NEW STRUCTURE OF SHAFTS CONSTRUCTED IN ROCK MASS WITH SIGNIFICANTLY STRONG RHEOLOGICAL PROPERTIES

ABSTRACT

The paper presents a patented and copyright protected concept of constructing a shaft lining that goes through rock mass having strong rheological properties and being susceptible to leaching. In the case of salt layers, especially on significant depths (over 900 m) the relative convergence of the heading contour may amount even to 40 ‰/year. That results in the fact that any other method of securing the shaft lining, e.g. by making it flexible, will not be sufficient to ensure the stability of the shaft reinforcement geometry. In the new shaft lining concept the excessive rock creep into the outbreak inside diameter will be removed by local and controlled leaching of the shaft cheeks by means of fresh water directed through a porous medium of the contact layer behind the watertight tubing lining. The paper presents the structure of such lining and an outline of the construction technology.

In order to implement such a lining, a typical tubing will be applied. A separate design and manufacturing will be required for the technological rings used to control the leaching process behind the lining.

KEYWORDS
Shaft construction, shaft lining.

INTRODUCTION

The Polish shaft construction industry is expected to go through a process of development in the nearest future and as a result several shafts will have to be sunk or deepened. A well prospering KGHM Polska Miedź plant, if it is to maintain its world standards and the exploitation potentials, will have to move its mining operations towards the north and to move its operations increasingly deeper in order to follow the subsiding copper deposit. All of the newly sunk shafts have to go through salt layers of thickness of up to 200 m that are deposited on the depth of approx. 1000 m, which – considering very strong rheological properties of the salt – indicates a substantial hazard of the so called deformation pressure on the shaft lining.

If the easily soluble salt can be leached by a stream of fresh water, the phenomenon can be applied to remove the salt rock that creeps towards the shaft breakout inside diameter. With this objective in mind it is necessary to work out a new structure of shaft lining and to implement a new technology of shaft lining construction with the application of such lining. The issue has been basically solved and patented in the Section of Underground Civil Engineering of the Department of Geomechanics, Civil Engineering and Geotechnics within the Faculty of Mining and Geoengineering in the AGH- University of Science and Technology. However, practical implementation of the new solution involves further research and investigations that will make it possible to:

- determine the indispensible physical, chemical and geomechanical parameters of the salt formation under investigation,
- describe mathematically the salt leaching process on the cheeks of the shaft heading,
- estimate the parameters of the technology of leaching the salt cheeks behind the shaft lining,
- adjust the technology of sinking to the mining and geomechanical conditions,
design and manufacture new elements of shaft lining that are indispensible when sinking, checking and correcting the exploitation.

As the lining that follows the presented solution can work properly only when it is equipped with innovative systems of measurement of rock mass pressure onto the lining and an automatic system of its reduction, it can obviously be called a partially intelligent lining.

**MAKING SHAFT LINING FLEXIBLE AS A WAY TO INCREASE ITS LOAD-CARRYING CAPACITY AND DURABILITY**

A hitherto very extensive scientific research in the area of the co-operation between the lining of underground headings and the rock mass proves evidently that making nearly every lining flexible improves the load-carrying capacity of the artificially made rock mass-lining system and increases significantly its durability. That is presented in fig.1 (Czaja, 2002) where the replacement of a rigid lining characterized by 2a by a flexible lining 2b or 2c clearly lowers the load-carrying capacity balance point of the “rock mass – lining” system $W_b$ and $W_c$ below the load-carrying capacity $R_{lb}$ of the lining represented by line 3, thus guaranteeing its stability and durability.

![Figure 1](image)

Figure 1. Co-operation scheme between shaft lining and rock mass depending on lining type (Czaja 2002)

*Where: 1 – heading breakout contour dislocation curve, 2 – stress and strain characteristics of the heading lining: 2a – rigid, 2b – degressively flexible, 2c – progressively flexible, 3 - boundary load-carrying capacity of the lining, $w$ – co-operation points of the lining and rock mass, $u_o$ – initial displacement of cheeks, $u_a$, $u_b$, $u_c$ – displacements resulting from the strain of the lining made flexible, $p_o$ – lining load-carrying capacity, $p_{eg}$ – rock mass load-carrying capacity after the redistribution of the state of stress, $p_a$ – load-carrying capacity of the rock mass – lining structure.*

