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THE ESTIMATION OF RE-EXPLOITATION POSSIBILITIES OF PART OF RESERVES LEFT IN EXPLOITATION FIELD NUMBER 2 IN THE "KŁODAWA" SALT MINE ON THE EXAMPLE OF THE CHAMBER KS-21/600

Ocena możliwości wznowienia eksploatacji części zasobów pozostawionych w polu eksploatacyjnym nr 2 Kopalni Soli „Kłodawa" na przykładzie komory KS-21/600

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Abstract: In the article the actions are presented, which were undertaken to restart the exploitation in chamber KS-21 on working level 600 in the "Kłodawa" Salt Mine. The chamber had not been extracted during the exploitation of working level 600 because of the fact that the heading was the way of haulage of excavated material from the so called "part A" of the chamber. The re-exploitation in that place requires getting a deviation from the operative rigour in connection with driving the heading in the salt diapir. In order to attain that, many activities were done to confirm the hypothesis that re-exploitation does not threaten the stability of field number 2.

Key words: salt mining, chamber system, numerical modeling of rock mass

Treść: W artykule przedstawiono podjęte działania poprzedzające wznowienie eksploatacji w komorze KS-21 na poz. 600 w Kopalni Soli „Kłodawa". Komora ta nie została wybrana w trakcie eksploatacji poz. 600 z uwagi na fakt, że chodnik komorowy stanowił drogę odstawy urobku z tzw. „części A" komory. Wznowienie eksploatacji w tym miejscu wymaga uzyskania odstępstwa od obowiązujących rygorów w związku z prowadzoną eksploatacją w wysadzie solnym. W związku z tym przeprowadzono szereg czynności, których celem było potwierdzenie hipotezy, że podjęcie eksploatacji nie stanowi zagrożenia dla stateczności pola nr 2.

Słowa kluczowe: górnictwo solne, system komorowy, modelowanie numeryczne górotworu

INTRODUCTION

The "Kłodawa" Salt Mine is the only Polish salt mine, which mines rock-salt by means of the "dry" method. The mine runs mining in Kłodawa area salt diapir – the biggest in Polish Depression. The diaper with the longitudinal axis running towards NW-SE direction is approx. 26 km and maximum width of 2 km. The deposit of salt rocks was squeezed out of the depth of approx. 6000 m. in the highest points of the diapir lying at the depth of 100 m under the surface.

The mining area is located in the central part of diapir and comprises of approx. 8 m in accordance with the strike of the diapir with the width of 2 km.

The Salt Mine "Kłodawa" mines the deposit of rock-salts of high degree of purity and natural white colour with the grey or pink shade. Despite relatively little depth of cover, the shallowest level of working floor is located at the depth of approx. 450 m underground (level 450). in the mine there are three separated basic levels (450, 600 and 750) and an inter-level one. Actually, the exploitation takes place between the levels 600 and 750.

The basic system of exploitation is the low chamber system. The vertical dissection module is 25 m (15 m – the chamber height, 10 m the inter-level shelf), and the horizontal module 30 m (15 m – the chamber width, 15 m the inter-level pillar), which is in force till level 600. Below the exploitation is done with the preservation of 30-metre vertical module and the same horizontal module, although the thickness of the shelves and pillars was extended at the cost of decrease in the dimension of cross-wide chambers (Andrusikiewicz 2010).

In the exploitation area of the "Kłodawa" Salt Mine during its almost 60-year-old operation, some parts of non-extracted reserves were left. They were usually left because of technological reasons – parts of them were protective pillars for opening-out headings (inclined drifts), transport and communication.

Because of looking for the reserves in the exploitation area number 2, 10 places about were located, which had not been mined but can be potentially converted into salt chambers. The possible restart of the exploitation refers mainly to the ones on the levels 600, 630 and 660, which were mined in the years 1980–2002. On the levels left below (690, 720 and 750), actually there is the planned mining of the deposit.

In the article, on the example put in practice, the "algorithm" of the actions preceding the restart of exploitation was presented in the places that were abandoned during the previous years, but which exploitation will enable the increase in taking advantage of the deposit. It has to be pointed out that these actions are taken in order to prepare the appropriate expertise documentation, which firstly has to answer the question whether the restart of exploitation can be done in a safe way for the mine, and secondly, if the answer to the first question is positive, it constitutes the ground for the application to the Chairman of Higher Mining Office to obtain a deviation from the operative rigour. The regulations of mining law univocally state that during mining in chambers of multi-level system in rock-salt diapirs, the operational sequence of mining chambers from the top to the bottom and alignment of pillars should be adhered (*Rozporządzenie...* 2002).

Therefore, the following issues should be determined:

- geological-mining conditions existing in the area of the deposit under research,
- geometric and spatial conditions resulting from the hitherto existing deposit cut in the area of the planned chamber,
- geo-mechanical effects of the designed exploitation,
- safety of mining.

