Calculation of principal stresses and their directions in selected cutting planes in rock drilling

***František Krepelka*[1], *Lucia Ivaničová*[1], *Milan Labaš*[1] *and* *Jozef Futó*[2]**

The paper is focused on the analysis of principal stress fields induced in the system of drilling tool-rock during the drilling process in immediate surroundings of their mutual contact. Various load conditions were analyzed, representing torque, loading only by axial thrust force and combined loading by concurrent action of torque and thrust force on the drilled rock.

***Key words**: principal stress, core-drilling bit, rock, FEM.*

Introduction

The main purpose of presented calculation is to find the size and direction of principal stresses in selected cutting planes of drilled rock while using the core-drilling bit with 8-cutting segments. Stresses have been determined in cutting planes C-D and C-E crossing the axis of symmetry of a core drilling bit as illustrated in Fig. 1. The Figure 1 shows selected area of drilled rock in a shape of a cylinder of diameter 2x63,25 mm and height 40 mm. Due to a multiple symmetry of the body, a circular segment was selected as a computational model depicted in the Fig. 1. Presented dimensions of the model were determined based on previous calculations so that the stress conditions were not significantly affected in the area of immediate contact of tool and the rock (Krúpa, Pinka, 1998; Vašek, Krúpa, Pinka, 1999). The stresses were determined in concurrent action of torque M_k = 5,5 Nm and axial thrust force F_p = 55 00 N.

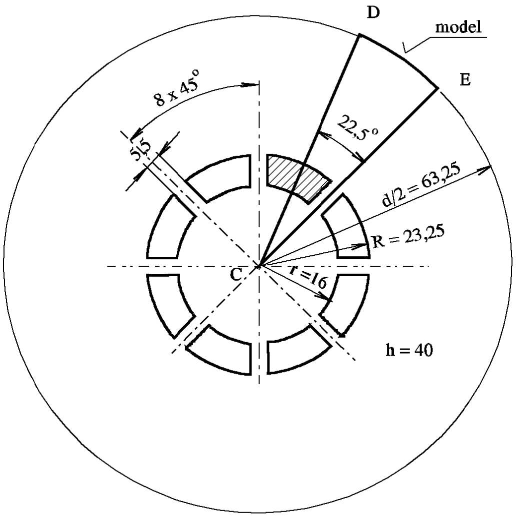

Fig. 1. Computational model.

Calculations were performed using the software COSMOS/M, version 2.95. (Ivančo, Kubín, Kostolný, 2000). Computational model contained 24346 body elements of TETRA4 type and 5099 nodes. Isotropous material of drilled rock with following material characteristics was considered in the calculations: Young's modulus of elasticity $E = 7{,}7.10^4$ MPa, Poisson's ratio $\mu = 0{,}21$.

---

[1] *Ing. František Krepelka, CSc., Ing. Lucia Ivaničová, PhD., Ing. Milan Labaš, PhD.,* Institute of Geotechnics, Slovak Academy of Sciences, Watsonova 45, 043 53 Košice, Slovak Republic, krepelka@saske.sk

[2] *Ing. Jozef Futó, PhD.,* Institute of Control and Informatization of Production Processes, Faculty of Mining, Ecology, Process control and Geotechnologies, Technical University of Košice, Boženy Němcovej 3, 043 84 Košice, Slovak Republic

Calculations were performed in two basic load conditions responding to individual loads, i.e. to torque (load condition LC1) and to axial thrust force (load condition LC2).

The first load condition LC1

The first load condition considers the action of torque M_k = 5,5 Nm, which induces tangential pressure p_t

$$p_t = \frac{M_k}{8 \cdot \int_r^R \left(\pi / 4 - 2 \cdot arcsin \frac{h}{2 \cdot \rho} \right) \cdot \rho^2 \cdot d\rho} \qquad (1)$$

Where h – height of sample (mm), ρ – friction angle (°). For torque M_k = 5,5 Nm the tangential pressure equals to p_t = 4,79822 MPa.