The universality of the lining made flexible has been proved by a worldwide use of the steel flexible lining where the flexibility is reached by determining on the joints the friction force on the level of...
the required support capacity of the lining set. At present there are several methods of making linings flexible (Czaja, 2002). The process is limited by the required geometry of the heading which must provide adequate technological functions. In dog headings, especially temporary ones, significant geometrical changes are acceptable. However, in long-term headings such as mining shafts, shaft bottoms or other capital headings the basic dimensions must remain unchanged for a very long period of time. In the case of mine shafts – due to the hoisting operations and the presence of several installations highly sensitive to deformations such as cage guides, pipelines, cables – the guarantee of long-term stability of the ginning is absolutely necessary.

CONVERGENCE OF CHEEKS IN HEADINGS CONSTRUCTED IN HARD ROCK

The analysis of the world bibliography (carried out i.a. in A.Maj’s doctoral thesis – Maj, 2009) results in the conclusion that the size of the wall convergence in a heading sunk in salt rock mass depends on several factors such as: the type of salt (different in every Polish mine), the depth of the deposition of the heading, its age and the in situ temperature. It can be concluded from the research conducted by Bieniasz and Wojnar (Wojnar, Bienbiasz, 1995), (Bieniasz, Wojnar, 2007) that there is a significant diversification of the convergence in different salt deposits (fig.2). For example, the relative convergence observed in the Wieliczka salt mine at present amounts the values close to zero, while in the case of the salt in the Sieroszowice deposit it ranges from 40‰/year at the early stage of the heading construction to 10‰/year after a few years of exploitation (Maj, 2009)

![Figure 2. Dependence of the convergence speed on the type of salt and the depth of deposition (Bieniasz, Wojnar, 2007)](image-url)
Having assumed for the LGOM copper basin the smallest creep of the shaft outbreak contour with the diameter of 10 m in the outbreak at the level of 10 ‰/ year, an annual decrease of the shaft diameter by approx. 100 mm can be expected. Such intensive convergence cannot be compensated by any known method of making the lining flexible.

THE CONCEPT OF SHAFT LINING IN SALT ROCK LAYERS

According to specialist computations and practical observations in the salt rock section, the rheological strain of the salt rock (Flisial, 2005) may in a short time cause an excessive load on the final structure of the shaft lining. Restructuring the shaft lining while the shaft is operating is absolutely improbable as it would have to be closed for adequately long periods of time. Thus the lining must be designed in a way that would make it possible to remove the creeping salt rock from the inside diameter of the shaft.

According to the invention made at the AGH and described in the patent document, registration number P 399219 (Czaja, Kamiński, 2012) … the investigated layer of rock that is susceptible to leaching is first insulated internally while the screens insulating it from the adjacent rock and the lining are kept tight. Then, when the rock load exceeds the assumed value, the leachable rock mantle that faces the lining is leached periodically for a period of time indispensible to decrease the load to the assumed value. In the case when the leachable rock has significant thickness, it is divided into layers that are isolated tightly by inner screens and subsequently the layer selected on the basis of the lining load measurements is leached. In a simple technological set the leachable rock mantle is leached along the whole perimeter facing the shaft lining.

Since salt is easily soluble in fresh water, the new lining structure should enable contact of the whole salt body surface with the fresh water brought in. The saturated solution obtained should then be taken out of the shaft lining area. Practical experiments will indicate what water should be applied; whether it should be still water that is periodically exchanged, still water diluted by fresh water or circulating water moving in a laminar or turbulent way. It can be concluded that between the final shaft lining that creates an inner cylinder and the rock, the area should be organized in that way enabling two functions:

a) transfer of the load from the rock to the shaft lining,
b) a controlled flow of fresh water behind the final lining.

