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Application of an Engineer of Record (EoR) for safety benefits in water storage dams

Aplicação de um Engenheiro de Registro (EoR) em barragens de acúmulo de água: benefícios na segurança

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ABSTRACT

The dam safety depends heavily on the organizational structure, the developer's philosophy, and the involved actor's technical responsibility. In this context, the present research aimed to: introduce the concept of Engineer of Record (EoR); discuss their influence on the continuous improvement of dam safety, propose a work plan for this professional applicable to water storage dams, and estimate the costs associated with their team. Since mining dams have experienced recent accidents, safety laws, and methodologies are more stringent for these structures. Therefore, based on this experience, a list of actions for the EoR was proposed, targeted explicitly at water storage dams, divided into two stages: the first to comply with the National Dam Safety Policy (NDSP); and the second focused on the continuous improvement of the safety of these structures. Additionally, a cost estimate was conducted, resulting in a value of $ 0.15 per m^3 consumed for implementing an EoR team.

Keywords: Dam safety; Engineer of Records; Dam safety legislation.

RESUMO

A segurança de uma barragem depende fortemente da estrutura organizacional, da filosofia do empreendedor e da responsabilidade técnica dos atores envolvidos. Neste contexto, a presente pesquisa teve como objetivos: apresentar o conceito de Engenheiro de Registro (EoR); discutir sua influência na melhoria contínua da segurança; propor um plano de trabalho para este profissional, aplicável às barragens de acúmulo de água e estimar os custos associados à sua equipe. Considerando que as barragens de mineração têm enfrentado acidentes recentes, as leis e metodologias de segurança são mais rigorosas para estas estruturas. Portanto, com base nesta experiência, propôs-se uma lista de ações para o EoR, especificamente voltada para barragens de acúmulo de água, dividida em duas etapas: a primeira, para atendimento da Política Nacional de Segurança de Barragens (NDSP); e a segunda, voltada à melhoria contínua da segurança dessas estruturas. Adicionalmente, realizou-se uma estimativa de custos, chegando ao valor de R$ 0,15 por m^3 consumido para a implantação de uma equipe de EoR.

Palavras-chave: Segurança de barragens; Engenharia de Registro; Legislação de segurança de barragens.

INTRODUCTION

Human activities depend on water supply and often on some form of dam structures. Water is necessary for the most diverse activities, from obtaining food and irrigating crops to using electricity. In addition to that, the production of most objects, such as utensils, tools, machinery, and the like, depends on raw materials from the mining process. In these processes, dams are present for tailings disposal, sediment containment, or water accumulation.

Understanding the context of the importance of dams in society, and the proximity of human occupations to these ventures, there is an extreme need to guarantee the safety of the structure since, in the event of its rupture, there is a wide range of possibilities of damage, in the social, environmental and economic spheres. As an example, one can list the significant accidents with Brazilian dams, according to Tschiedel et al. (2019): Hydropower Plant (HPP) Pampulha (1954); Orós Dam (1960); HPP Euclides da Cunha and Limoeiro (1977), Poquim (1979), Santa Helena (1985) Fernandinho (1986) and Pico São Luiz (1986); Emas Novas (1995); Rio Verde (2001), Cataguases (2003), Miraí (2006), Espora (2008), Apertadinho (2008), Algodões (2009), Camará (2004); Laranjal do Jari (2014), Herculano (2014), Analândia (2011), Boa Vista do Uru (2014), Vacarao (2014), Coronel Sapucaia (2015), Zampieri (2015), Buritis (2014), Fundão (2015), Alta Grande (2016), Fazenda Felícia (2016), Fazenda Guavirova (2016), Balneário Ayrton Senna (2016), Rincão dos Kroeff (2017), Cacimba Nova (2017), Barreiros (2017), Lageado (2017) and Brumadinho (2019). In addition, in the Dam Safety Report (DSR) for 2020, published by the National Agency of Water and Basic Sanitation (ANA) (Agência Nacional de Águas, 2021), 44 accidents were reported in this period alone (Agência Nacional de Águas, 2021).

Given the severe impacts caused by dam accidents in Brazil, legislation is being strengthened and becoming more discerning. For example, the new Resolution No. 95 from the National Agency of Minning (ANM) (Brasil, 2022) can be mentioned, which presents the most up-to-date methodologies and parameters based on the leading international agencies focused on dam safety. In this Resolution, a new concept can be observed, the figure of an Engineer of Records (EoR) who provides constant support to the entrepreneur, proposing actions aimed at the continuous improvement of dam safety, supported by sound engineering practices and international standards (Brasil, 2022).

According to Dam Safety Report (DSR) for 2020 (report that was presented in 2021), it appears that dams that store water are in a more critical situation from a safety point of view since of the 44 accidents recorded only in 2020, 40 were from water accumulation dams (Agência Nacional de Águas, 2021). Already in 2021 (report that was presented in 2022), more 13 accidents were recorded, been 12 from water storage dams (Agência Nacional de Águas, 2022).

