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# Stability Analysis of Dahaizi Dam under Different load Conditions

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**ABSTRACT:** Mathematical modelling using finite element methods in the field of dam and river engineering is continuously growing in recent years. This powerful tool is applied for modelling several types of dams, such as (earthen dams). The current study aims to extend the clear understanding of side slope stability and seepage beneath the Dahaizi Dam (Earth Dam) for different water levels and seismic force conditions. Results obtained from the Slide program revealed that the average flow rate of seepage at maximum, normal, and minimum water levels were  $35.5 \text{ m}^3/\text{d}$ ,  $28.15 \text{ m}^3/\text{d}$ , and  $1.641 \text{ m}^3/\text{d}$ , respectively. The Exit Gradient at all different water levels was less than 1.0, and maximum seepage velocity is within permissible limits. The stability of the Dahaizi Dam slopes was checked via the Morgenstern-Price method. Results revealed that the upstream and downstream sides of the dam have a direct effect on the factor of safety, with the minimum factors of safety (circular slip surface [0.835, 1.645, 1.864]) (block slip surface [1.162, 2.166, 2.172]), respectively. From the results, the Dahaizi Dam can be concluded to be safe against the danger of piping and slope failure for normal condition load, but it was critical in some cases of seismic load conditions.

**KEYWORDS:** Seepage; Slope Stability; Safety Factor; Dahaizi Dam; Finite Element Method.

## I. INTRODUCTION

Hydraulic structures are important components in the design of engineering structures and flow networks. Examples of hydraulic structures include dams, regulators, and barrages. They are used for multiple purposes, such as water storage, water transport, water control, energy dissipation, flow measurement, and sediment control.

The analysis of seepage through earth dams is important in dam design. It is conducted to calculate the amount of losses from a reservoir, estimate pore pressure distribution, and locate the position of free surfaces. These processes are used to evaluate dam stability against shear failure. In addition, studying the hydraulic gradient provides a general idea about potential piping [Sherard, 1963]. The analyses of slope stability and earth dam seepage are important to ensure the stability of structures.

Slope stability is an important aspect of geotechnical engineering. In general, linear problems, such as predicting settlements and deformations and calculating flow amounts due to steady and transient seepage conditions, are highly sensitive to the finite element solution. Its capability to solve complex problems has popularized the use of the finite element method in slope stability and seepage analyses in recent years [Pham, 2013].

The current research aims to examine the influence of different water levels on dam slope by conducting finite element analysis and investigate the failure mechanism. Slope stability and seepage analyses performed using computers are simple tasks for engineers when the slope configuration and the soil parameters are known. However, selecting a slope stability analysis method is a difficult task. Site conditions and failure observation data must be combined to determine the cause of failure, defining the slope stability analysis method to be used in the research. Hence, the theoretical context of each slope stability analysis method should be explored to evaluate slope failure and determine the reliability of the results. Given its simplicity, 2D slope stability analysis is one of the methods commonly used by engineers.

Many researchers studied stability of dam by using Finite element method. Aqeel et al. [Kubba, 2013] studied the checking of the safety of the upstream slope in an earth dam against sliding failure. It was found that the results obtained by hand calculation were close to the results obtained from the computer software in terms of safety factor value.

Obaid [2002] used a computation procedure by which the most critical slip surface and its relevant minimum factor of safety is obtained. He used this computation procedure to re-analyze the stability of upstream side slope of a zoned



earth dam (Haditha dam ) and found that the dam is safe under the different water level condition (minimum, maximum, and normal water levels).

In this work, presented a novel analysis of Dahazi Dam, the seepage behaviour of an earth dam is calculated by using the finite element method through simulation program (Slide version 6.2) to simulate the phreatic seepage line of Dahazi Dam under different loading conditions. Slide software is one of the most popular geotechnical programs based on finite element analysis. It can consider various analyses, such as stress-strain, seepage, slope stability, external loading (linear, distributed, or seismic), and water drawdown in a reservoir. Slope stability is analyzed using the Morgenstern Price method. Then, the minimum safety factor is determined, and the critical slip surface location is identified.

