

# Simulation of Transcendental Deformation Mode of Interchamber Pillars and Ore Deposit in the Course of Development of Bauxite Resources at Great Depth on the Example of Mine «Sevuralboksitruda»

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**Abstract.** The publication describes the problem of transcendental deformation mode of interchamber pillar and ore deposit associated with the formation of hazardous zones in the rock mass in process of development of rockburst-hazardous rock masses at the great depth. Geomechanical software PRESS 3D URAL is used to assess the impact of the range of geological and technological factors on the mode of interchamber pillars deformation and ore deposit. The software allows to solve spatial problems in the elastic-plastic formulation. The results of step-by-step modeling of different mining and technical situations with a test of the bearing capacity of interchamber pillars showed that some of them can't withstand the mountain pressure and go to the transcendental mode of deformation with subsequent destruction. Identification of the destroyed pillars allows to adjust the boundary conditions of loading the ore mass. At the same time the neglect of transcendental mode of deformation of interchamber pillars can lead to an undervaluation of the stress level in the ore mass by 1.5 or more times. This can lead to an error in predicting the parameters of zones dangerous due to rock bumps.

## Introduction

The problem of determining of transcendental deformation mode of interchamber pillars and ore deposit especially actual in the process of deposits development of the North Ural bauxite basin. The reason is due to the complexity of the mountain pressure control in the process of application chamber-and-pillar system of mining of ore deposits in which rock bumps are possible. The main feature of the chamber-and-pillar development system is the maintenance of room space by the ore pillars, which prevent the collapse. Safety of working conditions and accident-free operation is ensured by the stability of the roof exposures of room spaces and interchamber pillars, which depends on the correctness of the definition of their parameters (size of the roof span and size of the pillar). If the size of interchamber pillars chosen incorrectly the consequences of their destruction will be catastrophic and can lead to injury of workers, disruption of the production process, etc [1-5].

Experience in the development of deposits of the North Ural bauxite basin at great depths shows that the boundary part of the ore deposit can be in conditions of elastic or transcendental deformation. For example, in the case of presence in boundary part of the ore deposit strong and stiff varieties of bauxite (motley bauxite) it's characterized by elastic deformation. Transcendental deformation of the boundary part of the ore deposit is characterized by the presence of less strong varieties of bauxite. Early determination of the deformation mode of the boundary part of the ore deposit allows to determine stress state and, as a result, to identify areas of potential danger in which a rock burst can occur [6-12].



Thus, the study of deformation mode of interchamber pillars and ore deposit with respect of the influence of a wide range of geological, mining and technical factors is an relevant task for the theory and practice of the development rock-bump hazardous ore deposits.

### Research objective

The purpose of research is to determine the regularities of changes stress-strain state in the ore deposit under transcendental loading of interchamber pillars in the process of underground development of ore deposits of complex geological structure to improve the efficiency of mines operation at great depth.

### Methods

The regularities of formation zone of maximum stress state in the boundary part of the ore deposit at it's different thickness are shown in Figure 1a. Figure 1b shows a refined epure of stresses acting in the interchamber pillar of variable thickness.

