BASIS FOR DAM SAFETY LEVEL ASSESSMENT IN HANOI CITY BASED ON CURRENT DATA STATUS OF EARTH DAM MONITORING

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Abstract: *According to general assessments in the world as well as in Vietnam, one of the main causes of dam failures is seepage and structural instability. Monitoring equipment arranged in the dam body plays an important role in providing information to help operations managers early identify risks and have timely treatment plans. However, dams in Hanoi city have only installed water level monitoring equipment and a few reservoirs have installed saturation line monitoring equipment in the dam body. To make the most of existing monitoring data, the article presents the results of assessing the level of dam safety in the city according to the current status of earth dam monitoring data for 2 typical cases, including: (i) The project is installed with water level monitoring equipment. Through dam inspection, seepage appears on the downstream slope of the dam, outside the drainage equipment; (ii) The project is synchronously installed with water level monitoring equipment and saturation line monitoring equipment in the dam body.*
Keywords: *Dam monitoring, dam safety, dam safety level, Hanoi reservoir dam.*

1. INTRODUCTION

According to a review by the General Department of Irrigation (now the Irrigation Department) [1], 7,342 irrigation dams and reservoirs have been built in Vietnam. Among them, earth dams are the most common; in Hanoi, 117 dams are all earthen. Due to the water permeability and deformability of soil, the problems of seepage and deformation of the dam need to be considered in the design as well as during the operation and exploitation of the project.

According to Cheng Cuiyun and colleagues [2], there are 5 common causes of dam failures in China, including: (1) Causes of floods, accounting for 50.6%; (2) Cause of construction quality, the dam or the dam's foundation cannot control the problems of seepage and stability, thereby causing underground erosion, landslides and subsidence, accounting for 38%; (3) Causes of management and operation, accounting for 5.3%; (4) Other causes due to human impact or incidents from related works, accounting for 4.6%; and (5) The cause has not been found, accounting for 1.5%.

In Vietnam, statistics of 17 broken earth dams in Vietnam in the past 30 years show that, there are 4 common causes [3], including: (1) floods, accounting for 59 %; (2) seismic and geological, accounting for 6%; (3) seepage, accounting for 12%; (4) stability and structure, accounting for 23%.

It can be seen that in addition to failure due to floods, which account for the highest proportion, seepage and structural instability are also the main causes. Monitoring equipment arranged in the dam body plays an important role in providing information to help operations managers early identify risks and have timely treatment plans.

Currently, the monitoring equipment for irrigation dams in Hanoi city is not synchronized, and the required monitoring

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equipment has not been fully arranged. Monitoring equipment mainly focuses on water level monitoring; Only very few dams have saturation line monitoring equipment installed in the dam body; There is only one project that has installed displacement measuring markers on the dam surface. However, carrying out cyclic displacement measurement has not been done due to its complexity and high technical requirements, requiring specialized monitoring equipment and personnel with expertise in surveying. Currently, agencies managing and operating dams and reservoirs in Hanoi city do not have the human resources to conduct monitoring and assessment of displacement themselves, but must hire consultants to perform this task.

Thus, the question is, with monitoring items deployed at a specific reservoir, which can be fully installed or only partially installed, how to support operations managers to Assess the safety level of the dam through limited, inconsistent or incomplete monitoring data *(There are reservoirs with only upstream and downstream water level measuring devices installed; Some with additional measurement tubes to monitor the saturation line in the dam body; only one dam that was installed a system of displacement measuring markers (subsidence, horizontal))*

This article will present the basis, method, and calculation process for dam safety assessment for two typical cases of actual installation of earth dam monitoring equipment in Hanoi city, including Case 1: The project is installed with water level monitoring equipment. Through inspection, exit point of the saturation line on the dam's downstream slope, outside the drainage equipment; (ii) Case 2: The project is installed synchronously with water level and saturation line monitoring equipment in the dam body.

The goal of the article is to support dam managers and operators to self-inspect and evaluate the safety level according to dam monitoring data. However, the dam safety assessment based on displacement monitoring data requires support from a consulting agency and the dam operator cannot implement it themselves, so this content will not be mentioned in this article.

2. INTRODUCTION TO IRRIGATION DAMS AND RESERVOIRS IN HANOI CITY

In Hanoi, there are 117 irrigation dams and reservoirs that are within the scope of regulation of Decree No. 114/2018/ND-CP dated September 4, 2018 of the Government on safety management of dams and reservoirs. The People's Committee of Hanoi City issued Decision No. 4412/QD-UBND dated August 20, 2019 promulgating a list of large, medium and small irrigation dams and reservoirs in Hanoi, there are 09 large dams and reservoirs; 20 medium-sized dams and reservoirs and 88 small dams and reservoirs.

