Arch. Min. Sci., Vol. 57 (2012), No 1, p. 93–105

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.2478/v10267-012-0007-4

KAJETAN D'OBYRN *

THE STABILIZATION OF THE ROCK MASS OF THE WIELICZKA SALT MINE THROUGH THE BACKFILLING OF THE WITOS CHAMBER WITH THE USE OF INJECTION METHODS

STABILIZACJI GÓROTWORU KOPALNI SOLI „WIELICZKA" POPRZEZ LIKWIDACJĘ KOMÓR „WITOS" Z ZASTOSOWANIEM METOD INIEKCJI

The Wieliczka Salt Mine is the most famous and the most visited mining industry monument in the world and it requires modern methods to ensure rock mass stability and tourists' security. Both for conservation and tourism organization reasons, the group of Warszawa-Wisla-Budryk-Lebzeltern-Upper Witos Chambers (Photo. 1, 2. 3) located the Kazanów mid-level at a depth of 117 m underground is extremely important. Discontinuous deformation occurring in this Chamber complex was eliminated by comprehensive securing work with anchor housing, but their final securing and stability is conditioned by further backfilling and sealing the Witos Chambers situated directly beneath. In the 1940s and 1950s, the Witos Chamber was backfilled with slag from the mine boilerhouse. However, slags with 80% compressibility are not backfilling material which would ensure the stability of the rock mass.

The chambers were exploited in the early nineteenth century in the Spizit salts of the central part of the layered deposit. The condition of the Upper Witos, Wisla, Warszawa, Budryk, and Lebzeltern Chambers is generally good. The western part if the Lebzeltern Chamber (Fig. 1), which was threatened with collapse, was backfilled with sand. In all the chambers of the Witos complex, local deformation of ceiling rock of varying intensity is observed as well as significant destruction of the side walls of pillars between chambers. No hydrogeological phenomena are observed in the chambers. It has been attempted to solve the problem of stability of the rock mass in this region of the mine by extracting the slag and backfilling with sand, erecting concrete supporting pillars, backfilling the voids with sand, anchoring the ceiling and the side walls, the use of the pillar housing. The methods have either not been applied or have been proved insufficient to properly protect the excavation situated above.

In order to select the optimal securing method, a geomechanical analysis was conducted in order to determine the condition of the chambers with particular emphasis on the pillars between the chambers. The analysis demonstrated the need to backfilling the Witos Chambers in order to improve the strength parameters of the pillars and the cross-level ledge. The next step consisted of selecting the sealing mix and testing how the additional burden and improving the slag strength parameters shall affect the stability of the excavations of the Kazanów mid-level. In order to determine the optimal composition of the backfilling mixtures, formulas of sealing brine slurries have been developed. Laboratory tests were also conducted concerning the strain parameters specifications of slags extracted from the Witos Chamber. Taking into account the slurry tests, and in particular, the density, strength and strain parameters, the optimal composition of the sealing mix was selected. The analysis of the results of numerical recalculations demonstrate that even the use of highest-density mixtures, backfilling(sealing) of the Witos Chambers

* "WIELICZKA" SALT MINE S.A., PARK KINGI 1, 32-020 WIELICZKA, POLAND.
FACULTY OF ENVIRONMENTAL ENGINEERING, CRACOW UNIVERSITY OF TECHNOLOGY, WARSZAWSKA 24, 31-155 KRAKÓW, POLAND

should not cause significant disturbance of the current tension in the surrounding rock mass. The long-term impact of sealing should lead to improvement of the strain levels on the ledges between Level III and Kazanów mid-level chambers.

The positive results of applying in the Mine of injection slurries for sealing and stabilizing the rock mass and the construction of the injection node on the surface of the Kosciuszko shaft area have allowed resuming work in the Witos Chambers. The main injection over 1,000 m long pipeline was constructed from the injection node through the Kosciuszko Shaft and along Level III of the mine. The sealing of the Witos Chambers complex was divided into three areas (Fig. 2) separated by backfilling dams. Each region was connected to an injection and venting pipeline, and areas of possible injection material off-flow from backfilling locations were secured. Once that the Chambers are sealed with the use of the pipeline seven bore holes will be drilled from excavations situated above through which the sealing slurry will be administered. The operation will serve to eliminate any voids and re-seal the slag, and it will be conducted until pressures of approximately 0.5 MPa on the bore hole collar is achieved.

As past experience indicates, injection slurry formula can be regularly adjusted adequately to the changing geomechanical parameters and the type of sealing work at the Wieliczka Mine.

