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RESEARCH ON ANTI-SEPARATION AND ANTI-OVERTURNING OF CONCRETE BLOCK STRUCTURES OF A SPILLWAY WITH A PROTRUDING HEAD DURING CONSTRUCTION

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Abstract

In concrete gravity dams, reinforced concrete, and its components, depending on the working conditions of the concrete in separate parts of the dam during the operation period, should be divided into concrete zones with different intensities. However, many projects choose to construct the spillway's overhang to save concrete, still assuring working conditions while creating the most cost-effective cross-section of the spillway. Although this will result in a proper partition of the concrete, anchoring the connection between the blocks must be secured; otherwise, the block may separate and even become eccentric and spill over. This may result in objects falling, works being destroyed, and a significant safety danger. This study approaches to ensure the safety of spillways with overhanging blocks by calculating and analyzing the risk of block separation and overturning, thereby giving a suitable solution for pouring volume and creating the best anchor connection to keep the whole dam safe and stable during construction and operation.

Keywords: concrete gravity dams; reinforced concrete; spillway's overhang; separation of block concrete; stable of concrete dams.

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1. Introduction

The construction of a dam creates a high barrier that prevents the water from flowing downstream. Jesung Jeon (2009) indicates that: For large dams, the water pressure from the reservoir is very large, and in addition to other loads acting on the dam, there is a risk of dam failure [1]. Therefore, it is very important to design a dam to make it work stably and safely. With a higher dam, the water storage increases and so does the difficulty to convey the minimum flow, water exceeding the maximum storage level and flood water at the downstream. Gravity concrete spillway is a kind of construction to remove flood flow. During the operation of the spillway, erosion can also occur through the cracks in the internal spillway body, which is one of the leading causes of embankment dam failure [2]. When designing the spillway, in addition to the requirement to ensure stability, the cost of construction investment is also considered, i.e., the cost must be reduced [3]. In Fig. 1, the design of the concrete gravity dam cross-section is described, in which: NRWL is Normal Rising Water Level; DFL is Design Flood Level; CFWL is Check Flood Water Level; WLDCDF is Water Level Downstream Corresponding to Design Flood; DWLCTF is Downstream Water Level Corresponds to the Test Flood; MDWL is Minimum Downstream Water Level; MEWLU is Minimum Extraction Water Level Upstream.

Therefore, depending on each working area in the dam body, the designer needs to divide it into the following four regions, as presented in Fig. 1 [4], in which: I is the outer area of the dam and parts thereof are exposed to the atmosphere but not submerged; II is the outer area of the dam within the

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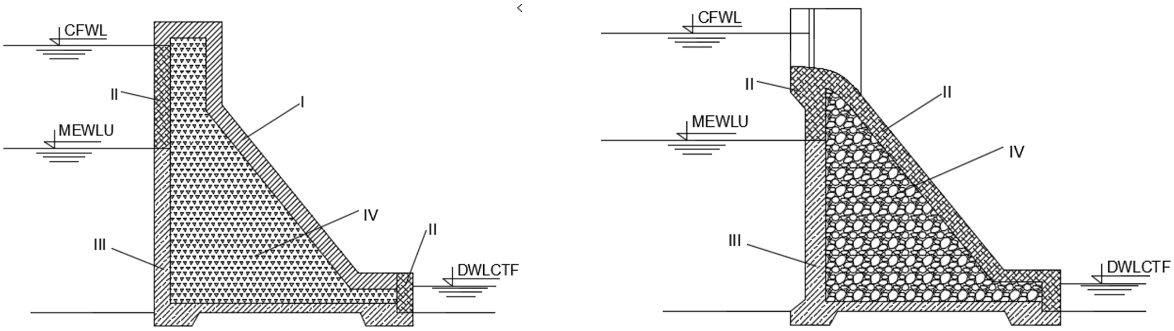


