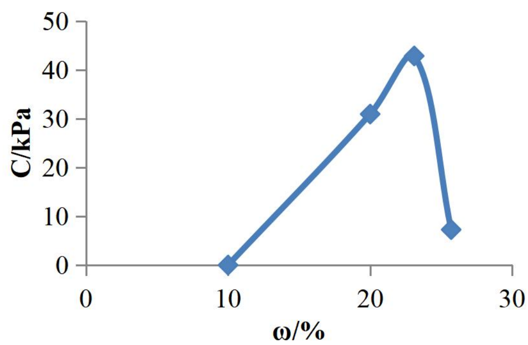


Figure 2. Relationship between strength parameters and moisture content in triaxial test

The analysis shows that the shear strength parameters C and φ values show a certain trend with the change of moisture content ω value (figure 2): the φ value of soil in the slip zone gradually decreases and the speed of decrease gradually increases when ω increases and decreases sharply when the $\omega >$ is 20%. To a large extent, this is due to the increase of ω leading to the intensification of soil lubrication and softening, the weakening of bite between soil particles, the decrease of friction resistance, and the decrease of φ value. With the increase of ω, the C value of the slip zone soil first increases and then decreases sharply, which is due to the increase of moisture content when the ω value is low, the role of cemented substances between soil particles is gradually strengthened, and the C value gradually increases. When the ω increases to a certain extent, the cemented substance between the soil particles begins to be dissolved by water, and the cementation effect begins to weaken, resulting in a decrease in the C value of the soil.

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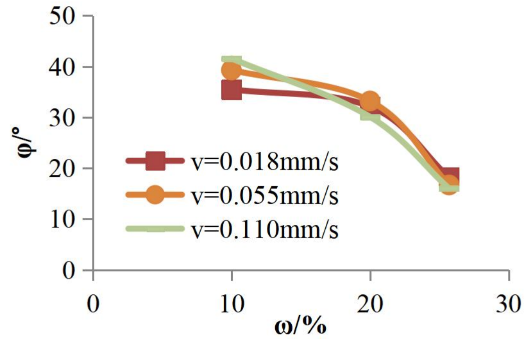
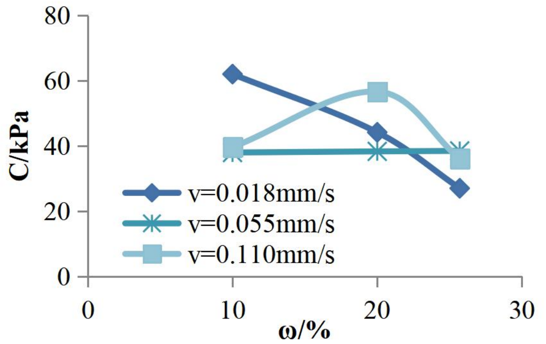
4.3 Ring Shear Test

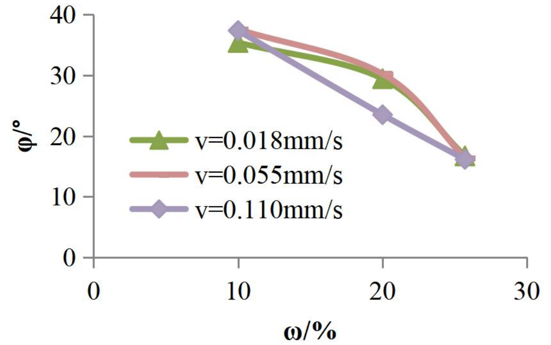
The SRS-150 automatic unsaturated soil dynamic ring shear instrument is used to complete the high-precision dynamic ring shear test [21], and all tests are carried out by single-stage shear [22]. Samples with moisture content of 10%, 20% and saturation (25.7%) were taken respectively, and the comparative tests were carried out under three different shear rates: 1°/min (0.018mm/s), 3°/min (0.055mm/s) and 6°/min (0.110mm/s), mainly to study the effects of different moisture content and different shear rates on the peak strength index and residual strength index of slip zone soil. The test results are shown in figure 3.



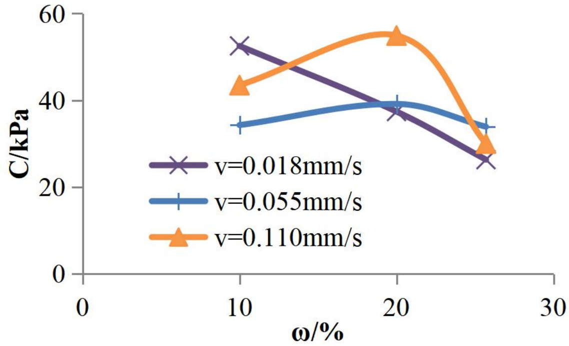
(a) The relationship between peakφ and ω



(b) The relationship between peak C and ω



(c) The relationship between residual φ and ω



(d) The relationship between residual C and ω

Figure 3. Relationship between shear strength index and moisture content of soil in slip zone with different shear rate in ring shear test

It can be seen from figure 3 (a, c) that under three different shear rates, the residual internal friction angle and the peak internal friction angle both decrease with the increase of moisture content, and the speed of reduction gradually increases, and its value decreases sharply when the ω > is 20%. This is the same as the triaxial test, and the analysis shows that the cause of its formation is the same. For the shear rate, the larger the soil shear rate at low moisture content, the greater the peak internal friction angle and the residual internal friction angle. When the moisture content ω =20% of the soil increases, the friction angle value in the soil first increases and then decreases as the shear rate increases. When the soil mass is saturated, the larger the shear rate of the soil mass, the smaller the peak internal friction angle and the residual internal friction angle, but the degree of value change is small. This indicates that the shear rate shows different regularity changes for soil with different moisture content, and observing the final result value can be found that its influence is not very large.

It can be seen from figure 3(b, d) that the influence of shear rate and moisture content on the C value of cohesion is not obvious. Since the soil samples taken in this test are all slip zone soil samples after high-speed large displacement of landslides, only the large shear rate is analyzed, and the residual cohesion under high moisture content can be seen, and the C value shows a trend of first increasing and then decreasing with the increase of moisture content, which is the same as the results of the triaxial test.

5. Conclusion

Based on the detailed investigation of the geological characteristics of landslide engineering, this article mainly conducts physical and mechanical tests on the slip zone soil, analyzes the changes of the physical and mechanical indicators of the slip zone soil before and after the violent sliding of the landslide, and conducts a comparative analysis of the shear strength index values of the sliding belt soil under the three test conditions of straight shear, triaxial and ring shear, and mainly draws the following conclusions:

(1) According to the various characteristics of this landslide, the development process is divided into four stages: the early stabilization stage - the creeping deformation stage - the vigorous sliding phase - the post-slide stop stage (next sliding stage).

(2) Physical experiments were carried out on the slip soil in the creeping deformation stage and the post-slide stop stage of the landslide, and the parameters such as moisture content and dry density were further confirmed that after the occurrence of the landslide, the properties of the slip zone soil deteriorated, the moisture content increased, the plasticity and compressibility increased, and the related physical parameters such as the porosity ratio of the soil in the leading edge slip zone did not change much.

(3) Through the comparative analysis of the test results of the creeping deformation stage of the landslide and the post-slide stop stage, it can be concluded that the C and φ values of the slip zone soil after violent sliding are greatly reduced, indicating that the landslide sliding has caused a large degree of shear damage to the slip zone soil. With the increase of moisture content, the friction angle in the slip zone soil gradually decreased, and the rate of decrease increased sharply when the $\omega > 20\%$, and the cohesion mainly showed a trend of first increasing and then decreasing with the increase of moisture content.

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