Estimation of general and set steps of roof caving in rock mass with excavations at mining. Numerical modelling.

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Abstract. The results of 2D modelling of rock mass elements fracture are shown in the article. The results of modelling are in a good agreement with empirical and theoretical estimations of roof caving steps for the flat-dipping coal seams when the horizons are not so deep (less than 600 m). The estimations of the general and set steps of roof caving are given for the lava conditions at different lengths of the main roof containing sandstone.

1. Introduction

The modern techniques of mining of mineral resources cause a sufficiently non-equilibrium state of rock mass surrounding the underground openings. That is why it is very important to choose the parameters of support machines in order to provide the safe conditions of work for miners, machines and other equipment.

According to different data, a proved coal reserve is enough for approximately 200 years of mining and makes an essential share in energetic complex of many countries which is going to be equal to gas and oil industry by 2030. However, the negative manifestations of rock pressure at mining decrease an economic effectiveness of mines because of different accidents, such as rock bursts, roof collapses and so on. These accidents cause fracture of prepared excavations, coal headings. Practice of rock pressure management demands an understanding of general features of damage accumulation in elements of rock mass at mining of mineral resources, for example, coal. The knowledge of general and set steps of roof caving is necessary for correct choice of lining parameters.

The modern methods of geomechanical modelling provide an opportunity for investigating the stress-strain state evolution of rock mass at different horizons of underlying coal seams if the structural, elastic, non-elastic and strength characteristics are taken into account. Then the steps of general and set steps of roof caving could be estimated. The amount of geotechnical problems is rather wide. The majority of investigations are dedicated to the estimations of a stress-strain state around the underground tunnels or excavations with analytical [1-3] and numerical [4-7] solutions of the boundary problem. The results of these estimations provide good information about disintegration of rocks around the excavations and/or tunnels due to plastic deformations. To our mind, the most interesting papers concern the temporal mechanical behaviour of rock mass with excavations as soon as it supposes the investigation of stability of development workings, rock mass elements (roof and floor) and the influence of rock pressure manifestation during mining [8-11]. The stability and/or the development of inelastic strains/fracture around the underground openings is usually considered as the boundary problem of the media with tunnel of a circle or other cross-section form subjected to multi-axial loading [6, 7, 12]. The minority of the papers is observed concerning the problems of modelling the damage accumulation at coal face moving in rock mass elements [13-15]. This paper is dedicated

to numerical modelling of non-elastic deformation and the fracture of rock mass elements at coal face moving.

2. Mathematics

The mathematical model includes the fundamental conservation laws of continuum mechanics: conservation of mass, impulse, energy:

$$\frac{d\rho}{dt} + \rho\,div\,\overline{\upsilon} = 0\,,\,\rho\frac{d\upsilon_i}{dt} = \frac{\partial\sigma_{ij}}{\partial x^j} + \rho F_i\,,\frac{dE}{dt} = \frac{1}{\rho}\sigma_{ij}\frac{d\varepsilon_{ij}}{dt}$$

The equation of state (EOS) is taken in the form of isotropic Hooke's law.

$$\dot{\sigma}_{ij} = \lambda\left(\dot{\theta}^T - \dot{\theta}^P\right)\delta_{ij} + 2\mu\left(\dot{\varepsilon}_{ij}^T - \dot{\varepsilon}_{ij}^P\right)$$

The non-elastic deformation of rock mass elements is described within the Drucker-Prager model with a non-associated flow rule.

$$f\left(\sigma_{ij}\right) = \frac{\alpha}{3}I_1 + I_2^{1/2} - Y$$

The components of inelastic strain rates tensor are defined according to the Nikolaevskii plastic potential.

$$\dot{\varepsilon}_{ij}^p = (S_{ij} + \frac{2}{3}\Lambda(Y - \frac{\alpha}{3}I_1)\delta_{ij})\dot{\lambda}$$

The fracture of the rock mass elements is considered within the theory of damages accumulation.

$$D = \int_{t_0}^{t}\frac{(\sigma_{\text{тек}} - \sigma_0)^2 dt}{\sigma_*^2 t_*}\,,\sigma_* = \sigma_{0*}(1 + \mu_\sigma)^n$$

In more details, an applied model is considered in [16].