To achieve the aims mentioned above, the operating range of actions was determined, which should be put in practice and analyzed in relation to the future exploitation, and which consist of:

- selecting the location of the potential chamber and its surrounding, which will require a visit at the mine in order to determine the conditions of headings' preservation;
- analysis of the archives in the possession of the mine and possible scientific descriptions, publications, etc, referring to the problems under research;
- doing the laboratory testing of the salt samples taken in the area of the designed chamber;
- analysis of tests and measurements of headings' convergence (if there were any done before);
- building the numerical model and its calibration;
- numerical analysis of the task and resulting conclusions, which will be the grounds for bringing out the final expertise.

THE LOCATION OF THE DESIGNED CHAMBER AND ITS SURROUNDING

The chosen location of the potential chamber was cross heading N-E no. 91on level 600 located in the axis of the chambers KS-21 (Fig. 1).

In the axes of chambers KS-21 above level 600, a system of drifts is located enabling transport within the level and the inclined drift enabling communication between the levels 550–575. From level 630 to level 720 mining chambers were made. On level 750 in axis KS-21 a dog heading was excavated, which will be enlarged to the size of a chamber in due time. Chamber headings KS-20 and KS-22 (Fig. 2) are in the neighborhood of the designed chamber KS-21.

After the detailed location of the chamber, the next step was a visit at the place in order to determine the technical conditions of the headings located close to the designed chamber. During the visit the headings on the levels from 575 to 630 between the axes of the chambers KS-20 and KS-22 were checked. As no alarming symptoms were observed, which could reflect the instability of this part of the mine, the check-out was limited to the set out headings. The only phenomenon that could arouse some anxiety was a fall-off of a big salt spalls from the roof floor in chamber KS-22/575. After that incident the chamber was stopped and the mining has not been restarted up till now. The chamber condition has been unchanged since the occurrence of that event, which was confirmed by the particularly detailed examination that the chamber quite frequently undergoes.

