

Environment

Dams safety: an analysis of safety management and the difficulties of its supervision

Segurança de barragens: uma análise da gestão de segurança e as dificuldades de sua fiscalização

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ABSTRACT

Despite the notable benefits that dams bring to society, they involve immediate and potential risks and impacts, which makes dam safety extremely important. This narrative review paper compares dam safety concepts, including that established in the Brazilian National Dam Safety Policy – PNSB, as well as analyzes the supervision difficulties reported by Brazilian federal and state agencies. Several national and international institutions define dam safety, but considering those presented in this paper, convergency was found out regarding the concept of maintaining structural integrity and operational safety in order to preserve life, health, property and environment. Dams in Brazil are inspected by several public bodies, depending on their priority use and the domain of the body of water in which they are located, each with prerogatives to regulate the matter. In view of the significant increase in the amount of accidents and incidents in 2019 and 2020, it is clear that there is a vulnerability to be corrected in the safety management of Brazilian dams due to their dependence on the treatment of deficient or non-existent technical information and on a lack of specialized staff in dam safety for inspection activities.

Keywords: Dams safety; Dams inspection; Dams accidents

RESUMO

A despeito dos notáveis benefícios que as barragens trazem para a sociedade, elas envolvem riscos e impactos imediatos e potenciais, o que torna a segurança de barragens algo extremamente importante. Este artigo de revisão narrativa compara conceitos de segurança de barragem, entre eles o estabelecido na Política Nacional de Segurança de Barragens – PNSB, bem como analisa as dificuldades de fiscalização reportadas pelos órgãos federais e estaduais brasileiros. Diversas instituições nacionais e internacionais definem segurança de barragem, mas considerando as apresentadas neste artigo, foi encontrada convergência para o conceito de manter a integridade estrutural e a segurança operacional

a fim de preservar vida, saúde, propriedade e meio ambiente. As barragens no Brasil são fiscalizadas por diversos órgãos públicos, a depender do seu uso prioritário e do domínio do corpo d'água em que se encontram, cada um com prerrogativas de regulamentar o assunto. Diante do significativo aumento nos registros de acidentes e de incidentes nos anos de 2019 e 2020, percebe-se uma vulnerabilidade a ser corrigida na gestão de segurança de barragens brasileiras devido sua dependência de tratamento de informações técnicas deficientes ou inexistentes, e de uma carência de efetivo de profissionais especializados em segurança de barragens para a atividade de fiscalização.

Palavras-chave: Segurança de barragens; Fiscalização de barragens; Acidentes de barragens

1 INTRODUCTION

Some inventions greatly helped the evolution of humanity, among them the construction of dams to store water and thus guarantee its uses. The construction of dams has enabled a better quality of life, as having water is a basic condition for a society to develop. The construction of dams allowed the growth of cities and made it possible essential activities such as agriculture, livestock, urban and industrial water supply, hydroelectric generation, flood and drought control, etc. Dams can be of various types and sizes, built with the most different materials and techniques, and can contain large volumes and energy.

Despite the benefits that dams bring, they involve risks and impacts because, since when they are built, they demand the flooding of large areas for the formation of the reservoir, impacting the flora, fauna, relocation of communities, etc. In addition, dams can accidentally release large volumes in a short time, causing very severe human, environmental, social and property consequences, which makes dam safety something very important, presenting itself as one of the aspects of water safety, in terms of management of water-related risks and disasters.

With the aim of making a critical analysis of dams safety management based on the data published in 2020 in the Dams Safety Report of the Brazilian National Water Agency - ANA, this narrative review paper analyzes and compares different concepts of dams safety, as well as presents the Brazilian National Dam Safety Policy and the characteristics of dams inspection activity in Brazil, the difficulties reported by the inspection bodies themselves and the evolution of accidents and incidents within the ten-year interval in Brazil.

2 DAMS SAFETY - CONCEPT

The National Policy for Dam Safety in Brazil - PNSB, established by the Law nº 12.334/2010 and updated by the Law 14.066/2020, defines dam safety as “a condition that aims to maintain its structural and operational integrity and the preservation of life, health, property and environment”.