Dams and reservoirs are scattered in 7 districts and towns of Hanoi, including Son Tay town and districts: Ba Vi, Soc Son, Chuong My, My Duc, Thach That and Quoc Oai. Among them, Ba Vi district has the highest number of dams and reservoirs of all types, followed by Soc Son.

Irrigation dams and reservoirs make an important contribution to economic and social development, especially serving agricultural production, flood control and creating environmental landscapes. However, most of the projects were built in the 60s and 70s of the last century with limited funding, calculation data, design experience, and construction techniques. The majority of mall lakes were constructed with rudimentary equipment, and many dams and reservoirs are no longer suitable for today's extreme rain and flood conditions. On the other hand, human resources to manage and operate dams and reservoirs are not enough to meet demand, especially for small lakes that lack funds for regular maintenance and repair. Besides, so many lakes have been damaged and degraded, which cause a high risk of insecurity and threat to people's

lives and property in the downstream area.

Currently, the arrangement of monitoring equipment for irrigation dams and reservoirs in Hanoi city is not synchronized, and the required monitoring equipment has not been fully arranged. Monitoring equipment mainly focuses on water level monitoring *(23 large and medium-sized water reservoirs have been installed with automatic water level measuring equipment)*; Only 03/09 large reservoirs including Dong Mo (Son Tay town), Ham Lon and Dong Do (Soc Son district) have installed saturation line monitoring equipment in the dam body *(however, At Dong Mo reservoir, 03/28 seepage monitoring pipes in the dam body are clogged; the seepage monitoring pipes at Dong Do lake are no longer working)*. Only Ham Lon reservoir has a displacement measurement mark on the dam surface, but since the project was upgraded, repaired and put into operation from the end of 2020 until now, the inspection and assessment of displacement at the project has not been implemented and there is no monitoring data in the initial cycle (cycle 0) as a basis for future assessments.

3. RESEARCH BACKGROUND AND METHODOLOGY

3.1. Methodology

To solve the raised problems, the research uses the following methods:

Theoretical method: From calculation requirements, check the dam safety according to current standards and regulations, based on boundary conditions *(water level documents, design documents, physical and mechanical criteria, characteristics of dams and reservoirs)*, develop technical problems to provide corresponding standards for assessing dam safety on the basis of site inspection results and observed data.

Experimental method: Apply the general theories that have been given, conduct calculations for actual projects to verify, and provide corresponding standards for assessing the level of dam safety.

3.2. Calculation tools

Geo-Studio is a popular software for permeability and stability calculations using the finite element method. This software is specialized in analyzing geotechnical problems such as: permeability, stability, stress strain. Geo-Studio is set up in separate modules to be used for each specific analysis, but modules can also be used in pairs to analyze effects simultaneously. It is widely used in real-world construction calculations due to its simplicity of use, user-friendliness and reliable results.

3.3. Basis and process of calculation

3.3.1. The levels represent the working status of the dam

The working status of the project is expressed in 3 levels [4]:

Level 1: normal working status, measurements of monitoring quantities are within the normal working limits of the dam. The project is allowed to be exploited according to design.

Level 2: measurements exceed normal limits, the project changes from normal to abnormal working status. The project is still allowed to be exploited, but at a limited level and must have increased monitoring.

Level 3: measurements exceed the critical value, the project changes from an abnormal working state to a state at risk of being sabotaged. Exploitation must be limited or stopped (*lowering the water level or draining the reservoir*).

3.3.2. Calculation basis

The location of the seepage saturation line in the dam body and the outlet point located on the downstream slope of the dam, in addition to the drainage equipment, are important information that can help project managers assess the current safety status of the dam:

If the seepage saturation line is located too high, over time there will be a risk that the seepage line will develop and be outside the drainage equipment, above the downstream slope. According to National Standard TCVN

11699:2016 on Irrigation works - Dam safety assessment, if "The exit point of the saturation line on the dam's downstream slope is outside the drainage equipment", the dam quality is assessed as poor, it is necessary to immediately implement proactive measures to ensure safety and conduct detailed surveys, investigations to determine the cause, and scope of the damage.

