Risk-Based Classification of Industrial Waste Storage Facilities

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Abstract

This paper presents the risk-based classification systems for industrial waste storage facilities that are the most commonly applied worldwide. In line with this dual perception of waste storage facilities, either as reservoirs that impound solid-liquid or just liquid material, the application of the systems considered here, depends on the actual purpose of these structures. Therefore, it is necessary to bear in mind the multiple differences between these two types of facilities and the results obtained should be taken with certain reserve. The aforementioned systems have been applied in the case of several waste storage facilities in Serbia and the results obtained were analysed for comparison. Even though the classification systems are generally based on subjective assessments and views, it may be noted that they can provide a solid foundation in the risk assessment process as a form of preliminary risk assessment. Certainly, we should not ignore the fact that in a realistic risk assessment it is still necessary to pay more attention to all the risk aspects associated with the management of waste facilities, while the actual risk evaluation must rely on scientifically based analyses.

Keywords: industrial waste storage facility (IWSF), classification of IWSF, risk assessment

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Introduction

In most cases, the industrial waste storage facilities are used for permanent waste disposal. The waste accumulated in these facilities is mostly fine grained and often contains heavy metals and other hazardous substances. Ordinarily, waste is disposed of in the form of slurry, and it is known that water, if not controlled, can disturb the stability of these facilities. Their size vary from small waste facilities with capacities sufficient to sustain only a few years of disposal, to extremely large waste facilities whose height exceeds 100 m, and actually the largest dam ever built is a dam constructed of flotation tailings, the Syncrude Mildred Lake Tailings Dyke in Canada, whose length is 18 km and the height reaches 88 m [1].

Due to these facts waste storage facilities are a priori considered as hazardous and as a major environmental threat. Needless to say, a large number of recorded accidents and failures certainly contributed to this stereotype. Accidents at industrial waste facilities make up about three-quarters of all major environmental disasters caused by mining operations. These accidents are ranked 18th-greatest hazard, after earthquakes, cholera, floods etc. [2]. There is an evident increase in the number of failures and accidents occurring at industrial waste storage facilities over the period from 1960 to 2010, as shown in Figure 1 [3]. The increase in the number of accidents consequently has an impact on risk increase and it is estimated that potential risk increases 20 fold per 1/3 century [4].

The assessment of risks associated with WSF management, certainly deserves paying attention to and the risks evaluated should be presented in a transparent way that will allow taking adequate measures for failure and accident prevention.

Dual Perception of Industrial Waste Storage Facilities

Before any risk assessment, it is crucial to determine the type of WSF. Hydraulic storage facilities of industrial waste can be analysed in two ways:

- As facilities for solid and liquid phase disposal
- As conventional hydro-technical water storage structures.

For risk assessment purposes, it is common practice to consider these two types of storage facilities as equal, although this may results in unrealistic estimates.

The key characteristics of embankment dams at solid waste storage facilities that differentiate them from water retaining dams are as follows [5]:

- Viscosity of deposited material,
- Shorter lifecycle,
- Longer construction period,
- Significant consequences in the event of failure,
- A variety of construction methods, some of which do not provide adequate stability during seismic movement, etc.

Industrial waste embankment dams are 10 times more likely to fail than conventional water retaining dams [6]. In the world, there are about 3500 tailing dams and between 25000 and 48000 large water storage dams [3]. Even though the number of tailing dams is significantly lower, their failure rate is almost equal, which supports the fact that the risk of tailing

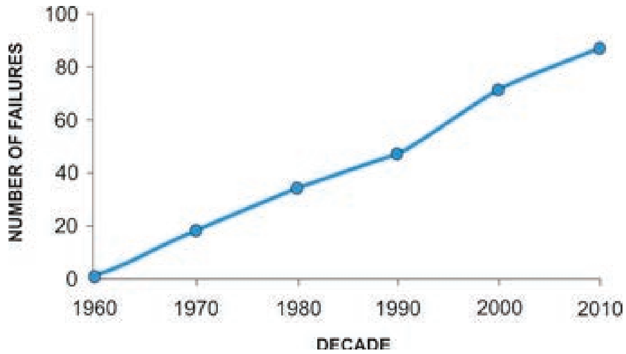

Fig. 1. Accidents at Waste Storage Facilities over the period from 1960 to 2010 [3]
Rys. 1. Wypadki na składowiskach odpadów przemysłowych w latach 1960–2010

dam failure is greater than in case of water storage dams [7].