Table 1 – Examples of dam safety definitions according to national and international references

Reference	Definition of Dam Safety
PNSB	Condition that aims to maintain its structural and operational integrity and the preservation of life, health, property and environment.
World Bank	It refers to the factors that influence the safe operations of the dam structure and adjacent structures, and the potential of the dam to adversely affect human life, human health, property and the surrounding environment. This means that dam safety is also concerned with the adequacy of dam operations and maintenance, as well as its plans for dealing with emergencies and limiting the negative impact of existing dams on human life, human health, property and the environment.
FEMA	It is the art and science of ensuring the integrity and viability of dams so that they do not offer unacceptable risks to the public, property and the environment. It requires the collective application of engineering principles and experience and a risk management philosophy that recognizes that a dam is a structure whose safe function is not explicitly determined by its original design and construction. It also includes all actions taken to identify or anticipate deficiencies and consequences related to failures and to document, disclose and reduce, eliminate or remedy, to the extent reasonably possible any unacceptable risks.

Source: Authors (2022)

In line with the definition of the PNSB, the National Water Agency – ANA considers that “a safe dam is a well-maintained dam, in which efforts, energy, attention, resources and trained professionals are directed towards a good conception, a good project, a construction that follows good engineering procedures and for the stages after construction: first filling, maintenance, operation and decommissioning, if applicable”.

In order to compare different definitions of dams safety, table 1 presents the definition

of the PNSB together with the definitions of the Federal Emergency Management Agency – FEMA (Federal Guidelines for Dam Safety, Glossary of Terms, April 2004, Federal Emergency Management Agency – FEMA, USA) and the World Bank:

Considering the definitions presented, the objectives below are convergent:

Keep:

Structural integrity.
Operational safety.

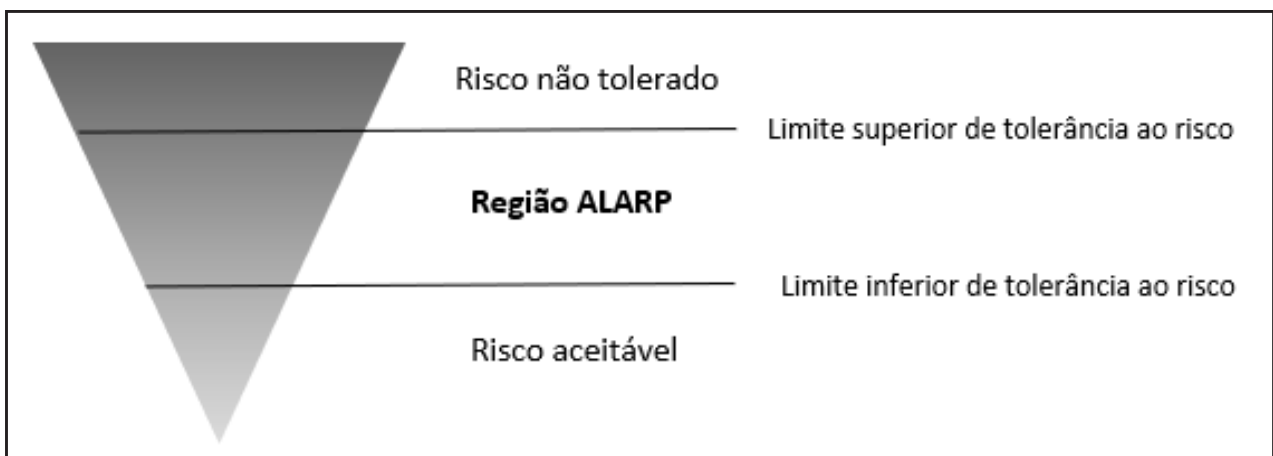
With the aim of:

Preservation of life.
Health preservation.
Property preservation.
Preservation of environment.

However, in a more detailed reference than those shown in Table 1, FEMA additionally considers in its definition:

- Risk management beyond original design and construction.
- The concept of risk tolerability; and
- The ALARP (as low as reasonably practicable) principle, shown in figure 1 below, for the implementation of possible risk control measures.

