USE NUMERICAL MODELING FOR ESTIMATING THE STABILITY OF ROOM - PILLAR – CEILING SYSTEM FOR EXPLOITATION METHOD WITH SMALL ROOMS AND SQUARE PILLAR

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Abstract: Along with the increasing power processing of computers, it has developed a third approach to research - numerical modeling - which synergistically complement the theoretical approach and the pure research. In rock mechanics „the model" is the concept of a simplified representation of the mechanical behavior of the rock massif, the macroscopic sample. Modeling can be defined by a law of behavior or behavior change criterion, which is the shape of a mathematical relationship between stress, strain and their derivatives according the time between main stress or between applied forces and displacements on a plane of discontinuity rock massif. [6] In this paper we consider the size of the study area around the underground opening, significantly reduced to cover the surface of the model for varying stresses and strains.
Keywords: *Numerical modeling, stability, room, pillar, ceiling*

1. Presentation of rooms and square pillars exploitation method

Rooms and square pillar exploitation method consists in excavation by drilling-blasting of spaces called rooms, among abandons the parallelepiped square base pillars, called room fender.

The ore from undergrowth floor is divided into the intermediary floor with around 20 meters, which is made up of rooms and pillars. General direction of operation is downward and theoretically can be 2-3 operation simultaneously. Extraction of a sublevel reserve can be done in advance or retreat to the main job opening. In the first case, the cross-mining works is executed normally up to the pillar edge, attacking one side of the extraction chamber and begin shaping the pillars, Figure 1.

When these rooms have a length equal to the width plus the width of the pillar room, we can proceed to attack the mining work parallel to the main room, having instead a multiplicity of fronts. When these rooms have a length equal to that of a room addition, is a new development of pillar rooms, figure 2.

Applying the method of operation with small rooms and square pillars, enable the development of a single sublevel of a large number of fronts active in different phases of technological operations (drilling, explosive load, exhaust gas, transportation of the drilled deposit etc.)

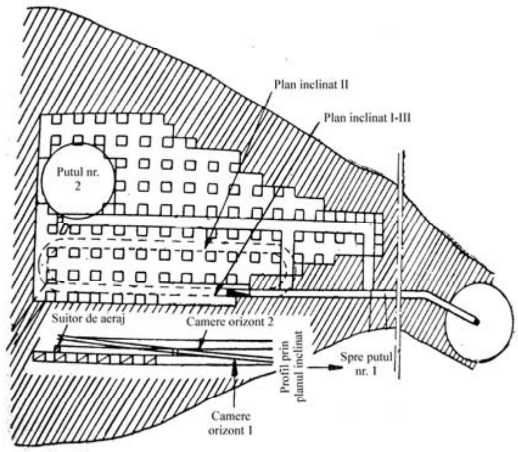

Figure 1. ***Exploitation method with small room and square pillars [7]***

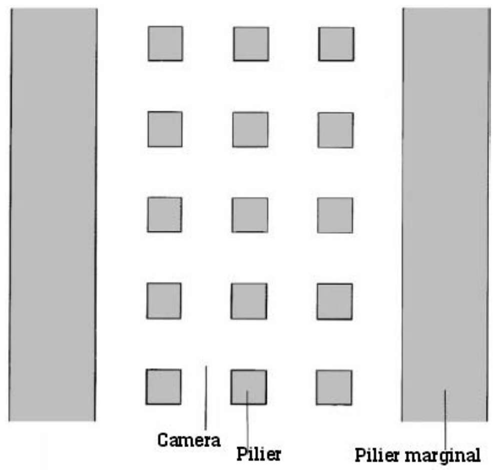

Figure 2. ***Layout of room and pillar in a level***

This method is widely applied for salt exploitation in Romania and abroad.

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Exploitation method with small rooms and square pillars, used in most mines, has a number of advantages:

- provision of equipment is easy;
- creates the possibility of opening a larger number of active fronts;
- network of ventilation is much reduced;
- can easily avoid any sterile area.

