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Research Article

A Lateral Unconfined Swelling Test for Swelling Rocks

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A simple experimental equipment and test scheme is designed to estimate the swelling deformation under the lateral unconfined condition with coupling effect of uniaxial load and water-rock interaction. This paper carried out the swelling test under the lateral unconfined condition and analyzed the qualities of lateral unconfined swelling of weak swelling rock by applying simple self-designed saturated equipment to the swelling test on the platform of microcomputer-controlled rock shear rheological tester RYL-600. As a result of this study, the following conclusions were derived: (1) considering the coupling effect of load and water, the stress level is considerably lower than the mudstone-saturated uniaxial compressive strength, and it is discovered that the coupling effect is striking. (2) The swelling reveals the demonstrable time effect, which increases rapidly at the beginning of the swelling deformation, and after that, the deformation tends to maintain a certain value. (3) Both the rate and the scale of swelling deformation are restrained by the axial load.

1. Introduction

The swelling of the soft rock is one of the most intractable problems in underground engineering [1]. The swelling pressure and deformation of the soft rock swelling with water frequently results in a series of engineering problems, like the cracking of underground cavern, the floor heave, the cracking of road and its roadbed, the landslide and collapse of slope, and the destruction of the upper structure caused by the differential settlement of swelling rock foundation. The project design of swelling rock area embarks on the indoor tests about the reasonable prediction and the accurate confirmation of the swelling rock qualities. The swelling order of peat was concluded with the test of the uniaxial swelling test by Huder and Amberg [2] in 1970. Then, the International Society for Rock Mechanics [3, 4] proposed the idea of swelling rock of the shaly. The free swelling test and the lateral confined swelling instructed by the norm can conclude the swelling qualities of swelling rock easily and quickly. Yang et al. [5] presented a way of testing the qualities of lateral confined swelling and invented the related equipment which was applied to define the swelling qualities of remolded swelling rock samples. With the test of swelling qualities under the lateral restriction Zuo et al. [6] figured out the negative logarithmic function relation between the axial stress and swelling ratio of argillaceous slate during the process of its swelling. Vergara et al. [7] improved the measuring system and loading system of uniaxial consolidation equipment recommended by ISRM, which can better control the measurement of swelling deformation by the stress boundary condition. Pimentel and Anagnostou [8] bettered the loading system and the lateral confined device of the uniaxial expander and merged several independently controlled expanders which can effectively measure the long-term mechanical properties of swelling rock such as swelling, creep, and chemical-mechanical effects; later Pimentel [9] summarized the current tests of expansibility of swelling rock and states the experimental equipment and methods should be further advanced to meet the needs of various swelling rock projects.

However, many of these researches of expansibility of swelling rock can be traced back to the test methods of expansive soil, either applying a uniaxial or an improved uniaxial consolidation equipment to obtain the swelling qualities of swelling rock under the stress of lateral confinement or multidimension. As to the projects of expansive soil, including dam, roadbed, and large area of foundation, they can all be simplified as the one-dimensional compression problem under the lateral confinement. Nevertheless, for some projects of swelling rock, like slope and protection of mine prop whose initial stress is changed due to the excavation and loading, the stress boundary condition of practical engineering can be better reflected as these projects are simplified as the one-dimensional problem under the unconfined lateral condition. Meanwhile, the swelling rock is less likely to lead to lateral deformation resulting from the confinement of the lateral confined steel loop during the conventional swelling test of consolidation equipment, and it will not produce any yield failure no matter how big the vertical load is, so this kind of test cannot check the failure mode of swelling rock during the action of load.

Accordingly, for this kind of engineering projects the practical stress boundary condition cannot be well reflected applying the test of expansibility recommended by norms. This paper carried out the swelling test under lateral unconfined condition and analyzed the qualities of lateral unconfined swelling of weak swelling rock by applying a simple self-designed saturated equipment to the swelling test on the platform of the microcomputer controlled rock shear rheological tester RYL-600.

