CALCULATION AND IMPLEMENTATION OF BOTTOM DISCHARGE IN DAMS: THEORETICAL AND PRACTICAL GUIDE

CÁLCULO E IMPLEMENTAÇÃO DA DESCARGA DE FUNDO EM BARRAGENS: GUIA TEÓRICO E PRÁTICO

CÁLCULO E IMPLEMENTACIÓN DEL DESCARGA DE FONDO EN PRESAS: GUÍA TEÓRICA Y PRÁCTICA

https://doi.org/10.56238/sevened2026.008-167

Jonathan Joaquim de Morais[1], Girlene Figueiredo Maciel[2], Rodrigo Martins Ribeiro[3], Mateus Chagas dos Santos[4], Amanda da Rosa Lena[5], Fernán Enrique Vergara Figueroa[6], Joel Carlos Zukowski Junior[7]

ABSTRACT

Bottom flushing operates by allowing water stored in the reservoir to be released through structures located at the base of the dam. It is a structure designed to control the controlled release of water from the reservoir, ensuring the stability of the dam and controlling water levels. This component is essential in damming to ensure the structural safety of the dam and the efficient management of water resources. This article offers an integrated approach to the calculation and implementation of bottom discharges in dams, with a focus on inverted siphons, based on hydrological and normative studies. Combining theory, legislation and practice, the aim is to provide a practical and complete guide that covers everything from the theoretical foundations to the execution of the installation. The objective is to simplify the process for engineers and technicians, ensuring the safe and efficient operation of dams, in addition to meeting environmental and regulatory requirements.

---

[1] Master's Student in Environmental Engineering. Universidade Federal do Tocantins (UFT).
E-mail: jonathanjm.eng.c@gmail.com Orcid: https://orcid.org/0009-0008-2362-0962
Lattes: http://lattes.cnpq.br/1804331466956569

[2] Dr. in Natural Resources. Universidade Federal de Campina Grande (UFCG). E-mail: maciel@uft.edu.br
Orcid: https://orcid.org/0000-0001-9217-3731 Lattes: http://lattes.cnpq.br/9377355626452682

[3] Master's Student in Environmental Engineering. Universidade Federal do Tocantins (UFT).
E-mail: rodrigo@pleiade.eng.br Orcid: https://orcid.org/0009-0006-0075-4859
Lattes: http://lattes.cnpq.br/0873059368885932

[4] Master's Student in Environmental Engineering. Universidade Federal do Tocantins (UFT).
E-mail: chagasmateus2000@gmail.com Orcid: https://orcid.org/0009-0004-1900-8384
Lattes: https://lattes.cnpq.br/5594405175252978

[5] Master's Student in Environmental Engineering. Universidade Federal do Tocantins (UFT).
E-mail: amandadarosalena@gmail.com Orcid: https://orcid.org/0009-0005-1826-245X
Lattes: http://lattes.cnpq.br/1289596665086548

[6] Dr. in Environmental Technology and Water Resources. Universidade de Brasília (UnB).
E-mail: fernan@uft.edu.br Orcid: https://orcid.org/0000-0003-1643-2564
Lattes: http://lattes.cnpq.br/4356137674634041

[7] Dr. in Energy Systems Planning. Universidade Estadual de Campinas (UNICAMP).
E-mail: zukowski@uft.edu.br Orcid: https://orcid.org/0000-0002-5070-5274
Lattes: http://lattes.cnpq.br/0062084279231594

Keywords: Bottom Discharge. Dams. Inverted Siphon. Hydrological Calculation. Dam Safety.

RESUMO

A descarga de fundo em barragens opera permitindo que a água armazenada no reservatório seja liberada por meio de estruturas localizadas na base da barragem. É uma estrutura projetada para controlar a liberação controlada de água do reservatório, garantindo a estabilidade da barragem e controlando os níveis de água. Essa componente é essencial em represamento para garantir a segurança estrutural da barragem e a gestão eficiente dos recursos hídricos. Este artigo oferece uma abordagem integrada para o cálculo e implementação de descargas de fundo em barragens, com foco em sifões invertidos, baseando-se em estudos hidrológicos e normativos. Combinando teoria, legislação e prática, busca-se fornecer um guia prático que engloba desde os fundamentos teóricos até a execução da instalação. O objetivo é simplificar o processo para engenheiros e técnicos, garantindo a operação segura e eficiente das barragens, além de atender às exigências ambientais e regulatórias.

Palavras-chave: Descarga de Fundo. Barragens. Sifão Invertido. Cálculo Hidrológico. Segurança de Barragens.

