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NEW RECONSTRUCTION TECHNOLOGIES OF SAFETY PILLAR IN MINES**NOWOCZESNE TECHNOLOGIE ODBUDOWY FILARA BEZPIECZEŃSTWA W KOPALNIACH**

Safety pillars are made around mines as a protection measure. This is especially important in salt mines where the surrounding waters are most hazardous. Without maintaining safe conditions the mine may be water-flooded as it was the case in one of the Polish mine “Wapno”. An original technology linking pipeline injection and hole injection methods has been used for the reconstruction of a safety pillar in the Salt Mine “Wieliczka”. This solution turned out to be successful when on 13 April 1992 the mine was saved from flooding after a disastrous water flux to the transverse working Mina. The presented technology can be efficiently used in various mines at the stage of designing, though their exploitation to the closing stage.

Keywords: safety pillar, mine, pipeline injection, hole injection

Dla zapewnienia bezpieczeństwa wokół każdej kopalni należy utworzyć filar ochronny. Szczególnie jest to istotne w kopalniach soli, dla których otaczająca je woda jest największym zagrożeniem. Nie zachowanie odpowiednich warunków może się skończyć nawet zatopieniem kopalni, co miało miejsce nawet w Polsce – Kopalnia „Wapno”. W pracy opisano oryginalną technologię iniekcji rurociąkowej połączoną z iniekcją otworową zastosowaną do odbudowy filara ochronnego w Kopalni Soli „Wieliczka”, która pozwoliła ją uratować przed zatopieniem po katastrofalnym dopływie wody, który wystąpił 13 kwietnia 1992 roku w poprzeczni Mina. Przedstawiona technologia może być z powodzeniem zastosowana w różnych kopalniach i to na etapie od ich budowy, poprzez czas eksploatacji aż na etapie likwidacji kończąc.

Słowa kluczowe: filar bezpieczeństwa, kopalnia, iniekcje rurociąkowa, iniekcja otworowa

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1. Introduction

Providing security of work to miners has become increasingly important issue nowadays. Among the most serious hazards are methane occurrence and water fluxes in workings, especially in salt mines. The technology incorporating hole injection and pipeline injection methods has been used for the reconstruction of safety pillar in the area of transverse working Mina at the IV level, 175 m bs. This method turned out to be a successful option, as the disastrous water flux of 13 April 1992 had been stopped and the unique historical salt mine saved. The technologies have been proved to be applicable in various mines both at the stage of regular activity and during the closing operations.

2. Pipeline injection method

The Salt Mine “Wieliczka“ has a complex geological setting, described in the works by Garlicki & Wilk, 1993 and Garlicki & Szybist, 1995. The interior is protected against the flux of the surrounding water with the clayey-gypsum protective screen. However, under the influence of earlier mining activity the screen has been either damaged or considerably weakened, causing a loss of tightness and consequently water flux of considerable amounts of water with solids to the workings. The pipeline injection method allows for tight filling of the to-be-closed voids. This solution has been patented (Gonet & Stryczek et al., 1995), with AGH University of Science and Technology as the holder of the patent rights.

The basic advantage of the method lies in the possibility of pumping sealing slurry from the surface to the endings of closed workings. This was very important in the Wieliczka situation where considerable amounts of sealing slurry had to be administered to the transverse working in a short time. The choice of this solution was also dictated by other reasons (Gonet & Stryczek, 2001):

- considerable distance of the transverse ends from the shaft,
- lack of rails enabling transport to the transverse working,
- small size and location of the transverse in the mine, making preparation and injection of sealing slurries impossible.

Preparation of ends of the working to be closed lies in building a suitable number of pumping pipelines, vent-pumping pipelines, vent pipelines and making an injection plug (Gonet et al., 2011). The number of pipelines, their length and location of ends mainly depends on the length of the working to be closed, build of its roof and rheological parameters and efficiency of applied system for slurry preparation. The scheme of pipelines in the working’s end has been presented in fig. 1. Injection of the slurry has to be preceded by making a pumping pipeline in the shaft, linking the pump on the surface with the end of the pumping pipeline, built in the injection plug. It should be emphasized that the pumping pipeline can be used many times as after completing the injection works it should be thoroughly washed, best with fully saturated brine in the salt mine conditions.

