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In situ non conventional shear tests for the mechanical characterisation of a bimrock

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ABSTRACT: Six non conventional in situ shear tests were carried out in order to investigate the strength properties of the Shale Limestone Chaotic Complex bimrock at the Santa Barbara disused open-pit mine. The testing procedure ensures that the failure surface is free to develop in a tortuous way along block/matrix contacts, thus allowing for the evaluation of the bimrock strength parameters by taking into account the influence of blocks, and ultimately to overcome the size limitation of laboratory specimens. The evaluated operative strength parameters show an overall larger friction angle and a lower cohesion compared to that of the clayey matrix, in agreement with the common bimrock mechanical behaviour.

1 INTRODUCTION

The Shale-Limestone Chaotic Complex bimrock (hereafter referred as SLCC) outcrops over a wide slope in the Santa Barbara disused lignite open-pit mine (Italy). The SLCC is characterised by a grey clayey matrix containing calcareous rock blocks in a matrix-supported fabric (Fig. 1) (Castellucci & Cornaggia, 1980; Abbate et al., 1981; Pini, 1999; Coli et al., 2008, 2009).

According to the Santa Barbara mine reclamation program, a detailed characterisation of the SLCC strength properties was carried out, aiming at modeling the mechanical behaviour of the SLCC taking into consideration the influence of the volumetric block content. During the past years, in fact, the SLCC has been the object of several studies that assumed it as a homogeneous body governed by the mechanical properties of the clayey matrix only (D'Elia et al., 1988; Tommasi, 1996; D'Elia et al., 2006).

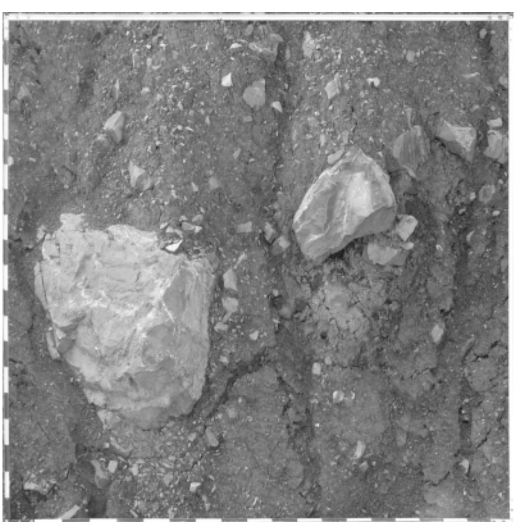

Figure 1. Typical aspect of the SLCC bimrock. Picture edge is 2 m in size.

In order to overcome the inadequate size of laboratory specimens and namely to take into account the influence of blocks, six non conventional in situ shear tests were carried out on specimens of 0.3 m^3 in volume. The testing procedure ensures that the shear plane is free to develop inside the specimen and to negotiate in a tortuous way along the block/matrix boundaries; thus differing from the ISRM Suggested Method for In Situ Shear Tests (ISRM, 2007). This aspect has a very important role in shear tests performed on bimrocks: the main consequence for the presence of blocks, in fact, is an increase in tortuosity of the shear plane that causes the increase in shear strength.

The Mohr-Coulomb operative strength parameters c and ϕ were calculated for each test through the simplified Bishop limit equilibrium criterion, after a detailed survey of the shear plane was made through a laser total station.

2 SHEAR TESTS

2.1 *Description of the test*

The testing procedure adopted in the present study and described below, was inspired by the one performed by Li et al. (2004) and Xu et al. (2007) (Fig. 2, Fig. 3).

A bimrock specimen with a length of 80 cm by 80 cm wide by 50 cm high is excavated at a shallow depth into the slope. The bottom and the back sides of the specimen are in continuity with the rock mass,

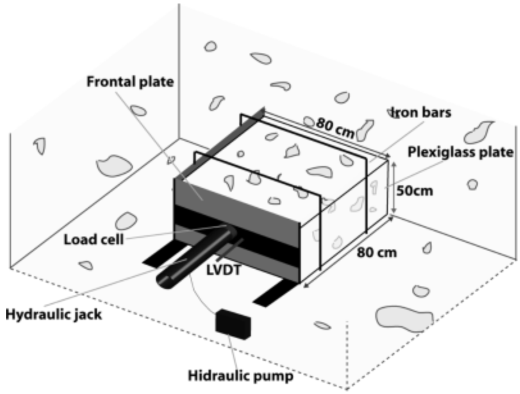

Figure 2. Schematic representation of the shear test apparatus.

