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RESEARCH OF POSSIBLE ZONES OF INELASTIC DEFORMATION OF ROCK MASS

Abstract. In the given work the sizes of conditional zones of inelastic deformations near mine excavations are determined at the combined development of the "Akzhal" deposit. Numerical analysis was carried out by the method of boundary integral equations with a stepwise loading of the rock mass. Modeling of geomechanical processes was carried out by an elastoplastic model of deformation. The refinement of physical and mechanical properties of rocks was carried out with the help of RocLab. In preparing the initial data for numerical analysis, the main strength index of rock mass was the geological index of strength GSI. When specifying the strength parameters, a transition is established from the strength of the sample to the strength of the rock mass. The research was carried out with the mine excavations at a depth of 100 to 500 m with a lateral pressure coefficient of 0.6 to 1. The dependence of the sizes and shapes of the possible zones of inelastic deformation around the mine excavations on the coefficient of lateral pressure and the depth of the excavations was established. Based on the results obtained, it is possible to assess the geomechanical state of the contour part of the rock mass, and also take into account the choice of types and parameters of fastening of mine excavations.
Keywords: zones of inelastic deformations, geological index of strength, strength criteria, numerical analysis, joint condition, coefficient of lateral pressure, mine excavations.

Introduction. The technogenic impact on the untouched rock mass leads to a change in the stress-strain state of rocks in the contour part of the mass. More preferable in justifying the stability parameters of mine excavations are numerical methods of investigation, which allow a lot of possible initial data to be taken into account.

Numerical simulation allows to quickly analyze the geomechanical state of the mass due to instantaneous interpretation of the change in the stress-strain state of the rock mass and the visualization. The advantageous aspect of numerical simulation is the creation of an identical geomechanical model of the investigated area with maximum allowance for the mining-geological and mining-technical conditions of the deposit.

The task of the research work is to determine the size of the given zones of inelastic deformations (fracture zones) near the mine excavations in the conditions of the "Akzhal" deposit.

Materials and methods. When assessing the stability of mine excavations, it is very important to choose the correct model for the behavior of the contour part of the rock mass. First of all, it must take into account the possibility of non-linear deformation of rocks near the mine excavations and the possibility of developing a zone of destruction in area [1].

To determine the possible zones of rock destruction (zones of inelastic deformations) around the mine excavations, a method of step-by-step loading by the method of boundary integral equations was adopted, which is implemented using the Hi-Fi application program developed at the Karaganda State Technical University.

Hi-Fi programs allow to take into account a wide variety of forms and sections of preparatory and cleaning excavations, the influence of a number of located excavations for the development of an effective method of supporting workings and developments of steeply falling ore bodies, joint condition of rock mass, which is an important factor for the correct determination of the fracture zone. In addition, the calculation program is easily adapted to various mining and geological conditions [2].

The task of modeling is to determine the coordinates of the joint contour, based on information on the stress-strain state of the mass. In this case, the vertical section of the mass with a notch is considered, the geometry of which was determined by typical sections of the production. The contour is represented by a polygon. The geometry of this polygon is given by the coordinates of the nodes (vertices of the polygon). Since the entire region outside the output contour is an infinite number of points, and a numerical analysis of the stress state at all points is impossible, in our case we confine ourselves to considering a finite number of points (n) located in a strictly defined order. All the investigated points are located on the rays (m) emerging from the middle of the sections at a fixed distance from each other on the ray (figure 1).

