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Effect of Geometric Parameters on the Slope Stability of the Asphaltic Core Rockfill Dams Using Quasi-Static Analysis

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ABSTRACT

In the current paper, the effect of different geometric parameters of Rockfill dams with asphaltic cores in the Quasi-static slope stability analysis is studied. The analysis has performed in 2D mode. In this regard, using the geometry of the dams built in the countries that own this industry, many behavioral models have been created at eight different height classes, three different cases of upstream and downstream slopes, as well as three different impounding states including “End of Construction”, “Full Reservoir”, and “Half-Full Reservoir”. The upstream and downstream slopes of each case are the same. The asphaltic core in three different thicknesses, plus two-position forms of vertical and oblique have been modeled. All the models on the Bedrock foundations are considered. The Limit Equilibrium method has been selected for the Quasi-static stability analysis. The results reveal that the highest safety factor is related to the “End of Construction” state in all the models, and the lowest is related to the “Full Reservoir” state. In the case of a “Full Reservoir”, at all height classes and slope cases, the safety factor of the upstream slope is lower than the downstream slope, which indicates the need for further investigation of the upstream slope. In the “Half-Full Reservoir”, at all height classes and slope cases, the upstream safety factor is less than the downstream, which indicates that the upstream slope is critical in this state. In the continuation of the study, more results are presented in the form of comparative tables and diagrams.

Keywords: Quasi-Static Analysis, Slope Stability, Slip Circle, Asphaltic Core, Factor of Safety, Rockfill Dam, Limit Equilibrium.

1. INTRODUCTION

Although today it is widely believed that the category of dam construction is among the modern technologies and relies on today's advanced achievements. But historical records, and remnants of ancient civilizations such as the construction of weirs in the past, show that the knowledge of dam construction and exploitation of water, as the most important factor of life and development, has always been considered by humans societies. This industry has gone through its growth path and is known as the best human attainment for optimal water use. Among the range of earthfill dams considered by designers and owners of this knowledge, the Asphaltic core Rockfill dam, which is a new type of cored dam, is noteworthy. The Asphaltic core Rockfill dams have valuable advantages such as proper core sealing, low permeability, higher execution speed, and low sensitivity to climate changes. Therefore, performing stability analysis to achieve greater safety factors and also further evaluating the behavior of this type of dam in different impounding states is very important and can be considered by the experts. A Rockfill dam is stable and balanced when the applied stresses in each part of the dam are less than the mobilized resistance. For the design process of embankment and Rockfill dams, the relative degree of stability is measured by a criterion called the “Factor of safety” which is abbreviated “FOS” in this article. Obviously, the higher this criterion, the greater the stability of the dam. For this purpose, engineering organizations around the world have always tried to provide values as reasonable safety factors in the stability analysis of earthfill dams for different operating conditions.

1.1. Brief History of Previous Studies

Ljupcho Petkovski, via a dynamic analysis of the Knezhevo asphalt core rockfill dam with a height of 80.5m in Macedonia in a full reservoir state, found that in the normal operation of the dam, the critical slope for the dam stability is at the upstream side. He also ensured adequate safety against the risk of dam failure during an earthquake [1].

Examining the Storvatn Dam, Hoeg concluded that if the slopes were steep, a relatively large shear strain would appear in the upper part of the asphalt concrete core. He also showed that rockfill dams with asphalt concrete cores have sufficient resistance against seismic phenomena [2].

After studying the Storvatn dam in Norway, Valstad et al. used Newmark's research to show that the asphaltic core in the areas adjacent to the dam crest would crack [3].

Helge Saxegard has studied the history of dam construction with asphalt concrete core technology in Iran, including Meijaran, Meiduk, and Shour River dams. The results show that the asphaltic core of an earthfill dam which is located in a seismic area, can withstand severe shocks without cracking or water leakage. For such a dam, seismic resistance depends on proper design and proper zoning in the dam geometry [4].

Safapour and Salehi investigated the stability of earthfill dams with asphalt concrete core in conditions of permanent seepage, end of construction, half-full reservoir, and rapid drawdown. They have concluded that the dam structure has a proper behavior against different static loading conditions. Also, according to the recommendations of international standards, the reliability coefficients obtained in all the conditions are more than the allowable values [5].

Akhtarpour and Khodaei studied the Shour River dam in Iran under different impoundment conditions. By performing nonlinear numerical analysis using the finite difference method, they found that cracks appear in the upper part of the core, and the most vertical deformation occurs near the crest and above the upstream slope [6].

Salemi and Baziar studied the Meijaran Dam in Iran and, through numerical analysis and various experiments, found that the behavior of the asphalt concrete core in severe earthquakes is acceptable and the dam is safe [7].

