Plastic Flow Modeling in Rock Fracture

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Borehole methods and methods of mining using combines and ploughs will be widely used in Karaganda (Kazakhstan) in lavas and short faces. Therefore, special requirements are applied to the modelling of rock destruction processes. The results should show the possibilities of improving the strength of the tool, as well as the processes that occur under pressure on the rock. The specifics of solids fracturing by a tool are described. These processes are accompanied by the formation of a plastic wedge and a thin, curved body between surfaces of a cleaved element and destructed rock. The surfaces of dislodged elements have alternating rough and smooth areas. Such zones are formed by low-frequency acoustic radiation, which can be observed during fracturing of rock cores by a punch and optically active, organic glass with a controlled speed of crack motion. The fracturing direction is predicted along paths of principal stresses and can have poorly predictable areas in zones of isoclines convergence leading to the intersection of surfaces. The element models that extend the capabilities of research, taking into account a plastic flow of rock and drilling tool for boreholes, were developed. In these studies, there can be taken into account various factors: the structure of the rocks in the face and the scheme of their collapse behind the face, the depth of the work. This is especially important for lavas and short faces. The use of 2-3 research methods (destruction of rock samples and other solid materials, studying stress-strain state (SSS) by optical and finite element modelling) is a prerequisite for obtaining accurate results.

Key words: *plastic wedge, focusing, thin body, crack path, finite element, optical modelling*

Introduction

As the analysis of mining technologies shows, the borehole methods for hydrocarbon development will be widely used in the development of oil, gas and coal fields. The depreciation of drilling bits sharply reduces the effectiveness and increases the length of drilling due to the need to extract the whole drilling assembly from the depths of up to 3000 m. So the special requirements are imposed on modelling of rock fracture by a tool (Pinka et al., 2007; Bujok et al., 2013; Ġofranko et al., 2014; Flegner et al., 2016; Wittenberger et al., 2015; Wittenberger et al., 2017). Rocks are plastically deformed under pressure of tools during drilling, but this process has not been explored. In the process of fracture of equivalent materials with tools of different forms, the best conditions for observing the plastic zones appeared for rolling tools and cylindrical punches.

For rocks near the faces (mudstones, siltstones, sandstones) and partly coal beds D6 and K12 of the Karaganda coal basin, these processes are similar. In new technologies for the development of coal seams, degassing wells are to be drilled from the earth surface, as well as from mine workings. The use of tunnelling combines with power capacity will be 2-3 times greater than now. Technologies of coal mining by short faces and angular conveyors will gain development. On thin layers of "Kazakhstanskaya", "Tentekskaya" mines there will continue introducing plough lavas. In this case, the rock pressure and the depth of the work will affect the processes of destruction of rocks and coal. Mining pressure also depends on the patterns of rock formation and the features of their collapse behind the lava. The layers of rocks hang over the face, collapse or smoothly drop on the collapsed pieces of rock and the length of layers depends on the pressure on the layer where there works a combine or a drill.

Modelling such schemes is possible on the basis of finite element technologies, and such models are used here (Ansys). Their general principles in the transition to details are presented in (Grzejda, 2014; Dodagoudar et al., 2015; Witek et al., 2016; Ğazuka et al., 2016) where for the accuracy of the results, the methods of constructing the grid, especially for contact problems are important (Grzejda, 2014). In (Hosseini, 2014) the use of these methods to the technical schemes of excavation is presented. Typically, there is carried out the interaction of CAD/CAM/CAE systems. In Ansys, we often solve static problems, and in Adams, we first determine the possible dynamic component that is then used in Ansys. However, even licensed software tools

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have errors, and especially in accurate studies, so additional techniques are needed. They are often used in models where there are used the fragments of the general technological scheme that makes it possible to clarify the processes that are not visible on the general scheme. In them, there are also can be used finite element modelling. For example, considering the interaction of tools and rocks with a highly deformed zone where special requirements are imposed on the construction of the grid. There can be effectively and quickly carried out the study based on optical modelling (organic glass of SD type), as well as in the destruction of rock samples, organic glass and other solid materials. The use of SD makes it possible to visually observe the process of plastic deformation and the development of cracks. In this work, we are more interested in the plastic flow that is clearly visible for the main rocks of the Karaganda coal seams.

Material and Methods

The use of methods (Yang et al., 2017) which discuss the energy principles of loading the face of lava layers of the roof is more complicated. Our schemes are different and require forming for each individual scheme of new conditions and new solutions, and this leads to large formulas. A universal solution of the plane problem given in also provides for finite element modelling. However, we build models in 3D and take into account various schemes of rock collapse down to the earth surface. This makes it possible to determine the nature of rock loading at the tool, affects the force and the direction of failure. This data can then be used to model individual fragments.

At optical model operation geometrical and power scale was kept (Eq.1; Eq.2):

$$\mu_g = L_n/L_m \qquad (1)$$

$$\mu_f = F_n/F_m \qquad (2)$$

where: L_n, L_m ï the sizes in nature and model, F_n, F_m ï forces in nature and model.

Scale for the relation (ɽ dʒ/ɽ dʑ) can be chosen randomly (ɽ dʒɖ ɽ dʑ- elastic modulus of model and nature). Scale of stress (Eq.3) (Borissov, 2005):

$$\mu_{ů} = \mu_f \, . \mu_g^2 \qquad (3)$$

The traditional formula for modelling stress multiplying the geometric by the square of the power scale (Trumbachev et al., 1962).

The plastic layer was modelled and as a viscous liquid. Material characteristics are in Table 1.

Tab. 1. Characteristics of materials.

