

Article

Study on Threshold Values of Safety Control Indicators for Rapid Drawdown of 200~300 m High Earth-Rockfill Dams

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Abstract

High dams and large reservoirs serve flood control, power generation, water supply and ecological security, where rapid safe drawdown is vital for emergency handling and long-term safe operation. Targeting undefined rapid drawdown control standards for over-200 m ultra-high earth-rockfill dams, this study selects 200 m, 250 m and 300 m earth core rockfill dams for finite element calculations of transient unsaturated seepage and slope stability under varying drawdown rates. It analyzes how drawdown rate, drawdown depth and dam height affect dam safety, and tests the sensitivity of rockfill shear strength indices. Results reveal rapid drawdown produces prominent phreatic line lag, which worsens with faster drawdown and taller dams. Slope safety factors fall then rise during water level decline with a critical minimum, and taller dams respond more sensitively to drawdown rate. The allowable drawdown limits are 10 m/d, 8 m/d and 6 m/d for 200 m, 250 m and 300 m dams, paired with maximum safe drawdown depths of 108 m, 140.4 m and 154.8 m. Rockfill cohesion c is highly sensitive at 0–40 kPa; each 2° rise in internal friction angle φ lifts the safety factor by roughly 7.3%. The findings offer theoretical and technical references for drawdown facility design and emergency regulation of reservoirs with dams exceeding 200 m.

Keywords: high earth-rockfill dam; rapid drawdown; drawdown rate; drawdown depth; safety factor



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1. Introduction

High dams and large reservoirs [1–3] are key infrastructure to ensure national energy security, water security and sustainable economic and social development, and play an irreplaceable strategic role in basin flood control, hydropower generation, water supply and ecological security. With the continuous advancement of hydropower development in the Jinsha River [4,5], Yalong River [6,7], Lancang River [8–10] and other basins in southwest China, a number of 200 m-class and 300 m-class ultra-high earth-rockfill dams [11,12] have been completed and put into operation. The operation safety of high dams and large reservoirs has become a focus of great attention in the industry and society.

In recent years, emergencies such as earthquakes, heavy rainfall and debris flows have occurred frequently. Barrier lake and mountain landslide river-blocking events have occurred many times in the Jinsha River, Yarlung Zangbo River, Niulan River and other

basins [13–16], which have put forward higher requirements for the emergency disposal capacity of water conservancy and hydropower projects. After a disaster occurs, rapid and safe drawdown [17,18] is the most direct and effective measure to reduce the risk of dam break of high dams and large reservoirs and curb the chain expansion of disasters. Accidents such as the dam instability caused by landslide surges in the Cascade Mountains of the United States in 1966 [19], the barrier dam break disaster on the Nosteyuko River in Canada in 1983 [20], and the Hongshiyuan Barrier Lake danger during the Ludian Earthquake in Yunnan in 2014 [21,22] have all provided painful lessons that the safe drawdown and emergency risk control capabilities of high dams and large reservoirs are directly related to public safety and the overall stability of the basin.

During the reservoir drawdown process, complex mechanical and physical coupling effects occur between water and the rock and soil mass of the dam body. On the one hand, water–rock interaction deteriorates the soil structure and reduces particle bonding and shear strength [23,24]. On the other hand, the rapid drop of reservoir water level causes a significant lag in the phreatic line inside the dam body, and pore water pressure cannot dissipate in time, leading to a decrease in the effective stress of the dam slope, an increase in sliding force, and a significant weakening of anti-sliding capacity [25,26]. Many earth-rockfill dams at home and abroad have experienced upstream dam slope landslides due to out-of-control water level drop rates [27]: in 1970, the upstream surfaces of the left and right dam sections of Qiyi Reservoir in Jiangxi Province became unstable due to the excessive drop rate of the reservoir water level; in 1979, the Shiziyuan Earth-Rockfill Dam in Hubei Province suffered an upstream dam slope landslide caused by a sudden water level drop during emptying and maintenance, which seriously threatened the safe operation of the hub. The above engineering practices show that scientifically controlling the reservoir water level drop rate is the core link to ensure the safety of drawdown.

