NATECH events at the tailing dams – risk, hazard and vulnerability assessment

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Abstract The hydraulic structures, particularly for dams, including the Tailing dams, are similar to other industrial installations from the point of view of risk management. The damages in case of accidents in hydraulic structures, both due to NATECH or exclusively human causes (as: terrorist sabotage, etc.) could be compared with great natural disasters, with great damages (S. Mara et al, 2007). The paper assesses the vulnerability of the tailing dams against the NATECH events and proposes further structural and non structural measures in order to avoid any casualties and damages due to the failure of this hydrotechnical structures, extensively used both in the mining and chemical processing minerals industry.

Key Words NATECH accidents, risk evaluation, extractive industry, environment, tailings dam

Introduction

In Europe, the development of new technologies for mining extraction (especially for precious metals exploitation) lead to new exploitation operations, which emphasize the need for better and safer requirements to be adopted both at the EU and candidates countries level (S. Mara, SN Vlad, 2010) (including Spain, Turkey and Romania where this activity is developed due to existence of the gold mines).

The risk management involving Tailing dams operation are difficult to assess, not only for dams owners (exploitation), but also for local authorities, population and economical units from the exposed areas. The protection measures to be undertaken in order to minimize the effect of a possible accident are very expensive because of the detailed analyses and evaluation of the safety exploitation situation.

The lessons learned from the detailed analyses of past accident at mining tailing dams, for example the last one occurred in Romania, on 30 January 2000, at "Aurul" Mine Tailings Recovery Plant near Baia Mare in north-western Romania, are very important for the improving of the safety measures of this type of hydraulic structures. The achieving of a steady safety operational conditions, through a proper dam risk management, is supported both by the authorities and the population, considering the great number of losses and great damages at the worldwide level in case of dam accidents. Therefore the achievement of the safe exploitation conditions includes the following requirements:

1 The monitoring of the exploitation programs;
2 The existence of the protection and security system;
3 The implementation of the security and protection measures for assuring a proper land management in the dam's area or in its proximity;
4 The installing of the measuring and control equipment for the control of the dams behavior in time;
5 The existence of an authorization procedure for the safety functioning;
6 Population and socio-economic units information and alert system, in case of failure;
7 The implementation of the interruption, re-utilization or abandonment procedure.

Because of the new requirements of the new Seveso II directive, the Romanian competent authorities have to implement the new safety requirements related to the tailing dam operation. It has to be specified that the Directive 96/82/EC has been transposed into the Romanian legislation by GD 95/2003 (further amended).

Methods

The measurement of the risk associated to natural hazards requires the use of a unitary system of procedure, for better correlation of the characteristics of different locations and their potential hazards. In order to manage such risks, the tailing dam owners have to assure proper operating programs, by implementing adequate measures to reduce the risks of an accident. The type of the required assessment can vary, based on the degree of potential risk and their potential environmental impact. A useful tool for the mining companies must be the use of a common methodology based on quantification of the risk components and on specific standard system of criteria, indices, and notes.

Risk is defined as the probability of an event multiplied by an evaluation of the adverse consequences if such an event occurs (vulnerability):

Risk = Probability × Vulnerability (S. Mara, SN Vlad, 2007).

The NATECH Risk values could be substituted by an averaged hazard coefficient for different natural hazards, based on a matrix evaluation, as follows

$$K(m)=\sqrt{\frac{K(a)\times K(b)}{6}\times[K(c)+K(d)+K(e)+K(f)+K(g)+K(h)]}$$

Where the Ka-h indices are described in the table no. 1.

