MEASUREMENT OF STRESS CHANGES CAUSED BY THE EXCAVATION OF RADWASTE DISPOSAL CHAMBERS

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INTRODUCTION

For final disposal of Hungarian operational and decommissioning LLW and short-lived ILW produced by Paks Nuclear Power Plant a new facility (National Radioactive Waste Repository - NRWR) is under construction at Bátaapáti in a granitic host rock. After a 12-year-long preparation process two inclined shafts were constructed using drill and blast technology to reach the repository depth. Having obtained the required licences and the acceptance of the Parliament and the local community the construction of repository began in September 2008. The structures of underground infrastructural background (water pumping plants separately for construction and final disposal activities, compressed air and electricity plants, etc.) and the loop tunnel system hosting the disposal chambers have been constructed until 2010. The first two underground disposal chambers were completed in September 2011. The customer of the project is PURAM, the main contractor is MECSEKÉRC Co.. KŐMÉRŐ (RockStudy) Ltd. is charged with performing and evaluating the geotechnical and rock-mechanical measuring program.

The disposal chambers with 12 m maximal span were excavated mainly in two stages (top heading and bench) but the designers required the splitting of top heading under the worst geotechnical conditions. The determination of actual advance and the applicable supporting system have been based on Barton's Q-system, following the NGI-method. Q-values (controlled by RMR- and GSI-values) are provided by detailed geotechnical documentation of each face. Supporting system consists of systematic rock bolting and shotcrete for more competent rocks and lattice girders combined with shotcrete and steel nets at the fault zones. No watertight lining or inner shell structure was applied.

Construction of a radioactive waste disposal should have wide-ranging investigation and design program (Hudson&Feng, 2007). Thus a comprehensive geotechnical monitoring system was applied inside the chambers both for controlling the occupational safety and for collecting data usable for the verification of designer's assumptions and calculations. In addition to the numerous optical convergence and load indicator sections, 4 radial MPBX-extensometers, 8 load cells for controlling rock bolts, 6 two-directional gauges for measuring the deformation of shotcrete have been installed and continuously measured. 6 CSIRO HI-cells were installed for determining 3D distribution and magnitudes of stress changes around the chambers during tunnelling which have provided important data for verification of the design.

APPLIED INSTRUMENTATION

From all the direct stress change measurements KŐMÉRŐ used instrumentation in the chambers of Bátaapáti NRWR which is able to 3D stress determination. The cell and the measuring principle were developed by the Australian company, Commonwealth Scientific and Industrial Research Organisation (CSIRO). Among several types of CSIRO cells KŐMÉRŐ used the so called Worotnicky-type, hollow epoxy-cells - the Hollow Inclusion (HI) cells (hereafter CSIRO HI cells), shown in Fig. 1.

Fig. 1: CSIRO HI-cell before installation

The construction and measuring principle of the CSIRO HI cell is detailed in Worotnicky & Walton (1976). In the cylindrical cell there are 12 strain gauges in defined directions (axial, 45°, 90°and 135° to the borehole axis) and a thermistor to provide a check of possible temperature changes at the HI cell sites. There are more strain gauges with the same orientation. Through this redundancy of measured values the data loss caused by failure of a channel is minimized and it is possible to recover the results.

Into the hole of the cell goes the adhesive, which will be automatically and smooth laid to completely fill the cavity between the measuring cell and the borehole wall. The strain gauges – on the epoxy grouted cell with known elastic moduli - response differently to the stress changes. The signals come out of the borehole through a shielded cable with 16 conductors. The signals of the strain gauges can be defined with an electrical measurement using the Wheatstone bridge automatically or manually. The 3D distribution and magnitudes of stress changes can be calculated with the algorithm published by Fama & Pender (1980). The mathematical interpretation of stress changes by continuummechanical approach appears in many specialist book (Asszonyi at al., 1980; Asszonyi & Kapolyi, 1981; Jaeger at al. ,2007).

