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Geological hazards at the main dam of Dap Troi reservoir, Ninh Binh Province, Vietnam

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ABSTRACT

Dap Troi Reservoir is an irrigation lake in Dong village, Yen Son ward, Ninh Binh province, Vietnam (formerly Quang Lac commune, Nho Quan district), Vietnam, covering an area of more than 50 hectares and has been firmly constructed since 2006. The irrigation reservoir consists of two dam sections: the main dam, which extends nearly 457 meters in a northwest–southeast direction, and the spillway dam, approximately 200 meters long along a north–south meridian. The reservoir plays a vital role in flood control, water storage, irrigation, agricultural production, and domestic water supply for thousands of households in Quang Lac and Son Ha communes, Nho Quan district. Seepage-related geological hazards along the dam axis have been recorded over recent years, causing significant safety concerns for the dam structure and anxiety among local residents living surrounding the area. Geological and geotechnical investigations, utilizing a combination of geophysical methods, including electrical resistivity tomography (ERT) and ground-penetrating radar (GPR), exploratory drilling along with hydrogeological testing and soil sampling and analysis, have identified the geological locations where seepage anomalies occur. Based on these findings, effective anti-seepage measures can be proposed to ensure the safety and stability of the Dap Troi reservoir.

Keywords: *Geological harzard, Dap Troi Dam, Ninh Binh, Vietnam.*

1. Introduction

Geological hazards affecting hydraulic infrastructure are the result of a complex interplay of multiple factors, among which geological conditions play a decisive and foundational role. A systematic understanding of the engineering geological characteristics of dikes and reservoirs, along with the timely detection of potential hazards, is essential for planning effective, cost-efficient maintenance, upgrades, and protection measure.

Dam failures result from complex, often unpredictable factors, including geological conditions (lithology, tectonics) and external drivers (topography, hydrology, climate change, floods). Many small reservoirs were built to outdated standards with limited data and inadequate spillway capacity, making them vulnerable to extreme events.

Structural degradation, poor construction quality, and outdated design practices further increase failure risk. In addition, limited management capacity, lack of monitoring, and unsafe human activities (e.g., encroachment on safety corridors) reduce the ability to detect and respond to hazards in time.

Dap Troi Reservoir is an irrigation lake in Dong village, Yen Son ward, Ninh Binh province, Vietnam (formerly Quang Lac commune, Nho Quan district) (Figure 1). Covering over 50 ha and completed in 2006, it comprises two dam alignments: a nearly 457 m main dam (Northwest- Southeast direction) and a nearly 200 m spillway dam (near North-South direction). The reservoir plays a key role in flood control, water storage, and supplying water for agriculture and local communities (Ninh Binh Statistics Office, 2022; Department of Agriculture and Rural Development of Ninh Binh Province, 2021).

Since 2020, seepage has been observed at the dam's downstream toe, as confirmed by field surveys and reported in media sources. Visible leakage flows from the dam body are evident (Figure 2 and 3). According to local sources, this seepage has significantly affected the livelihoods of residents. During the rainy season, persistent waterlogging disrupts rice cultivation, while in the dry season, water shortages are reported. Furthermore, one of the major leakage points lies adjacent to an inter-village road, impeding local transportation and raising safety concerns.

During the year of 2021 and 2022, Ninh Binh Province implemented several seepage mitigation projects on the main dam of Dap Troi Reservoir to ensure structural safety and enhance flood control capacity during the rainy season (Ninh Binh Irrigation Co., 2021). Post-treatment monitoring indicates that the mitigation measures effectively reduced seepage through the dam body. However, significant seepage at the dam toe persists (Figures 4 and 5), suggesting that underlying seepage pathways remain active and have not been fully controlled.

Field observations indicate that the reservoir margins and surrounding slopes are generally stable, with no significant signs of landslides. The spillway dam, constructed of concrete, shows no evidence of instability or geological hazards; however, localized seepage is observed on the downstream slope. Geological hazards are mainly concentrated along the main dam section (To Xuan Ban et al., 2023).

Two major seepage zones have been identified. At location N-01, water flows continuously in a stream, eventually draining through a concrete ditch into nearby rice fields, with an estimated flow rate of several tens of cubic meters per hour. At location N-02, seepage appears as slow filtration rather than flowing water, but remains active (Figure 1).

This study aims to investigate the underlying geological and structural causes of toe seepage at the Dap Troi Reservoir and to propose effective remedial solutions..