While the probability of the disaster is generally known, the potential consequences of a disaster can be difficult to quantify and this involves a lot of unknown factors. Therefore, special attention has to be given to assessing vulnerability. So, at national level, for each tailing dam, a ranking of natural hazards that could affect earth stability (such as floods, earthquake, landslides and freeze-thaw)should be done. This approach could lead to the prioritization of needs and measures to be used by local or national authorities involved in natural or anthropogenic risk management. In ad-

***Table 1** NATECH risk evaluation criteria for the Romanian territory.*

No. crt.	symbol	Classif. criteria	NATECH potential (p)					
			Low		Medium		Increased	
			NATECH potential (p) and correspondent risk coefficient					
			zero	reduced	medium	medium high	high	very high
			0	< 0.10	0.10-0.30	0.31-0.50	0.51-0.80	>0.80
1	**Ka**	Lythologic	Massive rocks, compact or fissured		The majority of the sedimentary rocks which belongs to recent cover formations (i.e. delluvium, colluvium and prolluvium deposits) and soft/altered bedrocks semi-rocks category (stratified pelitic rocks, clay schists, marls and limestones, altered epizonal schists and/or igneous rocks		Not lithfied detrital sediments, i.e. saturated and soft clays, montmorillonite clays, dusts and fine-medium size sands, salt breccia, etc.	
2	**Kb**	Geomorphologic	Horizontal relief plan, affected by incipient erosion, mature valleys of the hydrographical network		Hills associated with piedmont and plateau areas, fragmented by hydrographical networks with advanced evolution stage, surrounded by versants with medium elevation and low to medium slopes		Relief characteristic of hill and mountains area, highly affected by recent valleys with high versants parallel with the layering	
3	**Kc**	Structural	Massive bodies of igneous origins, horizontally stratified sedimentary rocks, metamorphic rocks with horizontal schistosity		Main geological structures are folded, faulted and fissured; salt piercing domes; front of thrust nappes		Geo-synclines with flysch formations and marginal depressions with molasses; Strongly deformed structures, i.e. faulted, folded, traversed by fissure stockwork	
4	**Kd**	Hydrologic and climatic	Arid areas, with reduced annual precipitations. The flow discharged on the hills and mountains river beds are generally controlled by precipitation from these areas. Sedimentation on river beds whereas lateral erosions restricted to high-floods events.		Medium precipitation. The main hydrograhic networks reached the maturity stage whereas their tributaries are still in incipient evolution stage. During the high-floods both vertical and lateral erosion occur. Significant transportation and deposition of solid debris		Calm long lasting precipitation, with increased probabilities of water infiltration through rocks. During showers runoff increases with transportation of solid material. Vertical erosion prevails.	
5	**Ke**	Hydrogeology	Flow of the ground water at very low gradients. The filtration forces are negligible. The hydrostatical level of the ground water is at the relatively high deep.		Flow of the groundwater takes place at moderate gradients. The filtration forces could influence the versants stability. The hydrostatical level of the ground water is less than 5 m deep.		Flow of the groundwater takes place at high gradients. Frequent springs occur at the base of the versants. The filtration forces could produce versants instability and triggering of landslides.	
6	**Kf**	Seismic characteristics	Seismic intensity of MSK scale lower than 6		Seismic intensity of MSK scale between 6-7		Seismic intensity of MSK scale greater than 7	
7	**Kg**	Forestry	Degree of covering with forest more than 80%. Deciduous forests with large trees.		Degree of covering between 20% -80%. Mixed conifer and deciduous forests with trees of various size and age.		Degree of covering with forest less than 80%.	
8	**Kh**	Human impact (anthropogenic)	No major buildings on slopes and artificial water reservoirs on slopes		Construction works (roads and railways, tunnels, quarries) of limited extension with protective works of the versants are found on the slopes.		Versants affected by dense water and sewage pipelines, roads, railways, tunnels, quarries, overloaded by waste dumps, heavy constructions. The accumulation lakes are present, moistening the lower part of the slope.	

dition, GIS maps may expose the potential adverse effects of landslides which can trigger NATECH multiple cause disasters. So far, this type of disaster was not commonly investigated in Romania. Even the use of multiple-hazard recognition is relatively recent in Romania, representing a new trend of research, with significant applied implications.

