Andrzej Gonet*, Stanisław Stryczek*

**METHOD USED FOR SAFETY PILLAR RECONSTRUCTION
ON THE EXAMPLE OF THE DUNAJEWSKI GALLERY
IN THE “WIELICZKA” SALT MINE****

1. INTRODUCTION

The total volume and length of all workings made in the “Wieliczka” Salt Mine during over 7 centuries equaled to over 6 million m³ and over 200 km, respectively. For many reasons, mainly due to imprecise recognition of geological build of the deposit, in the past some headings were drilled in the safety pillar, and some chambers were localized too close to the salt dome boundary. This resulted in many leaks, especially of waters coming from the Chodenice beds deposited beyond the northern boundary of the salt dome. In many cases water creates a catastrophic threat for the salt mines [1, 2, 8]. For this reason at the end of mine’s life the object is controllably flooded. However this procedure cannot be always performed. One of such examples is the “Wapno” Salt Mine in Poland [7]. Uncontrollable flux of huge amounts of water to the mine results in considerable damage, e.g. destroyed buildings on the surface above the mine and threatened life of people. For avoiding such situations a protection plan lying in the reconstruction of the inner safety pillar was worked to preserve the world’ unique historical object, i.e. “Wieliczka” Salt Mine for the future generations [1, 5]. One of such places is the Dunajewski gallery, connected with a leaching gallery and localized on level IV in the immediate vicinity of the Mina gallery. The catastrophic water flux to the Mina gallery, which started on 13 April 1992, caused severe damage to the mine and on the surface, questioning the existence of the historical route and part of Wieliczka town [10]. Many years’ efficient cooperation of academic workers from AGH UST and engineers

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

** Paper prepared within the statutory research program of the Faculty of Drilling, Oil and Gas, AGH University of Science and Technology no. 11.11.190.555

from the “Wieliczka” Salt Mine resulted in working out original technical and technological solutions [1, 3, 4], the implementation of which helped cut off the water flux to the Mina gallery, closing of the end part of the gallery and reconstruct the inner safety pillar in this area of the mine.

2. GEOLOGICAL BUILD IN THE AREA OF THE DUNAJEWSKI GALLERY

The northern part of the Dunajewski gallery is localized in the off-side safety pillar in the area of the lump deposit. Prior to being closed, it was inaccessible because of a caving. This gallery was connected with the neighboring Strzelecki gallery through a leaching gallery. Probably this was the planned leaching working which was never realized. The other end of the Dunajewski gallery was not accessible because of the caving in the area of the Dunajewski shaft IV, south of the leaching gallery. The working was available only from the leaching gallery.

The lump deposit looming in the gallery was characterized by a high concentration of green salt blocks of various size [6, 9]. The biggest block recognized in the analyzed area was polycrystalline green salt block, cut by the leaching gallery. East of it there were two bigger (contacting) blocks of typical green salt. The waste rock in the lump deposit in the analyzed area consisted of typical zuber (claystone with salt rock), and blocks of brittle marly clays. Cavings and rock slides formed at both ends of the gallery. Waste rock was cut with a network of fissures re-united with fibrous halite. Further to the north the clay-gypsum buffer plays a very important role in protecting salt domes against aquifers on the north of it. Marlyclaystones with gypsum inclusions dominate in it. The Chodenice beds, which are deposited north beyond it, are represented by sandstones of various compaction degree. Moreover these beds also consist of sandy claystones and marlyclaystones with sandstone inclusions. Tectonic disturbances caused that these sandy strata were torn into blocks of various size and moved from one another.