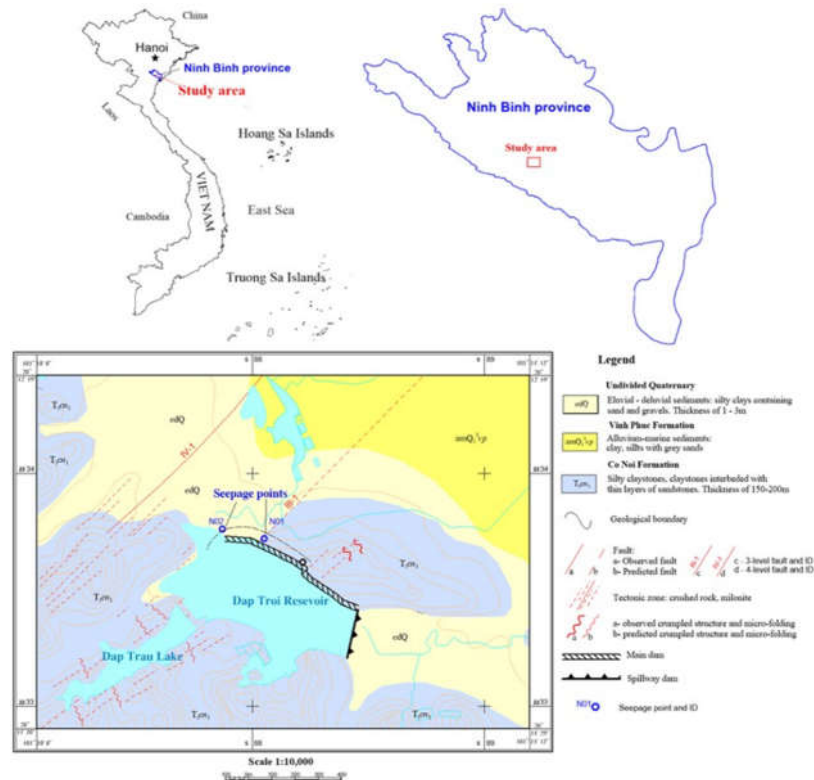


Figure 1. Sketch geological map of the Dap Troi Lake showing the locations of water leaking points



Figure 2. Seepage point with visible flow at the toe of the Dap Troi Reservoir dam (surveyed on 03/12/2021)



Figure 3. A seepage point at a residential house (on 03/12/2021)



Figure 4. First seepage point at the downstream toe of Dap Troi Dam (26/12/2022); seepage persisted after slope stabilization and grouting



Figure 5. Field survey at a seepage point located 15 m upstream of leakage point at the downstream toe of Dap Troi Dam (18/01/2023), when the reservoir water level was low

2. Methods

The study employed an integrated methodology combining field investigations, geophysical surveys, exploratory drilling, and laboratory testing to characterize geological and hydrogeological conditions and assess seepage at Dap Troi Dam.

Field surveys were conducted to investigate geological, engineering geological, and hydrogeological conditions in and around the reservoir. Water levels were continuously monitored within the lake and at identified seepage locations to evaluate hydraulic behavior.

Based on field results, optimal locations were selected for geophysical measurements. Geophysical surveys included Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR). These methods were applied to delineate subsurface structures, identify anomalies, and detect potential seepage pathway. GPR uses electromagnetic waves to image the subsurface by recording reflections from material contrasts. In this study, a GSSI SIR-30 system with a 100 MHz antenna (3207/3207A) and a 25–300 MHz filter achieved penetration depths of ~13 m. Surveys were conducted along two profiles: (i) the main dam crest and (ii) the downstream toe along the concrete road where seepage has been observed.

Electrical Resistivity Tomography was used to delineate subsurface structures based on resistivity contrasts, identifying lithological boundaries, karst voids, fractures, and saturated zones. In this study, ERT determined the thickness of Quaternary deposits and detected karst

cavities and fractured bedrock beneath the dam. A total of 26 soundings were conducted along four lines (DT2-1, DT2-2, DT2-3, DT1) in accordance with MONRE (2014). Results guided the selection of Well locations along the main dam axis.

Wells were drilled at critical positions to obtain lithological profiles, perform hydrogeological tests, and collect soil and rock samples for laboratory analysis. Based on field and geophysical investigations, three Wells (DT1, DT1-1, DT2) were drilled to characterize subsurface conditions and identify seepage mechanisms at Dap Troi Dam. The total drilled length was 130.5 m (DT1: 50.0 m; DT1-1: 30.0 m; DT2: 50.5 m). Packer tests were conducted in two sections of DT1 and three sections of DT2 to assess permeability.

A total of 21 soil samples were collected from Well cores and tested for physical and mechanical properties of the soils. The results provide a basis for assessing the mechanical characteristics of the dam foundation and identifying the causes of seepage at Dap Troi Reservoir.

The integration of geophysical data with field observations and drilling results provides a reliable basis for assessing subsurface conditions and supports recommendations for further investigation and remediation.