Once that the backfilling and sealing process in the Witos Chambers complex is completed, it shall be necessary to conduct monitoring activities in order to determine the processes occurring in the rock mass after the backfilling.

The properties of sealing mixtures qualify those for use in the environment both of salt mines and other mineral ore mines to stabilize the rock mass in the mining-geomechanical context precluding the possibility of weakening the rock mass strength parameters and at the same time sealing the rock mass and the loose material deposited in the excavation.

Keywords: salt mine, rock stabilization, sealing slurries, slag injection

Kopalnia Soli „Wieliczka" będąca najbardziej znanym i najliczniej odwiedzanym zabytkiem górniczym na świecie wymaga najnowocześniejszych metod zapewniających stabilność górotworu i bezpieczeństwo zwiedzających. Niezwykle ważny ze względów konserwatorskich jak i organizacji ruchu turystycznego jest zespół komór Warszawa-Wisła-Budryk-Lebzeltern-Witos Górny (Fot. 1-3) zlokalizowany na międzypoziomie Kazanów na głębokości 117 m p.p.t. Występujące w tym zespole komór deformacje nieciągłe zniwelowane zostały poprzez kompleksowe zabezpieczenie ich obudową kotwową jednak ich docelowe zabezpieczenie i stabilność warunkowana jest dosadzeniem i doszczelnieniem leżących bezpośrednio pod nimi komór Witos. Zespół komór Witos został w latach 40 i 50. XX wieku podsadzony żużlem z kotłowni kopalnianej. Żużle o ściśliwości 80% nie stanowią podsadzki, która zapewniałaby stabilizację górotworu.

Komory zostały wyeksploatowane na początku XIX wieku w solach spizowych łuski centralnej złoża pokładowego. Stan komór Witos Górny, Wisła, Warszawa, Budryk, Lebzeltern jest na ogół dobry. Zachodnia część komory Lebzeltern (Rys. 1) była w stanie zawałowym i z tego względu została podsadzona piaskiem. We wszystkich komorach zespołu Witos obserwuje się lokalne deformacje skał stropowych o różnym natężeniu oraz znaczne niszczenie ociosów filarów międzykomorowych. W komorach nie występują zjawiska hydrogeologiczne. Problem stabilizacji górotworu w tym rejonie kopalni starano się rozwiązać poprzez wybranie żużla i podsadzenie piaskiem, budową podporowych słupów betonowych, dosadzenie pustek piaskiem, kotwienia stropu i ociosów, zastosowanie obudowy podporowej. Metod tych nie zastosowano lub okazały się nieskuteczne dla prawidłowego zabezpieczenia wyrobisk nadległych.

W celu wyboru optymalnej metody posłużono się analizą geomechaniczną, której celem było określenie stanu komór ze szczególnym uwzględnieniem filarów międzykomorowych. Na tej postawie stwierdzono konieczność wypełnienia komór Witos w celu poprawy parametrów wytrzymałościowych filarów i półki międzypoziomowej. Kolejnym krokiem był dobór mieszaniny doszczelniającej i sprowadzenie jak dodatkowe obciążenie i poprawa parametrów wytrzymałościowych żużli wpłynie na stateczność wyrobisk międzypoziomu Kazanów. W celu określenia optymalnego składu mieszanin podsadzkowych opracowano receptury solankowych zaczynów doszczelniających. Przeprowadzono również badania laboratoryjne własności parametrów odkształceniowych żużli pobranych z komór „Witos". Biorąc pod uwagę badania zaczynów, a w szczególności gęstość oraz parametry odkształceniowe i wytrzymałościowe wybrano optymalny skład mieszaniny doszczelniającej. Z analizy wyników ponownych obliczeń numerycznych wynika, że nawet w przypadku stosowania mieszanin o największej gęstości podsadzenie (doszczelnienie)

komór Witos nie powinno spowodować istotnego zaburzenia stanu naprężenia panującego w górotworze otaczającym. W dłuższej perspektywie czasowej wpływ doszczelnienia powinien przejawiać się w poprawie stanu naprężenia w półkach pomiędzy poziomem III a komorami międzypoziomu Kazanów.

