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FIRST RESULTS OF CONICAL BOREHOLE STRAIN GAUGE PROBES APPLIED TO INDUCED ROCK MASS STRESS CHANGES MEASUREMENT

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ABSTRACT
Using of shaped conical borehole bottom to determination of the stress tensor changes induced by changing of geomechanical situation is described in this paper. The measured strain changes on gauge probe are caused not only by the stress changes evocateg by progress of long wall. The some deformation started imediatelly after instalation when the long wal didn´t move. In paper are discussed the eventualities of this phenomenon too.

KEYWORDS: stress measurement, stress tensor, conical gauge probe, stress changes

INTRODUCTION

The questions of rock stress and its measurement are investigated in Institute of Geonics (IG) for a long time. Due to want to study of increasingly complicated geomechanical condition we have decided to use one of the relief methods – overcoring method for determination of stress tensor of rock mass.

We are using concept CCBO- compact conical ended borehole overcoring.- applied to conical shaped borehole bottom according to prof. Sugawara and Obara (Nakamura et al., 1999; Kang, 2000) who have been using the compact conical ended borehole overcoring system (CCBO) firstly. A conical shape of the strain gauge head CCBO makes the fixation of the probe in borehole easy and makes the measurement of stress in independent directions possible. It makes possible to reconstruct all stress tensor from one point of measurement. Development of device made for possibility of determination of the total state of stress tensor was started in the Institute of Geonics from experiences of prof. K. Sugawara and Y. Obara.

During development of wireless CCBO-equipment in IG the conical probe connectable by cable to registration apparatus was designed for testing of the some parts of hardware and software and the methodical procedures such as installation of a probe or the data acquisition procedures. It proved to be very good to use this cable-variant of equipment for long term monitoring of the tensor stress changes. In this case the relief phase – overcoring is not realized, the place of measurement is not demaged by overcoring procces. It is why we can use the installed conical gauge probe for long term monitoring stress changes. The results – the stress changes are related to installation reference stress state.

PRINCIPLE OF MEASUREMENT

The conical shape ensures different orientation of measuring gauges within space. Measurement of sufficient number of them before and after overcoring makes possible to figure out all tensor of rock stress. Using of conical shape of measuring surface brings together both advantage of measurement of all stress tensor in one position and advantage of simple installation and centering of gauges probe. The task has not analytical solution and the results are obtained by numerical calculation.

Scheme of siting of the gauge sensors on conical probe is shown in Figure 1.

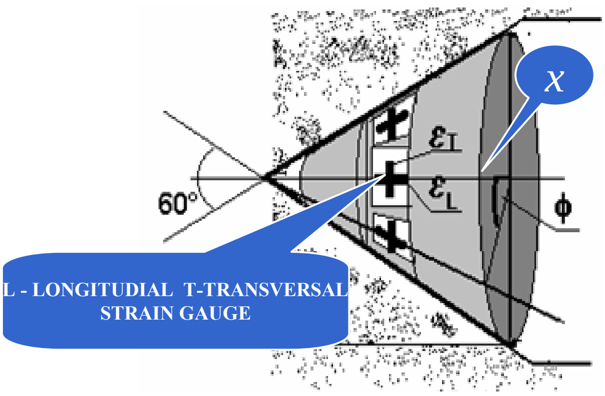

Fig. 1 Scheme of siting of the gauge sensors on conical body of probe.

Dependence of corresponding gauge sensor is formulated like:

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

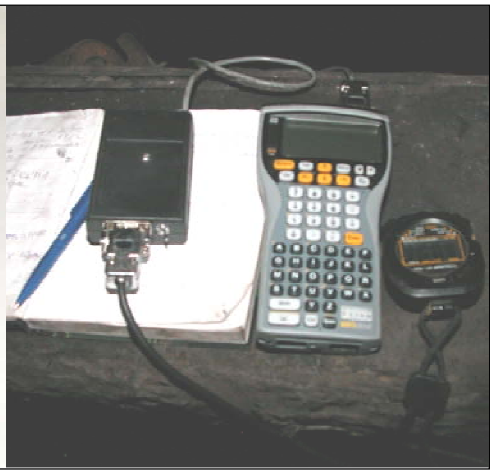

Fig. 2 A gauges probe for long term measurement of stress tensor (left side), registration unit PSION (right side).