3. Results and discussion

3.1. Geological Characteristics of the Dap Troi Reservoir Area

The geological structure of the Dap Troi Reservoir and surrounding area is derived from regional geological maps at scales of 1:200,000 (Hoang Ngoc Ky, 1999) and 1:50,000 (Vietnam Department of Geology and Minerals, 2005), extracted for the study area (Fig. 1)

Stratigraphy and Lithology

The studied area consists of two main units are present: Co Noi Formation (T_{1cn}): Terrigenous rocks (claystone, siltstone, thin sandstone, calcareous clay, limestone lenses) with clear NW–SE bedding. Quaternary sediments (Vinh Phuc Fm., Q₁^{2–3}vp): Variable thickness of clayey silt, sandy clay with gravel, and local laterite, forming the intermontane plain.

Structure and Faulting: The area lies within the Mai Chau–Tam Diep fault zone, between major NW–SE faults, with additional NE–SW faults intersecting the dam foundation. Field evidence shows strong deformation (fault zones III-1, IV-1), with folding and mylonitization at both abutments. The deformation zone exceeds ~400 m in width.

3.2. Subsurface structural characteristics from geophysical data

Figure 6 and 7 show profiles of electrical resistivity sounding at the measured line DT2-2 and DT2-3 respectively. Interpretation of geophysical profiles of reveal fault zones intersecting the dam alignment along survey lines DT2-1, DT2-2, and DT2-3. These tectonic faults are deep-seated, extending to depths of approximately 60–70 m, and trend predominantly NE–SW to sub-meridional.

The GPR results do not clearly indicate signs of seepage or cracking within the crest and toe areas of the dam in the investigated zone. However, localized anomalies can be observed at depths of approximately 3.5 m beneath the dam crest (Figure 8) and 4.0 m at the dam toe (Figure 9).

The geophysical results provide a key basis for the design and placement of Wells for engineering geological investigation along the main dam of Dap Troi Reservoir.

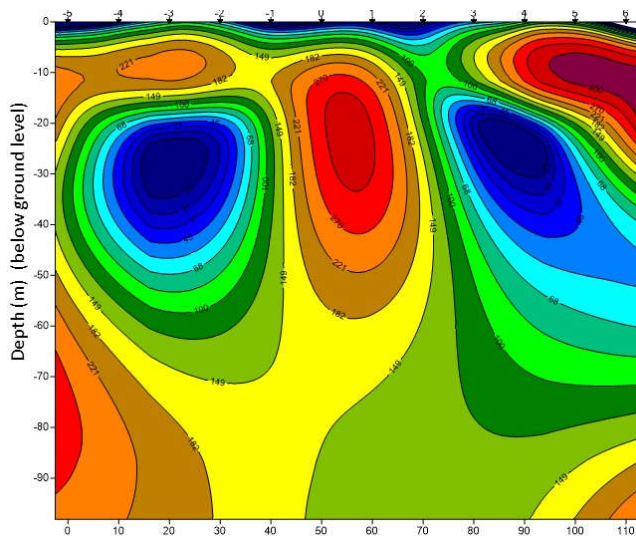


Figure 6. Electrical resistivity section along DT2-2 (blue zones indicate low-resistivity, water-bearing pathways).

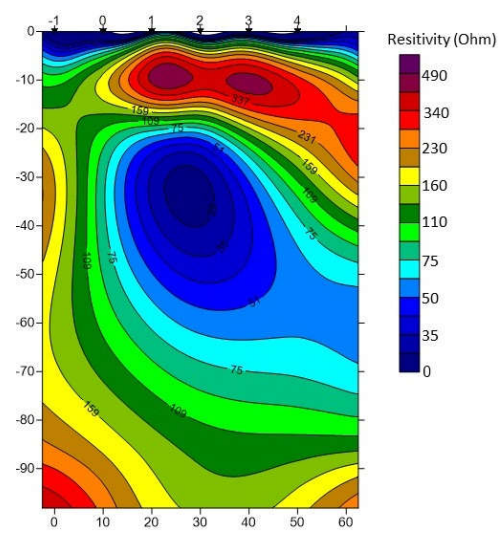


Figure 7. Electrical resistivity section along survey line DT2-3

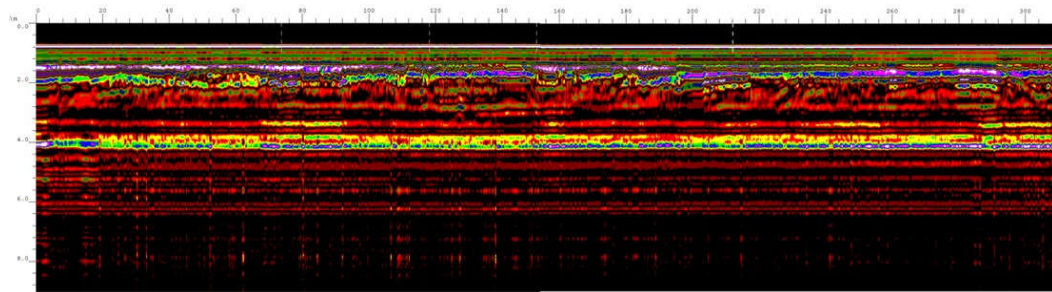


Figure 8. GPR results along the crest of the main dam at Dap Troi Reservoir (in the image, upward-convex features - reversed parabolic reflections - indicate anomalies occurring at depths of approximately 0–3.5 m

