Application of stimulation techniques on rock samples

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ABSTRACT

Stimulation techniques are commonly applied in crystalline rocks to increase extraction of underground resources; including oil, natural gas, geothermal energy, and even groundwater. In the framework of the research project STIROMAS (STImulation of ROck MASsif), the research aims at verifying the capability of creating a fracture network using hydraulic pulse fracturing method. The STIROMAS project is co-funded by the Czech Ministry of Industry of Trade in the framework of program "TIP" under Project ID FR-TI3/523.

1. INTRODUCTION

The 4-year research project (2011 – 2014) comprises of laboratory micro-sample, macro-sample and in-situ testing supported by simulation modelling techniques as well as review of rock types available in the Bohemian Massif. While the laboratory experiments are carried out on representative rock samples, the in-situ research is focused on tests in rock massif. In-situ experiments will therefore demonstrate natural conditions of rock massif, as the test will be affected by natural stress, deformation and stability of the rock environment considering also natural occurrence of cracks, fractures, lineation and foliation planes.

Expected results:

- verification of rock fracturing applying the hydraulic pulse fracturing;
- determination of pressures necessary for rock fracturing depending on rock properties;
- verification of the spatial extent of the fracture development depending on hydraulic fracturing technique, pressure and characteristic rock properties;
- determination of relationship between laboratory results and the pressure (method) required for in-situ fracturing;
- modelling and prediction of the fracture extend during linear/pulse hydrofracturing experiments.

2. HYDRAULIC FRACTURING

Hydraulic fracturing represents the main method to enhance the underground reservoirs productivity either for hydrocarbon or geothermal energy extraction (Economides and Nolte, 2000). Hydrofracturing can be applied on low permeable or impermeable rocks in order to develop the network of both extensive and very narrow fractures. Hydraulic fracturing is considered as a complex mechanism affected by numerous factors. The mechanism of the fracture system development in crystalline environment reflects the stress field of the rock massif, structure and texture properties, the character of the rock massif failure (discontinuity properties) as well as particular geotechnical parameters.

In general, the pressure fracturing can induce fractures up to hundreds meters long and 1 mm thick. The conductivity reflects the width of the fracture affected by the shear stress, fracture surface heterogeneity and rock strength (Rushing and Sullivan, 2003 In Reinicke et al., 2010).

The hydraulic fracturing is most frequently used for interconnection of not communicating areas with natural enhanced fracture system which leads to inflow increase. The purpose of hydrofracturing in Hot Dry Rock environment is to interconnect boreholes and facilitate the geothermal energy extraction from the crystalline basement.

3. RESEARCH PROGRAMME

The four-year research project (2011 – 2014) was in its first year focusing on micro-sample testing with linear pressure increase and later on with pulse regime. Consequently, the linear and pulse rock fracturing methodology is being verified for macro-samples and in-situ.

4. EXPERIMENTAL SITE

The experimental part of the project, i.e. the linear and pulse fracturing tested on micro-samples, macro-samples and in-situ, is carried out in Josef Underground Laboratory operated by the Faculty of Civil Engineering of the Czech Technical University in Prague. Particularly, side drifts JP-2 and SP-4 in the

Mokrsko-East belt have been selected for experimental purposes (see Figure 1). The underground testing advantages include working safety and constant temperature and constant humidity conditions for storage of tested material.

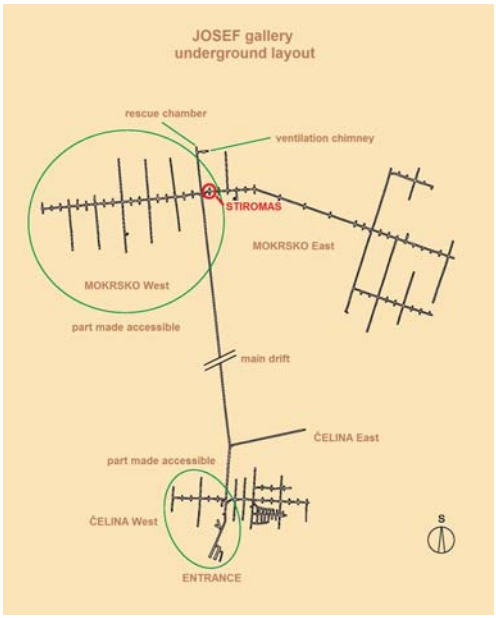

Figure 1: Location of the STIROMAS research workplace in the Mokrsko-East area, Josef Underground Laboratory (Czech Technical University)

5. HYDRAULIC TESTING

Two types of hydraulic tests have been selected for the project hypothesis verification:

- The first type of hydraulic tests is based on linear pressure increase in several steps up to the rock failure.
- The second type of hydraulic test intends to verify the pulse technology. The test will be performed in several steps. In the first step, the rock sample is tested up to the pressure corresponding to 1/3 value of the maximal pressure (the maximal pressure was determined previously during the linear test and correspond to the rock failure). Reaching this value (1/3 the critical pressure), the facility will switch into the pulse regime following by pressure increase up to 2/3 value of the maximal pressure. After repeated pulse regime, the pressure is at the final stage increased to its maximal value (see Figure 2).