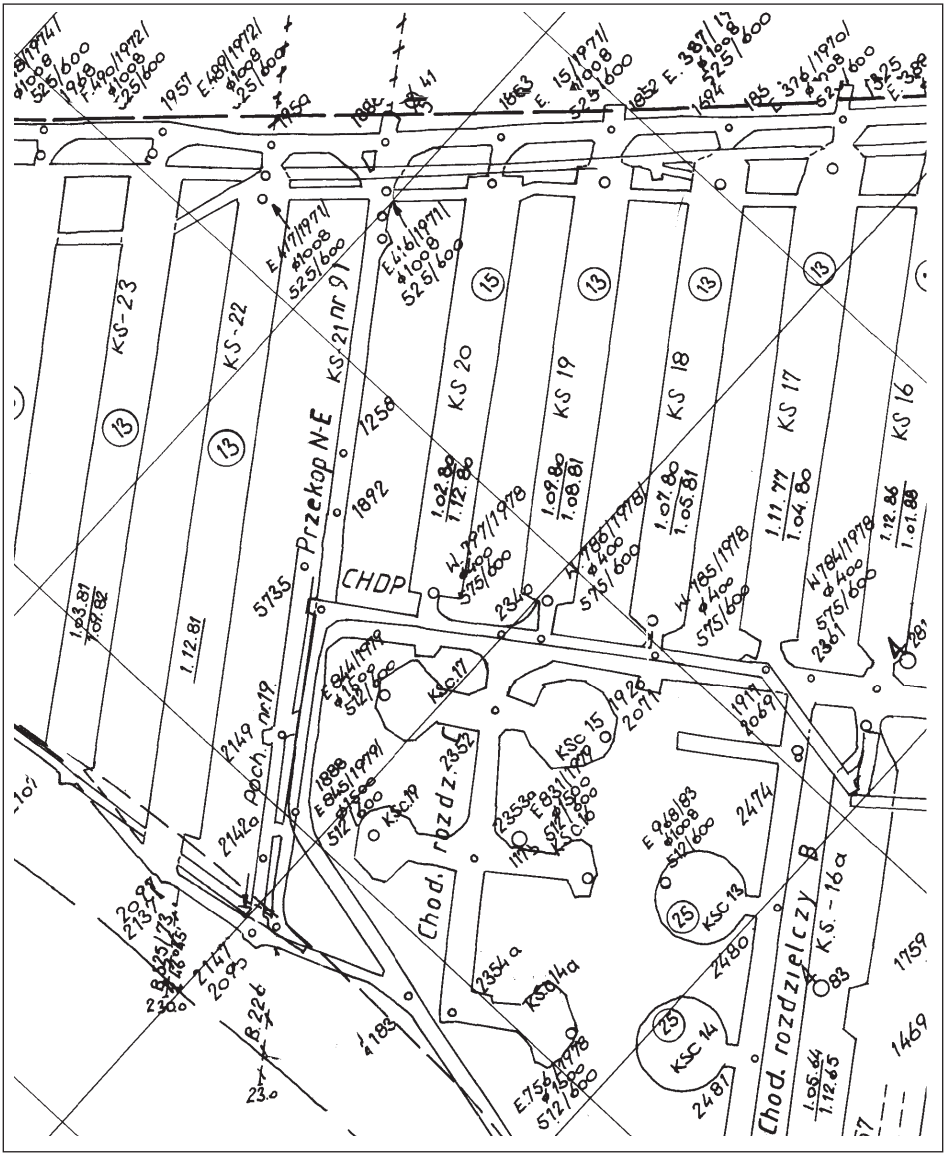

Fig. 1. Map sector of level 600 in the field no. 2

Fig. 1. Wycinek mapy poziomu 600 w polu eksploatacyjnym nr 2

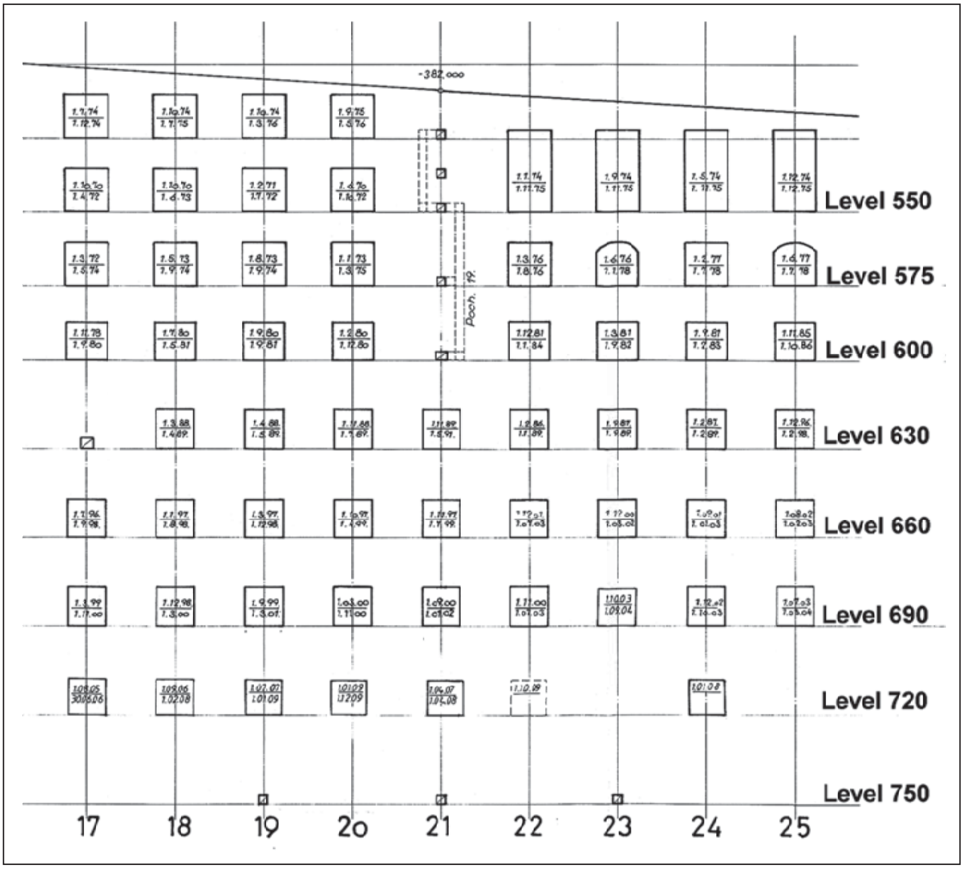

Fig. 2. Part of vertical section through field no. 2

Fig. 2. Fragment przekroju pionowego przez pole eksploatacyjne nr 2

If it turned out that in the examined headings some alarming phenomena occur (e.g., intensive spalling of side walls, etc), then the examination should include other chambers in order to determine the possible borders of these phenomena.

THE ANALYSIS OF THE ARCHIVE MATERIALS

The equally significant element of the work done is the analysis of archive materials in the possession of the mine, such as geological documentation, all kinds of maps and elaborations made by order of the mine. in the case under discussion, the work (Köhsling & Jagiełło 1988) was particularly interesting, which referred to, among others, the non-mined block of chambers KS-21.

A few conclusions from this work are worth mentioning because from the time perspective they show how carefully and in detail these kinds of problems were approached:

a) "(…) Exploitation of chambers in these widened pillars will not cause negative disturbances in decomposition of strains. The exception is block KS-21 because of its neighborhood to high cylindrical chambers where it cannot be said about regular decomposition of stresses in joints: inter-level shelf – pillars (...)".
b) "(…) in perpendicular of chambers KS-21,theoretically the chambers of the width 13 m can be made only in eastern section from the distribution drift to mother entry air-heading – leading to cylindrical chambers of the height on the level 525 m – 10 m, 550 m – 15 m, 575 m – 15 m and 600 m – 15 m. (…) The second section of perpendicular KS-21 from the entry drift to cylindrical chambers – till the western edge of the field no. 2 is recommended to be left non-mined because of the close neighborhood of cylindrical chambers (...)".
c) „(…) Because of the neighborhood of cylindrical chambers in the western part of the heading as well as the presence of the chambers of the height 28 m on level 550 m (to 523 m) – in the eastern part of the heading – making chambers KS-21 is not recommended, because in this volume of the salt deposit occurring strains cannot be modeled, and their disturbance can cause destruction of these chambers as it happened in KS-22/575 (...)".