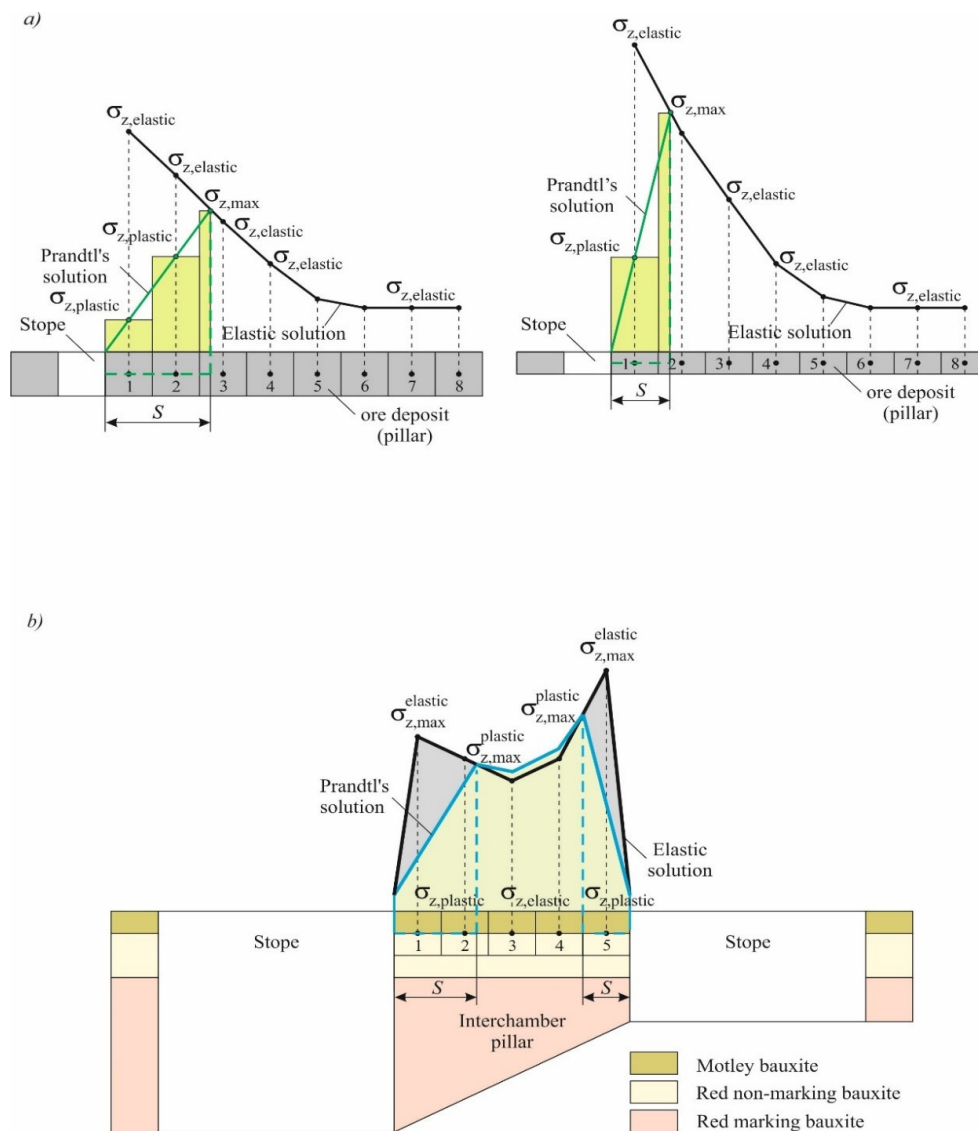


Figure 1. Regularities of limit state zone formation in ore deposits (a) and interchamber pillar (b) with variable thickness

The account of transcendental deformation mode of interchamber pillars in mined-out space is carried out according to the following scheme.

At the first stage, stresses in ore elements are calculated by taking into account their elastic deformation with using the modified method of boundary integral equations. This method is the basis of the software product PRESS 3D URAL, that allows to solve spatial problems of elasticity theory taking into account the natural and man-made flexibility of ore deposits and pillars [2, 10, 11]. The following mining-and-geological and mine technical factors are taken into account:

- mined-out spaces and construction units, which can be arbitrary in size and configuration;
- arbitrary location of construction units relative to boundaries of mined-out spaces;
- various physical and mechanical properties of enclosing rocks and ores;
- the changing thickness of the ore deposits;
- parameters of tectonic disturbances;
- the thickness of relieve slot.

At the second stage, the calculated elements are checked for resistance to allowable stresses, identify the destroyed elements. In the destroyed elements of the initial base the values of the elastic modulus are replaced by deformation modules. After that the estimation of the bearing capacity of the calculated elements is carried out. The transition of the calculated element to the transcendental state is determined from the condition:

$$\sigma_{z,total} \geq 1.4 \cdot \sigma_{comp} \cdot \frac{d}{m}, \quad (1)$$

where  $\sigma_{z,total}$  – total compressive stresses acting in the calculated elements, MPa;

$\sigma_{comp}$  – tensile strength of the ore sample for uniaxial compression, MPa;

$d$  – linear size of the smallest side of the calculated element, m.