Shiravi and Razmkhah with a comprehensive parametric stress-strain analysis on several numerical models with different thicknesses of asphaltic concrete core in four time stages of impoundment found that increasing both vertical and oblique asphaltic concrete core thicknesses, leads to decreasing the maximum shear stress in Full Reservoir state but it increases in other states of impoundment. Also, increasing the height parameter leads to increasing both horizontal and vertical displacements. The maximum total stress decreased for all operating time stages as the upstream slope reduced [8].

By analyzing the static and dynamic stability of the 22 m Gidabo Dam in Ethiopia, Gemeda has conducted a case study on the feasibility of replacing a clay core with an Asphalt Concrete Core (ACC) with GeoStudio software. In the proposed design, the thickness of ACC is 0.5 m, the upstream slope is equal to 1: 2.0 and the downstream slope is in the range of 1: 1.75 to 1: 2.0. In this comparison, the stability of the slopes under different loads has been evaluated. The safety factors calculated for the upstream and downstream of the dam and their comparison with the minimum values indicate that the dam will be safe. Examination of vertical and horizontal displacements at the end of construction also shows the stability of the dam after the earthquake therefore, the ACC core execution is preferable to the clay type [9].

1.2. Purpose of the Research

This paper aims to do a Quasi-static stability analysis of several behavioral models of asphaltic core Rockfill dams, to evaluate the effect of changes in the main geometric parameters on the stability of their slopes, and measure the factors of safety (FOS) in different impounding states. The quantity of the FOS obtained from the stability analysis indicates the safety margin of the structure against the occurrence of shear failure. The above behavioral models were first created by following the real geometry of dams built around the world at eight different heights as eight guiding dams. Then, by making several combinations of changes of the slopes and the form of the asphaltic core of the guiding model of each height class, many other models have been created in different impounding states to study and compare in the mentioned height class. The same process has been followed for the models of other height classes.

The Quasi-static analysis is one of the applied methods to study the seismic stability of earthen slopes, according to which, a fixed maximum seismic spectrum pattern with its appropriate seismic acceleration is selected to apply the seismic lateral force to the structure. Afterward, the reflection of different fluctuation modes in the structure is obtained. Also, the Limit Equilibrium method has been selected for stability analysis. In the analysis, an earthquake with the acceleration of a_x=0.35g in the horizontal direction has been applied to the models to evaluate the behavior of the upstream and downstream slopes of the dam in this condition. Also, the vertical component of the earthquake in the calculations is assumed to be zero.

The effects of changes in geometric parameters in the analysis are presented in the form of comparative envelope diagrams that show the safety status of the dam, and the FOS values of models in terms of different heights. To create the behavioral models and the analysis process, professional Slope/W stability analysis software, one of the professional software for slope stability analysis in geotechnical engineering, has been used. Today, this software as a useful tool that helps professionals in research, design, and implementation [12].

2. Methods

2.1. Height Classes of Dams

In this study, an attempt was made to select the geometric parameter of height in such a way as to cover a suitable range of height dimensions in the behavioral models. Consequently, based on Table 1, following the natural dams designed in the world, the guiding dam models in terms of height, in eight height classes of 50 m, 60 m, 70 m, 80 m, 90 m, 110 m, 120 m, and 170 meters have been divided and examined distinctly.

Table 1. Selected guiding dams' geometries for analysis [8].

Dam Title	**Location**	**Height (m)**	**Class of Height**
Quxue	China	170	**170**
Storgolmvatn	Norway	125	**125**
La Romaine 2	Canada	110	**110**
High Island West	Hong Kong	95	**90**
Zletovica	Macedonia	85	**80**
Schmalwasser	Germany	76	**70**
Berdalsvatn	Norway	65	**60**
Megget	United Kingdom	56	**50**

2.2. Crest Widths and Freeboard Water Level

The role of the freeboard is to protect the dam against water overflow. The freeboard is the distance between the dam crest and the highest water level of the reservoir in the most critical flood. The freeboard calculations depend on the wave at the lake's surface, which is a function of wind speed, duration, and length of the lake. The value of the geometric parameter of freeboard, assuming a dam with an average height of 100 meters, has been calculated based on the criteria presented by the Committee of Large Dams and has been assigned to all behavioral models equal to 5.0 meters.

According to the statistics of large dams built in the world, the width of the dam crest usually varies between 6 to 12 meters and generally increases with increasing the height of the dam. In this research, as shown in Table 2, the dams' crest widths, by following the guiding dam of each height class, have been assigned to behavioral models.

