Study of evolution law of cracking for swelling mudstone of Sichuan central Redbeds in hydration process

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ABSTRACT

Several cracking test of swelling mudstone of Sichuan Central Redbeds are conducted on the condition of hydration. Based on tests result, the process of crack development in mudstone, its influencing factors and cracking mechanism are analysed. The results show: (1) the cracking process can be divided into three stages: moisture absorption and crack generation, crack development and rapid expansion, and stabilization. Initial water content is negative correlation with cracking degree, and soaking water absorption has a greater cracking degree than capillary water absorption. Influenced by the content of clay minerals, the overall cracking degree of mudstone is larger than that of argillaceous sandstone. (2) In the process of moisture absorption, the swelling deformation of mudstone is uneven, and this uneven expansion also changes with time. (3) The cracking of swelling mudstone is caused by uneven swelling and softening effect. The uneven swelling of mudstone is caused by: i) The spatial distribution of clay minerals is not uniform; ii) The whole process of moisture absorption is not uniform in space; iii) There are visible or invisible initial cracks inside the swelling mudstone.

Keywords: Sichuan central redbeds, crack development, cracking mechanism, uneven swelling

1 INTRODUCTION

Fracture is one of the important factors affecting the performance of expansive geotechnical engineering \[1-2\]. On the one hand, the fracture cuts the rock and soil into a block shape, which destroys the integrity of the rock and soil body: On the other hand, it also provides an infiltration channel for rainwater or other water sources, further causing swelling-shrinkage deformation and expansion of the fracture of the expansive rock or soil. At present, the influence of fracture on the engineering properties and engineering problems of expansive geotechnical engineering has attracted the attention of relevant scholars \[3-6\]. At the same time, there are also many cracking test results of rock and soil. Ma Jia, et al \[7\] designed an experimental device that can precisely control the humidity, study the process of crack evolution under changing environmental conditions, reappears the process of crack formation, propagation and extending: Zheng Shao-he, et al \[9\], from the point of view of linear elastic mechanics and unsaturated soil mechanics, studied the initial cracking mechanism and the quantitative expression of initial cracking depth of expansive soil under surface evaporation conditions. Lu Zai-hua, et al \[12\], reached the crack evolution of Nanyang remolded expansive soil during drying and wetting cycles with computerized tomography, and according to the CT images, the original cracks in soil developed, new cracks gradually generated and at last, a crack net came into being. These researches \[7-15\] are all based on dehydration processes or dry-wet cycles. The main research is the evolution law and extension mechanism, of shrinkage cracks in expansive soils. Related studies on disintegration of swelling rock indicate that because of swelling and strength softening of expansive rock, it also has the development and expansion of the crack under the condition of hydration\[16-17\].

This paper takes the swelling mudstone of Sichuan central redbeds as research object, conducts several cracking test under normal temperature and normal pressure conditions using a simple device of cracking tests for mudstone. The process of cracking of swelling mudstone is analyzed, and the influences of different initial water content and moisture absorption methods on the cracking were studied. The main mechanism of the development of cracking is explained by analyzing

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2 EXPERIMENT METHOD

A simple device of cracking tests for mudstone is shown below. The swelling mudstone studied in this paper is selected from a high-speed railway section in the typical Redbeds distribution area of the Sichuan Basin. The following table shows the results of indoor swelling test of mudstone. From the experimental data, the mudstone has significant expansion.

![Cracking test device](image)

**Fig. 1. A simple device of cracking tests for mudstone**

**Table 1. Expansive test result**

| Expansion index | Number of samples | Minimum | Maximum | Average value |
|-----------------|-------------------|---------|---------|---------------|
| Expansion force/kPa | 26 | 152.3 | 2025.2 | 741.3 |
| Axial expansion ratio/% | 25 | 0.9 | 7.92 | 3.08 |
| Disintegration | 8 | Within 4 hours of influent water, they collapse in the form of blocks and sheets |

In order to study the influencing factors of development of cracking, the cracking test of samples with different lithology and different initial water content under different moisture absorption conditions was carried out. There are 8 groups of tests totally, and the basic parameters of simples are shown in the following table.

**Table 2. The basic parameters of simples**

| NO. of sample | lithology | moisture absorption conditions | Initial water content/% | Thickness /mm | Diameter /mm |
|---------------|-----------|--------------------------------|-------------------------|---------------|--------------|
| 1             | mudstone  | soaking                        | 4.01                    | 23.82         | 65.51        |
| 2             | mudstone  | soaking                        | 2.95                    | 24.23         | 63.17        |
| 3             | mudstone  | soaking                        | 1.56                    | 23.92         | 64.35        |
| 4             | mudstone  | capillary                      | 4.01                    | 23.94         | 64.35        |

| NO. of sample | lithology | moisture absorption conditions | Initial water content/% | Thickness /mm | Diameter /mm |
|---------------|-----------|--------------------------------|-------------------------|---------------|--------------|
| 5             | sandstone | soaking                        | 3.90                    | 24.06         | 64.50        |
| 6             | sandstone | soaking                        | 3.37                    | 24.00         | 64.10        |
| 7             | sandstone | soaking                        | 2.56                    | 24.30         | 64.66        |
| 8             | sandstone | soaking                        | 3.34                    | 24.20         | 64.42        |

