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Experimental investigation of time-dependent deformation of soft rock along discontinuities

Authors:



Miodrag Bujišić, MSc. CE
University of Montenegro, Montenegro
Faculty of Civil Engineering
miodragb@ucg.ac.me
Corresponding author



Prof. **Zvonko Tomanović**, PhD. CE
GeoT d.o.o Podgorica, Montenegro
zvonko@geot.me

Research Paper

Miodrag Bujišić, Zvonko Tomanović

Experimental investigation of time-dependent deformation of soft rock along discontinuities

This study presents an experimental investigation of the time-dependent shear behaviour of soft rock discontinuities. Three marly limestone specimens obtained from the Pljevlja coal basin were tested under controlled laboratory conditions. The specimens had identical geometric characteristics but differed in discontinuity surface roughness (smooth, undulating and moderately rough). A dedicated experimental apparatus was designed and adapted to perform long-term shear tests under constant normal loading and incremental shear loading. The results demonstrate the significant influence of discontinuity roughness on shear resistance, displacement development and test duration. Given the limited number of published studies addressing time-dependent deformation of soft-rock discontinuities, the presented pilot investigation provides valuable insight into the governing mechanisms and establishes a basis for a comprehensive experimental programme.

Key words:

soft rock, time-dependent deformations, experiment, discontinuity, roughness

Prethodno priopćenje

Miodrag Bujišić, Zvonko Tomanović

Eksperimentalno ispitivanje meke stijene po diskontinuitetima u uvjetima ovisnim o vremenu

U okviru eksperimentalnih istraživanja posmične otpornosti po diskontinuitetu pri o vremenu ovisnim uvjetima provedeni su pokusi na tri uzorka meke stijene, laporovitoga vapnenca koja su uzorkovana iz otvorenoga bazena u Pljevljima. Uzorci su istih geometrijskih karakteristika, pravilnoga prizmatičnog oblika, pri čemu je na svakom oblikovana umjetna pukotina, koju odlikuju različite hrapavosti ploha diskontinuiteta (glatka, valovita i umjereno hrapava). Uzorci su ispitivani u laboratorijskim uvjetima, pri čemu je postojeća oprema modificirana i izrađen je dio nove opreme da bi se izveo primjeren eksperiment. Imajući u vidu skroman broj eksperimentalnih istraživanja vremenski ovisnih deformacija mekih stijena po diskontinuitetu (na globalnoj razini) ovim se radom želi dati znanstveni doprinos i prikazati prvi rezultati analizom podataka dobivenih konkretnim eksperimentalnim istraživanjem.

Ključne riječi:

meke stijena, vremenski ovisne deformacije, eksperiment, diskontinuitet, hrapavost

1. Introduction

This paper provides analysis of the results from pilot test, constituting more extensive experimental research within the scope of a scientific project by authors Miodrag Bujišić, MSc and Prof Zvonko Tomanović, PhD. Experimental part of the scientific project includes two segments – initial (trial) test and main test. The objective of this paper is to analyse the results obtained during a pilot experimental programme pilot test for the purposes of defining the scope of physical-mechanical parameters and the specimen loading level and determining most relevant parameters for key series of experimental tests. The primary objective of the project is to improve the understanding of behaviour of soft rock mass through experimental research. The next steps of the research within the scope of a PhD thesis, aim to add scientific value in terms of obtaining material characteristics of time-dependent behaviour of rock mass for the specimens of a simple geometric shape, while contributing to the examination of phenomenon of discontinuity impact on obtaining the foregoing parameters. The experimental programme was designed to investigate specimens with discontinuities, specimen size 30x15x15(cm) under controlled laboratory conditions, at constant normal loading with incremental shear stress and measurement of deformations. It is important to emphasize that this paper presents the results of a preliminary testing phase, whose primary objective was not the final determination of representative shear strength parameters of discontinuities, but rather the verification of the functionality of a specially developed experimental apparatus, determination of the loading range, and identification of the fundamental mechanisms governing time-dependent shearing along artificially created discontinuities. The obtained results represent the basis for defining the main experimental program, which includes a larger number of specimens, a more controlled loading regime, and a more detailed analysis of the mechanical and geometrical characteristics of discontinuities.

2. Overview of previous research studies

Overview of previous research studies suggests that relatively small number of scientists has engaged in experimental research of effects of long-term loading and unloading on time-dependent deformation of soft rocks. Time-dependent deformation of rock mass under constant stress is defined as creep. Creep depends on changes in stress state, temperature, moisture, air humidity etc.