There are several reasons why the risk of tailings dam failure is greater [8]:

• They are exposed to greater loading conditions than corresponding conventional water retaining dams, since clearly slurry density is higher compared to water density;

• The building technique anticipates a layered structure, whereby each new layer is completely or partially supported by a (muddy) layer formed during the previous filling cycle, that has weak load bearing properties, which reduces the overall stability of the structure;

• Tailings dams are formed as structures of homogenous materials (without the clay core) and the level of seepage water is generally high, so insufficient or damaged drainage is often the main cause of failure;

• As a rule, the downstream slopes of these dams are not protected against erosion;

• Due to liquefaction, the earthquake impact is more devastating in case of tailings dams than in case of other conventional fill dams;

• In our country, tailings dam auscultation is generally practiced less than in case of dams at hydro-technical structures, which reduces the possibility of timely response in the event of unacceptable deformations.

• In the event of dam failure, slurry waves reach higher maximum elevation points than water waves and these differences can range from 1 to 6 m.

According to Blight, (2010), there are several factors that demonstrate the increased risk of operating industrial waste storage facilities, and these are [9]:

• In case of water retaining dams there is a distinct difference between the material of which the dam is constructed, (concrete, stone, earth) and the material that are to be stored (water). Unlike water retention dams, this difference is hardly noticeable in case of waste facilities, since here embankment dams are raised of the very materials being deposited in the storage facility, except for the starter dams that are built of materials from borrow pits. This starter dam is used to outline the limits of the future WSF and serves as support for the subsequent layers filled with hydro-cyclone sand.

• Besides, considering the long period required to construct an industrial waste storage facility, which practically lasts throughout its entire life cycle, it is very likely to anticipate the involvement of up to three generations of employees who will work on its management and maintenance. Eventually, it is to expect a possible decrease in the level of their knowledge, skills and motivation, which would lead to an increase of risk.

• Water level monitoring is relatively easy at water storage dams since the construction is completed very quickly. The longer the construction lasts, as in the case of industrial waste dams, the more difficult it is to control the level of water over a longer period of time.

When analysing dam breach in the event of accidents it is necessary to take into account several basic differences. In world practice, more attention has been paid to dams at water and other liquid storage facilities and consequently numerous tools have been developed to tackle this matter. As opposed to that, less attention has been paid to embankments that impound solid and liquid mixtures and there is a considerable lack of numerical modelling software products that address the breach of dams at waste storage facilities, their use is much more complicated and data analysis much more complex, bearing in mind that waste in the form of slurry is more viscous than water, it may contain hazardous substances as heavy metals, there is no free flow, and the quantities of discharged slurry vary considerably [10, 5].

When breach occurs at water retention dams, all the water above the lower breach level will flow out, while this is not the case with waste disposed of in WSF. Based on previously recorded failures, these quantities range from 20 to 40% [11–18]. Figure 2 illustrates the comparison of these two cases.

At waste storage facilities there is a mixture of water, as a liquid fluid and waste as a solid material. Any movement of material from the waste facility

