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Swelling behavior of volcanic rocks under cyclic wetting and drying

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ABSTRACT

The swelling behavior of rocks can be affected by cyclic wetting and drying. This issue is of practical importance for the design and construction of underground structures in which the surrounding swelling rock mass could be subjected to moisture fluctuations. The present work investigates the cyclic swelling behavior of volcanic rocks from the Central Andes of Chile. The specimens were tested under oedometric conditions measuring the axial swelling stress and strain. The results indicate that the wetting and drying cycles have an impact on the swelling potential and that this occurs only after the rock is allowed to deform during the wetting phase. In addition, indirect estimations with the needle penetration test showed a decrease of strength and stiffness. This implies that conventional testing procedures may underestimate the long term swelling behavior and overestimate the mechanical parameters of these rocks.

1. Introduction

Swelling in clay rocks occurs if water is absorbed and stored in the interlayers of clay minerals, producing a volume increase. The amount of water adsorbed by the rock depends on its mineralogical composition and on the imposed boundary conditions. This type of rock swelling is a reversible process. If the rock does not disintegrate after wetting, its volume will decrease when water is removed from the interlayers of the clay particles and will increase again if the moisture returns.

It has been observed that the swelling behavior of some swelling rocks may be altered by wetting and drying cycles and that the swelling stress and swelling strain depend on the history of moisture changes.[1–3] The former implies that the swelling behavior assessed by conventional swelling tests will not provide an accurate estimation of the long-term swelling behavior of the rock. This issue is of practical importance for the design and construction of underground structures in which the surrounding swelling rock mass could be affected by moisture fluctuations. Cyclic changes in the water content around the excavation can be produced, for example, by seasonal rainfall, fluctuations of the air humidity or changes in the pressure or flow depth in a headrace tunnel.

The rocks investigated in this study correspond to volcanic rocks from the Tinguiririca valley located in the Central Andes of Chile. The presence of swelling rocks of volcanic origin in the Central Chilean Andes is known, and it has been reported by researchers.[4,5] In the recent years, this area has experienced the construction of tunnels associated to run-of-river hydropower plants. The study of the swelling behavior and the estimation of the swelling potential of volcanic rocks are relevant for future hydropower and infrastructure projects located in that region and it can be of particular interest for the maintenance or revision of existing shafts and tunnels.

The swelling behavior of the studied materials has been previously reported.[5] The authors showed that despite the high amount of swelling clay minerals (smectite) contained in these rocks, only moderate swelling behavior was measured on unconfined swelling and oedometric swelling tests. In a later series of tests, the swelling potential was activated by wetting the samples with a reducing solution, which removed the hematite coatings from the edges of the clay minerals thus, reaching higher swelling stresses.

The objective of the present study is to investigate the swelling behavior of these volcanic rocks under cyclic moisture changes. The assessment of the swelling behavior was performed by means of oedometric swelling tests. The results of two different types of swelling test were compared, in order to determine the influence of the deformation of the specimen on the swelling behavior when subjected to moisture changes. In addition, changes of the rock

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mechanical properties after cyclic wetting and drying were estimated.

2. Cyclic swelling of rocks

Rock swelling behavior under moisture changes has been addressed in the literature. Huang et al.[1] studied the cyclic swelling behavior of shales with tests aimed to determine the maximum swelling stress and maximum swelling strain under different temperatures. The study concluded that the temperature is of less importance and that the rock moisture content before the test has a great influence in the swelling behavior. The authors reported also lower swelling stresses and strains after a second wetting cycle, which they attributed to the growth of micro-cracks in the specimens.