The first page must contain the Title, Author(s). The main steps of the moisture cracking test are as follows: (1) Fix the camera and adjust the led light to make the photo quality better. (2) Open the control valve and fill the water supply bottle. (3) Under capillary moisture absorption, stop the water injection when the water level in the sample dish has not passed through the water-permeable stone; Under soaking moisture absorption, water is injected to a predetermined water level, so that when the rock sample is placed, the upper surface of the rock sample is not immersed in water. (4) Place the sample and start the test. (5) Take photos regularly according to the specified time. (6) After the test, measure the water content of different parts of the sample.

3 ANALYSIS OF TEST RESULTS

3.1 Cracking process analysis

A set of photos from the mudstone test process was selected for cracking process analysis, and the cracks formed during the test cracking process are depicted through CAD software. It is difficult to count the small cracks due to the influence of moisture absorption and muddy on the surface of the mudstone. Therefore, only the cracks can be easily identified, or the cracks can be developed into transfixion cracks finally. Through the analysis of the cracking process, the cracking process can be divided into three stages: moisture absorption and crack generation, crack development and rapid expansion, and stabilization.

I) Moisture absorption and crack generation

From the cracking process images of the sample, At the beginning of the test, the surface of the rock sample was hygroscopic and began to show fine microcracks, but the cracks were independent.

![Cracking images](image)

**Fig. 2. The images of phase I**

II) Crack development and rapid expansion

When developing to the medium term, small cracks may continue to develop or be closed by the effects of swelling. The cracks that continue to develop are increasing in width and length. At the same time, new fine cracks are continuously generated and developed, and existing cracks and new cracks are interlaced to form cracks penetrating the rock face.
III) Stabilization

At the end of the test, the cracks developed to a certain extent, and the width and area of the cracks remained basically the same, but there were still slight cracks slowly.

3.2 Analysis of influencing factors

After the test is completed, the final surface cracking area is compared with the surface area of the sample (Hereinafter referred to as 'surface cracking degree'). The final surface cracking degree after the test is summarized as follows.

Table 3. Final cracking degrees of simples

| NO. of sample | lithology    | moisture absorption conditions | Initial water content/% | Cracking degree/% |
|---------------|--------------|--------------------------------|-------------------------|-------------------|
| 1             | mudstone     | soaking                        | 4.01                    | 8.06              |
| 2             | mudstone     | soaking                        | 2.95                    | 12.80             |
| 3             | mudstone     | capillary                      | 1.56                    | 17.30             |
| 4             | capillary    | capillary                      | 4.01                    | 14.99             |
| 5             | argillaceous sandstone | soaking                    | 2.90                    | 28.20             |
| 6             | argillaceous sandstone | soaking                    | 3.37                    | 7.25              |
| 7             | sandstone    | soaking                        | 2.56                    | 7.96              |
| 8             | sandstone    | soaking                        | 3.34                    | 0                 |

It can be seen from the Table 2 that the smaller the initial water content, the greater the final surface cracking degree. As is showing in the following Fig.5, the initial water content is negative correlation with the cracking degree.

The following figure shows the histogram of the final surface crack of samples under different lithologies. From the histogram, mudstone samples have higher cracking degrees than argillaceous sandstone. No. 8 sample did not generate cracks during the test, so the fracture degree is zero. Mudstone is more prone to swelling and softening due to its more hydrophilic clay minerals, so its surface cracking degree is much larger than that of argillaceous sandstone and sandstone.

3.3 Displacement vector analysis of samples

In the process of moisture absorption, due to the different degrees of muddy depressions, expansion bulges, etc. on the surface of the sample, the computer recognition grid node is poor. Therefore, this paper uses GetData software to manually trace the pixel coordinates of the grid nodes in each photo of different time periods, and then draw the displacement vector diagram using matlab software. (The reference coordinate system is the coordinate system of time 0, and the displacement vector in the figure is enlarged by 3 times.)
It can be seen from the displacement vector diagram that during the moisture absorption process, the sample expands outward continuously, but there is always a point in each vector diagram that does not shift. This point is regarded as expansion center of the sample. From the change of the displacement vector diagram over time, the expansion center is also constantly changing and is not near the center of the sample, indicating that the hygroscopic expansion process is an uneven expansion, and this uneven expansion constantly changes over time.