Pozytywne wyniki stosowania w Kopalni zaczynów iniekcyjnych wykorzystywanych do uszczelniania i stabilizacji górotworu oraz budowa na powierzchni w rejonie szybu Kościuszko węzła iniekcyjnego stworzyły warunki do ponownego podjęcia prac w komorach Witos. Od węzła iniekcyjnego poprzez szyb Kościuszko oraz III poziomem kopalni został doprowadzony główny rurociąg iniekcyjny o długości ponad 1000 m. Doszczelniany zespół komór Witos podzielono na trzy pola (Rys. 2) oddzielone tamami posadzkowymi. Do poszczególnych pól doprowadzono rurociągi iniekcyjne i odpowietrzające oraz zabezpieczono miejsca możliwego odpływu iniektu z pól podsadzkowych. Po doszczelnieniu komór rurociągami odwiercone zostanie z wyrobisk nadległych siedem otworów przez które również będzie podawany zaczyn uszczelniający. Podawanie zaczynu otworami będzie miało na celu likwidację ewentualnych pustek i ponowne doszczelnienie żużli, a prowadzone będzie do osiągnięcia ciśnienia ok. 0,5 MPa.

Jak wynika z dotychczasowych doświadczeń, receptury zaczynów iniekcyjnych mogą być na bieżąco korygowane adekwatnie do zmiennych w warunkach KS „Wieliczka" parametrów geomechanicznych i rodzaju prac doszczelniających.

Po zakończeniu procesów podsadzkowo-doszczelniających w zespole komór „Witos" konieczne jest prowadzenie monitoringu w celu określenia procesów zachodzących w górotworze po zakończeniu podsadzania.

Właściwości mieszanin doszczelniających predysponują je do wykorzystania w warunkach kopalni soli jak i innych kopalniach surowców mineralnych celem zarówno stabilizacji górotworu w warunkach górniczo-geomechanicznych wykluczających możliwość osłabienia parametrów wytrzymałościowych górotworu jak i równoczesnego doszczelniania górotworu oraz materiału luźnego zalegającego wyrobiska.

Słowa kluczowe: kopalnia soli, stabilizacja górotworu, zaczyny uszczelniające, iniekowanie żużli

1. Introduction

In order to preserve the historic excavations of the Wieliczka Salt Mine, it is necessary to protect them against natural hazards occurring in the mine, which include water, collapse and gas hazards. A large number of mine excavations is located in the conservation protection zone and listed in the national register of monuments and the UNESCO List, the long experience in

Photo 1. The Warszawa Chamber, view towards the West

Photo 2. The Budryk Chamber, view towards South-West

Photo 3. The Wisla Chamber, view towards the West

securing activities along with the existing natural hazards identified so far as well as the results obtained through specialist geomechanical analysis indicate the necessity of conducting mining operations on a scale unprecedented in the world.

The scope of the securing work has been determined for the Tourist Routes and the Krakow Saltworks Museum excavations visited by a million tourists annually, both in the chambers themselves and the adjacent areas stabilizing the rock mass. Both for conservation and tourism organization reasons, the group of Warszawa-Wisla-Budryk-Lebzeltern-Upper Witos Chambers (Photo. 1, 2, 3) located the Kazanów at a depth of 117 m underground is extremely important. Discontinuous deformation occurring in this Chamber complex was eliminated by comprehensive securing with anchor housing. However, their final securing and stability is conditioned by further backfilling and sealing the Witos Chambers situated directly beneath.

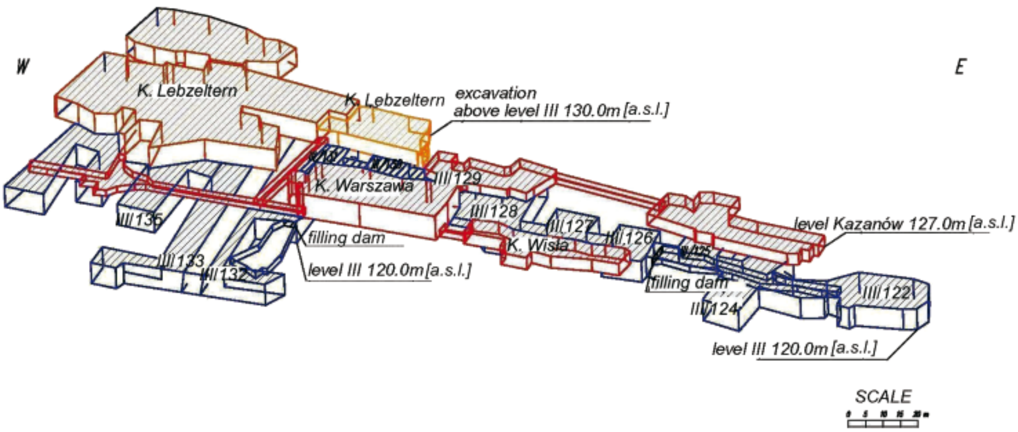

Fig. 1. Diagram of the spatial outlay of the Warszawa, Wisła, Budryk, Lebzeltern, and Upper Witos Chambers at the Kazanów mid-level and the Witos Chambers at Level III

Given the importance of the chambers of the Kazanów mid-level and an atypical manner of backfilling those in the 1940s and 1950s, the Witos Chambers located below, with slag from the Mine boiler house, the ensuring rock mass stability in this area is a very important task, and is at the same technically demanding and it requires applying special methods preceded by thorough research.

