Górnictwo i Geoinżynieria • Rok 31 • Zeszyt 3 • 2007

*Eva Hrubešová**, *Zdeněk Kaláb***, *Robert Kořínek**, *Petr Žůrek****

GEOTECHNICAL MONITORING AND MATHEMATICAL MODELLING IN MEDIEVAL MINE JERONÝM (CZECH REPUBLIC)****

1. Characteristics of the locality of interest

Locality of interest of monitoring measurements and mathematical model analyses as presented in this paper, it is the medieval tin mine Jeroným, located in the municipality Čistá (district Sokolov) in the western part of the Czech Republic. Historical mine working is located in the protected natural area Slavkov Forest and it is an unique monument of mining culture since the 16th century. Mine Jeroným is comprised of a complex system of mine galleries and wide openings in a number of levels located above each other, while at present the bottom part of the complex is flooded by water. Presently, two basic parts form the complex of historical openings — Old Mine Workings and Abandoned Mine Workings, which are separated from each other by a number of collapses (caved in rocks) of larger extent and both parts have their own entrances [3, 6].

From the geological perspective, the subject of discussion is massive granite, whose degree of weathering is not sufficiently known. The massive is characterised by numbers of cracks and fissures with different surface characteristics and filling materials, which can form flow channels for sub-surface water.

In the present time, this mining locality is not open for public, but in connection with the assumed utilisation of this part of the mine for the purposes of tourism, work started in 2001 to obtain more objective and concrete idea about the stress-strain and stability state of this shallow mine working.

* Faculty of Civil Engineering, VSB-Technical University of Ostrava, Czech Republic

** Institute of Geonics ASCR, v.v.i., Ostrava, also: Faculty of Civil Engineering, VSB-Technical University of Ostrava, Czech Republic

*** Faculty of Mining and Geology, VSB-Technical University of Ostrava, Czech Republic

**** This research is performed with the financial support of the Grant Agency of Czech Republic GACR No. 105/06/0068

2. Pilot monitoring observation of mine Jeroným

The purpose of present geo-mechanical and seismological monitoring is evaluation of the geo-mechanical stability of the part of the abandoned mine workings, checking of impact of mining activities on historical mining areas and the road above the mine workings, some of which lies at shallow depth under the land surface.

From the aspect of evaluation of stability of mine working Jeroným, geological monitoring is based on carrying out detailed structural-tectonic measurements and observation of movement of blocks in existing fissures. Development of cracks in mine working has been observed at 10 measuring stations by means of plaster and glass targets. Since 2001, quarterly recording of development of changes of convergence profiles in linear (16 measuring stations) and wide openings (5 measuring stations) is being made for checking purpose. Transverse convergence profiles in linear mine openings are measured by convergence props with elastic system and by optical reading the values always for vertical and horizontal direction. Range of measured is from approx. 3.5 m to approx. 11 m. This measurement does not show significant values of convergence, movements of measuring points at the periphery of linear workings are practically zero.

Four stations have been built for the measurement of the height of the mine water. Two points are located above the adit level near ancestral adit Jeroným. The other two points are located almost at the level of the ancestral adit Jeroným. O far, the fluctuation of height of mine water-level does not offer any logical explanation (for example [5]). It is evident that the mine water is being endowed particularly by flows of surface water. It is necessary to watch not only changes but also their dynamics, for detailed study of hydro-geological conditions in the mine workings. Therefore, a probe, based on pressure detector, has been developed for "continuous" measurement of change in water level. There are not enough measurements for detailed study.

Monitoring of seismic loading of working was initiated at stations, where sensors are installed directly in the mine working during the start of reconstruction of the ancestral adit Jeroným in 2004.

Registration apparatus PCM3-EPC3, developed by the employees of ÚGN, has been used in an atmosphere with high air humidity and dripping water. As the primary objective is observation of the influence of vibrations evoked by reconstruction of the ancestral adit, it is sufficient for this purpose to use sensors SM3 with upper limit of frequency 80 Hz (three sensors in geographical arrangement [2]).