	Materials	Elastic modulus, ɽ [ʄ pʘ]			Poissonôs ratio
Optical model operation	**Organic glass - block polystyrene**	ɽ = 2,700*10^4	Density, p = 1050, kg.m^{-3}	Breaking point: ů$_{ʦ}$= 42 ʄ PʘSoftening point: ʊfŋ= 100ᵌ	0, 35
Rock failure	**Aleurolite**	9,5*10^4			0,43
	Soapstone	6,5*10^4			0,47
	Sandstone	2,2*10^4			0,24
Finite element method	**Tool**	2*10^5			0,25
	Rock	0,18*10^4			0,35
	Plastic layer (viscous liquid)	1,6*10^3			0,45

In numerical modelling, in order to predict and to transfer the data to new schemes, it is necessary to determine the modulus of deformation (elasticity) and other characteristics of materials. However, the use of cores does not always give accurate results since after extraction from wells they are not in real conditions (Koneļný et al., 2015; Chalupa et al., 2017). Therefore, methods based on the comparison of static and dynamic elastic parameters can be used. In the study, there is used elastic velocity propagation of longitudinal and transverse waves performed in various conditions including reservoirs (Fei et al., 2016). There is also used the technology of analysis of T-matrices, and as a result, the system approach of the studies will be provided, the effects of separate factors having a sensitive impact on the process are considered. Knowing the modules makes it possible to achieve a sufficient correspondence between the results of the calculations and the data obtained from the measurements in the mines.

The above references permit to increase the accuracy of modelling taking into account porosity, damages and cracks in the rocks that leads to reducing the modules that were not previously taken into account. For example, when calculating stresses in a strongly deformed zone, the elastic moduli (Young moduli) and the Poisson coefficients vary with the tool, and their relationships are refined in the indicated sources. Moreover, the reliability of the model was tested on limestone samples from a core of a borehole (Chalupa, 2017).

When carrying out the studies, there were considered the elastic modulus (deformation) and Poisson coefficients for the conditions of the Karaganda mines. In the transition to theoretical prediction taking into account porosity and cracks in the material, the values of the modules, respectively, with the above references are reduced (Beissembayev, 2010). This is also permissible when calculating the rock pressure on the bed at the face and with the tool of the executive organs of combines, ploughs and drilling machines in the zone of plastic deformation.

The solution by the finite elements method (FEM) is made by compiling the equations of equilibrium of the model nodes. They are based on the matrix rigidity equations for the elements (Eq.4):

$$[K]_e \{U\}_e = \{F\}_e + \{P\}_e^q + \{P\}_e^g \tag{4}$$

Where: $[K]_e$ is the matrix of the model rigidity; $\{U\}_e$ is the vector of the nodal displacements; $\{F\}_e$ is the vector of the nodal forces; $\{P\}e^q + \{P\}_e^g$ is the vector of mass and surface forces.

Then there is compiled the general system of equations for the entire model (Eq.5):

$$[K]\{U\} = \{F\} + \{P\}^q + \{P\}^g \tag{5}$$

The vector of the stated external nodal forces. $F_i = \{F_i\}$ ï is the submatrix of the n_i force components applied at the node *i*.

$$?? = \begin{Bmatrix} ?1 \\ \vdots \\ ?? \\ \vdots \\ ?? \end{Bmatrix} = \begin{Bmatrix} ?1 \\ \cdots \\ ?? \\ \cdots \\ ?? \end{Bmatrix}$$

Results and Discussion

Research in optically active materials

When a cutter or punch is moving in rock, a thickened zone appears in the central zone or in front of them. It is less thickened at the outer edges of the contact zone, as the material behind it is displaced into a less dense zone. The central zone is narrowed, and the material compressed by the punch forms a plastic wedge (a cone for cylindrical punch), the material of which is thickened. This zone is sometimes called as the core. This is proved both by modelling in optically active materials when the wedge is visible, and by experimental fracture of rocks and coals by a tool (Khesin et al., 1969; Vasilyev, 1976). However, the wedge formation during coal cutting was not further explored, although, in the (Ĝazuka et al., 2016) by-step calculation of nonlinearly decreasing angle of the wedge thinning point, the experimental equations actually representing the beginning of a process similar to self-focusing shown in (Askaryan, 1973) were obtained.

In particular, G. Askaryan considered cavitation in rotating blades during operation of pumping units, which significantly damaged them. Gas in bubbles collapses during cavitations, and a cumulative jet with the pressure of more than 1000 MPa at the temperature up to 10000ęC is formed. The process is accompanied by thickening of particles in a narrowing jet when energy breaking the particles into smaller ones is reached. The resistance of the medium is characterised by jet slowdown and the formation of a typical wedge. The especially stressed zone will appear in the wedge edge where the maximum mechanical stress occurs. Along the axis, the wedge in the area of its sharp edge is stretched out and thickened, and the apex angle is close to zero, and, respectively, stresses sharply rise theoretically approaching to singularity what is known even from the classical task of the wedge elasticity theory. The process is non-linear and called as the wedge thinning. These processes are described as wave processes, but they are associated with the interaction of particles with the medium. So, for the acoustic self-focusing during cavitation, such particles are gas molecules; however, in accordance with (Askaryan, 1973), one can also calculate the material fracture energy.

The angle of the wedge point thinning increases during fracture of rocks with a non-linear increase in stresses in the experiment and a quite thin zone with properties different from that of the massif plastic wedge material is formed at the edge, (Fig.1, Fig.2), (Beisembayev, 2010; Khesin et al., 1969). Following the results of the destructed zone opening, the shape and properties of the material of the thin area at the wedge edge at the fracture moment are close to the state of fluidity. At the same time, it is well known that the fracture of rocks is accompanied by low-frequency radiation recorded by acoustic systems (Beisembayev et al., 2011; Bombizov, 2014; Borissov, 2005).

The pulses of a similar type are also recorded in the mines at the centres of fracture that, in particular, is used to predict areas of sudden coal and gas releases or earthquakes, since low-frequency radiation with a characteristic long wave easily penetrates through the layers of rock. It is also common to the process of cavitation.