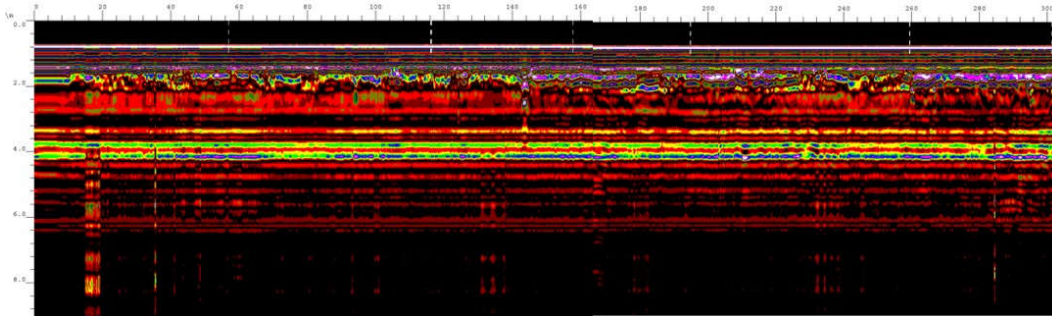


Figure 9. GPR results beneath the concrete road at the downstream toe of the main dam at Dap Troi Reservoir (in the image, upward-convex features—reversed parabolic reflections—indicate anomalies occurring at depths of approximately 0–4 m

Assessment of seepage and cracking hazards

Integration of monitoring data (2021–2023) with geological and geophysical investigations indicates that seepage control measures implemented during 2021–2022 have effectively mitigated seepage within the dam body. However, significant seepage persists at the dam toe, posing a potential risk of internal erosion (piping), progressive instability, and long-term structural failure.

Geophysical interpretation (ERT and GPR) reveals the presence of deep-seated fault zones intersecting the dam alignment (DT2-1 → DT2-2 → DT2-3), extending to depths of

approximately 60–70 m. These faults, trending NE–SW to sub-meridional, likely serve as preferential pathways for groundwater flow, contributing to sustained seepage beneath the dam.

Results indicate that the dam body consists mainly of unconsolidated materials (clay and clay–sand mixtures). Several anomalous zones were identified, likely representing voids or discontinuities associated with termite activity. These features may enhance seepage and pose risks of localized settlement, slope instability, and potential dam failure if not properly treated.

3.3. Engineering geological characteristics along the main dam alignment

Figure 10 shows the map and cross-section of engineering geology of the studied area. According to engineering geological classification, the weathering profile developed on the Co Noi Formations is divided into the following zones: Colluvial–residual zone (edQ): Clayey soil with rock fragments; thickness 1–7 m; widely distributed; consistency from plastic to loose; Moderately weathered zone (IB): Fractured bedrock with limonite infill along joints; brownish alteration along fractures; moderate strength; Slightly weathered zone (IIA): Weakly weathered rock with moderate fracturing; joints filled with hydrothermal minerals; high strength; and Relatively intact zone (IIB): Fresh, massive rock with minor fracturing; long core recovery; no secondary minerals (e.g., limonite); very high strength.