Initially a decision was taken that the ends of transverse working Kunegunda and Poniatowski located at II and III level, nearly above the transverse working Mina, should be closed (Stryczek et al., 1995). The potential main water flux was expected at the Tourist Route and the objects on the way, but the hazard was threatening the entire Salt Mine “Wieliczka“.

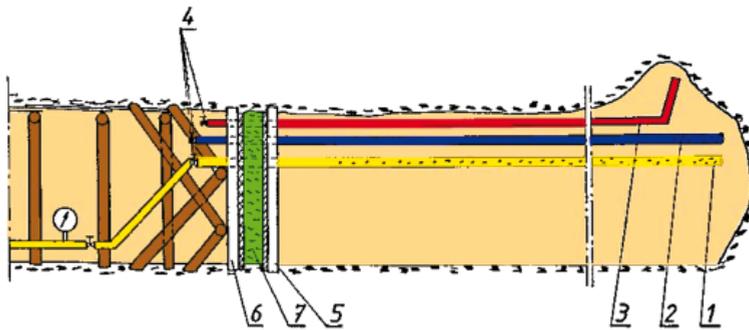


Fig. 1. Scheme of closing working's end with the pipeline injection method (1 – pumping pipeline, 2 – vent-pumping pipeline, 3 – vent pipeline, 4 – gates, 5 – inner dam, 6 – outer dam, 7 – injection plug)

The transverse working Poniatowski received 342 m³ and the transverse Kunegunda about 450 m³ of slurry (Gonet & Stryczek, 1992b). The closing of geomechanically inaccessible end of the transverse Badeni at the V level, i.e. over the transverse working Mina, was realized through a series of injection-vent wells drilled from the bottom of the transverse Mina. They were used for injecting over 250 m³ of sealing slurry (Stryczek & Gonet, 1993b).

In this way the direct neighborhood of the transverse Mina (where water with various solids content was flowing) has been protected. To limit the unfavorable influence of water flux on the rock mass, the draining wells D-1, D-2 and D-3 were drilled through the previously made dam. Their main task was to overtake the water flowing to the mine in its forefield, i.e. behind the protective clayey-gypsum screen, and then controllably discharge it through the pipeline.

3. Hole injection method

The hole injection method has been known and used in hydrotechnics for years. For this reason it will not be presented here in detail. Descriptions can be found in the literature, i.e. in a book by Stryczek & Gonet, 2000.

During the water flux to the transverse working Mina (Garlicki et al., 1994-95) a complex spatial system was formed between the end of working of the transverse Mina and various hydraulic connections with new caverns (fig. 2). Therefore, the following procedure of reinforcing and sealing the rock mass was proposed (Gonet & Stryczek, 1993):

- from longitudinal working Dunajewski to dam T-4,
- from dam T-4 to dam T-1 and the exploration gallery with an off-way,
- from dam T-1 to water dam.

Bearing in mind the security of miners, the following was suggested for the considerably weakened section between dams T-4 and T-1:

- first make a steel tunnel,
- fill out the space between rock mass and steel tunnel with sealing slurry,
- drill directional wells (fig. 3) of series A, C, E, F, H, P and Q, and carry out zonal injection 6 m long for wells of I, II and III order.

