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Study on Deformation Characteristics and Mechanism of Q₃ Loess Microstructure Before and after Wetting

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Abstract: Microstructure characteristics of loess is an effective way to study the physical and mechanical characteristics of soil under different conditions. Water content in sample of Q₃ loess is about 25% ,which was first subjected to X-Ray test to determine the main chemical components in loess and calculated the proportion in the sample. Test analysis shows the particle structure of the loess belonged to the granular structure type. CT scanning tests were performed on the sample before and after wetting. The changes of total number of pores, the maximum pore volume and the position of the centroid of pore of the sample were analyzed before and after wetting. The results shows that the soluble salts of loess have been dissolved after wetting.The volume of the pores of loess have been changed. Some increased, some decreased and others closed in volume. The change of the number of pores indicates that the sample formed obvious saturated zone, transition zone, conduction zone and humid zones after wetting. These results reveals the deformation characteristics and mechanism of Q₃ loess microstructure.

Key words: Q₃ loess; microstructure; CT scanning test; pore volume of loess; deformation characteristics

1 Induction

The microstructure is one of the basic characteristics of loess and reveals the formation conditions of loess, which is an effective way to study the physical and mechanical characteristics of soil and its variety under different conditions. Natural particles in loess are mainly composed of powder particles, with obvious large pores, and most of the soil particles are cemented by soluble salt crystals. The water sensitivity and dynamic vulnerability of loess are remarkable. The soluble salts in loess are caused to dissolve by rainfall infiltration, and the micro-cracks in loess changed in a certain. The water content have a great influence on cohesion and angle of internal friction, and the strength of loess can sharply decrease when it encounters water.

There are mainly two methods to study the collapsibility of loess: firstly, the qualitatively or quantitatively^[1-6] study the collapsibility of loess from the opinions of the soil composition, microstructure characteristics and mechanical mechanism of the loess by laboratory tests. Polarized light microscopes^[7] was used to conduct preliminary research on the structural of loess, and obtained some simple qualitative conclusions. Scanning electron microscope and mercury intrusion test^[8-10] were used to conducted in-depth research on the microstructure characteristics and pore structure of loess, the classification of loess microstructure were proposed from different views, and were examined the relationship between microstructure and collapsibility of loess. Experimental study^[11-13] has been conducted to reveal quantitative on the microstructure of loess.

Secondly, carrying out in-situ large-scale test pit immersion test or immersion load test, which can directly obtain the self-weight collapse deformation and the lower limit depth of the loess on the site^[14-23]. However, the method is so relatively little development due to its high cost and time-consuming, the workload is large.

However, how does the structure of the Q₃ loess change after the rain is humidified, how does the collapsibility process occur, what is the microstructure deformation and its mechanism. In response to these

problems, the microstructure deformation and mechanism of the Q₃ loess after wetting was carried out to study. Firstly, the chemical composition of the loess was determined by X-Ray. Secondly, the microstructure type of the loess was analyzed by the scanning electron microscope test. Thirdly, the immersion was scanned by CT, change in micro-cracks of loess samples were examined before and after wetting.

2 Microstructure test of loess

The sample of loess came from a natural loess slope in Shan-zidun Village, Lanzhou New District, and the soil belongs to Q₃ Malan loess.

2.1 X-Ray test of loess

X-Ray is as shown in Figure 1.

Fig.1 X-Ray

Figure 2 shows the XRD pattern of untreated loess. By comparing with the standard PDF card, except for the peak of quartz, the components of calcite (Calcite, CaCO₃, PDA#47-1144) accounts for a significant proportion, while magnesium is usually generated with calcium magnesium calcite.

Fig.2 XRD pattern of loess

Table 1 shows the proportion of the main chemical components of Q₃ loess. Q₃ loess contains the highest silica content, which accounts for about 64.18% of the total chemical substances. The content of calcium and

magnesium is relatively high. These are found in Q₃ loess mostly in the form of calcite and dolomite. The soluble salt of Q₃ loess appears mainly in the form of calcareous nodules.

Table 1 The content of main chemical components of loess

Composition	CaO	MgO	Al ₂ O ₃	SiO ₂	Fe ₂ O ₃	FeO	Na ₂ O
content (wt %)	10.06	2.81	13.28	64.18	3.26	1.37	1.85

Note: The table deducts the volatile components CO₂ and H₂O, and then recalculates the ratio.

