Experimental Study on Humidifying Deformation of Earthen Heritage Site under Deviator Stress Condition

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ABSTRACT. In order to address the safety issues caused by the tilting of the earthen heritage site, the unsaturated soil triaxial shearing and permeability instrument was used to conduct humidifying tests under deviator stress conditions. Studied the humidifying deformation characteristics of artificially prepared earthen heritage site by using glutinous rice slurry as a repair material. When the deviator stress is small, the glutinous rice slurry exerts a bonding effect, and the humidifying deformation of artificially prepared earthen heritage site is smaller than plain soil; the increase in deviator stress disrupts the bonding effect between glutinous rice slurry and soil particles, the lubricity of glutinous rice slurry leads to greater humidifying deformation of artificially prepared earthen heritage site than plain soil. When the net confining pressure is high, the sample is compressed and compacted, and the cohesiveness of glutinous rice slurry plays a role. The humidifying deformation of artificially prepared earthen heritage site is smaller than plain soil, the improvement effect of glutinous rice slurry is the best at this time.

Keywords: earthen heritage site; glutinous rice slurry; humidifying deformation; moisture content.

1 Introduction

Earthen heritage site are relics of human history and culture that exist in a certain environment, with high historical and cultural value[1]. In the northwest region of China, most earthen heritage site relics are made of loess mixed with a certain proportion of glutinous rice slurry. Due to the long-term exposure of most of these existing earthen heritage site relics to the natural environment, their mechanical properties are easily affected by the surrounding environment and change. For example, changes in additional loads caused by nearby newly built buildings, the rise of groundwater level caused by human activities[2], due to the cyclic effects of rainfall and evaporation, the earthen heritage site is subjected to new loads and changes in moisture content, produce cracks, peeling, collapse, and irreparable damage[3]. Therefore, it is urgent to study the

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soil mechanics performance of the earthen heritage site, which has important theoretical significance to provide theoretical and experimental support for the protection and restoration of the site.

Many scholars have conducted extensive research on earthen heritage site soil. [4]Research findings, under the action of rainfall and snowmelt, the migration of water and salt in the earthen heritage site is intensified, resulting in surface crusting, cracks, and the formation of salt alkali zones at the bottom of the earthen heritage site.[5]Study was conducted on the use of polyvinyl alcohol (PVA) treated soil as a weathering resistant material for earthen heritage site. [6]In order to improve the stability of earthen heritage site, research was conducted on seismic reinforcement technology for earthen heritage site.[7]In order to prevent the aging and weathering of earthen heritage site, a study was conducted on the use of soil mixed with gypsum as a restoration material for earthen heritage site.[8]Used conducting material analysis on the earthen heritage site, which was found that there was a cementitious substance called glutinous rice slurry inside.[9] Pointed out that glutinous rice slurry, as a natural material, has high viscosity, long-term strength, and good impermeability, making it an ideal repair material.[10] Founded that Amylopectin, the main component of glutinous rice slurry, could effectively improve the strength and water physical properties of earthen heritage site.[11]Founded that glutinous rice slurry has a certain biomineralization regulating effect, which can promote the formation of calcium carbonate, make the filling between soil particles more compact, and improve the strength and durability of loose samples.[12]Influence of glutinous rice slurry contained in earthen heritage site on soil properties was studied through mechanical tests, and the optimal ratio of glutinous rice slurry to soil for artificially prepared earthen heritage site was obtained. However, the above research on earthen heritage site remains in a general mechanical state.

There have been certain research results on the humidifying deformation of soil, mainly loess.[13]Influence of uniaxial, biaxial, and triaxial collapsibility tests on the collapsibility of loess is summarized, and it is found that the humidifying deformation of loess is related to the loading humidifying path.[14]Research has shown that loess collapses under load and humidity, and the volume deformation induced by humidification corresponds to the failure of the adhesive properties of the soil particles.[15]Studied the humidifying deformation characteristics of compacted loess under vertical stress.[16] Under deviator stress conditions, the failure strength of the undisturbed loess sample significantly decreases after being saturated with wetting. The lower the deviator stress level during humidification, the smaller the stable deviator stress value of the saturated soil sample. However, there is still little research on the humidifying deformation characteristics of earthen heritage site, especially in the state of deviator stress. Considering the changes in stress state and moisture content of the earthen heritage site due to the tilting of the walls over time and the influence of the surrounding environment, this article uses an unsaturated soil triaxial shear permeability tester to conduct graded wetting tests on artificially prepared earthen heritage site (90% loess and 10% glutinous rice slurry) and plain soil under deviator stress conditions, and compares and analyzes the influence of glutinous rice slurry as a repair material on the humidifying deformation of loess.