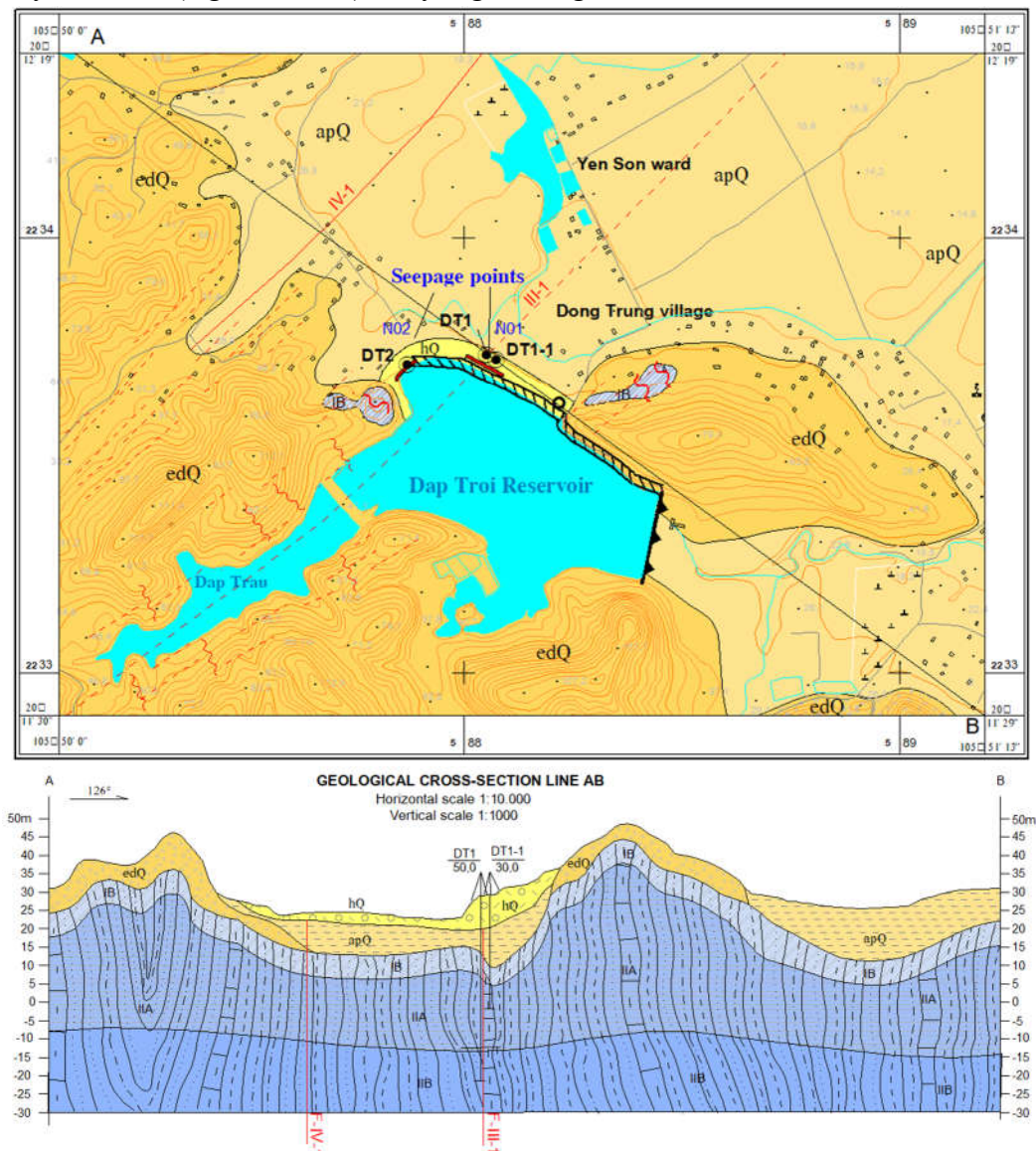


Figure 10. Sketch geoengineering map of Dap Troi Lake and surrounding areas

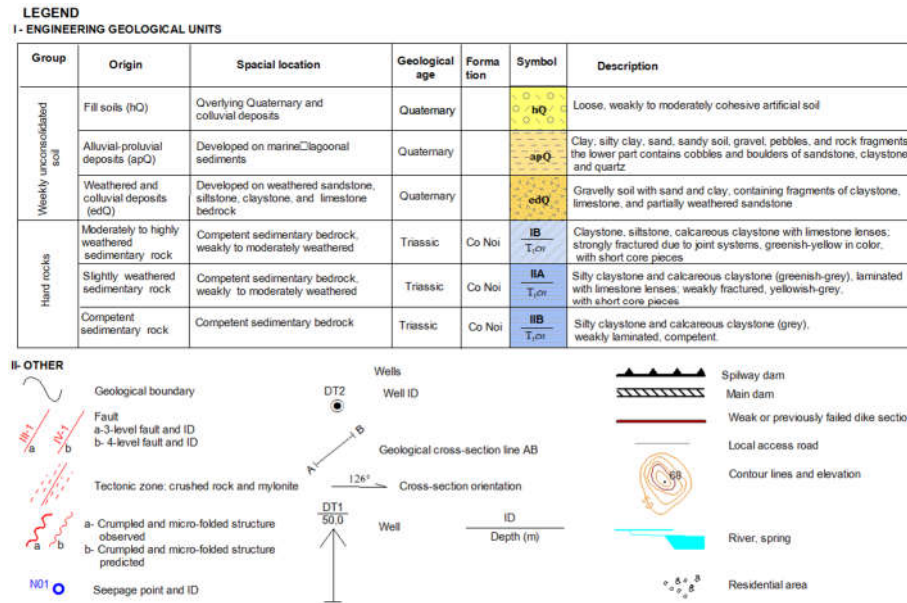


Figure 10. (continue)

3.4. Stratigraphy of Wells DT1, DT1-1, and DT2

Embankment fill soil (hQ) - Completely weathered (edQ) layers (fill, colluvial–residual soils): Thickness ranges from ~8–9 m at the dam toe (DT1, DT1-1) to ~11 m at the crest (DT2), and up to ~19 m in DT2 overall. Composed mainly of yellowish- to reddish-brown clayey soils with gravel, generally soft to plastic.

