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Tailings dam scenario: knowing to avoid new catastrophes

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Abstract: Mining is one of the key sectors of the Brazilian economy. However, despite its importance, tailings production is still significant and constitutes one of the greatest problems in this sector. Moreover, dam failure events have marked the history of the mining sector. From this perspective, this study aimed to assess the current scenario of tailings dams based on information contained in the SIGBM database. First, the number of dams included in the PNSB, their risk categories, potential damage, level of emergency, and other factors were observed. Then, data analysis indicated that Minas Gerais is the state with the largest number of dams included in the PNSB, with high CRI and DPA, dam construction by the upstream method, and dams classified as emergency level 3, thus requiring extra attention and interventions in order to ensure their safety.

Keywords: Mining; tailings dams; construction methods; regulations; dam safety.

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Introduction

This study addresses the issue of industrial mining with regard to the production and final disposal of tailings during ore beneficiation. Given the several recent incidents involving dam failure, the issue of dam safety has been significantly evidenced after the tragic episodes of the Fundão dam in Mariana (MG) in 2015 and the Córrego do Feijão dam in Brumadinho (MG) in 2019, highlighting the problem and requiring changes through new strategies as well as compliance with the national dam safety policy.

Brazil has important mineral deposits that constitute an expressive amount of the world reserves. Such deposits favor a strong relationship between the prospect and use of mineral resources, providing valuable inputs for the national economic development, territorial occupation, and national history (FARIAS, 2002).

According to Brazil's 2030 National Mining Plan (PNM), the mining sector is the basis for several production chains (MNE, 2010). Furthermore, this sector contributes 4.2% of the Gross Domestic Product (GDP) and 20% of total Brazilian exports, generating a million direct jobs, the equivalent to 8% of all industry jobs in the country. Therefore, mining contributes to the prominent international role of Brazil as a producer of niobium, iron ore, bauxite, manganese, and various other mineral resources (MNE, 2010).

However, the mining sector produces a significant volume of ore mass discarded during the beneficiation process (SOUZA JUNIOR; MOREIRA; HEINECK, 2018).

From this perspective, one of the main challenges currently facing this sector is the disposal of tailings produced during ore beneficiation due to mechanical or chemical processes that separate raw ore into mineral concentrates and tailings.

In order to dispose of the tailings produced after ore beneficiation, the mineral industry (metallurgy) releases the tailings slurry – a mixture of water and solids – into embankment dams built with compacted material in a single or multiple raising stages (CARDOZO; PIMENTA; ZINGANO, 2016).

For Soares (2010), dam construction can occur through traditional processes using compacted soil, e.g., the material resulting from ore beneficiation, or using sterile waste, which usually occurs in a single stage or eventually in two or three raising stages. This process should occur continually to allow the monitoring of results, eventual modifications, and improving the initial project. Therefore, every waste produced during production can be released and safely reused, minimizing the risks of accidents.

However, several episodes have marked the national mining trajectory in events related to tailings dam failure. Nevertheless, even with the knowledge about regulations and different technologies, dams continue to collapse and cause social, environmental, and social damage in affected areas. From this perspective, Duarte (2008) explains that such events are related to failure in complying with the proper technical criteria necessary for managing tailings dams.

The dam failure events occurred in Brazil in the last few decades (1986 – 2019) highlight the risks associated with dam construction, operationalization, and monitoring, especially after the deaths and negative environmental impacts caused by such events

(THOMÉ; PASSINI, 2018).

The several incidents include the dam collapse that occurred in 2015 in Samarco's Fundão dam in the municipality of Mariana-MG, resulting in 19 deaths, dozens of displaced families, and incalculable environmental damage in the region, and the Córrego do Feijão dam collapse in Brumadinho, which resulted in more than 259 deaths and 11 missing persons in 2019 (TOLEDO, RIBEIRO, THOMÉ 2016, apud THOMÉ; PASSINI, 2018).

According to Guimarães (2018, p. 20), "the environmental impacts and most significant risks to the mining industry are associated with tailings and sterile waste dams". Furthermore, tailings dam accidents have happened often and, in some cases, due to safety management issues (GUIMARÃES, 2018).

According to Carneiro (2018), the collapse of tailings dams can cause environmental impacts to water quality and availability, affect the riparian vegetation, and the soil microbiota and fertility. These impacts are caused both by the accumulation of sediments and their toxicity, especially due to the presence of amines, which increase the water and soil pH. However, the impacts on the riparian vegetation can be reversed as long as adequate physical containment and vegetation growth techniques are employed using species that are simultaneously tolerant to amine toxicity and capable of promoting soil aggregation.

According to Freitas et al. (2019), in the field of Public Health, dam failure can result in three consequences, either combined or not:

> (i) interruption of the regular local or regional day-to-day functioning, involving losses and damage (material, cultural, economic, and environmental) as well as the amplification of risks, diseases, and deaths; (ii) overload of local or state institutional capacities beyond their ability to act using their own resources; and (iii) change in the contexts of risk and disease production, including preexistent and new features created after the event, resulting in overlapped conditions of risk and environmental and human damage in the affected territories and populations, potentially lasting for months and years.

Gomes (2017) had already observed some undesired effects resulting from mining, e.g., environmental changes, land-use conflicts, depreciation of surrounding properties, degraded areas, and urban traffic problems.