To clarify the characteristics of such zones, fracture of a model made of optically active material with a trapezoidal hole was additionally done. It simulates production in underground. Organic glass is chosen as it is homogeneous, and it is easier to observe the laws of fracture in it. This gave an opportunity to find the characteristic features in an ideal environment, and then examine them in rocks. A goal was set to get a crack going from an upper angle. A modelling method with crack deceleration was used. A model of rock made of the optically active material was gradually loaded by metal platforms across the whole surface. They were approaching by screws through special springs where elastic deformation energy was accumulating, (Fig. 1).

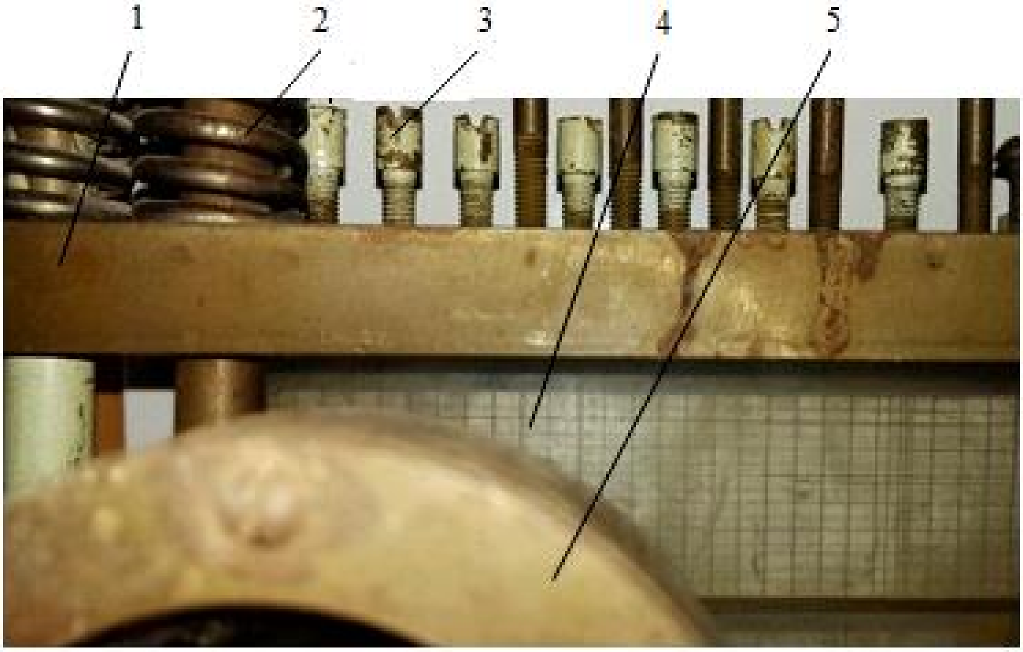

Fig. 1. Stand elements: 1 - platform; 2 - springs with screws; 3 - low-pitch screws; 4 - optically active model; 5 - polarizer.

The load on the surface in the contact zone of the upper layer and the platform was transferred by low-pitch screws through balls in holes.

So, the even load on the layer was put. After reaching the load for the model material close to the limit, gradual unloading of the low-pitch screw located above the working angle was done. This allowed making transfers of the stress-strain state (SSS) in a small area of the layer with a sharply reduced gradient of a stress change in the unloading area. As a result, the stress ratio necessary to begin fracture was reached, and the crack growth speed was reduced. At the same time, a cyclic glow was fixed in the crack area in the low light conditions, and the periodic switch-on of polarisation devices allowed measuring the changing picture of the stresses.

Research in the rock samples

The formation of a plastic wedge and fluid body is scrutinised in more detail for cases of fracturing rock cores loaded by punches when cleaving of a part of the material is possible (Fig.2). At the time of cleaving, a thin petal as a half disc is formed from the plastic wedge (cone) edge, which can be treated as an analogue of a cumulative jet during cavitation. As an extension of the wedge zone (core), it follows the shape of the cleaved element surface at the initial moment of its formation and is a thin body curved in the space between adjacent surfaces of the cleaved element and the surface of fracture on the core. Its shape reminds a fluid body thinning while moving away from the main core and ñfrozenò as a result of a sharp drop in pressure at the moment of separation of the cleaved material. The structure of the body and surfaces that it separates are different, and the petals are therefore easily separated from it, while the body and the plastic wedge (cone) are clearly different in shape.

In contrast to the conditions (Vasilyev, 1976; Askaryan, 1973; Beisembayev et al., 2011), petals are formed in a confined space of the rock capable to completely split along its curved surface. The incurvation of the fracture surface of the wedge and thin body is determined by vectors of stresses active in the body under the punch load given the area of its proximity to the core. The structure of such material is capable to ñfreezeò when removing pressure reminds famous in physics particles orderly shifted from each other under pressure that acquired an unstable (flowing) state. If the pressure is removed during fracturing, the residual linkages in particles return them to a stable ópackagedô state. However, one more possible explanation is that the petals structure quickly formed due to non-linear rise in stresses at every point of a petal as a result of the wedge narrowing without significant movement of the material in the zone. In this case, each petal part is formed of the same material, which was in that zone before thinning. In each case, the material in this zone will have different properties: a coefficient of elasticity goes sharply down, and a Poissonôs ratio goes up approaching a liquid value.

When studying the zone, the plastic wedge (cone) with petals is easily separated from the rock core, and the petal tips may fall and have notches due to their thinning. A clear wedge zone with growing petals can be achieved during rock fracture by a punch with a diameter of up to 10 mm and rock cores with a diameter of up to 50 - 60 mm, since, in such a case, the foundation of the wedge-shaped core has the same dimensions and is visually easily observable, it is also easily separated with a petal using the ordinary tweezers.