With regards to a solid rock mass (metamorphic and igneous rocks), creep deformation is insignificant. However, contribution of creep deformation to total value of deformation is considerable in case of soft rock mass, such as rock salt, marl, anhydrite, flysch sediment etc. The tests have shown that creep deformation occurs at different rates and is characterised by three stages, referred to as primary, secondary and tertiary creep. Most of the previously published experimental research in the world addressing the rock behaviour under long-term

loading at room temperatures was conducted on the rock salt specimens. (Gimm, 1968; Dreyer, 1974; Baar, 1977; Carter et al., 1982; Wallner, 1983; Hunche, 1994, 1995; presented by Cristescu N.D & Hunsche U, 1998; etc.). An incomparably smaller number of the published experimental research was conducted at room temperatures on marl or similar soft rocks that are characterised by significant creep deformations (clayey-marl, Cristescu, 1988; marl, Kharchafi and Descoedres, 1995), which represent a realistic work environment for construction of numerous underground structures. Within the examination of marly materials, the papers of authors from Montenegro can be singled out, according [1-8].

When it comes to testing of soft rock specimens intersected by discontinuities, the number of published papers is even smaller. A theoretical approach applied in the initial stage of research of this subject-matter to define time-dependent behaviour of rock mass has not yielded satisfactory results [2].

With advances in development of software tools, numerical modelling has been improved, thus enabling modelling of complex rheological situations which has allowed for better perspective of time-dependent behaviour of rock mass. Determining material parameters and constants which define rheological models of the rock mass behaviour is generally performed by means of laboratory or in-situ tests. A challenging task to determine material characteristics is a consequence of not only complex composition of rock material but also discontinuities which form and characterise the rock mass.

In terms of determining the characteristics of discontinuous rock masses, it is particularly important to define the range of roughness of the shearing, discontinuous surface. In addition to the standard, traditional methods of describing roughness with qualitative and quantitative characteristics, in recent years, with the technological progress of software tools, it is possible to define certain mathematical methods that connect the shear resistance of discontinuities and the roughness of discontinuous surfaces. In this regard, the following papers can be mentioned [14-17].

Previous tests conducted to form models that will represent time-dependent behaviour of rock mass are based on the analysis of monolith specimens of simple geometric characteristics and relatively simple stress state. Nevertheless, it is common practice to use these simple tests to represent with a satisfactory level of accuracy the behaviour of a far more complex stress-strain state of a real rock mass.

3. Experimental tests

3.1. Specimen and equipment preparation

Material used for testing has been sampled from the open pit Potrlica of the coal mine Pljevlja. A block of approximately 3.5 tons was extracted from the open pit mine, at depth of approx. 25m, measured from the terrain surface (Figure 1). Immediately upon excavation, the material was loaded on transport equipment and transported from Pljevlja to Podgorica (approx.



Figure 1. a) position of a bench from which the rock mass block was extracted, b) loading of the rock mass block



Figure 2. Specimens processed to target dimensions 30 x 15 x 15 cm



Figure 3. Examination of uniaxial strength of specimens

180 km). Special care was taken during transportation and unloading to preserve the in-situ structure and orientation of the extracted block., hence rock mass with unchanged geometry was prepared for processing.

A specialised plant for processing of stone was used to process material and form cuboid (prism) shaped specimens with dimensions 30 x 15 x 15 cm (Figure 2). During the preparation of the specimens, due to the very demanding processing (specimens splitting during cutting) of the soft rock mass from nature (irregular shape of rock specimen) into the desired shape of specimen, the processing success rate was approximately 50 %. Simultaneously, a semi-quantitative analysis of specimens was conducted the results of which confirmed the specimens are marly limestone, dominantly composed (93.0 %) of calcium carbonate (CaCO_3), while the remaining 7 % includes the following components: quartz 4.80 % (SiO_2), siderite 1.10 % (FeCO_2), muscovite 1.10 % ($\text{KAl}_3\text{Si}_3\text{O}_{10}\text{OH}_2$).

Sampled material was subjected to uniaxial compression strength tests (Figure 3), for different moisture content (from water-saturated to completely dry specimen). Resulting values for the material with natural moisture content are presented in Table 1. In the table, the specimens are marked with U_1 to U_5 . Weight of an empty container is marked with m_p , weight of a container holding a specimen with natural moisture content is marked with m_1 , and weight of a container holding a dried specimen is marked with m_2 . Uniaxial strength is marked with σ_c .