Cyclic unconfined swelling tests performed on mudstones have been reported.[2,3] In these studies, cylindrical rock specimens were left free to swell in the vertical direction. Several wetting and drying cycles were performed while the vertical deformation was measured. Both studies show an increase in the accumulated vertical strain with each further cycle. The vertical strain remained constant or decreased after each cycle until a maximum deformation was reached. A comparison of observations under a scanning electron microscope (SEM) of samples before and after the tests, showed changes in the rock's texture and structure.[2] According to the investigators, these changes are an indication of the phenomenon called “air breakage”.[6] This theory suggests that the breakdown of shales under moisture changes can be explained by the increase of pressure of the air trapped in the internal pores, which due to a fast humidity change will cause breakdown of the rock structure.

If the expansion of the rock is constrained, the swelling process will result in the development of stresses. Reported oedometric swelling stress tests on mudstone under cyclic wetting and drying exhibited an increase of the axial stress with each cycle.[3] The swelling stress developed in further cycles reached, in some tests, more than twice the stress of the first cycle. These results showed also that the increment rate of swelling stress decreased in each cycle before a stress limit was reached. Nevertheless, these tests were performed on an apparatus that did not allow control of the axial deformation of the specimen during the test and therefore the stress measured was accompanied by axial deformation.[7]

In the present study, the cyclic swelling tests were performed with and without controlling the axial deformation of the specimen. This allows to compare the effect of the deformation in the swelling behavior of the rock under cyclic wetting and drying which until now, it has not been addressed in the literature. The experimental results of the present study show that the deformation during the wetting (swelling) phase plays an important role in the swelling behavior. Additionally, the effect of the cyclic wetting and drying on the rock's mechanical parameters was estimated.

3. Studied material

The tested material corresponded to volcanic rocks from the Coya-Machalí-Formation in the Central Andes of Chile. The samples were collected at the Tinguiririca river valley, which is located about 150 km south-southeast of the capital Santiago (Fig. 1).

3.1. Petrographic description

Thin-slices of the rock samples were analyzed under a light-polarizing microscope. The analysis indicated that the rocks are

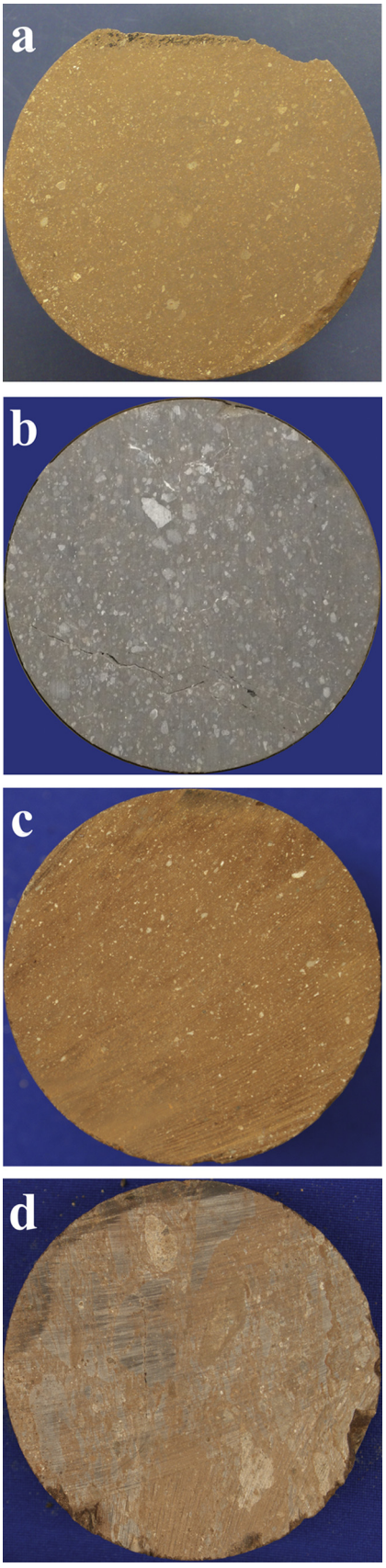

Fig. 1. Tested materials (a) R1; (b) N3; (c) R4, N4; (d) R14. (See Table 1 for the material description).