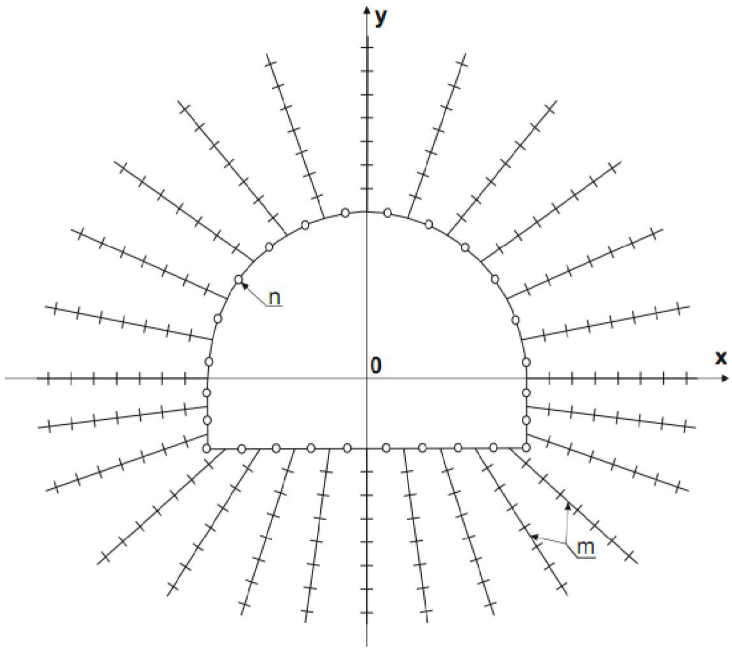


Figure 1 – Scheme of the location of the scanning beams

Carrying out the mine excavations violates the natural state of the rock mass, which leads to additional loading of the mass. This additional loading is divided into a number of stages. At each stage of loading, there is a stress-strain state of an elastic mass with a variable internal boundary (an elastoplastic problem is solved). At the first stage, this boundary is the output contour. At the second stage - the contour of the fracture zone that occurs during the first stage, etc. In this case, at each stage of loading on the internal circuit of the voltage the values are preserved, achieved at the previous stage of loading. It is assumed that the rock mass that fall into the fracture zone during further loading do not exert a resistance to deformation of the elastic part of the mass. Thus, at each loading stage, additional elastic displacements on the inner boundary of the elastic part of the mass take place without resistance, same as for a non-reinforced contour. At the same time, the deformations of this contour accumulated at previous stages remain unchanged [3].

Numerical analysis does not limit the number of destruction criteria, therefore, the shearing (Mohr-Coulomb) and discontinuous (the largest deformation stretching) criterion are used simultaneously.

The contours of the fracture zone are determined by the following equation [4]:

$$r_n = R_0\left(1+\frac{p-K}{nK}\right)^{\frac{n}{2}}, \quad (1)$$

where R_0 – radius (width) of excavation; $p=\gamma H$ – voltage acting in an untouched mass; K – maximum tangential stresses, n – number of stages of loading.

One of the main difficulties in the numerical simulation of geomechanical problems is the absence of initial data - parameters of the mechanical behavior of the rock mass.

The use of certain patterns of behavior of the rock mass, available in modern numerical analysis programs, becomes difficult or practically impossible if there is no reliable initial data for the parameters of the adopted (chosen) model.

The initial data for the calculation includes the geometric characteristics and mining-geological conditions of the mine excavations, the strength properties of the rock mass, additional information on the presence in the rock layers of the planes of weakening of the ordered joint condition, weak interlayers, as well as geological disturbance and the wetting of a particular deposit.

The preparation of the initial data for numerical analysis was carried out with the help of the program RocLab, which allows to quickly determining the strength parameters of the rock mass on the basis of the criterion of destruction of Hoek-Brown and Mohr-Coulomb.

One of the important parameters of the initial data is the indicator of the Geological Strength Index (GSI), proposed by Evert Hoek in the 90s of the last century [5].

The GSI indicator is determined by the diagram shown in figure 2, based on the results of processing mine studies.