DRILLING AND PREPARATION OF THE BOREHOLES FOR THE CSIRO HI CELLS

CSIRO HI-cells were installed inside the Chamber I-K2, at the end of geotechnical boreholes drilled ahead of initial face at such distance, which excludes the mechanical interactions between the actual chambers and the cells. (In Hungary this test was executed in the underground research laboratory in Boda Claystone Formation for the first time (Kovács 2006)). 4 cells were located at the boundary of rock bolting zone (2 at the roof (Bkc-7, Bkc-10) and 2 at sidewalls (Bkc-9, Bkc-11)) and 2 at centre line of pillar (Bkc-8, Bkc-12).

The drilling process began at tunnel face position of 55,3 m. The drilling process was made by ROTAQUA Ltd. with an electro-hydraulic core drilling machine DIAMEC 260 for the sidewall drillings and with a DIAMEC 250 for the roof drillings which are manufactured by ATLAS COPCO Ltd..

The first part of the boreholes was drilled with BQ (59 mm) core diameter. After that a centralized pilot hole was drilled for the CSIRO HI cells with EWG (37,7 mm) diameter size in a length of 0,5 m. The position of the pilot hole had been appointed in advance, but if the geotechnical condition was not appropriate for the installation the hole diameter was enlarged and drilled ahead until the geotechnical condition got well. That is why the cells are not in one section perpendicular to the chamber axis.

Fig. 2 shows the drilling draft with borehole length and cell positions in metres of the chamber.

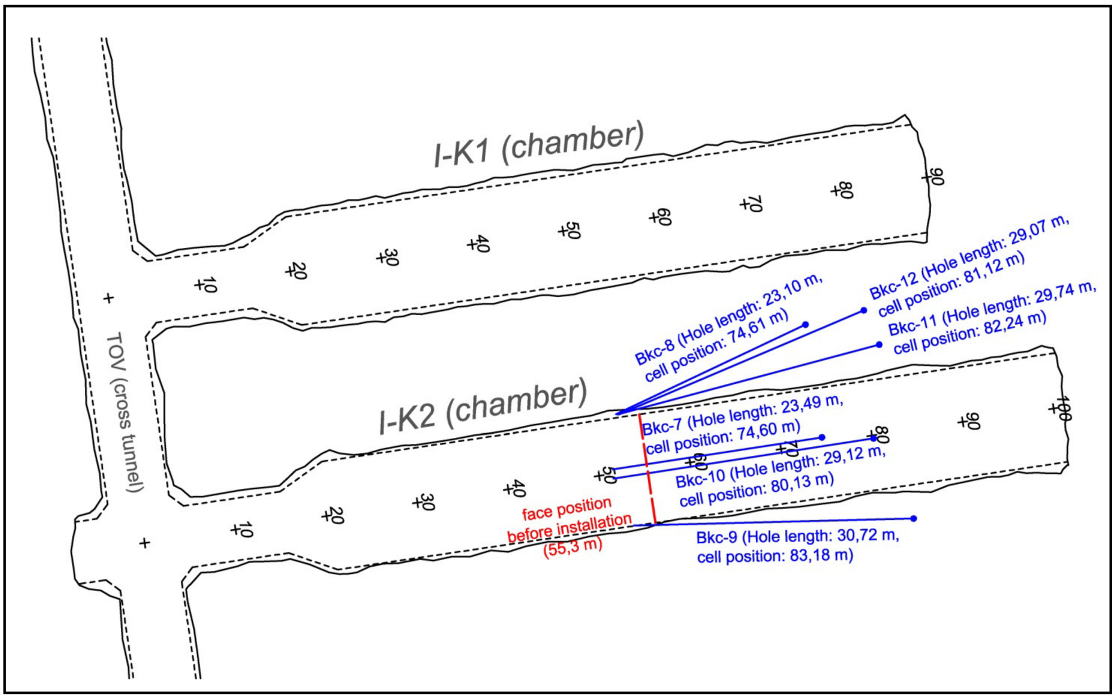

Fig. 2: Draft of the Bkc-7…Bkc-12 drillings and the position of the CSIRO HI cells