Domestic and foreign scholars have achieved a large number of research results around the influence of reservoir water level changes on the seepage and dam slope stability of earth-rockfill dams. Viratjandr et al. [28] numerically analyzed the law of slope stability under sudden water level changes and unsteady seepage, and clarified the controlling effect of phreatic line morphology on the safety factor. Berilgen et al. [29] pointed out that a sudden drop in water level will significantly reduce the safety factor of the dam slope, which will gradually recover with the dissipation of pore water pressure. Zhang et al. [30] summarized the failure modes of high dams and concluded that rapid drawdown is a key control condition for high core wall rockfill dams. Al-Khyat et al. [31], Omofunmi [32], and Aniskin et al. [33] carried out analyses on drainage measures, transient effects and multi-factor sensitivity respectively, providing a theoretical basis for drawdown safety control. Ri et al. [34] verified previous results using centrifugal model tests and determined that the contact surface between the core wall and transition material is the main weak seepage part. Despite considerable progress in the investigation of rapid reservoir drawdown, previous studies have mainly focused on conventional earth dams and medium-height embankment dams. Systematic investigations on transient seepage behavior and slope stability of super-high core rockfill dams exceeding 200 m remain limited. In particular, quantitative studies on the safe reservoir drawdown threshold for 300 m-class dams are still lacking. First, most previous studies have focused on conventional earth dams or steady-state seepage conditions, while the transient seepage response of high core rockfill dams subjected to rapid drawdown remains insufficiently investigated. Second, the coupled influence of drawdown rate, unsaturated hydraulic behavior, and hydraulic hysteresis on phreatic surface evolution has not been fully understood. Third, the relationship between transient pore water pressure redistribution and slope stability variation requires further clarification.

The main purpose of this paper is to clarify the threshold values of safety control indicators for rapid drawdown of ultra-high earth-rockfill dams above 200 m; the objectives are to (1) characterize the evolution of phreatic surface and pore water pressure under rapid drawdown; (2) reveal the hydraulic mechanisms controlling transient seepage behavior; and (3) evaluate the impact of transient seepage processes on slope stability. The findings provide new insights into the safety assessment of high core rockfill dams during rapid reservoir drawdown. For this purpose, a two-dimensional finite element model of a typical section of a high earth core wall rockfill dam is established to carry out calculations of the transient unsaturated seepage field and dam slope anti-sliding stability under different reservoir water levels and drawdown rates, systematically analyze the seepage characteristics of the dam body and the variation law of the dam slope safety factor, and finally propose the control indicators of safe drawdown rate and drawdown depth applicable to high dams and large reservoirs. The research results can provide theoretical basis and technical support for the design of drawdown facilities, emergency dispatching and operation safety guarantee of high dams and large reservoirs above 200 m.

2. Materials and Methods

2.1. Analysis Methods for Transient Unsaturated Seepage and Dam Slope Stability of Dam Slopes

(1) Governing Equation for Transient Unsaturated Seepage

The seepage of the dam body during the drawdown process obeys the theory of transient unsaturated seepage, and the governing equation is as follows:

$$\frac{\partial}{\partial x} \left(k_x \frac{\partial H}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_y \frac{\partial H}{\partial y} \right) + Q = \frac{\partial \theta}{\partial t} \quad (1)$$

where k_x and k_y are seepage coefficients in the x and y directions (m/d); θ denotes saturated volumetric water content (m^3/m^3); t represents time (d); Q refers to the flow rate (m^3/d), and H stands for the total head (m).

The governing equation was discretized in space using the standard Galerkin finite element formulation. After spatial discretization, the governing equation can be written in matrix form as:

$$C(H) \frac{dH}{dt} + K(H)H = F \quad (2)$$

where C denotes the capacity matrix related to the volumetric water content, K is the hydraulic conductivity matrix, H is the nodal total head vector, and F represents the external flux vector.

An implicit backward Euler scheme was adopted for temporal discretization, leading to:

$$\left[\frac{C}{\Delta t} + K \right] H^{n+1} = F^{n+1} + \frac{C}{\Delta t} H^n \quad (3)$$

Because both the hydraulic conductivity and water storage capacity vary with pressure head under unsaturated conditions, the governing equation is nonlinear. Therefore, the nonlinear system was solved iteratively using the Newton–Raphson method until the prescribed convergence tolerance was satisfied. The slope stability was evaluated using the limit equilibrium method with the simplified Bishop formulation.

(2) Unsaturated Shear Strength Theory

The double stress variable theory is used to describe the unsaturated soil shear strength, and the expression is:

$$\tau_f = c' + (\sigma_f - u_a)_f \tan \phi' + (u_a - u_w) \tan \phi^b \quad (4)$$

where c' is the intercept of the Mohr–Coulomb failure envelope on the shear stress axis at zero net normal stress and zero matrix suction at failure; $(\sigma_f - u_a)_f$ represents the net normal stress state on the failure surface upon failure; φ' denotes the internal friction angle corresponding to the net normal stress variable $(\sigma_f - u_a)_f$ ($^\circ$); $(u_a - u_w)$ refers to the matrix suction (kPa), and φ^b stands for the friction angle associated with matrix suction ($^\circ$).