## II. SLICING METHOD

In the slicing procedure, soil mass on the sliding surface is divided into multiple vertical slices, and the equilibrium of each slice is considered. The actual number of slices depends on the geometry of the slope and the soil profile. However, the division of mass into a set of vertical parts is not a statically defined problem. To obtain the safety factor by using slicing methods, assumptions must be made to exclude other unknowns. These assumptions play a key role in distinguishing among methods. Many computer programs use slicing methods to address the effects of complex slope geometry, changing soil and water conditions, and the external limit of loads. Consequently, these techniques are the most widely used in slope stability analysis [Albatineh,2006].

Morgenstern Price is a general slicing method developed on the basis of limit equilibrium. It requires a satisfactory force and moment equilibria acting on individual blocks. Blocks are created by dividing the soil above the slip surface. In this method, a simplified assumption is made to explain the relation between shear forces around slice (X) and the normal slice force (E). shown as Equation 1 [Bishop,1955]:

$$X = \lambda \cdot f(x) \cdot E$$

In accordance with [Fredlund2011] shown in Fig. 2, the normal force is derived from the equation of the vertical force equilibrium. The unknowns solved using the Morgenstern Price method are the safety factor, scaling coefficient ( $\lambda$ ), normal force (P), horizontal interslice force (E), and position interslice force. Following the calculation of the unknowns described above by using equilibrium equations, the vertical portion of the resulting force on the interslice forces (X) is determined, shown as Equation 2.

$$P = \frac{[W - (XR - XL) - \frac{1}{F} (c' \sin \alpha - ul \tan \phi' \sin \alpha)]}{m_\alpha}$$

Two safety factor equations are calculated: one for moment equilibrium ( $F_m$ ) and the other for force equilibrium ( $F_f$ ). The equation for moment equilibrium is adopted with regard to a particular point, shown as Equation 3.

$$F_m = \frac{\sum [c'l + (P - ul) \tan \phi'] R}{\sum (W_d - P_f)}$$

on circular slip surfaces;  $u = 0$ ,  $d = R \sin \alpha$ , and  $R = \text{constant}$ , shown as Equations 4,5.

$$F_m = \frac{\sum [c'l + (P - ul) \tan \phi']}{\sum W \sin \alpha}$$

$$F_f = \frac{\sum [c'l + (P - ul) \tan \phi'] \cos \alpha}{\sum P \sin \alpha}$$

For the initial iteration, the vertical shear forces (XR and XL) are set as null. First, the horizontal interslice forces are determined from the subsequent iterations, shown as Equations 6.



$$(ER - EL) = P \sin \alpha - \frac{1}{f} [c'l + (P - ul) \tan \phi'] \cos \alpha$$

In summary, the Morgenstern Price method considers both interslice forces, suggests the interslice force function  $f(x)$ , enables interslice force function selection, and calculates the safety factor for the force and moment equilibria [Aryal,2006]. This method is used to analyze slope stability, and it is applicable to the slip surface of any random shape [Baker,1980].

Seismic activities are associated with complicated wobbling patterns of acceleration and ground displacement, resulting in transient dynamic loads due to a dam’s inertia and water retention. Vertical and horizontal accelerations are incomparable, and the former is more complex. Both accelerations should be considered operational for design purposes in the least desirable context to achieve dam stability. Therefore, a conclusion can be drawn that horizontal acceleration works normally along the axis of a dam [Novk,2007]. When the seismic coefficients are determined, the seismic force shall be used as follows for each slice, shown as Equations 7.

$$\text{Seismic Force} = \text{Seismic Coefficient} * \text{Slice Weight}$$

### III. CASE STUDY

The Dahaizi Dam project is located at the southern district of Huili County of Liangshan Prefecture, China. The dam type adopts the gravel soil homogeneous earth dam. The Dam consist of three parts; body of dam, filter and foundation reinforced by stone column with curtain grouting material for ant seepage. the maximum dam height is 11.1m and the dam axis length is 304 m. the upstream slope is two-level slope, both 1:2.5, and the 10m wide horse track is set at the elevation of 1816m; The downstream slope is a two-stage slope with a range of 1:2.25 and 1:1.75 from top to bottom and a 1.0m wide track at 1815.00m. The cross section of the dam is shown in Figure 1,a. According to China Earthquake Zoning Map, the project area of peak ground motion acceleration is 0.10g, earthquake-proof engineering categories are graded and the geological parameters and feature water table for Dahaizi Dam shown in Tabs. 1,2

