Study on Preparation of Saturated Unstructured Loess and Its Strength and Deformation Characteristics

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Abstract. In the study of geotechnical damage mechanics, the weighted average of the mechanical deformation states of structurally undamaged and structurally completely damaged soils is used to describe the actual mechanical deformation properties of soils. In the past, when the saturated remolded loess was used to simulate the mechanical deformation of loess, the loess still had some initial structural strength. A method for the preparation of saturated unstructured loess is presented. The strength deformation characteristics of saturated remolded loess were compared by lateral compression test and triaxial shear test. The method of preparing saturated unstructured loess is proved to be reasonable.

Keywords. Loess, damage mechanics, unstructured, preparation methods.

1. Introduction

In terms of damage mechanics in geotechnical engineering, it is indicated that the actual stress state of soil structure is the weighted average of the mechanical state when soil structure is intact and the mechanical state when the soil structure is completely damaged [1-4]. Loess is considered as a typical structural soil [5-6]. The connections and interactions between aggregates of naturally deposited loess particles form the structure of loess. The structure formed by abovementioned connections and aggregates in structured loess results in a higher void ratio as compared to unstructured loess. When the loess structure is intact, its mechanical state can be described by the mechanical properties of undisturbed loess, while its mechanical state can be also described by saturated unstructured loess when the loess structure is completely damaged.

Due to the difficulties encountered in sample preparation of saturated unstructured loess, most scholars currently use saturated remolded loess to simulate the mechanical properties of loess when the structure is completely damaged [7-12]. However, the remolded loess still has some initial characteristics of cementation and grain arrangement [13-15], leading to initial shear and compressive strength. In another word, it is not appropriate to use saturated remolded loess to simulate the mechanical and deformation characteristics of the completely damaged loess. At the same time, some relatively large soil grains are removed after screening on sieves with diameters of 1 and 2mm during sample preparation of remolded loess, which results in discrepancy in grain size distribution between the prepared remodeled sample and the original natural loess. Therefore, studying the preparation method and mechanical and deformation properties of saturated unstructured loess is important in the field of damage mechanics in geotechnical engineering, and it also has significant engineering
implications. This study proposes a method to prepare saturated unstructured loess samples. Its mechanical and deformation properties is also investigated and compared with the saturated remolded loess by two stress-stain path tests. The proposed method is then validated and can serves as a benchmark method for future applications.

2. Preparation of Saturated Unstructured Loess

2.1. Sample Preparation Method
After the loess is sieved and saturated during preparation, the clay particles are not completely separated, thereby it still has existing "bridge" shape structure among soil grains, which results in initial shear and compressive strength in the test. Hence, the main objective of this study is to attempt to separate clay particles in loess during sample preparation.

A certain type and concentration of particle dispersant solution was proposed to use in the sample preparation of saturated unstructured loess. The dispersant solution aims to first form a bilayer at the surface of the solid particles. The polar end of the outer dispersant is hydrophilic, increasing the degree to which the solid particles in soils are wetted by water. As a result, the strong affinity increases, forcing the solid particles move away caused by the electrostatic repulsion. Thus, use of the dispersant in the loess can effectively avoid the formation of a large number of "bridge" shape structure during the deposit of the soil granules, thereby sample preparation of saturated unstructured loess becomes feasible and reliable. The choice of dispersant is based on the three recommended solutions in JTG E40-2007 Highway Geotechnical Test Standards [16]. They are sodium hydroxide, sodium oxalate, and sodium silicate, respectively. The three dispersants are suitable for acid soil (PH<6), neutral soil (PH=6.5-7.5) and alkaline soil (PH>8.5). The effectiveness of the three solutions was analyzed and discussed. The best dispersing solution was then selected as the dispersant for the preparation of saturated unstructured loess in this study.