2 Preparation and Test Method of Samples

2.1 Preparation of test samples

The soil used for the experiment is Q3 Malan loess from a construction foundation pit on Xianning Road in Beilin District, Xi'an City. The soil was taken at a depth of 4-6 meters, with a yellow brown color and uniform soil quality. There are some insect holes and plant root and stem holes, which are in a hard state. Its basic physical properties are shown in Table 1.

Table 1. Basic physical property indicators of loess

Dry density g/cm^3	Natural water content ω%	Plastic limit %	Liquid limit %	Specific gravity
1.52	15.5	17.4	29.8	2.71

According to literature research[12], this article uses glutinous rice slurry with a density of $1.04g/cm^3$ and a mass ratio of 90:10 between soil and glutinous rice slurry for testing. Weigh 150g glutinous rice flour with an electronic scale, measure 1000ml water with a measuring cylinder, heat and boil the mixture of glutinous rice flour and water, and dilute it with water after cooling.

After crushing and drying the loess, the soil is sieved through a 2mm sieve, and then glutinous rice slurry is added to the loess to prepare the artificially prepared earthen heritage site. The specific steps are: calculate the required mass of soil, glutinous rice slurry, and water to prepare the sample, mix the water, glutinous rice slurry, and loess evenly. As a comparison, make a group of plain soil without adding glutinous rice slurry, and place them in a sealed bag in a moisturizing cylinder for 48 hours.

The density of glutinous rice slurry in this article is 1.04g/cm3, which is not significantly different from the density of water. Therefore, we equate glutinous rice slurry with water. Assuming the mass of soil is A, the mass of glutinous rice slurry is B, and the mass ratio of soil to glutinous rice slurry is expressed as S: R, where S: R=A: B. The specific calculation is as follows:

$$M_1 = m_1 \times \omega$$

$$M_1 = A \times M_1 - B \times \frac{m_1}{A}$$

$$M_3 = M_1 - M_2$$

$$V_1 = \frac{M_3}{\rho_1}$$

In the formula:

M_1: The mass required to add water and slurry to the soil in order to achieve the target moisture content of the sample.M_2: To achieve the target moisture content of the sample, the quality of water needs to be added. M_3: Mass of slurry added to soil.m_1: The quality of loess. V_1: Volume of glutinous rice slurry. ρ_1: The density of glutinous rice slurry.

The sample size is 39.1mm * 40.00mm (in order to shorten the immersion penetration time, the height of the sample is 40mm), and the sample preparation method is layered sample pressing. The prepared sample is placed in a moisturizing cylinder.

2.2 Grading humidifying test plan under deviator stress conditions

The experimental instrument is an unsaturated soil triaxial shear permeability tester. This article mainly studies the deviator stress graded humidifying test under post humidifying action, compares and analyzes the humidifying deformation characteristics of artificially prepared earthen heritage site (S:R=90:10) and plain soil (S:R=100:0), and analyzes the effect of adding glutinous rice slurry on the humidifying deformation of soil. Firstly, the soil water characteristic curve of the sample under stress free conditions is measured using the axis translation technique. Based on the matrix suction value corresponding to the natural moisture content of 15.5%, which is 220kPa, the sample is first subjected to constant suction isotropic compression, and then subjected to deviator stress graded humidification (humidification to saturation) tests. The humidification is carried out in four stages, with moisture content of 15.5%, 18%, 21%, and saturation state respectively. The humidification steps are divided into: calibration of the instrument, saturation of the clay plate, experimental loading, matrix suction balance, graded application of net confining pressure, application of deviator stress, graded humidification, and experimental sample removal. The specific test plan is shown in Table 2.

