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Technical Note

Influence of humidity conditions on shear strength of clay rock discontinuities

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ABSTRACT

The shear strength of rock discontinuities strongly depends on the water content especially when the rocks contain clay materials. To assess the decrease in the mechanical properties of clay-infilled discontinuities due to water saturation, a series of direct shear tests was performed using an advanced shear box that allows the injection of water into the discontinuity. Results show that both the friction coefficient and the cohesion decrease when the discontinuity is saturated. Overall, the shear strength of the discontinuity is considerably reduced to approximately 50% of its original value. This reduction has to be accounted for when conducting stability analyses of rock slopes, dam foundations or underground openings.

1. Introduction

The stability of rock masses is largely affected by the humidity conditions which are, for example, responsible for landslides that occur after heavy rains. This is particularly true for stratified rock masses with clay-infilled discontinuities, because most of clay minerals are highly sensitive to water.

Beside the change of pore pressure distribution within the rock mass, an increase in the water content modifies the consistency of the clay and therefore its mechanical properties. Several landslides were caused by a sudden drop in the mechanical properties of the material associated with an increase in the water content. This was the case, for example, in the catastrophic events of the Vaiont Dam failure, where a landslide caused the sudden emptying of the reservoir (Hendron and Patton, 1987).

Despite some recent studies on this subject (Nara et al., 2011, 2012; Li et al., 2012), the mechanical behavior of clay-infilled rock discontinuities under direct shear test has not yet been fully investigated. Several loading conditions may be encountered, from static loading leading to creep (Zhang et al., 2012) to cyclic loadings that induce degradation of the rock discontinuities (Jafari et al., 2003). In terms of failure criteria, Indraratna et al. (2010) recently proposed an approach to account for discontinuity characteristics (roughness, thickness, etc.). However, it has to be remembered that, in order to extend laboratory results to the field, scale effects have to be taken into account (Vallier et al., 2010; Fujii et al., 2011).

In this framework, a testing program based on direct shear tests has been carried out on rock discontinuities in order to determine how much the shear strength is changed when the water content increases.

2. Testing program

2.1. Rock under study

The rock under study is a marl from the Dogger geological period, made up of approximately 50% clay, 30% carbonate and 20% quartz. The clay minerals are mostly illite with some smectite and some interstratified minerals. The natural water content of the rock specimens lies between 4 and 7% (Fabre and Pellet, 2006).

The main average physical and mechanical properties of this rock, reported in Table 1, were determined in previous studies, including sonic velocity measurements (Pellet and Fabre, 2007). Time dependent properties, shrinkage and swelling characteristics of intact rock specimens as well as hydro-mechanical properties and permeability have been also extensively investigated (Buzzi et al., 2007; Cariou et al., 2009).

2.2. Testing equipment and specimen preparation

Tests were carried out using a 3D shear box developed by Boulon (1995) in order to control stresses and displacements in the three spatial directions. The originality of this device is to make shearing possible by moving the two half boxes in opposite directions. This allows the normal stress to remain centered on the discontinuity,

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Table 1
Average values of mechanical and physical properties of the marl under study. After Fabre and Pellet (2006) and Pellet and Fabre (2007).

Density kN/m^3	Water content %	Porosity %	Saturation degree %	P-wave velocity m/s	UCS MPa
23.7	5.9	15.5	87	4200	26

therefore avoiding half box rotation. The tests can be performed with a Constant Normal Load or by imposing a Constant Volume with no joint dilation and no joint compaction. This equipment also allows the hydro-mechanical behavior of rock discontinuities to be studied using fluid injection into the center of the specimen. An extensive description was given by Hans and Boulon (2003) and by Buzzi et al. (2007). The overall dimensions of this equipment, which is shown in Fig. 1, are 1.2 m × 1.2 m.