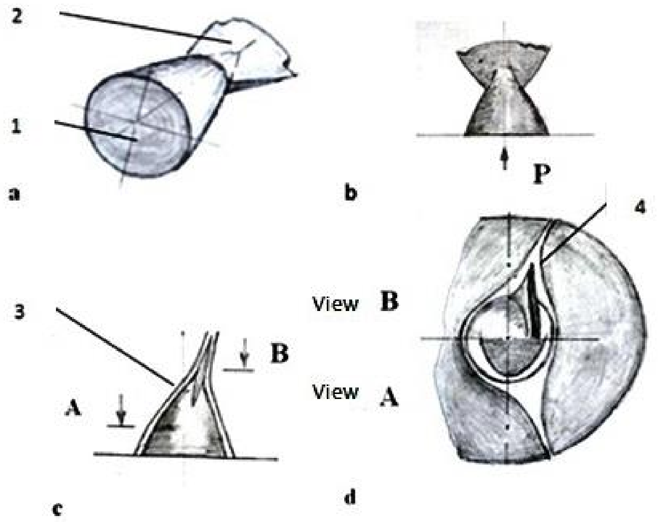

Fig. 2. Formation of ña thin fluid bodyò in a plastic core: Ө) formation of thin structures in a wedge-shaped core zone ; b) view from above with a symmetric sample split; ҧ) curved side view of a wedge during separation of a cleaved part from a core; d) view from above in arrows ɸ and Ɉ. 1 ï plastic wedge; 2 ï thin fluid body; 3,4 ï contours of separation surfaces; ɿ ï load direction.

The petals appear before a destructive crack separating the cleaved rock part, and the pressure in a petal is normally directed to its surface. The process of fracturing is therefore represented as follows: at a certain moment, the pressure reaches a value when a crack from stretching possibly appears on the petal contour as the massif on each side of the petals is stretched in opposite directions. The fact of cut and stretching during rock fracturing by cutters is well known, but the reasons for the first type of fracturing and formation of extensions were not previously set (Khesin et al., 1969). This is likely due to the experimental material (coal) chosen for fracturing which has a lot of cracks (Vasilyev, 1976).

That is why, the intensive chaotic cracking and brittle fracture of the material happened when the load was applied that did not allow to notice the classic petals, although the focusing process is theoretically described (a sharp increase in stresses in the zone of thinning) (Fig.2). The rock is more monolithic that allowed a clear recording of all stages of the process.

Fracture surfaces and modelling by the finite element method

The surfaces stretchable along the petals are broken in the joining point forming a corrugated surface of type 2 or 6 in Figure 3. In terms of the special features of surfaces, the fracture, in some cases, could be of such types as shift - sliding and separation (Khesin et al., 1969; Vasilyev, 1976). It is assumed that shifting surfaces are smooth 1, 3, while separating surfaces are rough 2, 4. They are interleaved in the fractured samples made of optically active material.

The reason for that is that the pressure formed by the petal surfaces creates another compression zone and another plastic wedge area, in which the secondary focusing is done. Then, it all repeats. It is difficult to fix the secondary petals in the rock due to the smaller size of the wedge zone and material crumbling. However, during fracture of the models made of optically active material, they are identified by fine dust partly found on smooth surfaces, as well as by the view of the surface itself, a perfectly smooth, and the fact of their alternation while remoting from the tool. For example, they are repeated in 2-3 sections in Figure 3a.