2. Evaluating the stability of elements for salt mining exploitation method with small rooms and square pillars

In this study we considered an exploitation of the deposit at a depth from the surface of between 130-150 m, rooms has 15 m wide and 8 m high, pillars have 15x15 m and a height of 8 m. Ceiling thickness is 7.5 m.

2.1. Setting up the width of rooms [1]

Considering the stress acting on the operating room, Ritter sets the general formula given in the form:

$$P = \gamma_a d\left(\frac{\gamma_a d^2}{48\sigma_t} - \frac{\sigma_t}{\gamma_a}\right) \quad \text{MPa} \qquad (1)$$

In this relation: the γ_a – unit density of salt, d - width of the room and σ_t - tensile strength of salt.

Applying this formula to the limit, taking into account the influence of time we obtained:

$$d_{optim} = 4\frac{\sigma_t}{\gamma_a} \quad \text{şi} \quad d_{\max} = 7\frac{\sigma_t}{\gamma_a} \qquad (2)$$

Accepting the values obtained from laboratory tests and for a safety factor n = 5, we obtain $d_{opt} \cong$ 20 m ; d_{max} = 35 m.

As the width of the room is 15 m, it follows that, the rooms are smaller than the openings limit and therefore they are stable.

2.2. Determining the depth of exploitation for which safety features are stable [1], [9], [10], [11]

G. Dorstewitz applying the photoelasticity process has established that the pillars are produced concentration of compressive stresses – at the edge of - the size of pillars depends on many factors: the shape and dimensions of the pillar, the distance between pillars, nature of salt rocks and properties of rocks from the roof to surface. After the experiment, the author concludes that the compressive stresses in the pillars are not uniformly distributed, and the concentrations at the edges of the pillar reached the value 3 σ_z. [9]

K. Kegel consider a uniform distribution of compressive stresses in the pillars, but with a stress concentration in the central part of the pillar and Professor M. Stamatiu opinions, which believes that sizing pillars supporting the hypothesis that can be accepted uniform distribution tensions in pillar, provided that acceptance of a safety factor to compensate for the rise in tensions on the outskirts of pillars. [10] [11]

Acknowledging these considerations and pass by the weight of the pillar, obtain this relation:

$$\sigma_p = \left(1 + \frac{L_c}{L_p}\right)^2 \cdot \sigma_z \qquad (3)$$

In this formula σ_p - average unit strain developed in pillar, L_c - room width, L_p - pillar width and σ_z - vertical component of the tension acting on the pillar.

For L_c = 15 m ; L_p = 15 m ; γ_a = 2,1. 10^4 N/m^3 and for different depths between 100 m and 200 m, are obtained the strain values between 4.2 and 8.4 MPa.

Considering that, in laboratory tests revealed a dilated threshold strain $\sigma_{lld} \cong$ 15 MPa, that the square pillars 15 m will maintain stability to the depth of [9], [11]:

$$H = \frac{\sigma_{lld}}{\left(1 + \frac{L_c}{L_p}\right)^2 \cdot \gamma_a} = \frac{15 \cdot 10^6}{4{,}2 \cdot 10^4} = 357{,}14m.$$

For completeness the results, it is necessary to confirm or adjust the data, following creep testing and modeling.

Current strain in a pillar is dependent on the stability of the salt of the pillar is formed, the amount of cohesion, internal friction angle, and its side-induced exponential formula may be determined as given by Walker:

$$\sigma_z = \frac{C}{tg\varphi}\left\{\left[1 + \frac{2\sin\varphi}{1-\sin\varphi}\right]e^{\frac{2tg\varphi}{h}.J\cdot x}\ 1\right\} \quad \text{(MPa)} \qquad (4)$$

In this relation C - cohesion = 40 MPa φ – internal friction angle = 550, h - height of the pillar = 8 m, x - distance from the edge of the pillar to the point for which the strain is determined.