Table 2. Selected guiding dams' crest widths [8].

Crest Width (m)	**9.5**	**7.0**	**6.0**	**9.5**	**8.5**	**8.0**	**7.0**	**9.5**
Class of Height	170	125	110	90	80	70	60	50

2.3. Bedrock Foundation

In executive considerations, the foundation of embankment and Rockfill dams are classified into two main categories. Rigid bedrock and loose bedrock. Hard and non-erodible rock foundations are the most suitable type of foundation for Rockfill dams. In this study, by assigning the rigid restraints to the bed of all the behavioral models, it is assumed that they have been sat on a rigid bedrock. Likewise, to simplify modeling, the foundation edges are cut on both sides, but they have been defined to be indefinite. Similarly, since the sealing operation of rock foundations is done by the Injection Curtain method at a penetration depth equal to one-third of the dam height or at least 10 meters below the rock surface [10], the foundation of each model, with a depth equal to one-third of its height is given in the calculations.

2.4. Upstream and Downstream Slopes of the Dams

The upstream and downstream slopes of the earthfill dams are functions of the type of material used, the condition of the foundation, and the dam's height. It is necessary to protect the upstream slope of embankment dams from damage caused by repeated waves impacts. Experiences have shown that the Rip Rap cover, which starts from the crest of the dam and continues to a safe level below the dead volume of the reservoir, is the best and most cost-effective protection of the upstream slope against erosion. In this study, the upstream and downstream slopes of the dams are considered equally for all behavioral models. Moreover, to facilitate modeling, zoning areas and core connection to the foundation have not been included in the creation of the models.

According to Table 3, to achieve more precise results, for each height class, three different slope cases of the dam have been assigned. In introducing the value of the slope, a right triangle is used in which “V” is the vertical side, “H” is the horizontal side, and the chord matches the slope.

Table 3. Different cases of upstream and downstream slopes.

Slope Case Name	Upstream Slope (V: H)	Downstream Slope (V: H)	Slope Angle to the Horizon (°)
Case-1	1.0: 2.5	1.0: 2.5	21.80
Case-2	1.0: 2.0	1.0: 2.0	26.56
Case-3	1.0: 1.5	1.0: 1.5	33.69

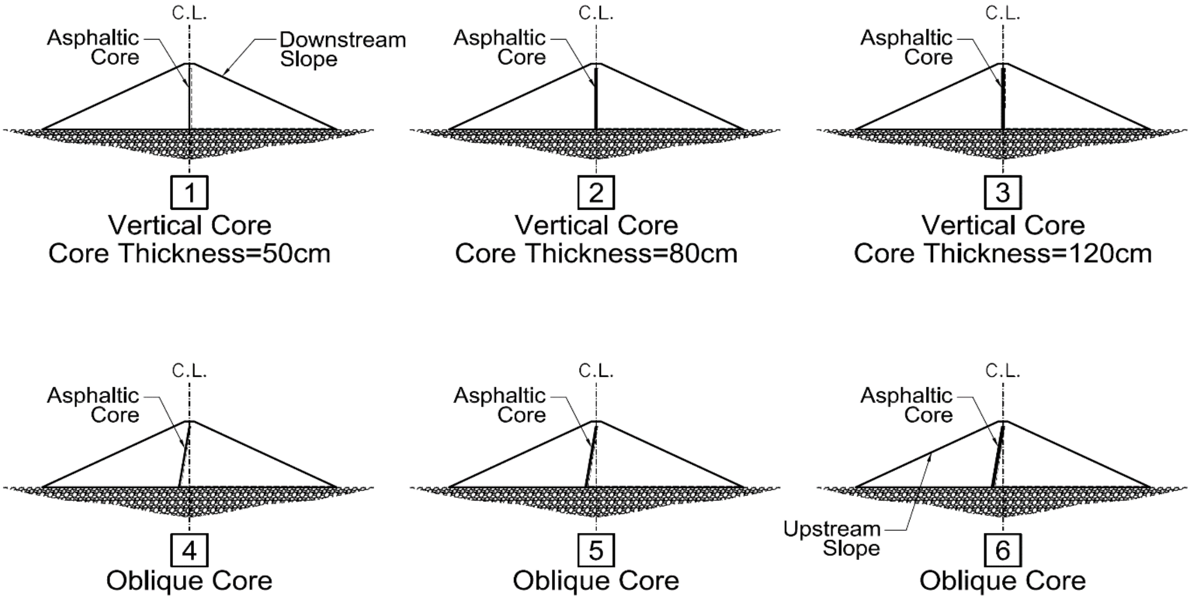
2.5. Asphaltic Core Forms

One of the most significant geometric parameters of the dams studied in this article is the thickness and form of the asphaltic core. The core must be flexible enough to withstand stresses due to various horizontal and vertical displacements caused by the movement of the structure and repair cracks due to asymmetric settlements. In cases where clay cores are not possible, asphalt cores are quite possible and economical. From an engineering point of view, the asphaltic core of a Rockfill dam, which is a type of thin diaphragm core, can usually be executed in one of the following ways:

- The Vertical asphaltic core, which is located on the central axis of the dam section.