Legal aspects of the tailing dam risk management

In order to prevent and mitigate the effects of natural disasters against the tailing dams, such as landslides, earthquakes, floods, severe rainfall, and freeze-thaw phenomena, legal measures to minimize the socio-economic impact are to be taken and have to include:

- Delimitation of all the areas where building is prohibited, in the documentation of urbanism and planning (cf. PUG above).
- Obligation to conduct geological surveys, including laboratory and in situ geotechnical tests, in order to know the properties of the soil and bedrock of the populated areas and those with a socio-economic activity.
- Implementation of special construction rules, which have to take into account the existence of natural hazards in the area [2].

Measures for prevention and reduction of natural risks have also to be implemented. They have to consist of the followings:

- Maintenance of the equipment and works for protection and mitigation of natural disasters.
- Control of the degree of land occupation and the completion of the specific land use and construction plans.
- Information of the population regarding the potential risks specific to their specific inhabited area.
- Systematic forecast of heavy rains since intense rainfall is one of the major collapse triggering factors, which might affect the tailing dams.

The lack of field studies, the absence of laboratory research, the lack of knowledge of the real situation from the point of view of stability and the characteristics of the usual ground parameters in the areas where it is intended to design and execute any type of tailing dams, can lead to NATECH failures producing countless material damages and sometimes human losses. Therefore we are proposing also a NATECH failure index in order to describe properly the collapse event susceptible for every tailing dam, as it follows (table no. 2).

The total value of the NATECH FC index is obtained by adding the values assigned to each criterion. It has to be specified that for every partial criterion, the appropriate number correlating parameter has to be chosen, in order to best describe the criterion. If parameters from two columns apply to the criterion, the lower numerical value has to be choosen.

Socio-economic implications of the NATECH disaster of the tailing dams and lessons learned from past events

Following the lessons learnt from recent tailing dam failures due to NATECH events (such as Baia Mare (2000), resulting in cyanide contamination of the Somes, Tisza and Danube River downwards to Danube Delta, before entering in the Black Sea, and Ajka (Hungary), leading to 10 human fatalities, 100 injured persons, 2000 destroied houses and 1000 ha of contaminated arable land, a common methodology for evaluation and mapping of the risk caused by the natural and technological hazards posed by tailing dams, to be implemented in order to elaborate vulnerability and risk maps, using a dedicated GIS for storage and information dissemination to decision makers at various levels, will be very useful both for extractive industry and nearby potentially affected local population.

Delimitation of the areas prone to natural risks, using GIS maps, also for prevention and attenuation of the effects, which are produced by the destructive natural phenomenon and to the risk posed by the tehnological hazards, will assure the population safety.

The newly implemented methodology proposed by this paper, for estimation of the vulnerability and risk that threatened the different forms of property, will better establish the responsibilities and the rules of land use development and planning of the territory. While the probability of natural and technological disasters occurrence is generally known or can be assumed, the evaluation of the consequences on the environment is difficult and involves a lot of uncertainties. A special attention will thus be given to the NATECH vulnerability assessment.

Using GIS facilities for developing vulnerability and risk maps for different hazards (natural disasters such as: floods, severe storms, earthquakes, landslides, forest fires and consequent technological disasters due to tailing dam failure), will be useful at the level of local adminstration. The methodology of elaborating the risk maps should be available and disseminated to all areas where the mining activities are present.

The newly implemented system for risk mapping should assist the stakeholders and the insurance companies for accurate evaluation of the needs from a single source of information (the GIS for hazards to be located at the county local public

Partial Criteria	Parameters and Indices			
1 population density in the downstream area	more than 20,000 inhabitants	300 to 20,000 inhabitants	scarcely populated	no population
	20	**10**	**5**	**0**
2 warning and alarm system	none	alarm system for local authorities	alarm system not tested or adapted by civil defence authorities	alarm system in place and tested by civil defence authorities
	20	**10**	**5**	**0**
3 Hazardous potential of the tailing dam waste material	mining tailing dam with dangerous toxic substances	Mining tailing dam with hazardous substances	Mining tailing dam with large quantity of inert sterile waste	only mining tailing dam
	20	**10**	**5**	**2**
4 economical entities in downstream area	industries with more than 100 employees	small industries	private workshops	no industrial activity
	10	**5**	**3**	**0**
5 land use around dam	agriculture	forests or pastures	uncultivated, barren	
	10	**5**	**0**	
6 environmental impact of potential failure	ecological disaster	significant effects	negligible effects	
	5	**3**	**1**	
7 effects of potential failure on river basin	failure of downstream cascade	jeopardising of flood control	no effects on flood control	
	15	**7**	**2**	