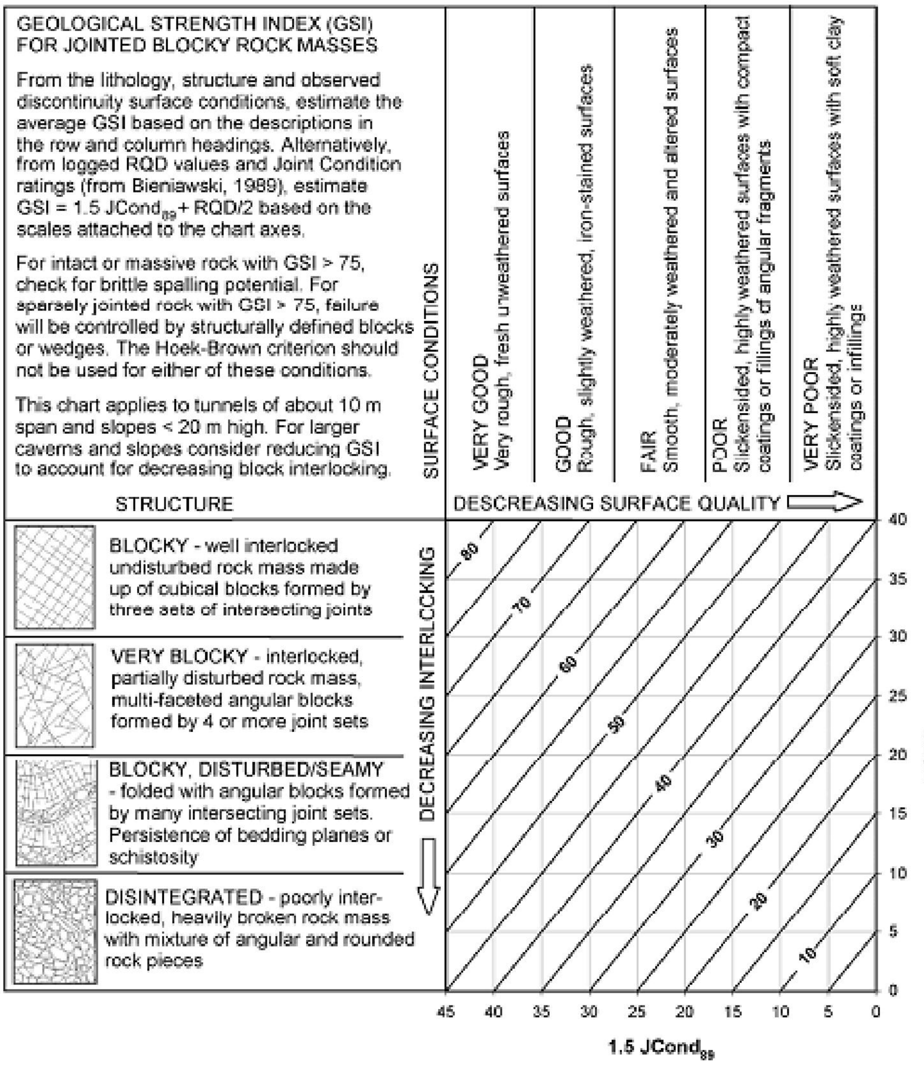


Figure 2 – GSI Indicator Definition Chart

The index is the initial data for refining the physical and mechanical properties of rocks using the RocLab program. The definition of GSI indicator is based on correlations [6]:

$$GSI = RMR - 5 \quad (2)$$

where *RMR* – the rating of the rock mass by Bieniawski [7] is defined as follows.

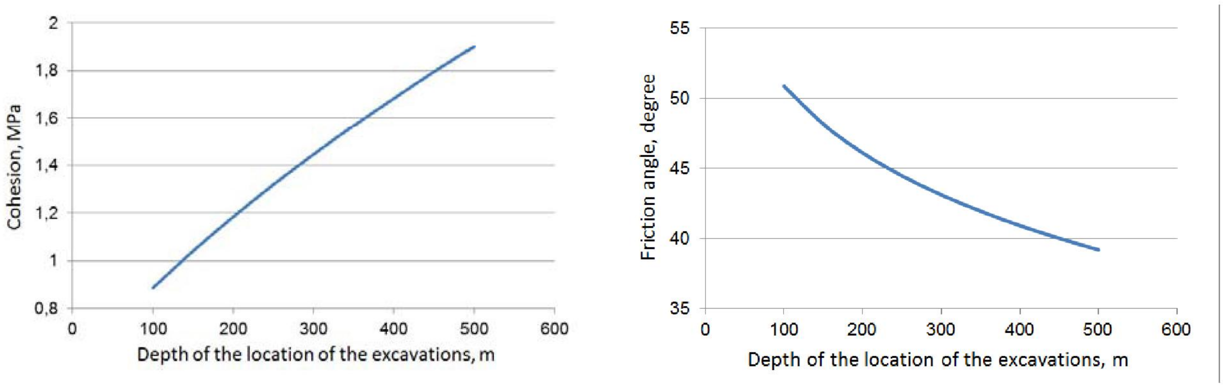
To clarify the strength parameters of the rock mass, detailed information is required on the physical and mechanical properties of rocks, which were determined on the basis of technical documents and mining-geological data of the “Akzhal” deposit. The “Akzhal” deposit is represented by rock formations. The ore-bearing rocks are mass, occasionally skarned and hornfelsed limestones and siltstones. Breeds are generally characterized as strong and medium strength.