- The Oblique asphaltic core, which is inclined to the upstream side of the dam.

In the following, six different forms of the asphaltic core, for three different slope cases mentioned in the previous section have been considered, following Figure 1.



Vertical Core
Core Thickness=50cm

Vertical Core
Core Thickness=80cm

Vertical Core
Core Thickness=120cm

Oblique Core
Core Thickness=50cm

Oblique Core
Core Thickness=80cm

Oblique Core
Core Thickness=120cm

Figure 1. Asphaltic core forms and their thicknesses.

Though from the point of view of experts in this field, reducing the asphaltic core thickness from the bottom to the top is not recommended, typically in the execution of dams with a height of fewer than 60 meters, the core is located vertically, and for the taller dams, its form is observed in oblique type. In general, a minimum thickness of the asphaltic core of 50 cm is recommended [11]. In this study, for the core, three different thicknesses of 50 cm, 80 cm, and 120 cm in two forms of vertical 1:0 (V: H) and oblique 1:0.2 (V: H) [2] in a stable condition have been used.

2.6. Dams Impounding States

The six different forms of the asphaltic core described in the previous section have themselves been studied under three different construction and impoundment states as follows:

Table 4. Reservoir impounding states.

Type	Condition	Abbreviation
State-1	Full Reservoir	**FR**
State-2	Half-Full Reservoir	**HR**
State-3	End of Construction	**EC**

The “Full Reservoir” means a state in which the rest of the reservoir is full, except for a height of five meters corresponding to the freeboard. The “Half-Full reservoir” is a condition in which the height of the water in the reservoir is equal to half its height in the full reservoir. The “End of Construction” refers to the situation that which the construction of the dam has been completed, and the water level of the reservoir upstream and downstream of the dam is equal to zero. Since to collect the direct water from the dam's body and foundation, drainage is required in the dam's structure, the effect of drainage has been included in the modeling to Keep the downstream slope as dry as possible.

It must be mentioned that in high Rockfill dams with different reservoir impoundments, vertical drainage of chimney filter attached to the core is very common. Chimney filter drainage plays a very important role to increase the downstream FOS, more control of seepage, and reducing the pore pressure in different construction and impounding states [13].

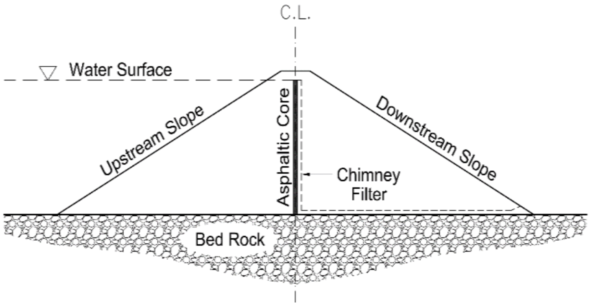


Figure 2. A chimney drain is used in all behavioral models.

3. Modeling

3.1. Boundary Conditions

When the dam reservoir is impounded, the pressure of water is applied to the dam’s upstream slope face and its foundation in proportion to the reservoir water level, the effect of which must be considered in the results. To this end, the water pressure should be defined as a kind of boundary condition to the affected surfaces. Downstream of the dam, the water level is defined on the foundation level and corresponds to it, but since there is no water height on the foundation located downstream of the dam, there will be no boundary conditions in that part.

3.2. Optimum Meshing Size

Slope stability analysis is performed by the Morgenstern-Price method and based on Grid & Radius equilibrium drawing method. This method is used to determine the critical slip circle. Accordingly, on one side of the slope, a set of points is drawn as "Grid" and on the other side, a set of lines are drawn as "Radius lines". Then, at the center of the grid points, circles are tangent to the radius lines. Finally, for each point, among the drawn slip circles and the reported FOSs, the lowest FOS is presented as the final and associated with the critical slip circle.