If the geotechnical condition met the previous requirements settled by KŐMÉRŐ the hole was checked with borehole television camera. This was important to avoid the stopping of the installation instrument in the borehole without tubing and avoid the situation when installation instrument do not reach the pilot hole centralized. Besides the risky conditions the borehole had to be injected and redrilled if there had been some water inflow from the pilot. Due to the mentioned preparing works all of the boreholes were suitable for the cell installation.

INSTALLATION AND MONITORING PERIOD

The CSIRO HI cells were ordered with a cable length of 40 and 45 m which is approximately the limit value of the measuring technology. Hence two dataloggers had to be installed, one on the northern wall of the chamber and one on the southern part. The datalogger is CR1000 manufactured by Campbell Scientific. The readings of 12 strain gauges and 1 thermistor could be integrated using multiplexer.

The producer executed the matching and calibration of the cells and dataloggers.

The installation should be very precise otherwise the cell or in the worst case the borehole will be lost. To avoid any problem every phase of the installation work has got a detailed checklist. Following that checklist during the installation work there wasn't any technological problem, the cells got into right position and operated well.

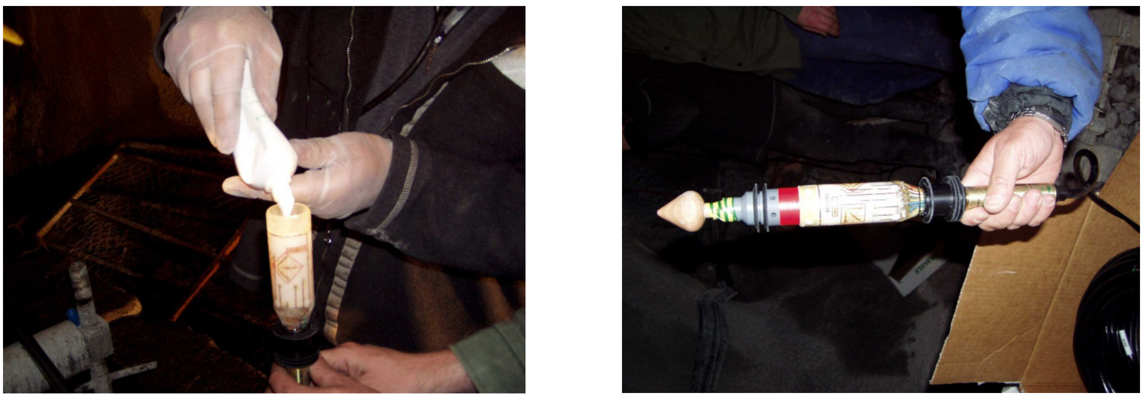

Fig. 3.: Filling the prepared adhesive into the CSIRO HI-cell (left) and the asembled cell prepared for installation (right)

Dataloggers fastened into incorrodible box were placed in steel boxes covered with shotcrete to protect those from the mechanical effects of blasting. To protect the cables from the anchor drillings the trace of the borehole was drawn on the wall after every advance.

During the monitoring period the data were read out and checked after every blasting therefore the loss of date could be minimized.