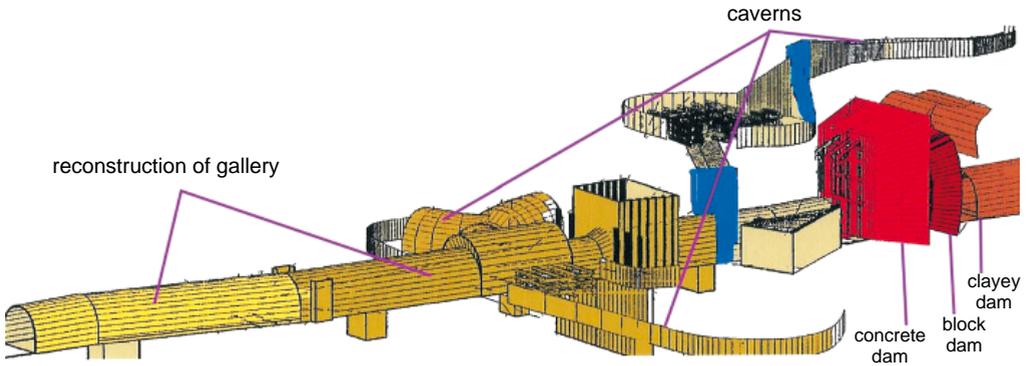


Fig. 2. Scheme of the end of the transverse working Mina

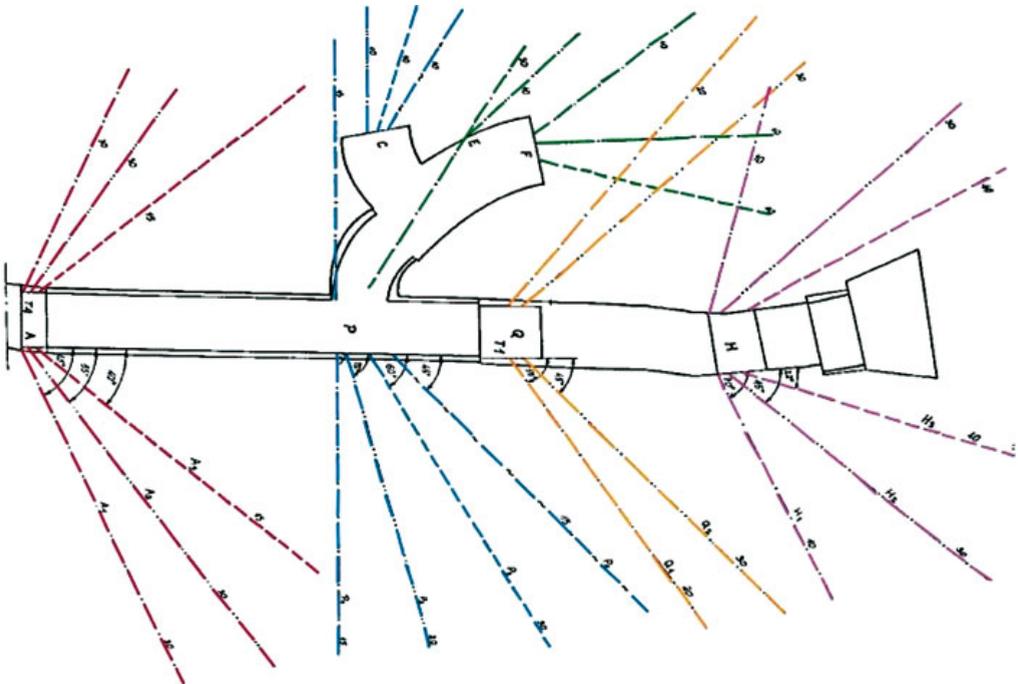


Fig. 3. Distribution of injection wells in the end of transverse working Mina

In the case of the section leading from dam T-1 to water dam, the following was proposed:

- build pumping and vent pipelines in the northern caverns to fill it out with sealing slurry,
- drilling H-series directional wells and performing zonal injection in wells of I, II and III order.

The longest time of absorption of the flux was observed for the draining well D-2 in the water dam; then water was discharged to the forefield of the salt deposit. Periodically the outlet of the well D-2 was spontaneously blocked. Two other drainage wells D-1 and D-3 in the water dam were used for collecting water or for measuring pressure of water behind the dam. Basing on the current monitoring records, plots were made to illustrate the character and amount of water, salt and solids getting to the mine. Generally, the flux in the transverse working Mina denoted as WIV-27 had a high rate as for a mine, and a low NaCl concentration, which was evidence of short circulation pathways in the rock mass and high flow rates. Leaks of similar characteristic are most dangerous for any salt mine.

Considerable amounts of water, pulsatingly flowing at small depths, used to carry solids and dissolved salt to the mine's forefield. This resulted in forming of voids in the rock mass confirmed by geophysical surveys; on the days of the disastrous flux they would also manifest in subsidence troughs or considerable fractures formation.

Exemplary unit absorptivities and volumes of injected sealing slurry in specific zones of the injection well of A and Q have been presented in fig. 4 (Dudek & Pietrusza, 1996).

