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RISK MANAGEMENT ON MEDJEDJA DAM ON TAILING STORAGE FACILITY, OMARSKA MINE PRIJEDOR

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ABSTRACT

Dams and tailing storage facilities are specific mining facilities that carry many potential hazards, and therefore risks. In this paper, for tailing mud damMedjedja andtailing storage facilityof the Omarska Mine near Prijedor, on the basis of the current state of the dam, past events, visual observations and specialist measurements, we have analysed possible accident scenarios, the likelihood of their occurrence, and their detrimental effects, including: loss of life, material damage, environmental consequences and impact on the reputation of the Company. The ISO standards and ICOLD recommendations related to dam risk management were used in the risk assessment.

Key words: *dam, tailing mud, risk assessment, risk analysis, risk management*

INTRODUCTION

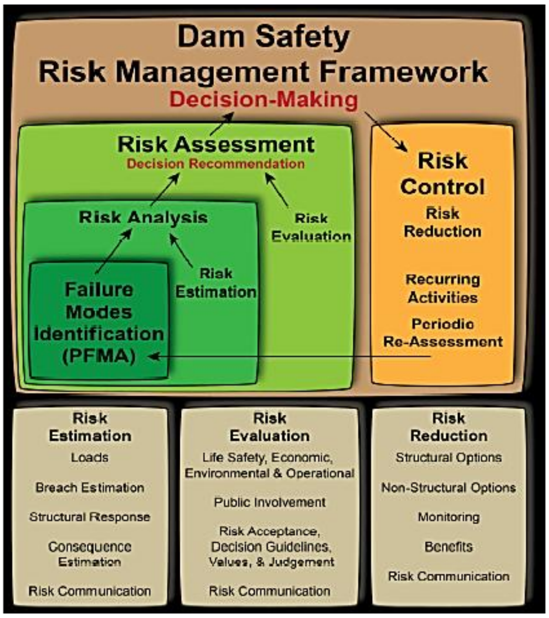
In technological processes of mineral processing, it is necessary to build a suitable dam for disposal of tailings mud (wastewater containing small particles of tailings and mineral raw material) in a certain area. These dams are usually constructed as dams made of homogeneous or heterogeneous material from the immediate environment or of material separated from tailings mud after cyclone process. Their service life lasts for several decades, which is why they must be monitored and managed all the time, whether they are in use or the process of disposal has been completed. Tailing storage facility dams carry more risks: threats to lives and human health, financial and material losses, the environment (pollution of water, soil, flora, fauna, etc.) especially in downstream areas, and the reputation of the Company managing them.

The issue of dam safety over the last six decades has attracted a great deal of attention from the public, several researchers, various agencies, and legislation to issue regulations, to help prevent and / or mitigate these risks. Many developed countries, especially the USA, England, Australia, Canada, the Netherlands, the EU and other countries have set up various agencies, bureaus and committees (FEMA, ANCOLD, BCHidro, ICOLD, etc.) to address dam safety issues, and have adopted risk management strategies to assess and manage risks for dams in their countries. Republic of Srpska and Bosnia and Herzegovina have not yet adopted adequate regulations in this field other than the risk management standards BAS ISO 31000: 2016 [1] and the mud characterization standard - Guidance on risk assessment, especially with regard to the use and disposal of mud BAS CEN / TR 15584: 2012 [2], and the laws and regulations relating to waste management [4] the Rulebook on the categories, testing and classification of waste [5] and the Rulebook relating to high dam observations [6,7,8]. For these reasons, ISO standards [1,9] EU directives and other regulations [10,11,12,13] and regulations of other developed countries [14,15,16,17,18,19,20] should be used in the design, use and management of dam's risks.