The conclusions above, and the third one (c), in particular, confirm that the authors intuitively "felt the rock mass", whereas the lack of technical possibilities, a good computer with appropriate software, did not allow them numerical modeling of the rock mass and headings made in it to confirm their feelings. At present these problems have been overcome, which can be proved by the work (Cała *et al.* 2010).

LABORATORY TESTING OF SALT SAMPLES

For geo-mechanical phenomena forecasting, which occur in salt rock mass in the neighborhood of headings, basic strength and strain parameters are used. The main source of information is laboratory tests of mechanical properties of the rocks that the mass is built of. The basic tests comprise of: single-axial compression tests (compression strength test, modulus of elasticity, Poisson ratio), uniaxial tension tests (e.g., while using Brazilian method), and creep test under uniaxial load test (salt viscosity).

The laboratory tests of the salt rock mass have done so far, univocally show the specific, different character of this medium in reference to other kinds of rocks. Due to that fact, appropriate testing should be planned as part of the results can be obtained in relatively short time with the assumption that time does not have a more significant influence on the obtained results. There are tests lasting for a few months, even years, which mainly refers to rheological tests in particular (Ślizowski *et al.* 2010).

It should also be considered that the results of laboratory tests are often different from the ones recorded in nature. That fact can be connected, among others, with the choice of the material for testing (e.g., non-representative place in heterogeneous deposit), imperfection of laboratory testing methodology, etc, and may come from the peculiarity of the tested rocks, which is clearly seen in case of salt rock mass.

For the needs of the case under discussion above, strength testing of uniaxial compression strength was done and triple-axial compression strength test and creep test, which was appropriately supplied with documentary evidence in the form of the report of research (Fig. 3). The reports will be the grounds for working out the representative results for particular tests and enable to come to general conclusions referring to rock mass in the area under research.

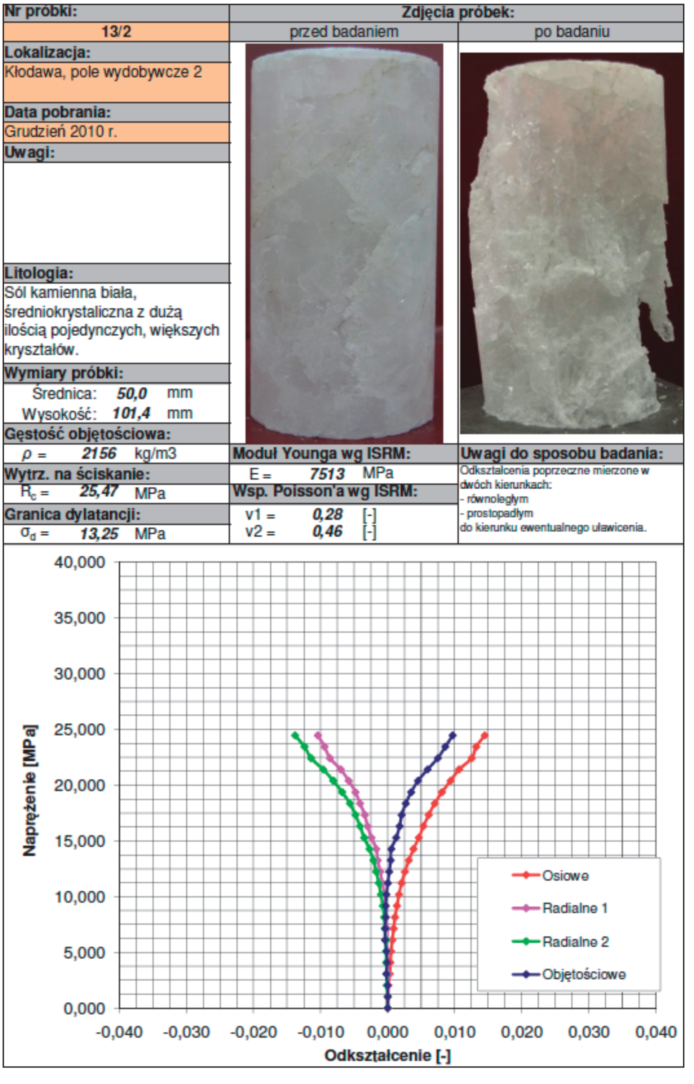

Fig. 3. Exemplary report of single-axial compression strength testing

Fig. 3. Przykładowy protokół z badania wytrzymałości na jednoosiowe ściskanie

NUMERICAL MODEL OF ROCK MASS IN THE AREA OF THE DESIGNED CHAMBER

(Cała *et al.* 2010)

To analyze the state of stress, displacement and strength/stress ratio in the area of the designed chamber KS-21exploitation, a lot of numerical calculations were done on the grounds of finite-difference method (FDM) with the use of the program FLAC3D.