Thus, the importance of the present study is based on the need to consider the practices adopted by the industrial mining sector while managing their tailings dams, from their conception to their decommissioning or de-characterization, in order to provide better operationalization and decision-making efficiency, thus achieving effectiveness in all stages of waste management.

In this scenario, this study aimed to assess the current situation of tailings dams with regard to the demands of the National Dam Safety Policy (PNSB) based on information contained in the database of the Integrated Management System for Tailings Dam Safety (SIGBM).

Tailings dams

Brazil has countless dams of different sizes and uses, including infrastructure dams for water storage, power generation, embankments or dikes to retain industrial waste, and tailings dams, among others (DUARTE, 2008).

Tailings dams can be defined as soil structures built to contain the materials resulting from ore beneficiation. Their construction comprises different stages over the operation time of a mine as waste is produced, which is deposited as a slurry, a mixture of solids and water (MATURANO RAFAEL, 2012).

Tailings are a solid material resulting from the crushing, milling, and eventual chemical treatment of the ore, with its characteristics varying according to the type of mineral and its treatment in the ore processing plant, having no economic value. Furthermore, tailings can be formed by materials with fine particle sizes and high plasticity, e.g., silt and clay compounds deposited as mud, or non-plastic materials (sands) with coarser particle sizes called granular waste (ESPÓSITO, 2000; LOZANO, 2006).

Tailings can be disposed of in underground mines, exhausted pits, piles, by dry stacking, through slurry disposal, or in tailings dams. Therefore, establishing one or another method to dispose of such waste depends on the nature of the mining process, the geological and topographical conditions of the region, the mechanical properties of the materials, and the potential environmental impact of the contaminant (DUARTE, 2008).

However, mining companies still prefer tailings dams since they can be built using soil, sterile waste, or even the tailings material itself. (DUARTE, 2008).

Construction methods

According to Carvalho et al. (2018, p. 362), tailings containment structures are built by initially raising a starter dike. This dike is usually built with borrowed soil, whereas the raising stages can be performed using the same material or mining waste. The raising stages allow increasing the usable volume of the tailings disposal basin.

It should be noted that the raising method should take into account the characteristics of the project: topography, hydrology, geology, subsoil types and properties, particle size and concentration of the waste, deposition rate, variation in the storage capacity of the reservoir with the increase in height, and availability of landscaping machinery and control teams (LUZ; SAMPAIO; FRANÇA, 2010).

Raising can be performed according to the following construction methods: (i) upstream, (ii) downstream, and (iii) centerline (SOUZA JUNIOR; MOREIRA; HEINECK, 2018).

In addition to these methods, there is also a single-stage method that consists of constructing a single dike raised at a single time and not requiring further raising (ANM, 2020).

Upstream construction method

In the upstream construction method, the bulk of the work is displaced upstream using the deposited tailings as part of the containment structure. The tailings are released upstream from the crest of the starter dike, forming a beach that will serve as a ground to support the new raised part. While the tailings are released, the coarser fraction is deposited close to the bulk, whereas the finer fraction (mud) flows or is directly released into the settling pond. However, Soares (2010) stressed that in order for the released material to be used as source material in the raising stages, it should contain from 40 to 60% of sand and low slurry density, favoring granulometric segregation.

According to Carvalho et al. (2018), the upstream method is favored by its simplicity and low cost. However, it is related to most tailings dam failure events worldwide.

Downstream construction method

The downstream method requires an impermeable starter dike usually built with compacted clayey material, in which the centerline (dam axis) is displaced downstream during the raising processes. The starter dike should have internal drainage (vertical filter and drainage mat), and its upstream embankment should be waterproofed with compacted clay or specific plastic blankets. In this method, only coarser waste can be used during the raising stages, and the dam can be projected to reach high heights by always incorporating the waterproofing and drainage systems during the process. Then, the tailing material is separated in a hydrocyclone, and the underflow is released into the downstream embankment under compaction and construction control (SOARES, 2010).

For Carvalho et al. (2018), the downstream method is more conservative than the upstream method and was developed to reduce failure risks due to liquefaction in areas with seismic activities or movements due to mining explosions.

Centerline construction method

The centerline method is an intermediate between the upstream and downstream methods. A starter dike is initially constructed, and the tailings are released peripheral and upstream to the dike, forming a beach. The subsequent raising is performed by releasing the tailings on the previously formed beach and the downstream embankment of the starter dike. In this process, the crest axis of the starter dike coincides with the axes of the dikes resulting from the successive raising stages. Thus, the structural behavior of the dams built according to this method is similar to the downstream method (SOARES, 2010).

According to Carvalho et al. (2018), the centerline method is an intermediate solution between the other two methods. It has greater stability than dams raised by the upstream method and does not require a volume of materials as large as in the downstream method.

Legislation applicable to dam safety

For Neves (2018, p. 10), the reason that led Brazil to propose and approve the law that established the National Dam Safety Policy (PNSB) "was the recognition of the high level of organizational problems responsible for the current state of abandonment of several Brazilian dams based on the vulnerable construction projects and operation of existing structures".