The test soil was taken from Xianyang City, Shaanxi Province, which belongs to the second terrace of the Weihe River. The soil is at a depth of 3 m below the existing grade and in grayish yellow. The undisturbed soil has large visible pores in it with consideration of a typical Q3 loess. The natural water content of the native soil is 16.2%, the liquid limit is 28.9%, the plastic limit is 17.6%, and the plasticity index is 11.3. It is classified as silty clay loess. For soil particles with a particle size of less than 0.075mm, three dispersants with different concentrations were selected respectively to perform the particle size distribution tests. The test results are presented in table 1.

| Table 1. Particle analysis results (different grain groups/%) |
|-------------------------------------------------------------|
| Dispersant species | Dispersant concentration (%) | Particle size (mm) | 0.075-0.005 | 0.005-0.002 | <0.002 |
| Hydrogen sodium | 1 | 86.7 | 10.8 | 2.5 |
| | 2 | 80.3 | 14.4 | 5.3 |
| | 3 | 79.9 | 12.2 | 7.9 |
| | 4 | 87.8 | 10.5 | 1.7 |
| | 4 | 69.7 | 21.2 | 9.1 |
| Sodium oxalate | 6 | 65.5 | 28.3 | 6.2 |
| | 8 | 51.2 | 32.3 | 16.5 |
| | 10 | 72.1 | 25.2 | 2.7 |
| | 2 | 85.3 | 12.2 | 2.5 |
| Sodium silicate | 4 | 72.7 | 11.7 | 15.6 |
| | 6 | 76.5 | 10.6 | 12.9 |
| | 8 | 81.5 | 9.7 | 8.8 |
It is indicated that three types of dispersants have different dispersing effects on loess particles under the predetermined concentrations. When the dispersant is sodium hydroxide, the dispersion effect is more prominent when the concentration is 3%; when the dispersant is sodium oxalate, the dispersion effect is the best when the concentration is 8%. In comparison, when the dispersant is sodium silicate, the dispersion effect is the best when the concentration is 4%. In order to compare the dispersion effect of the above three dispersants under the optimum concentrations, it is found that 3% sodium hydroxide can disperse 20.1% clay particles; 8% sodium oxalate can disperse 48.8% clay particles; and 4% sodium silicate can disperse 27.3% of clay particles. Consequently, 8% sodium oxalate is the most effective dispersant for preparation of loess. Therefore, 8% sodium oxalate solution was used in the experiments in this study. The method for preparing saturated unstructured loess is described in the following sections.

Pure distilled water was mixed with 4% sodium oxalate solution at a mass ratio of 200:1, and loess was added to the mixed solution and boiled to prepare loess slurry. The mixing mass ratio of sodium oxalate and loess is 6:1. The prepared loess slurry was then poured into a glass cylinder for a period of 20 days. During the deposition process, the cylinder must be placed in a cool and dry place to prevent excessive change in humidity between the surface of the slurry and the slurry inside cylinder. It eventually aims to avoid stress concentration on the surface of the slurry and tearing of the deposited soil to form penetration crack. After the deposition is completed, the soil is cut and trimmed to produce the standard size of sample for the subsequent tests. For the confined compression test, the sample is in a cylindrical shape with a diameter of 61.8 mm and a height of 20 mm; for the triaxial shear test, the sample is supposed to be in a diameter of 39.1 mm and a height of 80 mm. The prepared standard sample was placed into a saturator for saturation using the vacuum method. Then, a saturated unstructured loess sample was successfully prepared. Since the unstructured loess in the saturator is in a flow-plastic state, it is difficult to take it out from the saturator. Thus, after the sample was saturated, the sample together with the saturator was transferred into a freezer for 1.5 hours to avoid any possible damage during further sample extrusion.

2.2. Mechanism

As compared with the traditional method of using saturated remolded loess to replace the completely damage loess, the proposed method uses a dispersant to fully separate the aggregates in the loess during the sample preparation. The prepared saturated unstructured loess sample does not have the initial shear and compressive strength, and the test results are more reliable and accurate in terms of the mechanical deformation properties of the loess when the structure is completely damaged.