4 DISCUSSION ON CRACKING MECHANISM OF SWELLING ROCK UNDER MOISTURE ABSORPTION CONDITION

4.1 Analysis of causes of moisture cracking

Related disintegration test on mudstone of Redbeds studies have shown that the interaction between mudstone and water leads to the destruction of rock structure and the main cause of disintegration[17,18]. There are two main types of this interaction: The first type is that the moisture absorption of the hydrophilic clay mineral in the mudstone has caused uneven swelling, resulting in uneven internal stress of the rock, which causes the rock to produce disintegration cracks. The second type is the physicochemical action of cement and water in mudstone, including the dissolution of soluble cement, the moisture absorption of mud cement, etc. These all reduce the cementation strength between the rock mineral particles and weaken the structure of the rock. Therefore, the swelling and softening of the mudstone under moisture absorption causes the structure to break, cracking and eventually disintegration.

4.2 Causes of uneven expansion

The reason for the uneven swelling of the expansive rock can be analyzed from the following three aspects: non-uniform moisture absorption, uneven distribution of clay minerals, visible or invisible hidden cracks present in the original rock.

i) Spatial heterogeneity of the moisture absorption process

Under two moisture absorption conditions, The water absorption of the rock is extended from the local to the whole, and its moisture absorption is an uneven
process. During moisture absorption, the cracks are produced mainly in the wet zone (relatively wet zone) and the zone where the wet zone meets the dry zone.

Table 4. Water content in different areas after test

| No. of sample | 1   | 2   | 3   | 4   | 5   | 6   | Bottom Average value |
|---------------|-----|-----|-----|-----|-----|-----|----------------------|
| 1             | 11.20 | 11.86 | 12.43 | 12.29 | 13.00 | 12.69 | 15.21 | 14.51 |
| 2             | 25.78 | 24.26 | 34.89 | 33.23 | 29.02 | 14.40 | 24.96 | 25.70 |
| 4             | 16.70 | 14.08 | 15.63 | 14.81 | 17.14 | 15.25 | 15.36 |
| 5             | 27.40 | 26.49 | 35.20 | 32.03 | 31.60 | 31.62 | 31.46 |
| 6             | 28.40 | 8.53  | 20.74 | 29.14 | 27.16 | 39.73 | 5.35  | 9.70  |

Fig. 8. Water content distribution area of 2# (left) & 6# (right) sample.

After the test, the water content of different parts of the sample are measured, and the result is shown in the following table.

There are differences in water content between different surface layers and between the surface layer and the bottom layer, which indicates that, to a certain degree, the unevenness of the moisture absorption process leads to the unevenness of the moisture absorption and softening of the rock.

ii) Uneven distribution of clay minerals

Observing the cross section and longitudinal section of the original rock sample, the sandy or argillaceous aggregates on the section can be seen, which indicates that the clay minerals of the original rock sample are not evenly distributed.

In addition, after the sample absorbs water, the surface is muddy or swelled, and the surface of the sample is uniformly muddy with the advancement of the infiltration zone. Some parts of the surface of the sample are swollen and muddy, while other areas have no obvious muddy, and even some areas are drier compared to other areas. This difference of degrees of muddy and swelling of surfaces indirectly reflects the uneven distribution of clay mineral distribution.

iii) Visible or invisible initial cracks inside the swelling mudstone

The samples were scanned by electron microscopy, and it was observed that there were fine cracks inside some samples.

Fig. 9. Sandy aggregates on the cross section of sample

Fig. 10. Comparison of uniform muddy and non-uniform muddy

Fig. 11 Invisible initial cracks

Because of the low permeability of mudstone, its cracks are the main channel for water absorption inside the mudstone, and they are also the location of weak
cementation inside the rock mass. Under water absorption conditions, on the one hand, the fissure water dissolves and softens fracture surface, increases the pores of the rock sample, changes the pore structure, thus leading to new micro-cracks. On the other hand, water invades along micro-cracks due to surface tension, and these micro-cracks will strongly adsorb water molecules. The surface free energy reduced by this adsorption of water molecules is partially transformed into the mechanical failure energy that promotes the increase of the interfacial interface of the rock pores. Eventually, the rock deforms and destroys, and disintegrates. This causes deformation and destruction of the rock structure and eventually disintegration.

5 CONCLUSION

(1) The cracking process of swelling mudstone of Sichuan central Redbeds can be divided into three stages: moisture absorption and crack generation, crack development and rapid expansion, and stabilization. Initial water content is negative correlation with cracking degree, and soaking water absorption has a greater cracking degree than capillary water absorption. Influenced by the content of clay minerals, the overall cracking degree of mudstone is larger than that of argillaceous sandstone.

(2) In the process of moisture absorption, the swelling deformation of mudstone is uneven, and this uneven expansion also changes with time.

(3) The cracking of swelling mudstone is caused by uneven swelling and softening effect. The uneven swelling of mudstone is caused by: i) The spatial distribution of clay minerals is not uniform; ii) The whole process of moisture absorption is not uniform in space; iii) There are visible or invisible initial cracks inside the swelling mudstone.

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