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Procedia Engineering 149 (2016) 544 – 552

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Manufacturing Engineering and Materials, ICMEM 2016,
6-10 June 2016, Nový Smokovec, Slovakia

Determination of stress state in rock mass using strain gauge probes CCBO

Waclawik Petr[a]*, Stas Lubomir[a], Nemcik Jan[b], Konicek Petr[a], Kalab Tomas[a]

[a]*Institute of geonics CAS, , Institute of Clean Technologies, Studentska 1768, Ostrava 70800, Czech Republic*
[b]*University of Wollongong, Faculty of Engineering and Information Sciences, Wollongong, Australia*

Abstract

The strain gauge probes of different construction are typically used for determination of stress state rock mass. The modified overcoring method known as the Compact Conical ended Borehole Overcoring method (CCBO) for stress state determination in rock mass was designed in Institute of Geonics of the CAS (IGN) in cooperation with Kumamoto University in Japan. The implemented adjustment of the overcoring method consists mainly in omitting the overcoring phase (stress relief phase). The probe is glued directly to the conically shaped end of a borehole. The data logger located within the conical probe enables continual strain monitoring directly in the conically shaped end of the borehohole during the overcoring procedure. The conical probe used to monitor stress changes, named Compact Conical ended Borehole Monitoring (CCBM), can continuously monitor rock strain changes in key locations due to mining.
Many stress measurements using both strain gauge probes CCBO and CCBM were carried out in the last decade. These measurements were performed in varied rock mass adjacent to mine excavations. Most of the stress measurements were carried out in Carboniferous sedimentary rocks as part of the experimental work in the Czech part of the Upper Silesian Coal Basin (USCB). Several stress measurements were carried out during the mine development operations and associated geotechnical exploration work while constructing the Milasín – Bukov underground gas storage (BUGS) [1], as well as the Bukov Underground Research Laboratory (BURL) [2]. Both underground facilities were designed within Rožná and Olší uranium deposits situated on the north-eastern margins of the Strážek Unit consisting of the metamorphic rock formations. Several measurements were carried out in granitic environments (igneous rocks) as part of the international "Large-Scale Monitoring" (LASMO) project in Grimsel (Switzerland) and in Josef underground laboratory (Bohemian massif). The article presents the basic principles and the methodology of stress measurements in rock mass using strain gauge probes and the data analysis from the variable rock environments.

Peer-review under responsibility of the organizing committee of ICMEM 2016

Keywords: Compact Conical ended Borehole Overcoring method (CCBO); overcoring; rock mass; stress

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1. Introduction

Generally, the accurate knowledge of the stress-strain state in the rock mass adjacent to the mining galleries and underground openings is absolutely critical for the optimum support design in all parts of the underground workings affected by the stress redistribution.

The problems associated with high stress in rock and determination of stress magnitudes have been under investigation at the Institute of Geonics for a long time. With increasing mining depth and worsening of the geological and mining conditions, a suitable method to determine and monitor rock stress and stress changes due to longwall coal mining was needed [4]. During the past 20 years, the hydraulic fracturing method has been commonly used, but this method does not appear to provide satisfactory results because it does not allow determination of all stress tensor components or continuous observation of stress changes. Due to the long-term borehole stability the decision was made to develop a device which enables determination of all three principal stress components (σ_1, σ_2 and σ_3). Development of the device described in here is based on the experience of K. Sugawara and Y. Obara from Kumamoto University. They were the first to develop and use the compact conical-ended borehole overcoring system

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* Corresponding author. Tel.: +420-596-979-701; fax: + 420-596-919-452.
E-mail address: petr.waclawik@ugn.cas.cz

Peer-review under responsibility of the organizing committee of ICMEM 2016
doi:10.1016/j.proeng.2016.06.703

(CCBO) [5,6]. The conical shape of the CCBO probe provides a sufficient number of strain measurements in independent directions in one probe position in the borehole so that all values of the stress tensor can be determined. Two variants of the CCBO probe were developed at the Institute of Geonics. The first variant is equipped with a microprocessor for remote, wireless automatic recording of measured data on the probe's internal memory, and the second one can be connected to a data-logger and power supply via a cable. The CCBM device is used for long-term monitoring of stress tensor changes [7, 8].