Table 2 *Description of the NATECH failure consequences Index (FC) proposed for tailing dams.*

administration, in order to be consulted by the local population of stakeholders).

It has to be specified that generally, any damage assessment is made in order to ensure the compensation to the affected persons. The insurance companies have so far a weak involvement in the activities for preventing and reducing the effects produced by the natural and technological hazards in Romania. The insurance companies are unwilling to insure goods and properties located in natural disaster-prone areas. The great contribution of the financial resources for minimising the damages caused by the natural disasters (Table 3) are the funds allocated from the State budget and external credits.

The most frequently natural disasters in Romania which produced the greatest human losses and material damages, are as it follows: floods, earthquakes, landslides and storms.

Generally, the damages produced by the natural disaster can't be fully covered by the state funds, so a better involvement of the insurance companies (S. Mara, SN Vlad, 2008), which will be able to estimate their insurances primes depending the estimated risk for every property and facility, using the maps elaborated with the newly implemented multi-disaster risk evaluation methodology and NATECH failure index of the tailing dams, proposed by this paper, will solve the problem of indemnity for affected people by technological disasters involving waste mining activities.

Conclusions

The recent implementation of the newly Seveso II Directive, which refers to the control of major-accident hazards involving dangerous substances, in different industrial sectors, including mining activities, brings new additional uncertainties, because of insufficient risk evaluation and uncompleted data base at the European level, regarding the risk sources, represented by the tailing dams with dangerous substances. Also the newly implemented Directive on the management of the waste from the extractive industry (Directive 2006/12/EC) didn't clarify the procedural steps for evaluation of the risk against the environment of the mining tailing dam. The most

Disaster	Floods-drought	Land-slides	Storms	Earth-quakes	Forest Fires	Contami-nated Lands	Industrial Install-ations	Transport of Dangerous Goods
Severity								

Legend: high risk; medium risk

Table 3 *Disaster profile of Romania.*

important advantages given by a new risk weighting identification index, proposed in the paper, will reduce, once applied, the impact on the environment of the mining tailing dams. The presented considerations take into account the conclusions based on the practical experience from Romania. This new approach will improve the tailing dam risk assessment methodologies, in order to eliminate the possibility of technical accidents occurrence as a result of natural hazards (known as NATECH accidents), as in the case of the "Bozanta" tailing dam from Baia Mare in 2000, or the most recent disaster, of the red mud tailing dam from the aluminium industry, from Ajka, Hungary in 2010. The newly NATECH failure consequence index being proposed, once applied, will improve the damage assessment in the most unfavourable stability conditions. Moreover, several approaches are taken into consideration, in order to establish an improved standardized methodology of tailing dam evaluation, especially related with the activities of mining processing involving dangerous substances.

In Romania, there is a true need in supporting the local authorities in promoting a sustainable development in environmental factors management and land use development and planning. In this action, a good informational system projection and implementation for natural and consequent technological disasters (NATECH events) are of main importance for local authorities, environmental protection agencies and water management systems. The cartography of risk areas (for damaged areas inventory) will help to organize the local development, to promote projects for local protection of the population and of economical objectives.

The new approaches proposed by the paper, taking into consideration both natural and subsequent NATECH type technical disasters at tailing dams, will determine tighter connection between experts in the different fields of activities according to the different hazards, natural and technological, and will led to innovative aspects in the field of NATECH disaster mitigation and protection, in order to create sustainable development of local communities, located nearby mining industrial activities.

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