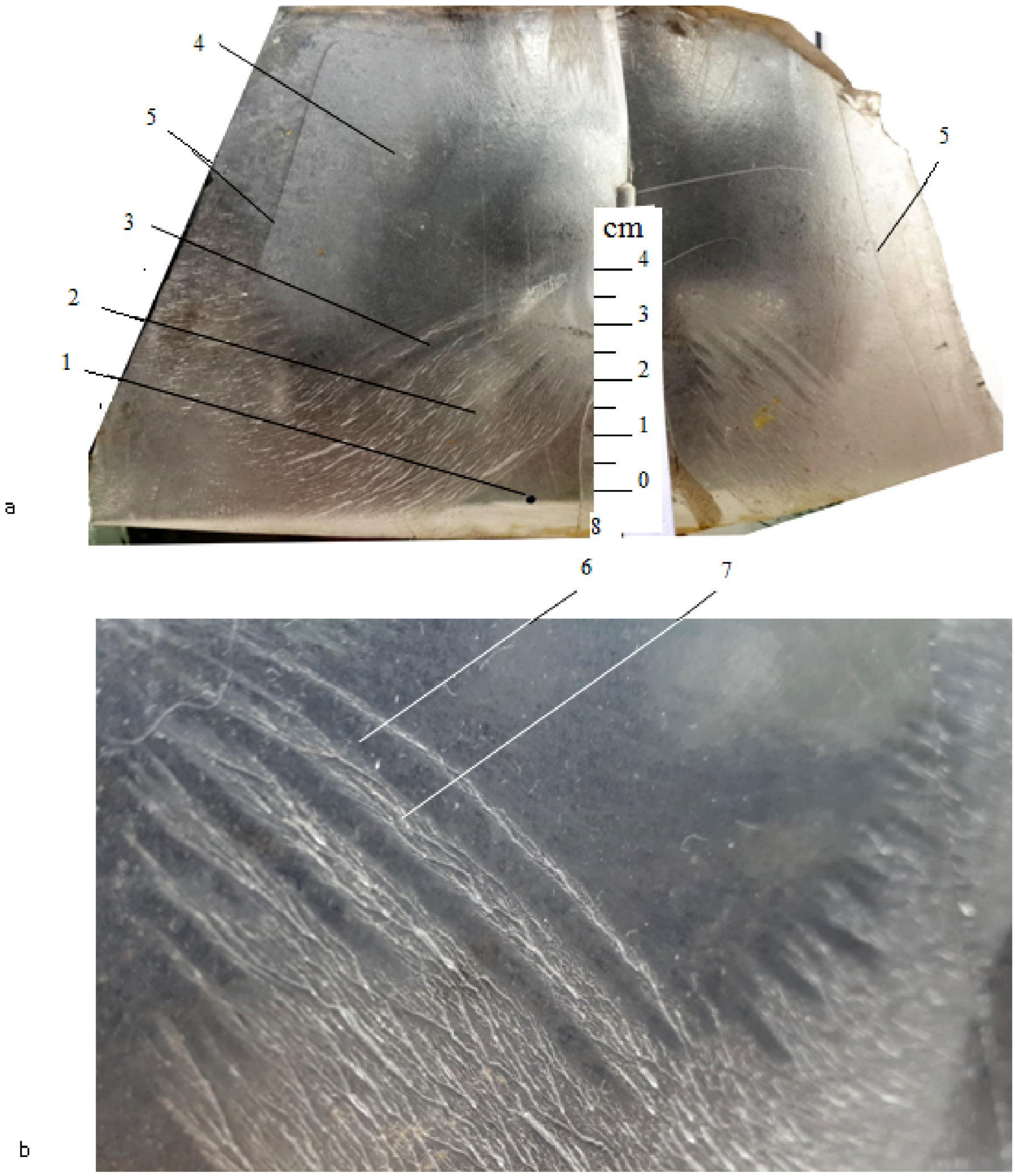

Fig. 3. Surfaces of separation of a cleaved element (organic glass of SD type): a) general view: 1,2,3,4 - alternation of macro smoothed and rough surfaces; 5 - natural line dividing surfaces repeating a contour of a cleaved element; b) increased left side of a cleaved element: 6 - micro smoothed surface; 7- rough surface; 8 - zone of even pressure for model fracture.

We call these repeating pictures as macro fracturing, where the area of one section is comparable with the area of a sample (surfaces 1-4). Micro-fracturing covers the processes inside one line of a section, as shown in 7, for example. The rough macro surfaces 2 (Fig. 3a) are formed from a variety of other surfaces having areas being smaller in tens of times, but there are also smaller macro formations of type 7 consisting of grooves reminding fractals, as well as smooth formations 6. Fracture of the optical material blocks (cross-linked polystyrene SD-3) was chosen because, in the beginning, one could identify their SSS under the load applied that made it possible to predict the paths of fracturing by isostatics (Beissembayev, 2010).

The proximity to the isostatics paths was confirmed by comparison with the real path during fracture of rocks, a block of coal and cement and optical material. The evidence of matching paths with isostatics is confirmed by the creation of artificial conditions of fracture altering the paths, for example, by additional baring of a sample, holes, etc. Analysing the features of the cleaved surface, it could be assumed that lines 5 appear in the zone of ñspecial pointsò, where the isoclines meet as the isostatics paths close to them abruptly change their direction, for which 5 are formed. This line fully repeats the contour of the separated element and is located at a distance of ~ 10 mm from all borders of the cleaved element outlining the separation border throughout the cleaved element. The surface finishing the fracture on line 5 is above the initial one by ~ 1 mm.

The location of special points is shown for two interacting tools set with pacet, (two between the tools symmetrically to 0ڲ- 0ڲaxis, and one on the left side on the bottom sample border, the free surface of the explored model, where a crack usually goes to) (Fig. 4a).

The isoclines with the parameters specified in degrees converge at these points. The left special point, out of the two between the tools, is located in the area of sharply curving isostatics, while the right one describes the isoclines. Though the isostatics at the special point between the tools sharply go to the opposite sides, the crack, as the fracturing shows, is located between the tools since the energy consumption rate here is much lower.

For a majority of lateral paths to the left of the tool going under the slope to the bottom surface slightly above the special point, the difference in energy consumption is small, but the distance to the free surface is much shorter, and the crack therefore abruptly changes its direction going to the near plane of the sample that is in the intersection of the fracture surfaces and defines the line 5 (Fig.3a).

The special points are well observed during the study of optically active thin samples (the task is close to plane). It is rather difficult to observe in the conditions of the general volumetric layout due to the ñdispersal through thicknessò, and the computational modelling based on the finite element method does not always help. However, as in the small sample, these points should be distributed near the cleaved element separation borders, as evidenced by the location of line 5.

To clarify the peculiarities of rock fracture in Ansys package, the modelling of 3D fracture process using a tool with cone-type, trihedral or tetrahedral sharpening was held. Two or one tools were installed into the prepared holes in a rectangular block. The tool was installed close to one of the free surfaces of the block so that it could be possible to cut an element from it. So, the conditions used for optically active models were repeated, and a plastic zone of the tools was modelled with its shape following the shape of the tool and the volume being chosen on the basis of stresses on the core surface equal to a limit value. The linear and non-linear solutions were reviewed.

In the second case, Solid 92 volumetric finite elements and CONTA - type contact elements were applied (Grzejda, 2014). They were introduced after the construction of an extremely fine grid in a contact zone and ensured sliding of the tool with a preset friction coefficient (0,05-0,3). The hard-pliant contact task was resolved: target-hard, contact-pliant surface choosing a tool surface for a target surface and a rock surface for a contact surface, since the deformation of the tool made of carbon steel was less than the rock deformation.

The stress analysis shows that there are two peaks of surge **ů**$_x$: the first is at the joint point of the tool with rock, the second is at some distance, though it could be either with the plastic zone or without it, (Fig. 4b). So, the cracks can form in at least two zones. The curves show the need for grid correction, for example, by comparison with data obtained on optically active samples. So, peaks **ů**ڲ in Figure 4b must be identical, while the grid symmetrical and smaller than in the example given. The curves in Figure 4c were obtained with high accuracy by optical modelling, and can also serve as a sample for grid optimisation. The grid model can be used afterwards for other forecasts as well. It was confirmed that crack paths are not stable and easily change their direction when the direction of load application is changed, and in particular, they depend on compliance with the modelling accuracy. So, the grid distortion by Ansys processor, that is adequate with load deviation from symmetry, can cause an abrupt change of ñcrack pathsò.

This is especially evident in plane modelling or thin destructible block (organic glass SD3), (Fig. 5). At the same time, the rule applies to both modelling and direct fracture of samples. Please note that the processes of plastic wedge formation in organic glass are visually easily observable. The whole area is crossed by a grid of mutually orthogonal ñslip linesò (Beissembayev, 2010).