The CCBO stress measurement is a method used to measure the existing stress in rock mass usually before mining begins. The principle of the method is the measurement of stress relief in the rock core, achieved by overcoring of the installed probe. The stress relief is calculated from the strain relaxation measured by the strain gauges during to overcore. The deformation characteristic of rock mass during overcoring is influenced by many factors such as the stress state, rock elasticity, temperature of environment, probe geometry etc. Physical-mechanical properties such as texture and composition of the rock of rocks have a significant influence on rock deformation characteristic during overcoring. The deformation responses in sedimentary, methamorphic or igneous rock are typically different.

2. Methodology and principles

2.1. Gauges probes Compact Conical ended Borehole Overcoring (CCBO) – principles and methodology

CCBO method is an in-situ measurement of stress relief in the rock mass. It uses the inherent behaviour of the releasing rock core from the initial stress field due to overcoring. Overcoring itself causes the rock core stress release, which is manifested by deformation response. Relationships between the measured strains along the perimeter of the probe provide the ability to calculate the stress state in which the rock was initially placed [3, 9, 8]

CCBO probe is a conical shaped device which allows determination of full stress tensor of the rock from only one borehole measurement. The strains in the tangential and the radial directions are measured through strain gauges located at the probe surface (Fig.1). The original probe design that contained eight strain gauge rosettes [5], was modified using the six strain gauge rosettes only (Fig. 1,2).

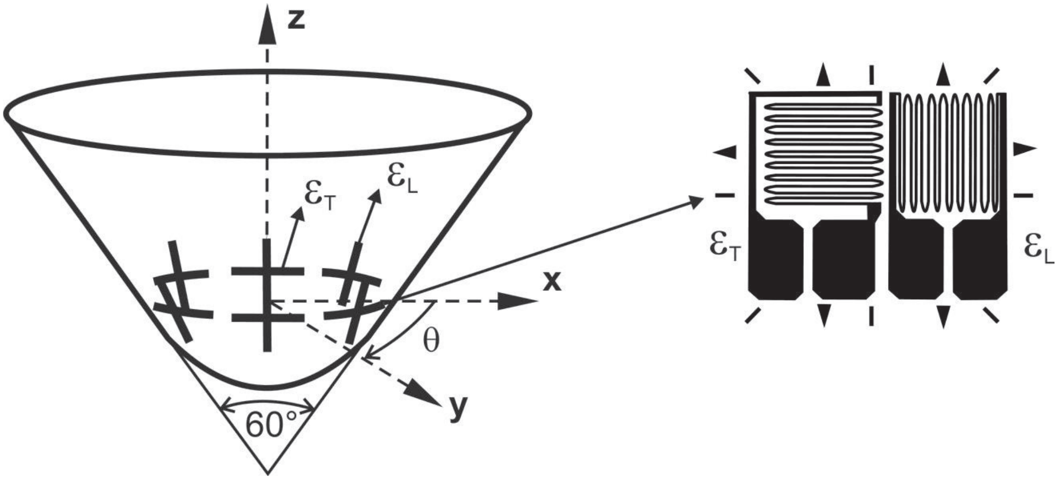


Fig. 1 Geometry of CCBO probe

The conical shape of the probe's surface has the advantage of measuring the stress tensor in one position and simple installation and centering of the probe straingauges. Relatively short compact segment of rock is required for application of this overcoring method.

Dependence of corresponding gauge sensor [10, 11, 12] is formulated by:

$$\varepsilon_\Delta^{\Phi j} * E = | A(\Delta;\Phi_j) | * |\sigma| , \quad (1)$$

where: $\varepsilon_\Delta^{\Phi j}$ - calculated deformation on gauge sensor of Δ type ($\Delta \in \{T,L\}$) and Φ_j adjusted to x-axis ($j \in \{1,\ldots\ldots m\}$, m-number of sensors); E –Young´s modulus; $| A(\Delta;\Phi_j) |$ is 6-elements row matrix; the elements depend on Δ type and Φ_j orientation of corresponding gauge sensor; $|\sigma|$ - stress tensor represented by column matrix ($|\sigma|^T = \{\sigma_{xx}, \sigma_{yy}, \sigma_{zz}, \sigma_{xy}, \sigma_{xz}, \sigma_{yz}\}$). Optimal stress tensor $|\sigma|$ of the system is found by method of least squares of differences of the corresponding measured $\varepsilon_{\Delta\Phi j}$ and calculated $\varepsilon_\Delta^{\Phi j}$ deformations.

2.2. Technical description of CCBO gauges probes

The CCBO probe is designed for boreholes of 76 mm in diameter. The waterproof probe body has a diameter of 55 mm. Six pairs of mutually perpendicular strain gauges are mounted onto the conical tip of the probe with apical angle of 60° at the level where the diameter is 38 mm.