The value of the total compressive stress, acting in the design element, is determined from the following expression:

$$\sigma_{z,total} = \sigma_z(\epsilon, \eta) \cdot \gamma H + \gamma H, \quad (2)$$

where  $\sigma_z(\epsilon, \eta)$  – additional stresses obtained in the calculated elements as a result of numerical simulation;

$\gamma H$  – weight of rocks column from the design element to the earth's surface, MPa.

At the final stage, the stress state of the ore deposit is estimated, taking into account the transcendental deformation mode of ore elements.

Assessment of stress state of interchamber pillars and ore deposits is carried out using the modified method of boundary integral equations, but in the calculated elements in which the condition (1) is satisfied, the values of the initial elastic modulus  $E_i$  are required to replace with the values of the reduced elastic modulus  $E_{ir}$ , having used the graphic dependence given in figure 2. Analysis of the graphical dependence (figure 2) shows that the value of the reduced modulus of elasticity  $E_{ir}$ , of the calculated element, depending on its shape coefficient, can be determined from the implementation of the following approximating linear dependence:

$$\frac{E_{ir}}{E_i} = a \cdot \frac{d}{m} + b, \quad (3)$$

where  $E_{ir}$  – the reduced modulus of elasticity (Young) of the calculated element depending on its shape coefficient, MPa;

$d$  – the width of interchamber pillar, m;

$m$  – the height of interchamber pillar, m.

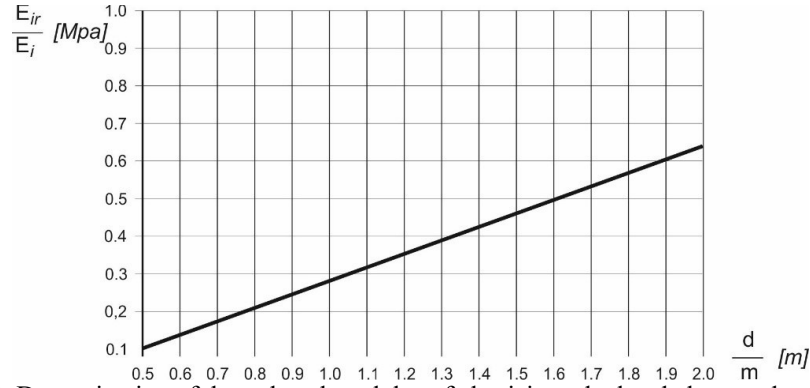


Figure 2. Determination of the reduced modulus of elasticity calculated element depending on its shape coefficient

The approximation parameters  $a$  and  $b$ , included in expression (3), are determined from the following two conditions: in case of uniaxial compression  $\frac{d}{m} = 0.5$ , we accept  $\frac{E_{ir}}{E_i} = 0.1$  in case of volume compression  $\frac{d}{m} = 3$  we accept  $\frac{E_{ir}}{E_i} = 1$ .

Taking into account the above, we obtain the following system of linear equations:

$$\begin{cases} 0.1 = 0.5 \cdot a + b \\ 1.0 = 3.0 \cdot a + b \end{cases} \quad (4)$$

Solving a system of linear equations (4) with respect to the approximation parameters  $a$  and  $b$ , we obtain:  $a = 0.36$ ,  $b = -0.08$ . Substituting the approximation parameters  $a$  and  $b$  in the expression (3), we obtain the following expression to determine the value of the reduced elastic modulus  $E_{ir}$  for calculated element, depending on it's shape factor:

$$E_{ir} = \left( 0.36 \cdot \frac{d}{m} - 0.08 \right) \cdot E_i \quad (5)$$

In the case of non-uniformity structure of the calculated element, we can use the scheme shown in figure 3.