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, μ- Poisson's ratio,

$|\mathbf{A}(\Delta;\Phi_j)|$ is 6-elements row matrix; the elements depend on Δ type and Φ_j orientation of corresponding gauge sensor:

$$|\mathbf{A}(T;\Phi_j)| = \{ a_{11}+a_{12}\cos(2\Phi_j), a_{11}-a_{12}\cos(2\Phi_j), c_{11}, d_{11}\sin(\Phi_j), d_{11}\cos(\Phi_j), 2a_{12}\sin(2\Phi_j)\},$$

$$|\mathbf{A}(L;\Phi_j)| = \{ a_{21}+a_{22}\cos(2\Phi_j), a_{21}-a_{22}\cos(2\Phi_j), c_{21}, d_{11}\sin(\Phi_j), d_{21}\cos(\Phi_j), 2a_{22}\sin(2\Phi_j)\},$$

$a_{11}(\mu)\ldots.d_{21}(\mu)$- the factors obtained from mathematic model of strain state geometry on cone surface, $|\sigma|$ - 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 all 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.

BASIC DESCRIPTION OF EQUIPMENT

Development of apparatus for overcoring method was started in our Institute some years ago. Idea of conical shaped borehole bottom was used. Apparatus is constructed for 76 mm borehole diameter. The bottom of borehole is shaped by the special conical drill bits. Apical angle is 60°. The probe is water-proof and it has 6 couples of mutually perpendicular gauge sensors (about Fig. 1) standardly. Apparatus for CCBO is designed on base wireless record of measuring data, firstly on base of infra-red communication, now with data record to memory inside gauges probe. Conceptual design, methodical procedures and partial results of apparatus development have been published e.g. in Staš et al. (2004, 2005a, 2005b, 2005c).

Due to want of testing of technological and methodical procedures, testing of functionality, range check and resolution the simplified variant of probe was prepared. This variant is connected with data logger PSION by means of communication cable (Fig. 2).

Laboratory testing has manifested full functionality of this probe. Its development has opened possible using of this concept for long term measurement of stress tensor changes (CCBM– **c**ompact **c**onical ended **b**orehole **m**onitoring) by cuting of overcoring phase. This type of device has been installed and used to monitoring of changes of stress distribution in area where impact of long wall advance is assumed (the mine areas of selected long walls in CSM and LAZY Collieries). The experimental results of Lazy locality are discussed now.

EXPERIMENTAL EXAMINATION

Diagnostic of so designed probe has been done in concrete geomechanical situation of selected long wall "140914" on Lazy locality. The situation is showed in Figure 3. The long wall is placed in 40th coal bed close to the fault "Ceres" and on the mating side the long wall underpasses the goafs of the 37th - 39th coal beds. The area contiguous to fault Ceres has been treated by relief blasting operation to limitation of unpredictable increase of stress state of rock mass during displacement of long wall.

The gauging stations have been realized as the boreholes of diameter 76 mm, about 8-16 m of long and drilled upward to sandstone overburden. After that the conical long term probes have been cemented into these boreholes on shaped bottom. Spatial arrangement and orientation of probes have been noted. The core samples were used to specification of the mechanical properties (Young´s modulus, Poisson