It might be summarised for the observed period that so far remarkable manifestation of instability of mine workings has not been detected. Seismic measurements have shown only small seismic loading due to transportation activities above the mine working and weak earthquakes from the nearby area Kraslice.

During the period of reconstruction of ancestral adits it significantly contributed to controlling of blasting works.

3. Mathematical model of the area of interest

3.1. Objective of mathematical modelling, concept of creation of model

Objective of mathematical modelling of mine Jeroným, can be divided into three partial objectives: to verify present stability conditions of the openings, to determine optimum localization for location of monitoring stations and forecasting of the stability development of the openings in connection with the future considered modifications of constructions (change of shape of wide mining spaces, driving of connecting galleries, change of water conditions) and the gradual degradation of rock environment.

For the purpose of effective modelling, it is necessary to divide the entire complicated complex of galleries and caverns into linear and wide openings and to accept certain shape simplification. In the first phase of the model computations, whose partial results are parts of this paper, the creation of the computational model of chamber K2 was considered. Priority of this part of mine complex in the process of modelling is given first of all by the fact, that particularly this chamber is one of the possible places of converging of the planned connecting galleries between old and abandoned workings. This planned construction modification will result to change in stress-strain situation in the existing chamber and it's surroundings.

Results of mathematical modelling should, among others, quantify those changes, determine extent of influence of mentioned constructional changes and evaluate the influence of these stress-strain changes on the stability situation of the area.

The model is developed from the documents prepared by detailed surveying of chamber K2 (Fig. 1), conducted in 2006 by Ing. Trnka.

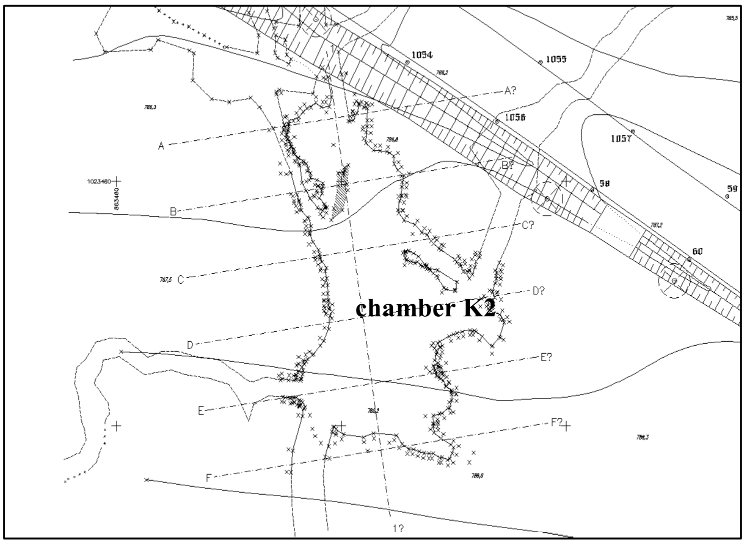

Fig. 1. Plan of chamber K2

As per prepared documentation, the chamber, in the realized section 1–1', has a length of about 30 m and the width and height are greatly varied — height from approx. 2 to 10 m, maximum width about 15 m, height of the massive at the chamber roof varies from approx. 44–51 m, 5 galleries at different heights lead into the chamber.

Methods of mathematical modelling of stress-strain and stability situation in the massive of mine Jeroným are determined first of all by specific geology and hydrology of the area of interest, properties of rock environment influenced by insufficiently known degree of weathering of granite massive, markedly irregular geometry of underground openings and the remnants of earlier productions as well.

Due to the discontinuous characteristics of the massive with a large numbers of cracks and fissures with different surface characteristics and filling materials, the applied numerical methods of modelling of continuum (for example, finite element method) may not often lead to objective results. Higher predictive ability and reliability of results of modelling could have been achieved by application of distinct elements methods (DEM), which was specially developed for modelling of cracked and fissured discontinuous environment (Cundall, 1971) and which was implemented to the programming systems UDEC a 3DEC (ITASCA, USA).