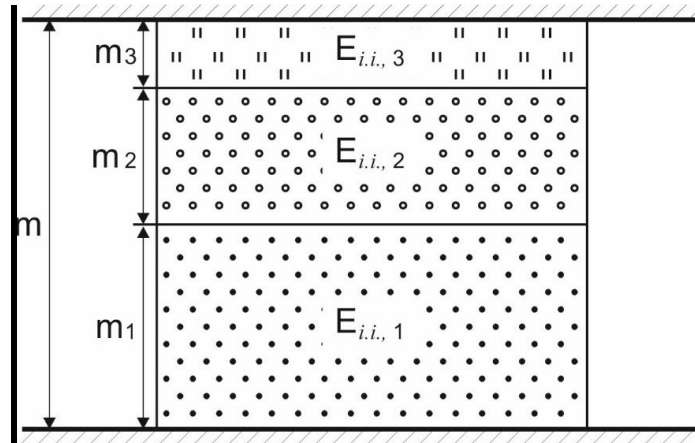


Figure 3. Scheme to determine the modulus of elasticity of the calculated element with its non-uniformity structure

The value of the elastic modulus in this case can be determined from the following expression:

$$E_i = \frac{m}{\sum_{i=1}^n \left( \frac{m_i}{E_{ii}} \right)}, \quad (6)$$

Control of the accuracy of calculations by value is carried out by the following expression. The indicator represents the ratio of the sum of the required loads in the mining-induced zone to the sum of the loads.

$$\delta = |\sum_{i=1}^n (P_i \cdot \Omega_i) / \sum_{i=1}^m (Q_i \cdot S_i)|, \quad (7)$$

where  $P_i$  – the calculated value of the additional stresses due to the influence of mining unit;  
 $\Omega_i$  – calculated element area, m<sup>2</sup>;  
 $Q_i$  – the load, which is removed from the soil of excavation ( $\gamma \cdot H$ );  
 $S_i$  – the area of the element, located in the mined-out space, m<sup>2</sup>.

The breakdown of the mining-induced zone into elements is considered satisfactory if the value deviates from the unit by no more than 10-15 %. For the numerical calculation of stresses in the ore deposit and pillars it is necessary to enter the initial information, characterizing the geological and technological conditions. At the first stage, the limits of integration are set to take into account the geometric dimensions of the boundary elements, belonging to both the rock mass and the developed space.

At the second stage, each boundary element of the ore deposit is assigned a Poisson's ratio and the modulus of elasticity of the enclosing rocks and ores, thickness of the design element and the thickness of relieve slot in the design element. In the elements, belonging to the developed space, boundary conditions are formed through the pressure angles, which allows to take into account the size of the developed space, the depth of stopping, incidence angle and thickness of ore deposits.

To clarify the mining-induced zone epure in the boundary part of ore deposit and pillars, taking into account the zone of the maximum stress state, the following provisions are used to calculate the parameters of the zone of the maximum stress state.

The width of mining-induced zone in the boundary part of ore deposit (pillar) is determined from the expression, developed by the scientists of the Institute VNIMI:

$$X_1 = \left( \frac{h}{2\tau_s} \cdot |K_{int}| \right)^{\frac{2}{3}} \cdot f(p), \quad (8)$$

where  $K_{int}$  – stress intensity factor at the edge of the pillar (ore deposit), МПа√м;  
 $h$  – thickness of ore in the boundary part of ore deposit (pillar), м.

The stress intensity factor is determined from the expression:

$$K_{int} = \sqrt{2\pi R \cdot (\sigma_{z,p} - 1) \cdot \gamma H}, \quad (9)$$

where  $R$  – distance from the edge of the pillar (ore deposit) to the center of gravity of the design element, m. The expression for finding the function  $f(p)$  looks like:

$$f(p) = 0.63 \cdot \left( \sqrt[3]{\sqrt{1+p} + 1} - \sqrt[3]{\sqrt{1+p} - 1} \right)^2, \quad (10)$$

where  $p = 0.57 \cdot \left( \frac{1.4 \cdot \sigma_{comp}}{K_{int}} \right)^2 \cdot \frac{h}{2}$