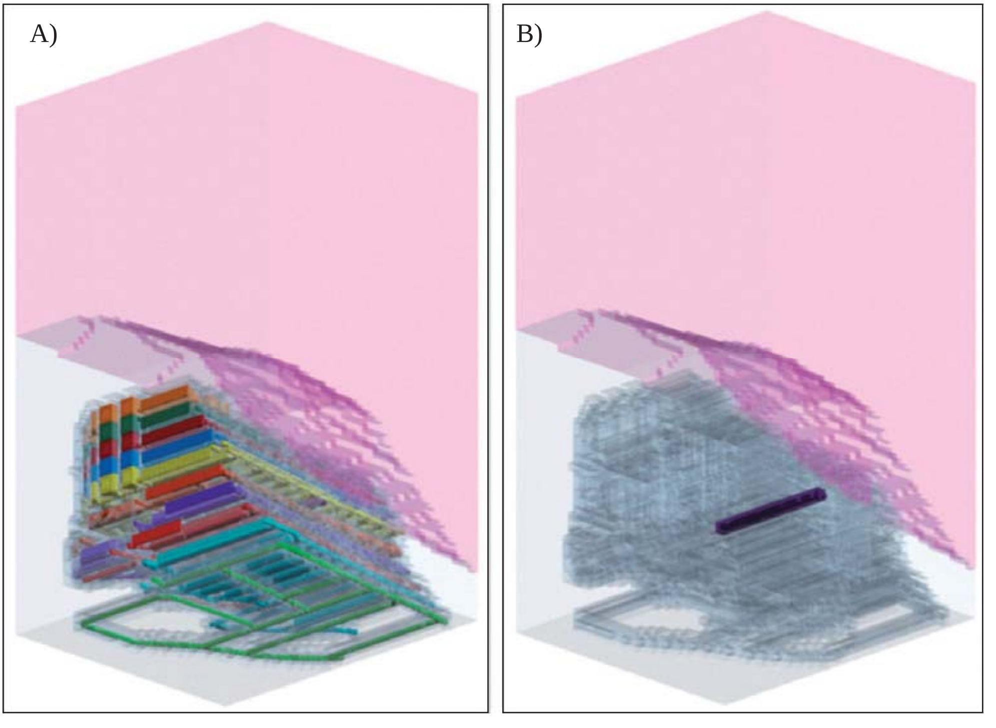

Fig. 4. Modeled section of rock mass (A). Localization of designed chamber KS-21 inside the elaborated model (B)

Fig. 4. Modelowany wycinek górotworu (A). Lokalizacja projektowanej komory KS-21 wewnątrz opracowanego modelu (B)

A three-dimensional model was made on the grounds of mining maps, on which the geometry of chambers, heading drifts and salt diapir were mapped. Due to geometrically diversified headings (both the shape of single headings and also their spacing are irregular) in the neighborhood of chamber KS-21, only a three-dimensional model can lead to reliable results of the analysis – it was mentioned in the projects done more than 20 years ago (e.g. Köhsling & Jagiełło 1988). The analysis was done on the rock mass section in the shape of rectangular prism of the dimension 400 m × 480 m × 760 m. inside which spacing of the headings and irregular shape of the deposit roof, which was determined on the grounds of geological profile, was mapped. It was assumed that the upper surface of the model corresponds with the surface of the area (Fig. 4A). Inside the model, the designed chamber KS-21 was located (Fig. 4B). The numerical model built consists of more than 844 thousand elements and 1,033 million nodes.

In the elaborated model it was assumed that the salt diaper is homogeneous similarly to the layer of overlay on it. For the both mediums elastic-plastic model was used with the condition of plasticity by Coulomb–Mohr, of the strength and deformation parameters presented in table 1.

Table (Tabela) 1

Strength and deformation parameters used in calculations

Parametry wytrzymałościowe i odkształceniowe zastosowane w obliczeniach

Parameter *Parametr*	Overlay *Nadkład*	Salt *Sól*
Unit weight [kN/m^3] *Ciężar objętościowy*	23.0	23.0
Young's modulus [MPa] *Moduł Younga*	6,000	15,000
Poisson's ratio [–] *Współczynnik Poissona*	0.25	0.25
Internal friction angle [°] *Kąt tarcia wewnętrznego*	30.0	35.0
Cohesion [kPa] *Kohezja*	1,000	5,333
Tensile strength [kPa] *Wytrzymałość na rozciąganie*	400	667

Numerical modeling by means of the program FLAC 3D enables to analyze in three dimensions and obtain a wide range of results including, among others, determination of stress and strength/stress ratio, quantity of the expected displacements. The results can be obtained for an optionally chosen point inside the model, and also optional intersection through the model. In the figures below (Figs 5–7) some chosen intersections of the analyzed case are shown, presenting the results of the chosen analyses before the chamber heading was made, and after it was done. Due to the size of the present paper, only a few characteristic figures are shown.

