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SEALING OF CAVITIES BEHIND THE CONCRETE LINING OF THE KINGA SHAFT IN THE WIELICZKA SALT MINE

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ABSTRACT
Long-term mining activities in the Wieliczka Salt Mine resulted in a fresh water flux of varying intensity to the salt formation behind leached caverns in the salt rocks.
Safety hazards of the Wieliczka Salt Mine have been discussed with a focus on the existing quality of the Kinga shaft concrete lining, as well as the disturbed geological, hydrogeological and mining conditions in the shaft vicinity.
The injection method, applied for the strength improvement of the concrete lining and for sealing of the surrounding salt formation, has been described.

INTRODUCTION

Technical-engineering conditions in concrete constructions, especially in shaft lining, belong to factors limiting the correct and economic performance of sealing with borehole injection methods.

The aim of injection works in shaft lining may be the following:
- direct improvement of physico-chemical properties of the lining;
- lowering water permeability of the lining.

The above objectives can be obtained only when
- technical design of injection procedure;
- design of injection technology;
- selection of recipes and technological parameters of sealing slurries;
- injection works

are performed correctly.

All kinds of physical discontinuities appearing in the shaft lining in the immediate neighbourhood play a crucial role in water permeability.
Physical discontinuities may form complex networks of fractures, which can be characterized by means of a number of properties, the so-called fracturing parameters, e.g.
- spatial orientation of fractures;
- linear dimension of fractures;
- degree of cracking;
- degree of divisibility.

From mathematical-engineering the point of view these parameters can be determined by means of measuring or calculation methods, e.g. unit water absorptivity index, permeability, porosity, filtration coefficients.

The aim of the paper is to present the technology of liquidation of voids behind the lining of the Kinga shaft in the Wieliczka Salt Mine with the use of clayey-cement slurries and borehole injection methods. Injection procedures carried out in the above mentioned object liquidated water leakages through the lining, creating conditions for uniform distribution of hydrostatic pressures acting on the shaft lining, and generated conditions in which the lining could co-operate with the rock mass.

TECHNOLOGIES OF WORKS FOR SEALING THE SHAFT STRUCTURE

Sealing of the shaft lining was realized by the borehole injection method.

This solution lied in making boreholes in the planned sealing area of the shaft and neighbouring rock mass followed by injection of sealing slurry under pressure.

Due to the varying technical and mining-geological conditions, grids of injection wells were made, at arbitrary length and order.

The wells were made with the use of varying techniques [1]:
1. order of injection works;
2. location of drilling wells;
3. rheological properties of sealing slurry;
4. injection pressure.

As a principle, the Kinga shaft and rock mass were sealed from the lowermost level towards the shaft site. The sealing operation was divided into a few stages concentrating on different parts of the shaft passing through the specific levels of the Wieliczka Salt Mine. And so, in line with the above principles, the lining between the floor and the level VII sealing was sealed in the first order. This was followed by making:
- the shaft lining below the level VIII.

At a depth of 197.97 to 296.53 m the shaft lining was made of bentinite bricks 0.5 m thick. First, vertical boreholes were drilled from gangways sited at the east and west part of the Kinga shaft, from the level VIII. At each side, 3 boreholes were drilled at about 1.5 m distance from the lining. Two boreholes in the gangway were located 0.5 m from the side walls, and the third one was in the gangway axis. They were shown in the Figure 1 as P8I, where 8 denoted that the holes were drilled from the level VIII and I signified that it was a vertical borehole from 1 to 6. The length of each of the boreholes was 11.7 m.

The second stage of sealing the shaft lining below the level VIII lied in making five sealing rings at 2.25 m distance from one another. Injection wells 2 m long and 60 mm diameter were made from inside of the shaft:
- shaft lining between levels VII and VIII.

First, two horizontal sealing rings were made, followed by vertical injection wells drilled from the level VII
- three sealing rings consisting of five horizontal boreholes, each 2.0 m long;
- three sealing rings consisting of five horizontal boreholes, each 0.7 m long;
- three vertical boreholes on the east side of the gangway, 1.5 m from the inside of the lining and 11.0 m long.