The dependence for determining the value of the normal stress in the mining-induced zone maximum from the side of in mined-out space is as follows:

$$\sigma_{z,max} = -1.4 \sigma_{comp} \frac{2X_1}{m}, \quad (11)$$

The proposed method of stress calculation in the mining-induced zone of the ore deposit allowed to adjust the software PRESS 3D URAL. This made it possible to determine stresses in the mining-induced zone, stress intensity factors, the size of maximum stress state zone in the boundary part of the ore deposit for any spatial configuration of the stopping zone, the ratio of the deformation characteristics of the host rocks and ores, parameters of relieve slot.

## Results

At the first stage, as a result of numerical implementation, the distribution of stress intensity of the total compressive stresses in the ore deposit is obtained, taking into account only the elastic mode of deformation of the interchamber pillars and ore deposit (figure 4).

At the second stage, the bearing capacity of the calculated elements of the ore deposit was checked, as a result of which a calculated scheme of the site with destroyed elements was obtained (figure 5).

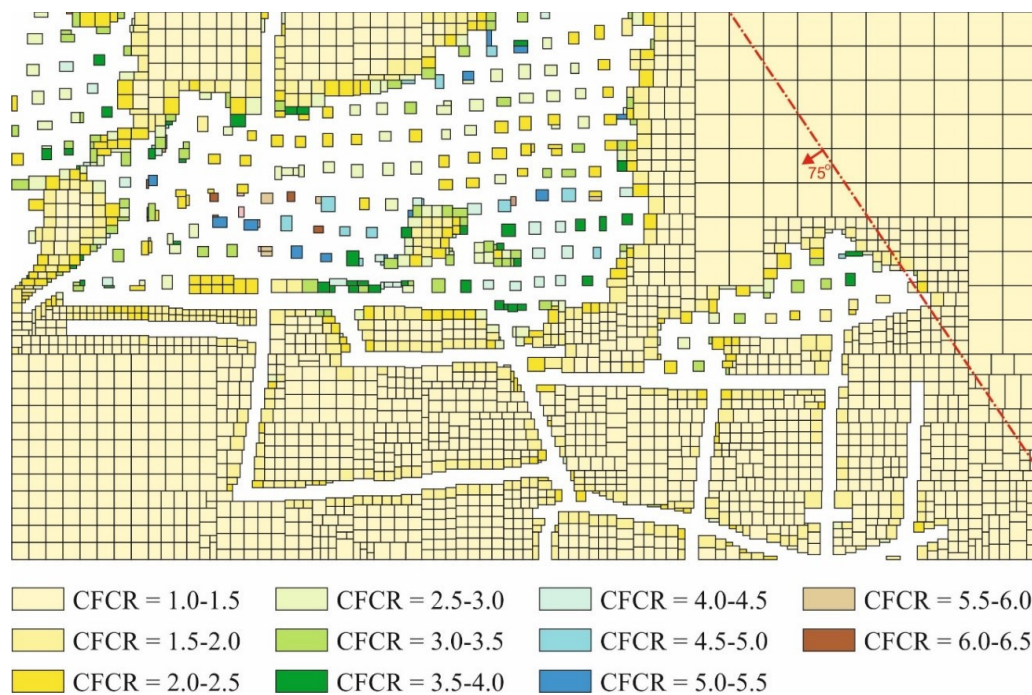


Figure 4. Assessment of the stress state of the ore Deposit by the modified method of boundary integral equations (CFCS – concentration factor of complete stress)