Figure 1 – ALARP principle (As Low as Reasonably Practicable)

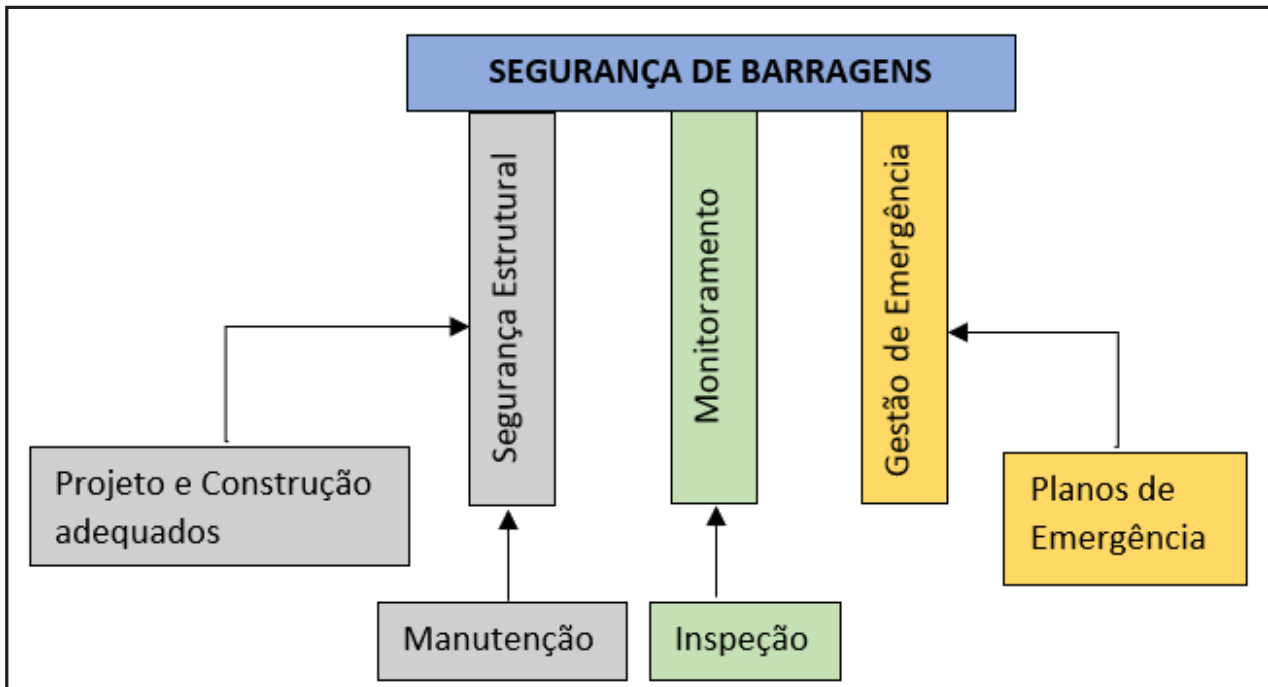


Source: Figure adapted from Chapter 38 - Risk Assessment Methodology | Elsevier Enhanced Reader. (2016)

In the ALARP region, the risk is tolerable only if its reduction is impractical or if its cost is very disproportionate to the improvement obtained.

Biedermann (1997) considers that dams safety can be achieved by relying on three basic pillars: structural safety (adequate design, construction and maintenance), monitoring and emergency management, as shown in figure 2 below.

Figure 2 – Basic pillars of dams safety



Source: Figure adapted from BIEDERMANN, R. (1997). Safety Concept for Dams: Development of the Swiss concept since 1980. *Wasser, Energie, Luft*, 89: 55-72

3 THE NATIONAL DAM SAFETY POLICY OF BRAZIL – PNSB

The Law 12.334/2010, updated by the Law 14.066/2020, established in Brazil the National Policy for the Dams Safety intended to the accumulation of water for any use; to the final or temporary disposal of tailings and the accumulation of industrial waste, as well as creating the National Information System on Dam Safety – SNISB. The PNSB applies to dams with at least one of the following characteristics shown in Frame 1 below.