For values of x between 0 and 50 cm we obtain values for σ_z ranging between 20.54 MPa and 98.54 MPa.

Taking into account the results of laboratory tests - uniaxial and triaxial - that $\sigma_{cmonoax.}$ = 220 Mpa and $\sigma_{ctriax.}$ = 421 MPa at a stress σ_x = 25 MPa we conclude that from one side of the pillar to mid, up to a distance of about 6 cm pillar requested monoaxially this part will be destroyed very quickly.

Its depth of pillar at a distance greater than 6 cm lateral tensions are felt induced and pillar is subjected to a triaxial request, which reached maximum triaxial strength about 23 cm from the edges.

2.3. Check the dimensions of pillars using I.D. Şeviakov theory [1], [2], [8]

Şeviakov examined in detail the problem of sizing pillars supporting the exploitation of underground salt and proposed a series of formulas for pillars of different shapes.

These formulations are based on the admission of the following assumptions:

- the lowest possible load on the pillars is conditional on the weight of all coverings rocks to the surface;
- vertical compressive stresses in horizontal sections of the pillars will be considered as uniformly distributed;
- the calculations must be introduce compressive strengths of rock, obtained by laboratory tests;
- failure to take into account a certain increase in resistance, higher compressive strength of the pillars whose height is smaller than the size of their base, as well as higher resistance to compression of the material when compared with the two-axis therefore the axis - is introduced in the calculations some reserves of strength.

Taking account of the assumptions mentioned, LD Şeviakov deduced the following general relation for calculating the allowable dimensions of the pillars [7], [8]:

$$SH\gamma_{st} + sh\gamma_S \leq s\frac{\sigma_{rc}}{n} \qquad (5)$$

in which:

H - depth to the surface, m;

h - the height of the pillars, m;

s - horizontal cross-sectional area of the pillar support, m^2;

S - horizontal sectional area of the prism cover rocks of the pillar, m^2;

L_{c1} and L_{c2} - width rooms surrounding pillars, m;

L_p - the width of the pillars, m;

γ_{st} - density of medium density of rock covers, N/m^3;

γ_s - average apparent specific density of the salt pillars, N/m^3 ;

σ_{rc} - breaking average effective resistance to compression of pillars.

n - safety factor, representing the resistance of support pillars (n = 2 ... 3 for salt rock, potassium salt).

So,

$$\frac{S}{s} = \frac{\sigma_{rc}}{nH\gamma_{st}} - \frac{h\gamma_s}{H\gamma_{st}} \qquad (6)$$

Based on this general formula it was established the following formula for calculating the width of the pillars:

$$l_p = \frac{l_c}{\sqrt{\frac{\sigma_{rc}}{nH\gamma_{st}} - \frac{h\gamma_{st}}{H\gamma_s}} - 1} \qquad (7)$$

For geomechanical conditions of salt rock considered in this study:

$$l_p = \frac{15}{\sqrt{\frac{25\cdot10^6}{6\cdot1,5\cdot10^6} - \frac{8\cdot2,5\cdot10^4}{2\cdot10^4\cdot150}} - 1} = 11,74m$$

So minimum pillar width must be at least 12 m. In real condition width of the pillar is 15 m, it will be able to take over tasks created by rock covers.