Geometric boundary conditions are presented in the Fig. 2. Conditions of antisymmetry were defined in the lateral cutting planes the tangential direction of cylindrical coordinate system. Zero displacements in tangential direction were defined as well.

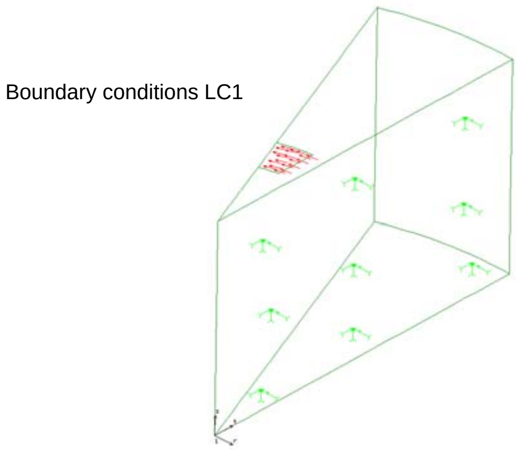

Fig. 2. Boundary conditions for the first load condition LC1.

The second load condition LC2

The second load condition LC2 regards the action of axial thrust force F_p, which induces normal pressure p_n

$$p_n = \frac{F_p}{8 \cdot \int_r^R \left(\pi / 4 - 2 \cdot arcsin \frac{h}{2 \cdot \rho} \right) \cdot \rho \ \cdot d\rho} \qquad (2)$$

For thrust force F_p = 55 00 N, the normal pressure equals to p_n = 4,79822 MPa. Geometric boundary conditions are presented in the Fig. 3. Conditions of symmetry were defined in the lateral cutting planes the tangential direction of cylindrical coordinate system and in the bottom base of the model; the zero displacements for the z-direction out of the cylinder coordinate system were defined.

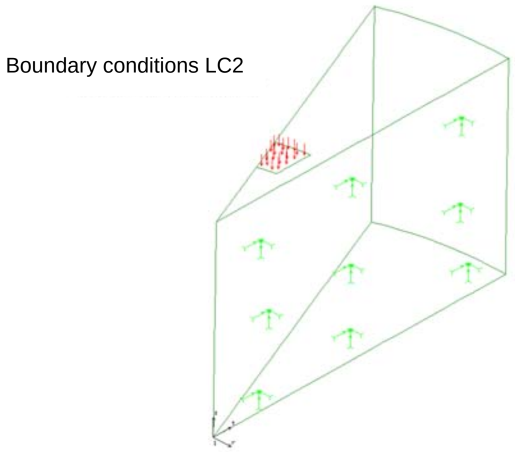

Fig. 3. Boundary conditions for the second load condition LC2.

Resulting stress state

Resulting stress responding to concurrent action of both torque and thrust force is given by a linear combination of the above-presented basic conditions using the scheme

$$LC51 = 1*LC1 + 1*LC2 \quad (3)$$

Following figures 4a, 4b, 4c and 5a, 5b, 5c show the vector-depicted directions of principal stresses distinguished with various colours according to their intensity, while acting in the planes C-D and C-E.

Figures 6 and 7 illustrate the behaviour of axial pressures induced on the upper edge of the planes C-D and C-E.

Cutting plane C-D

Cutting plane C-E

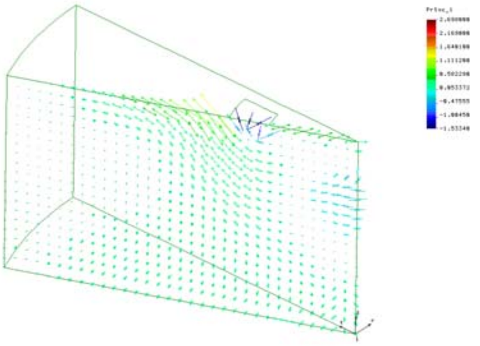

Fig. 4a. Principal stress σ_1 in plane C-D.

