Effect of Water Content and Dry Density on Mechanical Properties of Compaction Loess

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Abstract. Loess landslides in irrigation districts are common geological disasters in the world. Long-term watering will reduce the soil mechanical properties of the loess, leading to frequent occurrence of landslides. In this paper, using shear strength and compressibility test to explore the effect of dry density and water content on the mechanical properties of loess. The results show that the lower the water content, the greater the effect of dry density change on cohesion and at the same dry density, the internal friction angle of compacted loess decreases with increasing water content; the compressive strain of each test sample increases nonlinearly with the increase of vertical pressure, and the magnitude of the increase gradually decreases. Therefore water content and dry density play an important role in mechanical properties of compaction loess.

Keywords: Water content, Dry Density, Compaction Loess

1 Introduction
Loess refers to the yellow silt deposits carried by wind during the Quaternary in the geological age. It covers 10% of the continent in the world, including Asia, Africa, Central and Southern Europe, the Midwestern United States and northern France [1,2]. Among them, China has the world's largest loess area covering about 630,000 km², mainly distributed in Shanxi, Shaanxi, Gansu and Ningxia [3]. Loess is an aeolian deposit with displaying loose, grayish yellow, and sporadic white spotted salt film, containing rich in large holes and insects, occasionally showing plant roots and a few amount of granular calcium tuberculosis [4, 5]. It is an important issue to study the effect of water content on the internal structure and dry density of loess on the mechanical properties of compact loess. In past research, many researchers have done a lot of research on the relationship between the mechanical properties of soils [6-10]. Lin et al. used SEM and MIP to test and classify the microstructure and pore structure of loess in different regions and different strata [11], and explored the relationship between collapsibility and microstructure of loess. However, there are few studies on the mechanical properties of loess considering different dry densities and water content in one study.
In the light of these considerations, the impact of water content with dry density on the structure and internal structure of compact loess are explored in this article, based on shear strength and compressibility test. Furthermore, to understand the effect of artificial disturbance during remodelled process on geological engineering sensitivity, and report new findings explaining the connection about water content and dry density to mechanical properties about loess.

2 Test Design and Methods

2.1 Study area and samples
In this study, the loess used was from Yanan, Shaanxi City, China. Though exploring the well in the range of 2.5~4.0 m as original samples, the soil layer is Malan loess, displaying loose, grayish yellow, and sporadic white spotted salt film, containing rich in large holes and insects, occasionally showing plant roots; and a few amounts of granular calcium tuberculosis. In order to minimize changes to their properties, all the samples were retrieved by hand, sealed in plastic film inside a cylindrical iron bucket, and transported to the laboratory. The tested loess samples were light brown silty soil with slight plasticity. The main physical properties about the sample were tested following the ASTM 2006 standard test methods as listed in Table 1. A machine of Bettersize 2000 was used for performing loess particle size distribution testing. The results showed that the loess sample was mainly composed of silt (about 80.55%) and some clay (about 10.01%).

| Sample | In-situ density (g/cm³) | Natural water content (%) | Specific gravity | Plastic limit | Liquid limit | Plasticity index | Void ratio |
|--------|-------------------------|---------------------------|-----------------|---------------|--------------|-----------------|-----------|
| Loess  | 1.35                    | 12.3                      | 2.70            | 20.3          | 29.2         | 9.3             | 1.30      |

2.2 Sample preparation process
The loess sample was compacted into water content of 12%, dry density (g/cm³) of 1.55, 1.60, 1.65, 1.70, 1.75, and subjected to a graded compressibility and shear strength test. Loess samples were prepared according to the following steps: (1) Use a wooden hammer to crush the loess cut from natural materials and air dry it; (2) After the air-dried loess is sieved through a 2 mm sieve, mix a part of the water to reach a moisture content of 12%, then let it stand for a while to achieve moisture homogeneity; (3) the loess was statically compacted to a specific dry density in a specially designed metal mold. [12].

3 Results and Discussion

3.1 Shear strength
The most important parameters affecting the shear strength of loess are water content and dry density. So, it is proposed to test the compacted loess with the above two parameters, among the water content is set to 6%, 10%, 14%, 18%, and the dry density (unit is g/cm³) is set to 1.55, 1.60, 1.65, 1.70, 1.75, a total of 20 test samples. The shear test of each test sample is shown in Table 2.

Table 1. Basic characteristics of the testing samples.