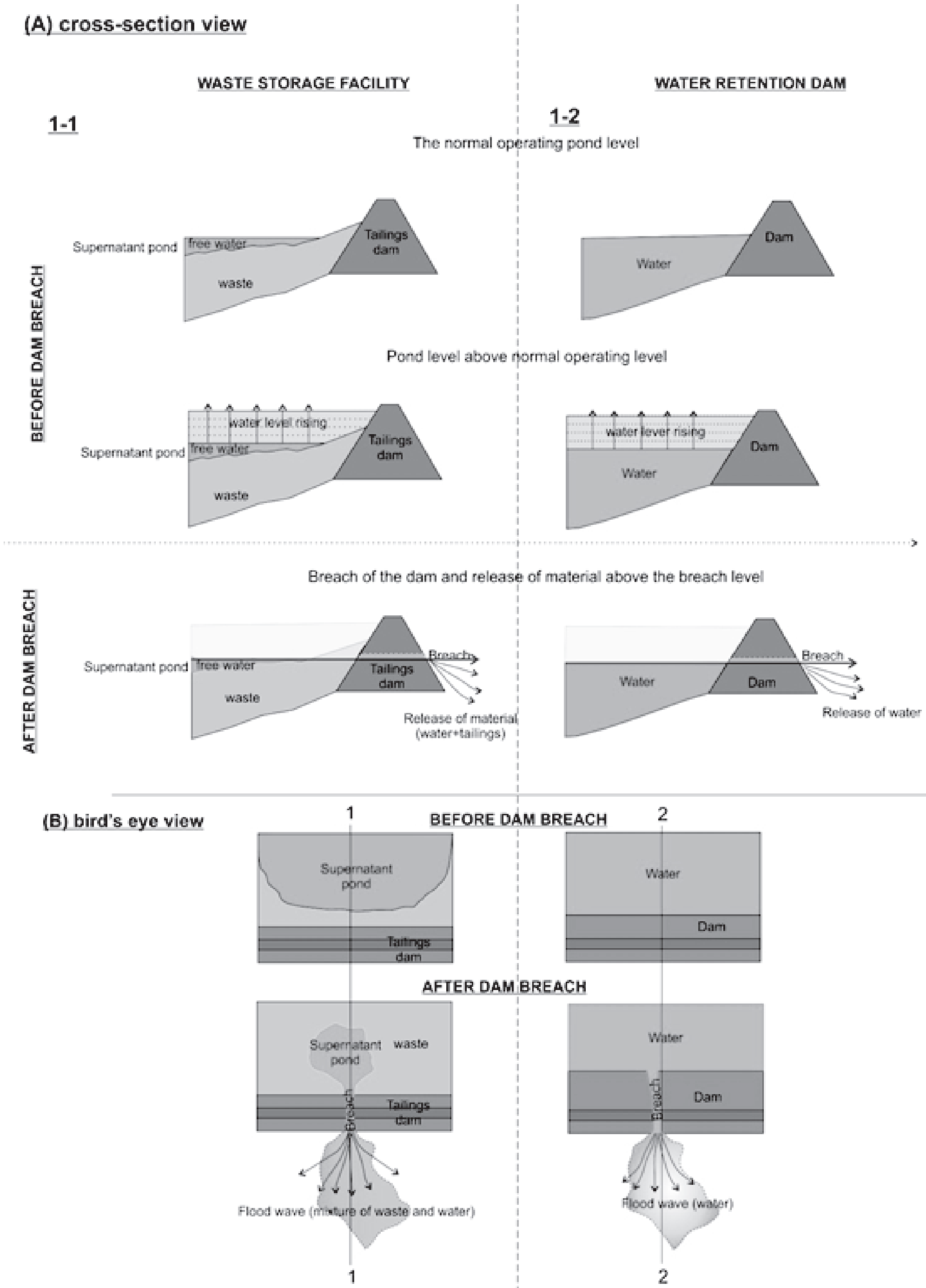

Fig. 2. Dam breach and discharge of accumulated material at WSF (left) and water retention dams (right)
Rys. 2. Przerwanie zapory i odprowadzanie nagromadzonego materiału w WSF (składowisku odpadów) (po lewej) i tamy retencji odpadów (po prawej)

energizes the liquid phase that will, under certain circumstance, also carry the solid phase. The liquid phase occurs among waste particles in the form of free water, impounded water and water trapped inside pores. The trapped water is partly free, because it simply fills the space between the particles, and to a degree it is bound to solid particles by adhesive forces. The distribution of free and trapped water inside the waste storage facility is very irregular, observing horizontal and vertical planes, but the changes in both planes are continuous.

As shown in Figure 2 in any version of events, only part of the deposited material will flow out if failure occurs at WSF, while in the case of water reservoirs, all the water above the lower level of breach or opening will flow out. Obviously, the dimensions of the breach (opening) will vary depending on the activity of waste material or water being discharged. Bearing in mind that water has the same characteristics throughout the entire reservoir; it may be assumed that all the water from the reservoir could flow out. On the other hand, this is practically impossible at waste storage facilities,