(3) Safety Factor of Slope Stability

The simplified Bishop method is used for the anti-sliding stability analysis of the dam slope, and the formula for solving the safety factor is:

$$F_s = \frac{1}{\sum W_i \sin \alpha_i} \sum \left[\frac{c'_i b_i + (W_i - u_i b_i) \tan \varphi'_i}{m_{\alpha i}} \right] \quad (5)$$

where F_s is a variable existing on both sides of the equation and solved via an iterative method; c'_i and b_i represent the soil cohesion (kPa) and the width of the soil slice (m), respectively; α_i and φ'_i denote the inclination angle of the soil slice bottom and the soil internal friction angle ($^\circ$), respectively; W_i and u_i stand for the gravity of the soil slice (kN/m^3) and the pore water pressure (kPa), respectively; and $m_{\alpha i}$ is the correction factor related to the inclination angle of the slice base.

2.2. Generalized Model Parameters

2.2.1. Profile and Geometric Parameters

Based on the typical profile conditions of many high earth-rockfill dams at home and abroad (see Table 1), the upstream dam slope ratio is concentrated in the range of 1:1.8~1:2.0, and the downstream dam slope is basically consistent with the upstream. Accordingly, the typical profile of the generalized model in this study is determined as follows: the upstream slope ratio is 1:2.0, and the downstream is consistent with the upstream (Figure 1).

Table 1. Summary of dam slope ratios of high earth-rockfill dams at home and abroad.

Serial No.	Project Name	Dam Height (m)	Slope Ratio	
			Upstream	Downstream
1	Rogun	335	1:2.40 1:2.00	1:2.00
2	Rumei	315	1:2.10	1:2.00
3	Shuangjiangkou	314	1:2.00	1:1.90
4	Nurek	300	1:2.25	1:2.20 1:1.70
5	Lianghekou	295	1:2.00	1:1.50 1:1.60
6	Nuozhadu	261.5	1:1.90	1:1.80
7	Chicoasen	261	1:2.10	1:2.00
8	Tehri	260	1:2.50	1:2.00
9	Guavio	247	1:2.00 1:1.80	1:1.80
10	Maija	244	1:2.25	1:1.50 1:2.00
11	Changheba	240	1:2.00	1:2.00
12	Chivor	237	1:2.00 1:1.80 1:2.2	1:1.70 1:1.80
13	Oroville	230	1:2.6 1:2.75	/
14	Keban	207	1:1.86	1:1.86
15	San Roque	200	1:2.00	1:2.00

Table 1. Cont.

Serial No.	Project Name	Dam Height (m)	Slope Ratio	
			Upstream	Downstream
16	Pubugou	186	1:2.00	1:2.00
17	Bennett	183	1:2.20	1:2.00
18	Takase	176	1:2.50	1:2.10
19	Fierze	166	1:2.60	1:2.75
20	Kremasta	165	1:2.75	1:2.00
21	Trinity	164	1:2.00	1:2.00
22	Talbingo	162	1:2.50	1:2.50
23	Xiaolangdi	160	1:4.00	1:3.00
			1:2.00	1:2.00
			1:2.60	1:1.75

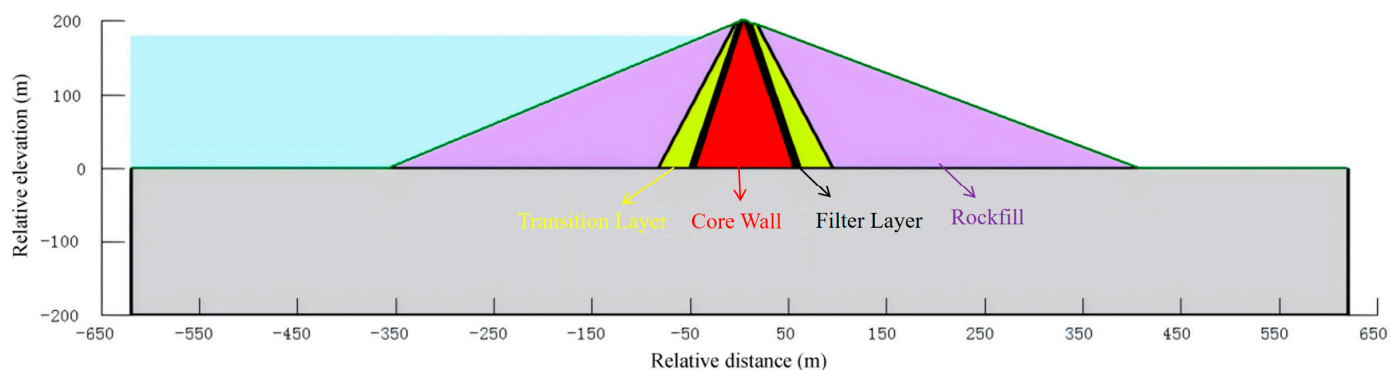


Figure 1. Typical profile of the generalized model.