Tab. 1 Geological Parameters of Dahaizi Dam

Index Name	Hydrauli c conductivity (m/s)	Cohes ion c (kPa)	Unit Weight p (kn /m3)	Friction Angle ϕ (degree)
Dam body	5.7e-7	12	17.95	0.413
Clay layer	6.6e-8	13	17.952	0.42
Organic Clay layer	5.6e-8	10	14.9112	0.3
Mudstone layer	3.1e-6	28.7	19.03	0.25

Tab. 2 Feature water table

Water level	upstream water level (m)	Downstream water level(m)
Normal water level	1821.70	1812.80
Minimum water level	1816	1811
maximum water level	1823.60	1815

The finite element method is adopted in the current analysis. A three-node triangle element is used to depict the domains. The mesh contains 30,000 elements and 12,766 nodes. The first step in this analysis involves selecting the number of elements. The values are selected when the number of elements becomes independent of the solution, shown in Figures1,b.

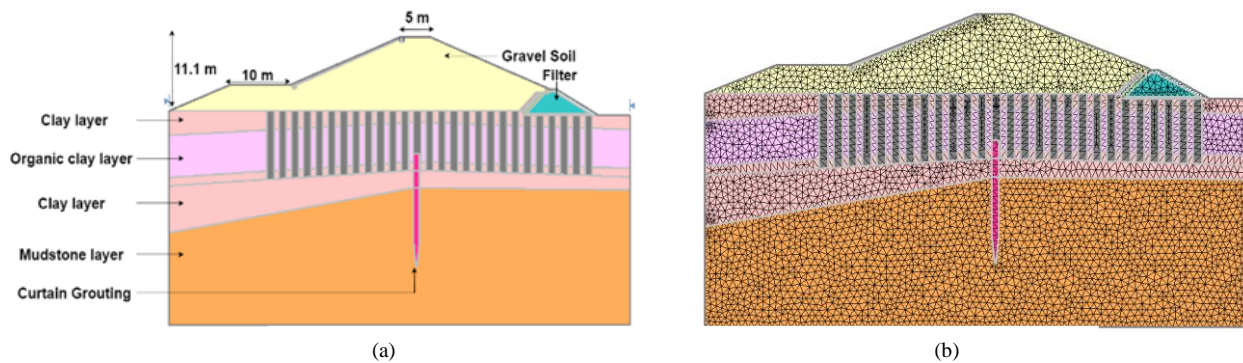


Fig. 1. Dahaizi Dam (a) Typical cross section of the Dahaizi Dam (b) Finite element method applied to Dahaizi Dam.

### VI. ANALYSIS RESULTS

To estimate the amount of water flow through the body and the Dahaizi Dam foundation was used via a Slide program software, and flownet shown in Figures 2. The flownet consists of streamlines, equipotential lines, velocity vectors, and phreatic line. Flownet presents an obvious fact that the stream and equipotential lines are normal to one another, which is consistent with the theory of seepage [Arshad, 2019].

