RISK MANAGEMENT IN THE CASE OF ROSIA POIENI TAILINGS POND (*)

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1. INTRODUCTION

Tailings ponds are currently an area increasingly interesting not only for the scientific community but also for civil society, both in terms of their role in various technological processes and, particularly, of their potential impact on the environment and population.

In terms of potential environmental impacts, tailings ponds present both a technological risk and one of stability. These impacts are directly related to the administration of tailings throughout the technological circuit as well as to the design and performance of the facilities for the tailings management. Technological risk refers to industrial pollution which induces toxic or hazardous substances into the environment due to deficiencies in the production process. Stability risk refers to breaking the stored tailings construction due to losing the structural stability or due to damaging its appurtenant structures.

Safety management of tailings ponds is a complex and difficult challenge for the owners, because these structures present a significant potential risk. The

(*) Gestion de risques du barrage de stériles miniers Rosia Poieni.
in house Safety Management System must provide the owner the ability to anticipate and manage all safety issues, and therefore the associated risks, before they produce incidents in the storage facility. The components of an adequate risk management system [1] are presented in Figure 1.

Fig. 1
Risk management components (after Kreuzer, 2000)
Composants de gestion des risques (d’après Kreuzer, 2000)

In order to provide an adequate risk management system one has to take into account the specificity of the risk definition as a product between the possibility of occurrence a hazardous event (failure in our case) and the size of its consequences. Effective failure of a structure has direct consequences but different in terms of severity, importance and magnitude. Damage can occur both in its own system of the facility and to the third parties. These can be damages to the people (difficult to quantify with limits imposed by humanitarian and political criteria), economic damages on objectives affected (with exact financial value, determined by technical, economic and financial optimization), social-economic damages (by interrupting or affecting some utilities - water supply, electricity, ways of communication, agriculture etc.), and damage to the environment (which cannot be reconstituted only through allocation of funds). Damages to third parties are consequences only in the case of failure with uncontrolled loss of the content.
Quantification of risk will take into account both the probability of failure and consequences size expressed in loss of life, property damage and unquantifiable effects. In Romanian practice risk quantification is currently achieved empirically by getting the proportional risk indices, and the method is used to establish the category of importance of tailings ponds and their ranking in terms of associated risk. In special cases the quantification of failure probability is performed on the basis of adverse event trees. By reassessment the failure probability, after establishing the constructive intervention program, the improved surveillance system and the adequate operating instructions, an objective quantitative measure is provided for evaluation of the effectiveness of these measures.

The case study of Valea Sesei TMF, within Rosia Poieni copper mining operation, underlines the usefulness of quantitative evaluation of risk for a proper risk management system.

2. SHORT DESCRIPTION OF VALEA Sesei TMF

Valea Sesei TMF belongs to S.C. Cuprumin S.A. Abrud in charge with the exploitation and processing of the largest poor copper ore deposit in southeastern Europe, Rosia Poieni open pit. It is a valley pond located on Velea Sesei River and dam section is approx. 6 km upstream of the confluence with Aries River. The general layout of the mining components is presented in Figure 2.

The main appurtenance structures of the TMF are presented in Figure 3. Tailings deposition in the pond is made alternatively from the dam crest during normal operation and in several points on the left side of the pond contour (on Carbunari and Geamana valleys) during the dam crest heightening. Hydraulic transport of tailings is gravitational from processing plant via two steel pipes DN600 mm along 8.7 km.

Waste rock dumps are located on the outer edge of the ore quarry, two of them (Geamana and Cuibar) on the slopes of Valea Sesei catchment. The material of mining dumps has an intense chemical-biological leaching process that cause strong acidification of the water (pH 1.9 to 3.5). The drainage of acid water is carried in the tailings pond, where are permanently collected some volumes, and they drain into the emissary through the water discharge system.
Tailings sludge flows from the processing plant with an alkaline pH, resulting in the preparation process of the ore. The pH of the slurry is raised to 11 to partially neutralize acidic waters collected in the pond from the dumps. Tailings deposition in pond is achieved in the way that acid water to be isolated in the
pond tail, and their leakage to the water discharge system to be carried out at flow rates as small as possible. In this way the acid water is kept out from the limestone dam.

Decanted water evacuation is accomplished through a system of three independent lines of penstocks that discharge water into a concrete outlet gallery with $D = 3$ m. The same gallery discharges floods caused by streams flowing into the pond. Overflow wells are made along the discharge pipe located on the right side of the pond (PREMO DN600 mm). They are raised with fiberglass elements of 0.6 m with flanges, for better resistance at the chemical attack of acid drainage.