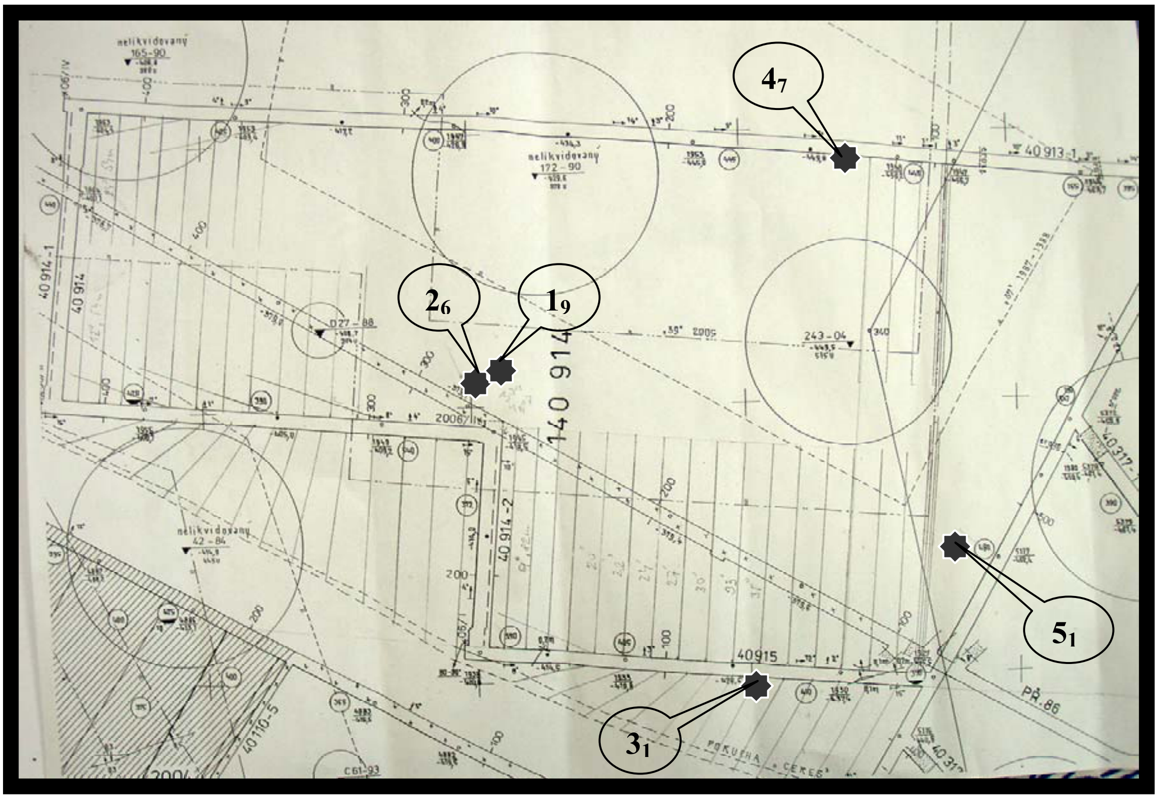

Fig. 3 Situation of the gauge probes locations around long wall N^o 140 914.

ratio), which are necessary to finished calculation of the stress changes. These mechanical properties were investigated standardly in laboratory on the cylindrical samples selected from the places closed to the conical bottom. Due to simplification of analysis the isotropic sandstone material was postulated (trasversal isotropic of sandstone was not contemplated).

The stars in Figure 3 mark the places where the probes have been installed and where measurement of this method is (or was) in progress.

Due to passage of a long wall front, a measurement on the localities 1_9 a 2_6 had to be stopped. The probes on the localities 3_1, 4_7 and 5_{13} are working and their values are periodically red and recorded.

A course of experiment is documented on the examples of the probes 1_9, 2_6 a 3_1. The probes 1_9 and 2_6 were placed horizontally in relatively the same place. Difference in vertical placing (15.8 m resp.11.3 m above of extracted coal bed) does possible to compare the changes of impact of long wall distance.

All monitoring of strain changes of selected sensors of conical gauge probes 2_6 resp.1_9 is shown in Figure 4 resp. Figure 5. With a view to better readibility of the graphs only the dependencies of „T“ type gauges were made visible.

Two different parts of behaviour of the gauges probes are able to observe after installation. Decreasing of the values (compressive loading) on all gauges takes place for long time (from cementing of probe during about 3 months up to start of long wall mining and after). This deformation has the same character on all sensors. It is compressive and time dependence of strain rate decreases. This deformation process evidently is not related to progress of long wall face. Strain record has shape of relaxation type. It has to be looked in procedure of stress calculations. The other type of strain starts to show itself after on-coming of long wall face to shorter distance then 50-70 m. These deformations conform to redistribution of rock stress in foreground of long wall face. It is possible to tell that significant deformations develop after on-coming of long wall face to down distance 30 m in this case.

The correlation of strain development versus change of distance to long wall face is visible very well. Due to technological problem the progress of long wall had to be broke from 20th to 23rd February 2007. In these days strain development on the gauges is halted respectively retarded (see Figure 4a respectively Figure 5a – grey zone). These influences are the more distinctive the more place is closely to extracted coal bed.