2.2 Scanning electron microscope test

The scanning electron microscope test MX2600FE, voltage 0~25KV, resolution 1.5nm, magnification 3~600,00 times, the instrument is shown in Figure 3.

Fig.3 MX2600FE

2.2.1 Image with magnification 500

Fig.4 500 scanning image of SEM

2.2.2 Image with magnification 1000

Fig.5 1000 scanning image of SEM

Scanning images of SEM in the Figures 4-5 shows that the structure of Q₃ loess are an obvious granular structure, and its particles are mostly plate-shaped and long columnar, and most of the particles are single-grain structures. The particles are mostly

point-to-point contact with clear pores. Under the action of earthquake load, the overhead structure of Q₃ loess support is prone to damage, small loess particles fall into the pores, and the large pore structure is squeezed into a microporous structure. Loess particles constitute the skeleton of the soil, which is the main factor determining the physical and mechanical properties of loess.

The framework particles play a supporting role in the loess, and their contact mode reflects the structural strength of the loess and is one of the important factors that determine the physical and mechanical properties of the loess. The water sensitivity of loess refers to its special sensitivity to water. In the natural hydrated state, loess has high strength and low compressibility, but when it is immersed in water or humidified, its strength drops sharply and its deformation suddenly increases. This characteristic is collapsibility and undrain shear of loess.

3 CT scanning test of loess

One of the main characteristics of Q₃ loess is that the soil contains a large number of pores. During the formation of Q₃ loess and during the soil formation process after formation, a microstructure is formed. This is the production environment of loess and the geophysical and chemical effects in the diagenesis process. The concentrated reflection of biochemical effects. Particle morphology, pore characteristics and degree of cementation are concentrated manifestations of the microstructure characteristics of loess.

3.1 Test introduction

The dual-energy coal and rock scanning analyzer system is mainly composed of dual-energy X-ray sources, high-resolution amorphous silicon area array detectors, and computer 3D scanning to build an image processing system as shown in Figure 6.

Fig.6 Dual energy scanning analyse for coal and rock

3.2 The loess sample

The height of loess sample is about 4.31cm, the diameter is about 1.78cm, the soil weight is 30.9g, and the moisture content of the sample before wetting is about 5%. According to the results of the field rainfall test, the sample was permeated with water content of about 25%. The samples before and after wetting are shown in Figure 7. The Figure 8 are the CT scanning tests of the samples before and after wetting respectively. A total of 45 scanned images are taken, and the distance between each layer is about 0.86mm.

Fig.7 The loess sample before and after wetting

Taking into account the flatness of the two ends of the sample, in order to obtain a more reasonable image of the internal structure of the sample, the scanned image was extracted from the 150th floor and ended at the 1050th floor. One scanned image is extracted for every 20 layers, and a total of 45 scanned images are obtained. The images from top to bottom are as follows.

Fig.8 Layers numbers of scanning image

3.3 Image of CT scanning loess sample before wetting

Fig.9 Image of CT scanning loess sample before wetting

3.4 Image of CT scanning loess sample after wetting

Fig.10 Image of CT scanning loess sample after wetting

The black-and-white contrast in the CT scan image refers to the density distribution of the detected object, that is, the cracks, holes and other defects inside the test sample. It is the density distribution map of the scan surface obtained by statistics. The black areas in the image represent low-density areas, with large differences in particle distribution, which are pores or dissolution pores of Q_3 loess. The white areas represent high-density areas, which are calcium cements or plates with higher content of Q_3 loess. The gray area (the transitional area from black to white) indicates the micro-joints, detrital particles, aggregates, pores and aggregates in loess. Therefore, the classification results of CT images can quantitatively analyze the dynamic changes of the microstructure of loess, and the damage process of loess structure can be analyzed through changes in different density regions.