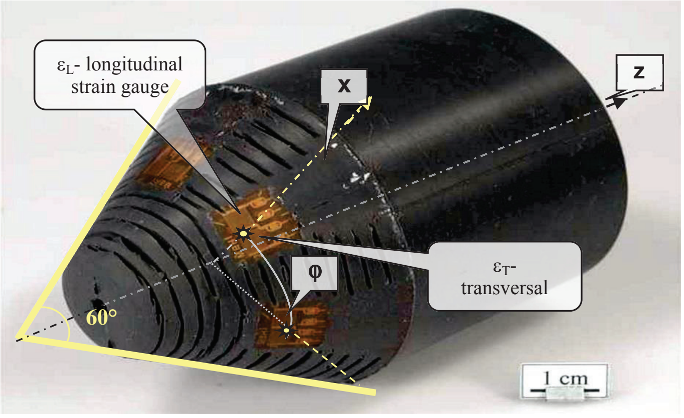


Fig. 2 Picture of CCBO gauges probe and representation of the coordinate system used

Simplified block diagram of new CCBO probe is presented in Fig. 3. Mechanical design of CCBO probe is shown in Fig. 4 [12].

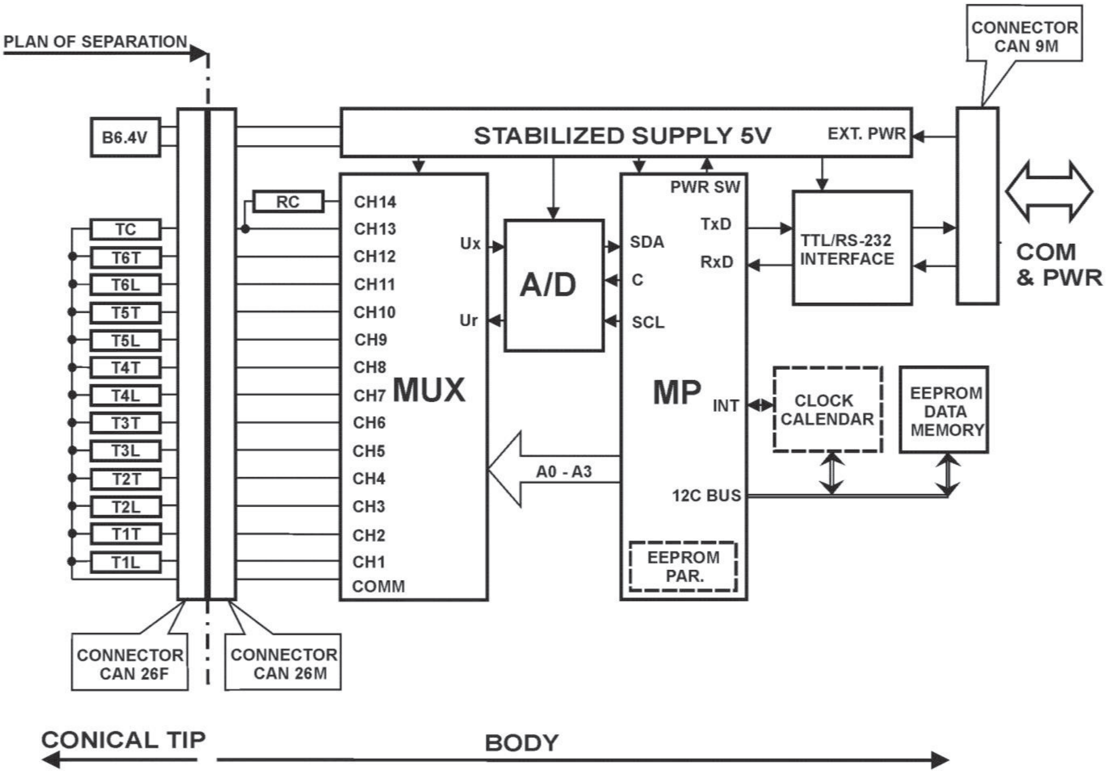


Fig. 3 Simplified block diagram of CCBO probe [12]

Probe consists of two principal separable parts:

- Measuring conical tip containing 6 strain gauge 2-element 90° tee-rosettes (longitudinal: T1L-T6L and transversal: T1T-T6T), and the compensating strain gauge TC is situated inside the tip but close to surface to achieve short temperature time response and good compensation during overcoring. TC is installed to special envelope which preserves it from mechanical stress. In the tip two 3.6V batteries are installed.
- Body of probe containing electronic multiplexed quarter strain gauge bridge MUX, analog-to-digital converter A/D, microprocessor MP, EEPROM data memory, stabilized power supply, TTL/RS-232 interface, serial input/output connector CAN 9M and clock-calendar chip (optional).