This way, this research seeks to apply concepts and methodologies adopted by the mining sector in dams that accumulate water, which today have the highest number of accidents, highlighting the role of the Engineer of Records (EoR).

MATERIALS AND METHODS

This research was based on a bibliographical survey of the main Brazilian legislation, international standards on dam safety, and the situation of water accumulation dams in Brazil. This way, it was verified that the main Brazilian inspection agencies published resolutions and ordinances focused on the subject to oblige entrepreneurs to comply with the NDSP (Brasil, 2010; Brasil, 2020).

In this movement, it was found that the ANM was the agency that published the most recent standard. Due to all the complexity of mining dams and the accidents that have occurred in recent years, it was also the agency that published a complete standard that follows the primary safety standards for international dams. Based on ANM Resolution No. 95 (Brasil, 2022), there was an obligation to maintain a responsible EoR for mining dams classified with high associated potential damage (APD) since the mining sector recognized the benefits of applying this professional, which contributes a lot to seeking continuous improvement of dam safety.

In Brazil, the company that produced the most technical knowledge applied to the EoR was the mining company VALE (Vale, 2022); thus, its organization of dam safety management was researched. Every change in structure was observed, and the application of new concepts (after the Fundão and Brumadinho breach), seeing that these encompass the EoR throughout the safety chain, in all dam life cycles, in the same way as recommended by international reference agencies in dam safety such as the Mining Association of Canada (MAC) or Canadian Dam Association (CDA) (Canadian Dam Association, 2013; Mining Association of Canada, 2022).

Analyzing the situation presented in the last Dam Safety Report (DSR) for 2021 (Agência Nacional de Águas, 2022), it was found that the dams in the worst condition from a safety point of view are the water accumulation dams. The vast majority do not meet the NDSP (Brasil, 2010; Brasil, 2020), do not have the Dam Safety Plan (DSP) (Brasil, 2010; Brasil, 2020), and lack various documentation and studies that support the structure's safety. The reflection of this lack of safety management can be seen in the accidents published in the DSR; were 57 accidents was registered, where the inspectors are water resources management bodies, indicating that the 52 casualties occurred with dams that accumulate water (Agência Nacional de Águas, 2022).

This way, two key points were identified: the problem of the safety of dams that accumulate water in Brazil and the recent issue of the application of the registration engineer in mining dams. As the ANM and the entire mining sector recognized that the application of this professional is necessary for their high-risk dams, an attempt was made to transfer this knowledge positively to the sector that today is in a more precarious situation regarding the safety of its dams.

Therefore, a work plan for the recording engineer will be proposed, adapting his function to be applied in the context of water accumulation dams. This plan was prepared based on the main national and international dam safety references. As the dams in question currently do not yet comply with the NDSP, a strategy was set up for the EoR to work to guide the entrepreneur to comply with Brazilian legislation and, subsequently, to monitor the performance of the structure in the search for continuous improvement of its safety. Figure 1 shows the applied methodology.