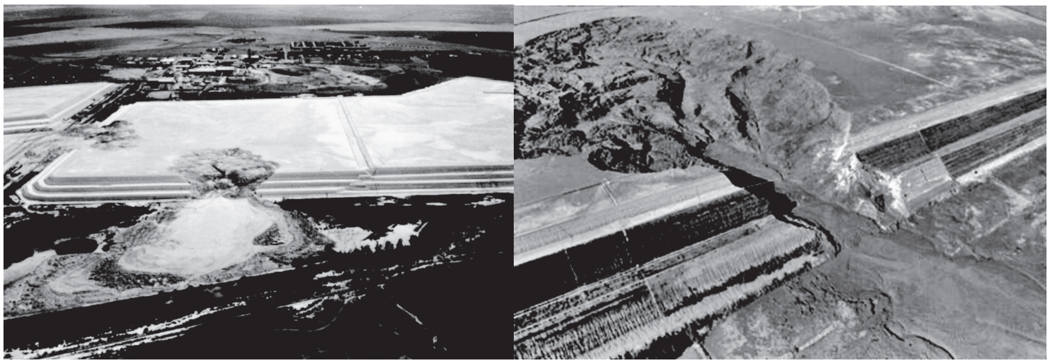

Fig. 3. A bird's-eye view of the dam breach in: a) Saaiplaas tailings facility [19], b) Merriespruit tailing facility, [19]
Rys. 3. Widok z lotu ptaka na przerwanie zapory a) składowisko odpadów Saaiplaas [19], b) składowisko odpadów Merriespruit [19]

Tab. 1. Overview of countries that have/have not established a classification of Mining Waste Facilities [21]
Tab. 1. Przegląd krajów, które nie mają / nie ustanowiły klasyfikacji obiektów górniczych [21]

Existing classification	Austria, Estonia, Finland, Portugal, Slovakia, Spain, Sweden, United Kingdom
Non-existing classification	Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Norway, Poland, Romania, Slovenia, the Netherlands, USA, Australia, Canada

since there is a significant difference between the lower consolidated layers and the surface layers and the movement of the former is difficult or impossible.

In spite of these facts speak many recorded failure cases. On the Saaiplaas tailings facility in South Africa in 1992, three failures are recorded with very small discharge, figure 3.a. The Saaiplaas tailings facility is not far from the Merriespruit facility which collapsed on the night of 22 February 1994, with discharge of 600.000 m^3 of disposed material, figure 3.b. [19, 20].

So, based on the above mentioned facts, it is possible to conclude that it is arguable whether the recommendations and tools intended for risk assessment at water storage dams could be applied in case of industrial waste facilities. When this is the case, the results obtained should be taken with reserve and all the circumstanced under which the assessment was made should be examined meticulously.

Risk-Based Classification of Industrial Waste Storage Facilities

It is necessary to make a clear distinction between the risk-based classification of industrial waste facilities and the risk assessment associated with their operation and management. Risk assessment is a highly complex process that often involves the risk-based classification as one of the first steps in this process.

Table 1 provides an overview of the countries that have established their own system for risk-based classification. Of the 32 countries that have been taken into consideration, only 8 countries have their own system [21]. Interestingly, among these 8 countries that have their own classification system, only in a few of them, major disasters have been recorded in the recent past, as in the case of Spain (Los Frailes, 1998) and Sweden (Atik Mine, 2000), which as it may be assumed, were motivated enough by the bad experience to undertake such an initiative.

However, many countries, in which the biggest ever recorded accidents took place, such as Italy (Stava, 1985), Romania (Baia Mare, 2000) and Bulgaria (Mina Plakalnitsa, 1966) still do not have their own classification systems.

It should be noted that some of the existing classification systems are based on schemes derived directly or slightly modified from systems aimed at classifying water retaining dams (e.g. Sweden, Finland, Austria and the United Kingdom) [21].

In Serbia, accidents at industrial waste facilities are not frequent, which is probably the main reason why a national risk-based classification or models for risk assessment have not been developed yet. Some of the major failures and accidents that took place in Serbia are shown in Table 2 and based on these data it can be concluded that all the recorded accidents have only had local effects, with no human casualties [22–26] .