Hydrogeological conditions of the analyzed area can be determined mainly on the basis of water-bearing Chodenice beds represented by fine, weakly compact, clayey and dusty sandstones. Owing to the very complex geological build of the dome, especially in the border area, these sandstones were strongly folded and cracked. They are a good water collector, where water can migrate through fissures and cracks. The biggest catastrophes in mines were associated with the Chodenice beds in the past. Presently they supply the most important leaks observed at levels I to VII. The Dunajewski gallery is localized between workings, where catastrophic water fluxes took place in the past, about 80 m east off the Mina gallery (catastrophic water flux of 1992) and about 440 m west off Collaredo 2 cross gallery (catastrophic water flux in Kloski gallery – level V and Collaredo gallery – level IV of 1868). The last 25 m of the Dunajewski gallery are part of the dome which were given the III degree of water hazard. No water leak was observed in the Dunajewski gallery, though the clayey rocks at the end of the gallery were slightly humid.

The Dunajewski gallery was accessible only on the side of the leaching gallery. After performing necessary preparatory mining works the injection pipeline and ventilation system associated with the pipeline injection technology were mounted [6]. Authors decided to implement this solution for the following advantages:

- sealing slurry can be quickly worked out on the surface; the components do not have to be transported to the area of the working and then the slurry does not have to be prepared on the spot;
- the voids can be tightly filled after injection pipelines, vent pipes and injection plugs are mounted;
- low price of all mine protection works.

A detailed description of activities aimed at waterproof liquidation of old workings follows the below steps:

1. Mount an appropriate number of delivery pipeline and vent terminals in the workings to be closed.
2. Perform cuts in the rock mass and build timber dams for injection plug.
3. Fill tightly the injection plug in the leaching gallery with special slurry (ca. 15 m³),
4. Stand to which the plug is fastened.
5. Administer special slurry worked out in the injection column near the Kościuszko shaft to the liquidated fragments of working after the injection plug. The assessed volume of the closed end of the Dunajewski gallery and the leaching gallery totals to 650 m³.
6. Drill 12 wells, each 15 m long, for sealing up, sealing the rock mass around the injection plug with the borehole injection method; liquidate the sealing up wells.

The places of the planned technological pipeline system in the closed galleries are shown in Figure 2.

The following assumptions were made:

- delivery pipelines RIK1, RIK2, RI1, RI2 and RI3 of total length about 350 m will be made of steel pipes $\phi 80$ mm or $\phi 100$ mm, coming from excessive technological pipelines, in galleries in level IV;
- vent pipes ROK1, ROK2, RO1, RO2, RO3, RO4 and RO5 of total length of ca. 560 m when the plug is localized in the leaching gallery, will be made of steel pipes $\phi 50$ mm, coming from excessive technological pipelines, in galleries on level IV;
- a suitable cut-off valve for minimum pressure of 1.6 MPa will be mounted at the end of each of the delivery pipelines and vent pipes, near the injection plug;
- outlets of ventilation wells will be protected with backfilling cloth;
- terminals of delivery pipelines RI1, RI2, RI3, RI4 will have perforation.

Fig. 2. Distribution of technological pipelines in the Dunajewski gallery and leaching gallery

Importantly for the closing procedure, appropriate sealing slurry should be selected. For reinforcing and sealing the salt rock mass the slurries should have well-adjusted technological parameters, accounting for the specific character of salt rock mass. The efficiency of sealing a salt rock mass depends on certain criteria [11, 13, 14].

The first of them is the congruence with the surrounding, i.e. the chemical composition of the slurries should chemically correspond to that of the sealed rock mass. The second condition is the pumpability criterion, i.e. the rheological model and technological parameters of the sealing slurry should be properly selected. The third requirement lies in providing appropriate strength and durability of sealing slurries, being a result of physicochemical processes. The slurries should provide the same (or comparable) mechanical properties of the formed body as natural properties of the rock mass.

One of the basic criteria of selecting sealing slurries was also an economic factor. For lowering the cost of materials, the brine slurries were made of relatively cheap ground blast furnace slag.