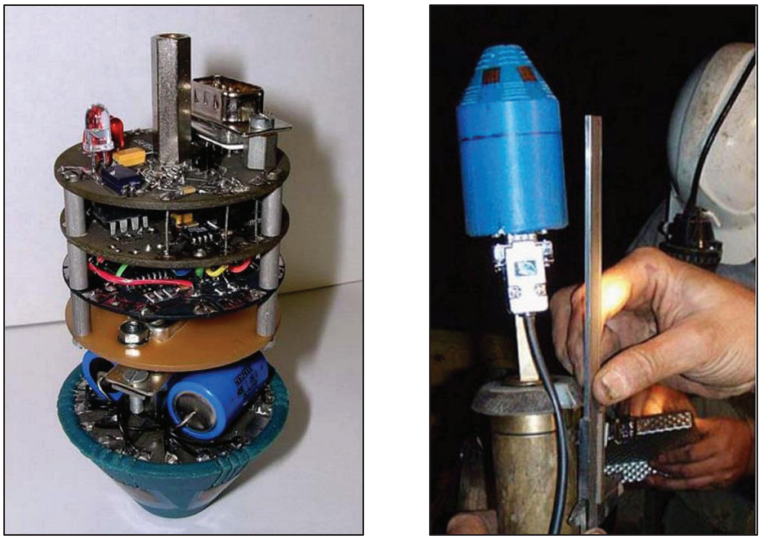


Fig. 4 Internal mechanical design of CCBO probe and the same probe prepared for installation

2.3. Installation procedure of CCBO gauges probes

The installation procedure of the CCBO probes:

- Drilling a borehole to the projected length - the quality of rock is regularly examined from the core samples,
- The borehole end is formed and polished by special conical drill bit (see Fig. 5),
- Checking the homogeneity of the shaped borehole bottom by TV inspection system - if the surface quality of the shaped borehole bottom is unsatisfactory (discontinuities, large grains, etc., see Fig. 6), it is necessary to continue drilling to a more suitable position and repeat the shaping and inspection process,
- Drying out the borehole bottom with compressed air, if the surface quality is evaluated to be satisfactory,
- Cementing the probe in place a special kind of resin glue (epoxy type) is used to cement the probes. The handling equipment is fitted with the device which detects the probe orientation, enabling (together with knowledge of the direction and the inclination of the borehole) the determination of the location of strain gauges in the space of the rock mass,

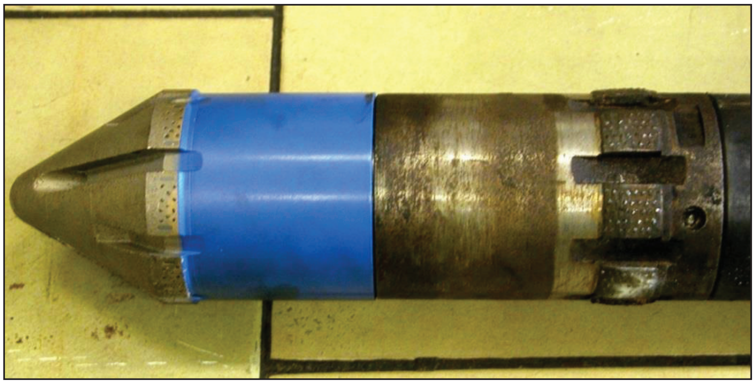


Fig. 5 Special conical drill bit used to form borehole end

- Overcoring the conical probe by a double tube core barrel with an inner diameter of minimally 62 mm. The length of overcoring is ca. 40 cm. The probe is ready for overcoring after appropriate setting time of the glue and removal of the handling rods,
- Pulling out the drill rods with overcored rock, including the CCBO probe,
- Exporting data from the probe to a personal computer for processing.