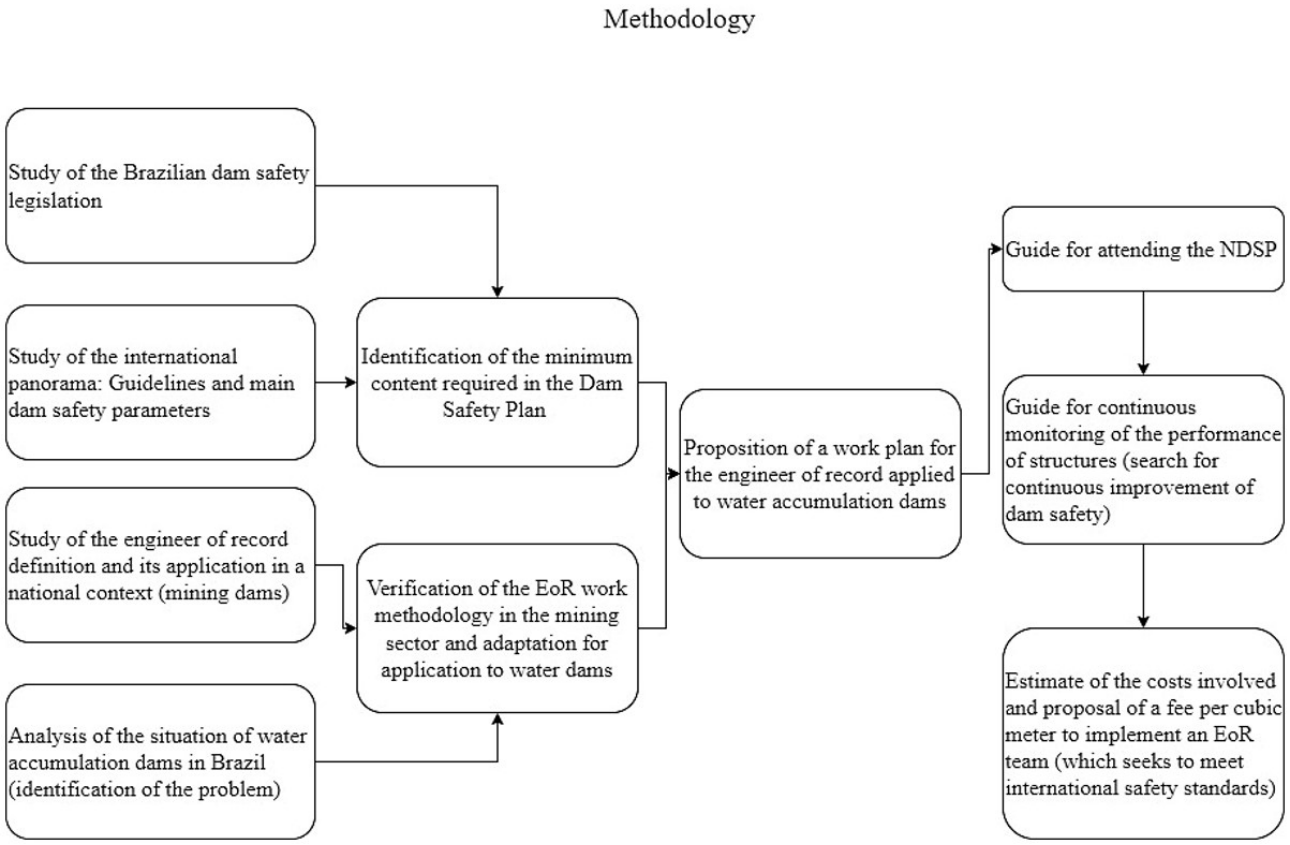

Figure 1. Methodology flowchart of this research.

RESULTS AND DISCUSSION

Dams that do not yet meet the NDSP

For dams that still do not have sufficient technical documentation to comply with the NDSP and local legislation, the EoR must start working with his team by requesting all existing information and a specialized field visit to the facilities. The view has two primary purposes:

- Alignment with the entrepreneur's team that will be the contact of the EoR team, providing support to carry out all demands related to dam safety that the EoR will act on. It is essential that the EoR create a structured database with all the information provided by the entrepreneur. Alignment of the work culture, establishing EoR as an external consultant, which performs independent analyses, but with the common objective of the entrepreneur, which is compliance with legislation and continuous improvement of dam safety;
- Knowing the facilities, checking in the field the current condition of the safety of the structure, and becoming aware of the main characteristics of the dams such as: construction material, instrumentation (when available), notable elevations (elevation of the crest, of the sill of the spillway system), dimension of the structure, width of the spillway, access conditions, state of conservation of the massif, abutments, overflow system, surface drainage, hydromechanical components, and other general information.

These checks are essential to identify project inconsistencies or subsequent monitoring of project preparation.

A meaningful action to be taken is the definition of crucial roles in dam safety management and the elaboration of the RACI matrix, which clearly and objectively defines the responsibilities of each member. Therefore, it is recommended that the matrix be prepared according to Appendix B of the "Application of Dam Safety Guidelines to Minning Dams" published by CDA (Canadian Dam Association, 2019), adapting it to the dam's life cycle phase and the reality of the entrepreneur in question (Canadian Dam Association, 2019).

With the definition of roles evident and the alignment between the teams, the EoR team must guide the entrepreneur to comply with the NDSP and local legislation. To this end, it must be based on the direction given by the Dam Safety Plan (DSP) required by the supervisory body of the dam in question. As all supervisory bodies must at least request a DSP, according to the requirements demanded by the NDSP, since this document will be used as an essential guide for the EoR's work plan in this research. However, it is emphasized that the EoR team must study the local legislation and verify the requirements of each DSP according to the different inspection bodies.

Thus, it is recommended that the EoR provide support to the entrepreneur in the preparation of the DSP (or the company hired by the entrepreneur to prepare the DSP) as detailed below:

- Volume I: General information

1. Identification of the entrepreneur: this activity depends only on the availability of the entrepreneur's information, such as Employer Identification Number (EIN), address, and the like;
2. Characterization of the enterprise: at this point, the EoR team must contribute with its experience so that remarkable and indispensable information for the characterization of the enterprise is exposed;
3. Technical characteristics of the Project and Construction: if there is material related to the project and construction of the dam, it is ideal that the EoR team evaluate the documents and support the preparation of this item, contributing with its experience so that it is exposed clearly the main characteristics of the project and construction, such as construction method and the like. The EoR team will verify the compatibility of the information made available in the project and that described in this item;
4. Indication of the area surrounding the facilities and their respective accesses to be protected from any permanent use or occupation: as the EoR team must have in-depth knowledge of the structure and its facilities, in this item, the team must contribute with its experience by helping to define the accesses and areas to be protected (together with the entrepreneur). The EoR should guide studies that help identify areas occupied by the formation of the reservoir lake in extreme conditions, flood spots, and the like; However, in Brazil, it is observed that the entrepreneur often has difficulty in hiring specialist dam safety companies to develop such studies and ends up using their EoR team for their execution;
5. Organizational structure, contacts of those responsible, and technical qualification of the dam safety team professionals: this is a task to be performed by the entrepreneur, but it is extremely important for the knowledge of the EoR;
6. When applicable, the indication of the entity responsible for the operational rule of the reservoir: when appropriate, the EoR must analyze the operating rules of the reservoir, to know the safety procedures and the special quotas; therefore, the team must have complete knowledge of this documentation. If the operational rules are not well defined, it is up to the EoR to direct and support the entrepreneur in the correct preparation of the document. This must have identification of the watersheds that surround the enterprise, description of the spillway system, operation details of the structures that make up the spillway system (hydraulic circuits, energy sources for maneuvers), and extreme flows supported (Agência Nacional de Águas, 2016);
7. Classification of the dam in terms of Risk Category (RC) and Associated Potential Damage: this is the crucial point of volume I of the DSP. All of the entrepreneur's obligations in relation to its structure depend on its classification. Thus, the EoR must be consulted and provide support in the preparation of these two classifications based on a technical safety inspection carried out by its team and on the analysis of all available information. It is interesting that the EoR team makes an independent classification, based on its studies, to then contribute to the entrepreneur or the company contracted to prepare the DSP.

- Volume II: Technical Documentation of the Enterprise

With the approval of Law No. 12,334 on September 20, 2010, which established the National Dam Safety Policy (NDSP), the adaptation regarding technical documentation was divided into two periods, before and after September 21, 2010.

1. For dams built before 09/21/2010: Basic and/or executive-level projects. In the absence of these projects, simplified studies regarding the geotechnical characterization of the massif, foundations and associated structures, geometric survey (topography) and hydrological/hydraulic study of the discharge structures: here is found another crucial point of the EoR's scope of work in the entrepreneur support. Often the dam does not have the basic or executive designs, or even has them but partially, or with questionable quality. Therefore, the EoR must evaluate the available material, and verify the need to prepare other studies such as an As-Is project; the EoR team must participate in the elaboration of these studies, if possible, leading them. As the EoR team will directly use the information that will be produced in these studies for the analysis of geotechnical stability and hydraulic stability, there is no one better to use other information's quality during the preparation of these studies. The EoR must monitor the development of the As-Is project and make partial revisions, mainly regarding the construction of geotechnical geological sections, hydrological studies, and the designs of the massif and spillway structures. Therefore, the final version of documents, such as As Is and similar studies, must have the EoR agreement. With this contribution of the EoR team of specialists, the base documentation for analyzing the safety of the dam will have guarantee of quality and veracity of the information;
2. For dams built after 09/21/2010: project as built (As Built): The same considerations of the previous item apply to this item since it is a key product for analyzing the safety of the dam;
3. Equipment manuals: must be included in the database that the EoR must assemble. This way, the company that prepares the DSP can consult its team to acquire this information;
4. Environmental licenses, grants, and other legal requirements: must be included in the database that the EoR must set up. This way, the company that is preparing the DSP can consult its team to acquire such documents. Also, this information is very important for the EoR to better understand the demands of the structure and the task of supporting the entrepreneur when questioned by the supervisory bodies.

- Volume III: Plans and procedures

1. Operating rule for discharge devices;
2. Maintenance planning: these two items must be part of the EoR database, the team must carry out an analysis of such information, contributing with its expertise on the subject.

If these plans and rules do not exist, the EoR team must be consulted and be part of the elaboration team, partially evaluating the materials, and the final documents must have the EoR agreement;

3. Monitoring and instrumentation plan: this plan is another key point in EoR's scope of work, since its team will use instrumentation data as a base to prepare dam stability analyses, the definition of the water table level in the compacted landfill, monitoring of rainfall data, reservoir level and other parameters that directly influence the structure's safety. Many water accumulation dams do not yet have instrumentation, so the EoR must lead the team that will produce this plan, guiding which instruments should be installed (for measuring geotechnical and hydrological variables), the position of these instruments and the frequency of data collection. In this regard, the entrepreneur depends on the experience of the EoR team;
4. Planning of dam safety inspections: as part of the EoR's scope of work is the continuous assessment of dam performance. To carry out this task, the EoR team must routinely perform technical safety inspections (for example, in mining dams, inspections are carried out monthly by the EoR team). Therefore, the team must be consulted to prepare the planning of inspections, in relation to the places to be inspected and the frequency. A good guide used to check the places to be inspected are the Conservation Status charts presented in the resolutions and ordinances of each inspection body. It is generally recommended that the permit access to the dam, the massif and the abutments is to be inspected (looking for cracks, settlements, surface surges and erosions), the condition of the surface drainage, the coating of the slopes, the presence of animals and bushes, internal drainage, reservoir (checking erosion processes, instability, and free edge), overflow system (looking for obstructions and damage to the structure), condition of instrumentation and hydromechanical components. A form must be prepared by the EoR team to be filled out at the time of the inspection, containing all these items. At the end of the inspection, the State of Conservation table applicable to the dam in question must be completed, and a report must be prepared containing this main information for registration. The frequency of inspection must be defined together with the developer's team based on the classification of the dam in terms of Risk Category (RC) and APD and the expertise of the EoR team. Dams with the worst safety condition, with high APD, high values of State of Conservation, and critical recommendations, can be inspected more frequently, like mining dams, on a monthly basis. Low-risk ones can be inspected on a quarterly or half-yearly basis;
5. Schedule of tests for hydraulic, electrical and mechanical equipment: this information must be available in the EoR database, and your team must know these procedures and the frequency of occurrence, to interpret possible changes in the instrumentation of the dam, support the entrepreneur in possible questions from the inspection bodies and the evaluation of the material, seeking points that may be adequate. When this documentation does not exist, the EoR team must be consulted for support in the elaboration.