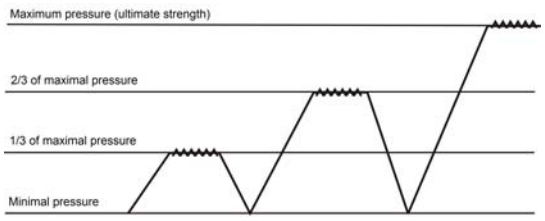

Figure 2: Hydraulic pulse fracturing chart

5.1 Representative rock types for testing

Considering the objective of the project, i.e. to develop a technology for pulse fracturing suitable for the most current representatives of non-plastic rocks, a representative set of rock samples designated for testing in micro and macro-scale have been introduced (Table 1). Two rock types (granite and dacite) come from the Josef gallery enabling further comparison of results acquired from micro/macro testing with in-situ experiments (Semikova et al., 2012). Other samples were sampled in active quarries in the Czech Republic.

Table 1: Selected rock types and quarry sampling sites selected for micro-scale and macro-scale testing.

Rock type	Micro-samples	Macro-samples
Metamorphic rocks		
Quartzite paragneiss	x	-
Migmatite paragneiss	x	x
Spilite	x	-
Orthogneiss	x	-
Amphibolite	x	x
Magmatic rocks		
Granite(Josef gallery)	x	-
Granite	x	x
Volcanic rocks		
Rhyolite	x	x
Basalt	x	-
Dacite(Josef gallery)	x	-
Reference sample		
Concrete	x	x

5.2 Micro-sample testing

Three sets of cylindric micro-samples (200 mm high, 96 mm in diameter) were prepared for each rock type:

- The first set of samples was used for the determination of basic geomechanical parameters (volume density, specific density, unconfined compressive strength, direct tensile strength, tensile splitting strength, permeability, porosity, modules).
- The second set of samples is used for hydraulic testing in laboratory conditions, with the stepwise pressure load.
- The third set of samples is designed for the pulse hydraulic fracturing.

The simulation of real stress conditions is ensured by chamber pressure corresponding to the geostatic stress depending on the simulated depth. Considering the analogy with the Josef site conditions, the chamber pressure is fixed at 2.5 MPa (corresponding to the 100 m thickness of the top layer).



Figure 3: Concrete sample C10 after testing: Chamber pressure 2,5 MPa, working pressure 13,5 MPa, start-up time 20 s, time interval with constant pressure 180 s (photo courtesy of ISATech)

Initial tests were carried out on trial concrete samples of C30/37 grade (see Figure 3). However, concrete samples were younger 28 days (this number of days corresponds to the concrete maturity). The purpose of the trial tests was to investigate the behavior of the sample at various test schemes as well as the effect of the chamber pressure. During the first testing scheme, the working pressure was fixed at value exceeding the assumed value of the critical pressure (the pressure corresponding to rock sample failure) so that the sample fractures within the linear start-up working pressure curve (variant A, see Figure 4). In the second testing scheme, the working pressure value is fixed under the critical pressure value and, after it is reached, it is maintained constant until the rock sample failure (variant B, see Figure 4).

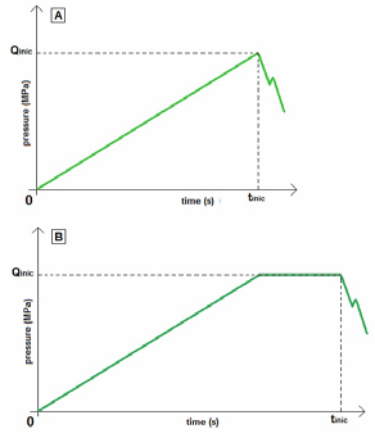

Figure 4: Two schemes of the course of tests: A. Working pressure is fixed above the critical pressure value; B. Working pressure is fixed under the critical pressure value – constant pressure maintained until the rock failure under the Q_{inic} pressure

Nine concrete samples were used for initial fracturing test, from which every 3 samples with constant chamber pressure. In total, three different chamber pressure values were tested: 2,5 (Figure 5); 6 and 10 MPa. After the subsequent determination of critical pressure, five samples were used for linear fracturing test with 6 MPa of chamber pressure and with fixed pressure value during 60s. Pulse tests were carried out with chamber pressure of 2,5 MPa and constant pressure increase/decrease 0,1 MPa and with different duration of fixed pressure, i.e. 60s, 120s, 180s (Figure 6). The pulse amplitude was 1 MPa and of 1 Hz frequency.