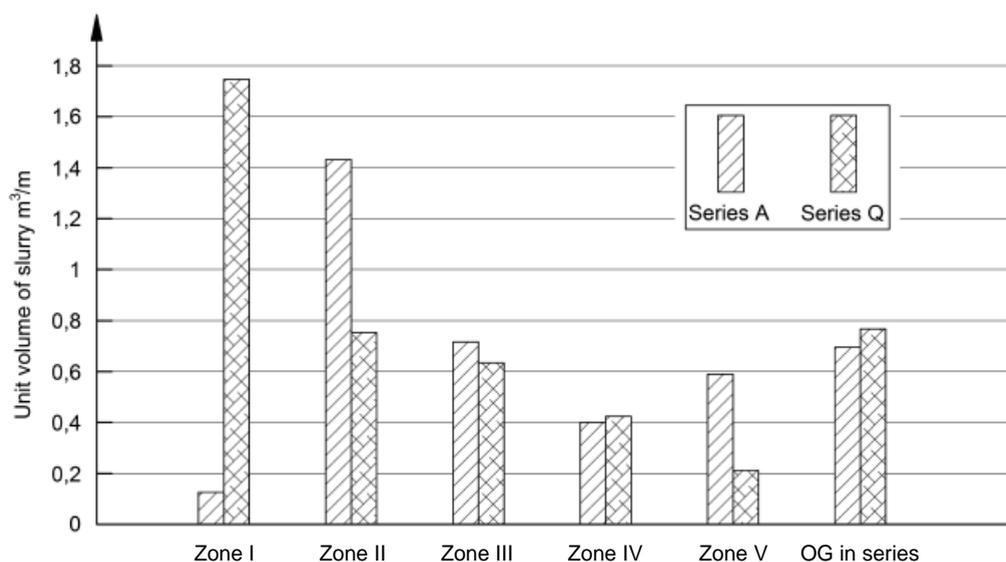


Fig. 4. Unit volume of injected sealing slurry in specific injection zones of wells of series A and Q

During injection works, the rock mass absorptivity was measured and the character of flow of the sealing slurry with the accompanying phenomena has been determined. The respective percentages have been shown in fig. 5.

After completing the hole injection at the end part of the transverse working Mina, the probable range of its sealing has been visualized in fig. 6.

All above works performed in the underground headings, also the realization of injection wells of specific series from the transverse working Mina were oriented to creating the so-called

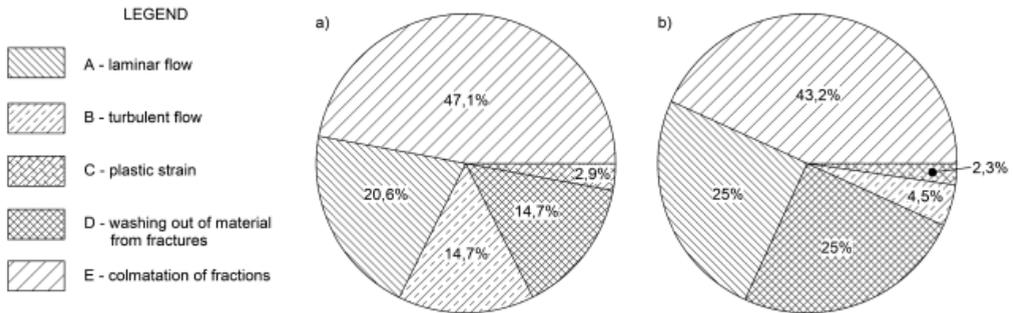


Fig. 5. Character of flow of sealing slurry with accompanying phenomena taking place in the rock mass under the influence of injected sealing slurry (a – series A, b – series Q)