DEM method enables to model real behaviours of mining blocks where discontinuities predominate, while taking into account their geometrical characteristics (direction, density, parallelism, outspread), surface characteristics, fillings and the influence of flow of water through discontinuities. This computational system, however, in comparison to computational systems based on the method of modelling continuum, puts higher demand on the creation of the model alone, quantity and quality of input characteristics of the environment. The computation is very much time consuming, even in the case of plane models. First of all, often the characteristics of discontinuities are not available with sufficient accuracies and reliabilities and mostly are determined only on the basis of more or less accurate professional guess. Application of these non-objective or inaccurate input data of computation in the method DEM, which essentially provides more objective real behaviors of discontinuous environment, may then lead to unreliable results and such results may include higher degree of non-objectivity in the end than in the case of application of the method of modelling of continuous.

From this perspective, the gradual modelling of the problems of chambers of mine Jeroným has been proposed starting from simple concept of plane model based on finite elements method to the more complicated 3D model solved by method of distinct elements.

Simple plane finite element model, with limited possibilities of respecting real discontinuous environment, enables to obtain basic idea about the stress-strain and stability situation in the area of interest and also enables the realisation of parametrical computations. Results of this partial phase of model computations have been presented in this paper.

The subsequent phase of modelling should have been based now on the use of the method of distinct elements with dominant influence of discontinuities. Assumption is to realise 2D as well as 3D discontinuous model by application of programming systems

UDEC a 3DEC. It is necessary to mention, that due to the geometrical complicacies of the whole modelled area, particularly the spatial model will require acceptance of some shape simplifications.

3.2 Model characteristics

The results of the first partial phase of modelling using the programming system Plaxis 2D have been presented in this paper. In all, six transverse sections A-F, as per survey documentation of Ing. Trnka, have been analyzed by modelling (Fig. 2).

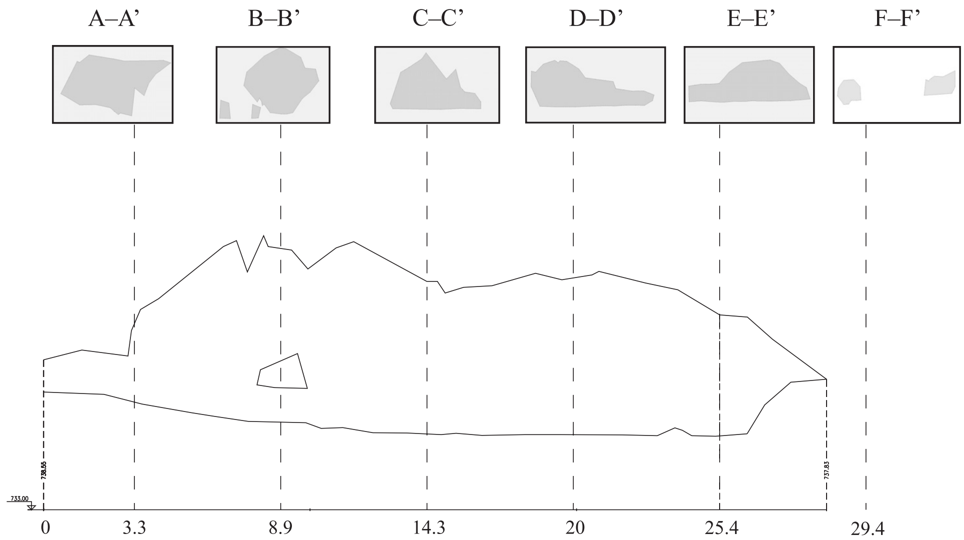

Fig. 2. Longitudinal section of chamber K2 marking the analysed transverse section

Characteristics of materials of rock environment entered into the model are in accordance with the average values of unit weight, strength in uniaxial stress, strength in transverse tensile stress, Young’s module of elasticity and Poisson’s number, which have been determined by laboratory tests by the staff of the Department for Laboratory Research of Geomaterials of the Institute of Geonics, Czech Academy of Science, Ostrava (Tab. 1).

TABELA 1

Table of input material characteristics of the model

Unit weight, kg/m^3	Compressive Strength, MPa	Tensile Strength, MPa	Young’s module, MPa	Poisson’s number
2578	76.2	6.84	19 080	0.28

3.3 Results of the first stage modelling

In each of the five considered sections the movement, stress, relative shear stress and degree of stability have been determined (the method used was method of reduction of strength characteristics “phi-c“ reduction).