- Volume IV Records and Controls

1. Operation records;
2. Maintenance record: must be included in the database that the EoR must set up. This way, the company preparing the DSP can consult its team to acquire this information. Still, such records are very important for EoR to better understand the behavior of the structure;
3. Monitoring and instrumentation record: if the entrepreneur does not have one, it is extremely important that the EoR team guides the preparation of this document, and the monitoring methodology since this information is essential for one of the main works of the EoR, the continuous assessment of the structure's performance;
4. Record of hydraulic, electrical, and mechanical equipment tests: must be included in the database that the EoR must set up. This way, the company preparing the DSP can consult its team to acquire this information. Still, such records are very important for EoR to better understand the behavior of the structure;
5. Dam Safety Inspection Report: this document is proposed by each inspection body regarding the minimum requirements and frequency of preparation; it is a highly complex and extensive document. Its elaboration is based on the analysis of the structure's geotechnical, structural, and hydrological/hydraulic stability. Therefore, it is recommended that it be produced by the EoR team since it has complete knowledge of the structure, all the necessary information and already performs continuous monitoring of the performance of the bus. This is a great advantage of having an EoR, and one of the actions that leads to continuous improvement, since as a result of this report, recommendations are proposed to adapt to any situation that may compromise safety. After preparing the safety inspection report, the EoR continues to guide and closely monitor whether or not the proposed recommendations are implemented, recording all actions. Also, from this document comes the dam stability statement, which is recommended to be prepared by the EoR, since this is the specialist who has the greatest knowledge of all the information mentioned so far.

- Volume V: Periodic review of dam safety

This document is proposed by each supervisory body regarding the minimum requirements and frequency of preparation. This is an extremely complex and extensive document. This document aims to carry out the entire technological review of the enterprise, evaluate all the studies developed, and apply updates in all areas. Thus, in the same way as ANM Resolution No. 95 (Brasil, 2022), the CDA (Canadian Dam Association, 2013, 2019) and the MAC (Mining Association of Canada, 2022), it is recommended that another team carry out such a study. The EoR team should serve as support, providing all the updated documents that are necessary for the review, such as topography, instrumentation data, and all the information that makes up its database, but should let another team do the periodic review in a way independent.

Thus, when EoR has access to the periodic review, productive discussions will be generated in favor of the continuous improvement of dam safety. It is very important for the EoR to integrate the teams of the entrepreneur and the contracted company, which will be involved in this study.

- • Volume VI: Emergency Action Plan

Likewise, the emergency action plan has its minimum requirement proposed by the specific inspection bodies for each type of dam, and they are also complex and extensive documents. EoR's contribution in this study is usually the supply of the necessary information contained in its database and with the contribution of its experience acquired from previous similar projects. Even so, it is important that they are involved in the document's preparation to promote the integration of the teams and verify that the information used is the most recent possible.

In this first work proposal by the EoR team, its role in leading the studies, guiding and supporting the entrepreneur and all the teams involved in the dam safety management system is clear. It is also emphasized that its focus should be on the main actions that contribute to the continuous improvement of safety, namely:

- Formation of a structured database containing all information made available by the entrepreneur, which are requested in the DSP, or necessary for studies and projects that incorporate the DSP. Such information can be constantly updated and it is up to the EoR team to record and control these documents;
- Being the centralizer of information and documents involving dam safety;
- Review all studies involving dam safety, contribute with their experience, provide guidance in order to seek improvements and verify the compatibility of the information used to prepare the studies;
- Ensure that all studies and projects related to dam safety follow the entrepreneur's safety management principles;
- Carry out the integration of the teams that make up the entrepreneur's and project's safety management and the teams hired to carry out the most diverse projects and studies;
- Verify that the dam is performing following the intentions of the entrepreneur's and project's safety management;
- Warn the developer of any critical discrepancies that directly affect the dam's safety to aid in decision-making.

DAMS THAT SERVE NDSP: SEARCH FOR CONTINUOUS SAFETY IMPROVEMENT

If the dam already has the necessary documentation to comply with the NDSP, in addition to guiding the entrepreneur in order to comply with the legislation, now the EoR team will work in order to seek the continuous improvement of the safety of the structure.

