Comparison of conventional and cyclic oedometer swelling tests on rock specimens

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ABSTRACT: The swelling behavior of rocks can be significantly affected by variations in moisture history, particularly through cyclic wetting and drying. The oedometer swelling test is widely utilized to assess the swelling characteristics of rock specimens. In this study, a comparison was made between conventional oedometer swelling tests and cyclic wetting and drying oedometer swelling tests on rock specimens. The objective was to evaluate the influence of cyclic wetting and drying on the resulting swelling curve. The slope of the swelling curve obtained from the cyclic test was more than double that of the conventional test. This comparison underscores the importance of accounting for cyclic wetting and drying conditions when assessing the swelling behavior of rocks and highlights the potential implications for long-term engineering projects involving rock structures.

Keywords: Cyclic swelling, Rock swelling, Oedometer swelling test, Opalinus Clay.

1 INTRODUCTION

When certain types of rock come into contact with water, they have the ability to absorb and retain water within their structure, resulting in an increase in volume. This phenomenon is commonly known as rock swelling.

Swelling rocks and swelling rock masses can have detrimental effects on the performance of foundations and the stability of underground excavations. When encountered in tunneling projects, swelling rocks can lead to perimeter convergence and cause damage to the support system of the tunnel.

Rock masses may undergo repeated fluctuations in water content due to changes in groundwater levels and evaporation, leading to continuous damage and weathering that affects its physical and mechanical properties. The disintegration of rock caused by wetting and drying cycles can increase water absorption and enhance swelling behavior. This phenomenon has been observed in various types of rock, as reported in studies by Diop et al. (2008), Hua et al. (2017), Jiang et al. (2022), Doostmohammadi et al. (2009), Vergara & Triantafyllidis (2015), and Selen et al. (2020).

The logarithmic equation that describes the relationship between swelling strain and swelling pressure, known as the swelling curve (Grob 1972), shows that swelling strain increases as pressure decreases. In this equation, the parameter K corresponds to a material constant and σ_0 is the swelling pressure obtained under constricted deformation (maximum swelling pressure).

$$\varepsilon = -K log\left(\frac{\sigma}{\sigma_0}\right) \tag{1}$$

Previous research has suggested that the correlation between swelling pressure and strain is not applicable for cyclic swelling due to the rock's progressive degradation and increased swelling behavior during wetting-drying cycles, as noted in studies by Vergara and Triantafyllidis (2015) and Selen et al. (2020). However, there is a lack of comparative analysis between conventional swelling tests and cyclic wetting-drying tests, particularly regarding the resulting swelling curve from both testing methods. This study aims to fill this research gap by conducting both conventional tests and cyclic wetting-drying tests on Opalinus Clay rock specimens.

2 TESTING METHOD

2.1 Specimen preparation

The rock specimens for the oedometer swelling tests were obtained from drill cores. The specimens were prepared by cutting them into discs, and a lathe was used to trim and shape them to fit well within the oedometer ring. Additionally, the lathe was utilized to ensure that the end faces of the specimens were flat and parallel to each other.

2.2 Conventional oedometer swelling tests

The oedometer swelling tests were conducted using a testing device, as depicted in Figure 1, which permitted the manual adjustment of both the vertical deformation and load on the specimen, as outlined in prior research by Vergara & Triantafyllidis (2015). The initial step of the tests involved swelling under restricted deformation to the specimens until the maximum swelling pressure σ_0 was reached, as specified by Madsen (1999).

Initially, a 0.1 kN axial load was applied to the specimen in the oedometer ring, and swelling was induced by adding demineralized water to the watering cell. During this process, the vertical deformation of the specimen remained fixed at zero, while the swelling load gradually increased until it stabilized after several days. Once the first step of the swelling test was completed, the axial load on the specimen was lowered and kept steady until a new equilibrium was achieved between swelling pressure and strain.

After the deformation was equilibrated, an additional step was initiated by unloading the specimen to a different load level. The specimen was then allowed to swell under the new load until the deformation stabilized.

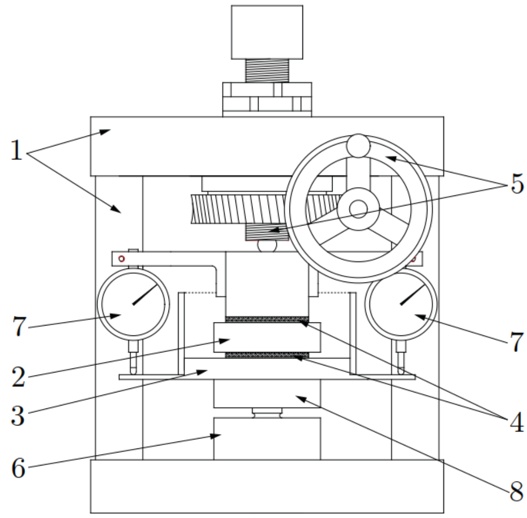

Figure 1. Oedometer swelling test Apparatus (1) Frame, (2) Ring and specimen, (3) Watering cell, (4) Sintered metal plates, (5) Manual spindle, (6) Load cell and (7) Dial gauges (Vergara & Triantafyllidis 2015).

