Behaviour of shales under uniaxial compression through suction paths

Martin Espitia[1 *], Bernardo Caicedo[2], and Luis Vallejo[3]

[1] Universidad Pedagógica y Tecnológica de Colombia, Sogamoso, Colombia
[2] Universidad de Los Andes, Bogotá, Colombia
[3] University of Pittsburgh, Pittsburgh, United States
* jairomartin.espitia@uptc.edu.co

Introduction

Recent experimental studies have evidenced the influence that total suction has on the behaviour of shales. Some studies that have focused on the role of total suction on the mechanical properties of Shales have generally shown increases of both strength and elastic modulus with suction (Pham et al. 2007; Wild et al. 2014; Valès et al. 2004). However, these studies have not widely considered hydro-mechanical effects on the differences between short-term and long-term rock strength. The purpose of this paper is to provide experimental data on this precise issue.

Material and methods

Material

The studied rock is an indurated Cretaceous Shale from the Belencito formation. This rock has generated stability problems on slopes and in underground excavations in the eastern Andes mountain range of Colombia. Its average mineralogical composition comprises 53.2% of clay minerals (kaolinite and illite), 29.0% of calcite, 11.0% of quartz, and less than 5.0% of other minerals (e.g. opaque minerals and Muscovite). Table 1 reports the index properties of the studied rock.

Table 1: Index properties of the studied rock

Property	Bulk density	Specific gravity	Water content	Liquid limit	Plastic limit
Value	2570 kg/m^3	2.76	1.34%	25	15

Methods

Specimen preparation

From blocks of rock, two cylindrical specimens, 20 mm in diameter and 50 mm in height, were bored perpendicular to the bedding plane. During sampling drilling, air pressure was used to minimize alteration caused by liquid water. Then, the ends of the specimen were cut with a power cut-off saw to the desired height of about 40 mm. Finally, the side surface and end faces were polished with a lathe.

Device and testing program

A device was designed and developed to induce specimen failure through suction reduction at constant axial stress. This feature let to evaluate the long-term strength of the studied Shale. The testing device designed and developed to perform coupled hydro mechanical tests in uniaxial loading conditions on rock specimens include a load control system and a suction control system. The load control system was used to maintain a constant stress during testing. Total suction was applied using the vapour equilibrium technique which controlled the relative humidity within a sealed system (Delage et al. 2008). Five saturated saline solutions ($CaCl_2$. $6H_2O$, K_2CO_3. $2H_2O$, $NaBr.2H_2O$, NaCl, and K_2SO_4) were selected to cover a range of relative humidity between 33% and 95%. Table 2 reported the hydric and stress paths performed in the suction path test 1 (SPT1) and the suction path test 2 (SPT2).

Table 1: Hydric and stress paths performed on two rock specimens

SPT1	Total suction (MPa)	102	151	151	7	-	-	-
	Axial stress (MPa)	0.1	0.1	29.8	29.8	-	-	-
SPT2	Total suction (MPa)	102	151	151	102	78	46	7
	Axial stress (MPa)	0.2	0.1	28.4	28.4	28.4	28.4	28.4

Results

Figure 1 shows data reported by Espitia et al. (2017) regarding the compressive strengths for different total suctions obtained from uniaxial compression tests (UCT) performed on the studied rock. According to Bieniawski (1967), this peak stress corresponds to the short-term strength of the rock ($\sigma_{peak.\ short\text{-}term}$). Also, Figure 1 presents the results for compressive strength obtained from the suction path tests. These results evidence the effect of the duration of the test in the strength. In fact, when comparing SPT1 and SPT2 which were tested at the same applied axial stress, SPT1 (duration of 7 days resulting from one step of total suction reduction) reach the failure at a lower value of estimated suction than for SPT2 (duration of 46 days along stepped reduction of total suction).

Despite the small number of results for the suction path tests, it is remarkable that the peak stress obtained from the suction path tests was between 75% and 80% respect to the peak strength obtained from the uniaxial compression tests. This observation is in accordance with the proposal made by Bieniawski (1967) who reported that $\sigma_{peak.long\text{-}term}$ is approximately equal to 80 % of the $\sigma_{peak.short\text{-}term}$.

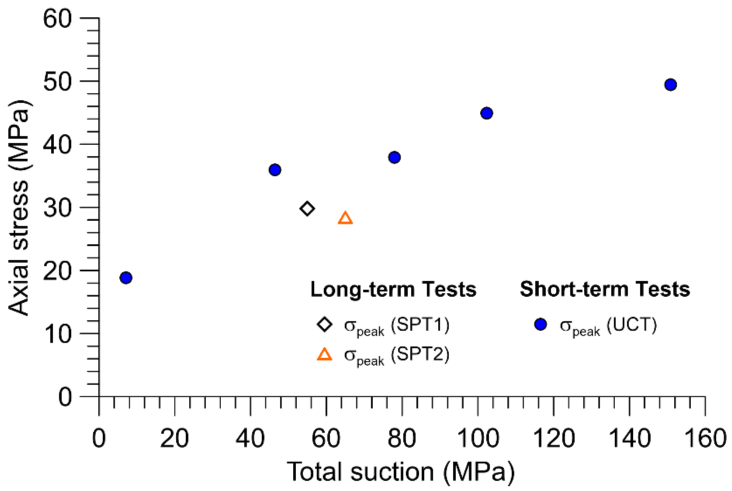

Fig. 1: Peak stress for suction path tests (SPT1 and SPT2) and uniaxial compression tests (UCT)

Conclusions

These results confirm that the proposal made by Bieniawski (1967) regarding long-term and short-term rock strength remains valid for hydro-mechanical behaviour.

References

Bieniawski ZT (1967) Mechanism of brittle rock fracture. Part I. Theory of the fracture process. Int. J. Rock Mech. Min. Sci. 4:395-406

Espitia JM, Caicedo B, Vallejo L (2017) Effect of suction and stress on Poisson's ratio of argillaceous rocks Geotech. Lett. 7:53-59 doi:http://dx.doi.org/10.1680/jgele.16.00138

Delage P, Romero E, Tarantino A (2008) Recent developments in the techniques of controlling and measuring suction in unsaturated soils. Paper presented at the 1st European Conference on Unsaturated Soils, Durham, United Kingdom

Pham QT, Vales F, Malinsky L, Nguyen Minh D, Gharbi H (2007) Effects of desaturation–resaturation on mudstone Phys. Chem. Earth., Parts A/B/C 32:646-655

Wild KM, Wymann LP, Zimmer S, Thoeny R, Amann F (2014) Water Retention Characteristics and State-Dependent Mechanical and Petro-Physical Properties of a Clay Shale Rock Mech. Rock Eng. 48:427-439 doi:10.1007/s00603-014-0565-1