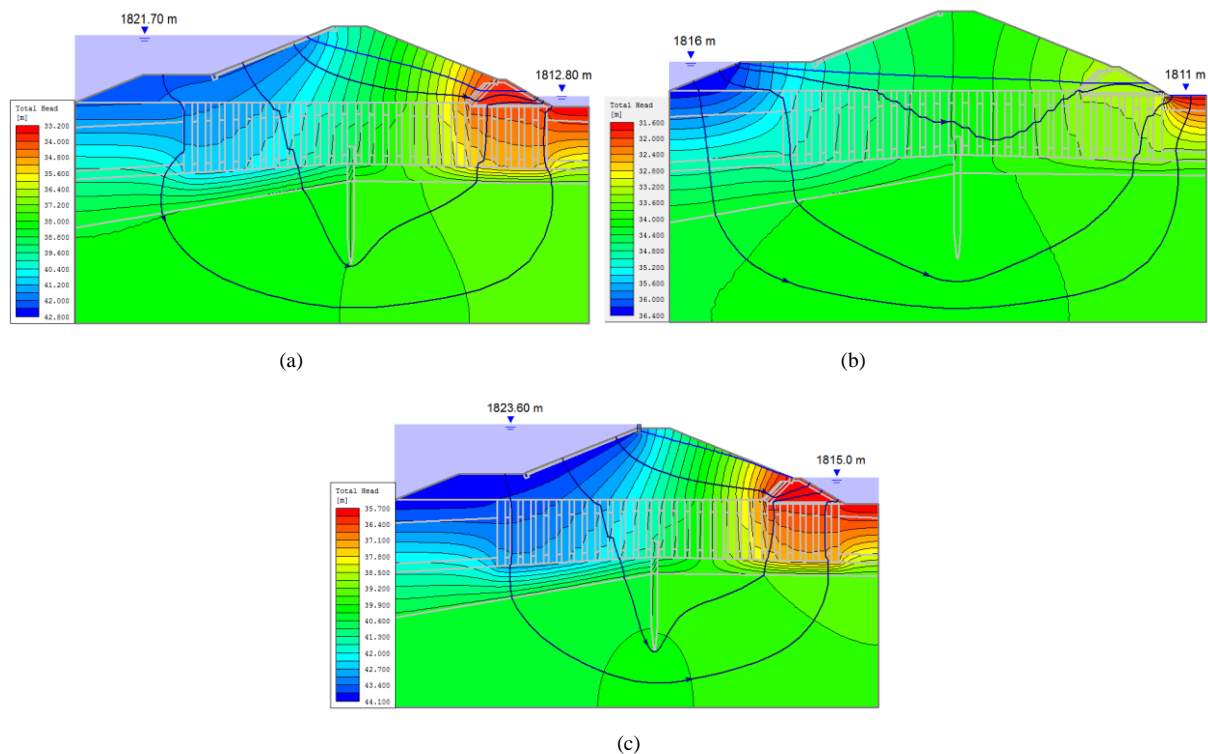


Fig. 2. Text Detection and Inpainting (a) Seepage flow for normal water level (b) Seepage flow for minimum water level (c) Seepage flow for minimum water level

The results also display the seepage flux, exit gradient, and maximum seepage velocity for the selected cross section at different water levels as shown in Table 3. The results revealed that minimum seepage (0.0055166 m<sup>3</sup>/d) was found when the water level in the dam was at lower elevation (EL 1,816 m). Furthermore, the maximum seepage (0.12665 m<sup>3</sup>/d) was recorded when the water level in the dam was at a higher elevation (EL 1,823.6 m). However, at normal water level (EL 1,827.7 m), the seepage was recorded (0.0926 m<sup>3</sup>/d).



Tab. 3 Computed seepage flux, exit gradient, and maximum seepage velocity for different water levels

Parameters	Water levels		
	minimum	maximum	normal
Seepage flux $m^3/d$	1.641	35.5	28.15
Exit gradient	0.0663	0.114	0.118
Max. seepage velocity $m/d$	0.055	0.219	0.380

By contrast, the output report also found that the pressure head increases with the increasing water levels in the dam. The graphical representation of Pressure Head Versus Distance along the base of the dam in three water levels namely, normal, minimum, maximum water levels, respectively, shown in Figures 3.