Review of the Most Commonly Used Risk-Based Classification Systems of Waste Facilities

One of the most commonly used classification systems in Europe and beyond is the categorisation according to the Directive 2006/21/EC of the European Union on the management of waste from extractive industries that proposes a simple division of waste facilities as follows [27]:

Tab. 2. Some accidents recorded at industrial waste facilities in Serbia
Tab. 2. Wybrane wypadki zanotowane na składowiskach odpadów w Serbii

Type of waste facility	Name of IWSF	Location	Present status	Cause of incident	Consequences for the environment and for the company
Copper flotation tailings	Veliki Krivelj – Field 1	Bor	Active	Overflow of water and slurry into the space between the starter dam and the protective embankment	No environmental damage
	Veliki Krivelj – Field 2	Bor	Completed	Damage to the collector that channels the Krivelj River at Field 2	No environmental damage
	RTH	Bor	Active	Burst of flotation tailings through collector lining	No environmental damage
	Saski potok	Majdanpek	Passive	Overflow of slurry, failure of the perimeter embank-ment with slurry spillage out of waste facility limits	Contamination of the Saski stream, Watercourse Class 1
	Valja Fundata	Majdanpek	Active	Burst of water and slurry through the karst cavity and spillage over surrounding area	River contamination, Several days of unplanned downtime in the Mine
Lead and zinc flotation tailings	Lece	Medvedja	Active	Incidental spillage of flotation tailings through the body of the embankment	Negligible
	Veliki Majdan	Ljubovija	Active	Dam failure due to heavy rainfall, spillage of slurry and water into the Drina River	Contamination of Crncanska river bed and of the Drina River at inflow
	Badovci	Badovci	Active	Overflow over the embankment crest	Negligible
	Kisnica	Gračanica	Passive	Overflow over the embankment crest	Negligible
	Gornje polje	Kosovska Mitrovica	Passive	Collapse of the dam allowing a burst of water from the waste facility into the Ibar River	Contamination of the Ibar River
Antimony flotation tailings	Stolice	Kostajnik	Completed	Breach of the tailings facility after the burst of the water pipe that runs through the body of the tailings facility. Pipe burst was caused by landslides at its side face	Contamination of the Kostajnicka, Korenita and Jadar Rivers and of the Drina River at stream inflow
Phospho-gypsum	Prahovo (old storage)	Prahovo	Active	Incidental spillage of contaminated water into the Danube River	Negligible
Ash and bottom ash	Kosovo A	Obilic	Active	Incidental bursting over and through the embankment	No environmental damage
	SKO	Kostolac	Active	Overflow over the embankment crest	Negligible

- Waste facilities classified under Category A:

– a failure or incorrect operation, e.g. the collapse of a heap or the bursting of a dam, could give rise to a major accident, on the basis of a risk assessment taking into account factors such as the present or future size, the location and the environmental impact of the waste facility; or

– it contains waste classified as hazardous under Directive 91/689/EEC above a certain threshold; or

– it contains substances or preparations classified as dangerous under Directives 67/548/EEC or 1999/45/EC above a certain threshold.

- All other waste facilities that do not belong to Category A.

This waste facility classification determines which investigations are required for permitting and design, which safety factors should be achieved, which level of emergency preparedness and plans are necessary and which material insurance level should be provided.

The classification of industrial waste facilities per size, which is proposed by the US Department of the Army, (1979) is based on the volume of storage space and on the height of the facility, depending on which of these two parameters is classified into a higher category (Table 3).

After a major disaster that occurred at the ash disposal facility Kingston in the US, the EPA was compelled to tackle seriously the problem of ash and bottom ash disposal facilities and it established a classification system based on hazard potential per upstream and/or downstream areas or locations remote from the waste facility. This system is based on FEMA (Federal Guidelines for Dam Safety) classification criteria, which adopted three classification levels of hazard potential, Table 4 [29].

When it comes to this classification, it is important to emphasize, that the terms; "low, high and significant hazard potential" indicate the potential for property damage or loss of human life and it does not refer to the condition of the waste facility dam. For example, waste facilities classified as Class1 (low hazard potential) may be in poor condition and on the other hand, Class 3 waste facilities (high hazard potential) may be in good conditions. Also, this classification may change if the conditions in the surrounding area are modified (e.g. construction of new houses in the vicinity). As for Class 3, it should not be taken for granted that the loss of human life is impossible. Although there is no direct loss of human life, a major accident could, for example, destroy the traffic routes, causing in this way, indirectly the loss of human lives.