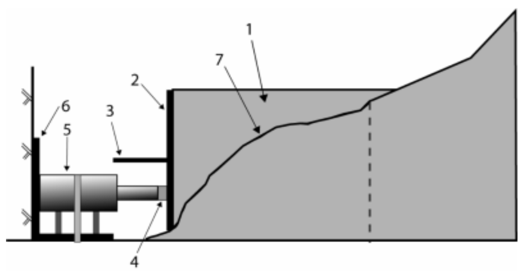

Figure 3. Testing scheme. 1) specimen, 2) frontal steel plate, 3) LVDT transducer, 4) load cell, 5) hydraulic jack, 6) support plate and holder for the hydraulic jack, 7) failure surface.

while a steel and a plexiglass plate are placed against the lateral faces, and blocked through a rigid framework of iron bars. Another steel plate with two bottom guides is leaned against the frontal face of the specimen, free to move horizontally within the lateral plates. No vertical load is applied on the top face.

An horizontal force is applied on the frontal plate through an hydraulic jack connected to a portable oil pump, capable of a maximum force of 180 kN, which is far over the maximum force applied during the test. In order to perform a strain-controlled test, a constant displacement rate of 0.05 mm/sec is set for the hydraulic jack.

The applied force and the horizontal displacement of the frontal plate are recorded and monitored in real time by a digital data acquisition system, composed by a load cell located in front of the jack stem, and by a displacement LVDT transducer. A laptop PC with a LabVIEW interface performs the visualization and the recording of the input signals.

During testing, it was impossible to monitor and quantify the drainage of the specimen, as well as to measure the excess pore pressure. Therefore the evaluated strength parameters ϕ and c must be considered as operative parameters in terms of total stresses (Mirata, 1974, 1991).

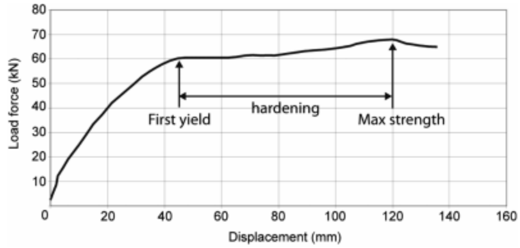

Figure 4. Double yield force-displacement curve of test P3.

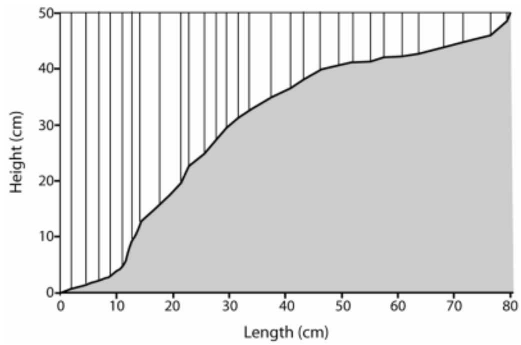

Figure 5. One of the four cross section of test P3. The upper sliding area is subdivided into several slices.

2.2 *Deformational behaviour*

Some of the force-displacement curves relative to the performed tests have shown a distinctive behaviour, characterised by two yield levels connected by a hardening phase (Fig. 4).

The first yield level is related to the deformation of the clayey matrix; it is followed by the hardening phase caused by the increasing influence of blocks. The second yield represents the maximum peak strength, followed by a decay in strength until the residual resistance is then reached.

The double yield curves have already been observed for other bimrocks (Li et al., 2004; Xu et al., 2007, 2008).

2.3 *Strength parameters*

At the end of the test the upper sliding bodies were removed and, for each of the failure surfaces, four detailed cross sections were drawn by means of a laser-scan total station.

The area of the section above the sliding profile was then divided into several slices (Fig. 5) and the strength parameters were calculated by means of the simplified Bishop limit equilibrium criterion (Table 1). For test P5 it was not possible to calculate the strength parameters because the force-displacement curve never reached a peak value within the entire length of the jack stem.