Floods from upstream tributaries transit the tailings pond, as there is no diversion gallery of water from upstream catchment. Floods are attenuated in the pond, and discharge systems for technological and affluent water were calculated to evacuate flood with ensuring 0.1%.

![Boundary between acid drainage and tailings](image)

The dam of the pond is a limestone rockfill structure. The starter dam has a height of 70 m and at the time when the paper was prepared it has reached 90 m after five successive raisings.

The starter dam is a limestone rockfill dam. Initial raising solution provided a downstream raising using the same rockfill quarry as a first step of 20 m high. The following raising steps were designed to be made of coarse tailings obtained by hydrocyclonage. Due to technological reasons the dam was actually raised in
upstream direction by using successive 3 m rockfill steps founded on tailings beach. At the time when this paper was made there are built 5 raising steps (see Figure 5).

It is important to notice that the foundation soil of the dam and the tailings pond footprint soil consists mainly of cretaceous deposits (calcareous marl, sandstones and limestone), covered with clay deposits, with low permeability. Consequently, the foundation is also vulnerable to acid drainage waters.

During all the years of operation the dam showed a good stability primarily due to its geotechnical characteristics, to suitable slopes and to the lowered position of the seepage line - depression curve. Drainage nature of the dam body is an important factor in its stability since there is no interstitial pressure.

3. QUANTIFYING RISK BY INDICES AND WEIGHTINGS

In this approach there are identified those components that have implications in triggering the failure mechanisms and the extent to which the damage or lack of complying with given technical specifications may lead to breaking the tailings dam [3]. The overall index related to safety is called the criticality index IG.

$$IG = CM \cdot PC \cdot DC$$  [1]
Where:
- CM - index expressing the component weighting in the failure mechanism;
- PC - index expressing the component failure probability;
- DC - index expressing the extent to which the component failure can be detected in advance.

The numerical indices are defined as follows:
- CM=5 if the component failure has a very important effect in starting the breaching mechanism, (CM=4...1 - important, moderate, low, insignificant);
- PC=5 - if the component failure is most likely, (PC=4...1 - likely, unlikely, most unlikely, improbable);
- DC=5 – if the component failure is very difficult to detect in advance, (DC=4...1 - heavy, moderate, easy, very easy).

Criticality indices are evaluated to rate the risk associated with identified components in order to establish work priorities and measures necessary, both for intervention and supplementing the monitoring system of the tailings pond. The results of the analysis performed for Rosia Poieni pond are presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>No</th>
<th>Component</th>
<th>CM</th>
<th>PC</th>
<th>DC</th>
<th>IG</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dam body (acid water action)</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>75</td>
<td>I</td>
</tr>
<tr>
<td>2</td>
<td>Outlet gallery (acid water action)</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>60</td>
<td>II</td>
</tr>
<tr>
<td>3</td>
<td>Upstream dumps sliding – flood</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>50</td>
<td>III</td>
</tr>
<tr>
<td>4</td>
<td>Storage capacity – dam overtopping</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>40</td>
<td>V</td>
</tr>
<tr>
<td>5</td>
<td>Outlet gallery subsidence – no discharge</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>25</td>
<td>VI</td>
</tr>
<tr>
<td>6</td>
<td>Overflow wells damage – lower discharge</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>45</td>
<td>IV</td>
</tr>
<tr>
<td>7</td>
<td>Raised embankments - stability</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>18</td>
<td>VII</td>
</tr>
</tbody>
</table>

Based on the results that underline as the major concern the action of acid drainage water the Romanian Water Authority has imposed as mandatory measure the containment of acid water volumes at the tail of the pond to prevent direct contact with the materials of the dam body and water evacuation system. The second action is continuous input of alkaline slurry in the tailings pond. Complementary action is dedicated to the dumps stored on tributaries that have to be change in terms of deposition.
4. QUANTIFYING RISK BY USING FAULT TREES

In the second stage the breaching probability of the pond dam was quantified on the basis on fault trees procedure. It was a means for identifying where the greatest potential risks are. The procedure was also used as a tool for evaluating changes in risk given certain actions and assumptions. The main possible failure mechanisms that may lead to the breach formation are presented in Figure 6. The most probable mechanism is breach formation due to downstream slope sliding. The dam crest overtopping is less probable due to a large storage volume available in the pond. Finally the acid drainage is very unlikely if the imposed measures are strictly observed.

\[
P_{0} = 1.37 \times 10^{-3}
\]
\[
P_{11} = 1.4 \times 10^{-4}
\]
\[
P_{12} = 1.4 \times 10^{-4}
\]
\[
P_{13} = 1.31 \times 10^{-4}
\]

\[
\frac{P_{11}}{P_{0}} = 5.8\%
\]
\[
\frac{P_{12}}{P_{0}} = 0.6\%
\]
\[
\frac{P_{13}}{P_{0}} = 93.8\%
\]

Fig. 6
Identifying the mechanisms producing the breach in the dam
Identification des mécanismes produisant des brèches dans le barrage

The next three figures present the fault trees for each of the identified mechanisms. The annual probability of the identified primary events, were determined based on statistics or by engineering judgment. The ways to increase the safety are defined based on the analyses results [2], [4]

Based on the probabilistic analysis, having in mind the main contributors to the failure event, the actual measures required for the safety management were defined.