Chart 1 – Characteristics that make the PNSB applicable to a Brazilian dam

Features
Massif size higher than or equal to 15 meters Total reservoir capacity greater than or equal to 3,000,000m ³ Reservoir containing hazardous waste according to applicable technical standards Medium or high associated potential damage category, in terms of economic, social, environmental or loss of human life High risk category, according to the supervisory body criterium

Source: Adapted from the Law 12.334/2010, updated by the Law 14.066/2020, which established the National Dam Safety Policy in Brazil

The brief objectives of the PNSB are:

- The prevention of accidents, disasters and their consequences ⁽¹⁾.
- Regulating safety actions throughout the dam’s life cycle (from planning, design, construction, first filling and first pouring, operation, deactivation, de-characterization and future uses of dams).
- Promoting the monitoring and follow-up of safety actions employed by those responsible for dams.
- Creating conditions to expand the dams control universe by public authorities.
- Gathering information that subsidizes the management of dams safety by governments.
- Establishing compliance of a technical nature that allows the assessment of adequacy to the parameters established by public authorities.
- Fostering a culture of dams safety and risk management.
- Defining emergency procedures and encourage the joint action of entrepreneurs, inspectors and civil defense and protection bodies in the event of an incident, accident or disaster.

¹ PNSB definitions:

Accident: impairment of structural integrity with uncontrollable release of the reservoir contents, caused by partial or total collapse of the dam or annexed structure.

Incident: occurrence that affects the behavior of the dam or adjacent structure which, if not controlled, can cause an accident.

Disaster: result of an adverse event, of natural origin or induced by human action, on ecosystems and vulnerable populations, which causes significant human, material or environmental damage and economic and social losses.

An important fundamental of the PNSB is that the entrepreneur is the legally responsible for the dam safety, for damages resulting from its rupture, leak or malfunction and, regardless of fault, for repairing these damages.

The PNSB has nine instruments, in which some stand out for the purpose of preventing dam rupture, namely:

a. The dams classification system by risk category and associated potential damage.

Dams are classified by inspection agents, by risk category, by potential associated damage and by their volume, based on general criteria established by the National Water Resources Council (CNRH).

b. Dam Safety Plan.

It comprises of minimum information such as identification of the entrepreneur; technical data of construction, operation and maintenance of the dam; organizational structure and technical qualification of the dam safety team professionals; procedure manuals for safety inspection and monitoring routes and dam safety reports; operational rule of the dam discharge devices; indication of the area surrounding the facilities and their respective accesses, to be protected from any permanent uses or occupations, except those essential for the maintenance and operation of the dam; Emergency Action Plan (EAP); reports of regular and special security inspections; periodic security reviews; identification and assessment of risks, with definition of hypotheses and possible scenarios of accident or disaster; flood map, considering the worst case scenario identified and identification and technical data of the dam's structures, installations and monitoring equipment.

- Its updating frequency, the qualification of its technical manager, its minimum content and level of detail are established by the inspection body of the dam.
- It must be available and accessible at the development site.
- Prepared and signed by a technical manager in charge, including an acknowledgment by the entrepreneur, in the case of an individual, or the

principal in the structure of the legal entity.

c. National Information System on Dam Safety (SNISB).

It comprises of a system for collecting, processing, storing and retrieving its information and includes dams under construction, in operation and deactivated.

- Maintaining information about incidents, accidents and disasters.
- Data entry is under the responsibility of each dam safety inspection body in Brazil.
- It is managed by the National Water and Basic Sanitation Agency (ANA).

d. Dam Safety Report – RSB.

Its preparation is annually coordinated by the ANA, containing information sent by Organs inspection bodies. It presents to society an overview of the evolution of the safety management of Brazilian dams and the implementation of the PNSB, and highlights the main events in the reference year.

The RSB is evaluated by the National Water Resources Council (CNRH) and then disclosed to the National Congress, the Legislative Assemblies, the Legislative Chamber of the Federal District and the Federal, State and District Governments.