The strength parameters relative to test P1, P3, P4 and P6 have the same order of magnitude, characterised by a high friction angle and a very low cohesion. This behaviour is also in agreement with previous studies on bimrocks that indicated an increase in friction

Table 1. Operative strength parameters. For each test, the displayed c and ϕ parameters are the mean of the values obtained for the four cross sections.

Test	ϕ °	c kPa
P1	43	6
P2	29	49
P3	48	6
P4	48	7
P5	–	–
P6	44	4

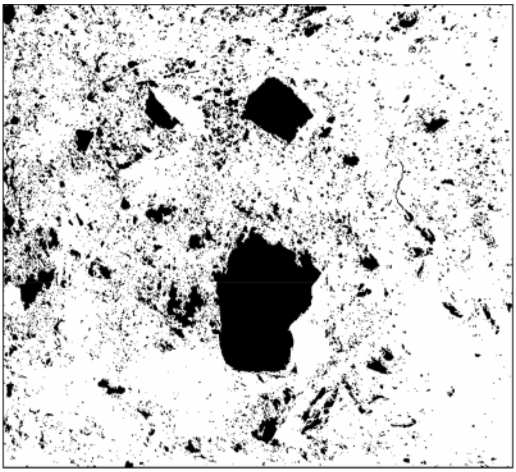

Figure 6. Binary image relative to the failure surface of test P3.

angle and a decrease in cohesion with the increasing in the volumetric block content (Lindquist & Goodman, 1994; Goodman & Alghren, 2000; Sonmez et al., 2004, 2006; Barbero et al., 2008; Pan et al., 2008).

Test P2, instead, is characterised by different values, closer to the ones of the clayey matrix (c'_p: 50–100 kPa; ϕ'_p: 20–25°, from D'Elia, 1991). This behaviour could be related with a much lower volumetric block content inside specimen P2 compared to that of the other tests.

3 ANALYSIS OF FAILURE SURFACE

The failure surfaces were also photographed and analysed by means of digital image processing in order to investigate, in this working phase, the relative percentage of surface covered by the exposed blocks (A_b) and to compare it with the strength parameters.

Collected pictures were scaled and then binarised through a specific segmentation algorithm, thus obtaining output images where the blocks are represented by black features over a white background (the matrix) (Fig. 6).

The A_b values relative to the failure surfaces are listed in Table 2.

It can be noted that test P2, whose strength parameters significantly differ from the other tests (Table 1), shows a very low A_b of 6%, while the other tests are all above the A_b of 16%.

Table 2. Percentage of area of the failure surfaces covered by the exposed blocks (A_b).

Test	A_b %
P1	16
P2	6
P3	23
P4	17
P6	19

Table 3. Comparison between the evaluated strength parameters of the SLCC bimrock and the ones of the clayey matrix (D'Elia, 1991).

SLCC Bimrock	ϕ °	c kPa
	29–43	6–49
Clayey matrix	ϕ'_p °	c'_p kPa
	20–25	50–100

Assuming that the differences in A_b are most likely due to a different volumetric block content inside the tested specimens (VBC), it can be inferred that a correlation between the strength parameters and the VBC exists and needs to be further investigated.

4 FINAL REMARKS

Six non conventional in situ large size shear tests were carried out in order to investigate the strength properties of the SLCC bimrock.

The tests gave very important results about the deformational behaviour of the SLCC. In particular, the force-displacement curves were characterised, in some cases, by a double-yield trend, related to the progressive influence of blocks on the shear strength of the specimen.

The evaluated operative strength parameters range from 29° to 48° for the friction angle and from 4 kPa to 49 kPa for the cohesion. These values differ from the ones of the clayey matrix only (D'Elia, 1991): as expected the bimrock has a larger friction angle and a lower cohesion (Table 3).

Even though the bimrock parameters are in terms of total stress, while the ones of the matrix are expressed in terms of effective stress, the comparison is very useful in order to have an indication about the respective magnitudes.

The relative percentage of the failure surface covered by the exposed blocks (A_b) was also investigated, resulting in a significant difference between the A_b of test P2, whose strength parameters are closer to the ones of the clayey matrix, and the A_b of the other tests.

In order to correlate the strength parameter with the actual 3D volumetric block content inside the specimens, a series of large size in situ sieving tests are currently being performed.

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