If the EoR team has not participated in the DSP elaboration process, and the entire work methodology has not yet been defined, it is necessary to apply the concepts presented at the beginning of the previous item, which show the importance of alignment with the entrepreneur's team, initial knowledge of the structure, creation of the RACI matrix, beginning of the formation of the dam safety information database and accreditation (when applicable) of the EoR.

With these concepts well defined, the EoR team should start work, creating a structured and complete database containing the following information (but not limited to these):

- Topographic survey;
- History of bathymetric surveys;
- Topographic registration of the massif;
- Topographic registration of spillover structures;
- Geological/geotechnical tests;
- Geological/geotechnical sections;
- Characterization of the massif's constructive materials;
- Complete record of all available instrumentation data;
- Series of hydrological studies and hydraulic monitoring;
- As Is project;
- As Built Project;
- Dam Break Study;
- All projects and studies that make up the DSP;
- All plans that make up the DSP;
- And all information involving the historical record of dam safety.

The EoR team must carefully study all this information, and seek a complete understanding of the structure. If any inconsistency is found, the EoR should seek out the entrepreneur's team to clarify possible doubts, and if the need for further studies to adapt the information is found, the EoR should guide the entrepreneur to carry out such action.

After studying and organizing all of the information mentioned above, the EoR team must begin its continuous monitoring of the structure's performance. Such action begins with the technical safety inspection, which must be carried out by a team composed of at least one Hydraulic Engineer and one geotechnician/geologist with experience in dams of equal complexity.

The field inspection must be carried out with a critical and rigorous eye, obeying the inspection plans and the forms prepared by the EoR team. The inspection script is evaluated on a case-by-case basis, but it is recommended that the team seek to analyze the following (but not limited to) items, recording the information in a field form:

1. Condition of access to the dam: it is important that clear criteria are defined such as "good", "regular", "poor", for the following items.

A. General conservation;

B. Conservation of slopes;

C. Conservation of drainage devices;

D. Conservation of the floor covering;

E. Specific remarks (dissertation field).

2. Condition of the foundation and abutments:

A. Crack check: inform exact location, length and opening dimensions;

B. Verification of settlements: inform the exact location, the observation of rebates, depressions;

C. Verification of surges: inform the exact location, and whether visible entrainment of solids was observed;

D. Identification of superficial erosions;

E. Verification of surface drainage (when applicable);

F. Verification of the presence of bushes and animals;

G. Verification of the internal drainage: if the drain is flooded, if it has colloids at the drain outlet, if it appears silted, with saturation around it, if there is visible entrainment of solids or if there is a change in the usual flow.

3. Reservoir:

A. Check the existence of erosion processes or instability in the surroundings;

B. Check the conditions of the freeboard;

C. Measure the limnimetric ruler at the time of inspection.

4. Spillovers:

A. Check the structural condition: look for damage that could compromise safety;

B. Observe if there are obstructions that reduce the flow capacity of the overflow system;

C. Check the functioning and structural condition of all its components (rapid channel, dissipation and restitution basin).

5. Instrumentation:

A. Check if it is possible to access the instruments;

B. Check that the instruments are installed and operating correctly.

6. Hydromechanical components:

A. Check that they are installed and operating correctly.

Finally, still during the inspection, the State of Conservation framework for the structure must be completed, as proposed by the supervisory body of the dam in question. The inspection of all points mentioned must be registered through photos with date and time. When possible, the inspection should be carried out with the aid of a drone, in order to have a better understanding of the structure, and to have images from angles that are not possible to obtain without using this device.

The form generated in this inspection must be part of a structure performance monitoring report, as well as the main observations made during the activity, and a brief photographic record (containing only key points for safety assessment).

With all the information generated by the safety inspection, the EoR team must start the performance evaluation report. It must contain the complete analysis of the instrumentation during the period in which the report is in force, the evolution of hydrological and hydraulic conditions, the analysis of the structure's flood transit, the stability analysis, the main points observed in the field on the inspection date, and other analyzes that are relevant to dam safety. It is very important that the team understands that this report is not a Regular Safety Inspection Report (RSIR), but an assessment of performance in the period in question, so the report must be clear and direct. It is suggested that it does not exceed 15 to 20 pages.

The dam performance assessment report must be conclusive and verify both the geotechnical and hydrological/hydraulic stability of the structure. At the end of this document, the most important item in monitoring the evolution of continuous safety improvement, the table of recommendations, should be prepared. Based on all the information studied, the EoR team must propose recommendations aimed at adapting any situation that may bring risks to the safety of the dam (when applicable).

It is of paramount importance that the performance evaluation report, prepared by the EoR, be appreciated by those responsible for the safety management of the dam. These must clearly understand the results of the report, and seek to meet the proposed recommendations. The process starts again with the next field inspection.

In addition to this activity, it is recommended that EoR prepare the RSIR, according to the frequency requested by the inspection body of the dam in question, and perform all the support work already highlighted.