One of the mechanisms for the preparation of saturated unstructured loess is that there are a large number of clay particles in the loess which form a relatively stable and non-dispersive aggregate and flocculation in water. During the preparation, the sodium ion in the sodium oxalate solution will be absorbed by the clay particles in loess to form a diffusion layer. When the diffusion layer reaches a certain thickness, the clay particles in the loess are gradually dispersed, and the aggregate and the flocculation are gradually decomposed. As a result, less "bridge" shape structure among soil particle will be formed in the deposit.

The second mechanism is that the loess has a special aggregate structure, and the aggregates are overlapped with iron oxide and alumina coatings to form “bridge-cementation” structure. From the perspective of colloidal chemistry, the negatively charged clay particles in the pellets and the positively charged iron oxide and alumina colloids absorb each other to form a certain complex, which is not easy to separate from each other. Because the sodium oxalate solution is alkaline that can increase the PH of the loess mud, thereby reducing the positive charge of iron oxide and alumina colloids, and the degree of mutual adsorption between them and the clay particles in the loess. Thus, a more dense deposit is formed with less "bridge" shape structure.
3. Validation of Saturated Unstructured Loess

3.1. Test Materials

Different native loess soils were collected from seven different regions. For each loess, three loess samples were prepared, i.e. undisturbed loess sample, saturated remolded loess sample, and saturated unstructured loess using the proposed method in this study. It is noted that the undisturbed loess sample is prepared by the cutting/trimming method. For the saturated remolded loess sample, the loess was first screened with the sieve of diameter of 1 mm, and then compacted to the same dry density as the undisturbed loess, and finally saturated by the vacuum method.

The above loess samples from seven different regions were numbered No. 1 to No. 7. Specifically, No. 1 was taken from a steep ridge next to the coal processing plant in Qujiang New District, Xi’an, Shaanxi Province, at a depth of 4-4.5 m, classified as Q3 loess; No. 2 was taken from a high side of Bailuyuan, Baqiao District, Xi’an, Shaanxi Province next to a slope, at a depth of 8-8.5m, classified as Q3 loess; No. 3 was taken from the foundation pit of Changfeng Street Station, Taiyuan Metro Line 2, Shanxi Province, at a depth of 10-10.5m, classified as Q3 loess; No. 4 was taken from Daqing Mountain in the outskirts of Lanzhou City, Gansu Province, at a depth of 12-12.5m, classified as Q3 loess; No. 5 was taken from a foundation pit of a transmission tower in Minxian County, Dingxi City, Gansu Province, at a depth of 3.5-4 m, classified as Q3 loess; No. 6 was taken from the foundation pit of Gouzhao Station of the Extension Project of Metro Line 1 in Zhengzhou, Henan Province, at a depth of 6.5-7 m, classified as Q3 loess; No. 7 was taken from the 8th Division of Agriculture, Shihezi City, Xinjiang Uygur Autonomous Region The foundation pit of a sewage treatment plant in Zhongjiazhuang Town, 144 Mission Field, at a depth of 2.5-3 m, classified as Q3 loess. The physical properties of the above loess are shown in table 2.

Table 2. Physical properties of loess samples.

| The loess species | Soil particles | Dry density (g/cm³) | Natural moisture content (%) | Liquid limit (%) | Plastic limit (%) |
|------------------|----------------|--------------------|----------------------------|----------------|-----------------|
| The loess 1      | 2.71           | 1.46               | 19.0                       | 31.6            | 20.5            |
| The loess 2      | 2.71           | 1.56               | 10.8                       | 30.2            | 20.0            |
| The loess 3      | 2.72           | 1.35               | 15.6                       | 33.2            | 22.1            |
| The loess 4      | 2.70           | 1.33               | 9.2                        | 31.5            | 21.8            |
| The loess 5      | 2.71           | 1.36               | 9.8                        | 29.5            | 21.2            |
| The loess 6      | 2.70           | 1.39               | 18.2                       | 33.5            | 21.1            |
| The loess 7      | 2.71           | 1.30               | 7.5                        | 27.5            | 20.1            |

3.2. Validation of Confined Compression Tests (or Consolidation Tests)

Confined compression tests were carried out on the three samples prepared for each loess sample, and the corresponding compression curves were presented in figures 1.