3. Results and discussion

The geological conditions of coal seams correspond to the flat-dipping formations at different angles. In the investigated case, the depth of the coal horizon is 300 m. In Figure 1, one can see the stratigraphic column. The corresponding physical – mechanical properties of each layer are shown lower.
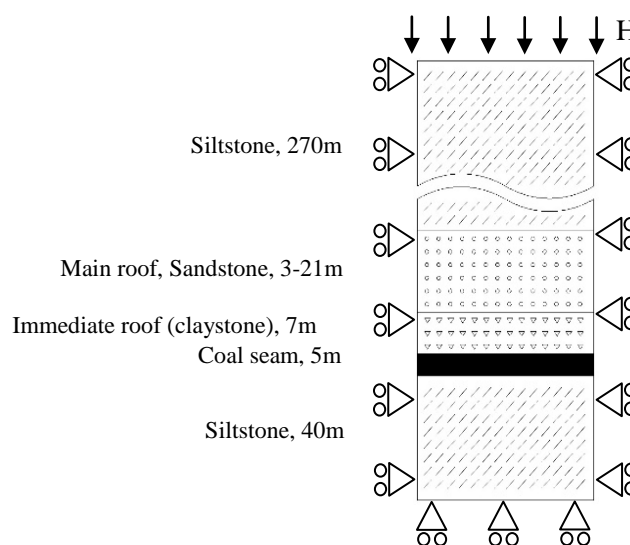

Figure 1. The geologic profile of the mine and the boundary.

The physical-mechanical properties are: ρ – material density, K – bulk modulus, μ – shear modulus, C_0 – initial cohesion, α – coefficient of internal friction, Λ – dilation coefficient.

The parameters of the rock mass layers are as follows:
- Siltstone layer: ρ=2.5g/cm^3, K=9GPa, μ=8.7GPa, C_0=7MPa, α=0.62, Λ=0.22
- Main roof, sandstone layer: ρ=2.2g/cm^3, K=12.8GPa, μ=5.34GPa, C_0=12MPa, α=0.6, Λ=0.12
- Immediate roof, claystone layer: ρ=2.5g/cm^3, K=9GPa, μ=8.7GPa, C_0=6MPa, α=0.62, Λ=0.22
- Coal seam layer: ρ=1.4g/cm^3, K=1.95GPa, μ=0.042GPa, C_0=4MPa, α=0.4, Λ=0.08

Figure 2 shows several patterns of a damage distribution in the main elements of rock mass after the mining process passes the corresponding distances at different heights of main roof. The results of modelling show the correlation between the increase of the main roof length and the increase of the general step of roof caving.
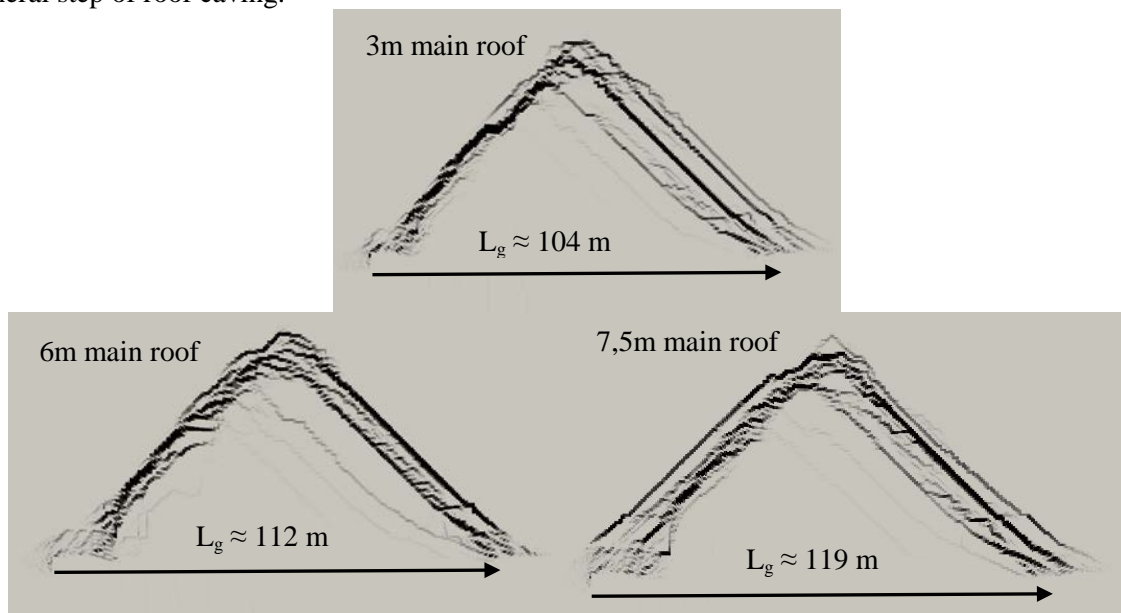

Figure 2. Estimations of the general step lengths for different lengths of the main roof.