Dam accidents occur because of the occurrence of natural hazards, technical damage, human activities, and combinations thereof. So far, many crashes and damages of tailing storage facility dams have occurred in the world, causing greater or less material damage, including the loss of life of innocent people. Here are just a few examples: collapsing of part of a tailing storage facility dam near Trento, Italy in 1985, part of a lead and zinc mine tailings storage facility dam Los Frailes Spain 1988, part of a gold mine tailings storage facility dam nearMerriespruit, South Africa 1994, tailings spill after thedam burst in aluminium production in Hungary in 2010, [21] and the last in a row is the case of the dam cracking of the Vale Company in Brazil in 2019 [22]. Damage and cracking of the dam due to the earthquake occurred at the dams: Shefield 1925, Loma Prieta 1989, Forster 1989, San Fernardo 1994 and MacDonald 1998 [14].

RISK MANAGEMENT

The risk management process is defined by BAS ISO 31000:2019 [1], ISO/IEC 31010:2019 [2], and ICOLD recommendations [18]. Risk management is the process of systematically applying management policy on identifying, analysing and evaluating risk, managing risk, monitoring and reviewing risk [1]. Risk management allows the risk to be considered and its acceptability assessed, and based on that assessment, it is possible to see what measures should be taken to eliminate the risk or reduce it to acceptable limits. Picture 1 shows the scheme of activities in the risk management process and their relationship.



Picture 1. Relationship between risk analysis, risk assessment and risk management

Risk analysis is the first component of risk management. It is part of the process in which potential hazards and events are identified (flood wave, earthquake, dam destruction, etc.), giving a quantitative or qualitative assessment of the likelihood of occurrence and magnitude of adverse effects (environmental, material and human casualties, etc.). Risk analysis is a very extensive and complex job that requires the involvement of prominent experts from different professional profiles.

Risk assessment is a process in which, using the results of risk analysis and other information in terms of costs and benefits, a decision is made on the acceptability of risk. The risk that can be controlled under certain conditions prescribed by regulations is acceptable. If the risk cannot be controlled under certain conditions, the risk cannot be accepted. In order to determine the level and dimensions of risk, it is necessary to define risk in terms of time and its stages, as precisely as possible. Risk involves the following stages [20]:

- Accident risk identification;
- Modelling of accident and consequence development;
- Vulnerability analysis (qualitative and quantitative ranking);
- Response mode (response to an accident);
- Post-accident monitoring;
- Disaster relief measures (recovery)

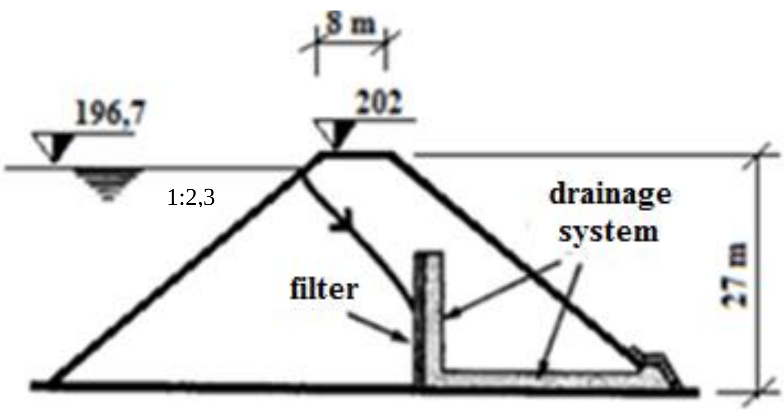
Risk communication is a very important component of an effective risk decision making process. It is not a separate component of the process, it must be integrated into all aspects of the process and is essential for the dam owner and other individuals and organizations that have a stake in or they might affectthedam [20].

CASE STADY

Basic information on Medjedja dam

For the purpose of disposal of tailings mud from the gravity-magnetic separation plant (GMS) of the Omarska Iron Ore Mine, on distance app 5 km (air lines), the earth dam Medjedja was constructed by partitioning 3 occasional watercourses. The dam was built in an area of seismic hazard rated at 7° MCS [23], and an earthquake of this magnitude could cause moderate to significant damage to the dam, eventual deformation at the crown and downstream slopes of the dam. It is important to note that the dam was constructed according to the parameters of seismic resistance to earthquakes up to 8° MCS 0. The dam is constructed as water-resistant with drainage system (Picture 2) and of the same material, which is in its base [24], whose geomechanical characteristics are:

- volume weight 20,00 kN/m^3
- cohesion 26.15 kPa
- internal friction angle 26.24 °
- water permeability coefficient 1e^{-7}.