2. Geological Conditions

Analyzing the geology of the Wieliczka layer is directly conditioned by its exploitation over a period of more than 700 years (d'Obyrn & Przybylo, 2010) and has been presented in a number of publications such as Aleksandrowicz et al. (2009). Below, we shall only focus the basic data concerning the described area of the mine.

The Wisla, Warszawa, Budryk, Lebzeltern and Witos Chambers were exploited in the early nineteenth century in the Spizit salts of the central parts of the layered deposit. Spizit salts in this part of the layer are characterized by the presence of several layers of rock salt separated by ingrown gangue of anhydrite marl type with variable thickness. The layers of the layered deposit incline southward at an angle of approximately 30° to 50°. Mudstone and sandy-clay partings with an admixture of anhydrite reach the thickness between a few centimeters and 1 meter and transmute by facies into claystones or sandstones with anhydrite. Anhydrite also occurs in layers with thickness of up to a few cm and in angular clusters with a diameter of 20-30 cm.

Due to the fact that the Spizit salt layer (in the area in question) underwent intense tectonic processes, its original profile has been heavily distorted. In the layer, profile multiplying, internal slicing and folding is observed on the side walls. Gangue partings are disrupted, cracked, and do not form a continuous layer. All lithological and structural elements of the layer vary in inclination and extent, but generally follow the parameters of the Spizit salt fold. In the vicinity of the chambers, thick pillars and ledges are found separating the Spizit salt layer from the weak rock of the blocky deposit.

The hydrogeological conditions of the layer (Brudnik et al., 2010) with the last disastrous inflow as well as the programs developed in order to protect the Mine against uncontrolled inflow of groundwater (Gonet et al., 2000; Garlicki et al., 2004) allow to clearly determine that the greatest hazard for the mine may be constituted by aquifers located on the north side of the deposit. The Poniatowski transverse (Fig. 2) at the Kazanów mid-level is an example of an excavation which crosses the northern limits of the deposit. In 1992, The northern end of the transverse was closed off with sealing slurries due to the water hazard. However, other than for the Poniatowski transverse, no hydro-geological phenomenon recorded as leaks are present in the area in question. In the Warszawa and Budryk Chambers periodical, disappearing condensation of saturated brine from ceiling has been observed. The condensation was associated with the migration of brine from higher-located Mine levels along the gangue partings. This phenomenon is also observed in the Upper Witos Chamber, and causes a weakening of the geomechanical parameters of rocks.

3. The technical condition of the Chambers

The condition of Upper Witos, Wisla, Warszawa, Budryk, and Lebzeltern Chambers is generally good. The western part of the Lebzeltern Chamber (Fig. 1) was classified as threatened with collapse and was therefore backfilled with sand.

At level III, at a depth of 130 m, a large complex of Witos Chambers is located, exploited by chamber-and-pillar method. The chambers and pillars of the complex are positioned perpendicular to the Warszawa, Lebzeltern and Budryk Chambers. The Witos Chambers complex (Fig. 2) has a length of approximately 300 m and a width of approximately 23 to 80 m. It consists of 19 interconnected chambers of regular cuboid-like shapes similar with heights ranging from 6 to 8 m. The chambers were exploited using explosives in a dry method, leaving pillars of a width of 6 to 10 m.

The greater part of the Witos Chambers complex has been filled to approximately 85% with slag, which is the backfilling material of these chambers. The thickness of the slag layer can be estimated at approximately 4 to 6 m, and its height in the chamber varies. The space remaining to fill does not exceed 1 m at the side walls, and approximately 2 m in the central part of the chambers. The volume of voids in the different chambers ranges from 48 to 340 m^3.