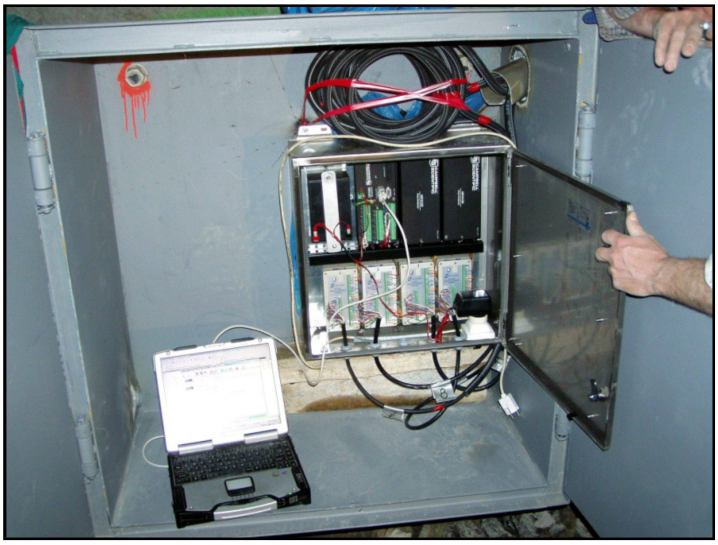

Fig.4.: The measuring-datalogger device is ready for working on the northern wall of the chamber

DATA PROCESSING

The raw data – in mV unit– were plotted continuously after every read out to check the function of the channels. This graph was also used to study which blasting had an impact on every single cell. In Fig. 5. data from cell Bkc-10 is shown. This was the only one which was damaged by blasting but it could be repaired and was able to measure the stress changes caused by advance.