In this scenario, Law No. 12,334 of September 20, 2010, established the PNSB for dams used for water accumulation for any purpose, final or temporary disposal of tailings, and accumulation of industrial residues, also creating the National Dam Safety Information System (SNISB), among other measures. This law was also meant to ensure safety standards and regulate, promote, and monitor the safety actions employed by those responsible for dams in order to reduce the likelihood of failure events and their consequences, especially together with the potentially affected population, encouraging a culture of dam safety and risk management.

- Accordingly, federal resolutions and ordinances were published to establish criteria, guidelines, and deadlines to meet the PNSB requirements for the management and safety of tailings dams in Brazil. These regulations are listed below and are organized in Figure 01:

- Resolution No. 13, of August 8, 2019: Establishes regulatory measures to ensure the stability of mining dams, notably those constructed or raised by the upstream method or by methods declared as unknown, and takes other measures (BRASIL, p. 1, 2019).

- ANM Ordinance No. 70,389 of May 17, 2017: Creates the National Tailings Dam Registry, the Integrated Management System for Tailings Dam Safety, and establishes the periodicity of execution or updates, among other measures (BRASIL, p. 1, 2017).

- CNRH Resolution No. 144 of the Ministry of the Environment, of July 10, 2012: Establishes guidelines for applying the National Dam Safety Policy, its instruments, and the role of the SNISB (BRASIL, p. 1, 2012).

- CNRH Resolution No. 143 of the Ministry of the Environment, of July 10, 2012: Establishes general classification criteria for dams according to risk, associated potential damage, and volume (BRASIL, p. 1, 2012).

- ANA Resolution No. 91 of March 02, 2012: Establishes the periodicity, technical personnel qualification, minimum content, and level of detail of the Dam Safety Plan and the Periodic Dam Safety Review (RPSB) (BRASIL, p. 1, 2012)

Figure 01: Legislation and acts that regulate tailings dam safety in Brazil

Type of Legislation	No.	Issuing Agency
LAW	12,334 of September 20, 2010	Presidency of the Republic.
ORDINANCE	70,389 of May 17, 2017	National Department of Mineral Production (DNPM).

RESOLUTIONS	No. 13, of August 8, 2019	National Mining Agency (ANM).
	No. 144 of July 10, 2012	National Water Resources Council (CNRH).
	No. 143 of July 10, 2012	National Water Resources Council (CNRH).
	No. 91 of March 02, 2012:	National Waters Agency (ANA)

Source: Provided by the authors.

Dam safety surveillance consists of monitoring the compliance with legal obligations established by the PSB and inspecting the physical structures of dams. Therefore, the bodies responsible for monitoring dam safety, according to their competencies (BRASIL, 2010), are listed below:

1) National Waters Agency (ANA), when granting the right to use water resources, observing the domain of the water body when the purpose is water accumulation;

2) National Electric Energy Agency (ANEEL), when authorizing or registering the use of hydraulic potential if the main purpose is generating hydroelectric energy;

3) National Mining Agency (ANM), when regulating and supervising mining activities for tailings disposal purposes;

4) National Nuclear Energy Commission (CNEN), when regulating, licensing, and supervising the production and use of nuclear energy if the purpose is the disposal of nuclear mining waste;

5) Water resources management bodies, when granting use permits for water resources if the purpose is water accumulation;

6) Licensing bodies, when granting environmental permits to dispose of industrial waste.

It should be noted that regulatory agencies should notify civil defense and protection agencies about inspections when there is the need to adopt emergency measures regarding dam safety (BRASIL, 2010).

Given its attributions, the ANM published Ordinance No. 70,389 of May 17, 2017, which creates the "National Tailings Dam Registry, the Integrated Management System for Tailings Dam Safety, and established the periodicity of execution or updates, the qualification of technical personnel, and the minimum content and level of detail of the Dam Safety Plan, the Regular and Special Safety Inspections, the Periodic Dam Safety Review (RPSB), and the Emergency Action Plan for Tailings Dams according to Law No. 12,334/2010, thus establishing the PNSB (BRASIL, p. 1, 2017).

According to the devices of Ordinance No. 70,389 (BRASIL, 2017), the tailings dams regulated by the PNSB should present at least one of the following features:

a) embankment height equal to or greater than 15m from the lowest point to the top of the crest;

b) total capacity of the reservoir equal to or greater than 3,000,000 m^3;

c) reservoirs that contain harmful waste according to the applicable technical rules;

d) average or high associated potential damage (DPA), in terms of economic, social, and environmental damage or loss of human lives, as defined by its Art. 6.

In turn, the DPA is defined as the "damage that might occur due to failure or malfunction in a dam, regardless of the likelihood of such events" (BRASIL, 2017, p. 5), which can be classified as high, average, and low considering the potential of losing human lives and the economic, social, and environmental impacts resulting from dam failure (BRASIL, 2010). This policy is based on the current and locational aspects of the dam, e.g.: (i) the total volume of the reservoir; (ii) the existence of downstream populations; (iii) environmental impacts; and (iv) socioeconomic impacts.

Dam identification with regard to the Risk Category (CRI) is made according to aspects that could contribute to a failure event considering the technical characteristics, the conservation status, and the Dam Safety Plan (PSB) according to Figure 02 (BRASIL, 2017).