2.3 Cyclic oedometer swelling tests

The same procedure as the conventional test was employed in the initial step of the cyclic swelling tests to obtain the swelling pressure under zero axial deformation. Once the swelling pressure stabilized after reaching the maximum swelling pressure, the water was drained from the watering cell, and the specimen was left to dry under ambient conditions. Following this, the watering cell was refilled with water, and the process was repeated. During the wet phase of each cycle, the deformation of the specimen was controlled to achieve a specified target value (deformation-controlled test). As a result, the swelling pressure varied in each cycle.

3 RESULTS

3.1 Conventional oedometer swelling tests

The maximum swelling pressure achieved under zero deformation was 2,0 MPa and 1.6 MPa for specimens CT-1 and CT-2, respectively. Figure 2a illustrates the swelling strain over time. These curves were generated by subtracting the immediate elastic strain after unloading the specimen. The pressure held constant during the unloading steps is shown.

The swelling curve was determined based on the equilibrated swelling strain and stress obtained from the three test steps: the initial step under constricted deformation and the subsequent two steps under constant load. The resulting swelling curves are presented in Figure 2b and exhibit a good fit to the data. The slope of the curves, represented by the material constant K in Eq. 1, are 2.48% and 1.95% for specimens CT-1 and CT-2, respectively.

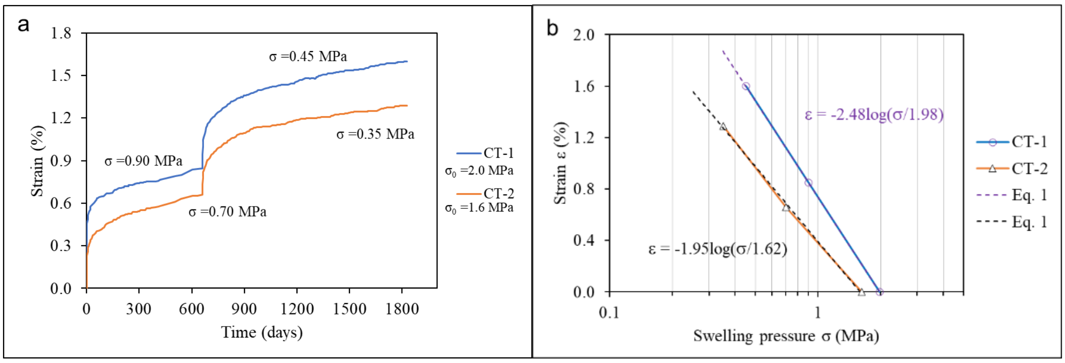

Figure 2. Results of conventional swelling tests. a) Swelling strain under constant load. b) Swelling strain vs swelling pressure and best fit of Eq. 1 (swelling curve).

3.2 *Cyclic oedometer swelling tests*

The equilibrated swelling pressure and strain from the cyclic tests are presented in Figure 3. The maximum swelling pressure in the first cycle reached 1.4 and 1.7 MPa. It is observed that under constant deformation, the swelling pressure increases with the number of cycles. The time required for equilibrium within the wet phase of a cycle was between 10 and 15 days.

Unloading of the specimen (to a new target deformation) was always performed at the beginning of the wet phase, allowing the specimen to swell more than in the previous cycle until reaching the target deformation. The target deformation was maintained for the following cycles until the next step (unloading to a new deformation) was performed.

The swelling curves estimated using all the equilibrium points are shown in Figure 4. Their slopes are 4.8% and 5.3%. The slope of the curves obtained from cyclic testing is significantly higher than that obtained from the standard test.

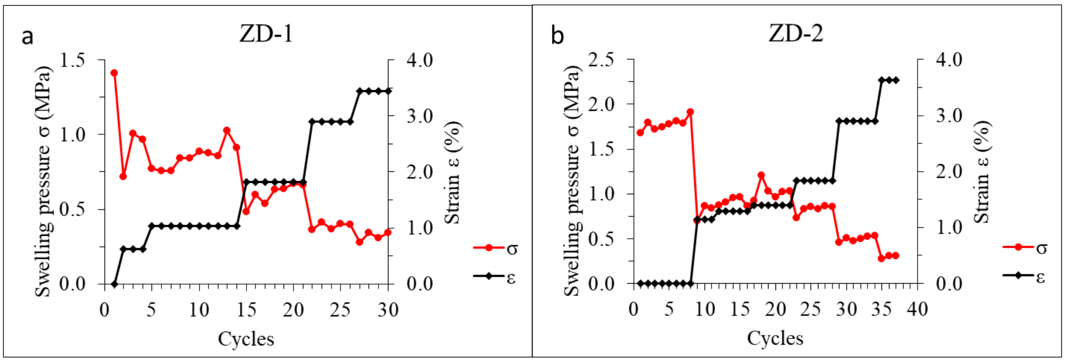

Figure 3. Results of cyclic swelling tests: a), b) Swelling strain and pressure over number of cycles.