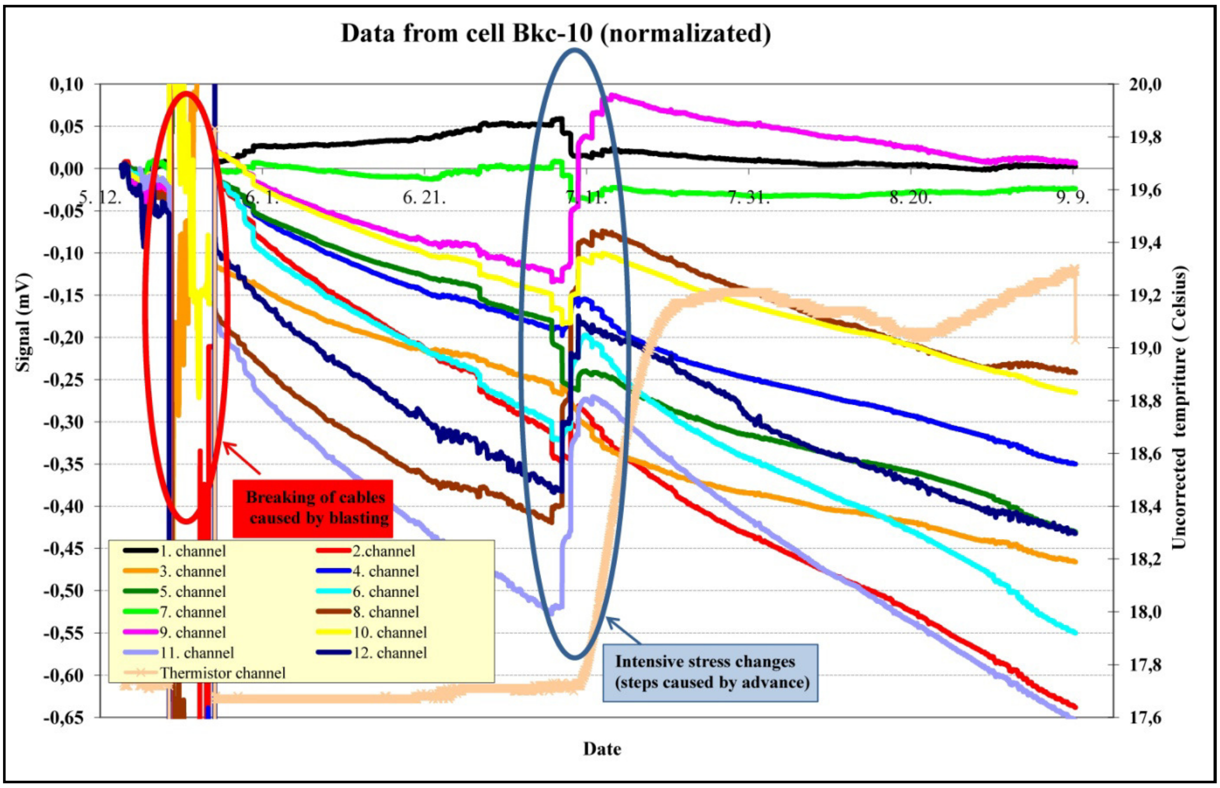

Fig. 5.: Raw data plotted against time during chamber excavation

The next step was the calculation of the strain drift correction as the strain gauges signal is not constant even if there is no advance. The measurement can't get rid of the gauge drift but it can be corrected if there is enough long stabilizing period.

After that each step caused by blasting can be calculated. The calculated values (mV) were converted in strain using the calibration values of the cells. The state of stress changes could be calculated with the calculated strain. The data processing was made with a program which was developed by the Australian ES&S (Stress2011_monitoring version) and works with iterative linear regression method. The algorithm of the software is based on the publication Fama & Pender (1980).

The program needs the following input data: general information to identify the test, orientation of the borehole, modulus of elasticity and Poisson's ratio of the rock and the adhesive, strain values and spatial position of the strain foil gauges. The properties of the adhesive were given by the manufacturer but for getting known the rock mechanical properties KŐMÉRŐ executed laboratory tests on core samples from the borehole.

As a final step the obtained stress values from the software were plotted as a function of the face position.

RESULTS

A principal result is that the stress changes could be defined detached at different excavation phases of both chambers (I-K1 top heading, I-K1 bench, I-K2 top heading, I-K2 bench). Furthermore the stress changes could be determined along the excavation section, in the critical points (roof and sidewall) and even in the centre line of the pillars. However with limited number of CSIRO HI cells the stress changes between and on the boundary of supported and unsupported zones could not be compared and the stress changes could not be defined entirely in the function of the distance from the excavation.

At the cells in the roof (Bkc-7, Bkc-10) the excavation of the top heading in Chamber I-K2 induced intensively decreasing stress changes (see Fig. 6.). The shape of the stress changes is similar on both cells. The largest decrease can be attached to vertical direction on both cells. At this excavation phase the significant stresses might be around zero in the supported zone but tensile forces occur right above this. This significant decreasing in the stress changes should be taken into account as rocks can bear much less tensile stress than pressure. That is why anchors have a great importance in the support system. The tunnel driving phases of Chamber I-K1 and the excavation of the bench in the Chamber I-K2 had minor effects.