In order to reduce dam overtopping risk:
- maintaining a minimal freeboard of water table in the pond (min. 3.5 m);
- continues monitoring of the water evacuation system;
- implementing of a backup system for water discharge.

In order to prevent the dam slope sliding:
- providing a proper drainage of the added raising dikes;
- consolidation of the beach in front of the dam before building a new raising dike
In order to prevent the adverse action of acid water:
- reducing the acid drainage from the waste rock dumps stored upstream;
- containment of acid water volumes at the tail of the pond to prevent direct contact with the dam body and water evacuation system;
- continuous operation of the processing plant that provides the alkaline slurry in the tailings pond.

![Fault tree for dam overtopping](image)

**Fig. 7**

*Arbre des défauts pour le déversement du barrage*

![Fault tree for downstream slope sliding](image)

**Fig. 8**

*Arbre des défauts pour un glissement de versant aval*
5. CONSEQUENCES ASSESSMENT IN THE CASE OF POND FAILURE

Consequences assessment of pond failure was made by global quantification using an index proportional to the consequences. In case of tailings pond failure, rapid and uncontrolled release of sludge content from the pond can produce the following effects:

(i=1) loss of lives (PVO);
(ii=2) damages caused to third parties (PMT);
(iii=3) effects on the environment (ME);
(iv=4) damages caused to the owner (PMD);
(v=5) indirect effects (EI).

A global index was defined in order to evaluate the effectiveness of the mitigation measures provided to reduce the consequences, as follows [5]:

$$ C = \beta \cdot \sum_{i} CG_{i} \cdot P_{e,i} \cdot \alpha_{i}, $$

[2]
Where;

$CG_i$ is the index characterizing the severity of each of the consequences ($i=1 \ldots 5$) in relation to the population at risk, to economic status of the area potentially affected, and civil society. For the Rosia Poieni pond, based on public consultation the CG values are the ones in Table 2

<table>
<thead>
<tr>
<th>Consequence category</th>
<th>$i=1$ PVO</th>
<th>$i=2$ PMT</th>
<th>$i=3$ EM</th>
<th>$i=4$ PMD</th>
<th>$i=5$ EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CG_i$</td>
<td>$10^5$</td>
<td>$10^3$</td>
<td>$10^3$</td>
<td>$10^2$</td>
<td>$10^3$</td>
</tr>
</tbody>
</table>

$P_{e,i}$ is the probability that a certain consequence effectively occurs, taking into account of the area potentially affected by the breaking wave and of the situation in the respective area. The probabilities were established based on engineering judgment.

$\alpha_i$ is characterizing the effectiveness of measures taken to limit or mitigate each of the effects ($i=1 \ldots 5$) of dam failure using population warning plans and pre and post-emergency measures. It is appreciated by a sub unitary coefficient $\alpha$, with values between 0 and 1.

$\beta$ is a correction factor that reflects the rate of breach development. Its values are in the range $0.1 \ldots 1$, with larger values for rapid failure. In the case of Rosia Poieni, with a rockfill starter dam the rate of breach development was considered slow ($\beta =0.2$).

The risk management policy provided several immediate measures:

- population training for warning-alarm reaction and evacuation routes from the affected area;
- building a downstream dike to temporary store and attenuate the wave of sludge and water;
- diverting the slurry delivery to a backup tailings pond until the breach is closed and the remediation are made.

The effectiveness of the proposed measures were evaluated by means of the global index of consequences comparing in terms of $\alpha$ values the existing condition AC and the improved one IC. The evaluation is presented in Table 3.
Table 3
Evaluation of the global index for existing (AC) and improved condition (IC)