In order to achieve more exact results in drawing slip circles and finally accurately calculating the safety factors of the slopes, thecorrect selection of the grid and radius lines is necessary for behavioral models. For this purpose, by validation process after sensitivity analysis, the various ranges of the number of lines have been tried. In this research, the number of Radius lines equal to 30 and the number of Gridlines equal to 40 have been selected and applied in the models. It should be noted that in this method, the point which has the most critical FOS should not be located at the corner of the grid system. Because in this case, there may be another point on the same side but outside the mesh that has lower reliability. Preferably, the point with the lowest FOS should be in the middle of the grid.

Also, validation has been performed by using static analysis of slope stability in full reservoir state and stable seepage to evaluate the stability safety factors of the upstream slope of the dams. The results are presented for different ranges of the number of grid and radius lines mentioned above, according to the diagram in Figure 3.

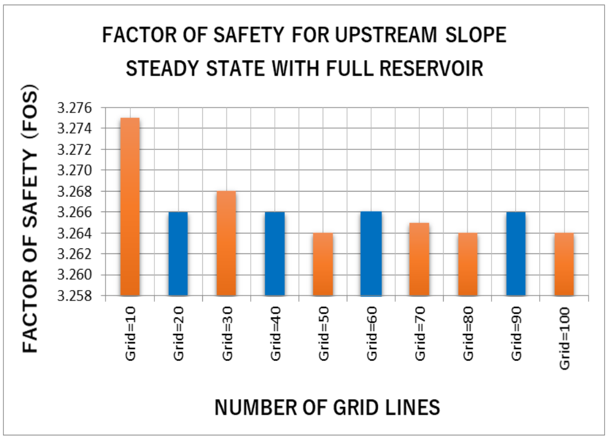


Figure 3. Presentation of upstream slope FOS values with Grid & Radius method.

In the current study, the minimum FOS for evaluating the stability of slopes for all the behavioral models is considered equal to 1.5.

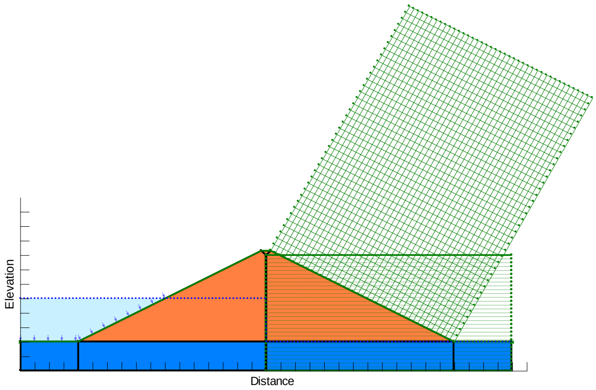


Figure 4. Downstream slope, height class of 90, and the "HR" state.

3.3. Quasi-Static Stability Analysis Assumptions

Since the strain values in the asphaltic core are limited, it is possible to assume the behavior of asphalt concrete core materials elastic with an acceptable approximation [15]. However, in addition to the core, linear elastic conditions apply to the shell and foundation materials. In this research, according to Table 5, geotechnical specifications of the materials for the asphalt concrete core, shell, and foundation zones, have been assigned based on the Mohr-Coulomb theory.

This model, which is expressed by the linear equation of $\tau = C+\sigma_n\times\tan\Phi$, is the most common method to present the shear strength of geotechnical materials. According to Figure 5, this equation represents a straight line that shows the relationship between shear strength (τ) and normal stress (σ_n). The intersection of the line with the shear strength axis indicates the cohesion (C), and the slope of the line indicates the material friction angle (Φ).

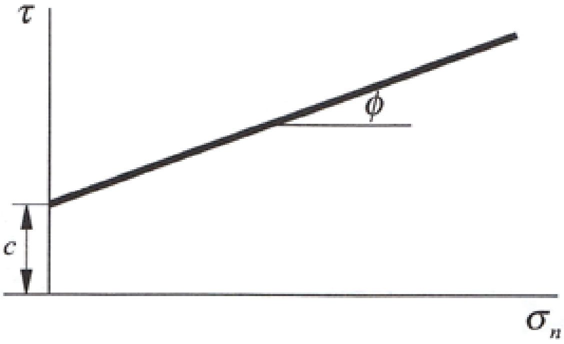


Figure 5. Mohr-Coulomb equation diagram.

The reasons for choosing the Mohr-Coulomb model can be mentioned as follows:

- Simplicity and easy physical understanding
- Validity for most soils
- The simplicity of its mathematical equation
- Low number of the parameters of its equation

Table 5. Materials and their characteristics.