First the slurry was injected to a timbered cement plug site. The injection of the sealing slurry to the plug site could be stopped only when the last vent pipe was discharging slurry, proving that the entire void space was filled. Then the valves installed before

the plug were closed on the injection and vent pipeline. Finally the main injection pipeline was flushed with saturated brine. Further injection works lying in the injection of sealing slurry to the liquidated space beyond the injection plug were continued after the sealing slurry was bonded in the injection plug.

The injection to particular pipelines was realized in the following order:

- a) When filling the injection plug in the leaching gallery:
 - pipeline RIK1,
 - pipeline RIK2.
- b) When filling the northern end of the Dunajewski gallery and leaching gallery behind the injection plug:
 - pipeline RI1,
 - pipeline RI2,
 - pipeline RI3.

Preparation of sealing slurries and their injection from the surface to the main pipeline in the w Kościuszko shaft were conducted continuously in an automated sealing slurry column localized in the neighborhood of the Kościuszko shaft. The slurry is prepared in about 3 m³ portions at an average rate of about 15 ratios per work cycle, i.e. 135 m³/day.

The necessary condition of applying sealing slurry to the liquidated space beyond the injection plug was the outflow from the “last” vent pipe, evidencing that the entire void was filled. At that point the valves on the vent and injection pipelines were closed, and the main pipeline was flushed with saturated brine.

After filling the liquidated section beyond the injection plug, the surrounding rock mass had to be sealed up with the borehole injection method. 12 injection wells were planned for making the injection plug, each of them 15 m long, and a casing 3 m long. Drilling of sealing up wells and the injection job were performed in two stages. First the outer circle of 6 injection wells was performed, then the inner one (also consisting of 6 wells). The wellbore axes were realized at an angle of 15° and 30° in respect to the longitudinal axis of the injection plug. The axes of particular wells in a given circle were shifted by 60° on the plane perpendicular to the longitudinal axis of the injection plug. The axes of wells in both circles differ by 30°. At each stage, first the successive odd-number wells were drilled, then the remaining ones. The number of wells in the circles and their spatial distribution were so designed as to perform the supplementing sealing up job for the space around the injection plug.

The sealing up wells were drilled with a typical little rig MDR 03 used in the “Wieliczka” Salt Mine for drilling jobs. After drilling a well with a cogged bit 76 mm in diameter and reaming it to 143 mm, the casing 127 mm in diameter, with centralizers, was tripped at a length of 3.0 m and sealed with slurry over the whole length of the casing.

Further drilling was performed in zones, each 4.0 m long, and the slurry was injected till the pressure of 2.5 MPa was obtained for 30 minutes. Injection jobs had to be stopped earlier when the slurry managed to break through into the gallery. After the slurry bonded, the works could be continued.

Further reduction of water hazard is certainly favored by efficient water-tight liquidation of end sections of the Dunajewski gallery and leaching gallery localized in the vicinity of the northern boundary of the salt dome and in the immediate neighborhood of the Mina gallery.

The necessity to close these galleries was expressed in the upgrade of the “A complex approach to the protection of historical ‘Wieliczka’ Salt Mine against water hazard” [5].

4. CONCLUSIONS

1. The closing of most northward galleries, especially the ones which go beyond the northern boundary of the deposit, is purposeful as it limits the hazard of catastrophic water fluxes from the Chodenice beds surrounding the salt dome from the north. This was confirmed in many expertises and opinions on water hazard in the “Wieliczka” Salt Mine.
2. A tight liquidation of end parts of the Dunajewski gallery and leaching gallery is an important element of many preventive actions realized at the “Wieliczka” Salt Mine to limit the water hazard.
3. Geomechanically, the liquidation of a fragment of a gallery by filling it tightly with material having similar properties as the surrounding rock mass was aimed at restoring the original condition without evoking negative effects in the neighboring galleries, taking into account their distance, size, shape and localization.
4. Resuming, the closed ends of the Dunajewski gallery and leaching gallery significantly improved the safety of the “Wieliczka” Salt Mine in its central part by restoring a successive fragment of the buffer separating historical underground galleries from the surrounding aquifer in the north side of the salt dome.