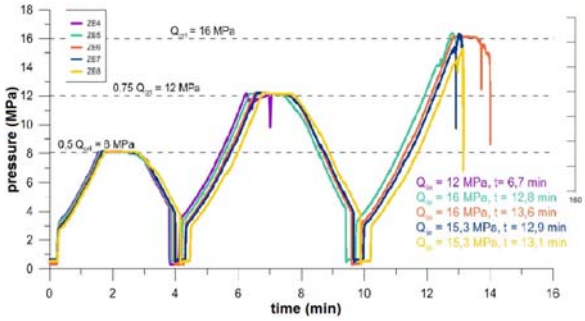

Figure 5: Linear hydraulic fracturing for concrete sample, chamber pressure 2,5 MPa and 60s duration of constant pressure level

The suggested methodology showed that the result of the linear pressure effect does not depend on the time duration of constant pressure level (tested up to 300s). For that reason, time of 60s was set as the duration of constant pressure level for hydraulic linear tests on rock samples.

On the other hand, during the pulse testing the influence of the pressure value decrease necessary for rock sample failure was registered for duration of pulse regime of 180s at minimum. For that reason, time of 180s was set as the duration of constant pressure level for hydraulic pulse tests on rock samples (Figure 6).

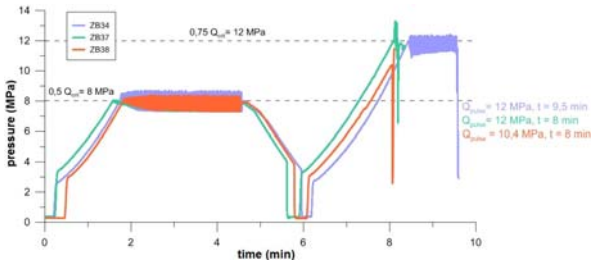

Figure 6: Pulse hydraulic fracturing for concrete sample, chamber pressure 2,5 MPa and 180s duration of constant pressure level

5.3 Macro-sample testing

Series of four samples – 2 pc. / 1 m^3 (1x1x1 m) + 2 pc. / 0,125 m^3 (0,5x0,5x0,5 m) is prepared for each selected rock type and concrete reference sample (Table 1), from which each dimension will be used for

linear vs. pulse testing for all samples. One middle bore is drilled in the middle of the sample for hydraulic pressure application. The bore will be specially equipped by a metal tube. Moreover, two observation bores will be drilled in samples having volume 1 m^3.

Macro-samples are first investigated for permeability and the degree of fracturing which is being determined from water pressure tests and ultrasound measurements, respectively.

The methodology for hydraulic fracturing of macro-samples is currently in preparation and will be applied during 2012. The methodology will be based particularly on findings resulting from previous micro-sample hydraulic testing. The hydraulic testing will be carried out also in Josef Underground Laboratory as specified earlier in the text.

To verify the identity of rock behavior of micro and macro-samples, the results from both ultrasound measurements will be compared.

6. CONCLUSION

Principle objective of the research project is to determine the relationship between linear and pulse pressure load and its effects on the rock stability. The conventional hydraulic fracturing method based on gradual linear pressure increase until the rock failure is tested in order to determine pressures necessary for the rock fracturing depending on the rock type.

The pilot test enabled to observe that the pressure value at the moment of the rock failure is considerably influenced by the test scheme variant. The scheme involving the pressure load up to the pre-defined value and there subsequent maintaining the pressure value for a certain time (variant B) confirmed the sample failure at lower working pressure values than would be necessary for linear pressure increase without maintaining pressure constant (variant A).

Pilot hydraulic tests on concrete samples also lead to modification of hydraulic pressure application which eliminated problems related to sample fracturing beyond the area of the chamber pressure effect. Experiments tested for various chamber pressures confirmed that with increasing chamber pressure the pressure corresponding to the rock failure also increases (in a linear way). Regarding the suggested methodology testing, it might be concluded that the result of linear pressure load is not dependent on the duration of constant pressure level (up to 300s). During the pulse testing the influence of the pressure value decrease necessary for rock sample failure was registered for duration of pulse regime of 180s at minimum. Therefore, duration of 60s and 180s was set for linear and pulse hydraulic fracturing, respectively.

Based on available results from concrete samples is obvious that the type of the pressure regime, i.e. linear versus pulse, has a fundamental influence on the pressure value corresponding to the rock failure.

Further research within the STIROMAS project will be focused on hydraulic fracturing of macro-samples, development of ultrasound measurements and mathematical modeling.

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