Tab. 3. Classification of waste facilities according to size [28]

Tab. 3. Klasyfikacja składowisk w zależności od wielkości [28]

Category	Volume of storage space [thousand m^3]	Height [m]
Small	60-1.200	8-12
Medium	1.200 - 61.000	12 - 30
Large	> 61.000	>30

Tab. 4. Classification of waste facility dams per environmental hazard potential [29]

Tab. 4. Klasyfikacja składowisk w zależności od potencjalnego zagrożenia środowiskowego [29]

Class	Hazard potential	Loss of human life	Economic, environmental and other losses
1	Low	None expected	Low and limited to waste facility
2	Significant	None expected	Probable
3	High	Probable, one or more casualties (fatalities)	Yes (but not necessarily)

Tab. 5. Classification according to hazard potential category [30]

Tab. 5. Klasyfikacja zgodnie z kategorią zagrożenia [30]

	Hazard potential category		
	Low (I)	Medium (II)	High (III)
$H \cdot \xi \overline{V}$	< 20	$20 - 200$	≥ 200
Risk to human life	~0	<10	≥10
Economic risk	Low	Moderate	High or extreme
Environmental risk	Low or moderate	High	Extreme
Social unrest	Minor (rural areas)	Regional	National

Tab. 6. Parameters considered in the risk assessment of large dams [32]

Tab. 6. Parametry uwzględniające analizę zagrożenia dla dużych składowisk [32]

Factor		Extreme	High	Moderate	Low
Capacity	milions m^3	>120	1-120	0,1-1	<1
	Risk factor	(6)	(4)	(2)	(0)
Height	m	> 45	30-45	15-30	<15
	Risk factor	(6)	(4)	(2)	(0)
Evacuation require-ments (No of persons)	Number	> 1000	100-1000	1-100	0
	Risk factor	(12)	(8)	(4)	(0)
Potential downstream damage		High	Moderate	Low	None
	Risk factor	(12)	(8)	(4)	(0)

Tab. 7. Risk class [32]

Tab. 7. Klasy ryzyka [32]

Total risk factor	0 – 6	7 – 18	19 - 30	31 - 36
Risk class	I (Low)	II (Moderate)	III (High)	IV (Extreme)

Tab. 8. Data on industrial waste facilities in Serbia

Tab. 8. Parametry składowisk odpadów przemysłowych w Serbii

Industrial Waste Facility	Volume of waste disposed of in the storage area [m^3]	Waste facility height [m]
Ash and bottom ash disposal facility SKO in Kostolac	43.000.000	23
Ash and bottom ash disposal facility Cirikovac in Kostolac	2.700.00	0
Ash and bottom ash disposal facility TENT-B, Usce	31.000.000	29
Old phosphogypsumdisposal facility in Prahovu	10.000.000	10
Flotation tailings storage facility Veliki Krivelj in Bor	170.000.000	100

In terms of industrial waste facilities as hydro-technical structures for water storage, the dams can be classified as large or small dams, based on their height and on the volume of available space, as shown in Figure 3 [30]. According to ICOLD, large dams fall into the category of dams that satisfy the criteria 5<H<15 m and V>3 cubic meters, where the height H is measured from the level of the river bed to the dam crest. Based on the same parameters the industrial waste dam can be assigned to a hazard potential category, as proposed by the French Committee for dams and reservoirs, Table 5 [30].

Each category suggests a different level of risk: risk to human life, economic, environmental risks and the extent of social unrest.

If the industrial waste dam is categorized as large, per ICOLD, (1989), the risk can be assessed from the parameters given in Table 6, and their quantification, based on proposed values leads to the final level of risk shown in Table 7.

Industrial waste facility classification systems applied in Serbia

Based on the proposed models, all major industrial waste facilities in Serbia were classified according to corresponding risks.

This classification takes into consideration the waste storage facilities for which the data on the height and volume of disposed waste are presented in Table 8, since these are the key parameters for most of the proposed classification systems. Other data, such as the number of endangered persons and damage are adopted [33–35]. Table 9 shows the results obtained.

The classification of these facilities into small and large dams was made according to the ICOLD classification and the results are shown in Figure 3.

Based on the data shown in Figure 3 it is evident that out of the five analysed waste storage facilities only the dam at the ash and bottom ash disposal facility Cirikovac falls into the category of small dams. The data on the amount of disposed waste is considered as the volume of storage space.