Values of maximum total displacements, localized above the roof of chambers, show the values in the range of 0.3–1.7 mm, in relation to the analyzed sections. Stresses are concentrated primarily to the lateral parts of the section, particularly in the transitional zones between the bottom of the chamber and the sidewalls and in the area of other sharp projections (Fig. 3). Degree of stability, determined as a ratio of real shear strength τ a shear strength τ_f, required to prevent failure, shows sufficient high values in the range of 2.4–48 in all analyzed sections and this documents sufficient stability of present situation in all those transverse sections.

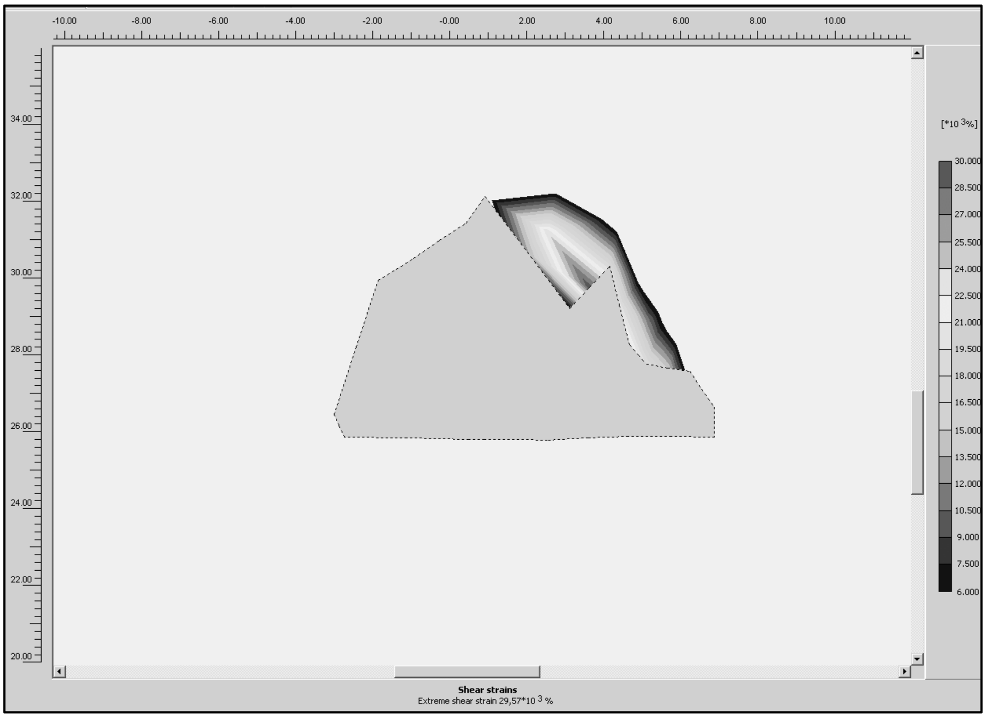

Fig. 3. Stress distribution around the cross-section E–E’

In all sections, there are areas with maximum shear deformation localized in the roof parts of sections and particularly again in the places of sharp projections (Fig. 4). Maximum values of total movements and values of degree of stability for particular sections are shown in table 2.