Lining structure in salt rock layers

In leachable salt layers the final shaft lining should consist of at least two columns (fig.3a)

- inner ring of the final tubing lining 3 and 4 (fig 3a),
- outer ring serving as the contact layer 5 (fig. 3a), which transfers salt rock load 9 onto the ring of final lining 3.
The inner ring of the final lining should:

- have adequately high load-carrying capacity,
- be completely watertight to the hydrostatic pressure height equal to the pressure of the brine column on the shaft section being leached,
- offer the possibility to monitor the space behind the final lining,
- offer the possibility to install an alarm warning about the increase of rock pressure onto the lining,
- offer the possibility to introduce fresh water and to remove the brine from the space behind the final lining, thus to conduct controlled leaching of the cheek section,
• have a structure that makes it possible to build a permanent control landing to carry out operations in a given lining section

The outer ring of the lining should consist of a contact layer made from loose aggregate of igneous rock that among other features has:
• complete chemical and physical resistance to fresh and salt water,
• adequate granulation that ensures the required flow of the leaching liquid (laminar or turbulent depending on future investigations),
• capacity to undergo significant strain perpendicular to the direction of the loading forces.

It is also possible to apply a solution used in extremely difficult mining and geological conditions, where behind the tubing column a thin layer of concrete lining, commonly called a concrete envelope, is made (compare fig.3b). It usually serves three functions:
• constitutes a contact layer for the tubing column,
• can serve as a foundation layer, creating the so called tubing and concrete lining,
• protects the cast iron tubing from the action of aggressive water coming from the rock mass.

The following elements must be applied vertically in the lining structure (compare fig.3):
• basic upper curb 1a (made in firm rock above the salt layer),
• basic lower curb 1b (made in firm rock below the salt layer),
• rings of technological tubing lining 4a, 4b, 4c dividing the lining column into shorter sections of 10 – 15 m,
• shaft lining column 3 made from typical cast iron tubing lining (fig. 4) applied at present in shaft construction.

The use of the technological tubing ring in this type of lining is a novelty and it must be designed and constructed for the purposes of this project. The outline of the tubing lining necessary to construct a technological ring is given in fig.4 and fig 5.
Figure 5. Special tubing applied to construct technological ring (author’s design)

Where: 1 – high-dimensional access and service hole, 2 – leaching holes, 3 – technological holes for the assembly of leaching collectors, 4 – injection and anchoring holes, 5 – ring assembly holes.

The tubings used to construct the technological ring according to fig.3 have a significantly bigger depth than ordinary tubings and are adjusted in a way that makes it possible for the whole diameter of the high-dimensional access hole to enter the space behind the final tubing or tubing-concrete lining.

The access holes 1 will enable the observation - either a visual one or with the application of introscopic cameras - of the space behind the final lining column. The holes will make it possible to monitor and control the behavior of the granular material in the contact layer. The adequately selected granulation of the contact layer material should enable its expansion if an excessive creep of the salt rock into the shaft occurs or it will make its reduction possible in case of an excessive leaching of the rock cheeks. The technological holes should also enable both adding the granular material from the contact layer or its removing. The expansion of the material signals the necessity to start leaching. In order to conduct this process, two hole are required to introduce fresh water and to remove the brine from the contact layer. A uniform lowering of the charge along the whole shaft perimeter signals that the cheeks have been leached in a uniform way.

The leaching can be carried out in two ways: by introducing fresh water from the top – then more intensive leaching of the upper layers can be expected, or by introducing fresh water from the bottom and removing the brine from the top – then the brine solution in the lower section will be successfully diluted in a forced way.

Since the backfilling layer does not bind in any way the inner lining with the rock cheeks as it commonly happens, it can be concluded that the inner lining column should be set on the basic curb that is constructed below the salt layers in the adequately firm and strong rock. In this case, the optimal way will be to sink the shaft across the hole layer of the salt from the top to the bottom in a temporary or preliminary lining, and then to construct the final lining column from the bottom to the top. To build the temporary lining, anchor linings made of plastics or carbon fibre can be applied. Cases of long lasting stability of salt chambers without any lining have been encountered in salt mining. Thus, it can be assumed that the whole section of a shaft can be temporarily kept without the lining and, if necessary, it can be secured by an anchor lining. After the breakout in the whole section has been completed, the basic curb can be constructed, and – from the bottom to the top – the inner column of the final lining can be built. The space behind the lining should be filled gradually with the granular material of determined properties.
Outline technology of shaft sinking in salt rock

In order to facilitate the construction of a lining section that is not bound permanently to the rock, it is necessary to sink the whole shaft section in the salt layers first, and then to construct the final lining from the bottom to the top.