Figure 02 – Risk Category Classification

TECHNICAL FEATURES	CONSERVATION STATUS	PSB
Embankment height	Reliability of drainage structures	Existence of documentation regarding the dam project
Length of the dam crest	Existence of percolation	Organizational structure and qualification of dam safety professionals and technical team
Flow of the project	Deformation and settlements	Manual of Safety Inspection and Monitoring Procedures
Construction methods	Embankment deterioration	Emergency Action Plan (PAE) – when required by the supervisory organ.
Auscultation	No description	Inspection and Monitoring Reports for Instrumentation and Safety Analysis

Source: Provided by the authors and adapted from BRASIL, 2017.

According to the classification table contained in Art. 7 of Law No. 12,334/2010, tailings dams are classified according to the CRI and DPA into classes A, B, C, D, and E, where A refers to the most critical structures, gradually decreasing until class E, according to Table 03 (BRASIL, 2017).

Dam classification into classes is meant to differentiate them with regard to their reach and frequency of safety actions required. Thus, it is a management planning tool that varies depending on the supervisory agency (ANM, 2020).

Ordinance No. 70,389/2017 also provides enterprises with a more detailed orientation about how to implement the Emergency Action Plan for Tailings Dams (PAEBM), which should be responsible for: (i) its update whenever there is any change; (ii) promoting internal training and participating in simulation exercises together with City Halls, Civil Defense, and the population of the Self Rescue Zone (ZAS), among others; (iii) providing municipal civil defense agencies with the necessary elements for preparing Contingency Plans; (iv) offering technical support to municipalities in actions of creation and development of Municipal Contingency Plans; (v) organizing, together with the Civil Defense, alert, communication, and guidance strategies to the potentially affected population in ZAS areas in emergency situations; (vi) disclosing the PAEBM and ensuring its knowledge by all parts involved; and (vii) setting up alert systems, such as sirens, in ZAS areas (COSTA; GONÇALVES; FURTADO, 2019).

According to Ordinance No. 70,389/2017, the PAEBM consists of a technical document prepared by enterprises in which potential dam emergencies must be identified, establishing actions to be carried out and the agents to be notified to minimize the damage and loss of lives (BRASIL, 2017). It should be noted that all PAEBMs should be updated whenever there are any changes: 1) in the emergency scenarios, 2) in the resources available in emergencies, and 3) in the contacts and telephones of the notification flowchart. Furthermore, this review should happen at every RPSB, thus implying the reevaluation of downstream embankments, their associated impacts, and the flood map update.

Therefore, the purpose of the RPSB is to diagnose the overall dam safety status by considering the current aspect of the dam with regard to the parameters of the project, the update of hydrological data, changes in upstream and downstream conditions, and indicating actions to be taken in order to maintain safety. The maximum time for the periodic review of the DPA level, according to Art. 15 of this ordinance, is: (i) high DPA: every 3 (three) years; (ii) average DPA: every 5 (five) years; (iii) low DPA: every 7 (seven) months (BRASIL, 2017).

Moreover, for continuously raised tailings dams, regardless of their DPA, the RPSB should be performed every 2 (two) years or for every 10 (ten) meters of raising, whichever comes first, with a maximum time of six months to conclude the review mentioned before (BRASIL, 2017, p. 17).

In addition to these obligations, enterprises should also register the tailings dams under construction, in operation, and those already deactivated but still under their responsibility directly with the SIGBM, integrating the National Tailings Dam Register according to the single paragraph of Art. 13 of Law No. 12,334/2010 and observing the periodicity expressed in Art. 4 of Ordinance No 70,389 (BRASIL, 2017).

Enterprises should also send to the ANM the Dam Stability Declaration (DCE) with a copy to the respective ART as per Annex III, individualized per dam and every six months, between March 1 and 31 and September 1 and 30 (BRASIL, 2017).

It should be noted that this ordinance also addresses cases of unregistering by closure or de-characterization of a tailings dam. In that case, the enterpriser is required to provide the ANM, through the SIGBM, with a document attesting the closure or de-characterization of the structure (BRASIL, 2017).

Methods

In order to achieve the objective of this study, a search was made with secondary data available in the external public module of the Integrated Management System for Tailings Dam Safety (SIGBM), on the website of the National Mining Agency (ANM), in the period from November 10 to 30, 2020, referring to the aspects required by the National Dam Safety Policy - classification, statistics, and location.

Based on these aspects and the following characteristics: 1) Included in the PNSB; 2) Construction method; 3) Risk category (CRI); 4) Associated Potential Damage (DPA); 5) Size per volume; 6) Class; 7) Need for PAEBM; 8) Maximum height; and 9) Emergency level, the data were individualized and organized into electronic spreadsheets, and subsequently arranged in graphs and tables representing the number and percentage of these structural features of dams registered with the SNISB.

Before this study, a bibliographic search was conducted in Google Scholar, Capes Journals, Capes theses and dissertations bank, Scielo, and public agency websites using the following keywords: tailings dams, mining, dam failure, and environmental impacts (barragem de rejeito, mineração, rompimento de barragem, impactos ambientais). This procedure was performed along with the analysis of ANM reports and legal background summarization based on retrieved theses, dissertations, articles, and legislation.

It should also be noted that this study was approved by the Research Ethics Committee (CEP) of the Federal University of Vale do São Francisco (UNIVASF) under protocol number 22348919.9.0000.5196, meeting all ethical requirements for research in the human and social areas as per Resolution 510/2016 (BRASIL, 2016).