In Figure 3 the comparison of the numerical simulation data along with the empirical data and the finite element modelling data is represented. It shows a good agreement.
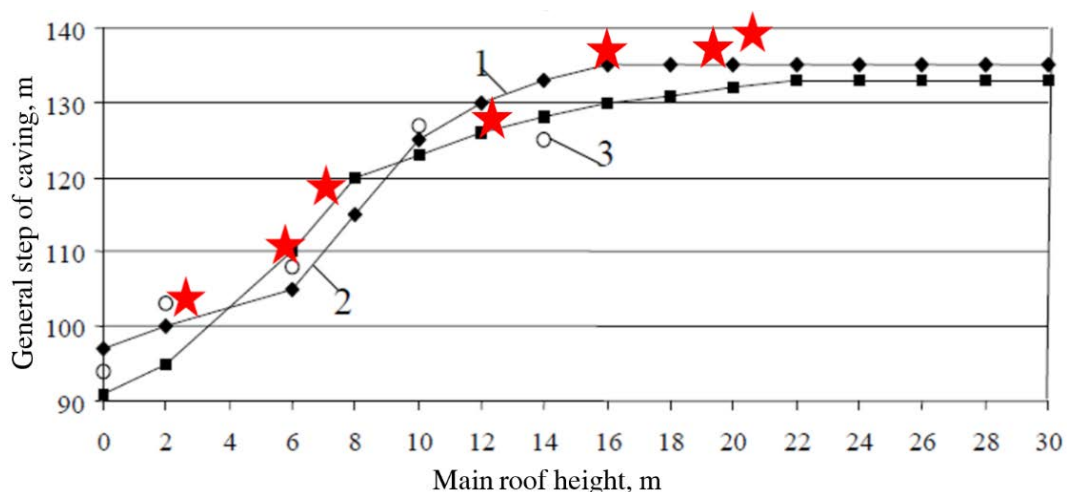

Figure 3. The dependence of the step of general caving on the length of the main roof, the obtained numerical modelling data are represented with red stars, other data are taken from [17].

As an example of testing calculation in 3D, one can see the distribution of inelastic strains accumulated in the roof and the floor of rock mass with excavation (Figure 4). The generalized

structural model of rock mass was taken for 3D case. The roof and the floor have the same physical-mechanical properties as those mentioned above. The width of excavation between the airway and a conveyer way is 120m, the horizon of coal seam is 450m, and the direction of excavation is along the Z-axis.
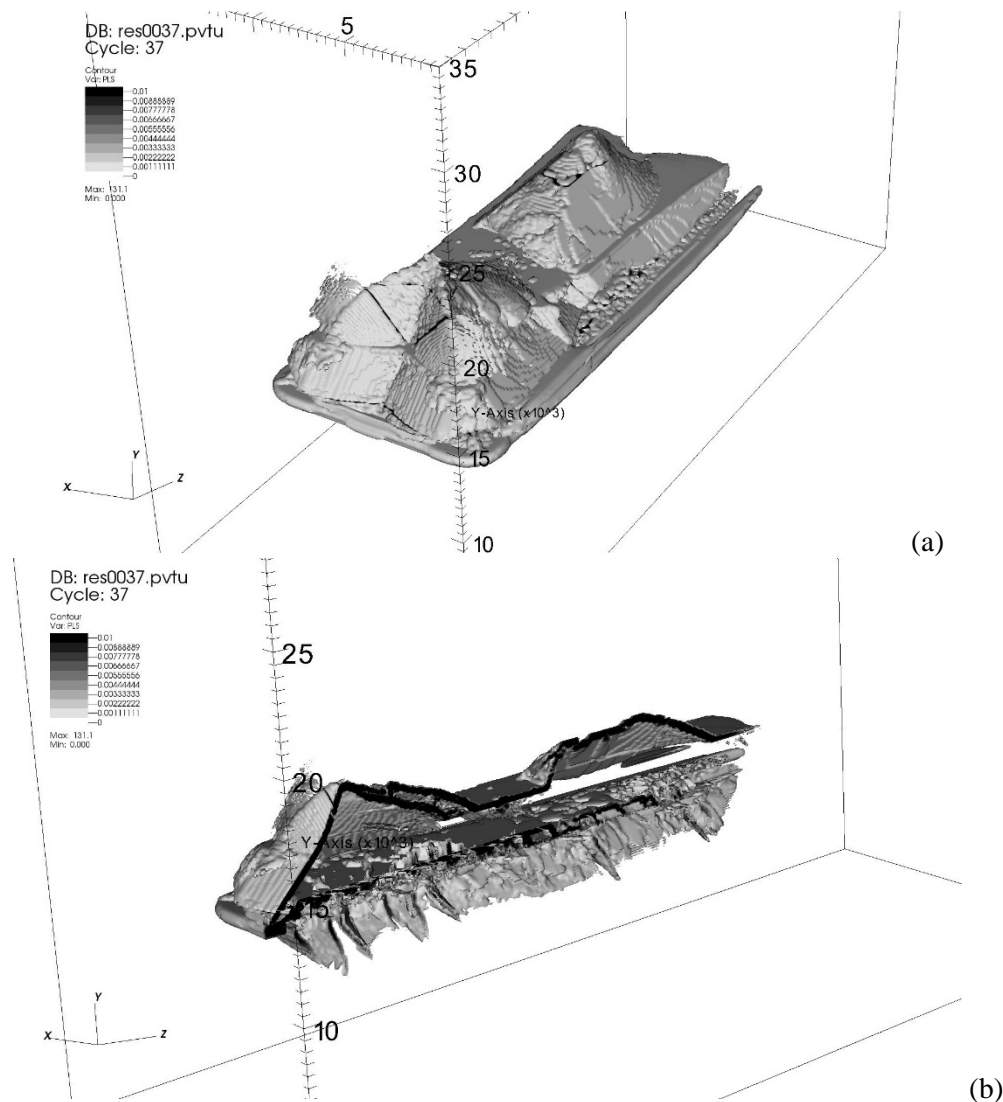