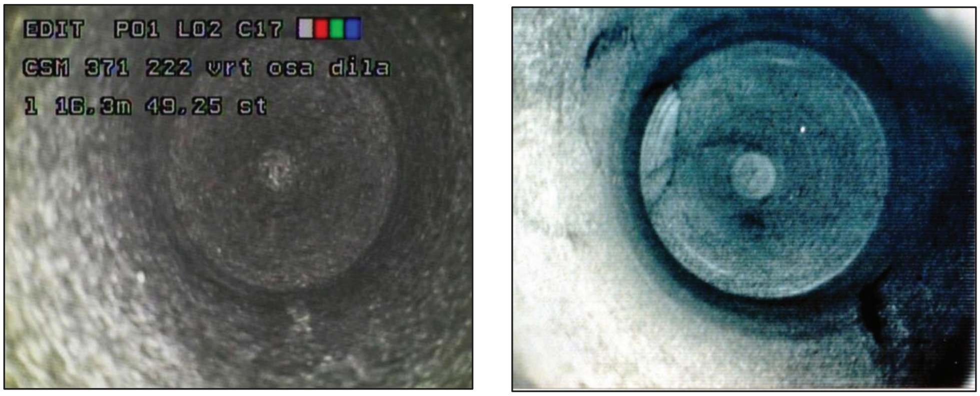


Fig. 6 Formed end of the installation borehole.
Left - suitable position. Right - not a suitable position, end of the borehole affected by joint.

3. Strain measurements in various types rocks

Physical-mechanical properties of rocks have a significant influence on rock deformation characteristic during overcoring process. Texture and composition of each rock type determine these properties. It is necessary to know physical-mechanical properties of rocks for correct determination of stress state in rock mass. In order to obtain the information about the qualitative parameters of rocks, the basic physical and mechanical properties of overcored rocks were studied. In particular, the bulk density ρ_0, uniaxial compressive strength (UCS) σ_D, Young's modulus E, and Poisson's ratio υ were defined. The properties of various rock types are shown in Table 1. Cylindrical samples with the length-to-diameter ratio (slenderness ratio) about 2:1 (45 mm in diameter, 95 mm high) were used to determine these basic properties. The bulk densities were calculated on the basis of measured dimensions and weight of the samples. Strength and deformation properties of rock were determined using the computer-controlled mechanical press ZWICK 1494 with a cylindrical testing cell to measure the longitudinal and lateral deformation in each sample. The compressive test was carried out at the loading rate of approximately 0.15 mm/min.

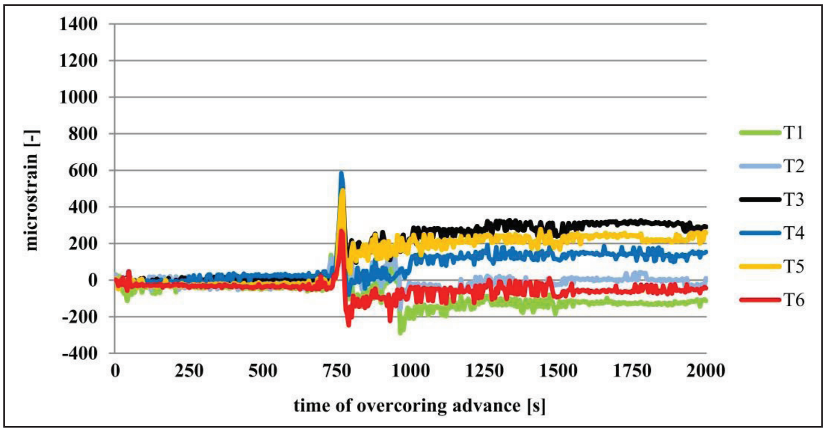
Table 1. Physical and mechanical properties of overcored rocks

Type of rock	ρ_0 [kg/m^3]	σ_D [MPa]	E [MPa]	υ [-]
Sedimentary (sandstone)	2400-2450	95 - 135	16300-26500	0.11-0.25
Metamorphic (gneiss)	2750-2800	70*-150	26000-35000	0.15-0.20
Igneous (granite)	2700-2850	120-145	45000-78000	0.23-0.30

*the less values influenced by orientation (ca. 45°) of metamorphic foliation

The correct determination of the stress based on the measured strains should include the characterisation of the rock mass and it's Young's modulus directional variation due to the rock anisotropy [13, 14, 15] to describe the most possible, true relationship between stress and strain. The principle of the overcore method is the stress relief of the rock core, which is formed by overcoring of the installed probe. The stress relief due to overcoring is manifested by deformation response of the rock core, which is monitored by strain gauges. The ovecoring measurement should be made in unfractured rock. The confidence of the strain measurement is enhanced by camera inspection in a borehole in order to avoid the probe installation in rock that is influenced by a local anisotropy and some structural inhomogeneity. So the surroundings of the measurement probe can be considered as a homogeneous, elastically responding rock core without any cracks and discontinuities. [16]. Due to various genesis, composition and structures in rocks it is variously difficult to find suitable overcoring position without structural inhomogeneity and fractures.