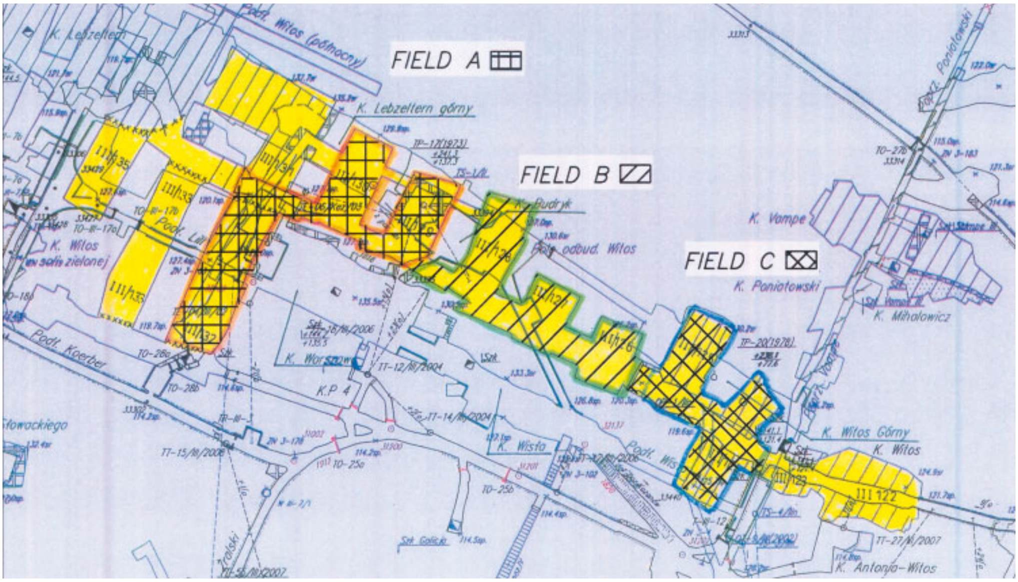

Fig. 2. Map of Level III of the Wieliczka Salt Mine including the chambers to be sealed

Backfilling and sealing works are planned in the eastern part of the Witos Chambers complex, which has been divided into three areas (Fig. 2).

Chambers of the „A“ area, with a height of approximately 5-6 m, are situated to the north and west of the the Warszawa Chambers situated above. Along the Chambers III/129, III/130 and III/131, a transportation gallery of a height of 1.2-1.5 m has been preserved, leading to the dam at the limit of area “B”. The technical condition of the Chambers is relatively good. In the chamber ceilings, only single cracks are visible. The height of the transportation gallery, and what follows the space to be backfilled, is of approximately 2 m. The western side wall of the chamber has been backfilled. In the area, thanks to concrete rings placed directly on the floor, it was possible to measure the thickness of the slag layer, which amounts to approximately 4.7 m. Although the “B” area is adjacent to the “A” region, there is no direct connection between the two. The line dividing the two areas is located under the gallery connecting the Warszawa and the Budryk Chambers, where a crib filled with the excavated salt is located.

The “B” area is not evenly filled with slag. The clearance between the slag heap and the ceiling is of approximately 1 m, and by the side walls – maximum 0.3-0.5 m. The III/126 Chamber adjacent to the III/125 Chamber is located directly under the edge of the Upper Witos Chamber and the effects of the ceiling ledge damage in the III/125 Chamber are visible in it. Along the area , a transportation gallery with a height of 1.2 m has been preserved. The ceiling of the Chamber is in good condition: only locally some flaking is to be observed on the mudstone in-layers.

Area ‘C’ consists of the III/125 and III/124 Chambers which have been backfilled with sand almost completely, with a preserved passage of a height of approximately 1.5 m. The overall condition of the roof in Chambers III/124 and III/125 and the accessible, exposed part is satisfactory. In the vicinity of the III/125 Chamber, in front of the ventilation dam a rubble created by heaping up the rock excavated from the Upper Witos Chamber is located. In the corner of the Chamber

III/125, located directly under the edge of the Upper Witos Chamber, effects of the destruction of the roof ledge and small-scale "contact" between the two chambers are visible. In the area of contact with the Upper Witos Chamber and the likely negative impact of the edge of the Chamber located above, local peeling of the ceiling layers is to be observed in the form of thick patches sticking out by 0.2-0.3 m. Originally, in the III/125 Chamber, a space existed extending from the floor of Level III to the Upper Witos Chamber. This space was filled with sand in order to align the backfilling level to the level of the Upper Witos Chamber at the Kazanów mid-level.

To sum up the technical condition of the chambers, it can be concluded that local deformation of rock slab of varying intensity and significant destruction of the pillars between the chambers side walls are observed in all the chambers.