RESUMEN

La descarga de fondo en presas funciona permitiendo la liberación del agua almacenada en el embalse a través de estructuras ubicadas en la base. Esta estructura está diseñada para controlar la liberación controlada de agua del embalse, garantizando la estabilidad de la presa y regulando los niveles de agua. Este componente es esencial en los embalses para garantizar la seguridad estructural de la presa y la gestión eficiente de los recursos hídricos. Este artículo ofrece un enfoque integral para el cálculo e implementación de la descarga de fondo en presas, centrándose en los sifones invertidos, basándose en estudios hidrológicos y regulatorios. Combinando teoría, legislación y práctica, el objetivo es proporcionar una guía práctica que abarca desde los fundamentos teóricos hasta la ejecución de la instalación. El objetivo es simplificar el proceso para ingenieros y técnicos, garantizando la operación segura y eficiente de las presas, además de cumplir con los requisitos ambientales y regulatorios.

Palabras clave: Descarga de Fondo. Presas. Sifón Invertido. Cálculo Hidrológico. Seguridad de Presas.

1 INTRODUCTION

Dams are closely linked to the social and scientific development of humanity. These are structures that can influence both the area around them and their rural and urban surroundings. For millennia, human beings have recognized the need to build reservoirs in order to contain surface waters for an individual or collective good (Rocha et al., 2024).

The bottom discharge system is used to control the water level in dams, with the aim of mitigating risks related to floods, ruptures and overflows. It consists of a mechanism that allows the controlled release of accumulated water, performing a specific function in the operation of dams, especially large ones (Silva et al., 2016). In specific contexts, such as in small-port dams or in places with water scarcity conditions, the use of bottom discharge can be considered dispensable (Aion, 2018).

Despite its importance, the application of bottom discharge is not yet widespread. In part, this is due to the risks associated with the operation, such as excessive vibrations in the gates, cavitation, and leaks. These factors can significantly impact the costs of building and maintaining the dam, as the device requires constant inspection and care. Due to the wear generated by cavitation and abrasion, Rocha et al. (2018) suggest that the continuous use of bottom discharge should be avoided to prevent structural damage.

An example in Brazil is the Pedra do Cavalo Dam, located in Bahia, considered one of the most important, as it is responsible for the water supply of the capital Salvador and its metropolitan region. Initially, the dam had a bottom discharge to help control the filling of the reservoir. However, after the water level exceeded the spillway level, the device was deactivated and ceased to be used.

On the other hand, other countries, such as the United States, Spain and Switzerland, have strengthened their dam safety legislation, requiring the inclusion of bottom discharges in new constructions and, in the case of Spain, even in existing dams.

This balanced approach between operational benefits and technical challenges has been debated in different contexts around the world, highlighting the importance of adapting best practices according to the particularities of each dam and region. In Brazil, although there is still no specific legislation on the subject, the National Water Agency (ANA) already recommends the implementation of this device as an essential practice for the safety and proper functioning of dams.

However, the operation of dams in Brazil still faces numerous challenges, especially with regard to the correct functioning of bottom discharges. These structures serve to ensure the safety, maintenance and efficient operation of the dams. However, it is estimated that more than 90% of the dams in the country have problems related to the management of this system, making it urgent to adopt practical and standardized methods.

Thus, bottom discharge in dams performs several essential functions, such as emptying the reservoir, both for scheduled maintenance and in emergency situations, in addition to allowing the removal of accumulated sediments and the renewal of water. This device is also crucial for maintaining regular flow in the river downstream, ensuring that water continues to flow through the dam structures, which contributes to the preservation of the local ecosystem.

This article aims to provide a guide for the calculation and implementation of bottom flush systems, focusing on the use of inverted siphons, an economical and easy-to-implement solution. The methodology is based on theoretical and practical studies, applicable legislation and technical standards such as ABNT NBR 12214 (1992) and ABNT NBR (2017), as well as practical examples applied to dams in Brazil. The central proposal is to ensure that, through a single source, the reader can understand the theoretical principles, follow the calculation formulas and apply the practical guidelines for installation, providing a complete solution for water management in dams.

The methodology adopted in this study was based on a bibliographic survey of academic papers, legislation and project guides on the use of bottom discharge devices in dams. As described by Manzo (1986), the bibliographic survey offers means to define and solve not only problems that are already known, but also to explore new areas where the problems have not sufficiently crystallized. This method allows researchers to support their analyses with parallel data and expand the reach of their findings.