Many stress measurements using the CCBO and CCBM probes were carried out in the last decade. These measurements were performed in varied rock mass formations. A lot of stress measurements were carried out in Carboniferous sedimentary rocks in the Czech part of Upper Silesian Coal Basin (USCB). Most of the overcore measurements were performed in sandstones due to its higher integrity. Deformation characteristic on the strain gauges during overcoring were very similar in this type of rock. The typical strain response of the sandstones during the overcore can be seen in Fig. 7



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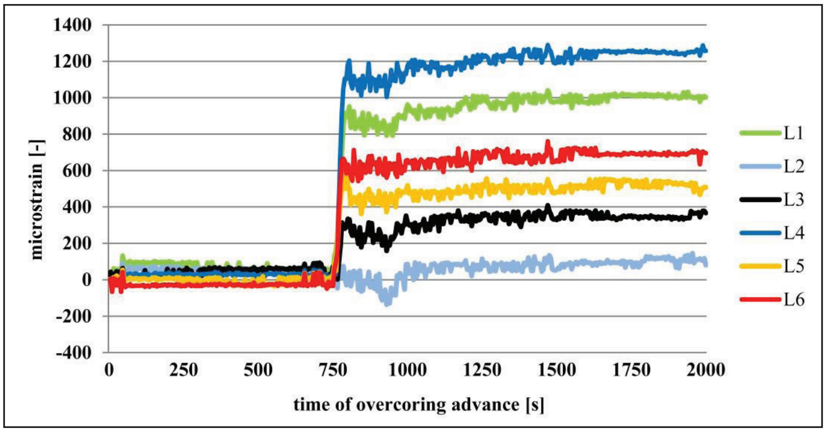
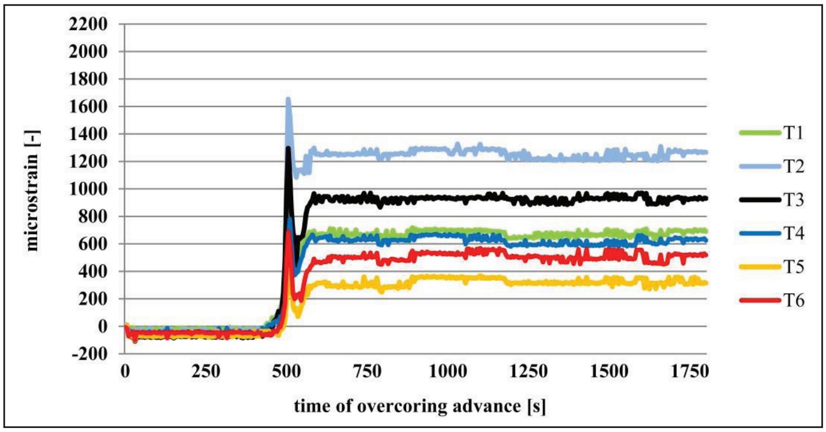


(b)

Fig. 7 Example of the overcoring strain response in sandstone
(a) Measured strains in the tangential direction. (b) Measured strains in the radial direction.