(a) Dam (b) Spillway

Figure 1. Parts of a gravity dam on a bed rock

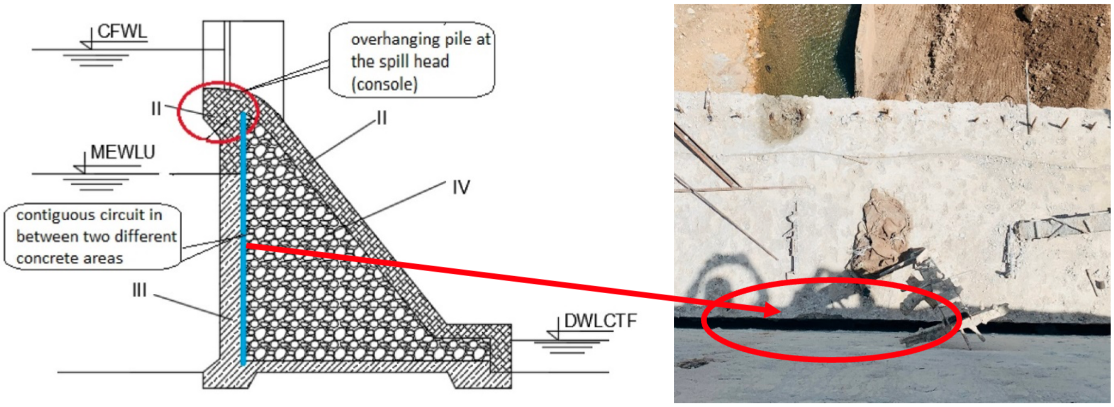
fluctuation range of the upstream and downstream water levels and the parts of the dam which are flooded from time to time, such as overflow, discharge, and energy dissipation tanks. III is the outer zone and the parts adjacent to the foundation, which are located below the minimum extraction water level upstream(MEWLU) and downstream. IV is the area within the dam body, limited by zones I, II, and III, including the concrete part of the structure adjacent to the closed voids of the dam.

According to the research of Nguyen Huu Hue (2010), in each concrete area, the concrete area is divided into concrete blocks, and the size of the pouring blocks is reasonably divided to ensure safety and sustainability [5]. Concrete regions in dams of all grades must meet the requirements listed in Table 1.

Table 1. Requirements for concrete in different regions of the dam

Requirements for concrete in different regions of the dam	Dam region	
	Concrete	Reinforced concrete
According to compressive strength	I-IV	I-III
According to tensile strength	I-III	I-III
According to impermeability	II-III	II-IIII
According to the limited elongation	I-IV	Not required
According to the durability against the cavitation effect of water	II-III	II-IIII
According to the abrasion resistance due to sediment flows and resistance to cavitation when the water velocity at the concrete surface is equal to and greater than 15 m/s	II	II
According to the heat release when the concrete sets	I-IV	Not required

However, when designing the spillway's most reasonable and economic cross-section, many projects choose to design the overhang of the spillway to save concrete while still ensuring working conditions shown in Fig. 2. However, this will lead to a reasonable division of concrete, and anchoring the connection between the blocks must be ensured. Otherwise, it will lead to separating the pouring block in the contiguous line between the two blocks of different concrete regions; even eccentricity of the entire pouring block with overhang is shown in Fig. 3. The collapsed items is shown in Fig. 5. As a result, structures will be damaged, and risks of property loss and unsafety for labor are very high [6].



(a) Cross section of spillway with division of concrete area

(b) Crack at the junction of two concrete regions

Figure 2. Crack at the junction of two concrete regions

According to the analysis results, the stress in the concrete block is mainly compressive; tensile stress only appears on the open surface outside the boundary, as shown in Fig. 3. This can be explained because, in the concrete block, there is an increase in the temperature of the concrete block, then the inner concrete tends to expand due to heat, so the main stress in the block is compressive stress. Meanwhile, the block on the outer surface of the concrete boundary that has a rapid temperature decrease (to the atmosphere) will tend to shrink, but because it is held by the inner layers with higher temperature, and is the cause of the growth. Generate tensile stress of the concrete layer at these locations [7].

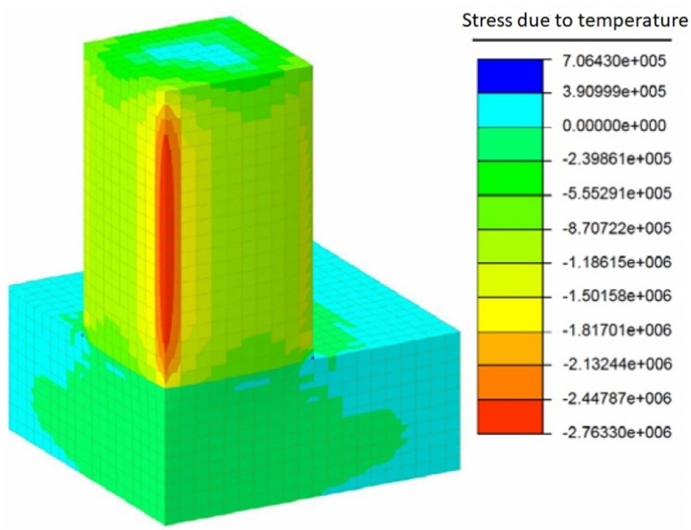


Figure 3. Simulation results Stress due to temperature

Jonas Enzell and Markus Tollsten (2017), in Thermal cracking of a concrete arch dam due to seasonal temperature variations, proved that: Concrete dams located in northern regions are exposed to large seasonal temperature variations. These seasonal temperature variations have resulted in cracking in thin concrete dams. Continuous monitoring and evaluation of existing dams are important to increase the knowledge about massive concrete structures and to ensure dam safety [7, 8].