During the research, various types of sources were consulted, such as scientific articles, technical standards, and national and international legislation. The studies cover several countries, including Brazil, India, Spain, the United States, Canada, Switzerland and the United Kingdom, which contributed to a global view on the application and challenges of implementing bottom discharges. In addition, manuals and technical bulletins from institutions such as the National Water Agency (ANA), which provide guidelines and practical recommendations on the installation and maintenance of these devices, were analyzed.

This method also included consulting ABNT standards, such as ABNT NBR 12214 (1992) and ABNT NBR 13028 (2017), which guide the design and construction of water control systems, ensuring that technical parameters are aligned with international best practices.

2 THEORETICAL FOUNDATIONS

The theoretical and methodological basis of this article follows the studies of Tomaz (2012), whose works are extremely recognized in the area of water resources and dam management. Its contributions are based on the methodologies for calculating bottom discharges in dams, which are essential for the maintenance of the structure and environmental preservation. These devices ensure the proper flow of water and prevent the accumulation of sediments, promoting the constant renewal of downstream water, in addition to controlling the volume of water in the reservoirs.

The bottom discharge is an important structure for the safety of dams, as it makes it possible to control the flow of water released downstream, both in normal operating situations and in emergencies, such as emptying the reservoir. In addition, it plays an important role in the preservation of aquatic ecosystems, ensuring the maintenance of the minimum ecological flow, as required by environmental standards (Rocha et al., 2018; Paulo et al., 2021).

Bottom discharges can be renewed in different ways, depending on the type of dam (earth or concrete) and its main function, such as supply, storage or energy generation. These variables directly influence the choice of the most compromised solution for bottom discharge. The main types include valve, pipe and siphon controlled discharges. The use of inverted siphon is especially common in earth dams that do not have a built-in bottom discharge, or where an existing discharge does not meet the ecological flow required for the region's water demand (Silva et al., 2016).

The inverted siphon uses the principle of atmospheric pressure to move water from a higher to a lower height, without the need for pumps. The water is conducted through an inverted "U" shaped tube, where the pressure at the highest point of the siphon is lower than the atmospheric, generating a continuous flow. This type of system is widely used in earth dams that do not have a built-in bottom discharge, being installed externally, which facilitates its implementation and reduces costs (Dini; Tabesh, 2014; Campos, 2020).

In addition, the use of inverted siphons is an efficient solution, especially when the region's water demand and the need for water renewal are not met by existing discharges. In projects that require greater operational flexibility and control over water flow, the siphon stands out as a practical and low-cost alternative. It allows for minimal intervention in the existing dam structure, while ensuring proper flow control and maintaining the desired water level in the reservoir (Abreu et al., 2018).

The implementation of siphon bottom discharges, especially in earth dams, also helps in the removal of sediments accumulated at the bottom of the reservoir, which is essential to preserve the reservoir's capacity and prevent siltation. This type of solution is particularly useful in regions where water level control is crucial to avoid problems of operation and environmental preservation (Campos, 2019; Abreu, 2019).

The structural and ecological importance of bottom discharges is widely highlighted in studies such as that by Paulo et al. (2021), which examine the effectiveness of bottom discharge in controlling water level and removing accumulated sediments. In addition, the devices act on the safety of the dam, avoiding hydraulic overload that can compromise structural integrity.

From a hydrodynamic point of view, the most used formulas for calculating flow include the Manning and Hazen-Williams equations. The Manning research is applied to determine the flow rate as a function of the roughness of the material, the ceramic diameter and the flow orientation, and is widely used in gravitational systems. On the other hand, Hazen-Williams engineering is used to calculate the pressure loss in hydraulic systems, whether settlement or gravity, since both involve pressurization, whether natural or artificial. The proper application of these formulas is essential for the correct sizing and operational efficiency of the flushing system (Silva et al., 2016).

3 REGULATIONS AND APPLICABLE LEGISLATION

In Brazil, the management and standardization of dam safety is governed by a series of laws and decrees that aim to ensure the protection of water resources and the safety of the infrastructures involved. State Decree No. 2,432/2005, of the State of Tocantins, establishes specific rules for the granting of the right to use water resources, with a focus on run-of-the-river dams. This decree defines that a minimum flow to guarantee ecological flow must be 25%, a measure that aims to maintain local biodiversity and minimize negative environmental impacts (Tocantins, 2005). This regulation is essential for the implementation of bottom discharge systems, ensuring that the use of water resources is sustainable and safe.

