OPENCAST MINE INTERNAL DUMP SANATION RISKS

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ABSTRACT
Scheduled maintenance of overall slope stability with efficient surface and underground dewatering and appropriate dump technology are the basic subprocesses that provide sustainable dump development process and minimize geomechanical, environmental, safety, and production risks. Neglecting these preconditions in the design phase often leads to slope sliding with high consequences due to dump dynamic realization and production losses. The sanation of damaged dumps includes risk assessment and additional geomechanical and hydrogeological explorations, as demonstrated by the example of the old internal dump of the opencast mine Field B in the Kolubara coal basin.

1 Introduction

Overburden dumping on opencast mines is the most important and complicated part of the mining process. The complexity is particularly pronounced in the case of internal dumps, and especially in the case of the disposal of slightly inclined beds in the direction of the advance of the work front. In practice, there is almost no opencast mine that does not have sliding problems on internal dumps. Therefore, all elements of the opencast mining process must be carefully planned, designed, and operated to minimize landslide risks according to the slope management interaction process. The process must integrate the geotechnical and hydrogeological exploration results with mine planning, operating practices, economic evaluation, production requirements, and acceptable levels of risk [4]. In addition to high costs, the sanation of a damaged dump also includes a risk assessment in mining project realization, in real time.
For a long period of time, many authors around the world have been paying great attention to the analysis and minimization of dump slide risks in the mining design phase with a presentation of many necessary sanation possibilities, and a lot of research has been carried out in this area [4, 5, 7, 8, 9,12].
The use of the proposed risk evaluation methodology for analyzing the opencast internal dump sanation risks in the design phase stage includes defining the influence of economic, technical, ecological and geotechnical parameters and appropriate failure consequence costs in accordance with the Life Cycle risk management approach and standard ISO 31000:2018 [1, 2, 6, 10, 11]. In addition to sanation costs, internal dump sanation process includes the highest cost of production losses with the postponement of the project implementation deadline [3, 10].

2 Methodology

For opencast mine internal dump sanation risk assessment, the quantitative probabilistic method V-FMEA (Value-Failure Mode and Effect Analysis) [10] was used, which was modified in the risk assessment part compared to the conventional FME(C)A method. It is based on the theory of probability and process reliability and maintains the simplicity of the FME(C)A method while eliminating the shortcomings of the conventional RPN (Risk Priority Number). For risk evaluation in V-FMEA, the RPV (Risk Priority Value) is defined, which is obtained by multiplying the subprocess failure probability with and without preventive activities P_f and the corresponding consequences based on the monetary value of expected all losses C, so that for each subprocess risk R is:

$$R = RPV = P_f * C \quad (1)$$

Figure 1 shows the methodological presentation of the modified V-FMEA method for assessing the risk of internal dump sanation, including the possibility of preventive protection of sub-processes.

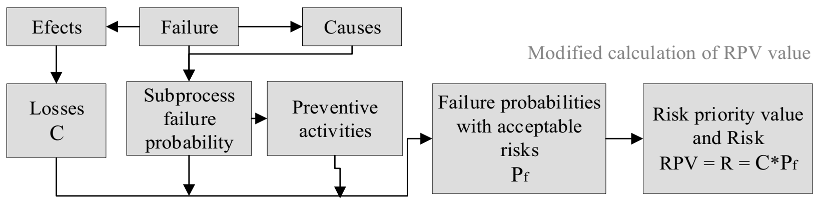

Figure 1 *Flow chart for modified method V-FMEA*

Reliability and failure probability subprocesses of phase realization of the overburden dump mining sanation project are the simplest to show by the existence of two states for each subprocess. In reliable condition S_r, the realization is carried out according to plan. From state S_r, it can go to failure state S_f with transition intensity a, in which delaying or failure occurs due to some of the internal or external causes. After solving the problems, the subprocess returns to state S_r with transition intensity b. The intensities of the transition from state to state (a, b) are reciprocal values of the duration of the state of reliability and restoration of subprocesses (T_r, T_f).

Subprocess reliability $P_r(t)$ in time t and delaying or failure probability $P_f(t)$ equations have the following form: $dP_r/dt = bP_f - aP_r$, $dP_f/dt = aP_r - bP_f$. Since $P_r + P_f = 1$ for each t, P_f can be expressed through P_r so that $P_f = 1 - P_r$, and solving these equations gives the value of P_f as a function of time t: $P_f(t) = 1 - P_r(t) = a/(a+b)(1-e^{-(a+b)t})$. When $t \rightarrow \infty$, the corresponding subprocess stationary failure probability because of project delays is obtained:

$$P_f = a/(a+b) \quad (2)$$

For mutually independent occurrences of subprocess failure, the overall risk is (1):

$$R_o = RPV_o = P_{f1}{*}C_1 + \ldots + P_{fi}{*}C_i = \sum_{i=1}^{n} P_{fi}{*}C_i, \text{ (Euro)} \quad (3)$$

where: R_o - overall sanation process risk

P_{fi} - failure probability of i-th subprocess ($i = 1, \ldots, n$)