When the tensile stress exceeds the tensile strength of the concrete, the adjacent concrete blocks will separate, as shown in Fig. 2. Moreover, to facilitate the construction of the spillway in the concrete areas, we divide it into small blocks suitable for the construction capacity in a day and ensure the technical requirements [9], shown in Fig. 4.

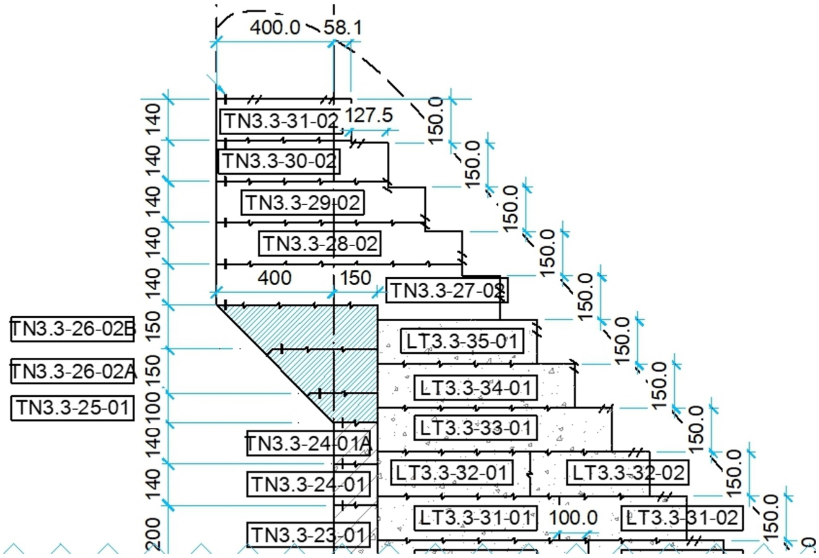
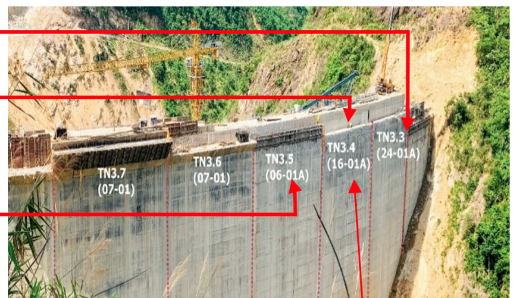


Figure 4. Division of concrete blocks by region of La Trong hydropower project, Vietnam

(a) Concrete blocks is TN3.3, TN3.4, TN3.5 just completed construction



(b) The concrete blocks were subversion

(c) The TN 3.4 concrete blocks were subversion

Figure 5. The blocks at the top of the spillway were overturned

Determining the size of the dump is a complicated problem for each project, especially large projects with complex structures and fast construction time. Studying the general shape of the commonly used gravity concrete dam cross sections in Vietnam, combined with the results of the study on the influence of the pour size on the thermal field, thermal stress field, and construction ability, we can choose a reasonable size of concrete block. During the construction process, the contact surface of the concrete blocks must be roughened to increase the sustainable connection.

However, when the construction does not meet the technical requirements for concrete pouring and the concrete is subjected to many other adverse impacts, the deterioration of the concrete weakens or damages the concrete. The deteriorated concrete could exacerbate other seismic potential failure modes, such as gate and pier failure and internal erosion. As previously mentioned, there is no one generic failure or incident event tree associated with reinforced concrete deterioration, rather the effects are typically reflected in the likelihood of events occurring for other potential failure or incident modes, such as the likelihood (probability) of open joints, offsets, surface tolerance and/or cracks and spalls [10].

And even spillways will lead to destruction during operation, as shown in Fig. 6.

Figure 6. 1999 Dam and Spillway Failure – Shi-Kang Dam, Taiwan
(Photo origin: https://hss.dk/shih-kang-dam-project-in-taiwan/)

From the research reviews and the situation of incidents like the above, in this study, we refer to the calculation of spillway stability, checking the tipping ability of the pouring block of the upstream boundary with the concrete protruding head towards the upstream of the spillway, thereby proposing solutions for pouring volume and the connection between blocks to ensure stable and safe working conditions in the construction and operation of the gravity concrete spillway.