<table>
<thead>
<tr>
<th>No</th>
<th>Consequence category</th>
<th>CG</th>
<th>$P_o$</th>
<th>$\alpha$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AC</td>
<td>IC</td>
</tr>
<tr>
<td>1</td>
<td>PVO</td>
<td>$10^5$</td>
<td>$10^{-2}$</td>
<td>0,5</td>
<td>0,1</td>
</tr>
<tr>
<td>2</td>
<td>PMT</td>
<td>$10^3$</td>
<td>$5\times10^{-2}$</td>
<td>0,5</td>
<td>0,3</td>
</tr>
<tr>
<td>3</td>
<td>EM</td>
<td>$10^3$</td>
<td>$10^{-1}$</td>
<td>0,5</td>
<td>0,2</td>
</tr>
<tr>
<td>4</td>
<td>PMD</td>
<td>$10^2$</td>
<td>$10^{-2}$</td>
<td>0,2</td>
<td>0,2</td>
</tr>
<tr>
<td>5</td>
<td>EI</td>
<td>$10^3$</td>
<td>$10^{-2}$</td>
<td>0,8</td>
<td>0,5</td>
</tr>
</tbody>
</table>

The evaluation shows that from $C_{AC} = 117$ the improved condition leads to $C_{IC} = 28,4$, that means that the preventive and intervention measures may diminish the dam failure consequences up to 5 times.

6. CONCLUDING REMARKS

Risk management for Valea Sesei TMF is particularly important due to the special condition created by the acid drainage from the waste rock dumps located on the slopes of Valea Sesei catchment area. The drainage of acid water is carried in the tailings pond, and the limestone dam of the pond has to be protected in order to maintain the dam safety.

In the first phase the criticality indices were evaluated to rate the risk associated with identified components and to establish priorities and necessary measures. As the major concern was the action of acid drainage the Romanian Water Authority has imposed as mandatory measure the containment of acid water volumes at the tail of the pond to prevent direct contact with the dam body and water evacuation system. Complementary, tailings sludge from the processing plant, with an alkaline pH, is used to neutralize acidic waters collected in the pond.

In the second stage the breaching probability of the pond dam was quantified on the basis on fault trees procedure. It was a means for identifying where the greatest potential risks are. The procedure was also used as a tool for evaluating changes in risk given certain actions and assumptions. Based on the probabilistic analysis, having in mind the main contributors to the failure event, the actual measures required for the safety management were defined.
The effectiveness of the proposed measures to diminish the failure consequences were evaluated by means of the global index of consequences comparing the existing condition and the improved one.

REFERENCES


SUMMARY

Valea Sesei TMF is a valley pond located on Velea Sesei River. The dam of the pond is a limestone rockfill structure. The starter dam has a height of 70 m and at the time when the paper was prepared the dam has reached 90 m after five successive raisings. Floods from upstream tributaries transit the tailings pond, as there is no diversion gallery of water from upstream catchment. Waste rock dumps are located on the outer edge of the ore quarry, two of them on the slopes of Valea Sesei catchment area.

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RÉSUMÉ

Le barrage de stériles de Valea Sesei retient un réservoir de vallée situé sur la rivière Velea Sesei. L’ouvrage est constitué d’un enrochement calcaire. Le barrage initial présentait une hauteur de 70 m et, au moment où ce document a été rédigé, il atteignait 90 m après cinq élévations successives. Les crues des affluents en amont passent par le bassin de résidus, car il n’y a pas de galerie de dérivation des eaux du bassin versant en amont. Les accumulations de stériles sont situées sur le bord extérieur de la carrière de minerai, deux d’entre eux étant sur les pentes du bassin versant de la Valea Sesei.

La gestion des risques pour le barrage de stériles de Valea Sesei est particulièrement importante en raison du drainage acide provenant des accumulations de stériles. Le drainage de l’eau acide est amené dans le bassin, et le barrage en calcaire doit être protégé afin de préserver sa sécurité.

Dans une première phase, les indices de criticité ont été évalués pour établir le risque associé aux composants identifiés et pour établir les priorités et les mesures nécessaires. La préoccupation majeure étant l’action du drainage acide, l’Autorité Roumaine de l’Eau a imposé, comme mesure obligatoire, le confinement des volumes d’eau acide en extrémité de bassin pour empêcher le contact direct avec le corps du barrage et le système d’évacuation de l’eau. De manière complémentaire, les boues résiduelles de la station de traitement, de pH alcalin, sont utilisées pour neutraliser les eaux acides recueillies dans le bassin.

Dans une seconde phase, la probabilité qu’une brèche se développe dans la digue du bassin a été quantifiée par l’intermédiaire de la procédure d’arbres de défauts, moyen pour identifier où se situaient les plus grands risques potentiels. La procédure a également été utilisée comme outil pour évaluer les évolutions de risque, compte tenu de certaines actions et hypothèses. Sur la base de l’analyse
probabiliste, et en tenant compte des principaux contributeurs à l'événement de rupture, les mesures concrètes nécessaires à la gestion de la sécurité ont été définies.

L'efficacité des mesures proposées pour diminuer les conséquences de la rupture a été évaluée au moyen de l'indice global des conséquences en comparant l'état actuel et l'état amélioré.