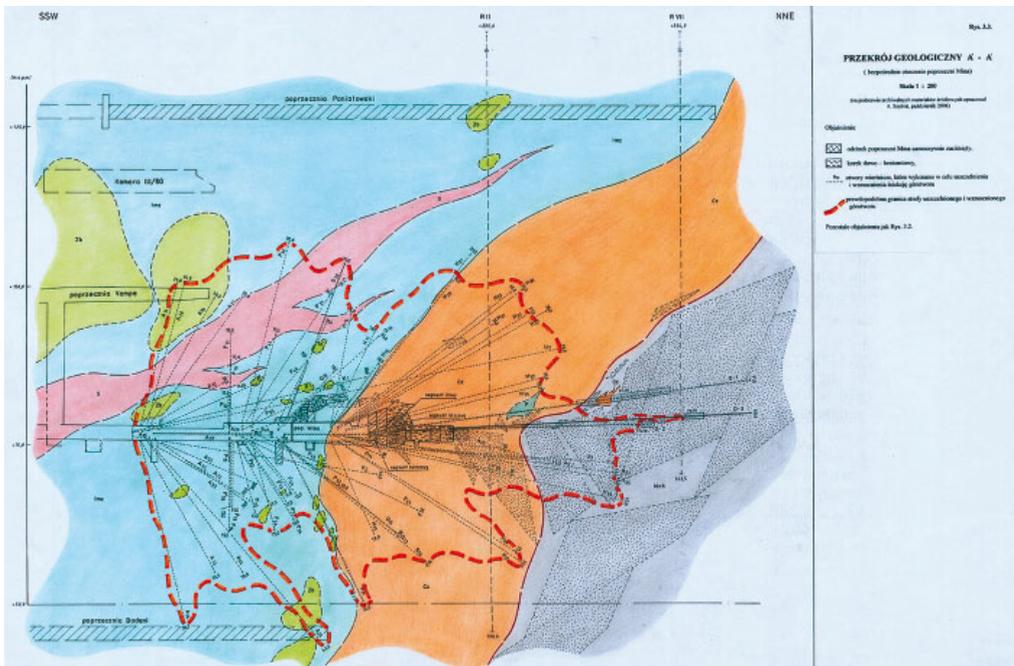


Fig. 6. Geological cross-section of end part of transverse working Mina with injection wells

sealing cap, and so, reconstructing the safety pillar at the northern border of the salt deposit (Gonet & Stryczek, 1995).

Sealing of the Wieliczka rock mass is very challenging as the geological setting is complex and diversified (Gonet et al., 1996). Original patented recipes have been worked out especially for this purpose (Małolepszy et al., 1994). They have very good rheological parameters (Stryczek & Gonet, 1998), meet technological requirements (Stryczek et al., 1997) and properly act with

the rock mass (Stryczek & Gonet, 2001). They have been used for a number of purposes for year and their technological and economic predominance has been confirmed. For instance, photo 1 illustrates an opencast with ideal adhesiveness to various materials.



Photo 1. Sealing plug at the end of transverse Mina

Additional protecting actions were performed from the surface and they were aimed at:

- filling the voids in the rock mass in the area of the subsidence trough,
- partial filling and reinforcement of the flow pathway from the northern subsidence trough to the transverse Mina (Stryczek & Gonet, 1993a).

Such works were undertaken on 4 May 1993 in the well SP-1, drilled as a piezometric well for the research-dewatering well TOS-1 (Brudnik et al., 2001).

It was generally confirmed that intense activities should be performed, both from the surface (Gonet & Stryczek, 1992a), and from the workings (Garlicki et al., 2001).

Consequently, the following actions were accomplished:

- reinforcing and sealing of clayey-gypsum screen around the salt deposit,
- filling of voids in the rock mass in the forefield of salt deposit,
- tight filling of workings in clayey-gypsum screen and in direct neighborhood of the deposit.

The rebuilding of the inner safety pillar in the area of the transverse working Mina required closing the wells D-2 and D-3 where the gates were closed and water has not flown into the mine since 15 October 2007 and filling of the end of the transverse from the dam T4 to water dam. The scope of protecting works has been evaluated positively by Rogoż, 2009. Owing to

a considerable volume of the closed end of the working (total of about 300 m³) the entire task has been divided into the following stages:

- performing main injection pipeline to the transverse working Mina (neighborhood of drilling niche),
- dismantling redundant pipelines and redundant equipment of the working in the closed section of the transverse Mina,
- preparing a pipeline \varnothing 100 mm, which discharges brine from washing of the main pipeline,
- increasing the existing drilling niche to the western part of the transverse working Mina (perform a cut at the opposite side of the transverse working; ca. 4.5 m wide at 2.2 m of depth, with the protecting wooden lining – analogous to the existing niche),
- dismantling fragments of existing lining of the transverse in the place of planned cuts in the working to intact rock mass,
- assembly of pumping and vent technological pipelines in the closed section of the transverse,
- dismantling of existing lining section in the transverse working (in the place of planned injection plug 3.8 m wide) and building wooden dams for the injection plug,
- developing a little dam ca. 0.8 m high,
- tight filling of the injection plug (ca. 28 m³ volume) with the slurry, resting time for binding – minimum 3 weeks,
- injecting slurry to the closed fragment of working with injection plug (estimated volume of this part of working about 272 m³), till it has been filled up tightly,
- drilling 20 wells, each 15 m long, and sealing up the rock mass around the injection plug with the hole injection method, closing of the sealing wells,
- dismantling of a little dam.

Preparation of sealing slurries and their injection (from the surface to the main pipeline in shaft Kościuszko) will be realized continuously in an automated centre where sealing slurries are being mixed, near the shaft Kościuszko. The slurry is prepared in ca. 4 m³ portions, with average daily rate of 32 m³.

The sealing slurry will not be administered in the closed end of the transverse working Mina when the outflow of the slurry through the vent pipelines proves that the entire void has been filled, analogous to the injection plug filling. Then the gates at the vent and injection pipelines should be closed, and the main pipeline washed.

After the closed section of the working has been filled, the surrounding rock mass should be sealed up with the hole injection method.

The so far experiences prove the usability of the pipeline and hole injection methods for the reconstruction of the tight rockmass in the Wieliczka area. It should be implemented at a wider scale for reconstructing the inner safety pillar in the Salt Mine “Wieliczka” so that in the future the mine can be viewed as a “safe submarine”, with gorgeous workings inside and shafts as “peroscopes” providing contact with the surface.

After performing those works, a safety pillar will be made, and it will definitely lower the water hazard from the northern forefield of the transverse working Mina in the Salt Mine “Wieliczka” (Rogoż, 2009). To make the protection complete, the following elements are planned to be made:

- upper safety pillar responsible for limiting the water flux to the roof of the salt deposit,
- side safety pillar along the border of salt deposit,

- lower safety pillar through the tight closing of lower levels,
- sealing up the rock mass around shafts.

The target model of mine's operation is based of various criteria resulting from the main tasks which have been set before a historical object at the beginning of the 21th century.

The fundamental criteria assumed for a structural model of a mine cover preserving chambers and galleries, which are directly connected with:

- historical value of the object,
- present and past functions of the object as a mine and its operation.

The remaining part of the mine should be so administered that it constitutes a protective area for the workings playing above mentioned functions.

The target functions of the Salt Mine "Wieliczka" will focus on the tourism and museum function as well as therapeutic and didactic aspects, which are already being realized to a certain extent.

4. Conclusions

1. The pipeline injection method proved its applicability for making safety pillars in the Salt Mine "Wieliczka". With this method the sealing slurry can be performed on the surface, then and easily transported at considerable distances to tightly seal hardly accessible parts of the working.

2. In view of numerous advantages, the pipeline injection method has been used, e.g. for closing the end parts of the transverse workings Poniatowski, Kunegunda, Outbuilding to the shafts Regis and Badeni. Owing to the considerable weakening of the rock mass in the liquidated transverse working Mina in the section between water dam and dam T-4, the pipeline injection method and hole injection method were used jointly. The works were divided into the following stages:

- closing of wells D-2 and D-3,
- introduction of pipelines for injection purposes,
- performing injection plug,
- performing pipeline injection operation,
- sealing up the injection plug with the hole injection method.

3. Working out of slurries for sealing up the injection plug and liquidated part of the working will be realized on surface in a dedicated injection section. The slurry will be administered through the main pipeline built in the shaft Kościuszko and in the underground workings.

4. To provide tight filling of the closed part of the working it is absolutely necessary to precisely follow the technology: starting from the preliminary works, through the proper selection of sealing slurry recipes, to the sealing of the injection plug. All works should be performed on top quality level.

5. Already performed and designed injection works are a continuation of earlier works, thanks to which the rock mass in the Salt Mine "Wieliczka" could be efficiently reinforced and sealed. Accordingly, the potential water hazard from the northern part of the mine, within the transverse working Mina has been lowered.

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