Results and Discussions

Tailings dams became a widely visible subject, generating challenges and discussions aiming at the safety of these structures. Thus, this study presents the current scenario of tailings dams with regard to the demands of the National Dam Safety Policy (PNSB) based on information contained in the Integrated Management System for Tailings Dam Safety (SIGBM). The data are organized by showing the dams: 1) Included in the PNSB; 2) Construction methods; 3) Risk category (CRI); 4) Associated Potential Damage (DPA); 5) Size by volume; 6) Class; 7) Need for PAEBM; 8) Maximum height; and 9) Emergency level.

Dams included in the PNSB – Based on data provided by the SIGBM, 860 dams were registered with the system, 436 of which are included in the PNSB, representing 51% of the total, with at least one of the characteristics contained in the single paragraph of Federal Law No. 12,334/2010 and its modification. On the other hand, 424 dams (49%) are not included in the PNSB, showing none of the characteristics contained in the cited article.

Table 03 demonstrates the number of dams per Federative Unit or states, highlighting those with the most significant presence of registered dams included or not in the PNSB. These states are: Bahia, Minas Gerais, Mato Grosso, Pará, and São Paulo.

Table 03: Overall number of dams included or not in the PNSB per FU

FU	Included in the PNSB	Not included in the PNSB	Overall number per FU
AL	0	1	1
AM	8	7	15
AP	5	8	13
BA	14	61	75
GO	10	6	16
MA	1	2	3
MG	216	149	365
MS	6	12	18
MT	53	54	107
PA	70	35	105
PB	0	1	1
PI	0	2	2
PR	3	0	3
RJ	1	1	2
RO	11	24	35
RS	4	2	6
SC	11	3	14
SE	2	1	3
SP	20	50	70
TO	1	5	6
TOTAL	**436**	**424**	-

Source: Adapted by the authors from SIGBM (2020).

Furthermore, among the cited states, Mina Gerais had 365 dams registered with the SNISB, of which 216 (25%) are included in the PNSB and 149 (17%) are not, corresponding to the highest concentration of registered dams (Table 03).

Dam classification according to construction method – Based on SNISB data, a significant portion (51%) of the total dams registered were developed in a single stage (Table 04). Among the other construction methods, downstream construction was employed in 170 dams, corresponding to 20% of the total dams registered. Centerline construction represents 9%, totaling 80 dams. With regard to upstream construction or other unknown methods, there were 64 dams, totaling 7%. There are also registered dams whose information was not provided or did not inform the construction method adopted, totaling 106 (12%) dams.

Moreover, the state of Minas Gerais has the highest number of dams built by the different construction methods. It should also be noted that 46 dams in that state were built by the upstream method, whereas the remaining states had a maximum of five dams constructed by this method (Table 04).

Table 04: Construction methods per FU

FU	Single stage	Downstre-am method	Centerline method	Upstream method or unknown	Data not provided	Total Dams
AL	0	0	0	0	1	1
AM	14	1	0	0	0	15
AP	5	2	0	0	6	13
BA	13	24	27	3	8	75
GO	4	5	3	3	1	16
MA	1	0	1	0	1	3
MG	221	66	16	46	16	365
MS	16	0	1	1	0	18
MT	12	49	18	0	28	107
PA	70	14	9	5	7	105
PB	0	0	0	0	1	1
PI	0	0	0	0	2	2
PR	1	1	1	0	0	3
RJ	2	0	0	0	0	2
RO	19	0	0	0	15	34
RS	3	0	0	2	1	6

SC	13	0	0	0	1	14
SE	3	0	0	0	0	3
SP	38	7	4	4	17	70
TO	4	1	0	0	1	6
TO-TAL	**439**	**170**	**80**	**64**	106	859

Source: Adapted by the authors from SIGBM (2020).

Dam classification according to risk category (CRI) – With regard to the risk category, 324 dams are classified as low risk, totaling 74%. However, 50 dams are classified as high risk, totaling approximately 11%, whereas 62 are classified as average risk, totaling 14% by considering the aspects that could influence the possibility of failure events based on technical characteristics, the conservation status, and the Dam Safety Plan as per ordinance No. 70,389/2017. According to the Risk Category of dams registered with the SIGBM, of the 50 dams classified as high risk, 43 are located in Minas Gerais.

Dam classification according to Associated Potential Damage (DPA) – With regard to dam classification according to associated potential damage, 60% of the 436 dams included in the PNSB showed high associated potential damage, meaning that 262 dams had significant potential of destruction in the case of failure or malfunction, causing losses of human lives and social, economic, and environmental impacts.

The data also show that 150 dams with high associated potential damage are located in Minas Gerais.

Dam classification according to Size per Volume- Based on the capacity of the reservoirs, a significant portion (61%) of the total dams were considered as very small-sized, meaning a volume capacity ≤ 500 thousand m^3, whereas 1% of the dams were considered as large-sized, with capacities ranging from 25 million to 50 million m^3, and 2% are very large, with a capacity ≥ 50 million m^3.

It should be noted that the state of Minas Gerais concentrates most dams with large and very large volumes, with 6 and 11 dams, respectively, whose capacities range from 25 million m^3 to ≥ 50 million m^3 of tailings in their structures.