The specimens used were marl cores retrieved from borehole. They were 79 mm in diameter and 80 mm in height. These specimens were then sawed in half; consequently the artificially created discontinuities were perfectly smooth. Afterwards, the two parts of the specimen were sealed in the steel half boxes using a cement mortar made up of a mixture of fast-curing cement and Vicat ordinary cement prepared with an optimal ratio to obtain maximum strength for a minimum curing time. Fig. 2 shows the two half boxes before and after assembly, ready to be tested. The external dimensions of a half box are 140 mm × 140 mm.

2.3. Testing program

The main part of the testing program was the direct shear tests that were performed on the marl discontinuities in parallel to the joint surface. Additionally, in order to fully characterize the rock discontinuities under study, a few swelling tests and some compression tests were performed prior to the direct shear test.

Direct shear tests were carried out under two different humidity conditions. The first series of tests were conducted on dry discontinuities and the second on discontinuities that had been saturated with water. The objective of these tests was to determine the effect of the humidity conditions on the mechanical properties including the friction coefficient and the cohesion of the discontinuities.

Direct shear tests were carried out with a shearing rate of 0.05 mm/s. They were performed with either a Constant Normal Load (CNL) or at a Constant Volume (CV). Both types of tests are able to determine if the discontinuity tends to dilate or to contract during shearing. The testing conditions of the performed tests are summarized in Table 2.

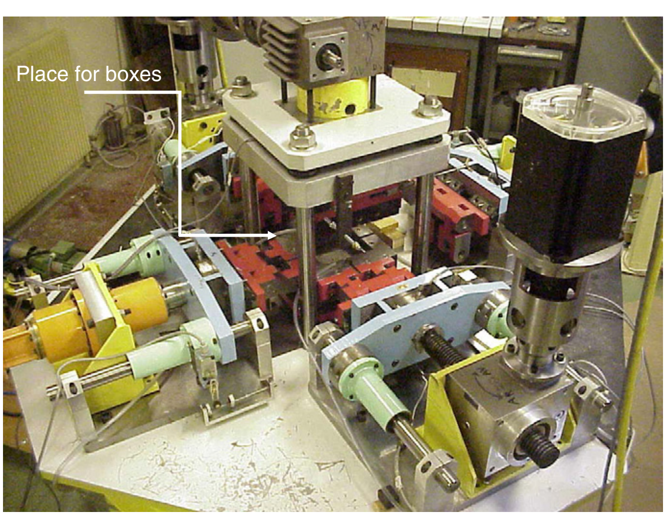

Fig. 1. Photograph of the shearing equipment (BCR3D). After Hans and Boulon (2003), reproduced with the permission of John Wiley Ltd.

Fig. 2. Specimen preparation: marl specimen sealed with a mortar in one half box (top picture); the two half box assemblies ready to be installed in the shear box (bottom picture); dimensions of the boxes are 140 mm × 140 mm.

3. Test results and discussion

3.1. Swelling test

To measure the swelling of the marl discontinuities, water was injected into the center of the specimen after having applied a little normal stress of about 0.1 MPa. Water injections were performed twice a day, 5 to 12 h apart. During the test, the normal displacement was kept at almost zero. Fig. 3 shows results for test TW-CV-21, where the displacement was controlled and the increase of normal stress with respect to time was recorded. After three days of water injection (4300 min), the normal stress stabilized to 0.58 MPa. We can therefore conclude that this clay is moderately susceptible to swelling due to the

Table 2
Shear test program and testing conditions: Constant Normal Load (CNL) and Constant Volume (CV).

Test	Joint conditions	Loading conditions	Stages of initial normal stress [MPa]
TD-CV-02	Dry	CV	2
TD-CNL-03	Dry	CNL	2, 5, 10, 16
TD-CNL-04	Dry	CNL	5
TD-CV-05	Dry	CV	5
TD-CV-06	Dry	CV	16
TD-CV-17	Dry	CV	5, 10, 12
TW-CNL-07	Saturated	CNL	2, 5, 10,16
TW-CV-21	Saturated	CV	5, 10, 12
TW-CV-23	Saturated	CV	2, 5, 10