Establish a certain connection between water content, dry density and cohesion. As shown in the Fig.1A, with the water content gradually raising, cohesion under each dry density decreases continuously. The higher the value of dry density, the greater the effect of changes in water content on cohesion. The lower the initial moisture content, the more moisture content increases, the bigger degree of cohesion weaken. With water content exceeding 14%, cohesion of loess is weakened, as the dry density differently. The difference in the cohesive force of the compacted loess will gradually decrease. Fig.1B shows that as dry density increased, the value of cohesion is increasing with moisture content. As the water content is greater than 14%, the impact of dry density change on cohesion is weak. It can also be seen from the figure that water content is less than 14%, dry density is less than 1.65 g/cm³, changing in dry density and moisture content can significantly affect cohesion.
Table 2. Shear strength parameters

| $\rho_d$ / g/cm$^3$ | $\omega$ / % | c / kPa | $\Phi$ / ° |
|---------------------|-------------|---------|-----------|
| 1.55                | 6           | 106.6   | 39.6      |
|                     | 10          | 50.8    | 30.2      |
|                     | 14          | 29.0    | 27.8      |
|                     | 18          | 16.4    | 24.6      |
| 1.60                | 6           | 131.3   | 40.6      |
|                     | 10          | 66.8    | 31.9      |
|                     | 14          | 37.1    | 28.9      |
|                     | 18          | 18.7    | 25.9      |
| 1.65                | 6           | 214.4   | 42.3      |
|                     | 10          | 109.1   | 34.8      |
|                     | 14          | 62.5    | 31.5      |
|                     | 18          | 26.5    | 29.1      |
| 1.70                | 6           | 245.4   | 43.6      |
|                     | 10          | 129.7   | 36.6      |
|                     | 14          | 80.8    | 32.5      |
|                     | 18          | 31.9    | 30.4      |
| 1.75                | 6           | 256.1   | 45.6      |
|                     | 10          | 146.2   | 39.2      |
|                     | 14          | 91.3    | 35.9      |
|                     | 18          | 36.3    | 34.7      |

Fig. 1. (A) Relationship between water content and cohesion (B) Dry density and cohesion

Fig. 2A illustrates that at same dry density, the internal friction angle reduce with increasing water content. The lower the initial moisture content, internal friction angle is more influenced by changes in water content. As the initial water content of the loess sample is greater than 14%, the water content increases again. Fig.2B suggests that at the same water content, the value of internal friction angle is raising with increasing dry density.
3.2 Compressibility test

From Fig.3 can know that the compressive strain of each test sample increases nonlinearly with the increase of vertical pressure, and the magnitude of the increase gradually decreases. In the case of same water content, the higher the dry density, smaller the compressive strain. as initial loess dry density is greater 1.65, if the dry density is increased, the compressive deformation does not change significantly, while the density is fewer than 1.65, increasing dry density reduces the compressive deformation. Significantly affected.

![Fig. 3. Compressive stress-strain relationship curve of compacted loess with same water contents at different dry densities](image)

(A) water content 6%

(B) water content 10%

(C) water content 14%

(D) water content 18%
The compressive stress-strain relationship curves of compacted loess were established (Fig.4). The compressive strain raising with increasing water content. For loess whose initial water content is fewer than 10%, the change of water content has a great influence on the compression and deformation of loess, especially for soils with a dry density of less than 1.65. When moisture content of the loess is more than 10%, The influence of moisture on loess compression and deformation increases with the increase of dry density. Meanwhile, the effect on soils with dry density greater than 1.65 is more important. Through the above analysis, water content and dry density jointly affect compressive deformation of compacted loess, which is two important indicators of the post-construction settlement in the high-filling project.
4. Conclusions

Based on original loess from Yanan, The Shear strength and Compressibility test were tested. The conclusion is shown below:

(1) The lower the water content, the greater the influence of changes in dry density on cohesion. When water content is more than 14%, the impact of changes in dry density on cohesion is small.

(2) Under the same dry density, loess internal friction angle decreases with the increase of water content. The lower initial water content, the greater the influence of water content on the internal friction angle of loess.

(3) For initial water content of loess less 10%, the change of water content has great influence on the compression and deformation of loess, especially for soils with a dry density of less than 1.65g/cm$^3$.

In conclusion, water content and dry density jointly affect compressive deformation for mechanical properties, which is two important indicators of the post-construction settlement in the high-filling project. We should pay more attention to these two points in future research.

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