Dam classification according to class – Dam classification according to class followed the sequence of letters A, B, C, D, and E by observing the combination between the CRI and DPA of each dam as per Annex I of Ordinance No. 70.389/2017, where "A" refers to the most critical structures (vulnerability), gradually decreasing until class "E".

The data registered with the SIGBM showed that about 9% of the total dams included in the PNSB are the most critical with regard to vulnerability and are classified as class A. In contrast, 53% show a small vulnerability reduction and are classified as class B. Next, 31% represent a greater reduction than the previous dams and are classified as class C. Finally, class D represents only 1% of the total, gradually decreasing until class E, which corresponds to 6% of the dams, with their CRI and DPA showing low criticality (Table 05).

Table 05: Number of dams per classes

Class	CRI	DPA	Number of dams	Percentage %
A	High	High	40	9
B	High Average Low	Average High High	229	53
C	High Average Low	Low Average Average	135	31
D	Average	Low	6	1
E	Low	Low	26	6

Source: Adapted by the authors from SIGBM (2020).

Dam classification according to the PAEBM - The PAEBM should be provided by all dams with high associated potential damage or whenever required by the ANM, and also by dams with average associated potential damage when the factor "existence of downstream populations" reaches 10 points or the "environmental impact" item reaches 10 points. Thus, the PAEBM will integrate the PSB as "volume V," corroborating Art. 12 of Law No. 12,334/2010 as per Annex II of Ordinance No. 70.389/2017.

It should be noted that approximately 61% of the dams should provide the PAEBM, whereas, for 39% of the dams, this obligation is not required.

Moreover, 272 dams provided the PAEBM, whereas, in 32 dams, the PAEBM is still under construction. It should also be noted that the supervisory agency does not require the PAEBM for 109 dams.

In compliance with the provisions of Art. 31 of Ordinance No. 7,389/2017, the data showed that 249 enterprises presented physical copies of the PAEBM for the city halls and municipal and state civil defense bodies, as seen in the graphic below.

Dam classification according to the Current Maximum Height – With regard to the maximum dam height, a determining aspect for inclusion in the PNSB, as established in the single paragraph of Art. 1 of Law No. 12,334/2010, 532 dams (or 62%) had heights below 15m. On the other hand, 299 dams (35%) had heights between 15.01 m and 60.01

m. The dams whose height was not informed summed 31, representing 4% of the total.

Dam classification according to the Emergency Level – With regard to the emergency level, most registered dams (about 95%) have no emergency declared. However, 4% of the dams are classified as emergency level 1, corresponding to situations with anomalies that result in a maximum score of 10 (ten) points in any column of Table 3 of Annex V, when Regular Safety Inspection (ISE) is then required. Moreover, 1% of the dams are classified as level 2, corresponding to situations when the anomalies were classified as either uncontrolled or not extinct, requiring new ISEs and interventions in order to solve them. Finally, four dams are classified as level 3, when rupture is imminent or already in progress.

The data allowed observing that the three dams classified as level 3 are located in the state of Minas Gerais, with no other state having dams classified in this emergency level.

Inspection – Since this study is exclusively related to tailings dams, and considering the attributions of the ANM according to the law that established the PNSB, the inspection and implementation of the Tailings Dam Safety Plans (PSBM) are the responsibility of the members of the Tailings Dam Safety Administration (GSBM) of the ANM (ANM, 2020).

Therefore, according to the Inspection Manual for Tailings Dams (DNPM, 2014), the inspection of such structures is performed in four stages.

The first stage consists of the remote management (office) of the information included in the SIGBM. This stage takes into account information such as notices of infractions and interdiction, instant alerts in case of possible abnormal situations, and the classification based on the CRI and DPA. The second stage consists of scheduling inspection visits using the degree or priority observed in the first stage. The third stage consists of the *in loco* visit, subdivided into two phases: 1) document analysis, in which the mandatory volumes of the PSB and PAEBM are verified, among other factors; and 2) field phase, when the visual inspection of all dam components is performed. Finally, in the fourth and last stage, the inspector prepares the inspection report indicating the actions to be taken, emission of notices or demands, or even interdiction orders (DNPM, 20214).

In 2020, due to the COVID-19 pandemic and the hiring of personnel meant to increase the technical rigor and effectiveness of inspections, the development of inspection actions by the agency was modified (ANM, 2021).

From this perspective, inspections were reduced, totaling 291 visits to 245 structures in 2020, corresponding to 28% of the 872 registered dams. Based on the number of dams included in the PNSB, 221 structures were inspected, corresponding to 50.8% of the total. With regard to dam classification according to Risk Category and Associated Potential Damage, inspections were made in 50% of the structures with low CRI, 28 %

with average CRI, 86 % with high CRI, and 5% of the dams that were not included in the PNSB. With regard to the DPA, the numbers are 27% for low DPA, 41% for average DPA, and 61% for high DPA (ANM, 2021).

Given the need to return to previously inspected structures due to potential emergencies and issues resulting from the inspections, complaints, or demands from control bodies, the ANM performed 45 inspections in 25 dams in the last year, representing 18 % of the total structures (ANM, 2021).

Conclusion

This study addressed the issues related to the production and final disposal of ore beneficiation waste regarding how the mining sector executes the construction of the structural project and respects the technical criteria and proper surveillance to prevent accidents.