C_i - expected losses due to i-th subprocess delaying or failure

among others, the following can be singled out for the sum of losses: C_o - preparatory organizational costs after failure, C_s - costs of slope rehabilitation, stabilization, and additional geotechnical and hydrogeological exploration and installation of measuring units, supplementing the drainage system and documentation, C_r - renewal of equipment and objects or change in dumping technology, C_p - possible costs due to production and deposit losses, which are dominant in practice, C_e - ecological and sociological negative effects; and C_h - costs of endangering health.

Maximum acceptable risks

If R_{max} is the maximum acceptable risk of delaying or failure of opencast mine internal dump sanation subprocesses and if P_{fmax} is the maximum acceptable delaying or failure probability in the same way, then according to the basic risk equation (1), the maximum acceptable sanitation failure probability is:

$$P_{fmax} = R_{fmax}/C \quad (4)$$

The maximum acceptable sanation subprocess failure probability defined in this way cannot be greater than the percentage of total costs due to its failure and is practically obtained without knowing the absolute value. Also, it is a clear conclusion that the failure cause with the highest costs/risk must be brought to a state of highest reliability in relation to other causes with lower costs/risk due to the consequences of failure.

3 Case study: Opencast coal mine Field B inside dump sanation risks

In the eastern part of the Kolubara Basin, lignite exploitation is carried out at the opencast mine Field C in the final phase and at the mine Field E, which is in the opening phase. These fields are a natural continuation of the previously closed opencast mines Field A, Field B, and Field D, with a unique coal deposit (Figure 3 - left). The internal dump of the mine Field A was recultivated too early, and the internal dump of the opencast mine Field B was neglected, so even as a large landslide, it is even more threatened by further risky disposal without prior sanation (Figure 2).

Figure 2 Neglected internal dump in Field B

According to the plan, by 2030, a large joint dump should be formed on the fixed internal dump of the opencast mine Field B and in the old opencast mine Field A zone (Figure 3 - left). When the sanation of Field B is complete, the joint dump can sustain about 400 Mm^3 of overburden by 2035 (Figure 3 - right). As there is no other place to dispose of overburden for opening the main coal seam of the Polje E opencast mine, the delay of the full annual coal production of 6 Mt would threaten the dynamics of mine development and the stability of the energy system with large financial losses, which necessitates the urgent sanation of the landslide at the internal dump site of the Field B mine.

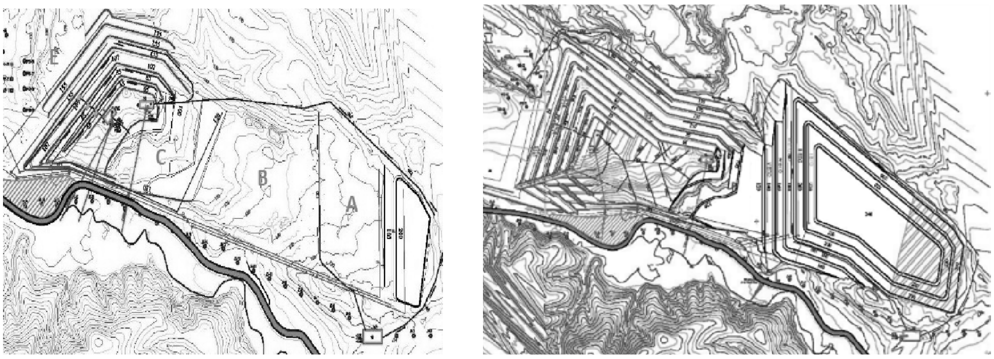

Figure 3 State of works on opencast mines with the internal dump sanation realization on the opencast mine Field B, the beginning of internal dump height raising on the mine Field A 2030 (left), and achieving full production at mine Field E in 2035

The Gantt chart in Figure 4 shows the realization of the sanation project of the opencast mine Field B internal dump under subprocesses whose delays are simultaneously failure causes. Additionally, the most important final Field A/B inside dump overload subprocess, because of which the remediation must be realized in principle. The geological project and exploration work started in 2023, and after the completion of reports, the mining sanation project is planned to continue until the end of 2024. In the same time interval, further unsafe disposal in that area should cease, old, neglected surface water dewatering objects should be revitalized and new well lines for pumping out groundwater should be added. After that comes the realization of full internal dump sanation until the end of 2027. The beginning of the formation of internal dump overload in the old opencast mine Field A on the east should begin in the middle of 2026, when the conditions were created for the unhindered progress of opencast mine Field E on the west.