ApQ layer (alluvial–proluvial deposits): Present only in DT1 and DT1-1, absent in DT2. Thickness increases from ~6.5 m (DT1) to ~10 m (DT1-1). Lithology is heterogeneous, including gravelly clay–silt with sub-rounded to angular fragments (1–5 cm), mainly claystone (brown–grey tones) with minor calcite pebbles, sandy clay and coarse sand with gravels and a plastic greenish-grey clay layer occurs at 14.8–15.0 m

Moderately weathered rock (IB Zone): This competent rock layer occurs at depths ranging from 15.5 to 25.3 m, approximately 13–15 m below the reservoir bed. The lithological characteristics of Zone IB include greyish-green silty shale, strongly foliated and locally sheared, with variable fracturing along steep planes. Minor calcite veins and sparse clasts occur. Transitions to silty shale and marl with near-vertical fractures infilled by clay

Slightly weathered rock (IIA Zone): This zone extends from a depth of 25.3 m to the end of the Well at 50.0 m. It consists of bedded calcareous claystone, generally massive and intact. Core samples are recovered as long, continuous pieces with no significant fracturing.

Relatively intact (IIB Zone): This fresh rock with minor fracturing, overlain by the IIA Zone..

Table 1. Summary of the physical and mechanical properties of the embankment fill materials and the soil layers beneath the foundation of the main dam of the Dap Troi Lake

#	Physical and mechanical properties		Sym bol	Unit	Soil layers			Standard s for weak soils
					hQ	apQ	edQ	
1	Grain size comp ositio	Gravel and pebble	-	%	37.0	36.8	12.1	
		Sand content	-	%	15.6	24.7	25.6	
		Silt content	-	%	31.8	24.5	48.2	
		Clay content	-	%	15.6	14.1	14.2	

#	Physical and mechanical properties	Symbol	Unit	Soil layers			Standards for weak soils
				hQ	apQ	edQ	
2	Natural moisture content	W	%	32.4	26.7	26.9	≥ 40
3	Natural unit weight	γ_w	g/cm ³	1.8	2.0	1.8	≤ 1.70
4	Dry unit weight	γ_c	g/cm ³	1.4	1.6	1.4	
5	Specific gravity	γ_s	g/cm ³	2.7	2.7	2.7	
6	Porosity	n	%	48.6	42.0	47.4	
7	Void ratio	e	-	0.9	0.8	0.9	≥ 1
8	Degree of saturation	G	%	91.8	95.4	79.0	≥ 80.0
9	Liquid limit	W _L	%	38.9	31.6	34.8	
10	Plastic limit	W _P	%	26.1	19.3	22.7	
11	Plasticity index	I _P	%	12.8	12.2	12.1	
12	Consistency index	I _S	-	0.5	0.6	0.3	
13	Cohesion	C	kG/cm ²	0.27	0.27	0.34	≤ 0,1
14	Internal friction angle	ϕ	độ	24.8	20.4	26.9	≤ 10
15	Compression coefficient	a ₁₋₂	cm ² /kG	0.042	0.043	0.027	≥ 0,01
16	Allowable bearing capacity	R ₀	kG/cm ²	2.84	2.73	4.12	0.5 – 1.0
17	Deformation modulus	E ₀	kG/cm ²	73	84	127	≤ 50

3.5. Permeability characteristics of soil and rock layers based on test results and observations during drilling

Packer tests were conducted at Wells DT1 and DT2 with a total of 5 test intervals — 2 intervals at DT1 and 3 intervals at DT2. The results of the Well water pressure tests are presented in Table 2. In the Wells, particularly DT1 and DT1-1, within the apQ layer, there were several zones of strong water flow, complete water loss, and visible water streams. These locations exhibited very high permeability.

The permeability test results indicate that the coefficient of permeability in the transition zone between apQ and IB is 0.46 m/day, in the IB & IIA layer is 0.53 m/day, and in IB, IIA individually is 1.1 m/day (Table 2). In Well DT1-1, from depths of 7m to 22m, underground flows were observed. In Well DT2, within the IB and IIA zones, from 18.8m to 44m, several sections exhibited strong to very strong permeability (Table 2). The nature of the permeability is closely related to the presence of fractured zones and karstic cavities.