In addition to state standards, Federal Law No. 12,334/2010, which deals with the National Dam Safety Policy (PNSB), is a regulatory framework that imposes clear guidelines on the construction, operation, monitoring, and maintenance of dams in Brazil. This legislation was created in response to several incidents that occurred in Brazilian dams, with the objective of ensuring that all dams meet minimum safety standards, not only structural, but also environmental (BRASIL, 2010). The Law was complemented by Law No. 14,066/2020, which increased the loss in the control of dam safety after tragedies such as Brumadinho and Mariana. The adoption of bottom discharges in this context is a practical response to the requirements imposed by this legislation, allowing dam operators to comply with the established requirements.

Another relevant standard for the planning and implementation of bottom discharges is ABNT NBR 13028 (2017), which provides technical guidelines for the construction and maintenance of earth dams. This standard covers everything from the initial design to the continuous monitoring of the structure, considering the environmental impacts and technical requirements to ensure the safety of the work (ABNT, 2017). The use of bottom discharge systems is especially important in earth dams, as it allows the removal of accumulated sediments and the control of the water level, avoiding structural overloads.

CONAMA Resolution No. 344/2004 also deserves to be highlighted, as it establishes minimum procedures for the evaluation of sediments to be dredged. These procedures are directly applicable to the use of bottom discharge systems, as they ensure that sediment removal is carried out in a safe manner and in compliance with environmental guidelines (CONAMA, 2004). In the context of dam operation, this resolution complements the other regulations, reinforcing the importance of maintaining strict control over sediment management.

In addition, the technical manual of the National Water Agency (ANA) recommends the adoption of bottom discharge systems as an efficient measure for the management of water resources in dams (Abreu et al., 2018). ANA, as a regulatory body, works in conjunction with state and federal regulations to ensure that all dams in Brazil are operated in accordance with the best practices of sustainability and water security.

In comparative terms, Brazil is still in the adaptation phase to comply with the requirements established in stricter international legislation, such as Spanish legislation, which requires that all new dams, and many existing ones, incorporate bottom discharge systems to maintain water and environmental security (Pereira, 2019). In the United States, dam management is widely regulated, with legislation disabling bottom discharge systems in all structures, especially in regions prone to drought and extreme water flow variations (Maia, 2023).

Thus, the Brazilian regulations on dam safety, and in particular on bottom discharges, are well established, but require constant adaptation and updating. The integration between state and federal legislation, as well as the incorporation of international best practices, is essential to ensure that dams in Brazil operate in a safe and sustainable manner. The alignment with ABNT NBR 12214 (1992), which addresses the sizing of water pumping systems, also complements safety standards to ensure that the flow of water is properly controlled (ABNT, 1992).

4 CALCULATION METHODOLOGY FOR INVERTED SIPHONS

Calculating the flow rate of a bottom discharge involves the application of hydrodynamic equations that consider factors such as the diameter of the pipe, the slope, and the roughness of the material used. The Manning equation, for example, is widely used to estimate water flow in inverted siphon systems, while the Hazen-Williams equation provides accurate estimates of head loss in pressurized systems (Silva et al., 2016).

These calculations are essential to ensure that the bottom discharge system operates within the safety and efficiency limits established by national and international regulations (Campos et al., 2019). According to Silva et al. (2016), the correct application of these equations allows the structure to be sized adequately, ensuring that the bottom discharge meets the flow demands and operates without compromising the integrity of the dam.

The methodology used in this article is based on the studies of Tomaz (2012). To calculate the flow (Q) of the water flowing through the bottom discharge, the Manning and Hazen-Williams equations are used. These equations consider the pipe diameter (D), the slope (S), and the roughness of the pipe material (n).

The Manning Equation is widely used to calculate the flow rate (Q) in open channels and partially filled pipes. It considers the roughness coefficient of the material (n), the hydraulic radius (R) and the flow slope (S).

$$Q = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2} \tag{1}$$

Where:

- What is the flow rate, m3/s
- A is the wet area, m2
- R is the hydraulic radius, m
- S is the slope, m/m

The Hazen-Williams Equation is applied to determine the pressure loss in full pipes.

$$Q=C\times D2,63\times S0,54 \tag{2}$$

Where:

- Q is the flow rate in m3/s
- D is the diameter in meters
- S is the unit head loss in meters per meter of pipe

- C is the coefficient that depends on the nature of the material used and the condition of the internal walls.

These equations make it possible to measure the volume of water to be released by the bottom discharge, ensuring safe and efficient operation (Campos et al., 2019; Tomaz, 2012). These formulas allow you to calculate the flow capacity and ensure that the system is correctly sized.