If the permeability saturation line is too low, it will lead to the risk of increasing the permeability gradient J, creating the risk of underground erosion of the dam body [5]

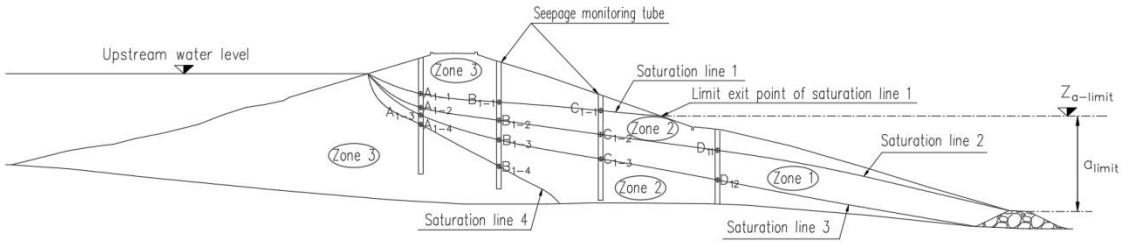

Figure 1: The working status of the dam according to the position of the saturation line in the dam body and the position of the exit point on the dam's downstream slope, corresponding to an upstream water level

Note:

Saturation line No. 1 (Upper limit saturation line): Determined according to the sliding stability condition of the downstream dam slope $K_{minmin} = [K]_{cp}$.

Saturation line No. 2: The saturation line has an exit point at the highest position of the drainage device at the dam's downstream slope.

Saturation line No. 3: The saturation line has an exit point at the lowest position of the drainage device at the dam's downstream slope.

Saturation line No. 4 (Lower limit saturation line): The exit point of the saturation line is in front of the drainage equipment, determined according to the dam's seepage safety conditions when $J_{ra} = [J]_{cp}$ *(the permeability gradient coefficient at the exit point of the saturation line is equal to the gradient coefficient permeability allowed)*. If at the exit point of the saturation line between the dam body and the foundation has $J_{ra} > [J]_{cp}$, the dam is unsafe because of seepage.

Table 1: Basis for dam safety assessment

No.	Value to be determined	Basis for calculation
1	Saturation line No. 1: Upper limit saturation line. - a_{gh}: limit height of the exit point location *(on the downstream slope)* of the upper limit saturation line. Z_{agh} - elevation corresponding to a_{gh}.	Determined according to the sliding stability condition of the dam slope. - The critical value is the limit on dam slope sliding stability, the allowable sliding stability coefficient $[K]_{cp}$ specified in TCVN 8216:2018, changes according to the level of the project.
2	Saturation line No. 2: The saturation line has an exit point at the highest position of the drainage device at the dam's downstream slope.	According to TCVN 11699:2016: The exit point of the saturation line on the downstream slope of the dam is outside the drainage equipment, the dam is assessed as poor quality.
3	Saturation line No. 3: The saturation line has an exit point at the lowest position of the drainage device at the dam's downstream slope.	

No.	Value to be determined	Basis for calculation
4	Saturation line number 4: Lower limit saturation line.	Determined according to the permeability stability conditions of the dam body. The limit value of the dam's seepage stability condition is $J_{ra} = [J]_{cp}$ according to TCVN 8216: 2018. - If the permeability gradient coefficient at the exit point of the saturation line is > $[J]_{cp}$, the project will lose its permeability safety.

3.3.3. Calculating and evaluating dam safety procedures based on water level monitoring equipment, dam inspection, seepage on the downstream slope

For each case of upstream water level (UWL), the calculation will determine the limit elevation of the location of the saturation exit point on the corresponding Z_{agh} downstream slope. Drawing a graph of the relationship between UWL and Z_{agh} will yield a graph showing zones 2 and 3 with the boundary line being the Z_{agh} values.

To evaluate the dam safety status (level 2, level 3), the manager looks up the UWL value and the actual exit point elevation of the saturation line on the downstream slope of the dam. Wherever the intersection point of the two observed values is located, the dam safety level is assessed at that level.

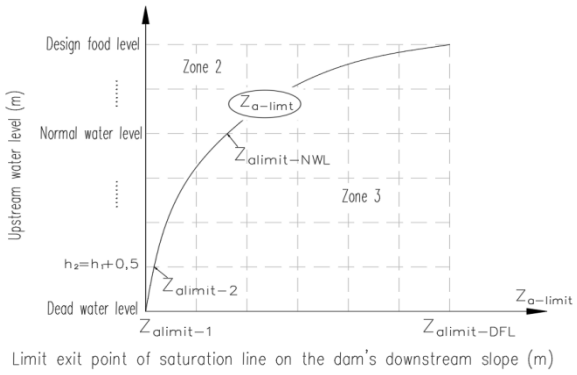

Figure 2: Relationship between UWL and Z_{agh}

3.3.4. Procedure for calculating and evaluating dam safety when the reservoir is synchronously installed with water level monitoring equipment and saturation line monitoring equipment in the dam body

To build a chart representing the working zones of the dam at a monitoring pipe, conduct calculations with many water level cases. For each UWL, the corresponding saturation lines 1, 2, 3, and 4 will be determined (see Figure 1). The intersection point of each monitoring tube being calculated with saturation lines 1, 2, 3, and 4 will be the limit values corresponding to that water level. Drawing a graph of the relationship between the UWLs and the limit values of the corresponding saturation lines for each monitoring tube will yield a diagram of the working partition of the dam at that monitoring tube.