2.2.2. Material Parameters

The dam shell material of a high earth core wall rockfill dam is the main body maintaining the stability of the dam body and is the partition with the most types of materials used. The dam body structure zoning of the model mainly includes core wall material, transition layer, filter layer and rockfill material. The physical and mechanical parameter values of each partition are shown in Table 2. According to statistics, the shear strength index range of dam shell materials from hard rock, weathered rock material, soft rock to sand gravel is $c = 0 \text{ kPa} \sim 350 \text{ kPa}$, and the internal friction angle index range is $\varphi = 35^\circ \sim 61.2^\circ$. Therefore, this study refers to the verified back-analysis parameters by Guo et al. [35], and formulates the most dangerous shear strength index $c = 0 \text{ kPa}$ and the conventional internal friction angle index $\varphi = 44.4^\circ$.

Table 2. Values of physical and mechanical parameters of each partition (the material parameters are from Guo et al. [35]).

Material	Saturated Permeability Coefficient (m/d)	C (kPa)	φ ($^\circ$)
Rockfill Material	69.1	0	44.4
Core Wall Material	3×10^{-5}	6.0	35.0
Transition Layer	25.9	0	53.8
Filter Layer	6.9	14.5	56.0

It should be clarified that the core wall material in this model is a clay–silt–fine gravel composite impervious material rather than homogeneous pure soft clay. Traditional pure

clay core usually has an internal friction angle close to 0° , but such material is rarely applied to dams higher than 200 m due to excessive compression deformation and cracking risks. The shear strength indices of the core wall ($c = 6.0$ kPa, $\varphi = 35.0^\circ$) are quoted from the verified back-analysis results of a real high core rockfill dam in Guo et al. [35], which can accurately reflect the mechanical characteristics of gravel-mixed clay core materials in high dam projects.

2.3. Calculation Scenarios

In this study, three representative dam heights of 200 m, 250 m, and 300 m were selected to represent the typical range of high core rockfill dams currently in operation or under construction in southwestern China. These dam heights were chosen to systematically investigate the influence of dam height on transient seepage behavior and slope stability during reservoir drawdown.

For each dam height, eight reservoir drawdown scenarios were established with drawdown rates ranging from 4 m/d to 18 m/d at intervals of 2 m/d (i.e., 4, 6, 8, 10, 12, 14, 16, and 18 m/d). The selected drawdown rates were determined based on engineering operation requirements, published studies, and potential emergency reservoir operation scenarios. They cover both routine reservoir regulation conditions and rapid drawdown situations that may occur during flood control or emergency reservoir dispatching, thereby representing both typical and extreme operating conditions for high dams and large reservoirs in southwestern China.

The upstream and downstream slope ratios of the dam were both set to 1:2.0. The initial reservoir water levels were 180 m, 230 m, and 280 m for the 200 m, 250 m, and 300 m dams, respectively, while the final reservoir water level for all cases was set at the reservoir bottom. The duration of each drawdown scenario was determined by the ratio of the total drawdown depth to the prescribed drawdown rate. The detailed settings of each calculation scenario are shown in Table 3.

Table 3. Research scenario settings.

Scenario No.	Dam Height (m)	Upstream Slope Ratio	Downstream Slope Ratio	Drawdown Rate (m/d)	Initial Water Level (m)
Scenario 1	200, 250, 300	1:1.20	1:1.20	4	180, 230, 280
Scenario 2	200, 250, 300	1:1.20	1:1.20	6	180, 230, 280
Scenario 3	200, 250, 300	1:1.20	1:1.20	8	180, 230, 280
Scenario 4	200, 250, 300	1:1.20	1:1.20	10	180, 230, 280
Scenario 5	200, 250, 300	1:1.20	1:1.20	12	180, 230, 280
Scenario 6	200, 250, 300	1:1.20	1:1.20	14	180, 230, 280
Scenario 7	200, 250, 300	1:1.20	1:1.20	16	180, 230, 280
Scenario 8	200, 250, 300	1:1.20	1:1.20	18	180, 230, 280

3. Results

This paper establishes a two-dimensional calculation model of the typical section of the dam, and studies the variation laws of the seepage field and dam slope safety factor of the high earth core wall rockfill dam slope under different reservoir water levels and drawdown rates by the finite element method.