An artificial crack (Figure 4) was formed on each specimen intended to be tested in a trial (and subsequently in the main part of the experiment). Crack-forming was controlled by cutting (splitting) of specimen in the length of 1 cm at half height (at

Table 1. Uniaxial strength of cylinder-shaped specimens 12 x 5 cm

Specimen condition	Specimens (U1-U5)→	U_1	U_2	U_3	U_4	U_5	W_{sr}, σ_{csr}
Cylinder-shaped specimens with natural moisture content, formed from the cuboid (prism) shaped specimens, stored at day temperature, paraffin-coated, wrapped in foil	m_p [g]	4.9	4	5.3	5.4	4	Key: U_1-U_5 → specimens m_p → Weight of empty container, m_1 → weight of container with specimen with natural moisture content m_2 → weight of container with dried specimen
	m_1 [g]	41.7	36.7	49.7	36	43.9	
	m_2 [g]	37.4	33.2	45.6	32.7	40	
	$m_1 - m_2$ [g]	4.3	3.5	4.1	3.3	3.9	
	$m_2 - m_p$ [g]	32.5	29.2	40.3	27.3	36	
	W [%]	13.2 %	11.9 %	10.1 %	12.1 %	10.8 %	$W_{sr} = 11.66 \%$
	σ_c [MPa]	18.14	17.98	17.11	16.28	17.02	$\sigma_{csr} = 17.31$

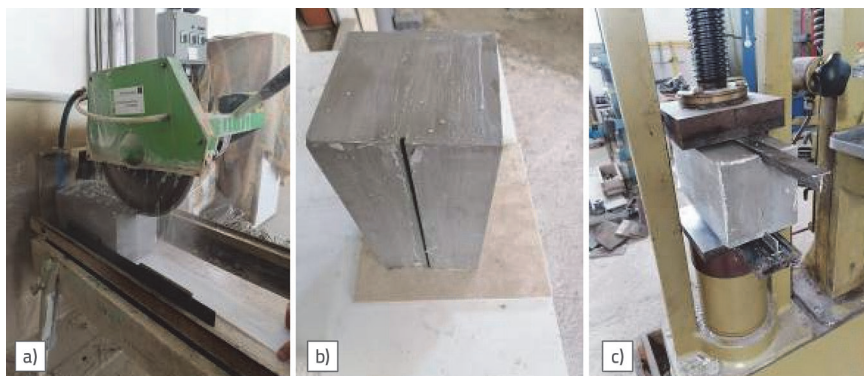


Figure 4. a) Cutting a groove at the specimen centre; b) Cut groove of 1 cm depth; c) Forming of discontinuity

approximately 7.5 cm). At the cut grooves, using a cylinder (Figure 4c) to apply loading at a controlled rate, the specimens were divided into two, approximately equal halves (Figure 3), followed by forming of discontinuity planes of different roughness (Figure 5.b). Upon defining discontinuity planes, all specimens were wrapped in foil. Previously, after the geometry had been formed, all the specimens were paraffin-coated to preserve their natural moisture content.

With the specimens prepared, the next step was to design new and modify the existing equipment to be used for uniaxial and triaxial creep testing of the intact rock specimens. The scope of pilot programme provided for testing of three specimens of different roughness. For this purpose, one existing frame was specifically prepared at the laboratory of the Faculty of Civil Engineering. This test frame dates to about 20 years ago, when it was used for testing of marly material which was sampled from the same site for the purposes of the research conducted by Prof Zvonko Tomanovic, PhD. The frame operates on the principle of lever arm and deadweight. The apparatus is centred in relation to the position of a specimen to be subjected to the test and according to the needs of the normal force loading level. Enabling for testing of specimens along the formed shear surfaces, steel moulds were formed for placement of the specimens (Figure 4.a). Considering the height of the half-specimen is approx. 7.5, the internal height

of the mould is 5 cm, to allow for the undisturbed shear behaviour along the discontinuity planes. Thickness of walls and bottom of the steel mould is 1 cm. The specimens are fixed using a factory produced mortar for casting and grouting, which takes several hours to set after having been poured to fill the voids between the specimen and the mould, making the specimen immovable in the mould. When fixing both halves of the specimen, attempts were made to have the two halves tight fitted to enable as much better simulation of the naturally closely spaced cracks.

To overcome friction that occurs in the apparatus, the experiment provided for adjustment of movable parts to fit over