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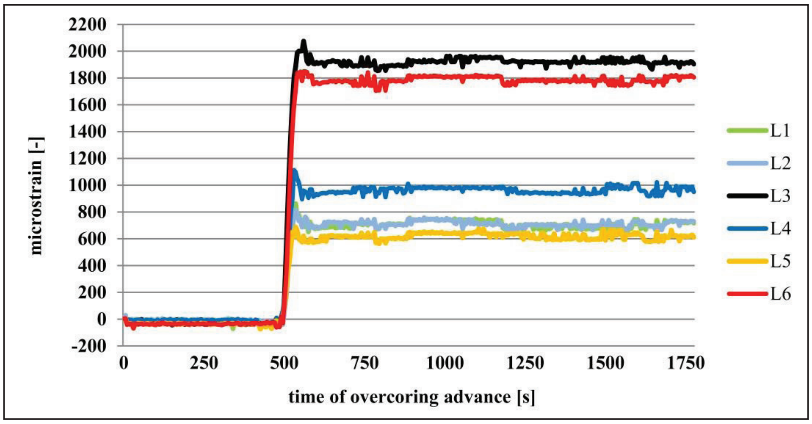
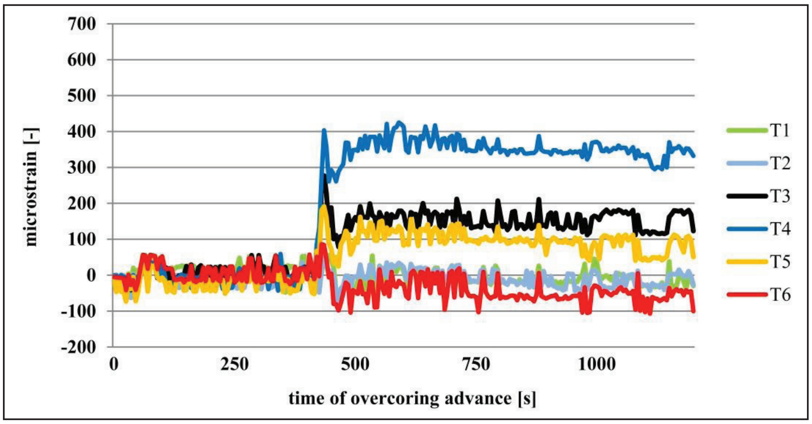


(b)

Fig. 8 Example of the overcoring strain response in granite
(a) Measured strains in the tangential direction. (b) Measured strains in the radial direction.



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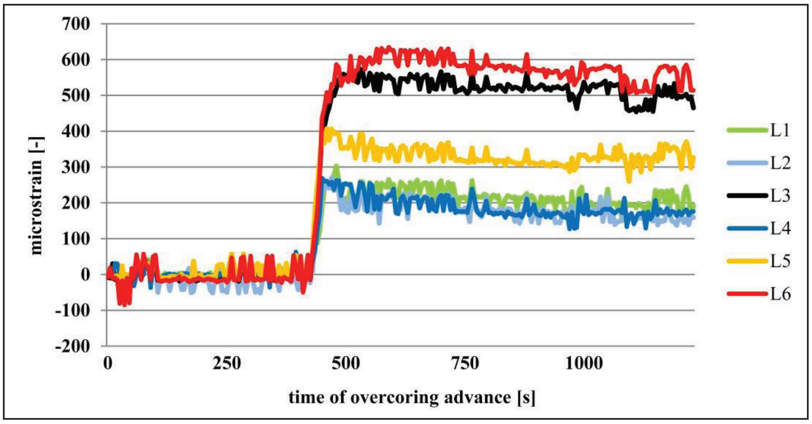
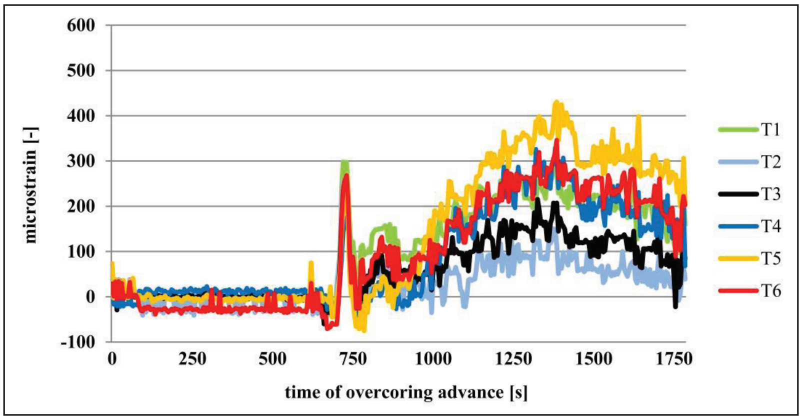


(b)

Fig. 9 Example of correct overcoring strain response in gneiss
(a) Measured strains in the tangential direction. (b) Measured strains in the radial direction.

Several measurements were carried out in the igneous rocks as part of the international "Large-Scale Monitoring" (LASMO) [3] project in Grimsel (Switzerland) and in Josef underground laboratory (Bohemian massif-Czech Republic). In both cases all of the overcored measurements were performed in granitic rocks. Deformation characteristic measured by the strain gauges during the overcoring process were very similar in this type of rock. The typical strain response of the sandstones is shown in Fig. 8.