2.4. Sizing ceilings using embedded boards premises [7]

Accepting for rock covers:

$\sigma_{t.acop}$ = 5 MPa and $\gamma_{a.acop}$ = 2,5.10^4 N/m^3 and salt, specifying that $\sigma_t = \sigma_{t.lab}$ x C_s or σ_t = 18 x 0,53 ≅ 1 MPa and considering a embedded floor plate, that the case studied, where the exploitation method with small rooms and square pillars and considering the depth of the surface to 130-150 m, 15 m wide rooms and 8 m high pillars were 15 m and 8 m side height floor ceilings are 7.5 m thick we obtain:

$$q_s = \frac{4\cdot256\cdot1,9^2}{32\cdot50} = 2,31 \text{ [MPa]}$$

$$h_{tavan} = \frac{4\cdot256\cdot2,1}{2\cdot3,22\cdot1,3\cdot100}\left[1+\sqrt{1+\frac{4\cdot3,22\cdot1,3\cdot100}{4\cdot256\cdot2,1^2}\cdot2,31}\right] = 6-6,5m$$

$$h = 6-6,5m$$

In the case of floor level, the weight of the load of the equipment and unrocked salt can be considered the same as for the additional load of the floor to the ceiling, such that: H_{etaj} = 6 – 6,5 m.

From checking the width of pillars showed that the side of pillars is 15m they maintain the capacity to a depth of 357 m.

Going to check the thickness of the ceiling resulting that the thickness required its 6 to 6.5 m

For safety coefficients with values between 2 and 3, we obtain values of h between 6 and 8.8 m.

It follows that the actual ceiling with a thickness of 7.5 m, has a safety factor of 2.5, which is a very small, relative to the work that is to say n = 4-5.

3. Numerical modeling for room - pillar – ceiling system, at the exploitation method with small rooms and square pillars

Because the dimensions of the space exploited is very high I set the dimensions of interest around underground excavation it was reduced to cover the surface model with the maximum stresses and strains change. Meshing was realized by the finite element model.

As a way of working to achieve 2D modeling is required following steps [6]:

- establishing limits on the area of interest;
- determining regions and geomechanical characteristics input;
- impose boundary conditions;
- establish baseline model;
- calculations and store of results.

3.1. Fundamentals of software Examine 2D

Examine 2D is a two-dimensional plane deformation based on indirect boundary element analysis of elastic stresses around underground excavations.

It is designed to be fast and simple to use as a tool for parametric analysis to investigate the influence of geometry and stress variation in situ rock stress, change due to excavation. Strain induced in the analysis plan can be observed the stress contour and the region around excavations. As a method for quantitative interpretation of the overload deviation (the difference between the main strain) around the opening contour resistance factor gives a quantitative measure of resistance induced by the user in accordance with the determination criteria for breaking rock massif. Border movement and contour deformation vectors can be drawn to illustrate the general trend of deformation.

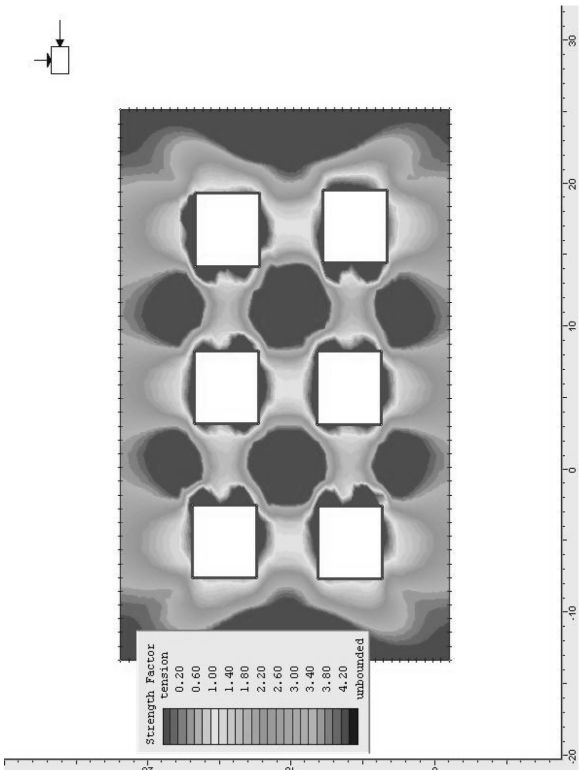

Figure 3. ***Representations of strength given by the Examine2D software***

Elastic boundary element analysis used in 2D Examine requires modeling material is homogeneous, isotropic or transversely isotropic and linear elastic.