The eastern part of the Witos Chambers complex (Chambers III/122 and III/123) was backfilled with sand with a passage preserved in the central part. The excavations are in a very good condition. The strongly folded ceiling testifies to the considerable convergence of the excavation, but no cracks or any evidence of a loss of stability are visible. It is currently not planned to seal these Chambers.

Chamber III/131 located underneath the Lebzeltern Chamber was not originally backfilled. As a result of the partial collapse of the ledge between the III/131 and Lebzeltern Chambers, a part of the sand with which the Lebzeltern Chamber was originally backfilled shifted to the chamber located beneath. The material was used for backfilling the Witos Chambers in the area of the Lebzeltern Chamber, and this part of the chambers is currently inaccessible. Also Chambers III/133 and III/135 in the immediate vicinity of the Lebzeltern Chamber have been completely backfilled with sand and are inaccessible.

4. The choice of the backfilling and sealing material

In the 1940s and 1950s, the Witos Chamber was partially backfilled with slag from the Mine boilerhouse. However, slags with 80% compressibility do not constitute backfilling material which would ensure the stability of the excavations situated above and they posed a serious technical problem for a number of years, preventing full securing of the rock mass in this region.

4.1. Previous work and securing concepts

The problem of backfilling the Witos Chambers was addressed in the 1980s by extracting the slag and transferring it to other areas of Mine; for this purpose, the entrance excavations to the Chambers were remade. However, because of mining and ventilation hazards (possibility of dust entering the Tourist Route) the project was abandoned.

Another project which was implemented particlly the construction in Chamber III/132, directly behind the stage of the Warszawa Chamber situated above, of four supporting pillars for spot support of the concrete ceiling (after some of the slag was extracted). The supporting pillars of a diameter of 1.2 m were situated at a distance of between 0.55 and 1.15 m from the eastern side wall of the Chamber. The distance between the poles is of approximately 3 m. However, the pillars' excessive rigidity and lack of to vertical convergence tolerance caused their considerable destruction and they do not provide efficient securing for the excavations located above.

One of the considered concepts of completing the closing off of the Witos Chambers consisted in backfilling them with sand with the use of a dry or a wet method. However, backfilling the remaining voids with sand is not possible due to the 80% compressibility of slag. Sand deposited on the slags would not reinforce the ceiling of the Witos Chambers, and vertical convergence processes in the excavation would continue until compressing the voids in the slags. This would also make it impossible to observe the process of excavations' compression, including the uneven settling of the ceiling. Also brine dripping from the backfill and forming the backfilling medium would increase the collapse hazard of the Chambers by increasing the rock humidity level and would negatively influence the air humidity in the excavations of the Tourist Route.

The ceiling in the Witos Chambers is too low even in their central parts to allow drilling or the erection of anchor housing without removing the slag. Anchor housing could strengthen the ledge between the chambers of the Kazanów mid-level and the Witos Chambers; however, it would not reduce the speed of the Witos Chambers compression. Also the strengthening of the pillars could prove ineffective as uneven convergence would lead to creating gaps in the floor of the chambers located above or the collapse of the ledge as in the Lebzeltern and Upper Witos Chambers.

Since the Witos Chambers have no historic value, the possibility of preserving them and applying support housing was not taken into consideration. Constructing crib housing in the chambers would require removing slag under the cribs in order not to sink into the slag. Otherwise, the cribwork would fail to support the ceiling just as in case of the sand filling.

4.2. Geomechanical analyses

A number of studies have been devoted to the problems of the stability of excavations, their complexes and the mine as a whole, most of those unpublished. Information concerning the modeling of stress in the salt rock mass can be found e.g. in the work of Kortas (2004, 2006). In analyzing the mining conditions, it should be noted that the total width of the exposed ceiling of the Warszawa-Budryk Chambers in the NS line amounts to approximately 35 m. Such a large span of exposed ceiling, with relatively low physico-mechanical parameters of the rock mass and a number of factors detrimental to their technical condition suggests that the pillar separating the Chamber and Budryk Warszawa is the weakest link in the strain system of the analyzed chamber complex.

The main directions of action aimed at ensuring adequate stability should focus on strengthening the pillar between the chambers through, among others, rapid and accurate backfilling of the Witos Chambers. The closing off of these chambers should contribute to equalizing the speed of settling the floor of both analyzed chambers, and thus at least partially eliminate the bending and shear stresses, which are mainly concentrated in the roof ledge above the Witos Chamber and the pillar. It should also be noted that the resistance of Spizit salt to bending and shearing is limited, much smaller than to compression, while the "in situ" strength in the analyzed region is significantly reduced by gangue layers occurring locally (Bauer et al., 2004).