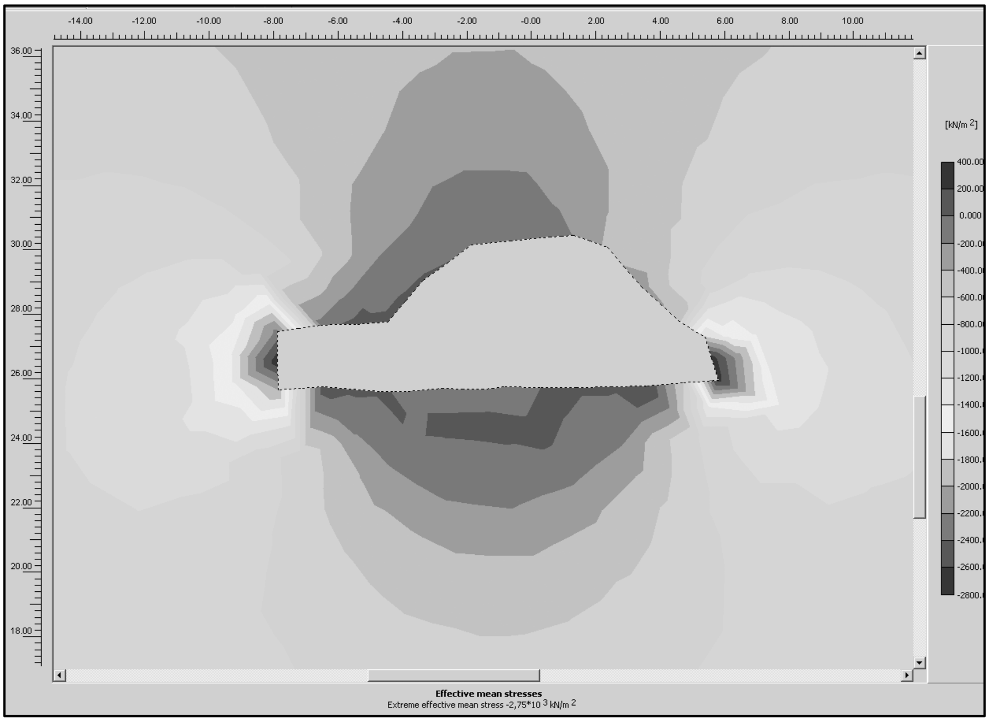

Fig. 4. Shear strain concentration in the overburden of the cross-section C–C'

TABELA 2
Resulting values of maximum displacements and degrees of stability for analyzed sections

Section	Maximum displacement, mm	Degree of Stability *F*
A–A'	0.66	47.7
B–B'	0.58	13.4
C–C'	0.9	2.4
D–D'	1.66	5.78
E–E'	1.44	36.3
F–F'	0.37	45.4

4. Conclusion

Research on stability of historical mine working Jeroným is based on repeated geological and geotechnical measurements, which is being conducted in a quarterly cycle since

2001. Distributed measurement system composes of three-component seismic stations, continuous measurement of change in mine water level (2 points) and movements in two most highly stressed fissures (other types of measurements are being prepared). Results of the first phase of mathematical modelling as well as the results of the geotechnical monitoring document sufficient stability of the present situation of the analyzed chamber K2 of mine Jeroným.

REFERENCES

[1] *Cundall P.A.*: A Computer Model for Simulating Progressive Large Scale Movements in Blocky Rock Systems. In Proceedings of the Symposium of the International Society of Rock Mechanics, Nancy, 1, 1971, II–8

[2] *Kaláb Z., Lednická M.*: Interpretation of Seismic Records of Vlastiny Operations Performed in Gallery Jeronym in Cista. Transactions, Civil Engineering Series, VI, No.2/2006, VŠB — Technical University of Ostrava, 155–160

[3] *Kaláb Z., Knejzlík J., Kořínek R., Žůrek P.*: Cultural Monument Jeroným Mine, Czech Republic — Contribution to the Geomechanical Stability Assessment. Warszawa, Publs. Inst. Geophys. Pol. Acad. Sc., M–29(395), 137–146

[4] *Knejzlík J.*: Distributed Kontrol and Measurement System for Monitoring in the Jeronym Mine in Cista (Czech Republic). Transactions, Civil Engineering Series, VI, No.2/2006, VŠB — Technical University of Ostrava, 181–187

[5] *Lednická M., Kukutsch R.*: Analysis of Mining Water Levels in Medieval Mine Jeronym. Transactions, Civil Engineering Series, 2007 (in print)

[6] *Žůrek P., Kořínek R., Michalčík P., Štěpánková H., Daněk T., Kukutsch R., Kaláb Z., Knejzlík J., Lednická M.*: Global Analyses of Geotechnical Problems in the Jeronym Mine, Period 2004–2005. Journal Coal, Mineral and Geological Survey, Czech Republic, 9, 2005, 31–34