2. Calculation diagram and method

2.1. Calculation diagram

Dam damage shown in Fig. 5 can be caused by the separation to create an open line in the middle of two areas of pouring blocks with different concrete strengths, leading to the disequilibrium and disproportion of the overhanging component at the spill head (console), center from the base area and lack of load-bearing reinforcement that holds this console block to the upstream wall. Therefore, the author approaches a problem and calculates the cases to verify the above statement with the calculation diagram described in Fig. 7. The water levels and symbols of the concrete area are shown in Fig. 1.

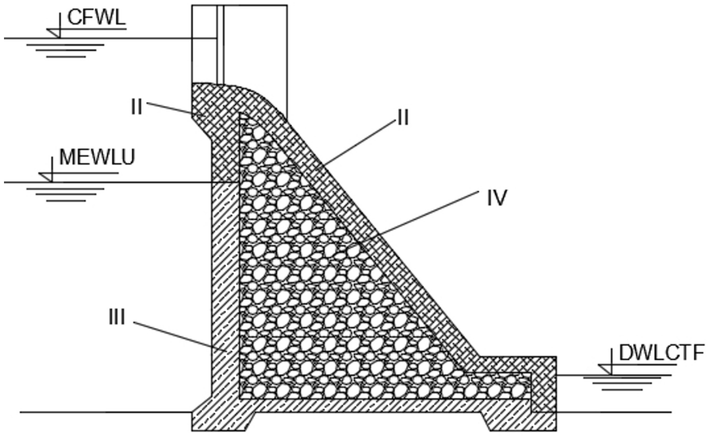


Figure 7. Representative cross-section of a spillway

2.2. *Calculation method*

An evaluation of the gravity spillway's structural stability was carried out in accordance with Vietnamese regulations [11, 12]. The method of determining the maximum stress of the section is calculated according to the following equation:

$$\sigma = \frac{\sum P}{F} \pm \frac{\sum Pe_y y}{J_x} \pm \frac{\sum Pe_x x}{J_y} \tag{1}$$

where $\sum P$ is sum of vertical forces acting on the ground; F is foundation area; e_x, e_y, J_x, J_y are eccentricity and central moment of inertia of the foundation; x, y are distances from stress-calculating points to the center of section; checking the flip stability according to the following expression:

$$K_l = \frac{\sum M_r}{\sum M_t} \geq [K] \tag{2}$$

where $\sum M_r$ is the total moment of anti-roll forces; $\sum M_t$ is the sum of the moments of the flipping forces; K_l is the flip stability factor.

Stable condition: The safety factor of the building according to QCVN 04-05:2012 [13].

Table 2. The allowable stable factor of safety

Load combination	Coefficient nc	$[K]_{stable}$	
		$[K]_{slip}$	$[K]_{Flip}$
Basic	1	1.30	1.20
Special	0.9	1.17	1.08

Based on the theory of calculating the durability of the spillway mentioned above, many authors study the application of information technology to calculate the stability and durability of the spillway, such as the study of Yenigun and Erkek [14]. A computer program is developed in the Java language (DAM_RISK) with the aim of determining the safety levels of spillways in existing dams (or dams in the planning or construction phase). In consideration of a possible risk, observed overflow values are used to determine the rehabilitation values that need to be known, thus producing data ready for technical and financial analysis. In fact, at present, many commercial pieces of software are used to calculate the stability and durability of spillways in the world, such as SHAP, GEO5, ANSYS, and

Geo-Studio Software [15]. In this study, the author used ANSYS software to calculate and test the hypothesis of mass separation, causing the overturning and pouring of concrete blocks.

3. Verification calculation

3.1. Input data for design

The data of the La Trong hydropower project are used to calculate and verify the above problems [3]:

a. Material specifications

The characteristics of concrete dam foundation are described in Table 3. The characteristics of this material are based on geological survey data of La Trong concrete dam foundation.

Table 3. Characteristics of concrete dam foundation

Parameter	Value
Static deformation module (GPa)	12.50
Dynamic deformation module (GPa)	18.75
Poisson ratio	0.25
Adhesive force C between concrete and rock foundation (MPa)	1
Angle of internal friction φ between concrete and rock foundation (°)	35
Density of saturated soil (T/m^3)	1.87

Criteria for calculating gravity dam concrete, Table 4 describes the characteristics of concrete dams. The characteristics of this material are based on concrete strength data of regions in Latrong concrete dam body. M15 is the material characteristic of region IV in concrete dams; M20 is the material characteristic of region III in concrete dams; M25 is the material characteristic of region II in concrete dams.

Table 4. Indicators of concrete strength

Parameter		Value		
		M15	M20	M25
Deformation module (GPa)	Static	21	24	26.5
	Dynamic	26	36	39.75
Poison ratio		0.15	0.15	0.15
Density (T/m^3)		2.40	2.40	2.40
Tensile strength (MPa)		0.63	0.75	0.88
Compression resistance strength (MPa)		7.00	9.00	11.00

b. Loads and effects

Table 5 describes the water level characteristics in the reservoir and downstream of the concrete dam. The characteristics of this material are based on the hydrological data of the La Trong concrete dam.