Picture 2. Dam with drainage system

The dam is 27 m high, the length of the dam crown is 485 m, and the width of the dam crown is 8 m. The height of the dam crown is 202 m asl. The slope of the dam is 1: 2,3. The inner slope of the dam is protected from the erosive effects of atmospheric water and waves by applying a layer of large-grained stones. In order to monitor the changes on the dam, 29 benchmarks were installed for surveying, 6point piezometers for measuring the piezometer pressure, 13 chemical piezometers for measuring the seepage waterlevel, 3 of which are on the berm of the dam. The Gradina reservoir, obtained by the construction of the dam, covers an area of 76.7 ha and a volume of 8 million m^3. The catchment area of this tailing storage facility is 163.5 ha [24]. The layout of the mud dam and tailing storage facility is shown in Picture 3.

Picture 3. Dam and tailing storage facility

The design elevation of the free water in the tailing storage facility is 196.70 m above sea level (asl). The average depth of free water in the lake is estimated at about 3-4 m, and the total amount of water at about 1.1-1.5 million m^3 of free water. The amount of free water should be reduced to below 0.5 million m^3 by further depositing mud. Part of the free water is returned through pipelines back to the GMS plant as process water and for the needs of the local population for irrigation of agricultural land [25].

Up to now, 7.327.996 m^3 have been deposited at the tailing storage facility [26], which makes the storage area almost filled with mud deposited. The remaining storage of 762.004 m^3 enables the disposal of tailings for another year, with a capacity of approximately 2.7 million tonnes of average grade raw ore. The construction of the second stage of the dam to an elevation of 208 m asl was cancelled, because meanwhile conditions were created for the disposal of tailings in the abandoned SP "Jezero", which is closer to the GMS plant.

The results of the granulometric tests of the composition of the deposited mud indicate that the average percentage content of grain size is +0.3 mm = 2.70%, -0.3 + 0.025 = 31.24% and -0.025 + 0.00 = 60.06%. The basic component in the chemical composition of mud is Fe_2O_3 with about 56%, followed by silica oxides with about 25%, and aluminium oxides with about 7%. Their combined share is over 87%.

According to BAS CEN/TR 15584:2012 [2] and the Rulebook on the categories, tests and classification of waste [5] and the instructions contained in the abovementioned Rulebook, as well as the chemical composition of mud and the quality of overflow water, it can be concluded that it is non-hazardous waste and can be categorized as 01 03 06, ie. as "non-Category A landfill".

RISK ASSESSMENT

There are several methods for risk assessment (PHA, HAZOP, HACCP, SWIFT, BIA, RCA, FMA/FMECA, consequence and likelihood matrix, etc.) [9],which take different information into account in the risk assessment process. For the purpose of assessing the risk of the Medjedja tailing storage facility dam, potential accidents were identified, the probability of their occurrence was determined, and then the severity of the consequences arising from them were determined. Risk is obtained as a function of the probability of an accident and the severity of the consequences.