As the final lining goes through salt layers of different thickness, its structure must ensure the possibility to monitor precisely the process of leaching the rock mass. To do this, the whole section of the shaft – in accordance with the presented idea – must be divided into smaller sections that are 10 – 15 m long. The sections should be insulated tightly from each other so that the fresh water introduced behind the tubing lining leaches uniformly the salt from the outbreak cheeks without creating asymmetric caverns or voids. Having considered the geo-mechanical properties of the salt rock, its susceptibility to leaching and the thickness of the salt formations, the technology of shaft sinking in these formations can be carried out in three ways:

a) in one section constructed from the top to the bottom without the preliminary or temporary lining – for salt layers less than 15 m thick,

b) in one section with a preliminary or temporary lining constructed from the top to the bottom and the final lining made from the bottom to the top – for salt layers whose thickness guarantees the maintenance of the shaft heading in the course of making the outbreak and the final lining,

c) a mixed one, in the case of salt layer thickness that excludes the possibility to introduce tubing lining.

With the aim to present the conditions when this technology can be applied, the expected masses of the 15 m long section of the final lining are given in table 1. It is clearly visible that the mass of the cast iron tubing lining is significant and the introduction of a section longer than 50 m is improbable considering the carrying-load capacity of the screw joints of particular lining rings. Thus, in the case of longer sections, the method of constructing the final lining from the bottom to the top should be used. It is also recommended that the smallest possible number of tubing picotage joints should be applied.

Table 1. The mass of 15 m long section of tubing lining

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Cast iron tubing</th>
<th>Monolithic concrete lining</th>
<th>Concrete envelope behind tubing</th>
<th>Tubing lining with concrete envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tubing ring diameter</td>
<td>m</td>
<td>7,6</td>
<td>7,75</td>
<td>7,25</td>
<td>-</td>
</tr>
<tr>
<td>Lining thickness</td>
<td>m</td>
<td>0,16</td>
<td>0,5</td>
<td>0,2</td>
<td>-</td>
</tr>
<tr>
<td>Lining material specific gravity</td>
<td>kN/m³</td>
<td>79</td>
<td>27</td>
<td>28</td>
<td>-</td>
</tr>
<tr>
<td>Lining ring unit volume</td>
<td>m³</td>
<td>3,8</td>
<td>12,2</td>
<td>4,6</td>
<td>-</td>
</tr>
<tr>
<td>Lining ring weight (h = 1.5 m)</td>
<td>kN</td>
<td>301,8</td>
<td>328,7</td>
<td>127,5</td>
<td>429,3</td>
</tr>
<tr>
<td>15 m long lining section weight</td>
<td>kN</td>
<td>3017,9</td>
<td>3286,9</td>
<td>1275,5</td>
<td>4293,4</td>
</tr>
</tbody>
</table>

More detailed principles of selecting the sinking method will be worked out following practical experience gained while sinking shafts in such conditions.

The construction of technological rings is a crucial element of shaft building in such conditions. Their structure in presented in detail in fig. 4. The role of the technological ring is to ensure both the monitoring and the control of all the processes behind the final lining and to guarantee the possibility to insulate
Hydraulically particular sections from one another. The height of the sections will be worked out in laboratory tests and in situ conditions. However, it should be assumed that the height should range between 10 – 15 m. In order to insulate the sections from one another, sealing injections behind the technological tubings and cuts in the salt rock filled with insoluble mineral material should be made.

**SUMMARY AND CONCLUSIONS**

The presented structure of lining and the technology outline are a completely new proposal, although based on hitherto practice of shaft construction. The patented technology takes the advantage of the common drawback of the rock mass that is easily soluble in fresh water. The mastering of the controlled leaching of shaft outbreak cheeks should become a new tool in counteracting the strain pressure onto the shaft lining.

The concept presented above requires further investigations as regards the properties of salt, the forecasting and measurement of salt rock creep into the shaft interior and its efficient and uniform leaching. After a regularly performed process of leaching, the granular backfill of the contact layer should be completely devoid of the liquid (the water and then the brine). The kinetics of leaching and the process control will be subject to further investigations and research.

**REFERENCES**


Flisiak D. (2005): Badania procesów reologicznych w górotworze solnym wywołanych użytkowaniem podziemnych magazynów gazu. Projekt badawczy KBN Nr 5T12A 01722 (not published)