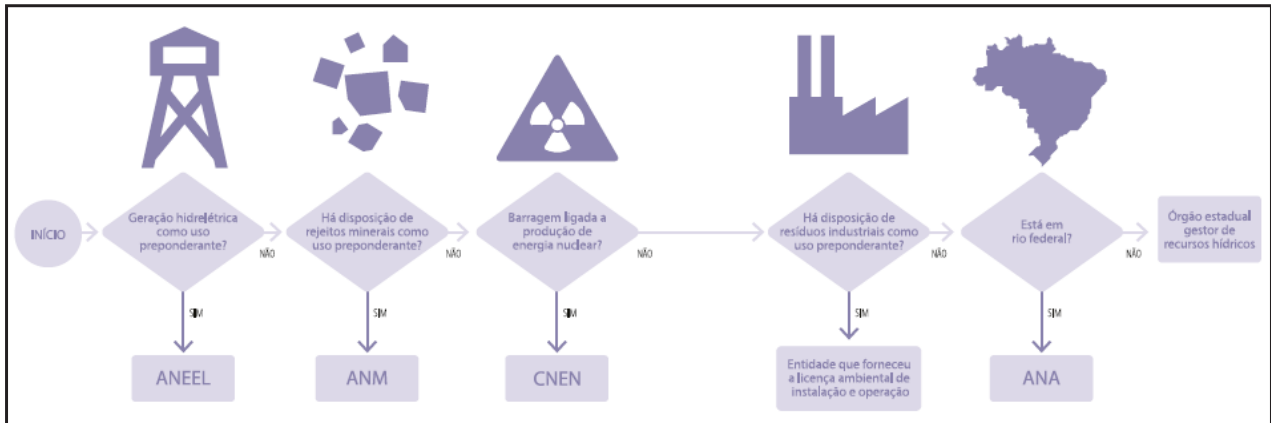
e. Monitoring of dams and water resources in its area of influence.

f. Good practice guides on dam safety.

4 DAMS INSPECTION IN BRAZIL

Dams in Brazil are supervised by public bodies. The diagram shown in figure 3 below presents the supervisory body depending on the priority use of the dam and the domain of the water body in which it is located.

Figure 3 – Public agencies that inspect dams in Brazil



ANEEL – National Electric Energy Agency

ANM – National Mining Agency

CNEN – National Nuclear Energy Commission

ANA – National Agency for Water and Basic Sanitation

Source: National Water and Basic Sanitation Agency / Dam Safety Report 2020

The supervisory bodies are responsible for:

- Registering the dam under its jurisdiction and editing its data on the SNISB portal.
- Issuing authorization to implement or regularize the dam (in the form of grant, concession, authorization, license for installation and operation of projects).
- Editing own regulations on dam safety.
- Classifying the dam according to the DPA - Potential Associated Damage and CRI - Risk Category and demanding from the entrepreneur measures that lead to the reduction of the risk category.
- Determining whether the dam is subject to the PNSB or not and requiring its Safety Plan, when applicable.
- Maintaining a communication channel to receive complaints and providing information.
- Inspecting the dams under its duty.
- Informing the civil defense and protection body when the inspection results in emergency measures.

4.1 Difficulties in obtaining basic information on inspectable dams in Brazil

Table 2 below presents the difficulties reported by the Brazilian inspection bodies in the ANA Dam Safety Report, version 2020.