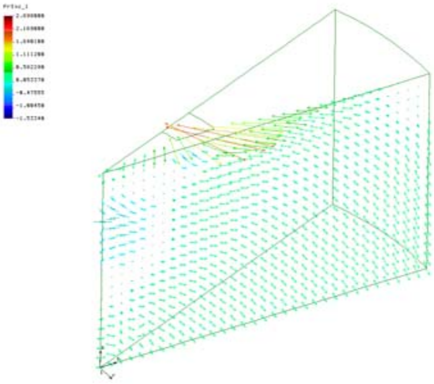

Fig. 5a. Principal stress σ_1 in plane C-E.

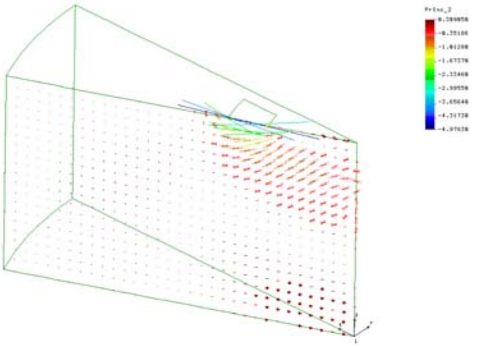

Fig. 4b. Principal stress σ_2 in plane C-D.

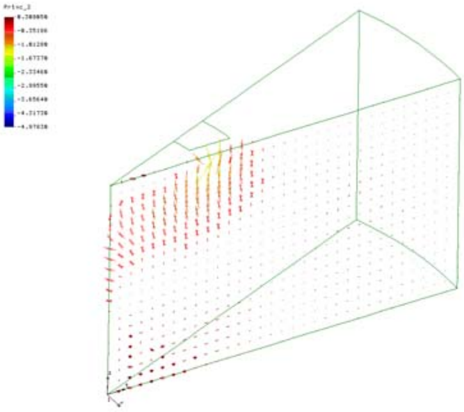

Fig. 5b. Principal stress σ_2 in plane C-E.

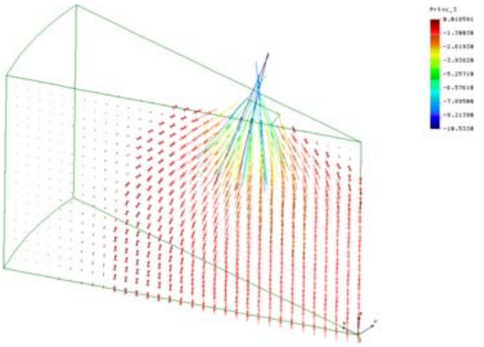

Fig. 4c. Principal stress σ_3 in plane C-D.

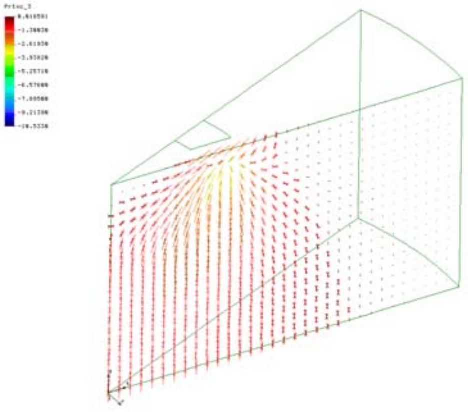

Fig. 5c. Principal stress σ_3 in plane C-E.

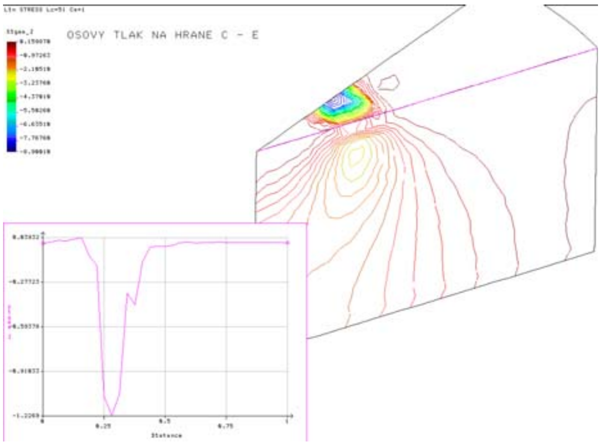

Fig. 6. Behaviour of axial pressures σ_z on upper edge of the C-E plane.