Further works were so scheduled as to seal the shaft and the neighbouring rock mass in compliance with applied technologies.

SELECTION OF SEALING SLURRIES FOR SECURING THE KINGA SHAFT

To efficiently seal and reinforce the Kinga shaft lining and the neighbouring rock mass, it was necessary to elaborate recipes for slurries adjusted to the variable geological conditions in the rock mass and also material making up the shaft lining. When working out recipes of sealing slurries, attention was paid to the good co-operation with the rock mass and increased durability in corrosion-aggressive conditions.

To elaborate sealing slurries for securing the Kinga shaft, the following solutions were applied:
- metallurgical cement CEM III/A – 32.5;
- alkaline activator – Na_2CO_3;
- mineral additives in the form of drilling bentonite silt;
- fully saturated Wieliczka brine.

Bentonite silt was added to the sealing slurry in order to:
- lower filtration of sealing slurry;
- lower sedimentation and increase stability, especially sealing slurries with increased water-mixing properties;
- adjust mechanical parameters of hardened sealing slurry to the parameters of sealed and reinforced rock mass and shaft lining;
- increase plasticity of hardened sealing slurry;
- lower permeability of hardened sealing slurry as a result of silt particles blocking the pores.

Sodium carbonate was used as an:
- activator of bonding time;
- plastifier;
- component securing good co-operation with the rock mass, especially of the clayey type.

Brine 1200 kg/m^3 from Wieliczka Salt Mine was used for making sealing slurries. Its chemical composition was as follows:

NaCl	305 g/l
Ca^{2+}	1.05 g/l
Mg^{2+}	0.22 g/l
NH_3	0.02 g/l
HCO_3^-	0.21 g/l
pH	7.5

Wieliczka brine is very aggressive to concrete and hardened cement slurries.

The type of injected sealing slurry through injection wells depended on:
- assumed range of penetration of the slurry beyond the lining;
- admissible slurry injection pressure;
- type and technical condition of shaft lining (porosity, permeability, filtration coefficient, fractures and hydraulic connections with external surfaces of the lining);
- technological parameters of fresh and hardened sealing slurry (density, rheological parameters, bonding time of slurry, mechanical parameters of hardened slurry).
- Injection works connected with sealing of the rock mass beyond the shaft lining and the lining itself will require minimum three recipes for saline sealing slurries (Table 1)
- basic slurry (SK1);
- slurry liquidating escapes from behind the lining and side walls (SK2);
- sealing-filling slurry (SK3).

Basic technological parameters of sealing slurries used for sealing and reinforcing the Kinga shaft lining and the surrounding rock mass are presented in Table 2.

Table 1 Mass of components used for making 1 m³ of saline sealing slurry.

No.	Components of slurry					Coefficients		Calculated average density of dry components of slurry, kg/m³	Calculated average mass of dry components of slurry, kg	Calculated density of sealing slurry, kg/m³
	Symbol of sealing slurry	Base slurry–fully saturated brine, m³	Metallurgical cement CEM III/A 32.5 NA, kg	Bentonite clay	Na_2CO_3 kg	Water-mixture w/m, -	Mixture-water m/w, -			
1	SK1	591	1158	23.64	0	0.600	1.660	2890	1182	1891
2	SK2	629	1027	20.69	20.96	0.706	1.416	2800	1069	1824
3	SK3	69	936.9	19.12	0	0.840	1.194	2890	956	1759

Table 2 Technical parameters of saline cement-bentonite slurry determined in 20 (±2) °C (293 K).