Most massive rock that will be modeled not have any of these properties. The degree to which real rock massif will be modeled alleged deviate from these properties, it should be noted when interpreting data from 2D Examine software. However, the stresses induced by the examiner calculated and displayed in 2D, shown for example in Figure 3, are found to be useful. Typically, for example, when optimizing the geometry of the trench and/or sectioned we must to avoid undesirable strain relief.

Examine plots of the 2D displacements are made only qualitatively illustrate the directions of regional deformation. The actual values of the displacements calculated using Examine 2D includes only elastic displacements due to the dig, set the example in Figure 4. This, in fact, may be a small part of the actual displacements measured in the field. In weak rocks cracked, the actual displacement can be several times the size of the elastic values calculated. In addition, displacements calculated directly dependent of the Young modulus of deformation, a value difficult to estimate.

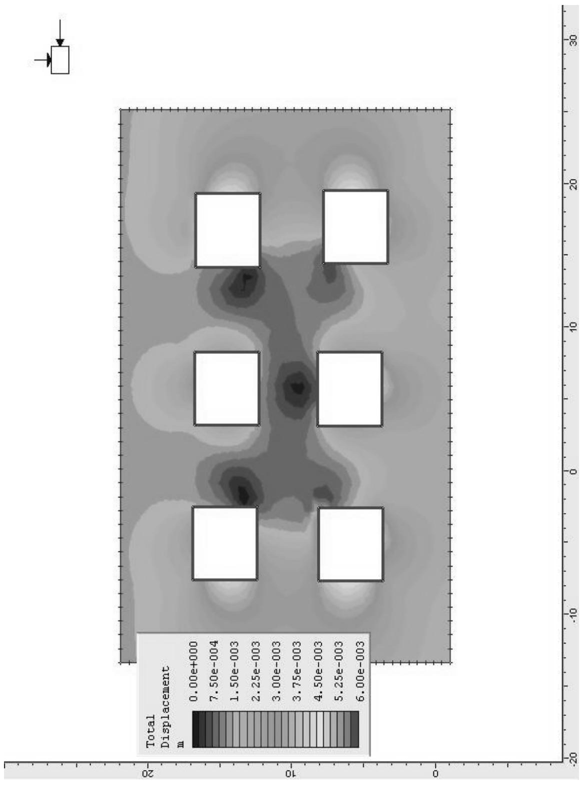

Figure 4. ***Representation of total displacements using Examine2D software***

The practice to perform multiple tests using a range of stresses and properties of the material to study the effect of each parameter, it is prudent in all cases. Briefly, the Examine 2D software is strong, but, is a limited tool.

Examine 2D has the following analysis and modeling capabilities:

- a single material with isotropic properties;
- elastic stresses / displacement analysis;
- strength factor (overstressing based on the elastic results) using Mohr-Coulomb criterion or Hoek-Brown generalized criterion; [3], [4], [5];
- constant or gravitational stress *in situ*;
- interactive modeling and parametric analysis;
- uniform pressure loading.

The following analysis and modeling capabilities are not available in 2D Examine:

- multiple materials;;
- plasticity / flow / progressive breakage;
- support (anchors);
- scaffold;
- joints;
- interstitial pressure (in pores);
- generalized load.

For a full analysis of stresses from underground and surface excavations, including the features listed above and others, it can be used Phase2, the finite element program.

3.2. Developed model of analysis

To estimate the stability of the resistance elements, columns and ceilings, we used *Examine2D* specialized software to calculate the efforts and displacements to underground excavations. It uses the finite element method and that of finite difference, the calculations for estimating being in two coordinates, and due to its simple use, multiple exploitation scenarios for different mining methods can be created.