2. Preparation of Test

2.1. Design of Test. The purpose of the lateral unconfined uniaxial swelling test is to study the rule between deformation of axial swelling and time of dry weak swelling rock upon the impact of both different axial load and hydration under the lateral confined condition. The big difference of this lateral unconfined uniaxial swelling test from the swelling test of conventional consolidation equipment lies in the fact that the rock samples can swell freely during the process of their hydrated swelling without any lateral confinement. The axis deformation rule of swelling rock shaped by both hydration and axial loads of dry rocks is explored with the different axial compression load made by the servopress. Four load levels are designed, 0.1 kN, 1 kN, 2 kN, and 2.6 kN, and so are their, respectively, corresponding axial stress levels, 0.05 MPa, 0.5 MPa, 1.0 MPa, and 1.3 MPa in the unconfined lateral test. The swelling test is intrinsically the free swelling test while the axial stress level is 0 MPa.

2.2. Test Equipment. The test equipment is composed of loading and saturation parts, and the loading equipment adopts the microcomputer servorock shear rheological tester RYL-600 produced by Changchun Zhaoyang Equipment Co. Ltd. as shown in Figure 1. The rheological tester RYL-600 consists of rigid reaction frame, servoloading system, automatic acquisition system, and computer control system, which can take the mechanical tests with many stress boundaries, like homotaxial, triaxial compression, and shear of rock. The ac servotest system is DOLI digital, the stability of prolonged pressure, ±2%; the greatest axial test force, 600 kN; the resolution rate of test force, 20 N; and the accuracy of test force, ±1%. The deformation range of automatic acquisition is as follows: axial direction 0–5 mm and radial direction 0–3 mm, with the accuracy of measurement ±0.5%. The saturation equipment of the rock sample is a simple self-made circular barrel of thick steel panel with an inner diameter of 110 mm and a height of 150 mm.

Figure 1: The microcomputer-controlled rock shear rheological tester (RYL-600).

2.3. Sample Description. The rock samples, a moderately weathered cretaceous red mudstone with weak dilatancy, are collected 15 meters below the surface in Zhuzhou, Hunan. This kind of rock with exposure to air is prone to weathering; accordingly, the samples should be sent to the lab and processed strictly conforming to the rock mechanical specifications within 12 hours.

The samples are determined with no abnormal wave velocity through the test of the wave velocity. The basic physical mechanics index of rock is obtained by the conventional rock mechanics test as shown in Table 1. The physical properties of rock samples are analyzed by using X-powder diffractometer D8 Advance produced by Brook AXS Co. Ltd., Germany. The X-ray diffraction (XRD) spectrum is shown in Figure 2. It is found that the red mudstone is mainly composed of clay minerals and clastic minerals by qualitative and semiqualitative analysis, and the percentage of mass content of various minerals in the red mudstone is shown in Table 2. The clay minerals include kaolinite, illite, montmorillonite, and chlorite, and their mass percentage is between 18% and 20%; while the clastic minerals consists of quartz, calcite, feldspar, mica, etc., and their mass percentage covers 80 percent of the total mass.

2.4. Test Procedure

(1) First, the processed rock samples are placed in the oven for 24 hours and cooled to room temperature in the oven.

(2) The saturation vessel is dried with a heater before installing the rocks, and the installation is shown in Figure 3. The sample is kept in the simple vessel and elicited by two force relay columns.

Table 1: The fundamental physical and mechanical properties of rock.

Percentage of saturation content (%)	Saturated unit weight (kN/m^3)	Uniaxial compression strength of saturation (MPa)	Uniaxial compression strength of dehydration (MPa)
5.65	25.94	4.5–5.6	20.4–25.6

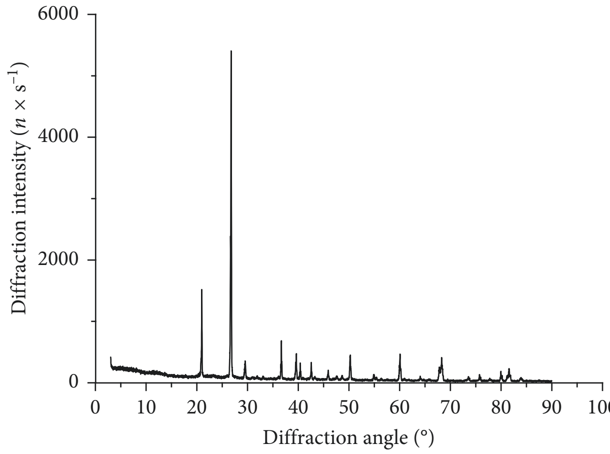

Figure 2: XRD spectrum of red mudstone.