According to ASCE, 1992, the siphon for rainwater conduction should have a maximum speed of 1.8 m/s, and if there are abrasive materials, the speed should be less than 3 m/s. Also according to ASCE, 1992, the pressure loss can be calculated using Manning's proposal, which is as follows:

$$HF = \frac{19{,}5\, n^2 \times L \times V^2}{R^{4/3} \times 2 \times g} \qquad (3)$$

Being:

- HF = Pressure Drop (m)
- n = Manning roughness
- L = Circumference Length (m)
- V = speed (m/s)
- R = hydraulic radius (m)
- g = 9.81 m/s²

Load losses must be calculated in curves, contractions, expansions, as well as in inputs and outputs.

We know the flow rate, we need to size the diameter of the siphon using the Darcy-Weisbach formulation or the Hazen-Williams formula. For pipes with a diameter of less than 50 mm, other formulas can be used, such as Flamant's. However, the great advantage of the Hazen–Williams formula is that it facilitates the choice of the roughness coefficient C, which is easier to estimate compared to the K values used in the Darcy–Weisbach formula. The formula for the pressure loss per meter (J) is given by:

$$j = \frac{10{,}643 \times Q^{1{,}85}}{C^{1{,}85} \times D^{4{,}87}} \qquad (4)$$

Where:

- J is the pressure loss per meter (m/m);

- Q is the flow rate in cubic meters per second (m^3/s);
- C is the roughness coefficient of the pipe according to Hazen-Williams;
- D is the diameter of the pipe in meters.

Table 1 lists some values for the Hazen-Williams roughness coefficient.

Table 1

Hazen–Williams roughness coefficient.

Material	Roughness coefficient C
New cast iron	130
Cement-coated cast iron	130
New steel	120
Steel in use	90
PVC	150
Cast iron in use	90

Source: Adapted from Dini and Tabesh (2014)

The formula for calculating the pressure drop in the tube section of length L is:

$$h_f = J \times L \tag{5}$$

Being:

- hf = loss of pressure in the stretch, in meters of water column;
- J = unit loss obtained by formula (4);
- L = Pipe length (m).

The speed in the Hazen–Williams formula is given by:

$$V = 0{,}355 \times C \times D^{0{,}63} \times J^{0{,}54} \tag{6}$$

Being:

- V = velocity (m/s);
- C = Hazen-Williams roughness coefficient (dimensionless);
- D = diameter (m);
- J = unit head loss (m/m).

The Hazen–Williams formula is applicable for high speeds, but is questionable for C values below 100, and its use is limited to speeds less than 3 m/s.

Mott (1994) presented a Hazen-Williams formula for any section, using the hydraulic radius. For units of the International System (SI), there are:

$$V = 0{,}85 \times C \times R^{0{,}63} \times S^{0{,}54} \quad (7)$$

$$hfL = L\left[\frac{Q}{0{,}85 \times A \times C \times R^{0{,}63} \times S^{0{,}54}}\right] \quad (8)$$

Being:

- V = average cross-section velocity (m/s);
- C = Hazen-Williams coefficient (varies between 100 and 140 for concrete);
- R = hydraulic radius (m) = A/P.

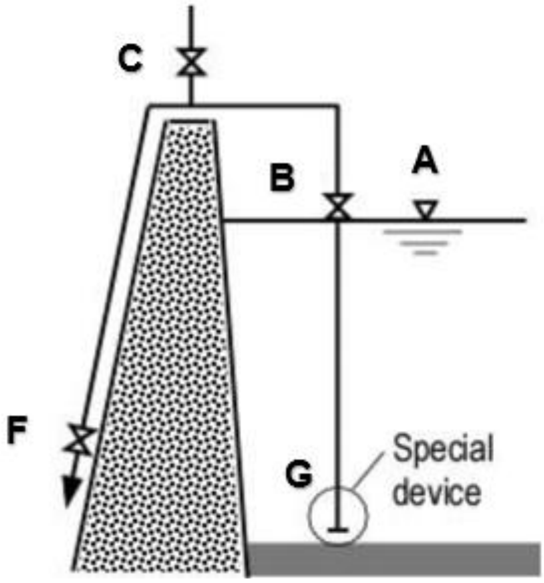
Analyzing a normal siphon, i.e., the siphon using Mott, 1994. Bernoulli's equation can be used, initially assuming that there is no pressure loss, although it can be easily used when considering distributed and localized load losses. If there are no localized and distributed cargo losses, we will have:

$$\frac{p}{y} + Z + \frac{V^2}{2g} = constante \quad (9)$$

However, localized and distributed cargo losses must be considered. Then, the calculation and application of Bernoulli's equation is detailed to specific points in the siphon system, using data from a bus. For this, values such as flow, suction length and localized losses are considered.