Development of the strains on locality 3_1 (Fig. 6) is a little different. The area is still situated relatively far from long wall face (> 100m). Immediate influence of long wall progress is not expected. Recorded constant strain rate has probably similar

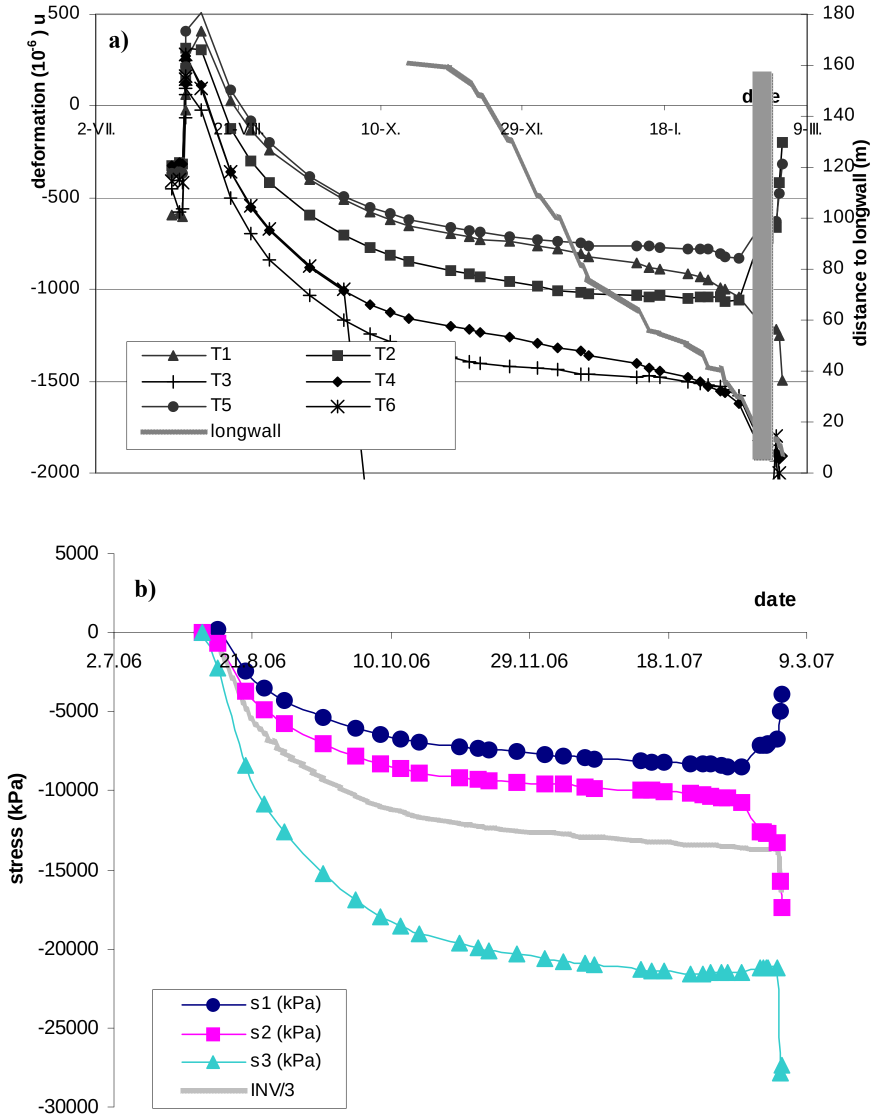

Fig. 4 Probe 2_{6} - a) record of deformation measurement on the gauges „T"-type, b) calculated stress representation of the gauges deformations.

source as the previous cases i.e. relaxation of rock as response on relief by borehole drilling or relief blast operation in this area. The distinctive changes of development of strain on L5, L6 and less distinctive T5, L3 gauges are visible at the turn of January and February. It can be induced by relief blast operation at 14 January or 4 February. They were done about 100m or 75m respectively from 3_1-point.

DISCUSSION

What is causation of "relaxation" development of strain changes before impact of long wall advance? It could be:

- Creep phenomenon of glue

Behaviour of strain development was investigated also in term of quality of used glue and quality of bonding of the sensors and rock. The main problem of these experiments is phenomenon – creep of glue. It was examined before beginning of in situ experiment. A steel sample was pasted on with gauges and it was placed into rheological press with defined loading. Some different types of the glues were used and examined for three months (Staš et al., 2006). AE 10 and Epoxy 531 have been found as usable glues. We have decided to use Epoxy 531. It combined with curing agent "Telalit" does possible to apply Epoxy 531 in wet rock conditions.

- Ageing of glue - contraction

Due to the glue is applied as very thin film and ratio of Young´s modulus of rock and glue is about 10, influence of contingent contraction is minor.