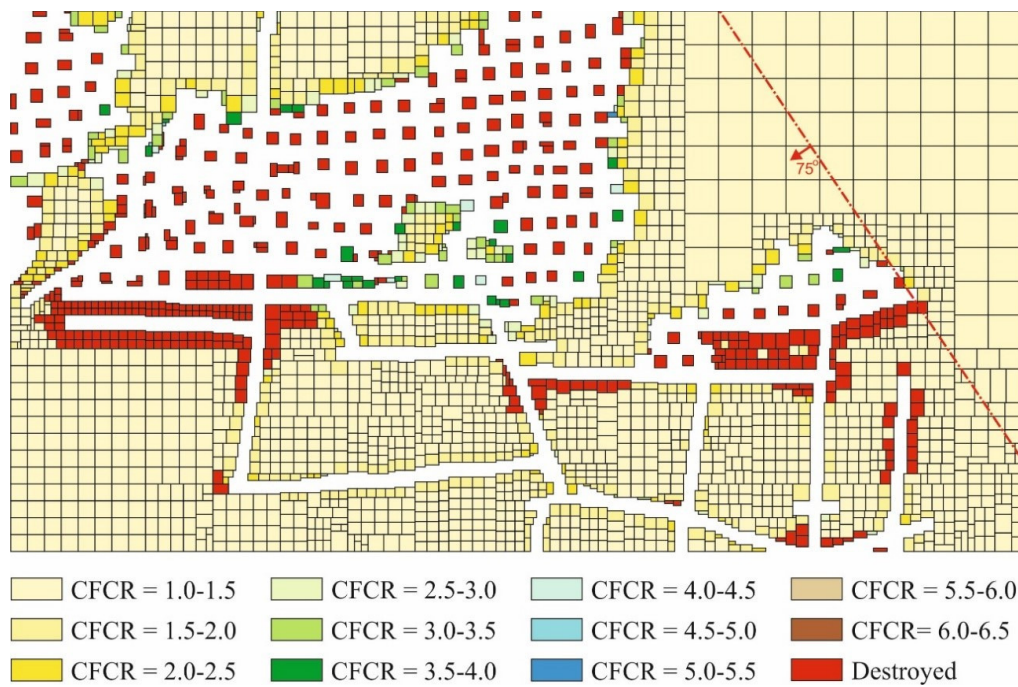


Figure 5. Determination of destroyed ore elements

At the final stage, as a result of adjusting the initial data (elastic modulus values), the following picture of the distribution of the coefficients of concentration of total compressive stresses in the ore deposit is obtained (figure 6).

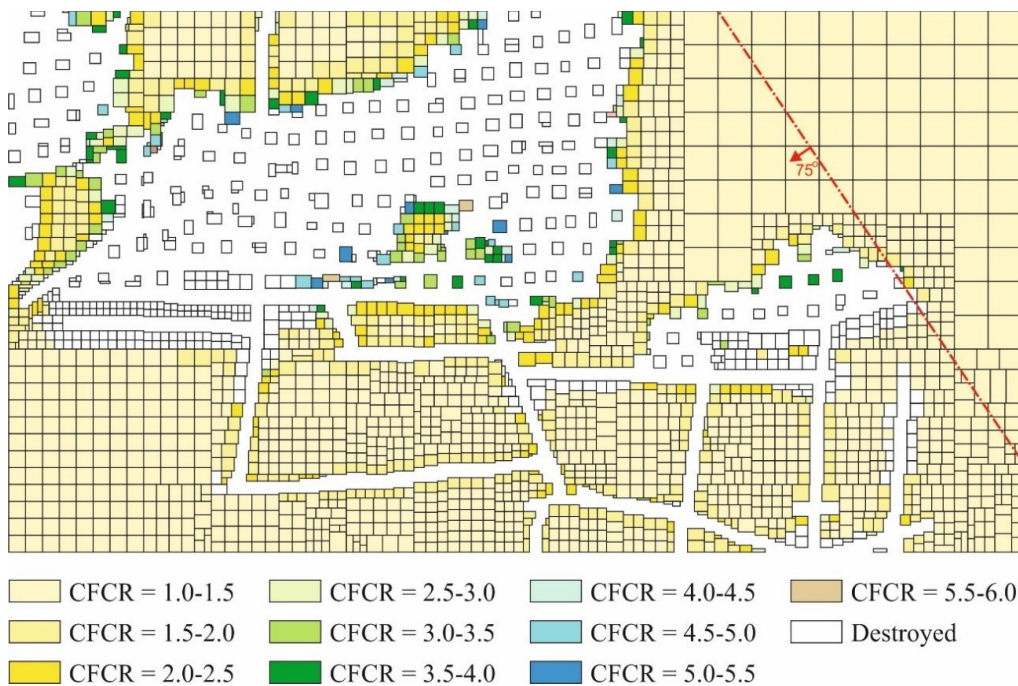


Figure 6. Results of the numerical evaluation of the stress state of the ore deposit, taking into account the destroyed ore elements