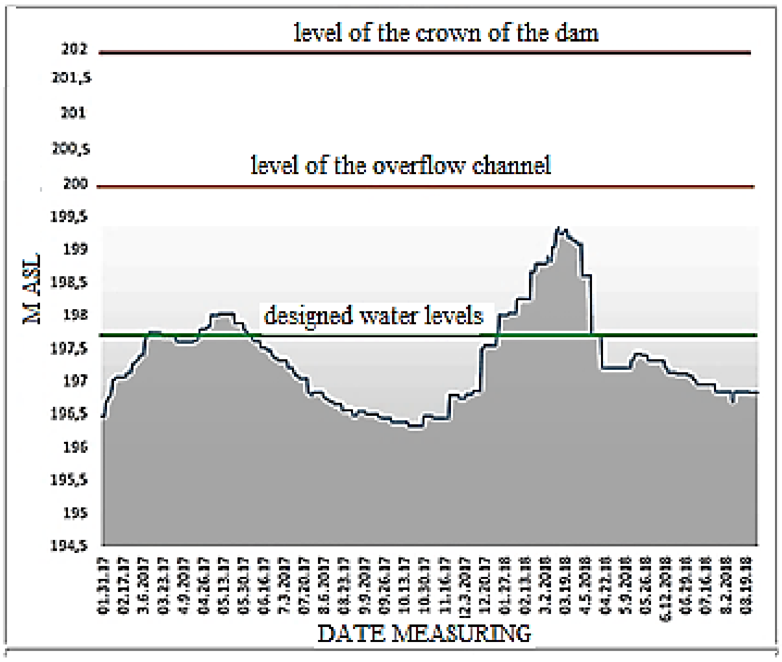
Risk assessment for the Medjedja dam was performed according to the 4x4 risk matrix and ICOLD [16] table 3 considering the impacts on: human life and health, economic damage, environmental pollution and Company reputation.

Analysing the current status of the dam, the project technical documentation and the books of records and reports kept, the following scenarios of damages to the dam are possible:

- Overflow over the crown of the dam,
- Damage due to static and seismic instability,
- Contamination of water flows by seepage waters from drainage system

a) Accident in the scenario of water overflowing over the dam crown

The disposal of tailingmud at the "Gradina" tailing storage facility was completed in July 2017. At the time of active use of the tailing storage facility, the water level in the lake depended on the flow of hydro-mix from the GMS, the need for GMS for return water, rainfall and the contour of the tailing storage facility and evaporation. Control of the water level in the reservoir by months in 2017 and 2018 (end month August) is given in Picture4, [25,26].



Picture 4. Graphic of water level in sedimentation lake during 2017 and 2018

In the observed period, the water level in the lake ranged from 196.32 (October 2017) to 199.29 (March 2017). The total oscillation of the water level was 2.97 m. Observed on a monthly basis, the oscillation of the maximum level was from -1.67 to +0.83 m and the minimum from -0.99 to +0.83 m [27]. Two situations are generally recorded, rising water levels from November to April / May and declining from April / May to October, with peaks in the spring months.

If we consider, the most unfavourable hydrological period in the region of the tailing storage facility "Gradina" from 19.06.-22.06.2010.when 172 l / m^2 of rain fell, which corresponds to the height of the water column of 0.172 m, it can be concluded that in ratio freeboard 2m there is no danger of overflow in the tailing storage facility's accumulation space. This is supported by the fact that the plan is to construct a safety overflow of rectangular section measuring 2.0x1.0 m with the bottom of the overflow at an elevation of 200 m asl, to keep the water level at the storage facility within safe limits [25].

b) Static and seismic instability-based accidents

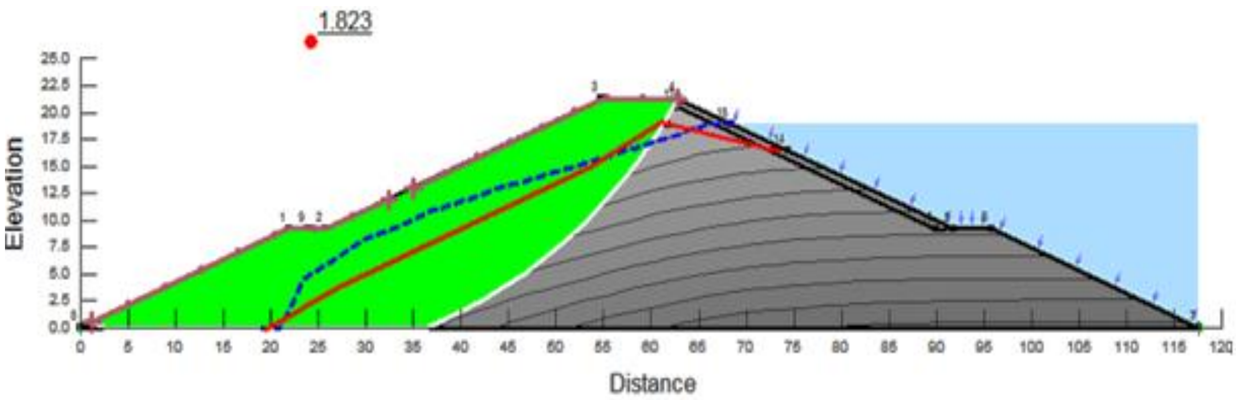
According to a 2017 seismic monitoring report of the dam [25,28] the strongest earthquake that occurred in the wider region of the tailing storage facility, at a distance of 24 km, was 3.2 units of Richter scale. In the narrower region, with a radius of up to 15 km, several weak earthquakes of up to