Table 2: The percentage of mass of various minerals in the red mudstone.

Minerals	Quartz	Calcite	Feldspar	Mica	Kaolinite	Chlorite	Illite	Morencite	Montmorillonite	Others
Mass percentage	40.85	20.47	12.84	8.41	6.96	5.24	2.52	1.16	0.81	0.74

Figure 3: Installation of test equipment.

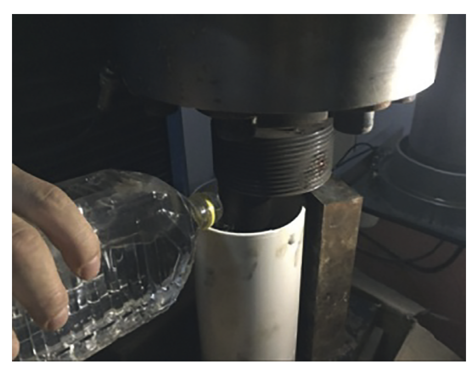

Figure 4: Hydration of dry red mudstone with water filling.

(3) Adjust the loading and collecting system after the dried rock is installed. Load to specify the stress level at −5 N/s and maintain stability.

(4) Add water into the simple vessel while the load becomes stable as shown in Figure 4.

(5) Steady the load at the specified stress level, and observe and record the swelling deformation qualities of red mudstone.

3. Test Results and Analysis

3.1. Sign Convention of Swelling Deformation. As shown in the following Figure 5, under the action of external forces, the rock produces a certain deformation, and the degree of deformation is called strain. The rock mechanics specifies that the compressive is positive while the compressive stress is positive and the tensile is negative while the tensile stress is negative. The compressive strain can be calculated as

$$\varepsilon_c = \frac{\Delta H}{H}, \tag{1}$$

where ε_c is the compressive strain, H is the initial height of the rock sample, and ΔH is the compressive deformation by external forces.

As the swelling rock swells absorbing water, the direction of swelling deformation is contrary to the deformation of rock under stress; therefore, the axial swelling strain of red

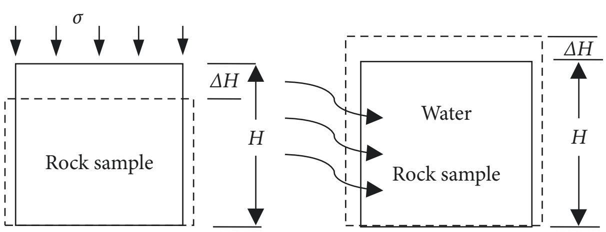

Figure 5: Sign convention of deformation.

mudstone is set as negative in the process of axial deformation in the paper:

$$\varepsilon_s = -\frac{\Delta H}{H}, \tag{2}$$

where ε_s is the swelling strain, H is the initial height of the rock sample, and ΔH is the swelling deformation.

3.2. Test Results. According to the fundamental mechanical properties of red mudstone, the unconfined swelling test of dry mudstone was taken with the four stress levels, respectively, 0.052 MPa, 0.53 MPa, 1.03 MPa, and 1.3 MPa, which are lower than that of the saturated uniaxial compressive strength. The results of the test are shown in Figure 6.

The relationship between swelling stress and time under different stress levels is obtained by the uniaxial swelling test under the lateral unconfined swelling condition, shown in Figure 6. The swelling stress is assumed to be positive while the compression deformation caused by the vertical load is negative in this paper. As shown in Figure 6, considering the loading of hydration and the coupling of swelling under the lateral unconfined condition, the curves can generally be divided into five stages. (1) Load to a specified load, maintain a period of time to a steady deformation, and then pour water quickly to immerse the whole rocks in it. The deformation of this stage is not the main concern in this paper. (2) A stage of rapid development of swelling after hydration. (3) A transitional stage of swelling deformation. (4) A stage liable to stability. (5) Failure stage: the failure occurs when the hydrated swelling rock is far lower than the stress level of saturation strength with a certain load. The figure shows that the axial load affects most swelling of the second stage after the hydration of red mudstone. The rate of axial swelling significantly reduces with the increase of axial compression, which indicates that the axial compression greatly inhibits the deformation rate of axial swelling. During the later period of saturation, the swelling deformation tends to become stable, and the relationship between the swelling deformation and the stress level is shown in Table 3 with the data processed. The load apparently restrains the swelling deformation: the deformation constantly decreases as the axial load increases. The relationship between the axial load and the swelling deformation is shown in Figure 7.