In order to assess the impact of backfilling the Witos Chambers on the excavations located above, a numerical simulation has been conducted of geomechanical phenomena and processes occurring in the region of the Witos Chambers complex and the surrounding chambers during the period preceding completing the sealing of the Witos Chambers and after filling them with mixtures of different composition and properties. To achieve this task, a dimensional model was constructed reflecting the geometry of voids in the analyzed region. On this basis, a geomechanical numerical model was created, taking into account the variability of the geological structure and the strength parameters, strain and rheological parameters of the rock backfilling mixtures and slag determined on the basis of archival materials, inverse analysis and tests. For these models, calculations were conducted concerning the condition of stress, strain and tension for the current state of affairs and the one projected after filling the selected chambers with backfilling material. In the calculations, the finite element model COSMOS/M software was used. The calculations were made assuming the elastic and elastic-plastic model of rock mass (Tajduś et al., 2009; Czaja et al., 2010).

The analysis of the maps of the smallest principal stresses σ_3 in the vertical longitudinal WE section at the stage of calculations without sealing work demonstrates that the largest concentrations of compressive stress in this section occur at the pillars between the Witos Chambers at Level III – the backstage and stage area of the Warszawa Chamber, reaching the value of 15 MPa. however, the concentrations of these stresses quickly recede, stabilizing at around 10 MPa. For the other pillars of the Witos Chambers complex, in the eastern part, the compressive stresses in the pillars do not exceed the value of 8 MPa. The analysis of the results of numerical calculations indicates that even if mixtures with the highest density were to be used, the backfilling (sealing) of the Witos Chambers should not significantly distort the prevailing stress in the surrounding rock mass. In the longer term, the impact of sealing should manifest itself in improving the stress condition on the ledges between the level III and the chambers of the Kazanów mid-level (Czaja et al., 2010).

5. Injection slurry selection

The positive results of applying injection slurries in the Mine for sealing and stabilizing the rock mass, and the construction on the surface in the Kosciuszko Shaft area of and injection node, have allowed resuming work in the Witos Chambers.

The properties of mixtures for filling voids and sealing of the rock mass have been the subject of patents (Stryczek et al., 1993) and scientific studies (Stryczek & Wisniowski, 2004, Garlicki et al., 2004). However, work on the selection of the adequate composition of the mixture in terms of strength (Stryczek et al., 2009) must also take into account the specificity of the rock mass in which the injections are planned.

In order to determine the optimal composition of backfilling mixtures, formulations of different brine sealing slurries have been developed, with the following main ingredients: granulated ground blast furnace slag, CEM I 42.5 Portland cement, brine, “Zębiec” bentonite and sodium carbonate Na_2CO_3. As these mixtures differ in density and strength and strain properties, tests were conducted to analyze their density, leveling, viscosity, filtration, flexural and compressive strength and setting time. Additionally, tests of strain and strength properties of were conducted on cylindrical samples made of various mixtures after 28 days of hardening. Laboratory tests were also conducted concerning the strain parameters of slags extracted from the Witos Chambers. These studies allowed selecting the optimal backfilling mixture (Czaja et al., 2010).

6. Work Technology

In the preparatory stage, the technical condition of the site was inspected and excavations ventilation assured. The next step consisted in laying the main injection pipeline made from ∅ 120 mm PE of a length of approximately 1,000 m from the injection node by the Kosciuszko

Shaft to Level III and on level III to the Witos Chambers area. Three branches were led from the main pipeline: to the T-2 dam, the Lebzeltern Chamber and the T-3 dam, from where ∅ 50 mm steel pipes were laid:

- area "A" – pipeline behind the T-2 dam and through the III/132, III/130, and III/129 Chambers to the peak point of the bank at the contact point between III/129 and III/128 Chambers, of a length of approximately 80 m.
- area "B" – pipeline behind the T-3 dam into the III/128 Chamber, pipeline behind the T-3 dam into the III/127 Chamber, pipeline behind the T-3 dam into the III/126 Chamber, of a length of approximately 110 m.
- area "C" – pipeline behind the T-4 dam into the III/125 Chamber, of a length of approximately 35 m.

Along the injection pipelines, vent pipes were led to the highest point in each area.

Before starting feeding the slurry, the injection pipeline should be rinsed with saturated brine at the beginning of the work shift and at its end. The brine used to rinse pipelines should not be discharged to the injected areas, since this would change the parameters of the injection slurry; it should be discharged into another area of the mine, to old backfilling areas, where, after purification, it will be channeled into the network of mine drainage pipelines.