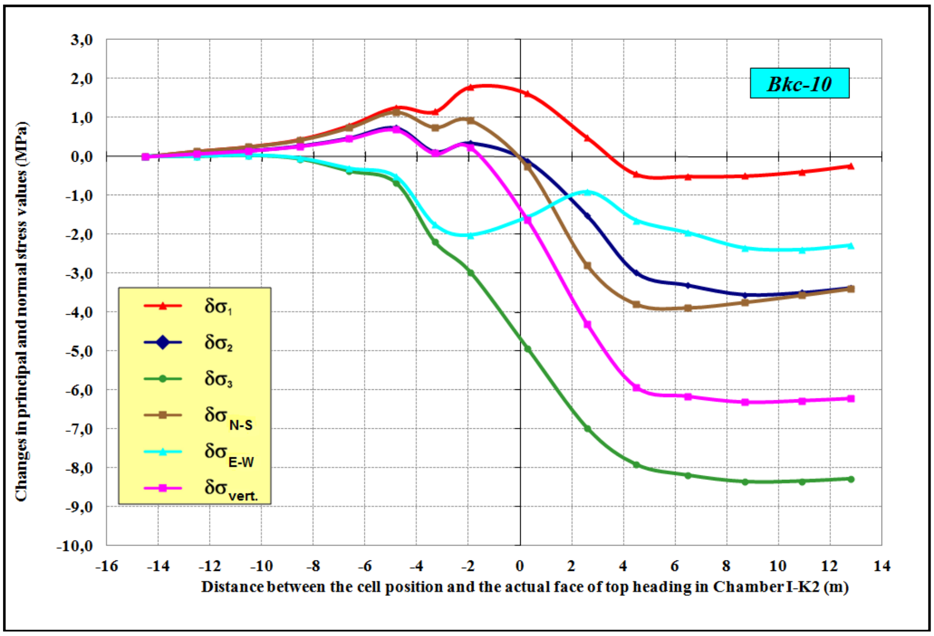

Fig. 6.: The stress changes at Bkc-10 HI cell

Bkc-9 and Bkc-11 cells were installed in the left and right side of the chamber in same height at the boundary of the supported zone. The cells show increasing stress level in different rate (2,5-5,0 MPa), generally in vertical direction during the advance of Chamber I-K2 (see Fig.7.). This effect was enhanced by the excavation of top heading in Chamber I-K1 in case of the cell was in the pillar between I-K1 and I-K2 chambers, but the advance in the bench caused intensive stress relief. It can be a very important note for the pillar size reducing and chamber optimization studies. The calculated response of the I-K2 bench advance provided important information. Both of the cells show significant stress relief (see on Fig.8.). This observation fits to the well-known principle of the mining and tunnel construction practice: if the top heading was supported and stable, then its enlargement downwards does not cause unfavourable geotechnical condition – till a limit which depends on the primary stress field. Both cells pointed out a tectonic element between the 92 and 94 m of the chamber. Previous in situ measuring program have proved also that discontinuities have a great influence on the structure (Kovács & Vásárhelyi, 2009).

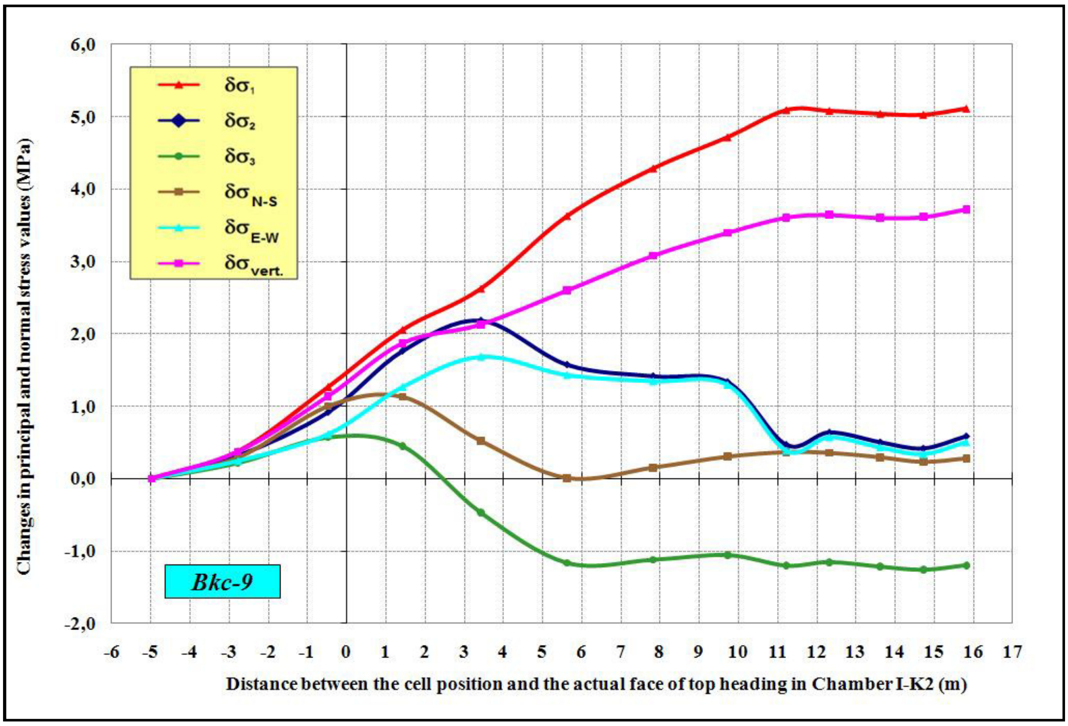

Fig. 7.: Stress changes at Bkc-9 cell as a function of the top heading advance in Chamber I-K2