RocLab program introduced the following data:

- intact uniaxial compression strength (sigci) - 60 MPa;
- geological index of strength (GSI) – 55;
- unbroken rock parameter (mi) – 10 (for limestone);
- disturbance factor (D) – 0 (characterizes the good quality of shooting works);
- intact modulus (Ei) – 21000 MPa (for limestone);
- the depth of the location of the excavations (H) varied from 100 to 500 m;
- the bulk weight of rocks (γ) is 2.7 t/m^3 or 0.027 MN/t^3.

When specifying the physic-mechanical properties of rocks, the following results were obtained:

- the cohesion of rock mass (figure 3a) varied from 0.9 MPa (at a depth of 100 m) to 1.9 MPa (at a depth of 500 m);
- the friction angle (figure 3b) changed from 39 degrees (at a depth of 500 m) to 51 degrees (at 100 m);
- tensile strength – 0.202 MPa, uniaxial compressive strength – 4.826 MPa.



a b

Figure 3 – Graphs of the change in the cohesion (a) and the friction angle (b) of the rock mass, depending on the depth of the mine excavation

Figure 4 shows the strength passport of the rock mass of the “Akzhal” deposit, depending on the depth of the mine excavations.

Also, when determining the strength parameters of rocks, the coefficient of structural attenuation was established, the value of which is 0.08.

The obtained data were used as initial data in a numerical analysis to determine the conditional zone of inelastic deformations (ZID) of rock mass around the mine excavations located at a depth of 100 to 500 m.

In the program of numerical analysis of the stress-strain state of the rock mass, the strength parameters of the rocks are given by the dimensionless coefficient in the joints $\sigma_{comp}/\gamma H$ and $C/\gamma H$ (figure 5). Also, as initial data, the friction angle of the rocks and the orientation of the joint systems relative to the mine excavation axis are introduced.

Results and discussion. The simulation was carried out taking into account three cases of laying the mine excavation in a rock mass with a lateral pressure coefficient (λ) from 0.6 to 1.

Analysis of the calculation results shows that ZID at relatively shallow depths (100 m) at $\lambda = 1$ is formed relatively uniformly around the excavation. With an increase in the depth of the mine excavations (from 200 m and more), the ZID in the roof and soil of the development increases in size and begins to approach the ellipse elongated in the vertical direction (figure 6a).