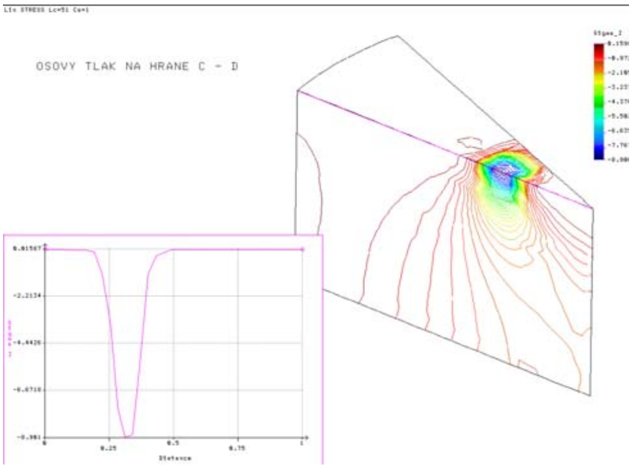

Fig. 7. Behaviour of axial pressures σ_z on upper edge of the C-D plane.

Conclusion

Manual computations in the past did not provide the detailed analyses, only the extended computer analyses enable to analyse the required. In manual analyses, the inputs had to be simplified in much more substantial extent than in computer analyses, which use real input data measured during the experiments. Analyses of stress state in drilled rock in immediate surroundings of acting core-drilling bit brought following findings:

1. Loading of drilled rock by torque M_k was simulated using the tangential pressure p_t acting on contact area.
2. Loading of rock by thrust force F_p was simulated using the normal pressure p_n acting on contact area.
3. Resulting stress condition was given by a linear combination of both load conditions and was determined for starting phase of the rock drilling process. Behaviour of stress fields was presented in the Figures 4-7.
4. Figures 6 and 7 illustrated axial pressures on the upper edge of cutting planes in the drilling direction.
5. Rock cutting is performed by a combination of torque and thrust force.

The main purpose of the research was to explain the mechanism of rock disintegration under the drilling bit. Common theories of rock cutting/disintegration mechanism suppose that the rock is subjected to direct cutting by segments of the drilling bit. Our research assumes that small rock particles are spalled due to combined action of thrust force and torque. Both theories were verified in the research, resulting in confirmation, than in case of hard rocks, the mechanism is closer to the spalling. This confirmed the use of vibration monitoring in rock drilling. Also, the forces acting under the drilling but segments have to be examined, whether the loading occurs due to thrust or torque forces, i.e. which of compressive or tensile or shear forces apply in the process. Further analyses have to be performed for explicit definition of rock failure mechanism in core-drilling of rocks, with eventual application on disc cutting of rocks.

Acknowledgement: This contribution is the result of the project implementation "Research Excellence Centre on Earth Sources Extraction and Treatment" within the Activity 1.2 Identification of mechanical properties of raw materials, supported by the Research & Development Operational Programme funded by the ERDF.

References

Ivančo, V., Kubín, K., Kostolný, F.: Program COSMOS/M. *Elfa, Košice, 2000. ISBN 80-88964-49-0.*

Krúpa, V., Pinka, J.: Rozpojovanie hornín, *1.vyd., Vydavateľstvo Štroffek, Košice, 1998. 205 p. (eds.) F.Sekula & J.Bejda. ISBN 80-88896-10-X.*

Vašek, J., Krúpa, V., Pinka, J. Rozpojiteľnosť uhlia a hornín reznými nástrojmi, *1.vyd. Vydavateľstvo Štroffek, Košice, 1999. 92 p. (eds.) J.Bejda & F.Krepelka. ISBN 80-88896-29-0.*