3.1. Analysis of Dam Slope Seepage Characteristics

The variation law of the phreatic line when the drawdown reaches the maximum depth in each scenario is analyzed. The variations in the dam body phreatic line under different dam heights and different drawdown rates are shown in Figure 2. The dam height has little influence on the distribution law of the phreatic line inside the dam

body. With the increase in drawdown depth, the height of the phreatic line inside the dam body decreases accordingly, but its drop rate is much lower than the increase rate of drawdown depth, and there is a certain hysteresis in the drop of the phreatic line. The faster the drawdown rate, the more obvious the hysteresis phenomenon. With the increase in drawdown depth, the phreatic line in the rockfill material gradually becomes convex upward. Due to the good water resistance of the core wall, high core rockfill dams subjected to rapid drawdown exhibit stronger hydraulic lag effects due to the large permeability contrast between the core wall and rockfill shell. Therefore, the pore water pressure inside the core wall cannot dissipate synchronously with reservoir lowering, resulting in a temporarily elevated phreatic surface within the core region. The phreatic line in the core wall part first rises sharply and then decreases, showing a pattern of high in the middle and low at both ends, with a highest point.

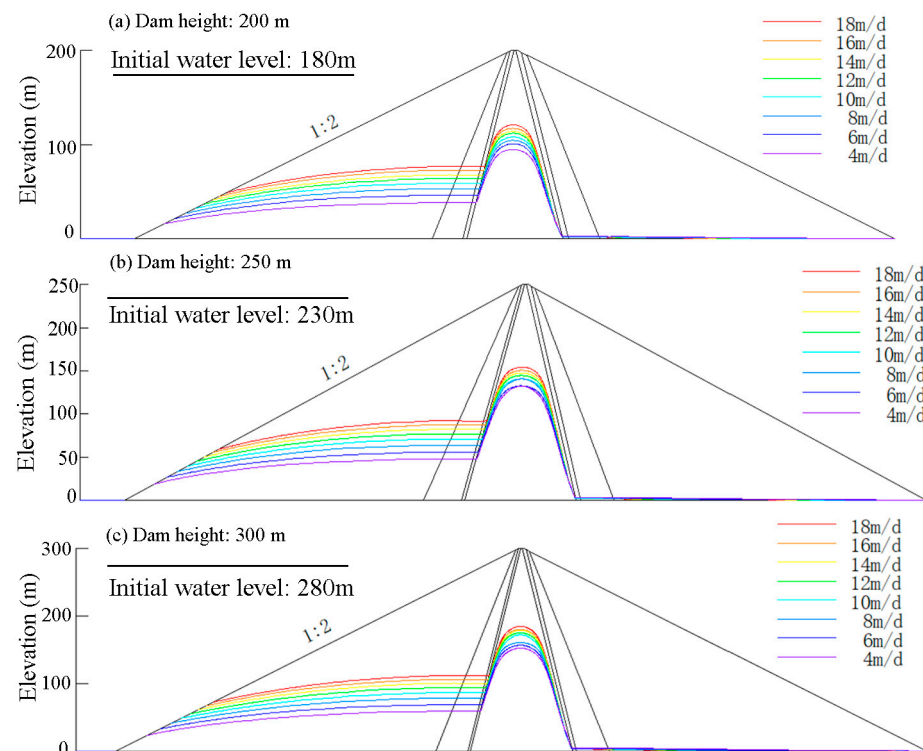


Figure 2. Distribution of phreatic lines under different dam heights and different drawdown rates.

The faster the drawdown rate, the higher the position of the phreatic line and the greater the height of the highest point. When the dam height is 200 m, the highest point of the free water surface line inside the dam body corresponding to the minimum drawdown rate drops to $0.46 H \sim 0.48 H$, while the free water surface under the maximum drawdown rate condition only drops to $0.59 H \sim 0.61 H$, with a difference of $0.13 H$.

3.2. Analysis of Dam Slope Anti-Sliding Stability

The variation laws of dam slope anti-sliding stability under different dam heights and different drawdown rates are shown in Figure 3. The results show that with the continuous drop of reservoir water level during the drawdown process, the stability safety factor of the dam slope shows a trend of first decreasing and then rapidly rising, and there is a minimum value of the safety factor during the drawdown process. The drawdown rate has a significant influence on the dam slope stability: the larger the drawdown rate, the faster the safety factor decreases, and the earlier the minimum value appears; at the same time, the overall level of the safety factor decreases with the increase in the drawdown rate.

Among them, under the low drawdown rates of 4~8 m/d, the decline process of the safety factor is relatively gentle; under the high drawdown rates of 10~18 m/d, the decline rate of the safety factor is significantly accelerated. According to Code for Design of Rolled Earth-Rockfill Dams (NB/T 10872-2021) [36], the minimum safety factor for dam slope anti-sliding stability under abnormal operation conditions is 1.1 (the red dashed line in the figure). Accordingly, during the process of drawing down from the highest water level to the reservoir bottom, the safe drawdown rate for the 200 m high dam needs to meet $v < 10$ m/d, the 250 m high dam needs to meet $v < 8$ m/d, and the 300 m high dam needs to meet $v < 6$ m/d.