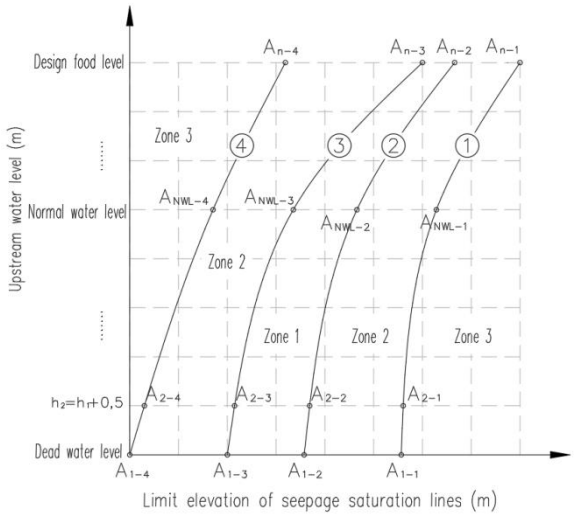

Figure 3: Working zones of the dam corresponding to saturation lines 1, 2, 3, 4 at monitoring tube A

To assess the status of dam safety (level 1, level 2, level 3), the operations manager looks up the value of the upstream water level and the height of the saturation line in the dam body at each monitoring tube. Wherever the intersection point of the two observed values is located, the dam

safety level is assessed at that level.

4. CALCULATION RESULTS

4.1. Applying calculation and assessment of dam safety at Co Dung reservoir, Thach That district

4.1.1. General information of the project

Co Dung reservoir is located in Tien Xuan commune, Thach That district, Hanoi city and was built and put into operation in 1963. The earth dam is 440m long, the largest height is 18.8m. The downstream slope of the dam has many large seepage areas.

To assess the current status of dam safety (level 1, level 2, level 3), the dam operators look up the value of the upstream water level and the height of the saturation line in the dam body at each monitoring tube. Wherever the intersection point of the two observed values is located, the dam safety level is assessed at that level.

Figure 4: Seepage areas on the downstream slope of Co Dung reservoir dam

4.2.2. Results of calculations, assessment of dam safety in practice

For Co Dung reservoir, the dam is a level II project and made of sub-clay soil, so the permissible safety factor for dam slope stability $[K]_{minmin}$ = 1.30 according to TCVN 8216:2018 - Design of compacted earth dams. Based on the calculation of upstream water level cases, the study has determined the corresponding Z_{agh} values and built the relationship chart Z_{UWL}~Z_{agh}.

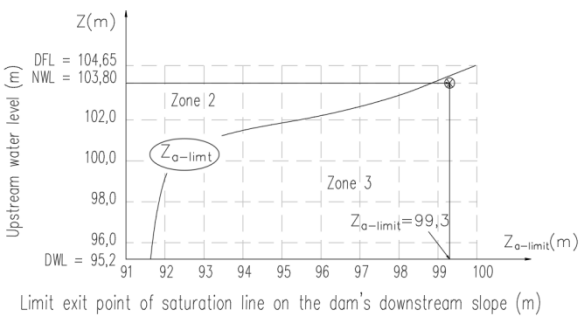

Figure 5: Z_{UWL} and Z_{agh} relationship diagram of Co Dung reservoir

From water level data and the current seepage status of the dam of Co Dung reservoir, the study has evaluated the safety level of the project:

Evaluation date: October 24, 2022.

The lake water level is at normal rising water level: +103.80 (m).

Location of the exit point of the saturation line on the dam slope: above the dam downstream slope, at an elevation of + 99.30 (m).

Comparing the actual elevation of the exit point location *(on the downstream slope)* of the saturation line in the earth dam body ($Z_{a\ actual}$) with the limit elevation determined at normal water level rise shows: $Z_{a\ actual}$ = 99,30 (m) > Z_{agh} = 98,8 (m). The dam is in an unsafety zone and not allowed to store water or must control the water level and needs to strengthen inspection, repair or upgrade.