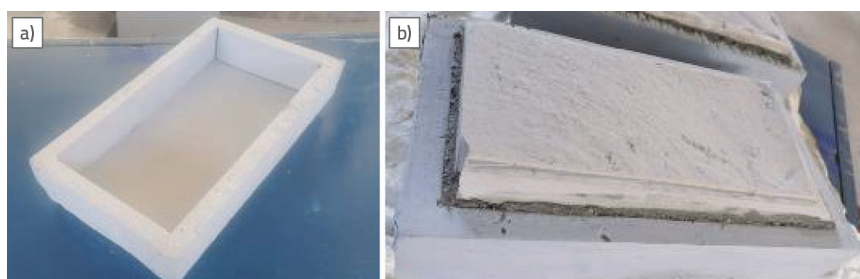


Figure 5. a) Steel mould; b) Half-specimen placed in the mould

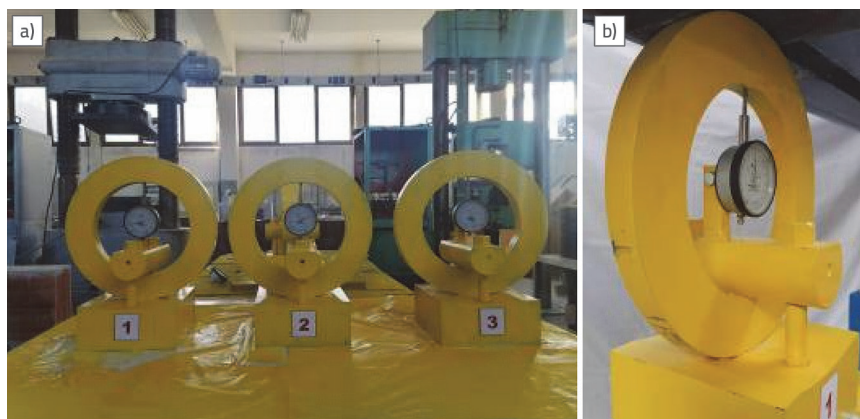


Figure 6. a) Rings with gauges for normal stress; b) Thickness of rings 1, 2 and 3 is $d = 2.0$ cm

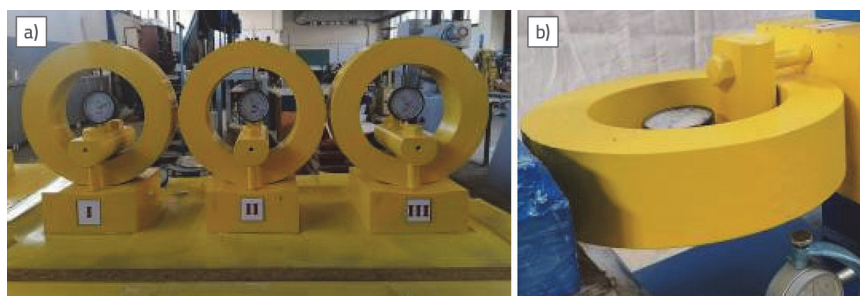


Figure 7. a) Rings with gauges for shear stress; b) Thickness of rings I, II and III is $d = 6.0$ cm

the cylinder-shaped steel elements, which will be described in detail in part 3 of this paper.

In addition to the specimens, frames, benches and rollers, key components of the equipment are elements for measurement of change in stress and strain. For this purpose, steel rings (dynamometers) were developed with a base plate on which gauges for measurement of normal and shear displacements were mounted. The steel rings are of the same diameter but different thickness due to a different order of magnitude (forces) occurring in the normal and shear direction respectively, which are the subject of measurement by dynamometers (Figures 6 and 7).

With setting of all components of the equipment, specimens prepared, and frames put in operation, all the conditions required for commencement of the experiment were fulfilled.

3.2. Specimen testing

Trial experimental test was performed using one frame (Figure 8). The experiment included testing of three specimens of different roughness, particularly 1) completely smooth plane of discontinuity, 2) extremely undulating discontinuity, and 3) moderately rough plane of discontinuity. For all three foregoing discontinuity planes, the testing was performed under three different constant levels of normal stress. Normal stresses of 0.1 MPa, 0.2 MPa and 0.4 MPa were applied. Limitation of the pilot programme of the experiment is reflected in the fact that within testing of one specimen, for each subsequently applied vertical loading, the shear occurred along the specimen surface that was altered to a certain extent because of the shear occurring for the previous (lower) level of normal stress. The vertical loading was applied using the system of lever arm and deadweight. However, the relevance of such tests derives from the way and sequence of tests. Namely, as the specimens were loaded with a normal stress of 0.1 MPa in the first phase, and then with 0.2 MPa in the second phase, care was taken to inspect the tested specimens after each phase, in fact, to establish the degradation of the tested shear surface. Given that in the first two phases there was no breakage or significant change in the shape of the discontinuity surface (the change was reflected in the form of surface marks due to friction), it was found that the discontinuous surface was almost undisturbed and suitable for the third phase of testing.

It should be emphasized that the experimental apparatus used in this research represents a specially developed laboratory system adapted for long-term time-dependent shear testing along discontinuities. Due to the specific configuration of the apparatus and the large dimensions of the specimens, the testing procedure did not fully correspond to standard ISRM direct shear testing procedures.

Within the preliminary phase of the investigation, testing was carried out using one shear frame, while three specimens with different discontinuity characteristics were successively tested under normal stresses of 0.1 MPa, 0.2 MPa and 0.4 MPa. After completion of each individual shearing phase, the specimen

was returned to its initial position, after which the next testing stage was performed under a higher normal stress level.