Further preparatory work will require boring three backfilling holes to the highest points of the ceiling of the III/132 Chamber and the creation of four backfilling dams:

- T-1 closing the "A" area from the west and separating the III/133 Chamber from the III/132, III/135 Chambers.
- T-2 closing the "A" area from the south and separating the III/132 Chamber from the III/134 Chamber.
- T-3 closing the "B" area on the east side.
- T-4 closing the "C" area from the east and separating the III/123 Chamber from the III/124 Chamber.

During the filling of voids in the Witos area with slurry, it is possible to feed slurry to two small shafts leading to this area and located on the western and eastern side of the injected part of the Witos Chambers. These two lead from Level III, from the Old Stables area to the Chamber III/132 and from the Vampe transverse on Level III to the III/124 Chamber. Both shafts have wheel-rim casing in timber, to which strips of canvas are to be nailed for ventilation.

The works will be conducted in three stages, based on the project and using the patent concerning filling the empty areas of the rock mass (Gonet et al., 1993).

In the first stage, after the preparatory work for the "A" and "B" areas, slurry will be fed into voids in the "A" area from the injection node by the Kosciuszko Shaft. First, the slurry will be fed by pipeline to the highest point on the ceiling bank at the contact point between Chambers III/129 and III/128. Leaven flowing from the tip of the pipeline will gradually fill the void limited backfilling dams. In the final phase of filling, the void will be filled up through backfilling holes from drilling stations located in the Lill Transverse and the ramp into the Lebzeltern Chamber. During the filling of voids in the "A" area, it is possible that slurry shall cross the bank between the III/129 and III/128 Chambers to the "B" area.

In the second stage, slurry will be fed into the voids in the "B" area to the highest point of the III/128 Chamber. Flowing from the tip of the pipeline, the slurry will gradually fill the void limited by the T-3 backfilling dam. At a later stage of works, slurry will be fed by pipeline to the highest point of the III/127 and then the III/126 Chamber. In the final phase of filling, the void will be filled up by the vent pipe.

In the third stage, once that the preparatory work for the "C" area is completed, slurry will be fed to the highest point of the III/125 Chamber.

The sealing work consisting in feeding slurry through holes drilled from excavations located above will be conducted in the inaccessible parts of the Witos Chambers, which have been filled with slag to an unknown degree. The injected slurry will fill the voids that may exist in these Chambers and seal the slag located there, once that the slurry fed in stages I, II, III, of the back-filling work binds. During the pumping of the slurry through the sealing holes, it is expected to reach a small level of pressure (up to 0, 5 MPa). In the case of low absorption, the preparation of the injection mixture and the feeding of slurry will take place at the drilling station, while in the case of high absorption of the mixture, injection will be fed from the node at the Kosciuszko Shaft. The final stage of work will consist in drilling additional sealing holes. In the "A" area, three sealing holes are planned, and in the "B" area, four holes. The slurry fed through the holes will fill any voids left after sealing through pipelines, and it will additionally seal the voids in the slags (Parchanowicz & Dębkowski, 2003; Parchanowicz, 2010).

7. Conclusions

1. The Wieliczka Salt Mine, the most famous and the most visited mining industry monument in the world, requires state-of-the-art methods to ensure rock stability and visitors' security.
2. Long experience of identifying hazards, securing work and stabilizing the rock mass in collaboration with leading mining scientific centers allow to continually improve securing methods used in the complex geological and mining conditions of the Wieliczka Mine.
3. The method of pipeline injection which has been developed and is continually improved, used so far for sealing the salt rock mass, has been applied in atypical sealing and stabilizing work in the chambers filled in the 1940s and 1950s with slag of 80% compressibility.
4. In filling the pores of the boiler slags placed in the Witos Chambers complex, the sealing slurries developed should significantly reduce slag compressibility and improve the strength parameters of the unusual filling material.
5. Past experience indicates that sealing slurries formulas can be regularly adjusted adequately to the changing conditions of geomechanical parameters and the type of sealing work at the Wieliczka Salt Mine.
6. After the backfilling and sealing process in the Witos Chambers complex are completed, it will be necessary to conduct monitoring activities to determine the processes occurring in the rock mass after the backfilling.
7. The properties of the described sealing slurries qualify those for the use in the environment both of salt mines and other mineral ore mines to stabilize the rock mass in the varied mining-geomechanical context and at the same time seal the rock mass and the loose material deposited in the excavations.

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Received: 06 September 2011