4.2. Calculation and assessment of dam safety at Ham Lon reservoir

4.2.1. General information about the project

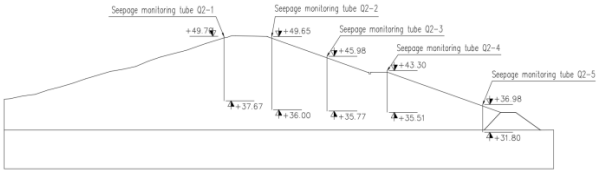

Figure 6: Monitoring route for saturation seepage in the dam body (Q2)

Ham Lon reservoir is located in Nam Son commune, Soc Son district, Hanoi city. The project was put into operation in 1998; repaired and upgraded in 2020. Currently, there are 04 monitoring routes for the saturation line in the dam body. Each monitoring route (Q1, Q2, Q3, Q4) has 05 monitoring pipes installed, including: 01 pipe upstream side and 04 pipes located on the downstream side. For monitoring route Q2, the monitoring route is located in the river bed cross section, where the dam height is the largest with monitoring pipes, including: $Q_{2\text{-}1}$, $Q_{2\text{-}2}$, $Q_{2\text{-}3}$, $Q_{2\text{-}4}$, $Q_{2\text{-}5}$.

4.2.2. Results of calculations and application of testing and assessment of dam safety in practice

Ham Lon reservoir's dam is a level II project, which is made of sub-clay soil, the permissible safety factor for dam slope stability $[K]_{minmin}$ = 1.30 according to TCVN 8216:2018. Based on the calculation of UWL cases, the study has built relationship charts between UWL and the limit elevation of the seepage saturation lines in the dam body.

The relationship chart between UWL and the limit elevation of the seepage saturation lines in the dam body at the $Q_{2\text{-}2}$ monitoring pipe (located at the downstream slope) of the Q2 monitoring route is shown in Figure 7.

Figure 7: Measuring and checking the saturation line of Ham Lon dam at the site

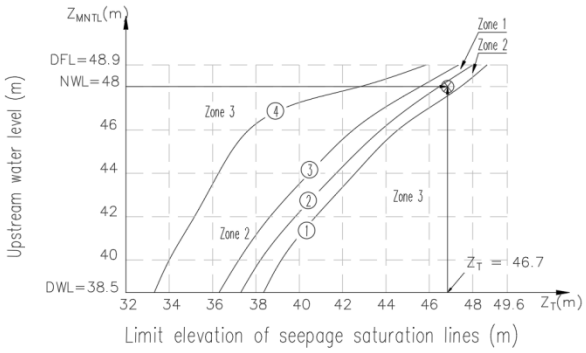

Figure 8: Relationship between UWL and limit elevation of seepage saturation lines at pipe $Q_{2\text{-}2}$

Conduct on-site inspection, and evaluate the safety level of the project based on the relationship chart $Z_{UWL} \sim Z_t$ at monitoring tube Q2-2:

Evaluation time: September 22, 2023.

The water surface is at normal water level: +48.0 (m).

Elevation of the observed saturation line at pipe $Q_{2\text{-}2}$: +45.20 (m).

Comparing the actual elevation of the observed saturation line at pipe $Q_{2\text{-}2}$ (actual Z_t) with the normal water level shows that the dam is working in a condition of measurements exceeding normal limits. The project is still allowed to be exploited, but at a limited level and must have increased monitoring.

5. CONCLUSION

In this study, from the requirements for calculating and checking dam safety according to current standards and regulations and on the basis of boundary conditions (Water level documents, design documents, physical and mechanical criteria, and characteristics of dams and reservoirs), the study has developed technical problems to provide corresponding standards for dam safety assessment for two

typical cases of actual installation of earth dam monitoring equipment in Hanoi city, including (i) The project is installed with water level monitoring equipment. Through inspection, it was found that the earth dam had seepage on the downstream slope of the dam, outside the drainage equipment; (ii) The project is synchronously installed with water level monitoring equipment and saturation line monitoring equipment in the dam body.

Through inspection and evaluation at two typical projects, it has been shown that the full installation of monitoring equipment according to current standards (TCVN 8215:2021 - Irrigation works - monitoring equipment) is very necessary for ensuring the safety of dams and reservoirs in Hanoi city. For Co Dung reservoir, if the saturation line in the dam body is not observed, the operators can not early identify possible safety risks. During an in-depth assessment, the dam was at level 3: the measurements exceeded the critical value, the structure changed from an abnormal working state to a state at risk of being sabotaged. At that time, exploitation must be limited or stopped (lowering the water level or draining the reservoir).

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