Table 2. Experimental plan for grading humidifying of artificially prepared earthen heritage site and remolded soil under deviator Stress

Moisture content ω/%	Matric suction s/kPa	Net confining pressure σ_3 /kPa	deviator stress q/kPa
15.5 (initial)	220	50	50、100
		100	50、100、150
		200	50、100、150、200
		300	50、100、150、200

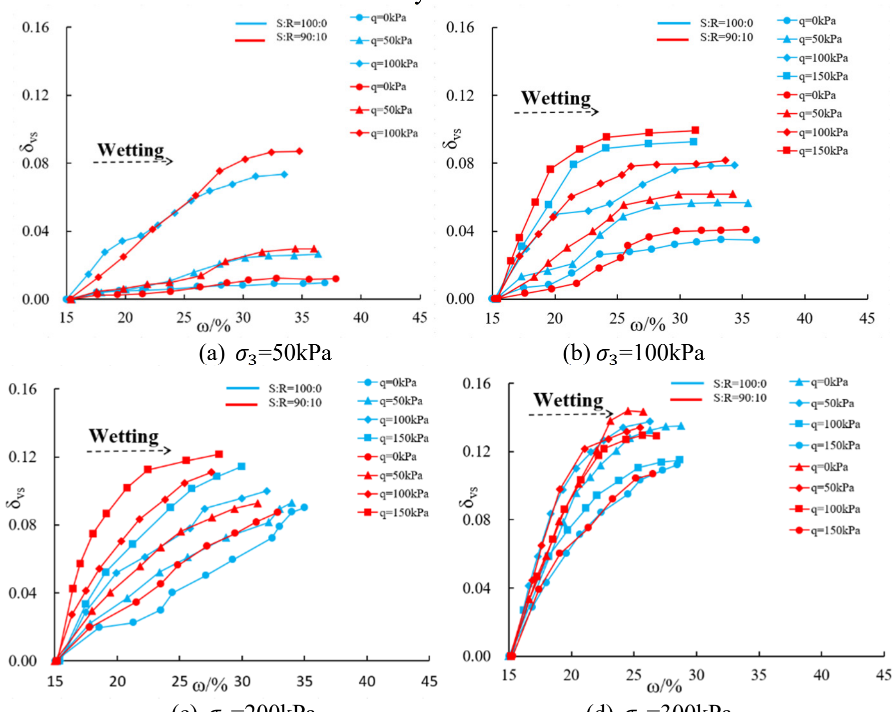
3 The Effect of Bias Stress on the Humidifying Deformation Characteristics

Under triaxial conditions, the soil undergoes deformation under load, which is called strain. Strain includes both volumetric strain and axial strain. In the process of graded humidification, the deformation of the soil caused by the increase of load and moisture content is called humidifying deformation, which includes humidified volumetric strain σ_{vs} and humidified axial strain σ_{1s}.

3.1 The relationship between humidified volumetric strain and moisture content

From Figure 1, it can be seen that when the deviator stress q and net confining pressure σ_3 are constant, the relationship curve between the humidifying volumetric strain and water content of artificially prepared earthen heritage site and plain soil is: as the moisture content increases, the suction between soil particles decreases, and the humidifying volumetric strain first increases rapidly and then slowly increases. When the humidifying reaches near the saturated moisture content, the growth of the humidified volumetric strain gradually stabilizes.

When $\sigma_3 \leq$200kPa, there is a significant difference in the humidified deformation between different deviator stresses. At this point, the deviator stress has a significant impact on the humidified volumetric strain. However, at $\sigma_3 \geq$300kPa, the difference in humidified volumetric strain between different deviator stresses is not significant, and the curve distribution narrows. At this point, the influence of deviator stress on the humidified volumetric strain is relatively small.



(a) σ_3=50kPa (b) σ_3=100kPa

(c) σ_3=200kPa (d) σ_3=300kPa

Fig. 1. Effect of deviator stress on the humidified volumetric strain σ_{vs} of artificially prepared earthen heritage site

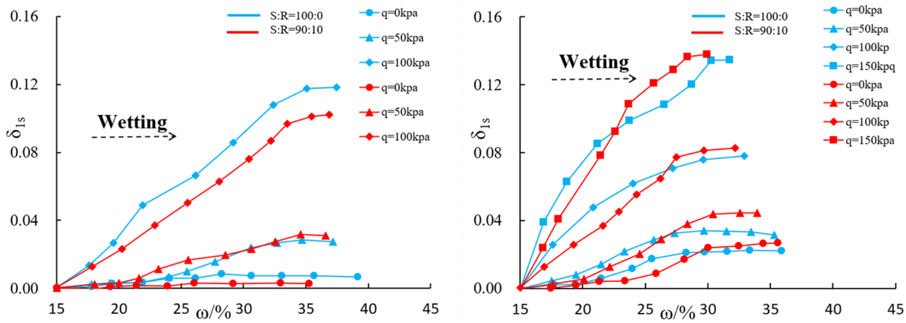
3.2 The relationship between humidified axial strain and moisture Content

As shown in Figure 2, when the deviator stress q and net confining pressure σ_3 are constant, the humidified axial strain of both increases with the increase of water content, which is consistent with the law of humidified volumetric strain.