For a room and pillar mine workings situated in a salt deposit at a depth of H=170 m, having a sterile cover about 40 m and $\gamma_{asr} = 2,2 \cdot 10^4\ N/m^3$ and σ_{rc}=25 MPa, for: l_p=14 m (pillar width); l_c=16 m (room width) the stability condition is established, even when is adopted l_p = 8 m, and l_c=22 m, although in reality, in this case, the strain Δ=1,36 situates us in the unstable domain, and using *Examine 2D* software we can observe the estimations made for deformation vectors layout, the deformation limits of the pillars and the paths of the state of stress upon the system of strength which was studied.

Also, analyzing the data generated by the software used we can appreciate that the system stability is satisfied.

4. Conclusions

Through numerical modeling in 2D carried out using the Examine2D program for supporting structures (rooms, pillar mine workings and ceiling), a program based on the finite element method, we have established the dimensions of the interest area around underground excavation, in such a way as to cover the surface of the model, where the variation of stresses and deformations is maximum. 3D modeling was avoided due to the large size of the model. The behavior chosen for simulation was the elastic-plastic Mohr-Coulomb type, with plane deformation hypothesis. [3]

The results lead to the possibility of fracture zones in the rooms, pillar mine workings and ceiling, reality that was also noted after visits to the salt mines, which use the exploitation method with small rooms and square pillar mine workings, figures 5 and 6.

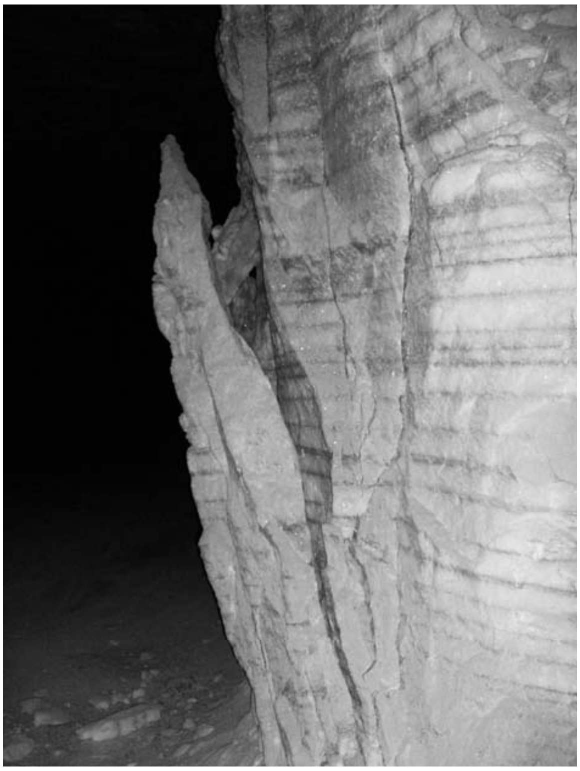

Figure 5. ***Pillar fracturing phenomena***

The test methods of dimensions developed by researchers are an important step in this field, by taking into account the specific characteristics of the rocks and generalization of limit equilibrium theory.

The calculating formula of optimal size for ceilings and pillar mine workings must contain the behavior variations of the salt, related to increased exploitation depth, respectively to tensions from pillar mine workings. Thus, if increases the exploitation depth, it is emphasized the plastic behavior of salt, therefore, a part of the given relationships can be applied up to a certain limit of the exploitation depth of the deposit. To determine the breaking load of the pillars we need an estimation of the real, natural behavior of pillars and ceilings, as close as possible.

Figure 6. ***Ceiling fracturing phenomena***

Under the conditions of exploitation methods of the salt deposit with rooms and pillar mine workings, the purpose of these elements is to fulfill the role of natural support, ensuring in this way a normal functioning of the production process.

For a rational dimensioning of pillars must accept the idea that must be known a few basic elements:

- the salt resistance of which the pillar is built;
- the size and way of distribution of the state of stress inside the pillar;
- the size deformation registered by the pillar under the stress action of the salt massif.

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