The basic aim in the analyses done is to determine the state of stress of the rock mass. Below, the horizontal intersections are shown, which illustrate vertical stresses at the height of 8 m above the floor of the heading (Fig. 5).

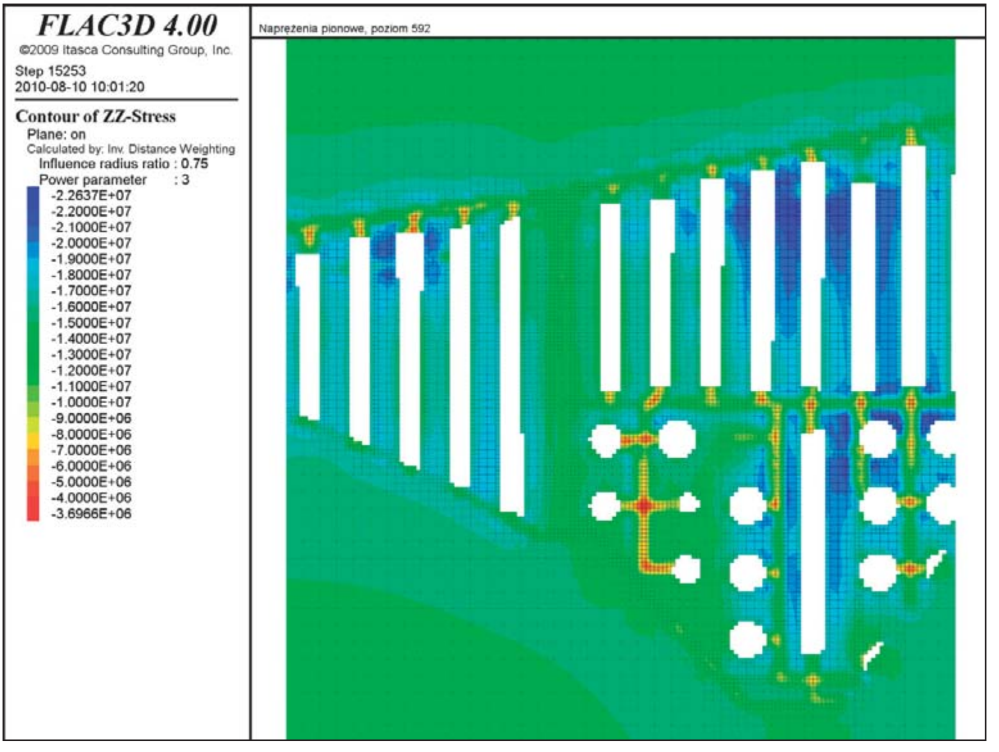

Fig. 5. Vertical stresses in the intersection of chambers' system on level 600 at the height of 8 m above the floor of the headings before chamber KS-21 was made

Fig. 5. Naprężenia pionowe w przekroju układu komór poziomu 600 na wysokości 8 m nad spągiem wyrobisk przed wykonaniem komory KS-21

Analyzing he figure above, owing to the colorful map of stresses, it can be easily observed that the zones of increased concentration of vertical stresses are seen in inter-chamber pillars. The dog heading, which the chamber is heading for KS-21, is not seen because its intersection was made under its roof floor, nevertheless, its "trace" can be seen.

From the engineering point of view, it seems more practical to analyze the maps of rock mass strength/stress ratio around the headings, from which these values can be directly read (strength/stress ratio in the presented figures should be understood as "reserves" of strength, in this case as factor of safety, which is calculated as strength to stress ratio). The exemplary figure illustrating the quantity of strength/stress ratio for initial state from the previous figure (Fig. 5) is presented in figure 6.

In figure 6, the zones are seen where the strength/stress ratio is close to 1 (side-wall zones of pillars), nevertheless in the key points its quantity fluctuates around value 1.5 and more. On that ground it can be stated that modeled headings are stable, which is confirmed in natural state.