With regard to the situation of tailings dams, data analysis showed that 60% of the 860 dams registered in the system had high DPA, whereas 11% are characterized as high CRI. Of these, the dams with high DPA and high risk of failure events are located in the state of Minas Gerais. It should be noted that Minas Gerais also presents the largest number of dams built by the upstream method, which is currently prohibited, also comprising the few dams classified as emergency level 3. These findings highlight the need for rigorous dam management inspections.

Based on the importance of inspections to ensure compliance with regulations, it is necessary to increase the number of ANM employees in order to intensify the mapping and monitoring of dams, thus ensuring their stability and reducing the risk of accidents.

Contributing with this objective, the Integrated Management System for Tailings Dam Safety (SIGBM) is an important management tool for tailings dams, both for the supervisory organ, with regard to the better planning and definition of strategies to monitor such structures, and also for enterprises, which can register their dams and update data whenever necessary. In addition, the external public is also benefited since this system provides an important opportunity to obtain specific technical information about the dams and allows understanding, participating, demanding, and inspecting these structures.

Therefore, it is necessary to broaden the system's database, e.g., by providing the PSB, the flood map, and the management of notices of infractions and interdiction related to the operation of dams in the public module of the SIGBM.

Finally, with regard to the limitations of this study, the data analyzed were collected until November 30, 2020, and since the Integrated Management System for Tailings Dam Safety (SIGBM) is dynamically updated, this highlights the need for new data. Therefore, we suggest that future studies should focus on diagnosing the progression of updates in tailings dams data to ensure the integrity of such structures.

References

AGÊNCIA NACIONAL DE MINERAÇÃO (ANM). Relatório anual de segurança de barragens de mineração, 2020. Disponível em: https://www.gov.br/anm/pt-br/assuntos/barragens/relatorios--anuais-de-seguranca-da-barragens-de-mineracao-1/RelatorioAnual2020Final.pdf. Acesso em: 01 dez. 2021.

AGÊNCIA NACIONAL DE MINERAÇÃO (ANM). Relatório anual de segurança de barragens de mineração, 2019. Disponível em: http://www.anm.gov.br/assuntos/barragens/relatorios--anuais-de-seguranca-da-barragens-de-mineracao-1/relatorio-anual-gsbm-2019-v-final, Acesso em: 04 maio 2020.

AGÊNCIA NACIONAL DE MINERAÇÃO (ANM). Nota Técnica - Resultado consolidado das declarações de condição de estabilidade. Março/2018. Disponível em: file:///C:/Users/Propriet%C3%A1rio/Downloads/Nota%20tecnica%20do%20resultado%20da%20Declara%C3%A7%C3%A3o%20de%20Condi%C3%A7%C3%A3o%20de%20estabilidade%20(1).pdf. Acesso em: 05 maio 2019.

BRASIL. Lei nº 12.334, de 20 de setembro de 2010. Disponível em: http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2010/Lei/L12334.htm. Acesso em: 01 fev. 2019

BRASIL. Resolução 91 da ANA, de 2 de abril de 2012. Disponível em: http://arquivos.ana.gov.br/resolucoes/2012/91-2012.pdf. Acesso em: 20 abr. 2019.

BRASIL. Resolução 143 do CNRH do Ministério do Meio Ambiente, de 10 de julho de 2012. Disponível em: http://www.cnrh.gov.br/resolucoes/1922-resolucao-n-143-de-10-de-julho--de-2012/file. Acesso em: 20 abr. 2019.

BRASIL. Resolução 144 do CNRH do Ministério do Meio Ambiente, de 10 de julho de 2012. Disponível em: https://sistemas.dnpm.gov.br/publicacao/mostra_imagem.asp?IDBancoArquivoArquivo=7234. Acesso em: 01 fev. 2019.

BRASIL. Portaria DNPM nº 70.389, de 17 de Maio de 2017. Disponível em: http://www.anm.gov.br/dnpm/documentos/portaria-dnpm-n-70389-de-17-de-maio-de-2017-seguranca-de-barragens/view. Acesso em: 01 fev. 2019.

BRASIL. Resolução nº 4, e 15 de fevereiro de 2019. Disponível em: http://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/63799094/do1-2019-02-18-resolucao-n-4--de-15-de-fevereiro-de-2019-63799056. Acesso em: 05 abr. 2019.

CARDOZO, F. C. C.; PIMENTA, M. M.; ZINGANO, A. C. Métodos construtivos de barragens de rejeitos de mineração: uma revisão. **Holos**, ano 32, vol. 08, 2016.

CARNEIRO, G. S. G. **Estudo das causas, impactos e medidas corretivas do rompimento de uma barragem de rejeitos, usando o caso da barragem de Mariana – MG**. Trabalho de Conclusão de Curso da Faculdade de Engenharia Civil (FECIV), da Universidade Federal de Uberlândia, 2018.

CARVALHO, P. S. L.; MESQUITA, P. P. D.; REGIS, R. D. D.; MEIRELLIS, T. L. **Sustentabilidade socioambiental da mineração**. BNDES Setorial 47, p. 333-390, 2018.

COSTA, D. P.; GONÇALVES, G.; FURTADO, A. S. O. Proposta de implantação do plano de ação de emergência em ciclos. **Revista Brasileira de Engenharia de Barragens** □ Comitê Brasileiro de Barragens. ano v, n. 7, fev., 2019.