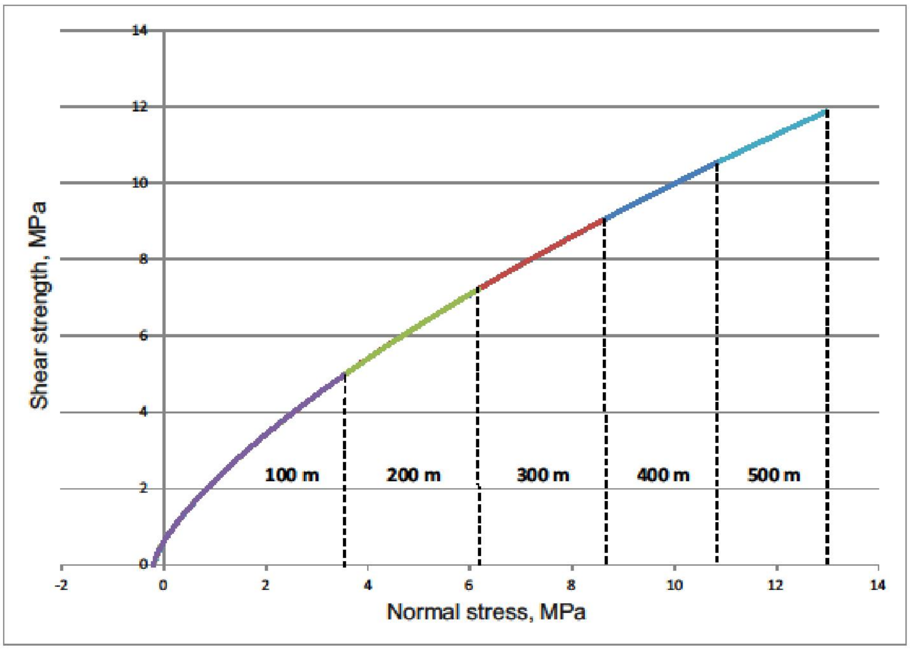


Figure 4 – Passport of rock mass strength

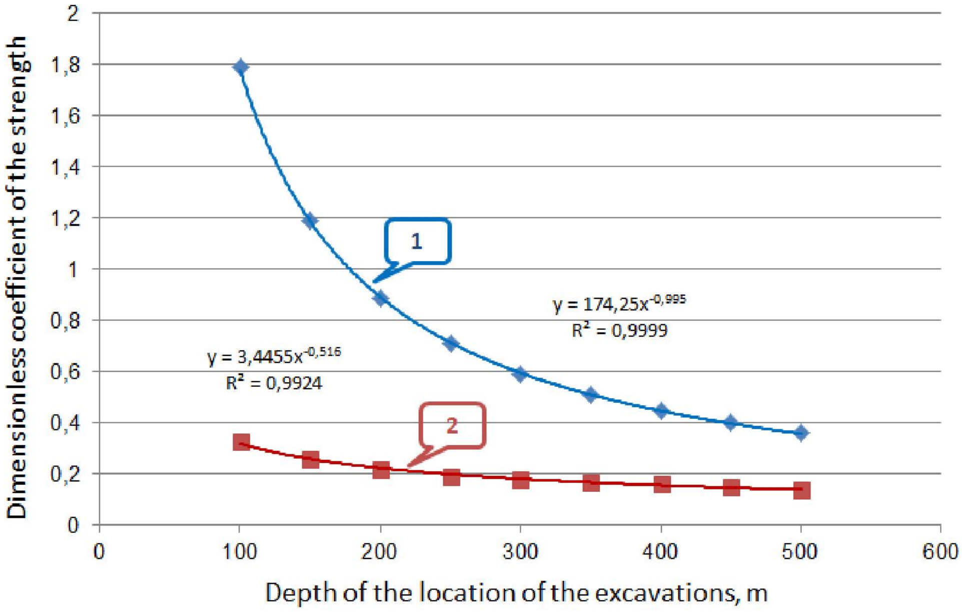


Figure 5 – Initial data for numerical analysis:
1 – index of uniaxial compressive strength, 2 – cohesion index

The dimensions of the ZID in the roof are from 0.8 (100 m) to 2.1 m (500 m) and in the sides of the mine excavation - from 0.5 to 1.3 m. At depths between 100 and 200 m, the size of the ZID is almost doubled (an increase of 87.5%), and from the depth of mine excavations from 300 to 500 m the dimensions of the ZID are relatively close.

Analysis of the configuration of ZID at $\lambda = 0.8$ shows that at the same depths (from 100 to 500 m) it has a relatively uniform shape around the formation. The dimensions of the ZID in the roof are from 0.3 to 1.6 m (from 100 to 500 m, respectively), and in the sides of the mine excavations vary from 0.4 to 1.2 m.