1.5 Richter scale units occurred, which are interpreted as consequence of mining at the mine. Earthquakes of this magnitude cannot cause damage to the dam.

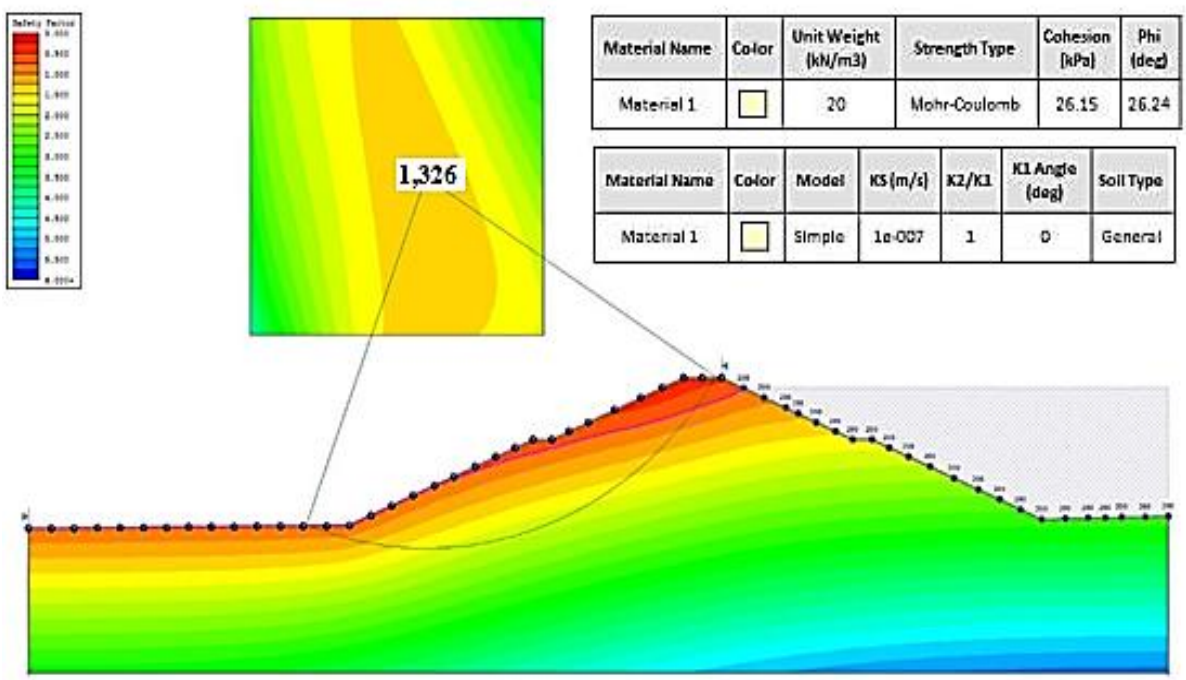
It is advisable to use a method of determining the likelihood of an accident based on a safety factor in the preliminary assessment of the risk of dam'sdamages due to instability. Results of the calculation of the safety factor for static conditions on the characteristic profiles of the Medjedja dam in the Omarska Mine for the period 2015-2018 are shown in Table 1 and Picture 5, and the result of the stability factor under seismic conditions for profile 16, (most sensitive), is shown in Picture 6.