This classification regards waste storage facilities as liquid phase reservoirs and applies the risk ranking system for large dams according to ICOLD, as well as the classification according to hazard potential categories [31]. Per hazard potential, only the ash and bottom ash disposal facility Cirikovac in Kostolac, falls into the "category of low hazard potential", while all the other facilities belong to the category that indicates a "high hazard potential".

The risk class for large dams, according to ICOLD is analysed only for the waste storage facilities that are classified as large dams. Interestingly, the class of

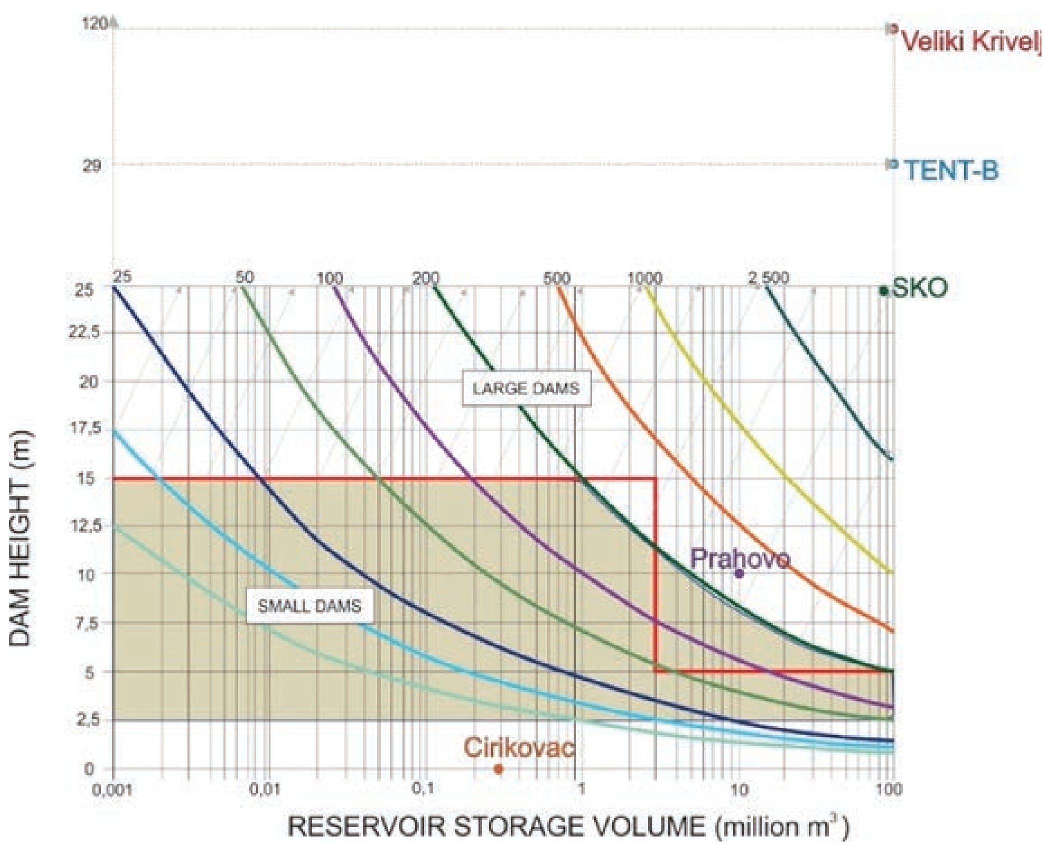

Fig. 3. Classification into small and large dams [30]

Rys. 3. Podział na małe i duże składowiska [3]

Tab. 9. Risk-based classification of waste facilities according to proposed models
Tab. 9. Klasyfikacja obiektów składowania odpadów według zaproponowanych modeli

Waste facility	EU Directive 2006/21/EC	French Committee	ICOLD	FEMA	US Department of the Army
Flotation tailings facility "Veliki Krivelj"	Category A	High (III)	III (high)	Class 1 (low hazard potential)	Large
Ash and bottom ash disposal facility "SKO"	Not category A	High (III)	II (moderate)	Class 2 (significant hazard potential)	Large
Ash and bottom ash disposal facility "Cirikovac"	Not category A	Low (I)	/	Class 1 (low hazard potential)	Small
Ash and bottom ash disposal facility "TENT-B"	Not category A	High (III)	II (moderate)	Class 2 (significant hazard potential)	Large
Old phosphogypsum disposal facility	Not category A	High (III)	I (low)	Class 2 (significant hazard potential)	Medium

waste facility according to size corresponds to the corresponding category for the classification of dams.