4 Test results

4.1 Analysis between image binarization and pore before wetting

Fig.11 The loess sample before wetting between pore and image binaryzation

4.2 Analysis between image binarization and pore after wetting

Fig.12 The loess sample after wetting between pore and image binarization

4.3 Analysis of the change of pore numbers in CT image before and after wetting

The pores of collapsible Q₃ loess are characterized by large numbers and large spaces. According to the pore size, they can be divided into three types: ultrafine pores, fine pores and large pores. Ultrafine pores and fine pores are also called intergranular pores. Intergranular pores constitute the main body of loess porosity, and the pores are slightly larger than the diameter of loess particles or aggregates. The occurrence of collapsibility causes damage to the loess structure, causing these intergranular pores to increase, decrease, or tend to close, and loess particles slip and fall into the large pores.

4.3.1 Analysis of the the maximum pore volume in CT image before wetting

Fig.13 The maximum pore volume before wetting

4.3.2 Analysis of the maximum pore volume in CT image after wetting

Fig.14 Maximum pore volume after wetting

4.3.3 Analysis of the change of pore numbers in CT image before and after wetting

Fig.15 The number of pore change before and after wetting

$$b = 0.049a^2 + 78.129a - 20252 \quad (1)$$

Where b is the numbers of pore change, a is the scanning layers of loess sample.

4.3.4 Comparison of the largest pore volume of loess before and after wetting

Fig.16 The maximum pore volume before and after wetting

4.3.5 Analysis of the maximum volume change of loess before and after wetting

Fig.17 The number of maximum pore volume change before and after wetting

$$V_1 = 3E - 14a^6 - 2E - 10a^5 - 4E - 07a^4 - 0.0004a^3 + 0.1664a^2 - 31.222a + 1921.1 \quad (2)$$

Where V_1 is change of maximum pore volume before and after wetting, a is the scanning layers of loess sample.

5 The affected area of loess collapsibility

The influence range of collapsibility (wetting radius) can be calculated by the following formula^[24]:

$$r = H(0.5 + m_\beta \tan \beta)$$

(3)

Where r is wetting radius after collapsing, H is thickness of collapsible soil layer, m_β is the coefficient of increase of water spreading to the side because the water permeability of each layer and interlayer is different, the variation range is 1~2, β is the diffusion angle from the flooding site to the side flooding; for loess and loess-like silt, $\beta=35^\circ$; For loess-like silty clay, $\beta=50^\circ$.

The penetration depth of Q₃ loess is directly related to its micro-cracks, and it is also the fundamental factor determining the penetration depth. When Q₃ loess meets water, water would first infiltrate along the cracks in loess, and the larger penetration of the cracks is, the deeper infiltration is. The soluble salt content of loess also have an important effect on the depth of soaking. After wetting, some of the soluble salts of loess would dissolved, new cracks would formed and the depth of soaking would increased.

6 Discussion

Figure 2 shows the high content of calcite and albite. The chemical formula of calcite is CaCO_3 , the chemical composition of CaO accounts for 56.03%, and CO_2 accounts for 43.97%. It often contains Mn and Fe, easy to break into small square pieces along its cleavage. The chemical formula of albite is $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$, and its theoretical chemical composition is Na₂O accounts for 11.8%, Al_2O_3 accounts for 19.4%, SiO_2 accounts for 68.8%. The appearance is generally white or off-white, the hardness is 6~6.5, and the density is 2.61~2.64 g/cm³. The calculation of the chemical composition of the loess in Table 1 is consistent with the analysis in Figure 2.

Figures 13 and 14 show the change of the maximum

pore volume of Q₃ loess before and after wetting respectively. Some of pore volumes of loess increase significantly after immersion, which indicates that the soluble salt in loess dissolves and new micro-cracks are formed.

Figure 15 shows that in the upper half of the sample, the number of pores increased significantly after wetting. The increase in the number of pores decreases rapidly with the increase of the height of the sample. Near the middle of the sample, the pores after soaking are smaller than the number of pores before wetting. After that, the number of pores after soaking remains basically constant. This indicates that the soluble salt in loess has a close relationship with the height of the sample. The closer to the end of the sample, the higher the degree of dissolution. After wetting, the distribution of the largest pores along the height of the sample is relatively uniform, and new pores are formed after wetting, and from the top to the bottom of the sample, it indicates that the original pores increase, decrease or close after the soluble salt is dissolved in water. Part of the pores are connected to form new seepage channels, and water can infiltrate from these pores more easily.

Figure 17 shows the change of the maximum pore volume. After wetting, some increase and some decrease. The change of the maximum pore volume fully shows that the micro-cracks of loess has changed after wetting. It is an effective way and means to analyze loess collapsibility.