Table 1. Overview of dam's safety factors for static conditions

Year	Profile 6		Profile 12		Profile 16		Profile 19	
	Rain period	Dry period	Rain period	Dry period	Rain period	Dry period	Rain period	Dry period
2015	2.219	2.437	1.846	2.017	1.845	1.952	1.924	2.151
2016	2.182	2.447	1,987	2.007	1.852	1.951	1.977	2.176
2017	2.406	2.381	1.911	1.933	1.897	1.913	2.011	2.112
2018	2.201	2.437	2.140	1.957	1.823	1.946	1.920	2.122



Picture 5. Dam stability factor in rain period on profile 16 for 2018



Picture 6. Stability factor of the dam in seismic conditions

For a seismic safety factor of 1,326 determined for the Medjedja dam and the first category of buildings to which the Medjedja dam belongs, an annual probability of $1x10^{-4}$ is obtained, which can be interpreted as "small".

c) Impact according to the scenario of pollution of water flows with seepage water from drainage system

The Medjedja dam contains pebble drain with 24 m^3/day flow [24], which should accept all the water that flows from the lake through the dam, andits execution is provided through 6 side extracts. Drainage water is continuously discharged into the Medjedja stream. In order to control the quantity and quality of water, all extracts are grouped into one site. Water quality from the drainage system is satisfactory, as can be seen from the results of measurements made in 2015, 2016 and 2017. Table 2 shows the results of measuring the quality of water from the drainage system at the time of disposal of tailings mud during 2016.

Table 2. Results of measurement of quality of water from drainage system of Medjedja dam in 2016.

Month	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	MDK
Temperature, °C	8.7	7.7	15.5	15.5	18.9	19.6	20.6	21.2	13.3	9.2	5.7	do 30
pH	8.44	8.22	8.4	8.3	8.4	8.4	8.04	8.46	8.4	8.32	8.2	6.5-9
Suspended particles,g/m^3	12	3	3	2,5	2,1	<2	2.4	2.5	2.3	<2	2.3	35
El. ConductivityμS/cm	287	239			318	346		337			364	
BPK5, grO_2/m^3	0.53	<3	<3	3.9	<3	<3	0.8	<3	<3	<3	2	25
HPK, grO_2/m^3	26	<6	<6	<6	<6	11	<6	9	6	<6	<6	125
NH_4, g/m^3	0.03	0.08	0.04	<0.01	0.01	0.01	<0.01	<0.01	<0.01	0.05	<0.01	10
N, uk. g/m^3	2.3	2.6	1.2	2.8	3.8	<1.0	3.5	<1.0	1.8	3.6	3	≤ 15
P, uk. g/m^3	<0.01	0.02	0.01	0.02	0.02	0.02	<0.01	0.05	0.01	0.01	0.01	3
Fe, mg/m^3	293	428	206	311	51	<50	264	141	893	138	165	2000
Mn, mg/m^3	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	500
Mineral oils, mg/m^3	<10	<10			<10	<10		<10		<10		500
Flow m/h	490	683	697	707	756	741	661	661	677	603	543	
Toxicity test	There are no toxicity elements (determined based on Daphnia Magna Straus, % waste waters in dilution)											<50

Based on these statements, the probability of each accident can be preliminary determined:

- Accident in the scenario of overflow over the dam crown - small
- Static instability accident - small
- Seismic instability accident - small
- Accident according to the scenario of pollution of watercourses from seepage water from the drainage system - small.

In assessing the consequences, the following were considered:

- human losses,
- economic consequences,
- environmental consequences,
- the reputation of the company.

For realistic risk assessment, it is very important to predict the characteristics of a flood wave, the formation of which would occur in the worst-case scenario, primarily the amount of spilled material from the tailing storage facility and the distance travelled by the flood wave. In the case of spilling of deposited material, over the dam crown or through the body of the dam, the flood wave formed would very quickly acquire the characteristics of laminar flow, since it would join the stream of the Medjedja stream and then the Gomjenica river, trough whose valley would progress further. For a rough estimate of the distance travelled, the so-called "danger zones", the Blight method may be used, according to which the maximum distance would be 2.7 km.