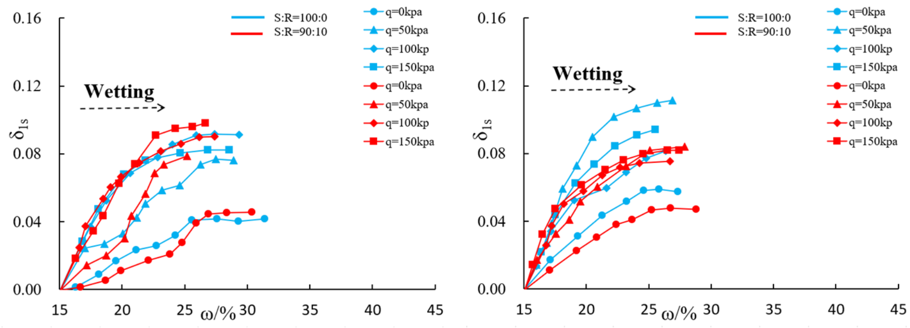
When σ_3=50kPa, q=0kPa, the humidified axial strain basically does not increase with the increase of water content, and the humidifying deformation is very small, at which point no collapse occurs. As the deviator stress increases, the humidifying deformation of the two becomes larger, and the soil begins to exhibit collapsibility. At this time, the humidifying deformation generated is smaller than that of the plain soil due to the cohesive force of the glutinous rice slurry added to the artificially prepared earthen heritage site. At this time, the improvement effect is obvious.

When the net confining pressure σ_3 is within the range of 100KPa and 200KPa, and the deviator stress is constant, there is a intersection between the curves of artificially prepared earthen heritage site and plain soil. Before the intersection, the glutinous rice slurry cohesion plays a role, and the humidified volumetric strain of artificially prepared earthen heritage site is relatively small; as the moisture content increases, the cohesiveness of glutinous rice slurry loses its effect after the intersection point, and the lubricity plays a role, resulting in a greater humidifying deformation of the artificially prepared earthen heritage site than that of the plain soil.

When the net confining pressure σ_3 is 300KPa, the humidifying deformation of artificially prepared earthen heritage site is smaller than that of plain soil. This is because when the net confining pressure is high, the pores between soil particles are small, making it difficult for water to enter the interior of the soil. The cohesion of glutinous rice slurry plays a cementing role, effectively reducing the humidifying deformation of the soil. At this time, the improvement effect is obvious.



(a) σ_3=50kPa (b) σ_3=100kPa



(c) σ_3=200kPa (d) σ_3=300kPa

Fig. 2. Effect of deviator stress on the humidified axial strain $\sigma_{1s}$of artificially prepared earthen heritage site

4 Conclusion

(1) The humidifying deformation of artificially prepared earthen heritage site and plain soil increases with the increase of moisture content; When the net confining pressure is constant, the difference in humidifying deformation between artificially prepared earthen heritage site and plain soil gradually decreases with the increase of deviator stress.

(2) When the deviator stress is small, the humidifying deformation of artificially prepared earthen heritage site is smaller than that of plain soil, and the improvement effect is good at this time. As the deviator stress increases and the moisture content increases, the humidifying deformation of artificially prepared earthen heritage site is actually greater than that of plain soil.

(3) When subjected to high net confining pressure, the humidifying deformation of artificially prepared earthen heritage site is always smaller than that of plain soil, and the improvement effect of glutinous rice slurry is the best at this time.

(4) When the net confining pressure of the earthen heritage site is large and the deviator stress is small, the humidifying deformation of the earthen heritage site after repairing with glutinous rice slurry will become smaller. It is suggested that in this case, glutinous rice slurry can be used as the earthen heritage site repair material.

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