- Change temperature

The gauge sensors are very sensitive to temperature fluctuation. During all experiment not

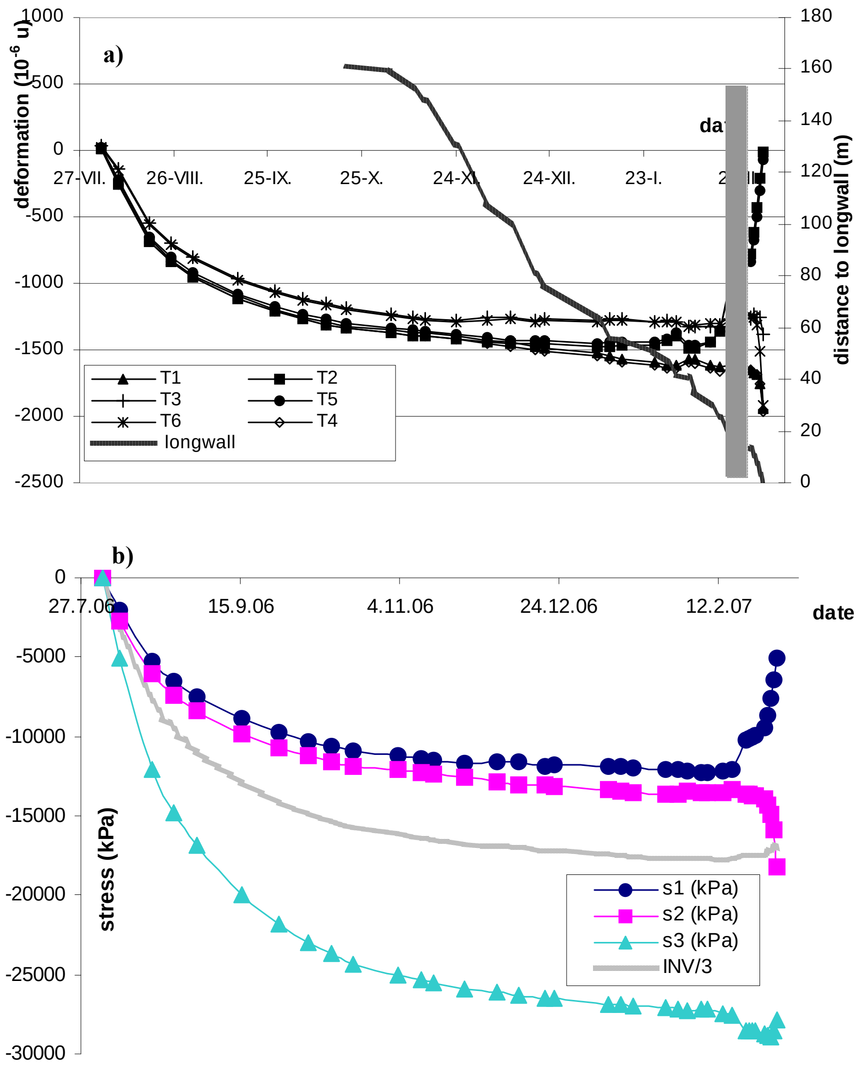

Fig. 5 Probe 1_9. a) record of deformation measurement on the gauges „T"-type, b) calculated stress representation of the gauges deformations.

only measuring gauges were recorded but no-load sensor for temperature monitoring was recorded too. By means comparison of them a temperature impact in strain measurement is removable. Influence of the temperature fluctuations was lower than $70*10^{-6}$ units resp. $200*10^{-6}$ units on the probes 1_9 resp. 2_6. It is considerably less than the values which were measured on measuring strain gauges.

- Relaxation of rock

If no unidentified geomechanical impact is supposed, a slow stress-strain relaxation of rock mass is the most probable cause of this phenomenon. It could be result of local relief of rock mass after drilling of the measuring boreholes. All of the gauge probes have been installed into boreholes promptly after their boring. They monitor a plastic strain process from beginning of relaxation.

SUMMARY

A new device for stress tensor measurement is developing on base relief overcoring method applied on conical shaped borehole bottom. In frame of this development the special probe interlocked to data logger was made to test some technological and methodical procedures and functionality of device. This type of device has been used to long term monitoring of the stress – strain changes. A functionality of this device was verified both in the laboratory conditions and in the conditions of Carboniferous rock mass. The changes of stress state of rock mass impacted by progress of long wall were investigated. This experiment demonstrated that monitored strain changes on borehole bottom are formed both by geomechanical situation based on a progress of long wall and perhaps by local