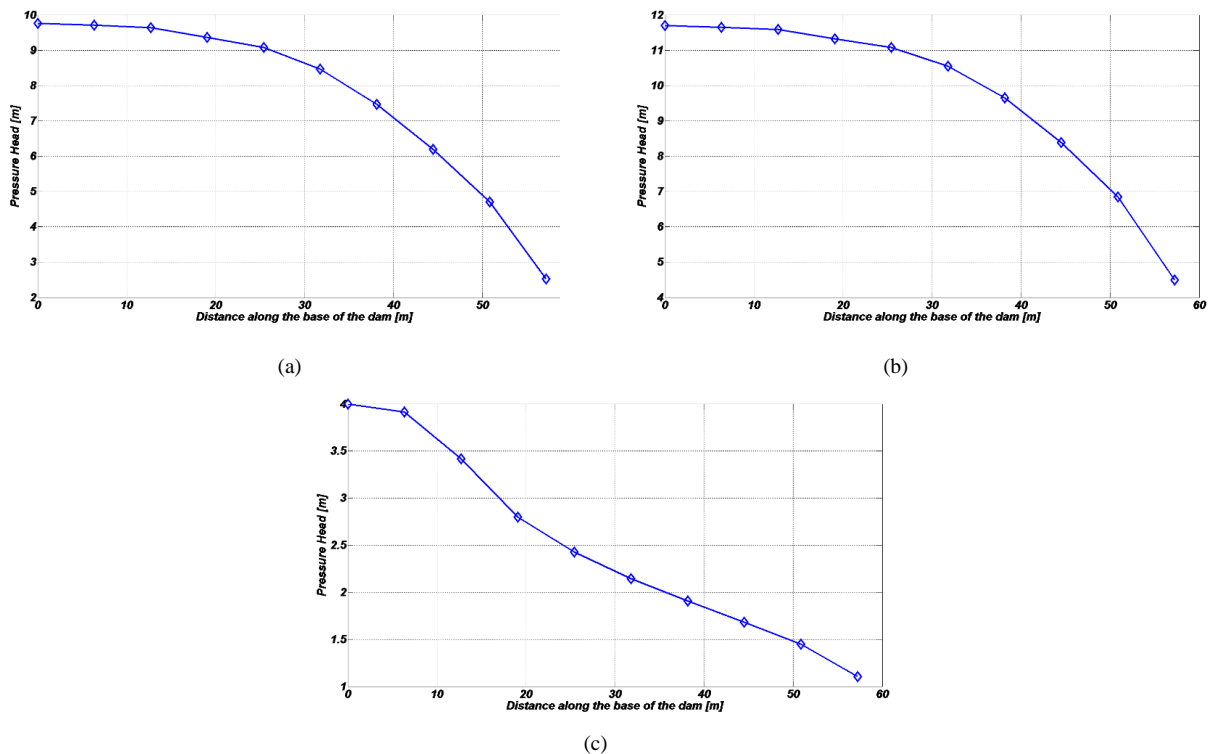


Fig.3 Pressure Head Versus Distance along the base of the dam (a) under normal water level condition (b) under maximum water level condition (c) under minimum water level condition

The results indicated that using the soils efficient shear strength characterization is necessary when conducting slope stability analysis. The computed safety factor obtained using a characterization of the soils total shear strength does not concur with the safety factor determined using the finite element method. The calculation results determine the law of changes in the least coefficient of safety with changes in water level and subsequently reflect the effects of different parameters and calculation methods on the slope stability analysis results. From the Slide software simulations, the minimal safety factors for all the loading cases can be observed to have only one critical surface close to the outer surfaces. The safety factor results are computed using the MorgensternPrice method without a seismic load, as shown in Table 4, under all water level conditions. However, the safety factor is reduced for seismic loads with a horizontal acceleration at 0.1 g, making the slopes unstable. Accordingly, the safety factors decrease with an increase in slope dip

and horizontal acceleration. Table 5 provides the safety factor values with seismic loads of 0.1 g and 0.15 g. The position of the critical slope surface and the safety factors obtained using the Morgenstern-Price method with and without seismic loads are illustrated in Figure 4.