Table 2. Summary of seepage characteristics of the dam fill and underlying foundation soils based on engineering geological and hydrogeological wells at Dap Troi Reservoir

#	Physical and mechanical properties		Symbol	Unit	Soil layers			Standards for weak soils
					hQ	apQ	edQ	
1	Grain size composition	Gravel and pebble	-	%	37.0	36.8	12.1	
		Sand content	-	%	15.6	24.7	25.6	
		Silt content	-	%	31.8	24.5	48.2	
		Clay content	-	%	15.6	14.1	14.2	
2	Natural moisture content		W	%	32.4	26.7	26.9	≥ 40
3	Natural unit weight		γ_w	g/cm ³	1.8	2.0	1.8	≤ 1.70
4	Dry unit weight		γ_c	g/cm ³	1.4	1.6	1.4	
5	Specific gravity		γ_s	g/cm ³	2.7	2.7	2.7	

#	Physical and mechanical properties	Symbol	Unit	Soil layers			Standards for weak soils
				hQ	apQ	edQ	
6	Porosity	n	%	48.6	42.0	47.4	
7	Void ratio	e	-	0.9	0.8	0.9	≥ 1
8	Degree of saturation	G	%	91.8	95.4	79.0	≥ 80.0
9	Liquid limit	W _L	%	38.9	31.6	34.8	
10	Plastic limit	W _P	%	26.1	19.3	22.7	
11	Plasticity index	I _P	%	12.8	12.2	12.1	
12	Consistency index	I _S	-	0.5	0.6	0.3	
13	Cohesion	C	kG/cm ²	0.27	0.27	0.34	$\leq 0,1$
14	Internal friction angle	φ	$\dot{d}\varphi$	24.8	20.4	26.9	≤ 10
15	Compression coefficient	a ₁₋₂	cm ² /kG	0.042	0.043	0.027	$\geq 0,01$
16	Allowable bearing capacity	R ₀	kG/cm ²	2.84	2.73	4.12	0.5 – 1.0
17	Deformation modulus	E ₀	kG/cm ²	73	84	127	≤ 50

Figure 11. Illustrates the engineering geological cross-section of the dyke body section between Wells DT1 and DT1-I, showing the alluvial and floodplain deposits (apQ layer). Figure 11 presents the engineering geological cross-section from the dam crest through the dam body at Well DT1 to the dam toe, simulating the seepage process from the Dap Troi reservoir bottom through the hydrogeological window (apQ layer) and karst-fractured zones.

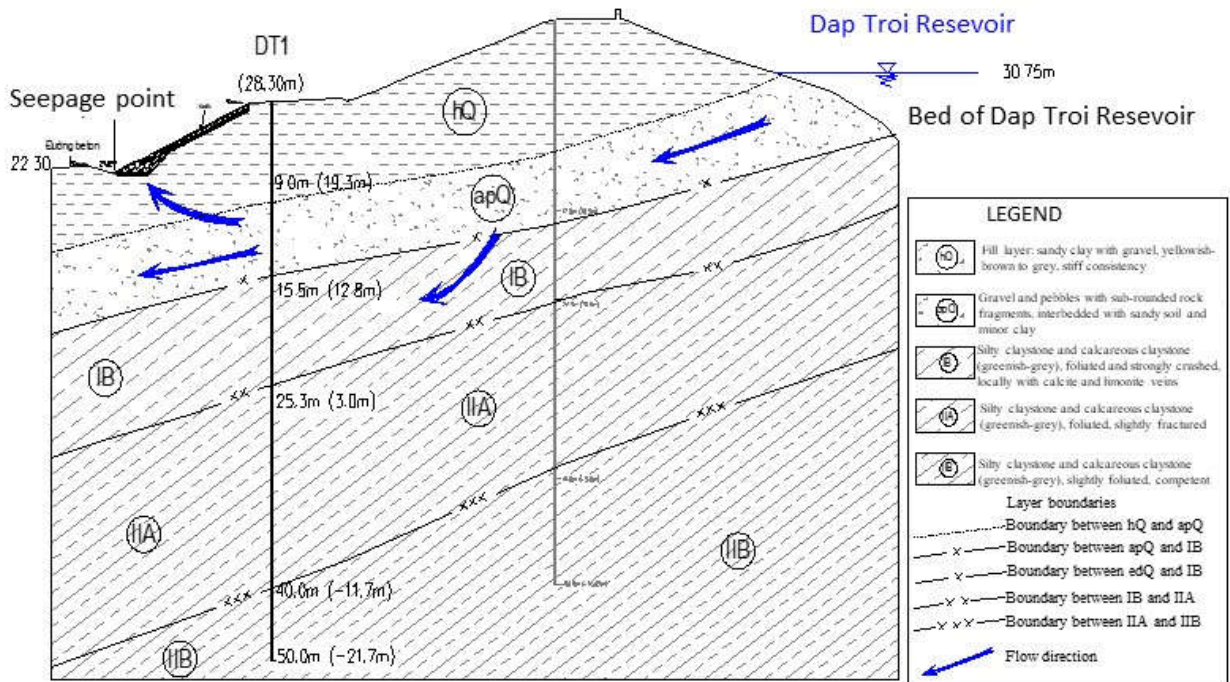


Figure 11. Engineering geological cross-section from the crest of Dap Troi Dam through its body (DT1) to the dam toe, illustrating seepage flow beneath the dam through the apQ layer

3.6. Causes of seepage hazards and proposed remedial measures

General Remarks

According to monitoring and analytical results, the apQ layer (alluvial and floodplain deposits) has a highly heterogeneous composition, including boulders mixed with clay and sand interbedded with gravel and cobbles. This leads to very high porosity, which facilitates water seepage.