REFERENCES

- [1] Garlicki A. et al.: *Studium możliwości likwidacji zagrożenia wodnego dla zabytkowej Kopalni Soli Wieliczka za pomocą bariery drenażowej lub ekranu izolującego*. Projekt Badawczy Zamawiany KBN nr PBZ 066-01, Kraków 1994–95.
- [2] Garlicki A., Szybist A.: *Ogólne założenia dla zabezpieczenia KS Wieliczka oraz nowy obraz geologiczny złoża wielickiego. Likwidacja zagrożenia wodnego dla zabezpieczenia KS Wieliczka*. Materiały z III Spotkania Stowarzyszenia PSGS, 1995.

- [3] Gonet A., Stryczek S.: *Sprawozdanie z likwidacji końcówek poprzeczni „Poniatowski” i „Kunegunda” w Kopalni Soli w Wieliczce*. Kraków 1992 [unpublished].
- [4] Gonet A., Stryczek S.: *Koncepcja izolacji przeciwwodnej Kopalni Soli „Wieliczka”, Konferencja Polskiego Stowarzyszenia Górnictwa Solnego*. Wieliczka, 18–19.09.1995.
- [5] Gonet A. et al.: *Aktualizacja „Kompleksowej koncepcji zabezpieczenia zabytkowej Kopalni Soli „Wieliczka” przed zagrożeniem wodnym”*. Kraków 2006 [unpublished].
- [6] Gonet A., Stryczek S., Garlicki A., Szybist A.: *Projekt techniczny likwidacji północnych końcówek poprzeczni Dunajewski i Strzelecki w Kopalni Soli „Wieliczka” S.A.* Kraków 2012 [unpublished].
- [7] Kortas G., Maj A.: *Okoliczności i skutki katastrofalnego wdarcia wód do kopalni soli w Wapnie. Uwagi do wydarzeń z sierpnia 1977 r.* Przegląd Solny, nr 10, 2014, pp. 101–106.
- [8] Rogoż. M: *Opinia dotycząca zabezpieczenia Zabytkowej Kopalni Soli „Wieliczka” przed zagrożeniem wodnym ze strony wypływu nr WIV-27 w poprzeczni „Mina”*. Katowice, styczeń 2009.
- [9] Stecka J. Przybyło J.: *Budowa geologiczna i warunki hydrogeologiczne górotworu w rejonie poprzeczni Dunajewski i Strzelecki poz. IV. Wieliczka 2012*. Archiwum Działu Geologicznego KS „Wieliczka”, Kraków 2012 [unpublished].
- [10] Stryczek S., Gonet A.: *Techniczne aspekty likwidacji katastrofalnego wycieku w poprzeczni „Mina” Kopalni Soli Wieliczka*. Konferencja Naukowo-Techniczna nt. „Wydział Wiertniczo-Naftowy AGH dla Kraju”, Kraków 16–17.06.1994.
- [11] Stryczek S., Gonet A.: *Predicting Rheological Parameters of Slag-Alkaline Slurries*. Archives of Minig Science, vol. 43, 1998.
- [12] Stryczek S.: *Prognozowanie czasu wiązania solankowych zaczynów uszczelniających*. Archives of Minig Science, vol. 45, 2, 1997 pp. 505–518.
- [13] Stryczek S., Gonet A.: *Dobór zaczynów do wzmacniania górotworu solnego*. Materiały Sympozjum Warsztaty 2001: Zagrożenia naturalne w górnictwie, Wieliczka, 29 maja–1 czerwca 2001. Polska Akademia Nauk IGSMiE, Kraków 2001, pp. 327–335.
- [14] Stryczek S., Gonet A.: *Solankowe zaczyny popiołowo-cementowe*. Wiertnictwo, Nafta, Gaz, nr 18/1, 2001, pp. 229–239.