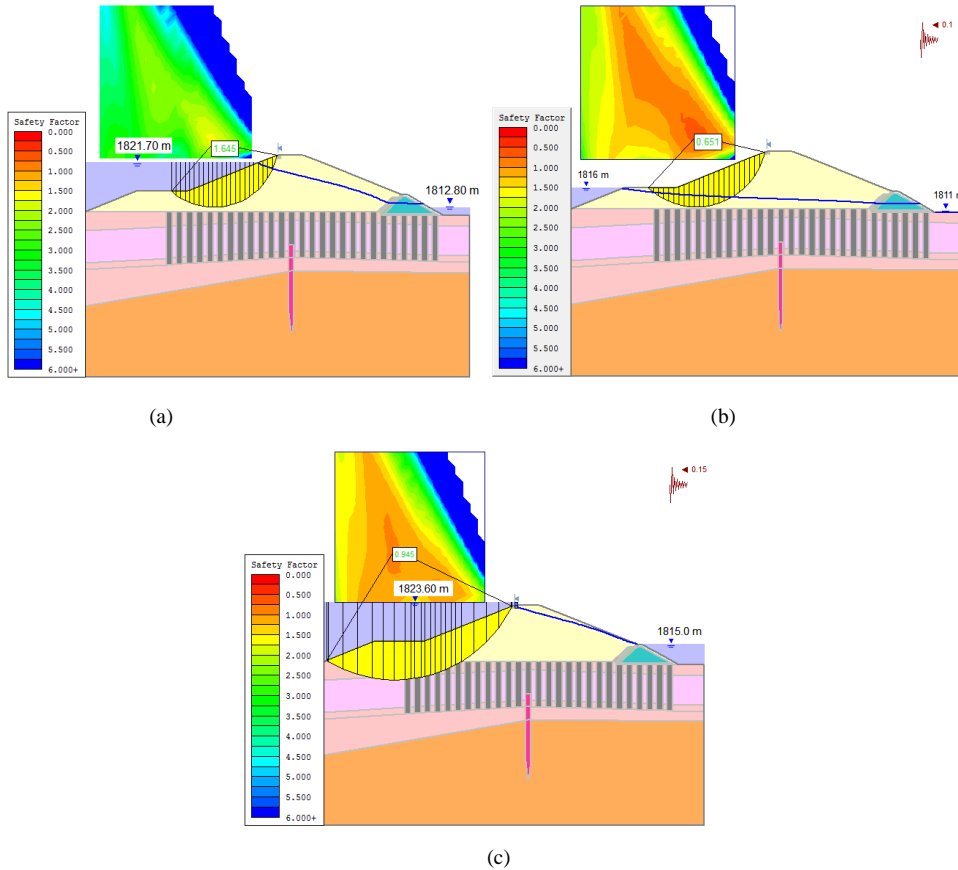


Fig. 4. Location and value of the most critical slip surface (circular slip surface) obtained using the Morgenstern–Price (a) method without a seismic effect(0) for normal water level (b) with a seismic effect (0.1) for minimum water level (c) with a seismic effect (0.15) for maximum water level.

Tab. 4 Computational results of minimum Safety factor without seismic load

Water levels	Type of Slip surface	upstream	downstream
Normal water level	Circular grid	1.645	0.791
	block	2.166	1.411
Max. water level	Circular grid	1.864	0.809
	block	2.172	1.021
Min. water level	Circular grid	0.835	0.775
	block	1.162	1.914



Tab. 5 Computational results of minimum safety factor with seismic load

Water levels	Type of Slip surface	upstream		downstream	
		e=0.1g	e=0.15g	e=0.1g	e=0.15g
Normal water level	Circular grid block	1.066	0.896	0.640	0.581
		1.182	0.957	0.913	0.871
Max. water level	Circular grid block	1.159	0.923	0.659	0.599
		1.171	0.957	0.744	0.757
Min. water level	Circular grid block	0.651	0.585	0.585	0.666
		0.800	0.688	1.425	1.549

On the basis of the slope factor of the security software analyses and studies on the stability of the terrains slope (after analysis), the data were divided into three groups of safety factors (FS) varying in landslide intensity are shown in Tab. 6 in accordance with Bowles [2019].

Tab. 6 Classification of slope stability (Bowles, 1991)

Safety factor	Slope condition
$FS \leq 1.07$	Unstable
$1.07 \leq FS \leq 1.25$	Critical
$FS \geq 1.25$	Stable

## VI. CONCLUSION

This research drew a set of conclusions by using the finite element method with Slide software to conduct a case study of Dahaizi Dam, including seepage and slope stability analyses. Clear convergence was observed in the results. The average seepage flow at maximum, normal, and minimum water levels were 35.5, 28.15, and 1.641 m<sup>3</sup>/d, respectively. The water loss in Dahaizi Dam ultimately increased, and the exit gradient value (less than 1.0) and maximum seepage velocity were within permissible limits, indicating the absence of piping danger under all water level conditions. That is, Dahaizi Dam is safe from seepage and piping dangers. The slope stability analyses of the upstream and downstream sides were checked using the MorgensternPrice method. The safety factor values changed with a change in slip surface type. For the upstream side, the results indicated that the safety factors were circular slip surface (1.45, 1.864, 0.835) and block (2.166, 2.172, 1.162) for normal, maximum, and minimum water levels. For the downstream side, the results showed that the safety factors were circular slip surface (0.791, 0.809, 0.775) and block (1.411, 1.021, 1.914) for normal, maximum, and minimum water levels. The value of the safety factor was more sensitive to seismic force. The safety factor was critical when seismic load was 0.15 g and 0.1 g under minimum water level condition. In accordance with the current study, the side slope stability of Dahaizi Dam was critical and unstable against side failure in some cases.

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