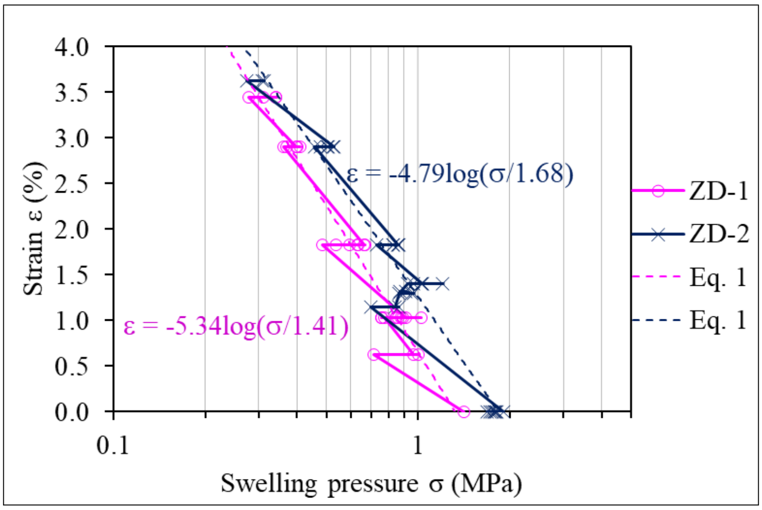

Figure 4. Results of cyclic oedometer swelling tests and best fit of Eq. 1 (swelling curve).

3.3 Discussion

The results clearly demonstrate the impact of cyclic wetting on the rock specimens. When deformation is maintained constant, the pressure increases. In the cyclic tests, the pressure increases under constant strain. After unloading, the pressure decreases, but then increases again with subsequent cycles. In some cases, the swelling pressure under a certain deformation is greater than the pressure obtained in a previous step under lower deformation, which contradicts the swelling curve given by Eq. 1. The slope of the swelling curve increases progressively as the specimen is unloaded and further cycles are performed (Figure 4). This indicates that the allowed deformation plays a crucial role in the behavior of the rock under cyclic wetting and drying. Allowing more deformation increases the impact of breakdown and disaggregation caused by the shrinking and swelling, as previously discussed by Vergara and Triantafyllidis (2015).

Figure 5 presents a comparison of the swelling curves obtained from all tests. The maximum swelling pressure varies among the tests, but the slopes of the curves are similar within each type of test. However, the slopes of the curves from the cyclic tests are much higher (*K* value) compared to the conventional tests. On average, the slope of the swelling curves from the cyclic tests is about 2.3 times higher than that of the conventional tests. This observation implies that a significantly larger deformation is necessary to achieve an equivalent reduction in swelling pressure. It can be concluded that under cyclic wetting and drying conditions, the expected swelling deformation is more than twice as pronounced as that observed under standard testing.

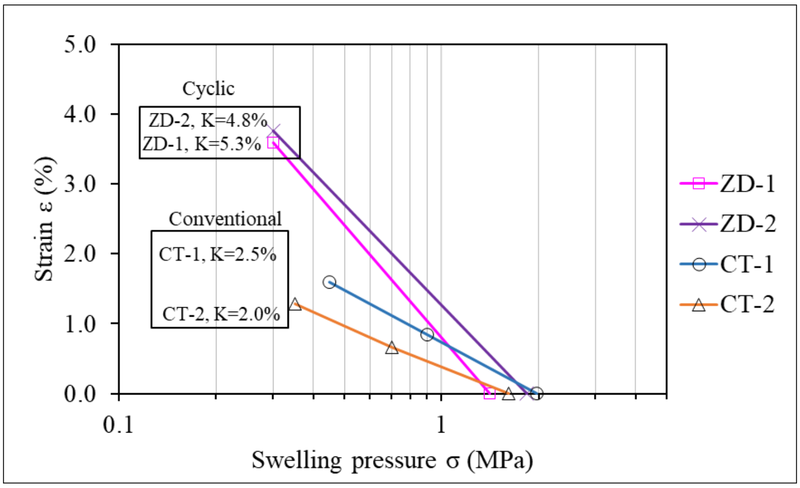

Figure 5. Swelling strain-stress relationship (swelling curve). Conventional tests (CT) and cyclic wetting and drying tests (ZD) are shown. The parameter K in Eq. 1 is given.

4 CONCLUSIONS

The maximum swelling pressure, reached without deformation, ranges from 1.4 to 2.0 MPa for all specimens. Grob's swelling curve (Eq. 1), fits well with the results of the conventional oedometer swelling tests. The obtained swelling curves from both tests are nearly parallel to each other.

Under cyclic wetting and drying, the swelling pressure tends to increase when deformation is held constant. The slope of the swelling curve increases progressively as the specimen is unloaded and further cycles are performed.

The results allow for a comparison of the impact of cyclic wetting and drying on swelling behavior and the extent of the increase in swelling behavior due to cyclic wetting. It is observed that the swelling potential during cyclic wetting and drying is higher, and the swelling deformation is more than double compared to that determined under standard conditions.

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