The IB and IIA zones consist of siltstone and sandstone with interbedded thin limestone lenses. In these zones, fractured gravel zones have developed, often associated with tectonic faults. As a result, porosity is also high, promoting seepage processes.

When the reservoir is impounded, under high pressure, water from the reservoir flows through the voids in the apQ layer, karst cavities, and fractured zones in the IB layer toward the downstream area and toe of the dam. A conceptual model of the seepage flow is shown in Figure 11.

It should be noted that for safety reasons, the geotechnical and hydrogeological drilling investigations at the main dam axis of Dap Troi reservoir were intentionally scheduled during the dry season — the period when water levels in the reservoir are at their lowest. However, even under these conditions, signs of strong seepage were observed during drilling, including water loss in Wells, stream-like water flows, and audible water sounds in Well DT1-1. If such drilling were to be conducted during the rainy season (from July to November), when the reservoir water level is high, the resulting hydraulic pressure would be significantly greater and could lead to much stronger flow at seepage-prone zones.

Causes of seepage hazards

Objective causes: The main dam axis is located within a major fault zone, where the bedrock is intensely fractured to depths of 40–50 meters. Along this fault zone, an ancient riverbed was eroded and subsequently filled with thick alluvial and floodplain deposits (apQ) composed of cobbles and boulders, with thicknesses exceeding 10 meters

Subjective Causes: The dam construction was carried out over multiple phases, and no official design or as-built documentation is available. As a result, it is assumed that during the embankment and construction of the Dap Troi reservoir, the apQ layer was not properly excavated and cleaned. Additionally, the fractured rock zones in the bedrock foundation were not pressure grouted for seepage control, leading to the formation of large void zones that allow water to flow from the reservoir toward the downstream area. During the backfilling process to fill the old streambed and form the downstream dam base (downstream dike body), the compaction and reinforcement work was of poor quality and did not meet technical requirements. The hQ zone, as shown in cross-section Figures 11, exhibits a very high porosity of up to 48.6%, even higher than that of the apQ zone. Consequently, the downstream dike body fails to function effectively as an impermeable blanket or hydraulic pressure relief layer.

Proposed Remedial Measures

To mitigate seepage hazards through the foundation, it is recommended to implement deep pressure grouting. The grouting Wells should fully penetrate the apQ layer as well as the karst cavities within the IB zone. Based on available data, the required depth of the grouting Wells, measured from the dam crest, is estimated to range from 25 to 35 meters on average.

4. Conclusions

The persistent water leakage from Dap Troi reservoir has significantly impacted the daily life and agricultural production of the local population. Leaked water has caused farmland to remain waterlogged during the rainy season and suffer from water shortages in the dry season. Additionally, the leakage point is located near the inter-hamlet road, disrupting transportation for local residents. The seepage issue in the Dap Troi dam body has persisted for many years.

The primary cause of seepage is due to the main dam axis being situated within a major fault zone, where the bedrock is intensely fractured to depths of 40–50 meters. Along this fault

zone, an ancient streambed was eroded and subsequently filled with thick alluvial and floodplain deposits (apQ), with cobble and boulder layers reaching thicknesses exceeding 10 meters.

To address seepage hazards through the dam foundation, it is recommended to apply deep pressure grouting. The grouting Wells should fully penetrate the apQ layer as well as the karst cavities in the IB zone. Based on current technical documents, the required depth of grouting Wells measured from the dam crest is up to 35 meters.

5. References

Ninh Binh Statistics Office, 2022. Ninh Binh Statistical Yearbook 2021.

To Xuan Ban, Le Tien Dung, Tran Van Duc, Nguyen Huu Trong, 2023. Study, investigation, and assessment of potential geohazards along dike systems and reservoirs in Ninh Binh Province, with recommendations for safety measures in response to climate change and sea-level rise. Provincial-level science and technology project, Department of Science and Technology of Ninh Binh Province.

Department of Agriculture and Rural Development of Ninh Binh Province, 2021. Report on the assessment of the current condition of dike systems, identification of critical vulnerable sections, and dike protection plans for 2021 in Ninh Binh Province.

Ninh Binh Irrigation Works Exploitation One Member Co., Ltd., 2021. Project: Seepage control and leakage treatment for the main dam of Dap Troi Reservoir, Quang Lac Commune, Nho Quan District, Ninh Binh Province. Client: Ninh Binh Irrigation Works Exploitation One Member Co., Lt.

Hoang Ngoc Ky, 1996. Geological map of Ninh Binh (F-48-XXXIV), scale 1:200.000.

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