The zone of plastic deformation is considered as conventionally liquid, (Fig. 6); the mechanical parameters are given in Table 1. When the tool moves, it expands until the ultimate stress for the core destroying is reached. When being destroyed, the core is divided into two parts, (Fig.7a). On the surface of core 3 in zone 4, according to the optical and finite element modelling data, there is a zone of increased tensile stresses. The rock does not withstand even a small stretch and therefore there is a crack that moves to the tool. Two lateral cracks move from the tool.

When there is destroyed plexiglas, the initial crack on the surface is not formed, and one part breaks from the block, (Fig.3).

Figure 7b shows the picture of lateral crack 2. It has been obtained by breaking a block of coal and cement imitating the formation. Its trajectory closely coincides with the isostatic curve of the principal stresses for optical models.

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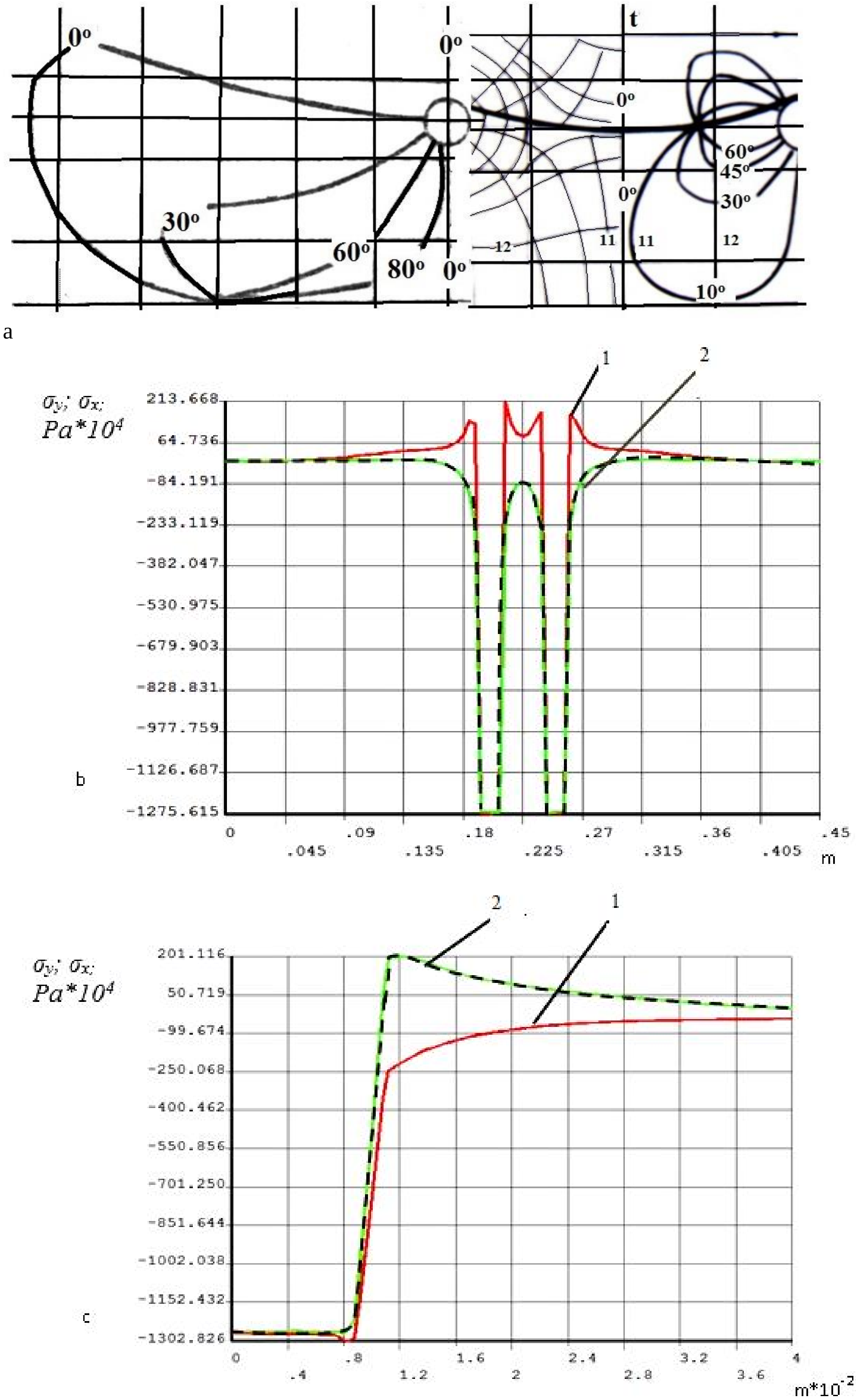

Fig. 4. Screenshot, the effect of two tools on a rock: Θ) field of isostatics and isoclines; stress ů - 1 and ů - 2 along the line between tools (b) and along a line from tool centre down to the surface (ŋ).

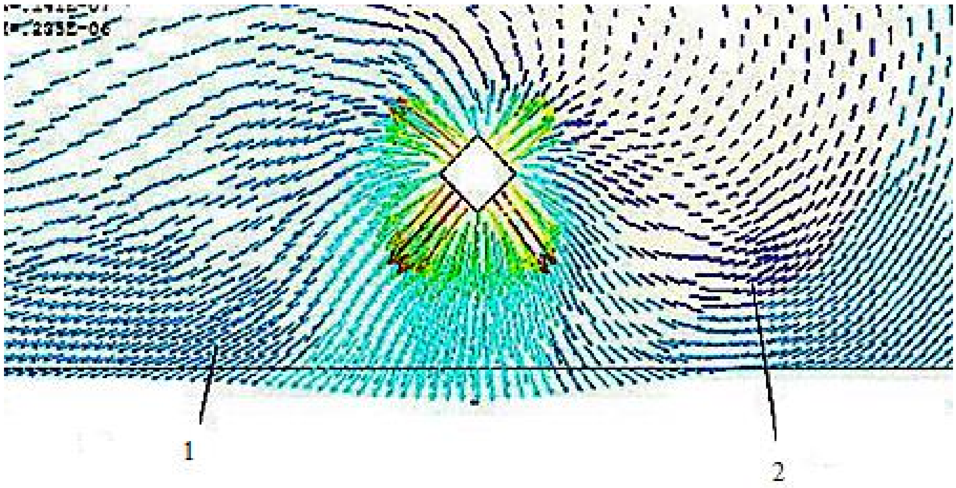

Fig. 5. Screenshot: paths of principal stresses: 1- isoclines convergence zone (optical modelling); 2 ï artificial distortion zone.