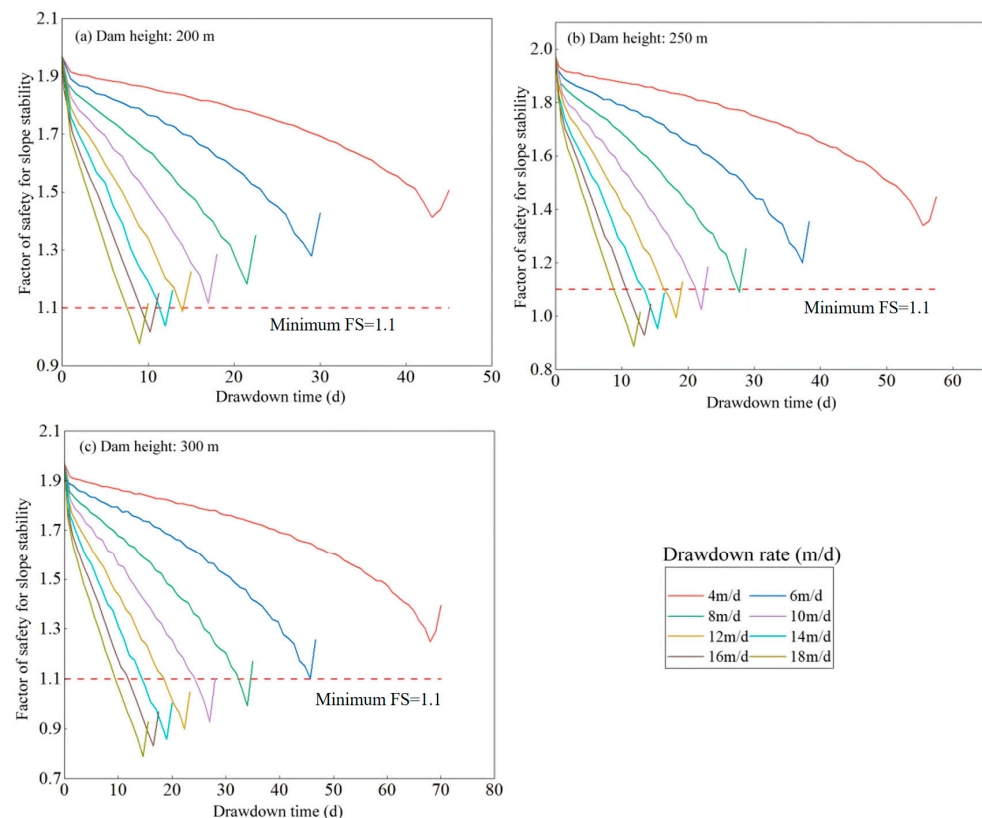


Figure 3. Variation in the factor of safety for slope stability with drawdown time under different drawdown rates and dam heights. (a) Dam height: 200 m; (b) Dam height: 250 m; (c) Dam height: 300 m.

3.3. Influence of Drawdown Depth on Dam Slope Stability

The water level change, reservoir water drawdown depth and sudden drop amplitude during the drawdown process will all affect the seepage stability of the dam body and the anti-sliding stability of the dam slope. An excessively deep drawdown water level may lead to seepage deformation of the dam body and landslide instability of the dam slope, while an excessively shallow drawdown water level may not meet the requirements of dry land maintenance of lower-elevation buildings of the hub and emptying the reservoir for disaster prevention.

In this paper, the drawdown depth is defined as the amplitude of the reservoir water level dropping from the highest water level to a certain water level; the maximum drawdown depth is defined as the drawdown depth when the dam slope stability coefficient reaches the control standard value of the stable safety factor, that is, the safe drawdown depth. The variation laws of dam slope stability under each research scenario are shown in Figure 4. It can be seen from the figure that considering the anti-sliding stability of the upstream dam slope, with the increase in drawdown depth, the dam slope stability safety

factor first gradually decreases and then rapidly increases, and the drawdown depth corresponding to the minimum safety factor value is close to the reservoir bottom. There is a maximum drawdown depth during the drawdown process, and the maximum drawdown depth is less than the initial maximum water depth in the reservoir. At the maximum drawdown rate, the maximum drawdown depth of the 200 m high dam is 108 m; the maximum drawdown depth of the 250 m high dam is 140.4 m; the maximum drawdown depth of the 300 m high dam is 154.8 m.