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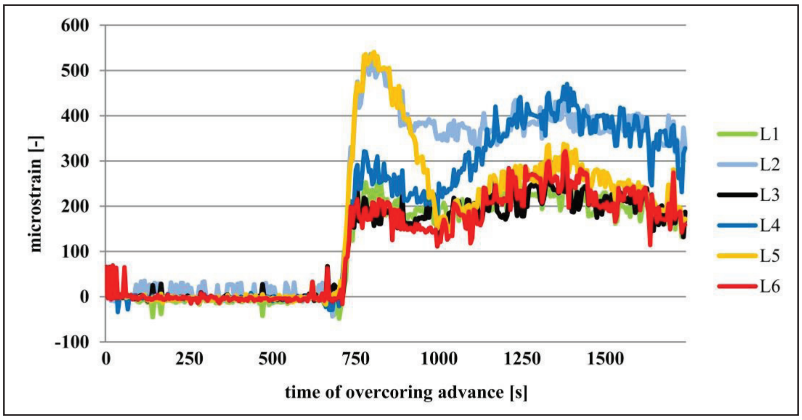

(b)

Fig. 10 Example of incorrect overcoring strain response in gneiss
(a) Measured strains in the tangential direction. (b) Measured strains in the radial direction.

Several stress measurements were carried out during the mine development stage and the associated geotechnical exploration work when constructing the Milasín – Bukov underground gas storage (BUGS) [1], as well as the Bukov Underground Research Laboratory (BURL) [2]. Both planned underground facilities have been designed within Rožná and Olší uranium deposits, which are situated in the north-eastern margin of the Strážek Unit which consists of the metamorphic rocks environments. Overcore measurements were performed in gneisses in this area. However the migmatized gneisses are typically formed by dark melanosome, rich in biotite and, more rarely, in garnet and light-coloured leucosome abundant in quartz, plagioclase and potassium feldspar [17, 18]. So the migmatized biotite gneisses have higher frequency of the metamorphic foliation planes created by biotite-rich bands or by dark-coloured melanosome layers. The habit of biotite itself is to form anisotropy along the predisposed joint planes. This complicates the strain response during overcoring. For this reason the deformation characteristic measured by the strain gauges during overcoring were different in this type of rock. Example of incorrect overcoring strain response in gneiss is shown in Fig. 10. The example of correct strain response in the gneisses is shown in Fig. 9.

4. Conclusion

The overcoring methods are very useful to measure stress state in rock mass. The CCBO probes, which were developed at the Institute of Geonics, were tested in varied rock environment. It is clear that the deformation characteristic of rock mass during overcoring is influenced by many factors such as the rock type, stress state in rock, temperature of the environment, probe geometry etc. Physical-mechanical properties of rocks have a significant influence on rock deformation characteristic during the overcoring process. Texture and composition of the rock determine these properties. As shown in the particular measurements presented here, the deformation responses of rock core vary for sedimentary, metamorphic or igneous rocks.

It is evident that the overcoring strain response depends especially on the stress state in rock mass at the measurement site. However, it is apparent that the rock type has a significant effect on the measured strain magnitudes. In the cases presented here, the largest strain responses were found in granite i.e. igneous rock. It should be noted that the granite was of a good quality and therefore the measurements were the least complicated. Suitable overcoring positions within the granite were easily identifiable. A large number of stress measurements were carried out in sandstones. Deformation characteristic on the strain gauges during overcoring process were very similar in this type of rock. Finding a suitable position for the overcore measurements in sandstones was sometimes difficult due to the sedimentary irregularities. For this reason, it was necessary to closely examine the sedimentary nature of rock mass at the measurement point. Several stress state measurements were carried out during the mine development operations and associated geotechnical exploration in Rožná and Olší uranium deposits. Overcore stress measurements were performed in migmatized biotite gneisses in this area. Migmatized biotite gneisses have higher frequency of the metamorphic foliation planes created by biotite-rich bands or by dark-coloured melanosome layers. The biotite exhibits extensive joint planes anisotropy. This fact can produce a complicated strain response during the overcoring processes. For this reason the deformation characteristics of the strain gauges during the overcore processes were different in particular cases for this type of rock.

It is noticeable that the deformation characteristic of rock mass during overcoring is influenced by many factors such as stress state in rock mass, temperature of environment, probe geometry etc. However the overcore stress measurements confirm that a significant effect on the strain response and deformation characteristic is due to the rock geological characteristics. The largest strain responses were measured in the granites, smaller in the sandstones and the smallest in the gneisses rocks. More measurements in various rocks types and conditions may be required to confirm the results presented here.

Acknowledgements

This research was financially supported by the Ministry of the Interior of the Czech Republic (project No. VH20162017002).

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