The authors are aware that such a procedure, particularly in the case of soft rock materials, may lead to partial degradation of the contact surfaces and changes in the local contact structure due to previous shearing. For this reason, the results presented in this paper have a preliminary character and were primarily used for verification of the experimental apparatus functionality, identification of the dominant mechanisms governing discontinuity behaviour, and definition of the methodology for the main experimental program.

The main experimental program was planned to use all three shear frames simultaneously, with each frame subjected to a different constant normal stress level. In this way, repeated shearing of the same discontinuity under different normal stresses would be avoided, which represents one of the main methodological limitations of the preliminary testing phase.

In order to ensure translational shearing and to limit undesirable displacements and rotations, steel guiding restraints were installed on the upper shear box, enabling controlled guidance of the lower box during shear displacement. Although the apparatus did not contain classical spherical seats characteristic of standard direct shear devices, it enabled stable load transfer and registration of the dominant deformation processes during the experiment.

Horizontal loading was applied to the specimen by a large hydraulic cylinder positioned vertically in an additional frame with deadweight. The preferred pressure of hydraulic oil was controlled by weight of the deadweight on the lever arm of the frame which transferred a multiplied load of the deadweight onto the cylinder pivot. In this way, controlled generation of hydraulic pressure was achieved, which was further transferred to the shearing system. By means of the oil supply system from the large cylinder (principle of communicating vessels) and all smaller vessels on the shear apparatus, the shear force was applied to the lower half of the specimen (lower fixed mould), as illustrated in Figure 8.



Figure 8. View of the apparatus during the experiment (visible shearing of upper and lower half of the specimen)

In the experiment, the mass of the added load was not measured, but the horizontal forces, namely shear stress and displacement values were measured. Namely, during the load adding, care was taken to ensure that the loading causes displacement due to the increase in shear stresses. Although the load causing shear stress and displacement was not numerically verified, care was taken to ensure that the load increments were approximate. The loading was done by adding concrete cylinders with a base diameter of 15 cm and a height of 30 cm (approx. 13 kg), which is approximately 16 kN/m² after multiplying by the frame levers. The loading was carried out by adding one or two mentioned elements, depending on the vertical load, that is, until the lower mold with the specimen was started. The shear load was applied by adding the mentioned load in the basket at the end of the lever, according to the system of moving the oil from the press with large clip to the presses with smaller clips, as previously explained.

Each subsequent loading was performed after the movement of the lower mold had completely stopped, until the final movement of 5 cm had been reached. Considering the length of the specimen of 30 cm, it was found that after a displacement of 5 cm, the lower mold, in addition to translational movement, begins to "experience" rotation, which is not in accordance with the plans and assumptions of the experiment.

Value of displacement of the lower mould, meaning differential displacement of the lower and upper half of the specimen along discontinuity was recorded by the mechanical device for displacement measurement (Figure 8).

As previously mentioned, the lower mould and the ring to which vertical loading is applied are placed on rollers to eliminate friction during the experiment duration. During the testing, it is required to maintain vertical loading constant, as it tends to change because of the vertical movement over the rough surfaces and changes in shear stress and strain. For such a reason, testing of the main series provides for introduction

of complementary components – equipping each load frame with optic cameras to enable 24h coverage of the testing. At the beginning of the trial series, it was observed that the hydraulic cylinder piston was fully extended in the length of 5cm. Therefore, this length was defined as the final displacement of the specimen. For the purposes of consideration and understanding of the experiment, it was identified that at approximately 7-8cm of displacement, the lower half of the mould started rotating about a shorter axis, hence the intended experiment would lose its meaning with such condition of the apparatus. The defined ultimate 5cm of displacement represents approximately 17 % of the total specimen length (Figure 8).

Within testing of the pilot programme of specimens, the experiment duration depended on the applied normal loading and the roughness of the discontinuity planes. The duration of the experiment conditioned recording of the data obtained in different time intervals, depending on a specific case.

The experimental apparatus used in this research represents a specially developed laboratory system adapted for long-term shear testing along discontinuities on large-scale specimens. Therefore, the testing procedure did not fully correspond to conventional direct shear devices, where spherical seats are commonly used to reduce moment effects and allow rotations. In this preliminary investigation, the objective was to verify the functionality of the developed system and identify the issues that must be taken into consideration in the main experimental series.

4. Collection, processing and analysis of the test results

Within the pilot programme of specimens, three specimens of different roughness of discontinuity planes were tested. For each specimen, tests were performed for three different constant values of normal loading of 0.1 MPa, 0.2 MPa and 0.4 MPa. At specimen testing for lower values of normal stress lower shear stress was also induced, with a shorter testing time. This is a common feature for all tested specimens.