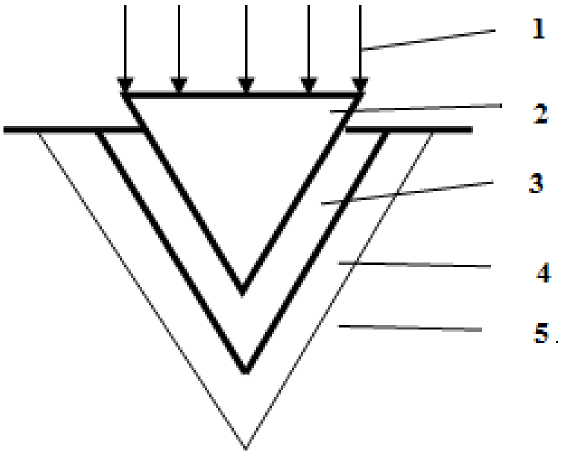

Fig. 6. Model diagram: 1- pressure; 2- tool; 3, 4 - positions of the plastic zone; 5 ï core.

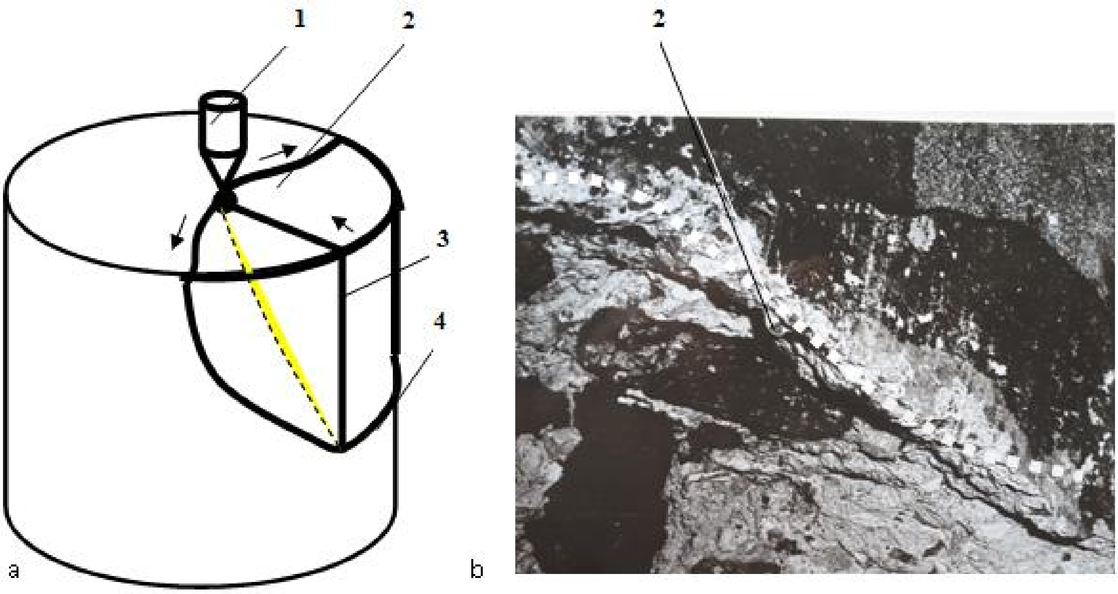

Fig. 7. Features of the crack trajectories: Ɵ- in the core; 1- tool; 2 ï lateral crack; 3 - initial crack on the surface; 4 ï core; b ï for the block of coal and cement.

Conclusions

Destruction in rocks is accompanied by low-frequency radiation detected by acoustic systems. In recent years they have been widely developed and permit to predict these processes in the subsoil. For example, they are necessary to identify the destruction of rocks over lavas in order to refine the design scheme for predicting the maximum pressure on the face. The load from the hanging layers is determined by the length and height of the layers in the worked space behind the lava. Moreover, accordingly by the load from them, one can judge the possibility of destruction that must be confirmed by detecting radiation. The obtained facts make it possible to obtain visual confirmation of these factors, to reveal the mechanism of destruction that in the future will permit to clarify both the energy of the processes and the working conditions of the tool. It is also important to predict the direction of the cracks development.

The experiments displayed good relevance between the forecast for isostatics and real results. At the same time, there are methodologies that allow building a path step by step, i.e. first a small section is built, then the next section gave the changed SSS, etc. (Beisembayev et al., 2011). The authors proceed from the fact that the appearance of a crack zone radically changes SSS. However, the methodology stemming from the initial SSS is confirmed in practice. Moreover, the loading put on massif reveals violations and consolidates a path by the creation of microzones that have reached the limit state providing a predictable path. These factors may be more important. It is necessary to take into account the time of crack growth as well: whether it is able to exert a fatal effect on dislocation so that it changes its path.

So, the analysis shows the validity of the two seemingly opposite approaches to the prediction of a crack path. The first approach is applicable for environments with high speed of crack growth, while the second for the disturbed environment. Please note that with a stepwise path building, one should proceed from identification of a new SSS at each step, within which the same isostatics hypothesis can be applied.