(a)

(b)

Figure 4. The distribution of accumulated inelastic strains in the rock mass elements in 3D modelling (a), a central cross-section (b).

4. Conclusions

The results of 2D and 3D modelling of damage accumulation in the rock mass elements are represented in the paper. The estimations of the initial (general) and set steps of roof caving are obtained. It is shown that the general and set steps of roof caving obtained in numerical modelling compared to the empirical estimations give the misfit error of about 10%. As the following investigations the developed model of rock mass will be generalized for the 3D case and a different angle of flat-dipping seams will be taken into account in order to estimate the dependency of the general and set steps of roof caving on the angle and depth horizon.

5. Acknowledgements

References
[1]   Chanyshev A I and Abdulin I M 2014 *Journal of Mining Science* **50** 18-24
[2]   Lu Y and Yang W 2013 *Journal of Central South University* **20** 1397-1404
[3]   Demin V F, Nemova N A Demina T V 2015 *Journal of Siberian Federal University. Engineering & Technologies* **1** 74-97
[4]   Roatesi S 2010 *Proceedings of the Romanian academy, Series A* **11** 11-18
[5]   Kiya O E and Hosseinitoudeshki V 2015 *WALIA Journal* **31** 172-174
[6]   Yang H Q, Zeng Y Y, Lan Y F and Zhou X P 2014 *International Journal of Rock Mechanics & Mining Sciences* **69** 59-66
[7]   Pardoen B, Collin F, Levasseur S and Charlier R 2012 *ALERT Workshop*
[8]   Pavlova L D and Fryanov V N 2004 *Izvestiya Tomskogo Politechnicheskogo Universiteta* **307** 76-79
[9]   Shabanimashcool M 2012 Ph. D. thesis, Norwegian University of Science and Technology
[10]   Nuric A, Nuric S, Kricak L, Lapandic I and Husagic R 2012 *Engineering and Technology* **6** 316-324
[11]   Khoshboresh A R 2013 University LAVAL, Canada 155
[12]   Zhu W C, Liu J, Tang C A, Zhao X D and Brady B H 2005 *Tunneling and Underground Technology* **20** 231-247
[13]   Verma A K and Deb D 2013 *International Journal of Geomechanics* **13** 181-192
[14]   Wang G, Wang H Y, Huang Q M and Su C Q 2014 *Computer Modelling & New Technologies* **18** 26-32
[15]   Kwasniewski M 2008 Continuum and Distinct Element Numerical Modelling in Geo-Engineering, Paper: 07-08 1-12
[16]   Makarov P V, Eremin M O and Kostandov Yu A 2014 *Physical mesomechanics* **17** 199-203
[17]   Hozyaikina N V 2012 *National Rock University, Dnepropetrovsk, Ukraine* 126