COSTS ESTIMATE OF THE EOR TEAM AND THE PROPOSAL OF THE RATE PER CUBIC METER

As an example, a countryside city in the south region of the state of Minas Gerais will be used, which has a population estimated by the Brazilian Institute of Geography and Statistics (IBGE) for 2021 of 21,353 inhabitants. This population is exposed to a level 3 dam failure risk, considered the most critical. This situation developed as a correct safety management of the structure was not applied.

Technical monitoring of the structure's performance, carried out on an ongoing basis by an EoR team, would not allow the situation to reach such dimensions. This dam showed signs such as cracks and upwelling. It was also demonstrated that one of the routine activities of the EoR team is the verification of this type of pathology and the definition of actions to correct them.

As a team of EoR specialists would act positively to prevent this situation from developing, it is interesting to estimate the costs of such professionals. Thus, considering that professionals would be hired as independent consultants, and would be remunerated for hours worked, with a team composed of a water engineer, a geotechnician, a geologist and the registration engineer, this estimate will be presented.

The reference of the values of hours worked by the professionals came from a consultation with the following bodies: National System of Research of Costs and Indexes of Civil Construction (SINAPI), reference of prices for works of Minas Gerais (SETOP), Superintendence of Development of the Capital (SUDECAP) from Belo Horizonte – MG. Table 1 shows the average adopted for each professional, it is worth mentioning that for the registration engineer the value of the consulting engineer was considered.

It is important to note that for a single small dam that accumulates water, the entire team is expected to spend a maximum of 80 hours a month (20 hours for each professional), where their activities would be field inspection and the preparation of the performance report. These 80 hours would be for the most critical scenario, with the evolution of dam safety, the number of hours worked per professional tends to decrease, until the dam reaches stability from a safety point of view. The shows an estimated cost per cubic meter of water consumption for the EoR team's application.

This initial estimate (of maximum total cost, considering 3 senior engineers) was made by dividing the total monthly costs or remuneration and expenses with transportation, accommodation and food (which are necessary for the team to travel to the safety inspection) by the city's total consumption in cubic meters. The average value of 150 l/person/day was considered, multiplied by the total number of inhabitants, multiplied by 30 days, reaching a volume of 96,088,500 liters of water for the whole city, in a period of one month. This volume in cubic meters is 96,088.5, which divided by the total cost of the EoR team results in R$ 0.15 per cubic meter (as shown in Table 2).

In the case of a single dam serving as a water intake point for more than one municipality, the costs of 0.15 R$/m3 can be apportioned among all the municipalities that benefit from the dam. This would result in a decrease in the unit cost per cubic meter.

For the case studied in this work of a city in the south of Minas Gerais, with the dam being used only for this municipality (without apportionment among municipalities), the additional cost for a family of 4 people, considering an average water consumption of 18 m^3/month would be R$ 2.70. Considering the average tariff of 3 R$/$m^3$, the water bill for this family would go from R$ 54 (related to water consumption) to R$ 56.70, resulting in a 5% increase.

This cost can be charged as a tariff, this way each inhabitant would pay R$ 0.15 per cubic meter for the dam in their city to be monitored by a team of specialists in dam safety, with the aim of meeting international safety standards.

BENEFITS FOR DAM SAFETY

From all the information presented in this research, it is possible to highlight the main benefits for the safety of dams, with the inclusion of a recording engineer in the monitoring of water accumulation dams, as follows:

- Change in dam safety management philosophy: the very process of implanting a registration engineer in the company already shows a change in the entrepreneur's philosophy in relation to dam safety management. The definition of key roles, the elaboration of the RACI matrix establishing the responsibilities of each main agent, and the role of the EoR as an independent consultant that works with the entrepreneur to contribute to continuous improvement, is a new concept that presents itself as an international trend in the subject. security measures for mining dams, but which can and should be spread to other dams. In addition to this new management organization culture, EoR brings with it the habit of working based on good dam engineering practices, international recommendations and cutting-edge technical knowledge.

Table 1. Reference value of hours worked.

	Source			
	SINAP MG (06/2022)	**SETOP (06/2022)**	**SUDECAP (06/2022)**	**Average**
Professional	Hourly rate	Hourly rate	Hourly rate	Hourly rate
Junior Engineer	R$ 84.80	R$ 81.09	R$ 81.12	R$ 82.34
Senior Engineer	R$ 131.94	R$ 125.44	R$ 121.30	R$ 126.23
Consultante Engineer	-	-	R$ 163.19	R$ 163.19

Table 2. Costs per cubic meter of water consumption for application by the EoR team.