No.	Symbol of sealing slurry	Mixture-water coefficient m/w, -	Density ρ, kg/m³	Cone fluidity AzNII, mm	Relative viscosity, acc. Ford cup No. 4	Sedimentation %	Specific filtration ΔP=0.7MPa	Plastic viscisity ηa, Pa s	Apparent viscosity at 600 rpm ηa, Pa s	Flow limit τ_y, Pa
1	SK1	0.600	1870	130	-	0	25/300	0.0963	0.117	21.434
2	SK2	0.706	1810	210	35	0.2	32/200	0.0618	0.073	11.445
3	SK3	0.840	1730	260	16	0.4	42/125	0.0290	0.036	7.051

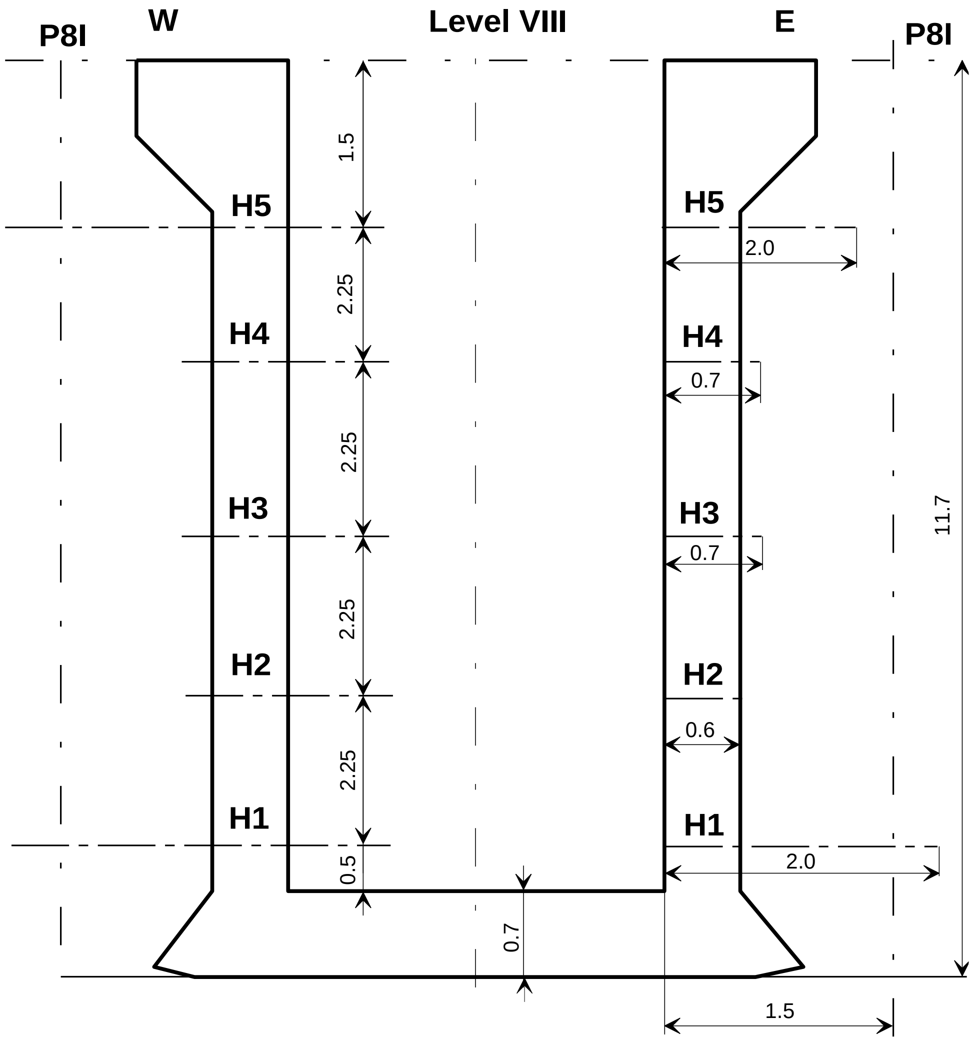

Figure 1. Location of injection wells below the level VIII.