Figure 7 shows the detail of changing in the stress state of the untreated area of non-industrial mineralization left in the developed space. Analysis of the results shows that the destruction of inter-chamber pillars in the developed space leads to an increase in the stress concentration by 50 % or more.

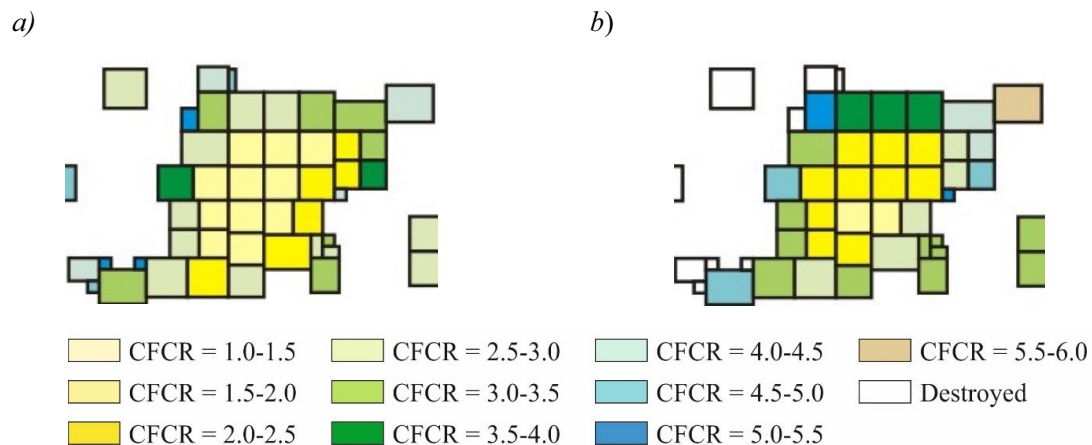


Figure 7. Changes in the stress state of the non-industrial mineralization site: a – without taking into account the destruction of the design elements; b – with the destruction of the design elements

Similar qualitative regularities of stress-strain state of interchamber pillars were identified as a result of widespread mining experimental studies, carried out on ores of Dzhezkazgan and Mirgalimsay, which is developing a copper-nickel deposits, using chamber-and-pillar system development. The reliability of the developed modified method of integral equations was confirmed by comparing the results of the numerical experiment with the results of mining and experimental work (mine "Kalinskaya" OJSC "SUBR"), as well as with experimental data of laboratory studies of the stress-strain state of interchamber pillars, using equivalent materials in the certified laboratory of rock modeling of the Scientific research center of geomechanics and problems of mining production in St. Petersburg mining University.

## Conclusion

The problem of formation of hazardous zones in the ore massif during the development of rock-bump hazardous ore deposits at great depths is associated with the transcendental deformation of interchamber pillars in the developed space. To determine the transcendent mode of interchamber pillars deformation and the ore deposit with the influence of a wide range of geological and technological factors can be used geomechanical software PRESS 3D URAL. The results testing of the bearing capacity of interchamber pillars showed that some of them do not withstand the mountain pressure and pass into the transcendental mode of deformation with subsequent destruction, which requires adjustment of the boundary conditions of loading of the ore massif. The neglect of the transcendent deformation mode of interchamber pillars can lead to error in predicting the parameters of zones dangerous due to rock bumps. At the same time the neglect of transcendent mode of deformation of interchamber pillars can lead to an undervaluation of the stress level in the ore mass.

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