To prove the statement in this research problem, this study accepts the input data that has been applied to design of La Trong dam as a case study. Based on the above data, the author will re-calculate the load components and focus on assessing the causes of the fault under construction, not yet filled with water for the representative cross-section shown in Fig. 7, at block TN3.4 shown in Fig. 5.

Table 5. Describes the water level characteristics

Parameter	Units	Value
Normal rising water level (NRWL):	m	200.00
Design flood level(DFL):	m	204.08
Check flood water level(CFWL):	m	204.65
Water level downstream corresponding to design flood(WLDCDF):	m	149.48
The downstream water level corresponds to the test flood(DWLCTF):	m	151.26
Minimum downstream water level(MDWL):	m	124.00
Density of water, γ_n:	T/m^3	1
Sand and mud elevation:	m	160.0

3.2. Verifying the flip stability and durability

Flip stability calculation diagram is depicted in Fig. 8.

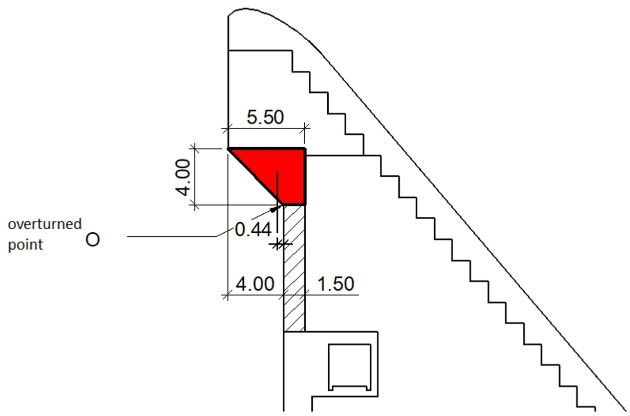


Figure 8. Flip stability calculation diagram

Data used in calculations:

Table 6. Dimensions and material characteristics of the concrete block used in the calculation example

Parameters	Unit	Value
L spill	m	1.00
H block	m	4.00
B_{top}	m	5.50
$B_{bottomblock}$	m	1.50
C dragBt	T/m^2	76.45
C dragBt (for 7 days)	T/m^2	57.34
L tensile	m	0.60
Concrete density	T/m^3	2.40
S block	m^2	14.00
V	m^3	14.00
G	T	33.60
C drag Fa	Mpa	365.00
C drag Fa	T/m^2	37206.93

Calculation results of moments are shown in Table 7.

Table 7. Calculation results of moments

STT	Force	Unit	Arm Lo	Mo (T.m)	Arm Lo'	Mo'
1	G block	T	0.44	14.80	1.19	−40.00
2	C tensile	T	0.30	10.32		
3	Steel fi16	T	0.11	4.11		

The above moment calculation results are used to check the roll stability coefficient at the overturning point "0" of the concrete pouring block, as shown in Fig. 8. The results of the overturning stability coefficient are shown in Table 8.

Table 8. Calculation results of stability and stress

Results	Unit	Value	Evaluation
K_{FlipO} =	-	0.98	< 1.08
σ_{yTL} =	T/m^2	– 84.27	Compression
σ_{yHL} =	T/m^2	129.07	Drag > $[\sigma]_{DragBT}$

The results in Table 8 show that the flip stability coefficient at point O: $K_{flip} = 0.98 < 1.08$. Overturning block does not guarantee stability against tipping. This has clearly demonstrated the incident of 3 concrete blocks TN3.3, TN3.4, TN3.5 being overturned and falling down. It is necessary to calculate the reinforcement solution to keep the concrete blocks stable.

Based on TCXDVN 305: 2004 regulations on construction of the contiguous part of concrete blocks: In order for the two layers of old and new concrete to stick together, you need to handle them carefully with measures according to technical regulations.

However, it actually happened during the construction process that the two dam body blocks and the vertical wall concrete block on the upstream side of some concrete dams were separated from each other (shown in Fig. 2). When calculating research, it is necessary to account for the disadvantage that the blocks separate from each other, that is, the adhesion force is considered to be equal to zero.