Figure 1

Siphoning in dam



Source: Tomaz (2012)

4.1 FIRST

The first step is to apply Bernoulli's equation to points A and F in Figure 1.

$$\frac{p_A}{\gamma} + Z_A + \frac{V_A^2}{2g} = \frac{p_F}{\gamma} + Z_F + \frac{V_F^2}{2g} + hf_{AF} + \Sigma ks \times \frac{V_F^2}{2g} \tag{10}$$

Being:

- HF = distributed head loss (m)
- Σks = loss of localized charges (m)$\frac{V_F^2}{2g}$

4.2 SECOND

The second step is to apply Bernoulli's equation to points A and B in Figure 1.

$$\frac{p_A}{\gamma} + Z_A + \frac{V_A^2}{2g} = \frac{p_B}{\gamma} + Z_B + \frac{V_B^2}{2g} + hf_{AB} + \Sigma ks \times \frac{V_B^2}{2g} \tag{11}$$

4.3 THIRD

The third step is to apply Bernoulli's equation to points A and C in Figure 1.

$$\frac{p_A}{\gamma} + Z_A + \frac{V_A^2}{2g} = \frac{p_C}{\gamma} + Z_C + \frac{V_C^2}{2g} + hf_{AC} + \Sigma ks \times \frac{V_C^2}{2g} \tag{12}$$

The proper implementation of these steps will result in the regularization of the Earth Dam in accordance with the requirements of the current environmental agency of your state. It is worth mentioning that the flow required for the system may vary according to the region, and it is therefore essential to monitor civil and environmental engineering for the correct sizing of the project and its precise execution.

5 EXECUTION AND INSTALLATION

After the calculations are completed, it is time to install the bottom discharge. Correctly following these guidelines ensures that the dam operates safely and efficiently, preventing structural failures and mitigating environmental risks. The correct and detailed instruction of the steps provided facilitates the process and ensures that the reader, by following the instructions, can execute the solution successfully (Tomaz, 2012).

To address the installation and execution of bottom discharge systems in dams, it is necessary to have thorough planning that is based on technical and normative guidelines that are already conditional (ABNT, 2017). These systems play an important role in the operation of dams, as they facilitate the control of water flow, the removal of sediments and the preservation of structural safety (CONAMA, 2004).

The successful execution of these systems cannot be achieved in a superficial way; on the contrary, it requires a detailed understanding of the processes involved, the materials used, and the tools used for the system to work optimally and flawlessly (Tomaz, 2012).

The process of installing a bottom flush system begins with the choice of the appropriate materials. According to Tomaz (2012), PVC pipes are often recommended for their corrosion resistance and ease of application. These pipes must be selected based on the ceramic calculation in advance, considering the pressure and flow of water that will be chosen by the system. In addition, ball valves and PVC connectors are widely used to ensure system flexibility, while sieve foot valves play a critical role in preventing clogging, allowing controlled passage of water and preventing coarse sediment from entering the system (Tomaz, 2012; Abreu et al., 2018).

Land preparation is another step in the installation process, involving cleaning and excavation to accommodate the pipes. This requires precision, as the inverted siphon system must be installed in phases and with the proper specification, in order to ensure the continuous flow of water. Measuring ground levels is an essential practice to avoid installation errors. The use of hoses with water, as described by Silva et al. (2016), is an effective method for measuring the ground level and adjusting the orientation of the orientation. This method, in addition to being simple, offers enough solutions to ensure that the siphon is positioned correctly, preventing future problems such as clogs and leaks.

During the installation phase, the assembly of the inverted siphon system must strictly follow the technical guidelines. All components, including pipes and valves, must be assembled precisely, complying with previously calculated pressure and flow specifications. The entrepreneur's manual (2024) details the importance of proper cuts in pipes, using care to ensure that the parts are perfectly aligned and connected. Any misalignment or failure in the arrangement can result in leaks, compromising the efficiency of the system. In addition, a constant check during installation is recommended to ensure that all installations are well adjusted and fixed.

After the system has been assembled, it is essential to conduct efficiency tests, especially to check the water flow through the bottom discharge system. The "bucket test" is widely recommended in manuals and studies on bottom discharge (Paulo et al., 2021), and consists of measuring the volume of water drained during a given period and comparing it with the values previously calculated. This method, while simple, is effective in verifying that the system is working as intended. For larger or more complex systems, the use of digital flow meters can be a more accurate alternative, providing real-time data on system performance (Dinini; Tabesh, 2014).