Zone Name	**Type of Material**	**Unit Weight**	**Poisson's Ratio**	**Cohesion Coefficient**	**Modulus of Elasticity**	**Internal Friction Angle**
		γ (kN/m^3)	ν	C (kN/m^2)	E (kPa)	**(º)**
Core	Asphalt Concrete	24	0.45	360	200000	28
Shell	Rockfill	22	0.25	40	100000	43
Foundation	Bedrock	22	0.40	350	200000	35

Similarly, in the current study, the water unit weight is assumed to be 9.38 kN/m^3, and according to the constant climatic conditions for all the models, the value of atmospheric pressure is assigned as 101.33 kPa. The slope stability analysis of behavioral models and the calculation of FOS are determined based on the limit equilibrium method and through the balance between moments and the normal and shear forces affecting the soil blocks above the slip surface.

The two FOS values of moments' balance and horizontal forces' balance are calculated and finally converged into a final safety factor [14]. Figure 6 shows the interfacial force function.

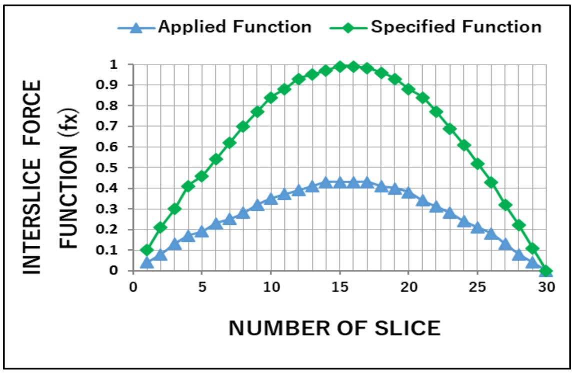


Figure 6. Interfacial force function [12].

Figure 7 shows, the critical slip circle of the downstream slope and the stability factor of a behavioral model in height class of 70 and Full Reservoir state.

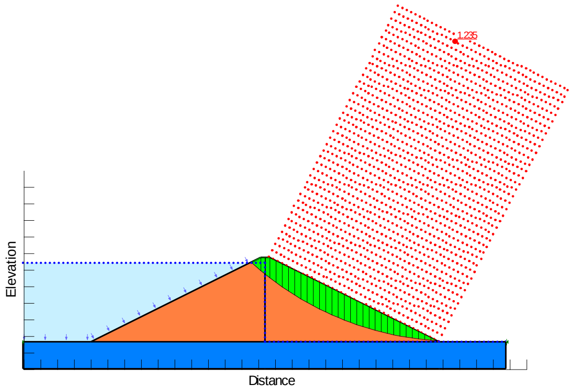


Figure 7. Critical slip circle of the downstream slope, height class of 70, and the "FR" state.

4. Results

4.1. Obtained Stability FOS Values and Graphs

As mentioned earlier, after the material specifications of each part of the dams have been assigned, quasi-static stability analysis based on Morgenstern–Price method is performed for all the behavioral models. Then, for each height class in different combinations of slope cases, core forms, and reservoir operating states, related diagrams to slopes FOS values have been prepared. Next, the results of each category are generated as envelope curves in the range of height parameter from low to high according to Tables 7 to 9, and the diagrams presented in Figures 8 to 13.

It is usually not logical to set a fixed value for the FOS quantity because its amount depends on many other functions. Engineering organizations worldwide have tried to provide values as an appropriate factor of safety in the stability analysis of earthfill dams in different conditions. Table 6 reveals the offered values of the US Army Engineering Organization.

Table 6. Minimum acceptable FOS for stability analysis of earthfill dams [16].

Impounding State	**Minimum Allowable Factors of Safety**			
	Downstream Slope		**Upstream Slope**	
	With Earthquake	Without Earthquake	With Earthquake	**Without Earthquake**
End of Construction	1.0	1.25	1.0	1.25
Half-Full Reservoir	-	-	1.25	1.50
Full Reservoir	1.25	1.50	-	-

These values are just an engineering recommendation, and finally, the design engineer must consider all aspects, uncertainties in estimating the parameters of shear strength and pore water pressure, and foundation condition to select the allowable reliability value.

Table 7. FOS of upstream and downstream slopes for “Case 1” in terms of height classes.