Maintaining the normal force constant proved to be demanding and complex, considering that because of the specimen shearing, meaning changes in shear stress and evident volumetric changes resulting from shearing as well as due to the friction of the load frame equipment, certain reduction or increase in value of the defined normal force occurred (as a consequence of intention towards vertical displacement of specimen in the course of shearing), requiring the force to be controlled not later than after one hour so as to adjust the force and retain a quasi-constant value of the normal stress.

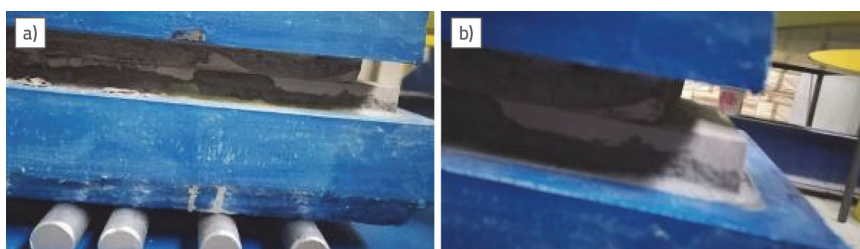


Figure 9. Displacement of upper half (a) in relation to the lower half (b) of the specimen along the shear surface

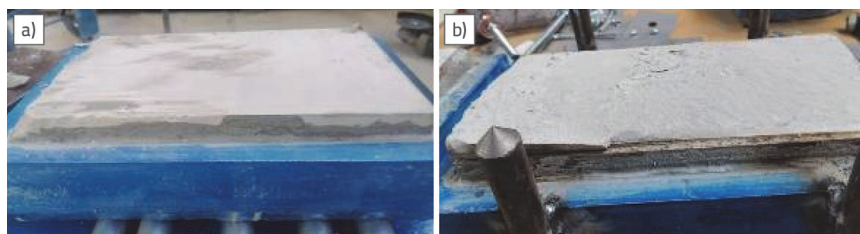


Figure 10. a) View of the shear surface after test on a smooth specimen; b) View of the shear surface after test on a rough specimen

For all specimens, the testing was performed starting from the lowest (0.1 MPa) to the highest normal stress (0.4 MPa), to minimise damage or altering of the tested shear surface. In case of a smooth specimen there was no concern about eventual change in the roughness of the shear surface, while the other two rough surfaces were not observed for any significant change in structure of the tested shear surface (Figure 10).

As a result of shear, the specimen with smooth discontinuity showed visible traces of the experiment (mainly in a form of shallow striations on the sliding surface), meaning visible traces on the surface which indicate to the shear displacement of surfaces, however without degradation or forming of fractured structures (Figure 10.a).

Specimens with rough discontinuities exhibited local asperity damage and fragmentation of microstructural features along the shear surface (fragments of small order of magnitude compared to the specimen dimensions) (Figure 10b). These observations suggest that the specimen with a distinctive waviness (unevenness) largely remained undamaged with a view to the consistency of the unevenness. This specimen as well as the specimen with moderate roughness were observed for damages, scattering of microstructures of the shear surface. As expected, increasing normal stress resulted in more pronounced damage to surface asperities.

During testing of the specimen with a smooth discontinuity surface (S_1'), the following maximum values of shear stress for corresponding normal stress were recorded:

$$\sigma_n = 0.1 \text{ MPa} \rightarrow \tau = 0.54 \text{ MPa}, \sigma_n = 0.2 \text{ MPa} \rightarrow \tau = 1.68 \text{ MPa}, \sigma_n = 0.4 \text{ MPa} \rightarrow \tau = 2.46 \text{ MPa}.$$

For the specimen with a distinctive unevenness (S_2'), the following maximum values of shear stress were obtained:

$$\sigma_n = 0.1 \text{ MPa} \rightarrow \tau = 3.9 \text{ MPa}, \sigma_n = 0.2 \text{ MPa} \rightarrow \tau = 4.92 \text{ MPa}, \sigma_n = 0.4 \text{ MPa} \rightarrow \tau = 6.72 \text{ MPa}.$$

For the specimen with moderate roughness of the discontinuity surface (S_3'), the following maximum values of shear stress were obtained::

$$\sigma_n = 0.1 \text{ MPa} \rightarrow \tau = 3.24 \text{ MPa}, \sigma_n = 0.2 \text{ MPa} \rightarrow \tau = 2.70 \text{ MPa}, \sigma_n = 0.4 \text{ MPa} \rightarrow \tau = 4.86 \text{ MPa}.$$

The obtained shear stress values should not be directly interpreted as classical Mohr–Coulomb parameters of intact rock material. The tests were performed along previously formed discontinuity surfaces, where the shear resistance resulted from the combined effects of friction, asperity interlocking, local dilation and partial degradation of micro-contact zones.