Keeping the bottom flush system in full working order depends on a regular maintenance routine. Sediment buildup in pipes can compromise system efficiency, especially in dams where sediment removal is a constant concern. Periodic cleaning is therefore essential to prevent clogging and ensure water flow (Rocha et al., 2018). In addition, inspecting connections and checking for possible leaks should also be part of the maintenance schedule. Standards such as ABNT NBR 16496:2016 provide detailed guidance on how to monitor and operate dam systems, ensuring that the correct procedures are followed to maintain the longevity and efficiency of the system (ABNT, 2016).

International experience also offers valuable examples on the improvement and maintenance of bottom discharge systems. Countries such as the United States and Spain have strict standards that exclude the installation of bottom discharge devices in new dams and even the adaptation of existing dams to incorporate these systems (Maia, 2023). These legislations reflect the importance of ensuring the structural safety of dams, as well as contributing to environmental protection by ensuring that water flow and sediment removal are managed effectively. In Brazil, although there is still no specific federal law for bottom discharge, manuals and guidelines from the National Water Agency (ANA) already recommend the adoption of such systems, based on international examples (Brasil, 2010; CONAMA, 2004).

The process of installing and maintaining bottom discharge systems requires careful planning and constant observation of environmental conditions, such as the variation in the water level and the amount of sediment accumulated in the reservoir. Periodic adjustments may be necessary to ensure that the system continues to function efficiently over time. More advanced systems, such as those incorporating monitoring sensors, can facilitate this process by allowing operators to make automatic adjustments based on real-time data (Paulo et al., 2021).

Ultimately, the installation of a well-planned and preserved bottom discharge system provides significant benefits, both in terms of structural safety and environmental preservation. Efficient sediment removal avoids the accumulation of materials that could compromise the integrity of the dam, while adequate control of water flow contributes to the sustainability of riparian ecosystems (Tomaz, 2012). The experience accumulated in other countries shows that the adoption of similar practices in Brazil could bring innovative advances to the sector, especially with regard to dam safety and water resources management.

In Brazil, the current scenario is promising, with the growing adoption of technical guidelines for the installation and maintenance of bottom discharge systems. As regulations become more stringent and practices align with international standards, the country is expected to advance in the efficient management of its dams, minimizing the risks and maximizing the benefits of these systems (Silva et al., 2016; Rocha et al., 2018).

Therefore, the execution of bottom discharge systems in dams is not just a technical issue; It also involves a commitment to safety, environmental preservation and compliance with standards and regulations. The combination of theory and practice described in this article provides a comprehensive guide for the implementation of these systems, offering an efficient and sustainable solution for the safe operation of dams in Brazil and other international contexts.

6 CONCLUSION

From the results obtained, it is possible to present a complete and integrated view on how to solve the problems of bottom discharge in dams. Through the combination of theory and practice, the reader is offered a guide that eliminates the need to resort to multiple sources, concentrating in a single document all the information and tools necessary for proper calculation and installation. The ultimate goal is to ensure that, by following this step-by-step, the professional can effectively meet the regulatory and operational requirements of dams in Brazil.

Thus, the importance of an efficient bottom discharge system cannot be underestimated. It plays a vital role in the safe operation of dams, helping to prevent sediment build-up and ensuring controlled runoff of water. A well-implemented system also contributes to environmental sustainability by preserving the ecosystems downstream of the dam.

The results provide a significant contribution to the implementation of practical and normative solutions in the context of Brazilian dams. By aligning the methodologies described with national and international technical standards, such as those of ABNT, it provides a guide that complies with current legislation, while facilitating the operation and maintenance of these structures.

In addition, the practices described here are widely applicable to other international contexts, as evidenced by countries such as the United States and Spain, which have already adopted stringent regulations on the use of bottom discharge devices. The adoption of similar solutions in other countries reinforces the need to implement well-planned and committed devices, ensuring the structural integrity of dams and contributing to more sustainable water management at a global level.