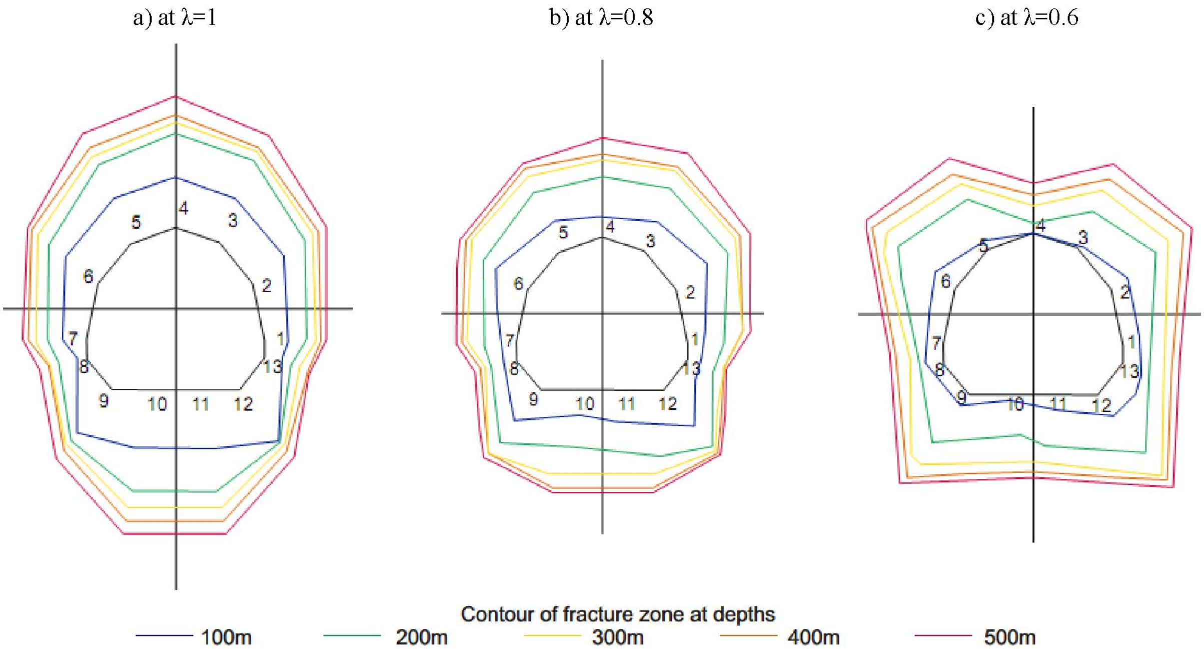


Figure 6 – Zones of inelastic deformations of rock mass around the mine excavations

In the case when λ = 0.6, the ZID has a more complex configuration and is formed in the lateral parts of the mine excavation. At shallow depths (100 m), part of the rock mass that adjoins the roof and the soil is quite elastic, which indicates the stability and absence of joint processes in these zones. With an increase in depth, a more explicit increase in the sides of the ZID occurs comparing to the roof of the mine excavation. The size of the rock destruction zone in the sides of the mine excavation is from 0.4 m (at a depth of 100 m) to 1.2 m (500 m). It should be noted that for this zone of the limiting state, the growth of the dimensions of the ZID is characterized regarding to the horizontal direction. Forms of the zone of destruction of rock mass around the mine excavation in all cases of stress state has a simple configuration that favorably influences the choice of types and parameters of fastening.

Thus, analyzing the results obtained, it should be noted that the shape and size of ZID around the mine excavations is largely determined by the depth of the mine excavation and the lateral pressure coefficient, the strength of the rock mass and the shape of the section of the mine excavation. With an increase in the depth of production, the growth of linear dimensions is typical, as well as the gradual aspiration to the shape of an ellipse elongated in the horizontal direction. In this case, the difference in the size of the ellipse of the zone of the limiting state is determined by the value of the lateral pressure coefficient, and the absolute dimensions of this zone - by the dimensions of the development and the strength characteristics of the rock mass.

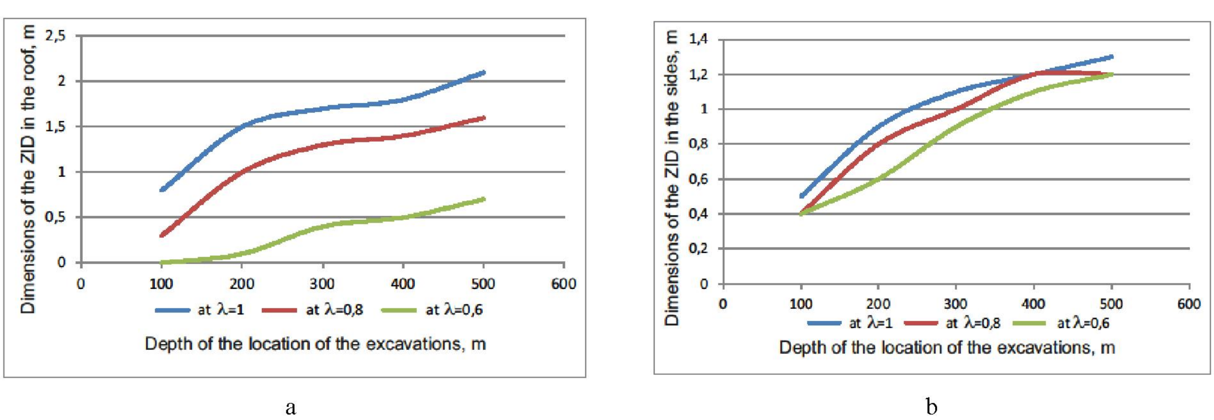


Figure 7 – Dependence of the dimensions of the ZID in the roof (a) and sides (b) of the mine excavations from the depth of the deposit

Conclusions. Numerical analysis by definition of ZID around the mine excavations by the method of boundary integral equations with a step-by-step loading of the rock mass allows taking into account a large number of mining-geological and mining-technical conditions of the deposit.