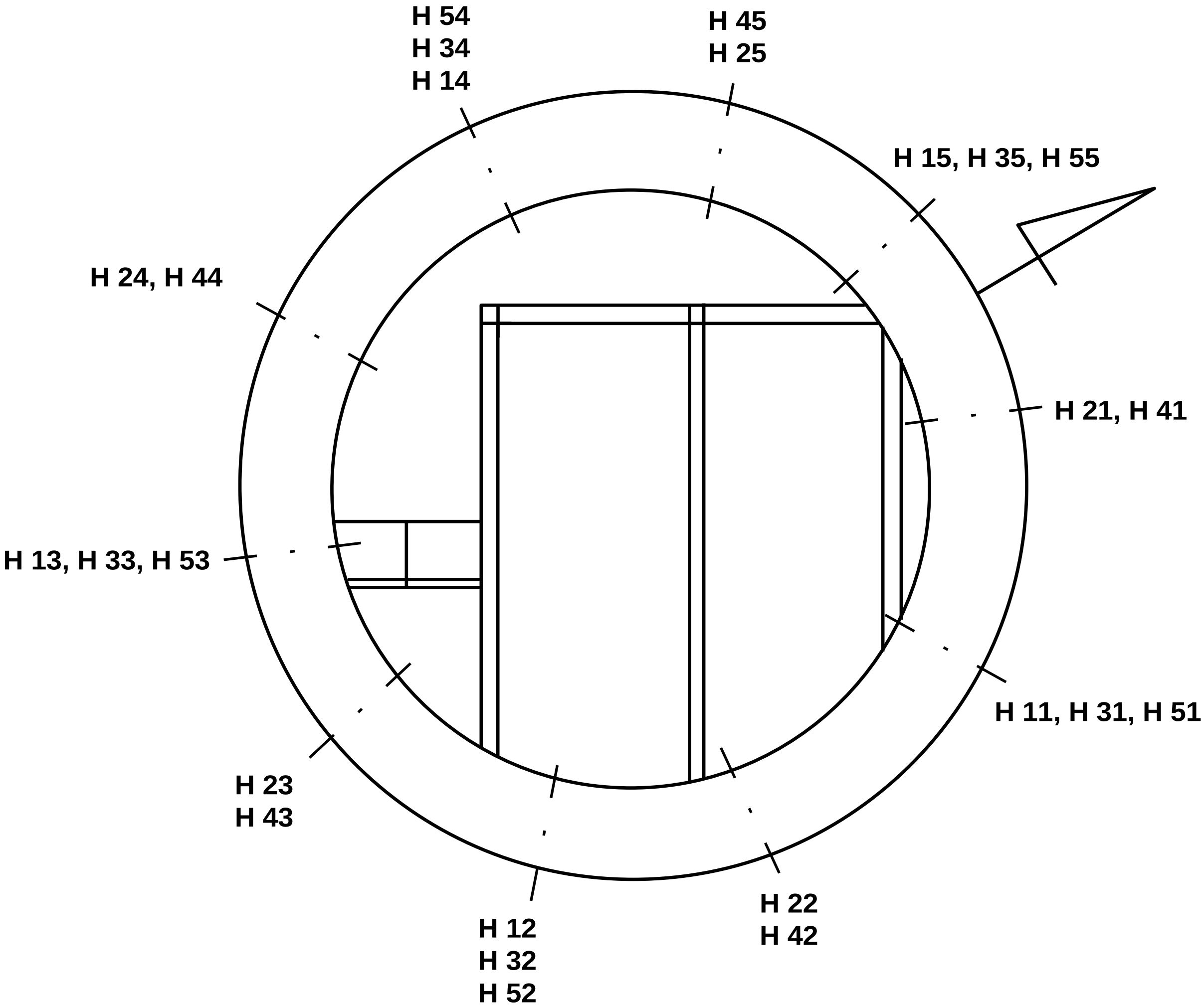

Figure 2. Location of injection wells below the level VIII in the Kinga shaft.

CONCLUSIONS

1. Many years exploitation of shaft linings under the influence of the rock mass and the surrounding waters often necessitates reinforcement and sealing of the lining.
2. Rheological properties of slurry, location of injection wells, order of injection works and final pressure at which slurry is injected are important parameters in the injection method used for improving the tectonic state of the shaft lining.
3. The applied slurries were made on the basis of fully saturated brine proved to be very useful in the conditions of the Wieliczka Salt Mine.

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