3.3. Verifying the stress-strain state of the block

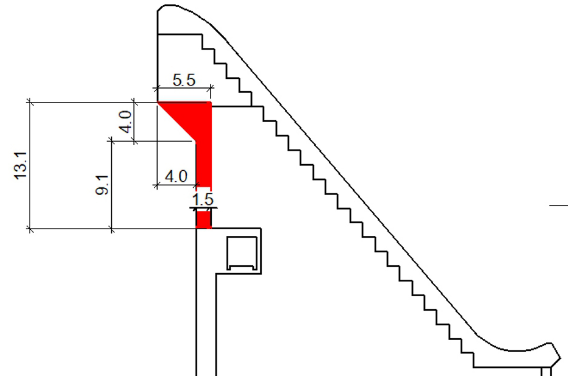
Based on the above input data, the author performed independent calculations using ANSYS software with the following construction combination:

a. Calculation displacement results

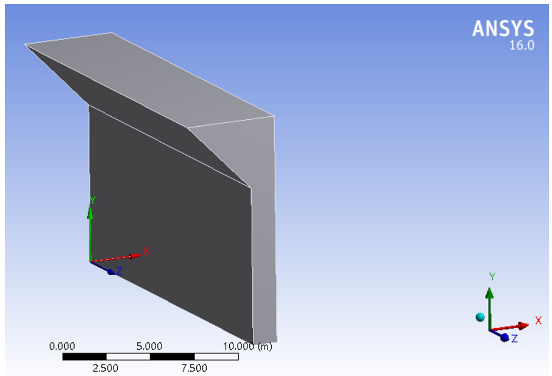
Based on the above input data and conclusions, the displacement calculation results using ANSYS software are shown in Fig. 10.

From the extraction results as shown in Fig. 10, it is confirmed that: if concrete blocks are had constructed separately in different areas, even during the construction process of the outermost blocks with protruding concrete parts, there would have displacement, the block is in danger of separating from the blocks in the area inside the concrete dam body.

When calculating the strength, stability, and crack resistance of the concrete dam and its components, the reinforced concrete structures of the dam must comply with. Design standard TCVN 9137-2012. In clause 6.2, the crack at the upstream surface adjacent to the water is not allowed and must not create a crack in the construction block in the dam, the maximum calculated displacement of concrete block is 5.4mm (shown in Fig. 10), which is larger than 5 mm. According to the regulation stated in TCVN, a such crack width is not guaranteed.

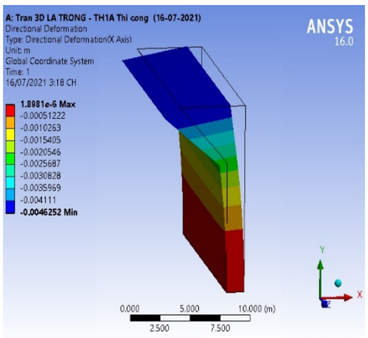


(a) Calculation diagram of stress - strain state

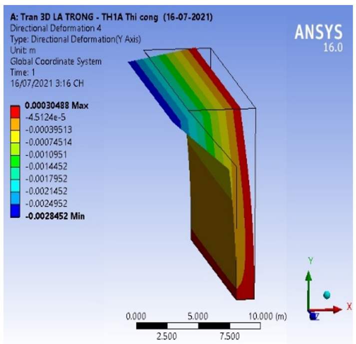


(b) 3D block calculation diagram in ANSYS

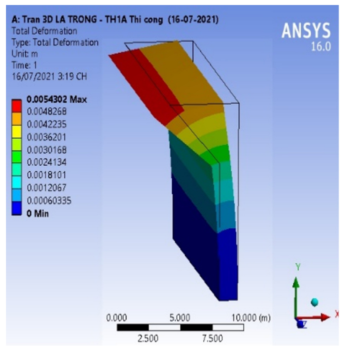
Figure 9. Calculation diagram of stress - strain state and 3D block calculation diagram in ANSYS



(a) Displacement in the X-direction



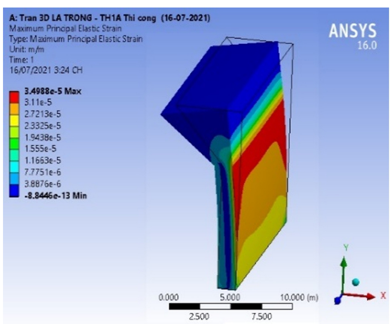
(b) Displacement in the Y-direction



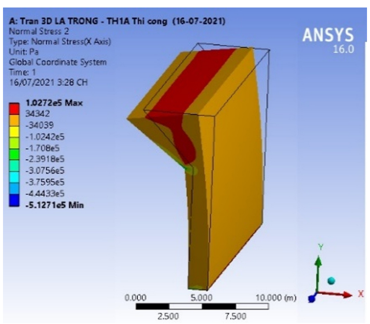
(c) Total displacement

Figure 10. Results of displacement calculation

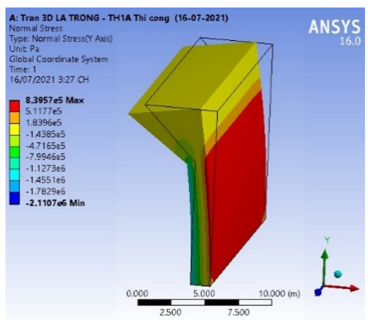
The calculated stresses using ANSYS software are described in Fig. 11.