In discontinuities characterized by pronounced geometrical interlocking and undulating rough contact surfaces, relatively low normal stress levels may lead to the occurrence of high apparent values of shear resistance angle and apparent cohesion. Such values are a consequence of mechanical interlocking, dilation and geometrically controlled shear resistance, rather than true material constants of intact rock.

Also, considering that during the preliminary phase the same specimen was successively tested under several normal stress levels, with repositioning between individual testing stages, partial changes in the contact structure of the discontinuity surfaces may have occurred. Therefore, the presented values should be regarded as preliminary results intended for understanding system behaviour and preparation of the main experimental program.

Additionally, considering the high calcium carbonate content of the tested marly limestone, the possibility of local temporary bonding effects at the discontinuity contact zones may have contributed to the observed response, which may additionally influence the mobilized shear resistance under low normal stress levels. However, such effects were not specifically investigated within the scope of this study and require further research.

In terms of the experiment duration, the specimens with rough surfaces of discontinuity lasted significantly longer, even up to two months, while the specimen with a smooth surface of discontinuity achieved maximum displacement for couple of hours.

For better comprehension of the obtained results and due to an extensive scope of all obtained correlation graphs, the next steps will show correlation graphs obtained for the tested specimens subjected to a maximum defined normal loading of approximately 0.4 MPa. Figures 1 to 3 display changes in normal and shear stress and displacements in correlation with the experiment duration.

The obtained results show that the values of maximum displacements are achieved in different time intervals for different specimens. In case of specimens for smooth

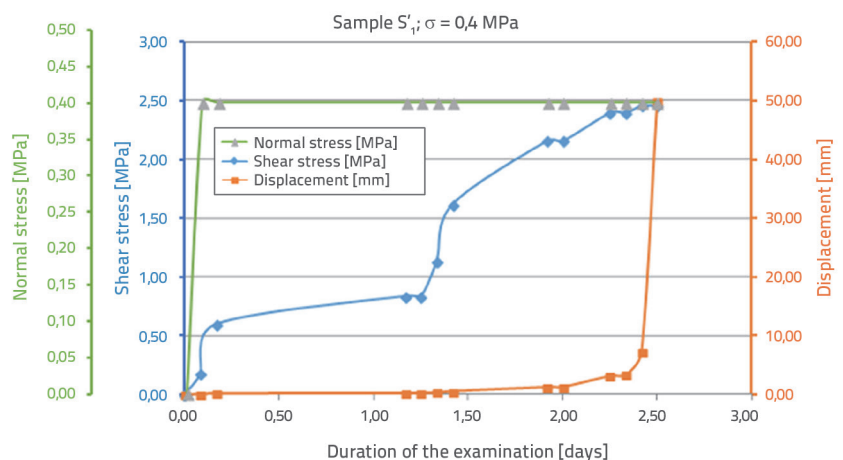


Figure 11. Change in stress and displacement increment during the experiment time, specimen S_1'

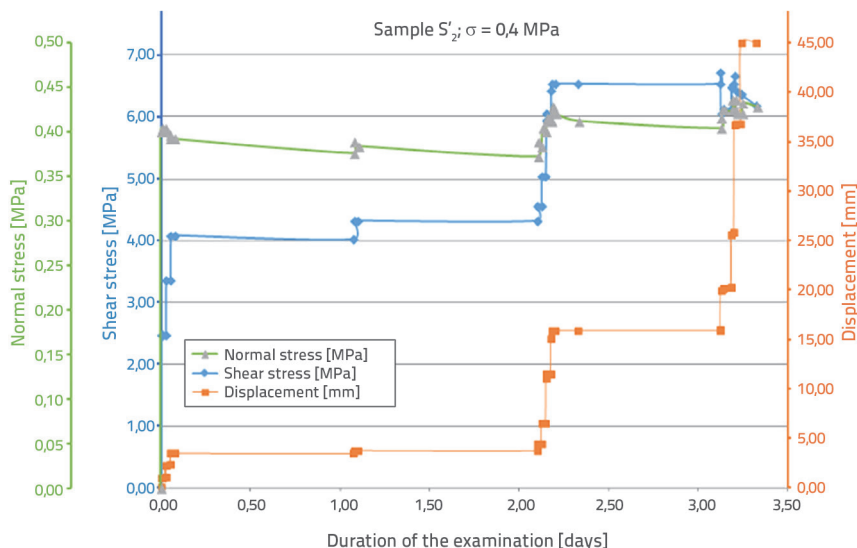


Figure 12. Change in stress and displacement increment during the experiment time, specimen S_2'