Height Class	**Upstream Slope**		
	EC	FR	HR
50	1.438	1.105	1.188
60	1.407	1.068	1.157
70	1.385	1.038	1.117
80	1.361	1.008	1.105
90	1.339	0.982	1.078
110	1.319	0.958	1.052
125	1.293	0.933	1.030
170	1.268	0.897	0.980

Height Class	**Downstream Slope**		
	EC	FR	HR
50	1.439	1.456	1.456
60	1.406	1.419	1.422
70	1.377	1.392	1.392
80	1.366	1.378	1.378
90	1.338	1.350	1.350
110	1.311	1.319	1.322
125	1.297	1.306	1.306
170	1.254	1.265	1.262

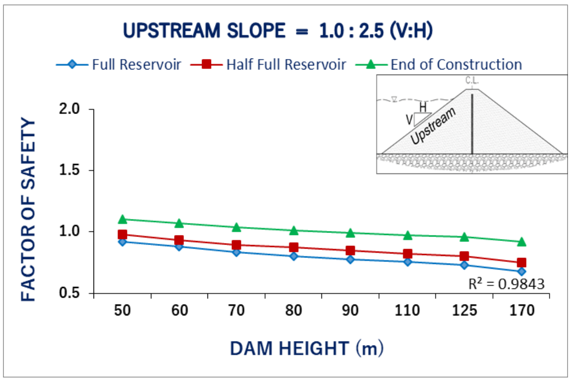


Figure 8. FOS of Upstream slopes for “Case 1”, in terms of height classes.

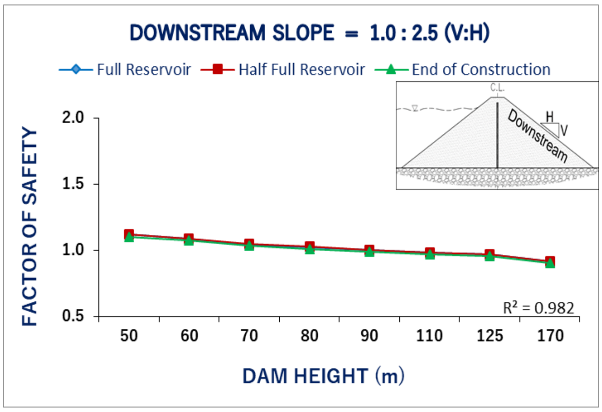


Figure 9. FOS of Downstream slopes for “Case 1”, in terms of height classes**.**

Based on the diagrams shown in Figures 9, 11, and 13, due to the assumption of the same level of water level downstream of the dam in all construction and impounding states, the results of calculating the stability safety factors of downstream slope in all three slope cases are similar. Also, regarding what is shown in Figures 8, 10, and 12, considering the diagrams obtained in the upstream slope, in all construction and impounding cases, the behavior of models is similar, and the difference is only related to the range of computational values.

Table 8. FOS of upstream and downstream slopes for “Case 2” in terms of height classes.

Height Class	**Upstream Slope**		
	EC	FR	HR
50	1.290	1.026	1.095
60	1.259	0.992	1.063
70	1.223	0.945	1.021
80	1.199	0.914	1.003
90	1.188	0.899	0.981
110	1.165	0.871	0.956
125	1.143	0.846	0.934
170	1.107	0.800	0.882

Height Class	**Downstream Slope**		
	EC	FR	HR
50	1.292	1.306	1.313
60	1.262	1.273	1.279
70	1.224	1.235	1.239
80	1.201	1.214	1.214
90	1.186	1.199	1.199
110	1.166	1.176	1.177
125	1.135	1.142	1.145
170	1.095	1.102	1.103

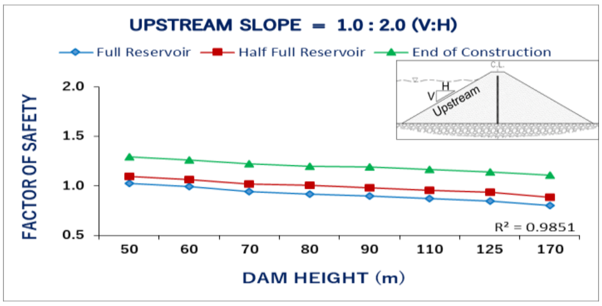


Figure 10. FOS of Upstream slopes for “Case 2”, in terms of height classes.

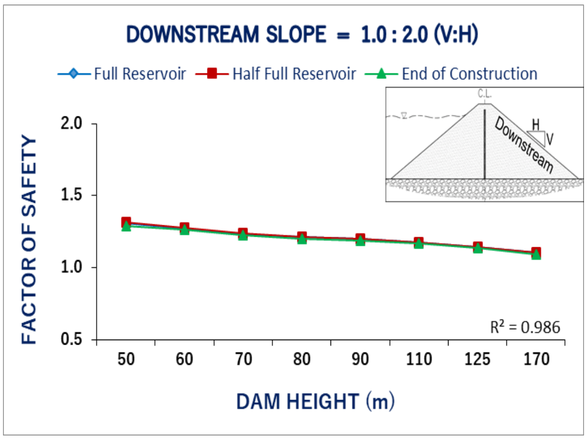


Figure 11. FOS of Downstream slopes for “Case 2”, in terms of height classes.