(a) Main elastic deformation



(b) Stress in the X-direction

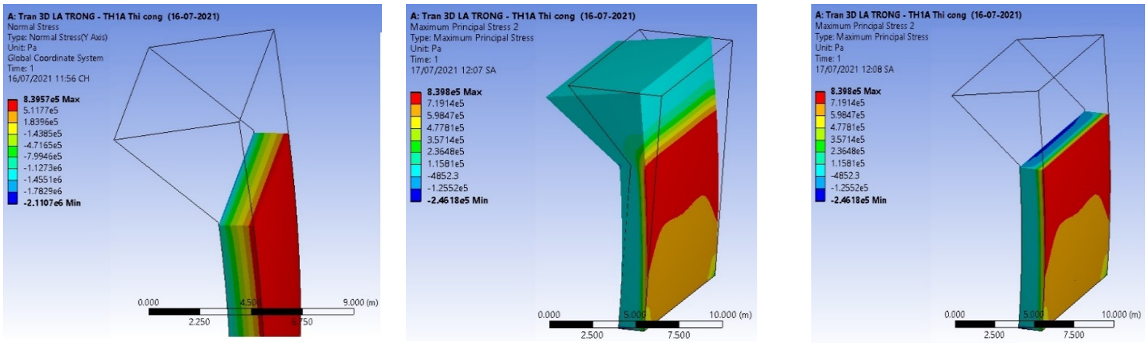


(c) Stress in the Y-direction

Figure 11. Result of Stress calculation

From the extraction results as shown in Fig. 11, the large stress areas are in red, it means that: there would have great stresses occuring at the inside surface of the blocks.

Calculating and arrangement of reinforcement in concrete dams comply with TCVN 4116:1985. To which, calculated compressive stresses in concrete must not exceed the calculated strength of concrete when subjected to compression. In case of internal tensile force, when the tensile stresses in the concrete exceed the allowable strength, that internal force will be completely resisted by the reinforcement. According to the results calculated (shown in Figs. 11 and 12), the maximum tensile stress value in the block is 839 MPa exceeding the tensile value of concrete, so the overflow concrete block does not guarantee the bearing strength.



(a) Stress in the X-direction of an upstream wall under the console block

(b) Main stress max

(c) Max principal stress of the upstream wall under the console block

Figure 12. Result of stress calculation

Max principal stress of the upstream wall under the console block is very large, the tensile stress values are located upstream of the overhanging spillway, which. Is greater than the allowable tensile stress of concrete shown in Figs. 9–12. Therefore, it is required to arrange load-bearing reinforcement to tie the blocks of the two regions, avoiding the separation phenomenon between blocks as well as to ensure anti-overturning for protruding blocks.

b. Solution to arrange reinforcement to ensure the stability of the protruding blocks

This section mentions the solution to arrange reinforcement to ensure stability for the protruding blocks at the top of spillway during construction and operation, arranging load-bearing reinforcement using ANSYS software is depicted in the figures below.

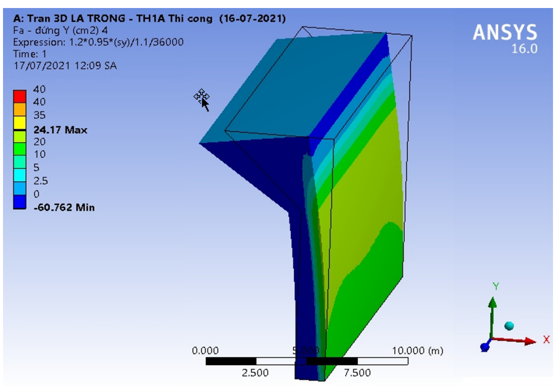


Figure 13. Distribution of load-bearing reinforcement

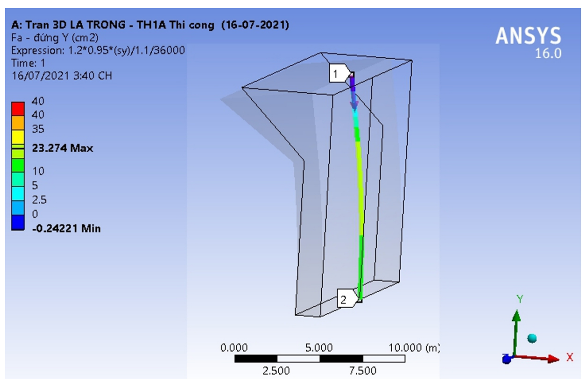


Figure 14. Distribution of load-bearing reinforcement in the vertical direction

The study calculated the new reinforcement section Fa = 22 cm^2/m to ensure the bearing capacity of the spill head (console). To ensure the bearing reinforcement, it is required to arrange the upstream surface of the spillway of the load-bearing reinforcement layer Φ24 vertically away from the upstream edge 1.4 m and Φ14 horizontally perpendicular to the flow, as shown in Figs. 13–15.