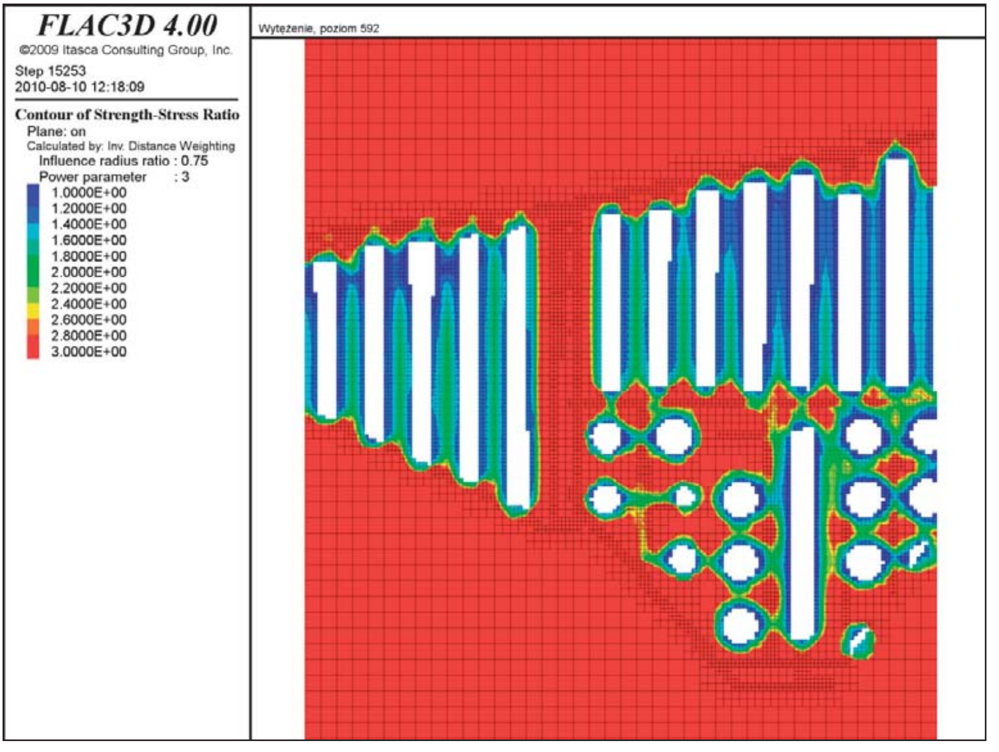

Fig. 6. Rock mass strength/stress ratio in intersection of chambers' system on level 600 at the height of 8 m above the floor of the headings before chamber KS-21 was made

Fig. 6. Wytężenie górotworu w przekroju układu komór poziomu 600 na wysokości 8 m nad spągiem wyrobisk przed wykonaniem komory KS-21

The next figure (Fig. 7) presents strength/stress ratio after chamber KS-21 was made.

Also in this figure, the places which could be the source of anxiety about the stability of the made KS-21 chamber are not seen. At present the chamber has been made and no alarming phenomena have been observed, therefore, it can be assumed that the accepted model was correct.

As already mentioned, some other dependence can be analyzed in an optional intersection through the model. in the case under research, two alternatives of driving a chamber were analyzed, which were different from each other with the direction of active end advance. The situation after each 10 m of chamber advance was analyzed. As seen, numerical methods and the used program enable "step by step" analyses in detail. Some imperfection of the program is the fact that it analyzes a situation without considering time parameter, which is quite significant in case of salt rock mass. Nevertheless, the program operates "on the safe side", which means that it accepts immediate formation of the whole chamber heading, and which is a more disadvantageous alternative than its analyses of its formation in time function.

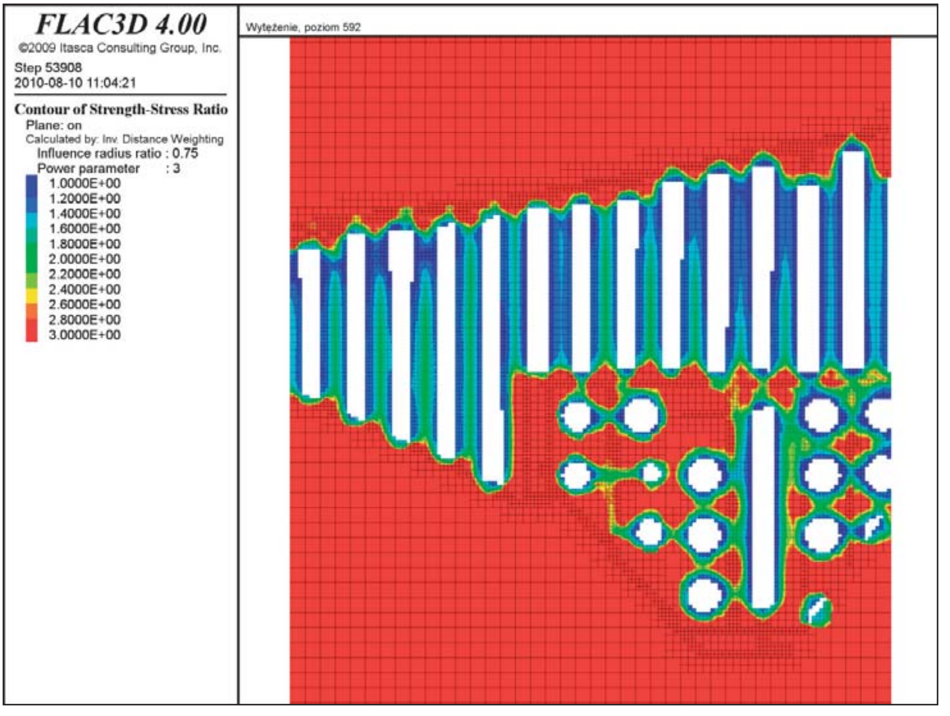

Fig. 7. Strength/stress ratio at the intersection of chamber system on level 600 at the height of 8 m above the floor of the headings after chamber KS-21 was made