The geological strength index (GSI) makes it possible to prepare correct initial data for the numerical analysis of the stressed state of the rock mass.

As a result of the numerical analysis, the dependences of the ZID dimensions on the lateral pressure coefficient are determined at a depth of mine excavations from 100 to 500 m.

An analysis of the change in the ZID near the mine excavations objective information about their stability and allows predicting possible displacements. The availability of such information will make it possible to reasonably approach the choice of methods and means for maintaining mine excavations during their operation.

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ТАУ ЖЫНЫСТАРДЫҢ СЕРПІМСІЗ ДЕФОРМАЦИЯЛАНУ АЯСЫН ЗЕРТТЕУ

Аннотация. Жұмыста аралас қазу жүйесімен өндіретін «Ақжал» кен орыны тау-кен қазбаларының маңайындағы серпімсіз пішіндену аяларының өлшемдері анықталды. Сандық талдау тау жыныстары сілемінің этапты жүктемеленуімен шектік интегралдық теңдеулер әдісі арқылы жүргізілді. Геомеханикалық үрдістерді модельдеу пішінденудің серпімдіпластикалық моделімен жүзеге асырылды. Тау жыныстарының физика-механикалық қасиеттерін нақтылау RocLab бағдарламасының көмегімен орындалды. Сандық талдау үшін бастапқы мәліметтерді даярлау барысында тау жыныстарының негізгі мықтылық көрсеткіші болып GSI мықтылықтың геологиялық индексі табылды. Мықтылық параметрлерін нақтылау кезінде үлгі мықтылығынан тау жыныстары сілемінің мықтылығына ауысымы анықталды. Зерттеу жұмыстары тау-кен қазбаларының 100 м-ден бастап 500 м-ге дейінгі тереңдікте орналасуы және бүйір қысым еселігі 0,6-дан 1-ге дейінгі жағдайда жүргізілді. Тау-кен қазбаларының маңайындағы серпімсіз пішіндену аяларының өлшемдері мен формаларының бүйір қысым еселігі мен тау-кен қазбаның орналасу тереңдігіне тәуелділігі анықталды. Алынған нәтижелер негізінде тау жыныстары сілемінің контур маңы бөлігінің геомеханикалық жағдайына баға беруге, сонымен қатар, тау-кен қазбалары бекітпелерінің түрі мен параметрлерін таңдауда ескеруге болады.

Түйін сөздер: серпімсіз пішіндену аялары, мықтылықтың геологиялық индексі, мықтылық критерийлері, сандық талдау, тасжарықтық, бүйір қысым еселігі, қазба.

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ИССЛЕДОВАНИЕ ВОЗМОЖНЫХ ЗОН НЕУПРУГИХ ДЕФОРМАЦИИ ГОРНЫХ ПОРОД

Аннотация. В работе определены размеры условных зон неупругих деформаций вблизи горных выработок при комбинированной отработке месторождения «Акжал». Численный анализ проводился методом граничных интегральных уравнений с поэтапным нагружением массива горных пород. Моделирование геомеханических процессов осуществлялось упругопластической моделью деформирования. Уточнение физико-механических свойств горных пород выполнено с помощью программы RocLab. При подготовке исходных данных для численного анализа основным прочностным показателем горных пород являлся геологический индекс прочности GSI. При уточнении прочностных параметров установлен переход от прочности образца к прочности массива горных пород. Исследование проведено при заложении выработки на глубине от 100 до 500 м при коэффициенте бокового давления от 0,6 до 1. Установлена зависимость размеров и форм возможных зон неупругих деформации вокруг горной выработки от коэффициента бокового давления и глубины заложения выработки. На основе полученных результатов можно проводить оценку геомеханического состояния приконтурной части массива горных пород, а также учесть при выборе типов и параметров крепления горных выработок.

Ключевые слова: зоны неупругих деформаций, геологический индекс прочности, критерии прочности, численный анализ, трещиноватость, коэффициент бокового давления, выработка.

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