Table 2 – Difficulties reported by Brazilian inspection bodies

(Continue)	
Main difficulties of supervisory bodies organs	Reported by:
Non-existent dam projects	ACRE - Acre Environment Institute (IMAC)
	ALAGOAS - State Secretariat for the Environment and Water Resources (SEMARH)
	Ceará - Secretary of Water Resources of Ceará (SRH)
	Espírito Santo - State Water Resources Agency (AGERH)
	Mato Grosso - Secretary of State for the Environment (SEMA)
	Minas Gerais – Minas Gerais Institute of Water Management – (IGAM)
	Paraíba - Paraíba Water Management Executive Agency (AESA)
	Pernambuco - Pernambuco Water and Climate Agency (APAC)
	Rio Grande do Norte - Rio Grande do Norte State Water Management Institute (IGARN)
	Santa Catarina - Secretary of State for Sustainable Economic Development (SDE)
Lack of technical staff specialized in dam safety	ACRE - Acre Environment Institute (IMAC)
	Amapá - Secretary of State for the Environment (SEMA)
	Espírito Santo - State Water Resources Agency (AGERH)
	Mato Grosso - Secretary of State for the Environment (SEMA)
	Pará - Secretary of State for Environment and Sustainability (SEMAS)
	Pernambuco - Pernambuco Water and Climate Agency (APAC)
	Rondônia - State Secretariat for Environmental Development (SEDAM)
Roraima - State Foundation for the Environment and Water Resources (FEMARH)	

Table 2 – Difficulties reported by Brazilian inspection bodies

(Continuation)

Main difficulties of supervisory bodies organs	Reported by:	
Lack of technical information on the dams by the entrepreneur	Amazonas - Institute for Environmental Protection of Amazonas (IPAAM) Bahia – Institute for the Environment and Water Resources (INEMA) Ceará - Secretariat of Water Resources of Ceará (SRH) Espírito Santo - State Water Resources Agency (AGERH) Mato Grosso do Sul - Institute for the Environment of Mato Grosso do Sul (IMASUL) Paraná - Water and Earth Institute (IAT) National Nuclear Energy Commission (CNEN)	
	Goiás - Secretary of Environment and Sustainable Development (SEMAD) Maranhão - Secretary of State for the Environment and Natural Resources (SEMA) Pernambuco - Pernambuco Water and Climate Agency (APAC) Piauí - State Secretariat for the Environment and Water Resources of Piauí (SEMAR) Rio Grande do Norte - Rio Grande do Norte State Water Management Institute (IGARN) Roraima - State Foundation for the Environment and Water Resources (FEMARH) São Paulo - Department of Water and Electric Energy (DAEE)	
	Limited budgetary resources of entrepreneurs	Bahia – Institute for the Environment and Water Resources (INEMA) Ceará - Secretariat of Water Resources of Ceará (SRH) Rio de Janeiro - State Institute of the Environment (INEA) São Paulo - Department of Water and Electric Energy (DAEE) National Water and Basic Sanitation Agency (ANA) National Mining Agency (ANM)

Table 2 – Difficulties reported by Brazilian inspection bodies

(Continuation)

Main difficulties of supervisory bodies organs	Reported by:
Lack of understanding of legal provisions by entrepreneurs	Acre - Acre Environment Institute (IMAC) Mato Grosso - Secretary of State for the Environment (SEMA) Minas Gerais – Minas Gerais Institute of Water Management – (IGAM) Rondônia - State Secretariat for Environmental Development (SEDAM) Tocantins - Nature Institute of Tocantins (NATURATINS)
Coronavirus pandemic	Rio Grande do Sul – Secretary of Environment and Infrastructure (SEMA) Rondônia - State Secretariat for Environmental Development (SEDAM) National Water and Basic Sanitation Agency (ANA) NATIONAL ELECTRIC ENERGY AGENCY (ANEEL)
Irregular use dams, that is, when there are no grants, licenses or registration of the dam	Acre - Acre Environment Institute (IMAC) Goiás - Secretary of Environment and Sustainable Development (SEMAD) Pernambuco - Pernambuco Water and Climate Agency (APAC)
Difficulties with logistics for displacement	Amazonas - Institute for Environmental Protection of Amazonas (IPAAM) Piauí - State Secretariat for the Environment and Water Resources of Piauí (SEMAR)
Lack of safety equipment	Amazonas - Institute for Environmental Protection of Amazonas (IPAAM)

Table 2 – Difficulties reported by Brazilian inspection bodies

(Conclusion)