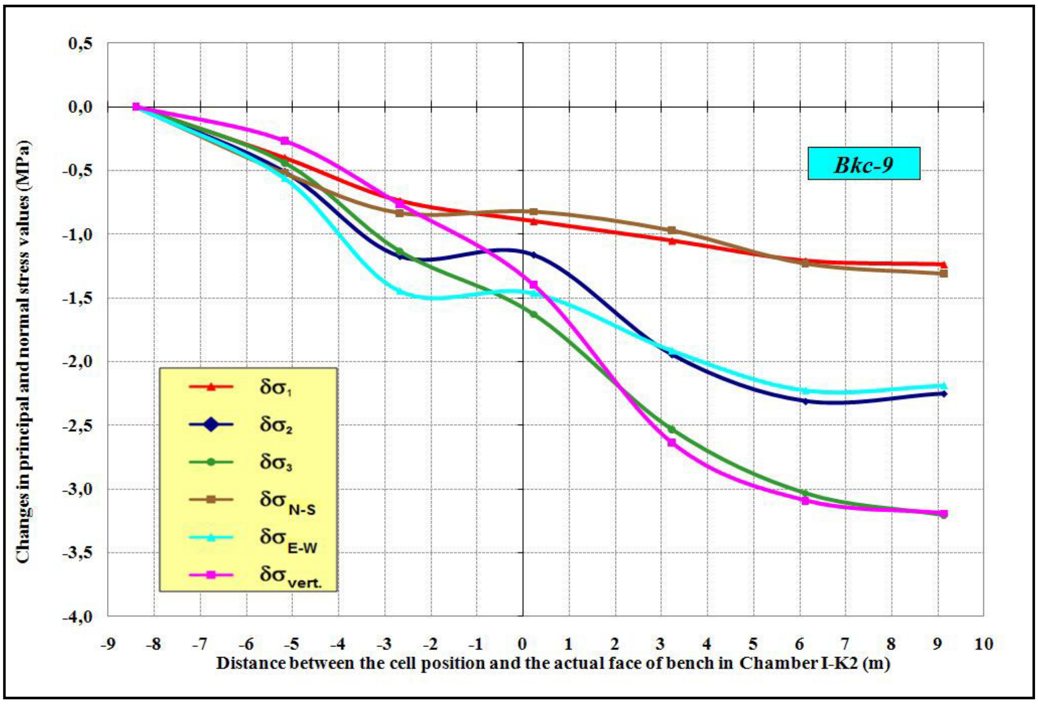

Fig. 8.: Stress changes at Bkc-9 cell as a function of the bench advance in Chamber I-K2

The cells in the centre line of the pillars (Bkc-8, Bkc-12) had similar response to the advance as Bkc-9 and Bkc-11, but naturally neither the top heading nor the bench excavation had such great influence on the cells as much on the ones nearer the wall. At these cells the bench excavation could reduce the stresses just in small rate. Measured increment of stress changes should be considered in pillar-size decreasing studies as it was of higher rate than it had been expected.

CONCLUSION

Stress change measurements help to understand the real rock mechanical condition of the rock mass. Results of the measurements have not shown stress changes neither in short nor in long term which might have implied a static problem. On the basis of this observation the shape, size, support system and excavation technology of the chambers and the size of the pillars suit the primary technological aims. Furthermore, practical data getting from the whole series of the measurement can be utilized directly for optimization of additional chambers and its static design work.

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