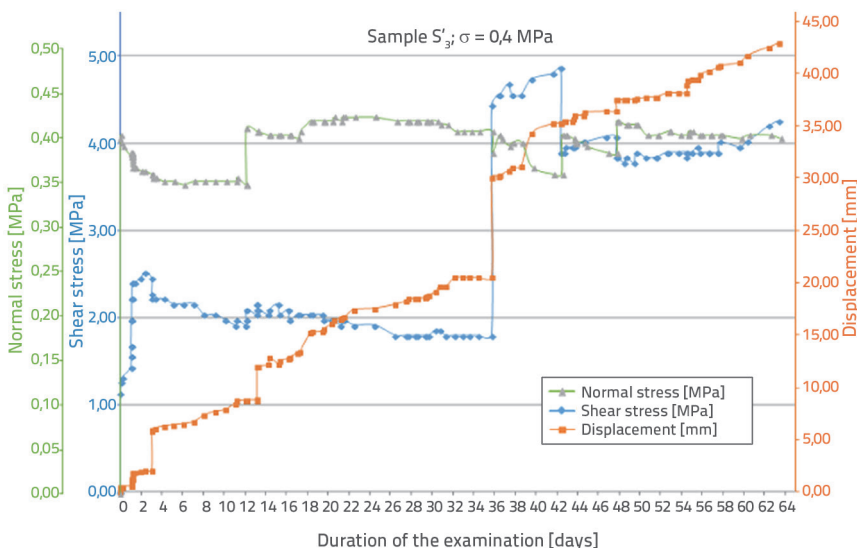


Figure 13. Change in stress and displacement increment during the experiment time, specimen S_3'

discontinuity surface, a maximum displacement is achieved within couple of hours. In case of specimens with a rough shear surface, a maximum displacement is achieved in a time interval measured by days.

Notwithstanding the specimen with a distinctive unevenness was tested within almost four days and the specimen with moderate roughness in almost 65-day period, the authors emphasize that the experiment in case of the specimen S_3' was conducted in the way that each subsequent increment of horizontal loading was added only after there were no more changes in the value of stress and displacement.

As regards the specimen with a distinctive unevenness (S_2'), the next loading step was carried out after the displacement increment below 0.2 mm/day was achieved. Different testing conditions (mainly deviation of normal stresses from the

constant value in order to monitoring the shearing behaviour of the specimen) were designed with an intention to consider all possible testing conditions, so that during simultaneous testing of specimens in three loading frames within the scope of the main series of the experiment, it would be possible to collect all data with adequate results that would allow for consideration of the phenomenology of behaviour of the soft rock discontinuity at shear forces – displacements in a good quality manner and with a sufficient number of specimens in terms of statistics.

This paper reports initial test results for shear of discontinuities in soft rock with a time-dependent effects. Further tests should provide for enough data that would form basis for rheological modelling, and especially introduction of time-dependent deformation as a parameter for modelling of the behaviour of rock mass, both the rock matrix and the behaviour of discontinuities.

5. Conclusions

The pilot experimental programme confirmed the functionality of the developed testing apparatus and demonstrated the feasibility of long-term shear testing on large-scale soft-rock specimens containing artificial discontinuities. A high-quality preparation is also reflected in the successfully obtained test results as well as in a minimum number of corrective activities that will be required for the

purposes of testing of the main series of the experiment relating to both equipment and testing protocol. Further test results should provide sufficient data for forming of a rheological model of shear behaviour along discontinuity of the tested soft rock, where a numerical formulation should also include the impact of roughness of the shear discontinuity surfaces on the shear strength of material and time-dependent deformation. The specimen testing showed that the time-dependent component of the shear displacement along discontinuity participates in the total deformation in a significantly high percent, being more than 50 % in case of the specimen S_3' .

It should be particularly emphasized that the presented results have a preliminary character. The pilot tests were conducted for the purpose of verifying the apparatus, determining the loading range, and identifying the fundamental mechanisms

of shearing along discontinuities, rather than for the final determination of representative shear strength parameters. Repeated testing of the same specimens under successively increasing normal stress levels represents a methodological limitation of the preliminary phase, since it may lead to partial degradation and changes in the contact conditions along the discontinuity surfaces. This limitation will be eliminated in the main experimental testing series through a larger number of tests and a more controlled loading regime.

Considering a relatively narrow scope of research, from a general point of view, the purpose of knowledge acquired within this research is to contribute to the understanding, perception and studying of soft rock mass and phenomenology of shear along discontinuity. At the same time, justification of previous research of the same material viewed through the acknowledged contribution in scientific papers of Prof Slobodan Zivaljevic, S. & Tomanovic, Z., addressing the intact rock, are another proof that the results of these researches of behaviour of discontinuities will greatly contribute to a better understanding of the behaviour

of soft (marly) rock mass intersected by fissures and formation of more realistic rheological models.

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