DEPARTAMENTO NACIONAL DE PRODUÇÃO MINERAL (DNPM). **Manual de Fiscalização - Segurança de Barragens de Mineração**. Brasília, 2014. Disponível em: https://www.gov.br/anm/pt-br/assuntos/arrecadacao/manuais/manual-de-parcelamentos-dos-creditos-do-dnpm. Acesso em: 01 dez. 2021.

DUARTE, A. P. **Classificação das barragens de contenção de rejeitos de mineração e de resíduos industriais no estado de Minas Gerais em relação ao potencial de risco.** Dissertação do Programa de Pós-graduação em Saneamento, Meio Ambiente e Recursos Hídricos da Universidade Federal de Minas Gerais, Belo Horizonte, 2008.

ESPÓSITO, T. J. **Metodologia probabilística e observacional aplicada a barragens de rejeito construídas por aterro hidráulico.** Tese de Doutorado em Geotecnia. Universidade de Brasília, 2000.

FREITAS, C. M.; BARCELLOS C.; HELLER, L.; LUZ Z. M. P. Desastres em barragens de mineração: lições do passado para reduzir riscos atuais e futuros. **Epidemiol. Serv. Saúde**, Brasília, 2019.

GUIMARÃES, J. I. **Impacto do rompimento de uma barragem de rejeitos de minério de ferro sobre a qualidade das águas superficiais**. Estudo de caso: Bacia do rio Doce. Dissertação do Programa de Pós-graduação em Saneamento, Meio Ambiente e Recursos Hídricos da Universidade Federal de Minas Gerais, Belo Horizonte, 2018.

GOMES, A. C. F. **Estudo de aproveitamento de rejeito de mineração**. Dissertação do programa de Pós-graduação em Engenharia Metalúrgica, Materiais e de Minas da Escola de Engenharia da Universidade Federal de Minas Gerais, Belo Horizonte, 2017.

LOZANO, F. A. E. **Seleção de locais para barragens de rejeitos usando o método de análise hierárquica**. Dissertação (Mestrado) □ Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia de Estruturas e Fundações. São Paulo, 2006.

MATURANO RAFAEL, H, M, A.. Análise do Potencial de Liquefação de uma Barragem de Rejeito. Dissertação (Mestrado em Engenharia Civil)□ Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2012.

SOARES, L. **Barragem de rejeitos**. Comunicação Técnica elaborada para o Livro Tratamento de Minérios, 5 ed □ Cap 19, p. 831□896. Rio de Janeiro: CETEM/MCT, 2010.

SOUZA JUNIOR, T.F.; MOREIRA, E. B.; HEINECK, K.S. Barragens de contenção de rejeitos de mineração no Brasil. **Holos**, ano 34, vol. 05, 2018.

THOMÉ, R., PASSINI, M. L. Barragens de rejeitos de mineração: características do método de alteamento para montante que fundamentaram a suspensão de sua utilização em minas gerais. **Ciências Sociais Aplicadas em Revista - UNIOESTE/MCR** - v.18.

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AMBIENTE & SOCIEDADE
25 anos años years

SciELO

Cenário das barragens de rejeito: conhecer para evitar novas catástrofes

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Alvany Maria dos Santos Santiago

Resumo: A mineração é um dos setores básicos da economia do Brasil. Apesar da sua importância, a geração de rejeitos oriunda do beneficiamento é significativa, tornando-se um dos grandes problemas no setor. Os acidentes relacionados ao rompimento de barragens têm marcado a trajetória da exploração mineral. Assim, este estudo buscou apresentar o cenário atual das barragens de rejeitos, tendo como base as informações contidas no SIGBM. Observou-se o quantitativo de barragens inseridas na PNSB, categoria de risco, dano potencial, nível de emergência entre outros. A análise desses dados indica que Minas Gerais é o estado que apresenta a maior quantidade de barragens inseridas na PNSB, com CRI e DPA altos, com barragens construídas pelo método a montante e declaradas no nível 3 de emergência, necessitando assim de redobrada atenção e intervenção para garantir a sua segurança.

Palavras-chave: Mineração; barragem de rejeito; modelos construtivos; legislação; segurança de barragem.

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Artigo Original

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Escenario de presas de relaves: saber evitar nuevas catástrofes

Suiane Rodrigues Leão
Alvany Maria dos Santos Santiago

Resumen: La minería es uno de los sectores básicos de la economía brasileña. A pesar de su importancia, la generación de relaves a partir del procesamiento es significativa, convirtiéndose en uno de los mayores problemas del sector. Los accidentes relacionados con la ruptura de presas han marcado la trayectoria de la exploración minera. Así, este estudio buscó presentar el escenario actual de las presas de relaves, con base en la información contenida en el SIGBM. Se observó el número de presas insertadas en el PNSB, categoría de riesgo, daño potencial, nivel de emergencia, entre otros. El análisis de estos datos indica que Minas Gerais es el estado con mayor número de presas insertadas en el PNSB, con alto CRI y DPA, con presas construidas por el método upstream y declaradas en nivel de emergencia 3, por lo que requieren atención e intervención adicionales. para garantizar su seguridad.

***Palabras-clave*:** Minería, presa de relaves, modelos constructivos, legislación, seguridad de presas.

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