On the other hand, the classes of waste facilities per hazard potential, proposed by FEMA and the classes according to the French Committee are very different, except in case of the ash and bottom ash disposal facility Cirikovac.

The classes of waste facilities determined according to size and proposed by the US Department of the Army range from small (Cirikovac), through medium (Prahovo) to large (SKO and Veliki Krivelj).

Serbia has not made an official classification of waste storage facilities according to the provisions of the EU Directive 2006/21/EC. Bearing in mind that this Directive allows the experts a wide margin in estimates of the harmful effects of deposited material, this categorization should be regarded as very subjective. As a consequence, according to the EU report for 2012 [36] in Italy, of 213 waste storage facilities, 126 fall in the category A, while in Greece, out of 2343, and in France, out of 4152 facilities, only one from each group is classified as category A. In Serbia, of the five waste facilities that were analysed, only the flotation tailings facility Veliki Krivelj could be really categorised as A, because it "contains waste that consists of substances classified as dangerous" (sulfidic heavy metals). Table 9 shows a comparative review of the classification of the waste facilities analysed herein.

Consequently, ash and bottom ash disposal facilities in Kostolac and Usce and the flotation tailings facility Veliki Krivelj can be classified as hazardous facilities according to their size and the amount of disposed waste. The old phosphogypsum disposal facility in Prahovo is moderately hazardous, while the ash and bottom ash facility situated in the depressed area of the abandoned surface mine Cirikovac is classified as non-hazardous.

Conclusion

Industrial waste storage facilities are a priori considered as hazardous and pose a large environmental threat. Recorded accidents at waste facilities show that the consequences can be very significant and may cause a large number of human casualties and material damage, which can amount to tens of millions of euros. With this in mind, it is very important to evaluate correctly all the associated risks and to present them in a transparent way. And it is precisely for this purpose that numerous risk-based classification systems have been developed and used extensively worldwide. Even though the risk-based classification and the risk assessment process should not be confused as equal, the results of applied classifications can be used as a useful guideline in the risk assessment process.

Also, when applying these classification systems it is necessary to take into account whether the waste facilities are regarded as reservoirs that impound only the liquid phase or storage facilities for both solid and liquid phase, given the evident differences between these two types of facilities.

The applied systems for the classification of all major waste facilities in Serbia, of which some are used as liquid phase storage facilities, while others are used as solid-liquid storage facilities, give extremely varied results and therefore should be considered with certain reserve and with constant awareness of all the differences therein.

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Klasyfikacja obiektów składowania odpadów bazujące na analizie ryzyka

W artykule przedstawiono oparte na analizie ryzyka systemy klasyfikacji obiektów do składowania odpadów przemysłowych, które są najczęściej stosowane na całym świecie. Urządzenia do składowania odpadów mogą pełnić różnorodne funkcje - zbiorników, w których składuje się substancje w stanie stałym lub ciekłym lub zboiorników do składowania cieczy, zastosowanie rozważanych tu systemów analizy ryzyka zależy od rzeczywistego celu tych obiektów. Dlatego należy pamiętać o różnicach między tymi dwoma typami obiektów, a uzyskane wyniki należy przyjmować z pewną rezerwą. Powyższe systemy analizy zostały zastosowane w analizie przypadku kilku składowisk odpadów w Serbii, a uzyskane wyniki zostały przeanalizowane w celu porównania. Mimo że systemy klasyfikacji są zasadniczo oparte na subiektywnych ocenach i poglądach, można zauważyć, że mogą one stanowić solidny fundament w procesie oceny ryzyka jako forma wstępnej oceny ryzyka. Oczywiście nie powinniśmy lekceważyć faktu, że w realistycznej ocenie ryzyka wciąż należy zwracać większą uwagę na wszystkie aspekty ryzyka związane z zarządzaniem obiektami unieszkodliwiania odpadów, podczas gdy faktyczna ocena ryzyka musi opierać się na analizach opartych na badaniach naukowych.

Słowa kluczowe: obiekty składowiska odpadów przemysłowych (IWSF), klasyfikacja IWSF, ocena ryzyka