It can be assumed that the effects of cavitation with the formation of a cumulative jet and mechanical fracturing of solid rocks are grounded in the principles of focusing, which in addition to general patterns have own characteristics defined by specifics of environments of micro and macro levels, in which they occur. So, the studies helped clarify the mechanism of cyclic rock fracture that allows clarifying the calculation of energetic of a fracturing process and explain the mechanisms of its identification. Some of its provisions can be applied in modelling, as well as choosing a drilling tool for holes and analysing the processes of bottom rock fracture.

Some provisions of the studies can be applied in the methodology of modelling and analysing mining equipment structural destruction processes, as well as in selecting drilling tools for making wells.

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References

Askaryan, G. (1973) Self-focusing effect. *UFN 111, Russia, pp. 249-260.*

Beissembayev, K. (2010) Specifics of tool fracture and general patterns of crack formation in rock massif, Topical issues of today's world. *International Scientific Journal, ed. (56): Bolashak-Baspa Publishing House, Karaganda, Kazakhstan, pp. 11-16.*

Beisembayev, K., Akhmetova, Zh., Aidarkhanov, A., Demin, V., Zhetessov, S., Nokina, Zh., Shmanov, M. (2011) Problems of systemogenesis of changes in form of bottom rocks of oil and gas deposits. *Mining Information-Analytical Bulletin (Scientific-Technical Journal), No.7, Mountain Book Publishing House, Moscow, Russia, pp. 20-26.*

Bombizov, A. (2014)Method for spectral-time analysis of electromagnetic radiation of rocks for detection of signs of geodynamic developments. *Journal Reports of Tomsk State University of Control Systems and Radio, ed. 1 (31), Russia, pp. 69-73.*

Borissov, V. (2005) Some patterns of fracture of rock samples by electromagnetic radiation recording. *GIAB. No.8, pp. 106-113.*

Bujok, P., Klempa, M., Porzer, M., Pavlus, J., Skupien, P. (2013) Determination of rock samples characteristics from the exploration perspective of the natural gas from unconventional types of deposits. *DOI:10.5593/SGEM2013/BA1.V2/S06.001, pp. 945 ï 950.*

Bujok, P., Porzer, M., Labus, K., Klempa, M., Pavluġ, J. (2013) Experimental modelling of abandoned shallow oil wells convergence. *Engineering geology, vol. 157, pp. 1-7.*

Chalupa, F., Vilhelm, J., Petruġálek. M., Bukovská., Z (2017) Determination of static moduli in fractured rocks by T-matrix model. *Acta Montanistica Slovaca. vol. 22, no. 1, pp.22-31.*

Dodagoudar G. R., Rao B. N., Sunitha N. V. (2015) A meshfree method for beams on elastic foundation. *International Journal of Geotechnical Engineering, vol. 9, pp. 298-306.*

Fei W., Huiyuan B., Jun Y., Yonghao Z. (2016) Correlation of Dynamic and Static Elastic Parameters of Rock, *Electronic Journal of Geotechnical Engineering, vol. 21.*

Flegner, P., Kaļur, J., Durdán, M., Laciak, M., Stehlíková, B., Pástor, M. (2016) Significant damages of core diamond bits in the process of rocks drilling. *In: Engineering Failure Analysis. vol. 59, pp. 354ï365.*

Grzejda, R. (2014) FE-modelling of a contact layer between elements joined in preloaded bolted connections for the operational CONDITION. *Science and Technology Research Journal, Res. J., vol. 8, no. 24, pp. 19ï23.*

Hosseini, N., Goshtasbi, K., Oraee-Mirzamani, B., Gholinejad M. (2014) Calculation of periodic roof weighting interval in longwall mining using finite element method, *Arabian Journal of Geosciences, vol. 7(5), pp. 1951-1956.*

Khesin, G., Babenkov, N., Ivanov, K. (1969) Stress distribution in drilling tool and rock, *TSNITEIugol Publishing House, Moscow, Russia.*

Koneļný, P., Lednická, M., Souļek, K., Staġ, L., Kubina, L., Gribovszki, K. (2015) Determination of dynamic Youngôs modulus of vulnerable speleothems, *Acta Montanistica Slovaca, vol. 20, no. 2.*

Ŀazuka, E., Ŀazuka, M. (2016) Application of ansys in teaching fem on the example of a loaded mars rover chassis. *Advances in Science and Technology Research Journal, Res. J., vol. 10, no. 32, pp. 269ï274.*

Pinka, J., Wittenberger, G., Engel, J. (2007) *Borehole mining, Koġice, Slovakia.*

Ġofranko, M., Ġkvareková, E., Wittenberger, G. (2014) Working fluids used for drilling deep boreholes. *Applied Mechanics and Materials, vol. 508, pp. 150-155.*

Trumbachev V.F., Molodtsova L.S. (1962)Methods of studying stresses in volumetric models by photoelasticity as applied to problems of rock pressure. // Sat. physical and mechanical properties, pressure and rock destruction. M: Publishing house of the Academy of Sciences of the USSR, 234 p

Vasilyev, L. (1976) Study of cleavage of a chip single element in rock cutting, *Nauka (Science) Publishing House, Novosibirsk, Russia, pp. 41-46.*

Yang, Y.X., Chang You Liu, Bin Yu (2017) The interaction between face support and surrounding rock and its rib weakening mechanism in hard coal seam. *Acta Montanistica Slovaca, vol. 22, no. 1, pp. 67-78*

Witek, M., Prusek, S. (2016) Numerical calculations of shield support stress based on laboratory test results, *Computers and Geotechnics, vol. 72, no. 2, pp. 74-88.*

Wittenberger, G., Ġofranko, M. (2015) Formation and protection against incrustation on the geothermal pipe by utilizing of geothermal water in the area of ńurkov (Eastern Slovakia). *Acta Montanistica Slovaca, vol. 20, no. 1, pp. 10-15.*

Wittenberger, G., Ġofranko, M., Végsöová, O. (2017) New deep - Well boring technologies of rock disintegration. *SGEM, vol. 17, no. 14, pp. 749-756.*