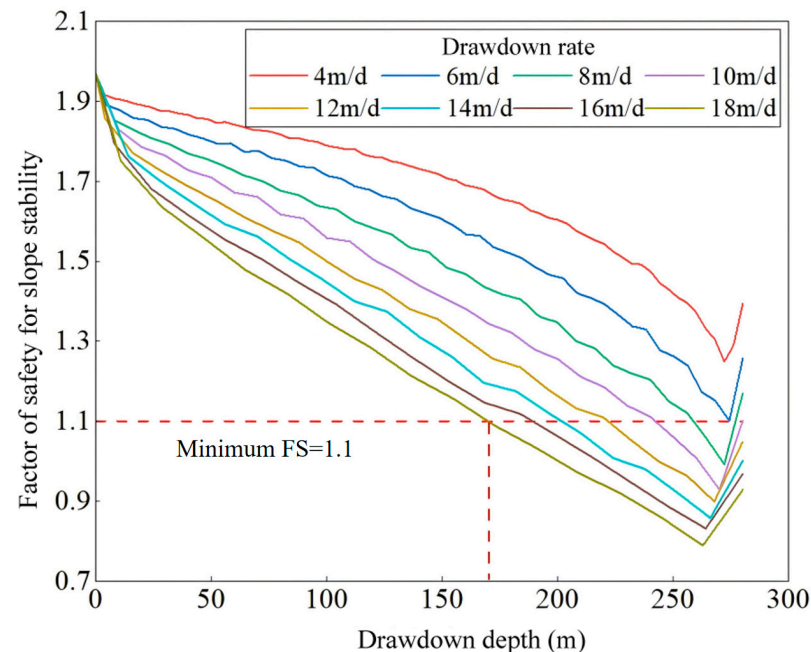


Figure 4. Variation in dam slope safety factor with drawdown depth under different drawdown rates.

4. Discussion

To further study the influence of the changes in the cohesion c value and internal friction angle φ value of the dam shell material on the minimum safety factor of dam slope stability, the sensitivity analysis of the two parameters is carried out by changing the c and φ values of the rockfill material respectively under the same conditions. The c value is increased in steps of 10 kPa, which are 0 kPa, 10 kPa, 20 kPa, 30 kPa, 40 kPa, 50 kPa, 60 kPa and 70 kPa respectively; the φ value is increased in steps of 2° , which are 36.4° , 38.4° , 40.4° , 42.4° , 44.4° , 46.4° , 48.4° , 50.4° and 52.4° respectively.

The influence of the cohesion parameter c value on the safety factor is shown in Figure 5a. It can be seen that for different dam heights, the influence law of the c value on the minimum safety factor of dam slope stability is the same. With the increase in the c value, the minimum safety factor gradually increases, and the dam slope stability gradually enhances. The increase degree of the minimum safety factor gradually decreases with the increase in the c value. When the c value is less than 40 kPa, the increase in the c value has a great influence on the improvement of the minimum safety factor; when the c value is greater than 40 kPa, the influence of the increase in the c value on the improvement of the minimum safety factor decreases rapidly until it tends to be unchanged. When the c value increases from 0 to 10 kPa, the minimum safety factor increases by 20%, while when it increases from 60 kPa to 70 kPa, the minimum safety factor only increases by 5.7%. Therefore, 40 kPa is taken as the sensitivity limit of the c value. Under the premise of the same drawdown rate, when the c value of the rockfill material is from 0 kPa to 40 kPa, the minimum safety factor can be increased by 20%, 16%, 14% and 12% respectively for every 10 kPa increase in the c value, and interpolation calculation is carried out for intermediate

values, which provides a reference for the control of the safe drawdown rate when the cohesion parameter of the rockfill material changes.