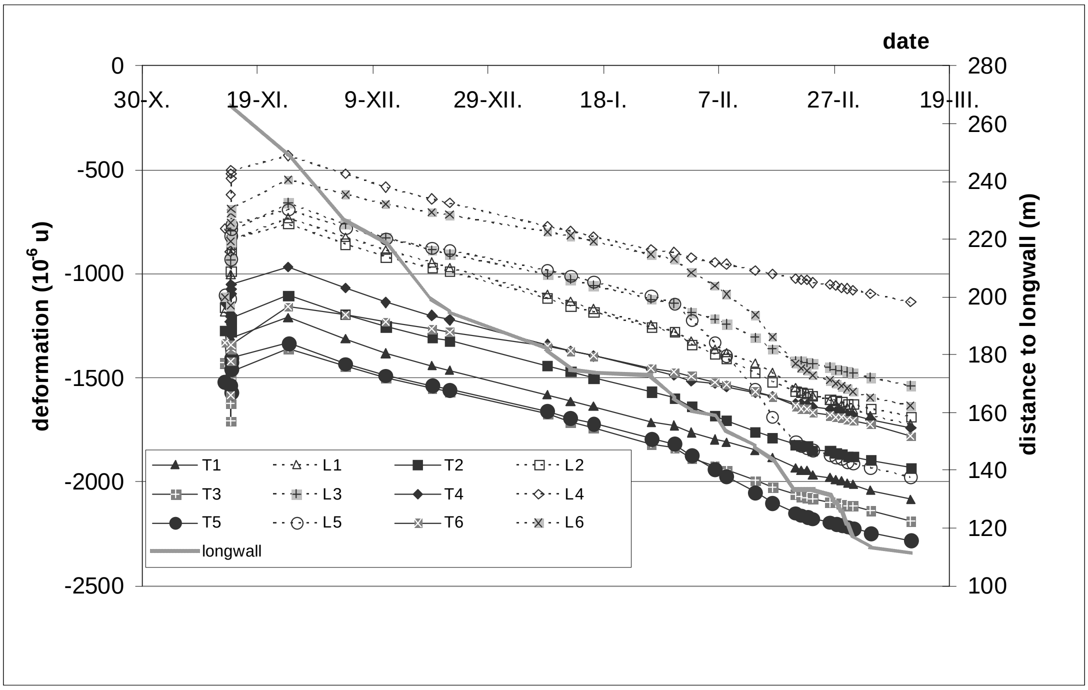

Fig. 6 Record of deformation measurement on the all gauges of the probe 3_1.

geomechanical situation based on stress redistribution after boring of measuring borehole and on plastic deformation of creeping rock material. Relatively high time consumption to stabilization of this deformation process after drilling measuring borehole and installation of the probes is shown.

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REFERENCES

Nakamura, N., Ohkubo, R., Obara, Y., Kang, S.S., Sugawara, K. and Kaneko, K.: 1999, Rock stress measurement for limestone open pit mine. In: Proc. of 5th Int. Symp. on field Measurements In Geomechanics, Singapore, Rotterdam:Balkema, 375-380.

Kang, S.S.: 2000, Measurement and interpretation on stress history of a limestone deposit. A dissertation for Degree of Doctor of Philosophy Kumamoto. Kumamoto University

Staš, L., Knejzlík, J. and Rambouský, Z.: 2004, Development of conical probe for stress measurement by borehole overcoring method. Acta Geodyn. Geomater. Vol. 1, No. 4 (136), 93-98.

Staš, L., Knejzlík,, J. and Rambouský, Z.: 2005a, Measurement of rock stress tensor by means of a conical probe. Proc. of the scientific works of the VSB-Technical University, Vol. 5, N°2 (2005), 179-191, (in Czech).

Staš, L., Knejzlík, J. and Rambouský, Z.: 2005b, Rock stress tensor measurement by a conical probe. Documenta geonica 2005, Ostrava, ÚGN AV ČR, 2005-(Kožušníková,A.), 134-149, (in Czech).

Staš, L., Knejzlík, J. and Rambouský, Z.: 2005c, Conical strain gauge probes for stress measurement In: (ed. Konečný P.) Proc. of Int. Symp. ISRM Eurock 2005 - Impact of Human Activity on the Geological Enviroment, A.A. Balkema Publisher, Brno, 2005, 587 – 592.

Staš, L., Knejzlík, J. and Rambouský, Z.: 2006, Conical strain gauge probe for stress measurement (development), (eds. Z. Aioutantis, K Komnitsas), In Advanced in Minerál Resources Managment and Environmental Geotechnology 2006 - AMIREG 2006, Hania, Greece, 523 – 528.