Since the storage facility contains unconsolidated mud, due to the micrometer size of the particles, it is likely that the water would pull a large portion of that mud with it during the breakthrough of the dam.

In the worst-case scenario, all the water could be leaking out, which could cause moving more mud, which amounts to app 2 million m^3 of deposited material and water.

Potential human losses can be determined using the Graham method, suitable for an earthfill dam, which proposes fixed mortality rates depending on the characteristics of the accident and the number of persons at risk. Given that there are 4 living units on the flood wave route, and assuming that on average there are four members of each family living, the number of people at risk is 16. Graham for a small serious danger, a warning time of 15 to 60 minutes and a full understanding by the people at risk proposes an average mortality rate of 0.002, which does not result in a single casualty to this number of people at risk [29].

The economic consequences would be local in nature, including the cost of clearing the surrounding terrain, repairing local damaged infrastructure and land remediation, as well as the cost of rebuilding residential properties that would be on the flood wave.

The environmental consequences would be somewhat more serious given that all environmental substrates are endangered. There is a fair share of arable land on the flood wave route. It is projected that the Medjedja stream and then the Gomjenica river would accept a large part of the poured material and their quality would be questioned in the event of an accident. After the accident, emission of the particles from the crusty surfaces of the poured material would occur and the air would be contaminated for some time.

The reputational consequences for the owner of the dam are small in the present state of the dam. Since the tailingmud will no longer be disposed, it is necessary to close and recultivate the tailing storage facility and to continue monitoring and following the condition of the dam and storage facility, on which will in the future dependthe level of risk and consequently the consequences on the reputation of the Company.

In view of the risks identified above and their significance for risk analysis, the recommendations of ICOLD Bulletin 153 [16] were used, which recommend a 4x4 risk matrix, Table 3, on the basis of which a risk ranking can be determined. It is recommended that the closed storage facility risk level be maintained beyond level 7 (high risk) and reduced to level 2 or lower (negligible risk).

Table 3. Risk matrix 4x4

		CONSEQUENCES			
		Very small	Small	Moderate	Big
POSSIBLITY	Big	Level 4	Level 5	Level 6	Level 7
	Middle	Level 3	Level 4	Level 5	Level 6
	Small	Level 2	Level 3 **"MEDJEDJA"**	Level 4	Level 5
	Very small	Level 1	Level 2	Level 3	Level 4

Based on the preliminary results obtained, it can be concluded that the risk of the Medjedja dam is at level 3, which is interpreted as low risk.

MONITORING ON THE DAM AND TAILING STORGAE FACILITY

In order to detect and eliminate adverse impacts on the stability of the dam and tailing storage facility in a timely manner, it is necessary to establish a monitoring system that would include:

- visual observation of occurrences and events on the dam and the environment (deformation on the basic terrain and slopes of the dam, occurrence of seepage water, erosion, damage to the drainage system and overflow structures, vegetation development on the crown and slopes of the dam)
- specialist measurements of parameters important for the assessment of the state of the dam (geodetic, hydrotechnical, seismic, meteorological, control of water quality from drainage systems)
- maintain an alert system in good working order, good cooperation and contact with residents regarding timely notification of dangers at the dam. In case the Medjedja dam collapses, in accordance with the Civil Protection Plan [30] in addition to internal human and material resources of ArcelorMittal Prijedor, engage the Civil Protection Sector of the City of Prijedor, Civil Protection of Republic of Srpska, B&H and the Government of Republic of Srpska in accordance with their competencies

CONCLUSION

By analysing the risk for the Medjedja dam, it can be concluded that the risk is at the third level and can be interpreted as small. It should be noted that the safety factors for static and seismic conditions were applied to the material from which the dam was constructed assuming no change in its characteristics. Therefore, for a more detailed risk assessment, it is necessary to include the aforementioned factor and more other details about the storage facility after its closure, which will follow in the coming period, and in particular to the modelling of the flood wave, whose characteristics condition the scale of the consequences and therefore the level of risk.

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