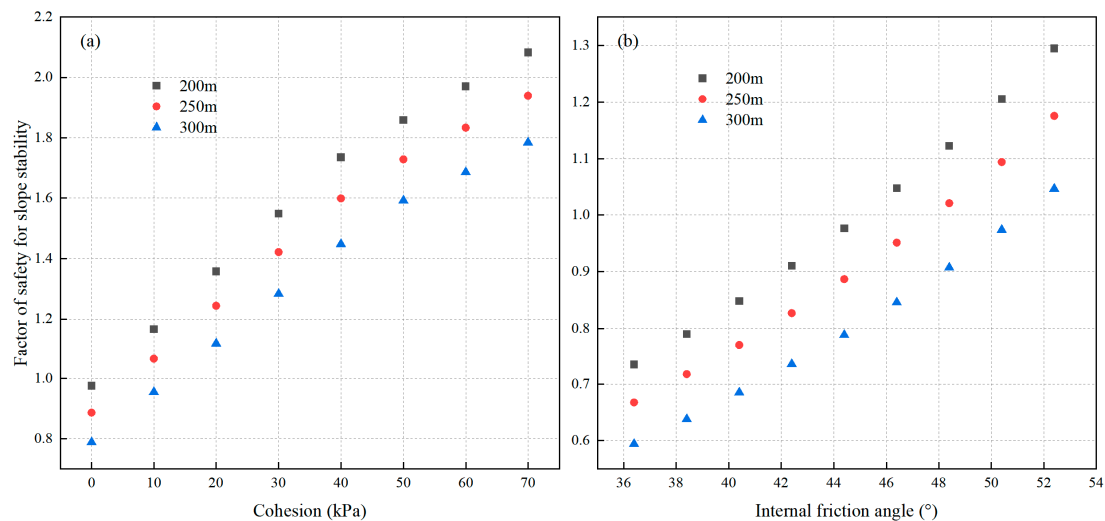


Figure 5. Effects of cohesion (a) and internal friction angle (b) on the factor of safety for slope stability.

The influence of the internal friction angle φ value on the safety factor is shown in Figure 5b. It can be seen that for different dam heights, the influence law of the internal friction angle φ value on the minimum safety factor is the same. With the increase in the φ value, the minimum safety factor gradually increases, and the anti-sliding stability of the dam slope gradually enhances. The increase degree of the minimum safety factor first decreases and then increases with the increase in the φ value. When the φ value is less than about 46.25° , the increase degree of the minimum safety factor is the smallest, but no matter how the φ value changes, the improvement degree of the minimum safety factor is basically stable at 7.3%. Therefore, 7.3% is defined as the influence degree of the φ value on the minimum safety factor. Under the premise of the same drawdown rate, when the φ value of the rockfill material gradually increases from 36.4° to 52.4° , the minimum safety factor can be judged by an increase of 7.3%, which provides a reference for the control of the safe drawdown rate when the internal friction angle of the rockfill material changes. In the engineering application of drawdown facilities for high dams and large reservoirs, the dam shell material parameters of each project are inconsistent. The cohesion c value adopted in this paper is 0, which is favorable for the stability of the dam slope when the material cohesion increases. Therefore, using the above data to control the drawdown depth is on the safe side. When considering the increase in the rockfill material cohesion c value, the minimum safety factor can be considered to increase by a 12% safety margin for every 10 kPa increase; when considering the increase in the rockfill material internal friction angle φ value by 2° , the minimum safety factor can be considered to increase by a 7.3% safety margin.

In the current work, we mainly focus on the phreatic surface evolution and slope stability under rapid drawdown conditions, while the distribution and dynamic variation in pore water pressure and matric suction inside the dam body are not analyzed quantitatively with visualized results. The coordinated evolution of pore water pressure and matric suction dominates the effective stress state of the upstream slope during water level fluctuation. Further research will carry out targeted analysis on the spatiotemporal characteristics of pore pressure and matric suction under different drawdown schemes, and explore their internal coupling mechanism affecting slope deformation and stability.

5. Conclusions

Aiming at the problem that the safety control indicators for rapid drawdown of ultra-high earth-rockfill dams above 200 m are not clear, this paper takes three grades of high earth core wall rockfill dams with heights of 200 m, 250 m and 300 m as objects, systematically studies the seepage and dam slope stability laws under different drawdown rates and drawdown depths through finite element numerical simulation, and carries out parameter sensitivity analysis. The main conclusions are as follows:

(1) There is a significant lag effect in the phreatic line of the dam body under rapid drawdown conditions, and the lag is more obvious with a faster drawdown rate and higher dam height; the safety factor of the dam slope shows a trend of first decreasing and then increasing with the drop of water level, and there is a critical minimum value, and the higher the dam height, the more sensitive it is to the drawdown rate.

(2) Under the typical profile conditions assumed in this study, including an upstream and downstream slope ratio of 1:2.0, rockfill material properties of $c = 0$ and $\phi = 44.4^\circ$, and the specified initial reservoir water levels, the safe drawdown rates for 200 m, 250 m and 300 m dams are less than 10 m/d, 8 m/d and 6 m/d respectively, and the corresponding maximum safe drawdown depths are 108 m, 140.4 m and 154.8 m in sequence.

(3) The shear strength parameters of rockfill materials have significant sensitivity. The cohesion has a prominent influence on stability in the range of 0~40 kPa, and the dam slope safety factor can be increased by about 7.3% for every 2° increase in the internal friction angle ϕ .

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Data Availability Statement: The data presented in this study are available on request from the corresponding author, because the data are part of an ongoing study.

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