Professional	Remuneration (hour) (R$)	Remuneration 20 hours (R$)	Costs (transportation, accommodation, food)
Water Engineer	R$ 126.23	R$ 2524.60	R$ 1000.00
Geotechnical Engineer	R$ 126.23	R$ 2524.60	R$ 1000.00
Geologist	R$ 126.23	R$ 2524.60	R$ 1000.00
Engineer of records	R$ 163.19	R$ 3263.80	R$ 1000.00
		R$ 10,837.60	R$ 4000.00
Total			R$ 14,837.60
Population			21,353
average daily consumption (l/person/day)			150
Monthly consumption (l)			96,088,500
Monthly consumption (m^3)			96,088.5
Cost/m^3			R$ 0.15

This way, the entrepreneur comes to understand such practices and adopt them to bring more security to his enterprise, changing the entire philosophy of security management, in favor of meeting international standards;

- Integration between teams and projects that involve the entire safety management of the dam: EoR's work experience shows that in the entrepreneur there are usually several multidisciplinary teams, such as the operation, maintenance, projects, safety management and similar teams. Thus, if these teams are not in full contact and aware of each other's activities, the safety of the structure may be jeopardized. EoR's role of centralizing all information makes it have a macro view of the structure's management and allows it to bring all the teams into line, so that together they reach the common objective of continuous improvement of bus safety;
- Increased quality of studies involving the safety of dams: many times the entrepreneur, in need to comply with the legislation, hires companies to carry out the necessary studies to prepare the DSP, or specific studies requested by the supervisory body. The entrepreneur's lack of experience in dam safety means that he is unable to interpret whether the material being produced by the contractors meets the need to faithfully represent the condition of the dam and all its characteristics. The EoR is fundamental in this regard, since it will use these studies to assess the stability of the dam, and relying on its experience in the subject, it contributes to the verification, orientation and correction of these studies still in the development phase. In the end, you have a study with reliable quality and the agreement of the EoR specialist team;
- Increased quality of plans and projects involving dam safety: in the same way that the entrepreneur hires some specific studies as previously mentioned, he also hires projects such as As Is and As Built, the elaboration of plans such as instrumentation, operation and others. Many times, the entrepreneur does not necessarily have the expertise to judge whether these plans and projects are being prepared correctly, if they are representative, if in fact they are being prepared according to the objectives of achieving continuous improvement of the structure. This way, the EoR has a fundamental role in carrying out this work of verification and validation of the plans and projects, which in the end generates a product of extreme quality that is actually used for the realistic analysis of the safety of the structure;
- Continuous improvement of the structure's safety: with the frequent follow-up of the EoR team through safety inspections and the elaboration of the performance evaluation report, the structure is closely monitored by a team of specialists, which allows for the significant evolution of the structure security.

CONCLUSION

This research sought to show the evolution of Brazilian and international legislation over time, verifying that laws and regulations evolve driven by accidents of great impact and loss of human life. As the accidents related to dams occurred in Brazil and in the world, the main agencies came together to prepare increasingly judicious and rigorous materials, seeking to create guidelines for good dam engineering practices, technical safety parameters and procedures that sought to continuous improvement of the safety of structures.

In Brazil it was no different, and after the accidents of great impact, loss of human lives and international repercussions, which occurred in the mining dams, the supervisory body of these structures and their owners initiated a pioneering action to update the legislation and the culture of the management of dam safety. Both the ANM and the mining companies relied on the international recommendations proposed mainly by the agencies: CDA, MAC, ICOLD, U.S.B.R. and ANCOLD. As a result, since 2020, mining companies, especially VALE, have restructured their entire mindset regarding safety management, introducing new concepts such as EoR.

The ANM following the evolution of safety in this period realized that the application of the EoR in mining dams was extremely beneficial, and in 2022 it elaborated its new Resolution n° 95, obliging the entrepreneurs to have an EoR for dams with High APD, and not limiting it to this, the new resolution brought a series of parameters and considerations created from the recommendations of the main international organizations, but adapted for the Brazilian context. This way, ANM Resolution No. 95 can be considered as a standard to be followed for the safety of compacted embankment dams, since it is fully updated and consistent with the international concepts of good practices in dam engineering.

According to DSR for 2021 published by ANA in 2022, the problem of safety of water accumulation dams was verified, since of the 13 accidents registered in 2020, 12 were reported by inspection bodies of water resources. Therefore, the research sought to positively overflow the knowledge recently obtained by mining companies for water catchment dams.

Initially, a survey of the main Brazilian legislation was carried out, followed by a survey of the main international guidelines and parameters for dam safety. A history of the EoR application was presented, its definition in current terms, its application in the context of mining dams in Brazil, and finally a quick assessment of the current scenario of water accumulation dams in Brazil.

Based on this collection of information, a work plan was proposed for an EoR team adapted for water accumulation dams, separating into two strategies: in the search for compliance with the NDSP, and after that, in the search for continuous improvement of the structure. A cost estimate for the application of an EoR team in a small water catchment dam in the south of Minas Gerais was also evaluated, showing an initial value of R$ 0.15 per cubic meter of consumed water. Finally, the main benefits of applying the EoR were listed, highlighting: Change in the philosophy of dam safety management; Integration between teams and projects that involve all dam safety management; Increased quality of studies involving dam safety; Increased quality of plans and projects involving dam safety and Continuous improvement of structure safety. Concluding, this way, all the objectives proposed for this research.

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