7 Conclusions

By carrying out X-Ray, scanning electron microscope, CT scanning analysis of loess samples before and after wetting, and using *Matlab* software, the law of changes in micro-cracks of the samples before and after wetting was obtained, revealing the nature of loess collapsibility after wetting.

Through the X-Ray test, the content of the main chemical components of loess are obtained. A large amount of calcium and magnesium of loess is mainly stored in the formation of calcite and dolomite, and the chemical substances constitute the soluble salt and the insoluble salt.

Scanning electron microscopy tests showed that the

structure of Q₃ loess belongs to the granular structure type.

The loess samples were CT scanned before and after wetting. The test showed that the gray scale of the CT image becomes deeper after wetting, and the position of the largest pore is changed after wetting. The centroid of the largest pore of the sample before wetting is located in the upper part, and it is more evenly distributed in the whole sample after wetting. The total volume of the pores is significantly reduced, and the total volume of the upper water-immersed layer tends to stabilize. The changes of these parameters reveal that the grain shape, pore characteristics and degree of cementation of loess have undergone significant changes after wetting. The saturated zones, transition zones, conduction zones and humid zones have been formed after wetting of loess samples.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflict of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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Figures

Figure 1

X-Ray

Figure 1

X-Ray

Figure 1

X-Ray

Figure 1

X-Ray

Figure 2

XRD pattern of loess

Figure 2

XRD pattern of loess

Figure 2

XRD pattern of loess

Figure 2

XRD pattern of loess

Figure 3

MX2600FE

Figure 3

MX2600FE

Figure 3

MX2600FE

Figure 3

MX2600FE

Figure 4

500 scanning image of SEM

Figure 4

500 scanning image of SEM

Figure 4

500 scanning image of SEM

Figure 4

500 scanning image of SEM

Figure 5

1000 scanning image of SEM

Figure 5

1000 scanning image of SEM

Figure 5

1000 scanning image of SEM

Figure 5

1000 scanning image of SEM

Figure 6

Dual energy scanning analyse for coal and rock

Figure 6

Dual energy scanning analyse for coal and rock

Figure 6

Dual energy scanning analyse for coal and rock

Figure 6

Dual energy scanning analyse for coal and rock

Figure 7

The loess sample before and after wetting

Figure 7

The loess sample before and after wetting

Figure 7

The loess sample before and after wetting

Figure 7

The loess sample before and after wetting

Figure 8

Layers numbers of scanning image

Figure 8

Layers numbers of scanning image

Figure 8

Layers numbers of scanning image

Figure 8

Layers numbers of scanning image

Figure 9

Image of CT scanning loess sample before wetting

Figure 9

Image of CT scanning loess sample before wetting

Figure 9

Image of CT scanning loess sample before wetting

Figure 9

Image of CT scanning loess sample before wetting

Figure 10

Image of CT scanning loess sample after wetting

Figure 10

Image of CT scanning loess sample after wetting

Figure 10

Image of CT scanning loess sample after wetting

Figure 10

Image of CT scanning loess sample after wetting

Figure 11

The loess sample before wetting between pore and image binaryzation

Figure 11

The loess sample before wetting between pore and image binaryzation

Figure 11

The loess sample before wetting between pore and image binaryzation

Figure 11

The loess sample before wetting between pore and image binaryzation

Figure 12

The loess sample after wetting between pore and image binaryzation

Figure 12

The loess sample after wetting between pore and image binaryzation

Figure 12

The loess sample after wetting between pore and image binaryzation

Figure 12

The loess sample after wetting between pore and image binaryzation

Figure 13

The maximum pore volume before wetting

Figure 13

The maximum pore volume before wetting

Figure 13

The maximum pore volume before wetting

Figure 13

The maximum pore volume before wetting

Figure 14

Maximum pore volume after wetting

Figure 14

Maximum pore volume after wetting

Figure 14

Maximum pore volume after wetting

Figure 14

Maximum pore volume after wetting

Figure 15

The number of pore change before and after wetting

Figure 15

The number of pore change before and after wetting

Figure 15

The number of pore change before and after wetting

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The number of pore change before and after wetting

Figure 16

The maximum pore volume before and after wetting

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