In figures 1, it is indicated that the compression curve of the three different loess sample was distinct. An obvious inflection point can be found in the compression curve of undisturbed loess. Before the inflection point, the void ratio changed slightly with the increase of the load, while after the inflection point, the void ratio of the varied considerably with the increase of the load. Because the initial strength of the sample can resist the surcharge loading to some extent in the beginning of the tests, however, the deformation increased rapidly when the load exceeded the initial strength. The compression curve of saturated remolded loess was gradually varied, but inflection point still existed by visual observation. It is demonstrated that the saturated remolded loess was considered as disturbed soils, and the initial stress state was greatly damaged, but the existence of the inflection point of the compression curve shows a certain initial structural resistance. Therefore, it is not appropriate to use saturated remolded loess to study the mechanical deformation characteristics of completed damaged loess. The compression curve of saturated unstructured loess appears relatively...
straight without obvious inflection point. Extending the compression curve in the reverse direction can approximately intersect the origin of the coordinates. It reflects that the initial shear strength of the sample approximately equals to zero, and there is no structural strength, which is also consistent with the basic properties of the completed damaged loess.

Figure 1. The compress curve of loess.
3.3. Triaxial Shear Test

The saturated remolded loess sample and the saturated unstructured loess sample prepared for each loess sample were subjected to triaxial shear test. The obtained stress-strain curves in the p-q meridian plane are shown in figure 2.

It figures 2, it is indicated that the shear failure envelop of the saturated unstructured loess approximately intersects the origin of the p-q meridian plane coordinates. It means that when the spherical stress of structured loess is zero, its generalized shear stress also equals to zero approximately. However, the shear failure envelop of saturated remolded loess has an intercept with the q-axis, which means that it still has initial structural strength, and its properties doesn’t conform
with the mechanical deformation properties of structurally completely damaged loess.

Table 3 shows the intercept of the shear failure envelop of saturated remolded loess and saturated unstructured loess on the q-axis of the generalized shear stress. This intercept also refers to the initial shear strength (initial structural strength).

| Soil                  | Sample 1: Saturated remolded loess | Sample 2: Saturated unstructured loess |
|-----------------------|-----------------------------------|--------------------------------------|
|                       | The loess 1                        | The loess 2                           |
|                       | 36.2                               | 29.7                                 |
|                       | The loess 3                        | The loess 4                           |
|                       | 22.5                               | 18.3                                 |
|                       | The loess 5                        | The loess 6                           |
|                       | 21.6                               | 7.1                                  |
|                       | The loess 7                        |                                       |
|                       | 7.1                                |                                       |
|                       | 6.7                                | 1.1                                  |
|                       | 0.9                                |                                       |

It is found that the initial shear strength of saturated remolded loess was relatively high in seven different regions, indicating that saturated remolded loess cannot replace the completely damage loess. While the initial shear strength of the saturated unstructured loess was very small. It can be considered that its initial shear strength was extremely small without considering the test error, which demonstrates that saturated unstructured loess does not have the initial shear strength, and its properties are consistent with the mechanical deformation properties of the completely damage loess.

4. Conclusions
(1) By comparing three different soil particle dispersants, it is found that 8% sodium oxalate solution has the best dispersion effect on loess particles.
(2) A new method is proposed for preparing saturated unstructured loess in the laboratory, and the preparation mechanism is analyzed and discussed.
(3) The strength and deformation properties of undisturbed loess, saturated remolded loess and saturated unstructured loess were compared and analyzed based on a series of confined compression test and triaxial shear test. The rationality of the properties of saturated unstructured loess is also validated.

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