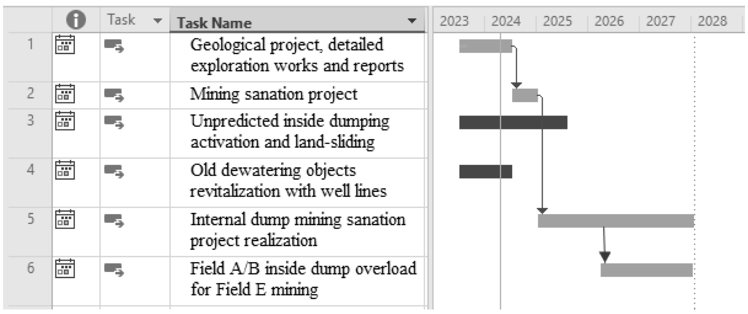

Figure 4 Gantt chart of the sanation project realization of the Field B internal dump by failure causes

After the completion of the new geological exploration and mining sanation project, the sanation is supposed to begin with the creation of a cut (Figure 5 - left), and then a support embankment for the stabilization of land sliding (Figure 5 - right). A preliminary assessment of the stability of the final overall slope, which includes initial cut in the coal bed and the formation of benches in the western part of the old dump with a total height of 80 m at an angle of 12 degrees and a pore pressure of ru = 0.3, is fully satisfactory, yielding a safety factor of F = 1.56 (Figure 5 - left). Under the same conditions, the reduced overall slope of the compacted support embankment at an angle of 11 degrees provides a desirable factor of safety for the high consequence of slope failure, which is F = 1.51 (Figure 5 - right). During the excavation, about 2 Mt of coal and 3 Mbm^3 of overburden were unearthed at the floor and slope of the old dump. The construction of the support embankment includes the construction of dewatering canals at the floor, the installation of 15,000 m^3 of crushed stone, the disposal of about 5 Mlm^3 of overburden with compaction of the material, and the installation of geogrid placement.

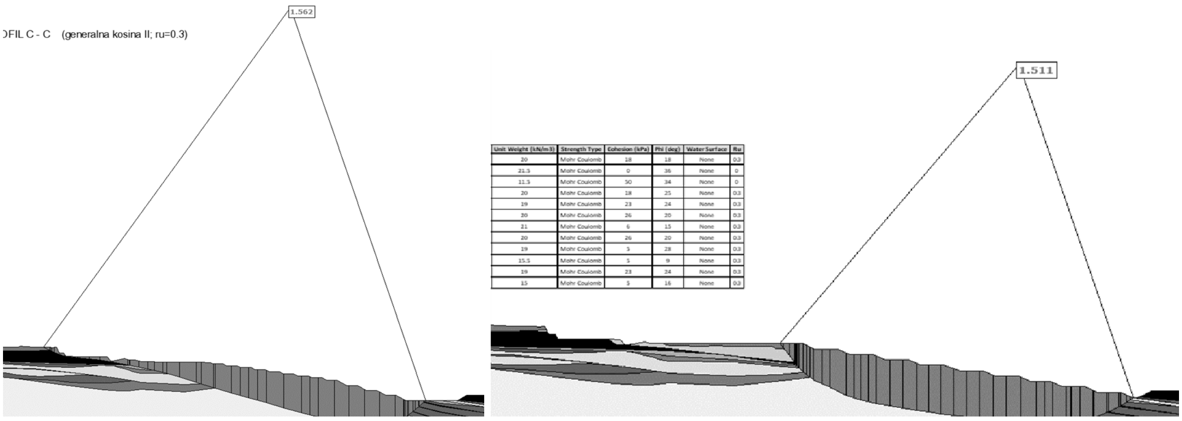

Figure 5 Stability of the overall slope of the rehabilitation initial cut (left) and stability of the overall slope of the rehabilitation embankment (right)

In accordance with the established methodology, a risk assessment was performed under subprocesses and with the determination of the risk priority value. Table 1 shows the distribution into priorities, risk intervals, and descriptions of risk values (M€), where a higher priority has a higher value [10]. The acceptable risk percentage value criterion (4) in relation to production losses was accepted.

***Table 1** Distribution into priorities, risks intervals and description of risk values (M€)*

Priority 1	Estimated risks in the interval 0 < RPV ≤ 0.5	Very low risk	(light green)
Priority 2	Estimated risks in the interval 0.5 < RPV ≤ 1	Low risk	(green)
Priority 3	Estimated risks in the interval 1 < RPV ≤ 1.5	Medium risk	(yellow)
Priority 4	Estimated risks in the interval 1.5 < RPV ≤ 2	High risk	(orange)
Priority 5	Estimated risks in the interval RPV > 2	Very high risk	(red)

Tables 2 and 3 shows subprocesses risk evaluation and ranking without (Option 1) and with preventive activities (Option 2).