Main difficulties of supervisory bodies organs	Reported by:
Differing classification criteria	Minas Gerais - Secretary of State for the Environment and Sustainable Development (SEMAD)
Very large diversity of dams	Santa Catarina - Secretary of State for Sustainable Economic Development (SDE)
Dam Safety Plans forwarded to the entrepreneur for review	São Paulo - Department of Water and Electric Energy (DAEE)
Limited budgetary resources of supervisory bodies	São Paulo - Department of Water and Electric Energy (DAEE)
Elaborated Emergency Action Plans usually do not have the participation of the community or Civil Defense	National Water and Basic Sanitation Agency (ANA)
Lack of transparency by the entrepreneur in order to correctly classify and rank the dams	National Mining Agency (ANM)

Source: Authors (2020)

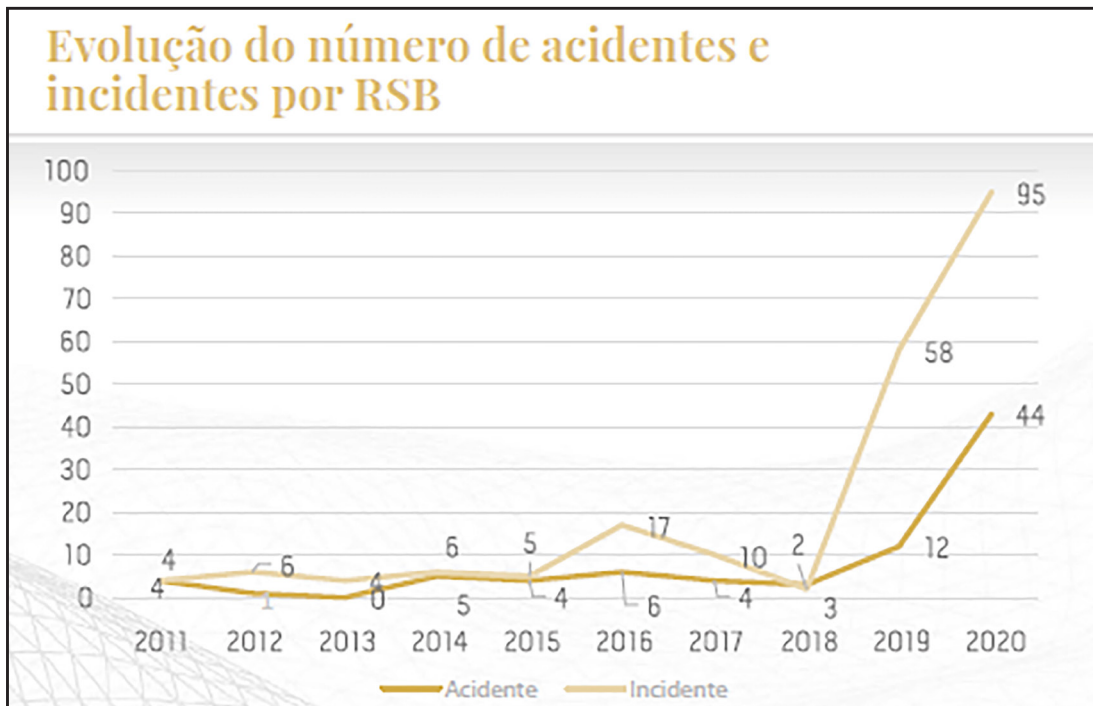
Most of these difficulties are reported for water accumulation dams for supply and irrigation purposes. It is noticed that the most frequently reported are:

- Non-existent dam projects.
- Lack of technical staff specialized in dam safety.
- Lack of technical information on the dams by the entrepreneur.

5 EVOLUTION OF THE NUMBER OF ACCIDENTS IN WATER CONTAINMENT DAMS IN BRAZIL WITHIN 10 YEARS INTERVAL

The graph in figure 4 below shows the evolution of the number of accidents and incidents reported by ANA each year in its Dam Safety Reports, where the significant increase in the records of accidents and incidents in the 2019 and 2020 is noticeable.

Figure 4 – Evolution of the number of accidents and incidents at dams in Brazil



Source: RSB 2020 – ANA

The ANA's 2020 Dam Safety Report attributed this increase in the frequency of accidents to heavy rainfall events that occurred in the first quarter of 2020 in the southeast and central-west regions of the country, which caused historic floods that ended up overflowing many cascading dams, causing some of them to break.