REFERENCES

Abreu, A. S., & outros. (2018). Análise preliminar do alcance de remoção de sedimentos por descarregadores de fundo em pequenas barragens [Anais]. Congreso Latinoamericano de Hidráulica, Buenos Aires, Argentina. Instituto Nacional del Agua. https://lume.ufrgs.br/bitstream/handle/10183/184432/001078959.pdf?sequence=1

Abreu, A. S. (2019). Análise experimental em modelo físico de estruturas hidráulicas de remoção de sedimentos em barragens: Descarregadores de fundo [Dissertação de mestrado, Universidade Federal de Pelotas]. Lume. https://lume.ufrgs.br/handle/10183/197881

Ainon, M. (2018). Remoção de sedimentos em reservatórios de barragens de usinas hidrelétricas através de descarga de fundo [Monografia de graduação, Universidade Federal do Rio Grande do Sul]. Lume. https://lume.ufrgs.br/handle/10183/184604

Associação Brasileira de Normas Técnicas. (1992). ABNT NBR 12214: Projeto de sistemas de bombeamento de água. https://www.abnt.org.br

Associação Brasileira de Normas Técnicas. (2017). ABNT NBR 13028: Construção e manutenção de barragens de terra. https://www.abnt.org.br

Associação Brasileira de Normas Técnicas. (2007). ABNT NBR 15514: Dimensionamento hidráulico de sistemas de drenagem. https://www.abnt.org.br

Associação Brasileira de Normas Técnicas. (2016). ABNT NBR 16496: Monitoramento de barragens de rejeitos. https://www.abnt.org.br

Associação Brasileira de Normas Técnicas. (2015). ABNT NBR 5419: Proteção contra descargas atmosféricas. https://www.abnt.org.br

Brasil. (2010). Lei nº 12.334, de 20 de setembro de 2010. Dispõe sobre a Política Nacional de Segurança de Barragens. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12334.htm

Campos, B. S. (2020). Análise do comportamento dos coeficientes de descarga em sistemas de sifão. Anais da ABRHidro. https://www.abrhidro.org.br/anais

Campos, E., & outros. (2019). Experimental study of pressure flushing of non-cohesive sediment through slotted pipe bottom outlet. Water Resources Management. https://doi.org/10.1007/s11269-017-177

Conselho Nacional do Meio Ambiente. (2004). Resolução nº 344, de 25 de março de 2004. Estabelece diretrizes e procedimentos mínimos para a avaliação de sedimentos a serem dragados. https://www.mma.gov.br/port/conama/legiabre.cfm?codlegi=432

Dini, M., & Tabesh, M. (2014). A new method for simultaneous calibration of demand pattern and Hazen-Williams coefficients in water distribution systems. Water Resources Management, 28, 2021–2034.

Maia, K. T. (2023). Segurança de barragens: Um estudo da legislação ambiental. Portal de Trabalhos Acadêmicos, 15(2). https://revistas.faculdadedamas.edu.br/index.php/academico/article/view/3050

Manzo, A. J., & outros. (1971). Manual para la preparación de monografías: Una guía para presentar informes y tesis. Humanitas.

Paulo, F. A., & outros. (2021). Experimental study of pressure flushing of non-cohesive sediment through slotted pipe bottom outlet. Revista Brasileira de Recursos Hídricos, 26, Article e01. https://www.scielo.br/j/rbrh/a/Rm7zgxsQBQSKwZP4PFkXVNK/

Pereira, L. F. (2019). Segurança de barragens no Brasil: Um breve comparativo com a legislação internacional e análise da influência da cobertura do solo de APPs sobre manchas de inundação: Estudo de caso da PCH Pedra Furada em Ribeirão/PE [Dissertação de mestrado não publicada]. Universidade Estadual Paulista "Júlio de Mesquita Filho".

Rocha, V. O. D., & outros. (2018). Importância da descarga de fundo em barragens [Anais]. XIV Simpósio de Recursos Hídricos do Nordeste, Maceió, AL, Brasil. https://anais.abrhidro.org.br/works/4635

Silva, J. C., & outros. (2016). Remoção de sedimentos em reservatórios de barragens de usinas hidrelétricas através de descarga de fundo. Universidade Federal do Rio Grande do Sul. http://hdl.handle.net/10183/154645

Silva, L. C. (2023). Avaliação de risco de acidentes em barragens de contenção de água: Uma contribuição para a gestão de segurança de barragens no Brasil [Dissertação de mestrado, Universidade do Estado do Rio de Janeiro]. BDTD. https://www.bdtd.uerj.br:8443/handle/1/20290

Tocantins. (2005). Decreto nº 2.432, de 6 de junho de 2005. Regulamenta a outorga do direito de uso de recursos hídricos. https://site.tocantins.gov.br

Tomaz, P. (2012). Sifão. In Curso de manejo de águas pluviais. Navegas.