***Table 2** Subprocesses risk evaluation and ranking by causes without preventive activities (Option 1)*

Cause/Subprocess/Process	**a**	**b**	**P_f**	**C** (M€)	**RPV** (M€)	**Risk priority**
Additional geological project, detailed exploration works and reports	0.083	0.333	0.201	3	**0.603**	**2**
Mining sanation project with stability and dewatering analysis	0.167	0.500	0.250	2	**0.500**	**1**
Unpredicted inside dumping activation with additional land-sliding	0.042	0.100	0.296	10	**2.960**	**5**
Neglected old dewatering objects revitalization and new well lines ending	0.083	0.143	0.367	7	**2.569**	**5**
Internal dump mining sanation project realization	0.028	0.125	0.183	8	**1.464**	**3**
Opencast Field A/C old internal dump preparation for Field E overburden	0.042	0.111	0.275	9	**2.475**	**5**

In Option 1, high failure probabilities values (2) for sanitation subprocesses risks evaluation and ranking by causes without preventive activities (Table 2) (1) lead to very bad results because for three subprocesses with Risk priority 5 as Very high risk. The other three subprocesses, from Medium to Very low risk, have mainly acceptable risks. Sanitation process overall risk for evaluation without preventive activities (3) is unacceptable at 10.6 M€. This indicates the need to reduce them by introducing preventive management and executive activities with reliability time reserves to a permissible maximum risk value of 40% of the possible production profit loss value, or a maximum acceptable risk value of 5 M€.

***Table 3** Subprocesses risk evaluation and ranking with successful preventive activities (Option 2)*

Cause/Subprocess/Process	**a**	**b**	**P_f**	**C** (M€)	**RPV** (M€)	**Risk priority**
Additional geological project, detailed exploration works and reports	0.056	0.500	0.101	2	**0.202**	**1**
Mining sanation project with stability and dewatering analysis	0.167	1	0.143	1	**0.143**	**1**
Unpredicted inside dumping activation with additional land-sliding	0.042	0.167	0.201	6	**1.206**	**3**
Neglected old dewatering objects revitalization and new well lines ending	0.083	0.250	0.249	4	**0.600**	**2**
Internal dump mining sanation project realization	0.028	0.200		5	**0.615**	**2**
Opencast Field A/C old internal dump preparation for Field E overburden	0.042	0.143	0.227	7	**1.589**	**4**

The results obtained in Option 2 indicate a significant reduction of sanation risk in the variant with successful preventive activities for all failure causes (Table 3), compared to the variant without preventive activities (Table 2). High risk value was obtained for opencast mines' Field A and B joint internal dump preparation for Field E overburden dumping and represents a priority due to catastrophic consequences. Unpredicted inside dumping extension still represents a serious Medium risk, so this subprocess must be carefully controlled. The revitalization of neglected old dewatering objects and realization of new dewatering well lines, as well as the entire realization of the sanation process, have acceptable low risks. Finally, geological exploration and mining sanation projects are expected to be very low risk. Sanation process overall risk with preventative activities (3) amounts to an acceptable 4.4 M€ in relation to possible product losses.
For the realization of Option 2, it is necessary to undertake maximum preventive organizational and technical activities with serious investments. That is why significant funds of €3 million have been earmarked for planned preventive activities to reduce process failure overall risk in the project life cycle. These investments, in relation to the overall risk of 10.6 M in Option 1, make up less than 30% of the of the losses, so they are favorable for the company.

Conclusion

The presented methodological approach for opencast mine internal dump sanation risk evaluation is based on the standard ISO 31000:2018 process and the life cycle risk management approach by using the modified V-FMEA method. The overall risk of the sanation process was obtained through selected subprocess risk assessments with calculations of failure probability and losses by causes in real time. The maximum acceptable company risk of internal dump sanation subprocesses delaying losses is obtained based on determining the failure probability as the optimal ratio between the costs to reduce the risk and the total consequences. Solving the complex problem of rehabilitation of the internal dump of the opencast mine Field B showed the possibilities of using the methodology for subprocess risk evaluation and ranking without preventive activities and for subprocess risk evaluation and ranking with successful preventive activities. Summing the subprocess risks gives the overall sanation risk by option. The big difference between options risk values of 6 million euros indicates that it is possible to justifiably invest 3 million euros in preventive activities for the acceleration and safety of rehabilitation works with additional mechanization, better organization and technological discipline, with management understanding that the planned preventive measures are necessary and useful for the company. In addition to being applied to all opencast mines for dump remediation, the developed methodology is also suitable for risk analysis of all basic mining processes.

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