The fitting correspondence between the axial stress and the axial swelling rate is concluded based on the experimental results.

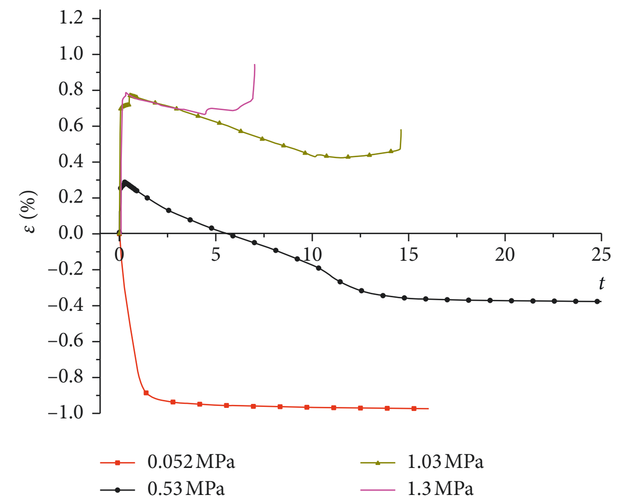

Figure 6: Relationship between swelling stress and time under different stress levels.

Table 3: Axial stress and swelling deformation scale.

Stress level (MPa)	0.052	0.53	1.03	1.3
Swelling rate	0.974	0.664	0.346	0.098

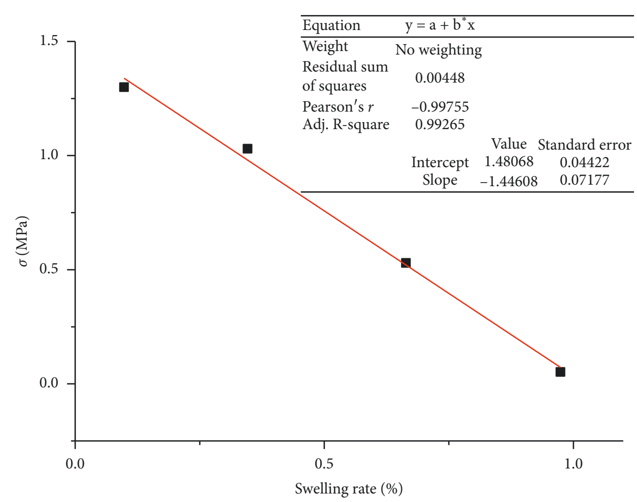

Figure 7: Relationship of axial stress and swelling deformation scale.

$$\varepsilon = a + b\sigma. \tag{3}$$

Swelling force is the maximum pressure required to keep the soil free from lateral deformation and vertical swelling by fully absorbing water based on the definition in *Standards for Fundamental Terms of Geotechnical Engineering* (GB/T50279-98). Thereby, the maximum swelling force under the unconfined condition is hypothesized allowing the free lateral swelling without the vertical swelling. Assume $\varepsilon = 0$, the scale of unconfined swelling pressure σ_0 with different types of red mudstone can be concluded according to Formula (2). The unconfined lateral swelling pressure

σ_0 of red mudstone in this experiment is drawn as 1.49 MPa based on the fitting results of this experiment.

4. Conclusion

Some conclusions are drawn in the paper with the unconfined lateral swelling test and the free swelling of red mudstone:

(1) The swelling qualities of red mudstone reveal the demonstrable time effect. At the beginning of swelling, the deformation increases rapidly, and after that, the deformation tends to keep a certain value.

(2) The axial load strongly restrains both the rate and scale of swelling deformation. The scale of the axial swelling decreases, the rate of swelling slows, and the time threshold value t_0 of swelling towards stability increases as the load grows.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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