6 CONCLUSIONS

Despite the notable benefits that dams bring to society, they involve risks and impacts, whether immediate (for the formation of reservoirs) or potential due to eventual rupture and uncontrolled release of large volumes in a short time, causing very severely human, environmental, social and property consequences.

Considering the dam safety definitions presented in this paper, convergency is perceived for maintaining structural integrity and operational safety in order to preserve lives, health, properties and the environment through risk management beyond the original design and construction; through the concept of tolerability of risks; via the

ALARP principle (as low as reasonably practicable) for the implementation of possible risk control measures; as well as through emergency monitoring and management.

The Law 12.334/2010, updated by Law the 14.066/2020, established in Brazil a National Dam Safety Policy – PNSB that applies to those that accumulate large amounts of energy, hazardous waste and the greatest risks/consequences.

Among the instruments that the PNSB has, it is noticed that the system for classifying dams by risk category and associated potential damage lacks information, which can lead to difficulties in prioritizing supervision by inspection bodies.

Although the entrepreneur is legally responsible for the safety of the dam he operates, including its damages and consequences, and, regardless of the existence of fault, for repairing these damages, it is clear that this legal responsibility has not been sufficient to correct the vulnerabilities of the dam safety management.

Dams in Brazil are inspected by several public bodies, depending on their priority use and the domain of the body of water in which they are located, each with prerogatives to legislate on the subject. There are several difficulties reported by them, the most frequent are:

- Non-existent dam projects.
- Lack of technical staff specialized in dam safety.
- Lack of technical information on the dams by the entrepreneur.

Thus, in addition to the significant increase in the records of accidents and incidents in 2019 and 2020, it can be concluded that there is a vulnerability to be corrected in the safety management of Brazilian dams due to their dependence on the treatment of deficient or non-existent technical information, and a shortage of professionals specialized in dam safety for inspection activities.

It can be concluded that dam safety management in Brazil has ample room for improvement, as it needs to increase the registration and classification of dams, as well as the qualification of effective inspection bodies and incisive actions with dam developers to fulfill their legal obligations.

REFERENCES

- AGÊNCIA NACIONAL DE ÁGUAS – ANA. (2021). Relatório de Segurança de Barragens – RSB 2020. Brasília: ANA.
- Bai, Y., Jin, W-L. (2016). Chapter 38 - Risk Assessment Methodology. In: Y. Bai.; JIN. W- L. (Eds.). Marine Structural Design. 2. Ed.) Oxford, Butterworth-Heinemann, p. 709-723, 2016.
- Butterworth-Heinemann, BIEDERMANN, R. (1997). Safety concept for dams: Development of the Swiss concept since 1980. Wasser, 89, 55–63.
- Lei nº 12.334, DE 20 DE SETEMBRO DE 2010. Estabelece a Política Nacional de Segurança de Barragens destinadas à acumulação de água para quaisquer usos, à disposição final ou temporária de rejeitos e à acumulação de resíduos industriais, cria o Sistema Nacional de Informações sobre Segurança de Barragens e altera a redação do art. 35 da Lei no 9.433, de 8 de janeiro de 1997, e do art. 4o da Lei no 9.984, de 17 de julho de 2000., Brasília, DF: 2010. Retrieved from: http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2010/Lei/L12334.htm.
- LEI Nº 14.066, DE 30 DE SETEMBRO DE 2020. Altera a Lei nº 12.334, de 20 de setembro de 2010, que estabelece a Política Nacional de Segurança de Barragens (PNSB), a Lei nº 7.797, de 10 de julho de 1989, que cria o Fundo Nacional do Meio Ambiente (FNMA), a Lei nº 9.433, de 8 de janeiro de 1997, que institui a Política Nacional de Recursos Hídricos, e o Decreto-Lei nº 227, de 28 de fevereiro de 1967 (Código de Mineração). Brasília, DF: 2020. Retrieved from: http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2020/lei/L14066.htm.

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