Fig. 7. Wytężenie w przekroju układu komór poziomu 600 na wysokości 8 m nad spągiem wyrobisk po wykonaniu komory KS-21

SUMMARY

Numerical analysis of chamber KS-21 exploitation on level 600 with the designed overall dimensions showed that exploitation does not significantly change the state of stress and strength/stress ratio in the area of the analyzed excavation field no. 2. The changes in stress values are of local character and refer to the direct surrounding of the chamber under research. It can also be univocally stated that load-carrying ability of newly-made and neighboring pillars (also close to cylindrical chambers), as well as the stability of the neighboring chambers is not also endangered. The inter-level shelves will not also suffer from destruction, which was confirmed after the analysis of the vertical intersections, not presented in the present article.

Two alternatives were analyzed because of the direction of chamber exploitation. After analyzing the results obtained, it can be stated that the direction of driving the chamber does not influence the area under research after termination of the chamber exploitation. Therefore, the exploitation of chamber KS-21 on level 600 can be made in two directions: from the side of distribution-entry drift at the edge pillar towards the entry drift to cylindrical chambers and contrariwise direction. The direction of exploitation depends solely on logistic conditions connected with the haulage of mine run.

The presented example of the analysis of making chamber KS-21possibilities indicates that with appropriate methodology of actions, the attempt to analyze other locations in excavating field no. 2 can be undertaken, of the ones abandoned in the past as the location of potential salt chambers. The preliminary analysis indicates that about ten chambers can be "recovered" at relatively low cost, mainly connected with the haulage of mine run. Assuming the average dimensions of a chamber, it can be assumed that about 35 thousand of Mg can be mined from one chamber, which all ten chambers constitutes half-year production in global balance of the mine. The analysis on the grounds of numerical methods should be carefully made because, on principle, the programs assume homogeneity of particular analyzed medium. The geological structure of the deposit is diversified and accepting the assumption mentioned above in an uncritical way, can lead to serious consequences. Because of that reason, as far as the conditions allow, the obtained results should be confronted with the actual state. The case of field no. 2 gives such comfort, therefore, such probability of incorrect estimation of the situation is minimal.

Undoubtedly, the advantage of the program used is the possibility of three-dimensional analysis. Most programs is limited to solving two-dimensional problems, which in the case under discussion, may lead to serious mistakes, because of the complicated, three-dimensional structure of exploitation headings. Three-dimensional analyses presents the actual situation within the built model in the closest to realty way.

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Streszczenie

W obrębie pola eksploatacyjnego nr 2 w Kopalni Soli „Kłodawa" zlokalizowano około dziesięciu niewyeksploatowanych miejsc, które można by przekształcić w komory solne. Na przedstawionym przykładzie zaproponowano „algorytm" działań eksperckich, które powinny dać odpowiedź na pytanie, czy wznowienie eksploatacji może się odbyć w sposób bezpieczny dla kopalni. W przypadku uzyskania pozytywnej odpowiedzi opracowana ekspertyza ma stanowić podstawę umożliwiającą wystąpienie do Prezesa Wyższego Urzędu Górniczego w sprawie odstąpienia od obowiązujących przepisów. Przepisy prawa górniczego jednoznacznie nakazują przy wybieraniu komór w układzie wielopiętrowym w wysadowych złożach soli zachowanie kolejności wybierania komór od góry w dół oraz osiowość filarów (*Rozporządzenie...* 2002).

W tym celu wytypowano miejsce potencjalnej komory na poz. 600 – komorę KS-21 (Fig. 1), która będzie zlokalizowana w sąsiedztwie wybranych już komór (Fig.2).

Po przeanalizowaniu dokumentów źródłowych oraz przebadaniu pobranych próbek solnych (Fig. 3) określono podstawowe parametry masywu skalnego (Tab. 1), które zostaną wykorzystane do budowy przestrzennego modelu numerycznego (Fig. 4). Tak zbudowany model poddano analizie metodą różnic skończonych (MRS) przy zastosowaniu programu FLAC 3D, pozwalającego na trójwymiarową analizę m. in. stanu naprężenia, wytężenia i przemieszczenia. Przykładowe wyniki obliczeń przedstawiono w formie graficznej w postaci map naprężeń pionowych (Fig. 5) i wytężenia (Fig. 6, 7), wykazując, że wykonanie komory nie zagraża stateczności pola nr 2.

W podsumowaniu wskazano na zalety przyjętego trybu postępowania i ewentualne zagrożenia związane z przyjęciem niewłaściwych danych do modelu numerycznego.