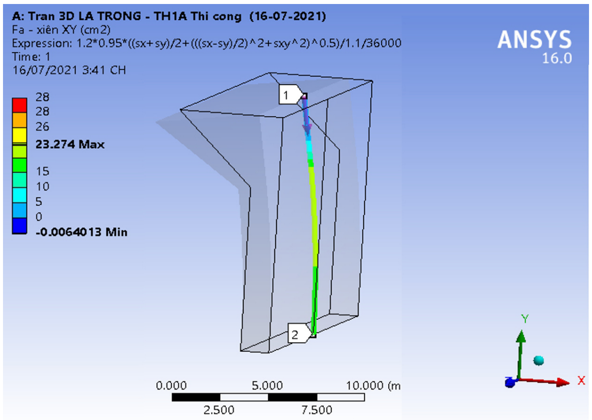


Figure 15. Distribution of load-bearing reinforcement in the principal stress direction

Extract the calculation results 1 typical example to demonstrate the displacement and risk of overturning of the overflow concrete block. From there, calculate and propose the arrangement of reinforcement with a specific example: La Trong concrete spillway, and at the same time give recommendations on the arrangement of reinforcement for the stability of this block (see Fig. 16).

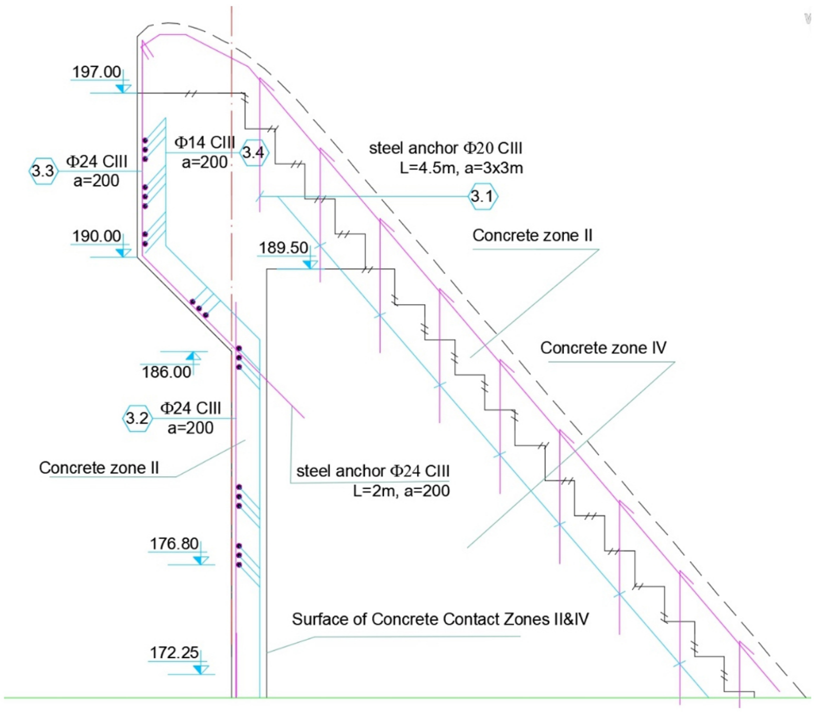


Figure 16. Example of reinforcement arrangement of concrete spillway

The arrangement of reinforcement of the overhang of the spillway is given by the author to illustrate the typical block. However, each project has a specific scale, which means that the size of the overhang of this spillway is also different, so it is necessary to calculate the appropriate steel layout for each project.

Based on the reinforcement calculation results it is necessary to arrange the steel bars properly to ensure the bearing conditions, the concrete blocks are linked together, and the whole concrete block is always stable, not overturned.

4. Conclusions

The study started with the actual incident and identified the problem. Since then, the author has carried out a calculation example and presented the results to demonstrate the cause of the incident. Next, the reinforcement arrangement inside the block region was also described. The findings addressed that the upstream concrete region of console structures need to to arrange the steel properly to ensure the bearing conditions. So, the concrete blocks are linked together, and the whole concrete block is always stable, not overturned.

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