Based on the results, at a constant height of the dam (a constant Height class), if the upstream and downstream slopes increase, the safety Factor values increase in all construction and impounding states. In a constant slope case, if the dam height is increased, the safety factor values on the upstream and downstream slopes decrease in all construction and impounding states.

Table 9. FOS of upstream and downstream slopes for “Case 3” in terms of height classes.

Height Class	**Upstream Slope**		
	EC	FR	HR
50	1.105	0.922	0.977
60	1.068	0.883	0.934
70	1.039	0.838	0.896
80	1.011	0.802	0.874
90	0.994	0.778	0.847
110	0.972	0.757	0.822
125	0.959	0.727	0.799
170	0.921	0.679	0.751

Height Class	**Downstream Slope**		
	EC	FR	HR
50	1.101	1.121	1.121
60	1.073	1.090	1.090
70	1.034	1.044	1.049
80	1.013	1.021	1.027
90	0.991	1.002	1.005
110	0.972	0.982	0.984
125	0.957	0.970	0.970
170	0.908	0.916	0.916

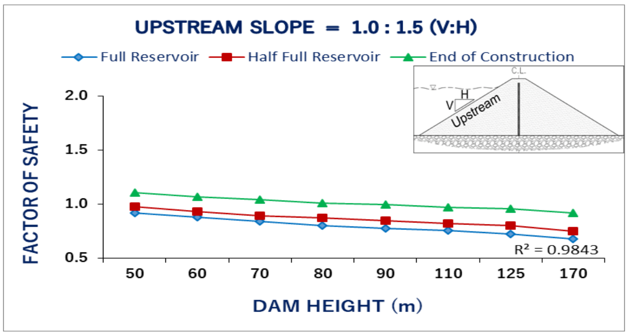


Figure 12. FOS of Upstream slopes for “Case 3”, in terms of height classes.

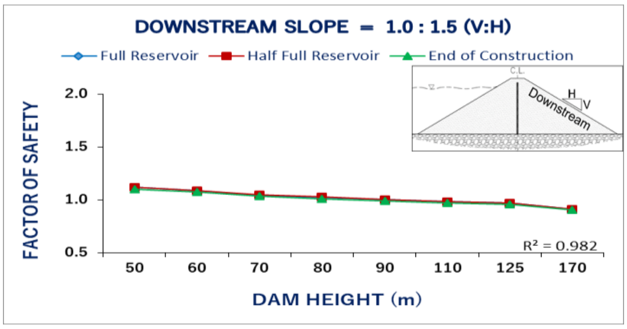


Figure 13. FOS of Downstream slopes for “Case 3”, in terms of height classes**.**

5. Conclusion

In this study, the effect of variations in geometric parameters of rockfill dams on the stability of their upstream and downstream slopes has been conducted by performing a quasi-static stability analysis. The analysis of three different impounding states of "EC", "FR", and "HR", has been carried out by producing several behavioral models in eight height classes, three different slope cases, and three forms of core position and thicknesses. In addition to the descriptive diagrams mentioned in the previous section, the following complementary consequences are obtained from the analysis of the models:

- Results indicate that the highest calculated FOS is related to the "EC" state, and the lowest is related to the "FR" state. It is obvious that the "HR" state after the "EC" state, has the highest safety.
- For all models with vertical and oblique cores, the results show that the thickness of the asphaltic core and its deviation has little effect on the slope factor of safety.
- In the "FR" state, at all height classes and slope cases, the upstream quasi-static safety factor is less than the downstream, indicating the need for further study of the upstream slope status in this impounding state.
- In the "HR" state, in all height classes and slope cases, the upstream quasi-static safety factor is lower than the downstream, indicating that the upstream slope is critical in this impounding state.
- Results show that at the "EC" state, in models up to a height class of 100 m, the upstream quasi-static safety factor is less than the downstream, and then with increasing height, the upstream FOS values have become higher than the downstream.
- In quasi-static analysis, with the effect of horizontal earthquake component on the models, FOS in all states of "EC", "FR", and "HR", for upstream and downstream slopes of the dams has been reported less than 1.5. This indicates the need for more detailed studies on the design and more attention to executive issues related to the safety of the dam.
- The safety factors of the behavioral models in three different impounding states (FR, HR, and EC) for each case related to core thickness (50 cm, 80 cm, and 120 cm) are shown side by side in Figure 14. This diagram has been prepared to compare the degree of stability of models of the same height with similar geometry, in different impounding states, but withthe same form and thickness of the asphalt concrete core.

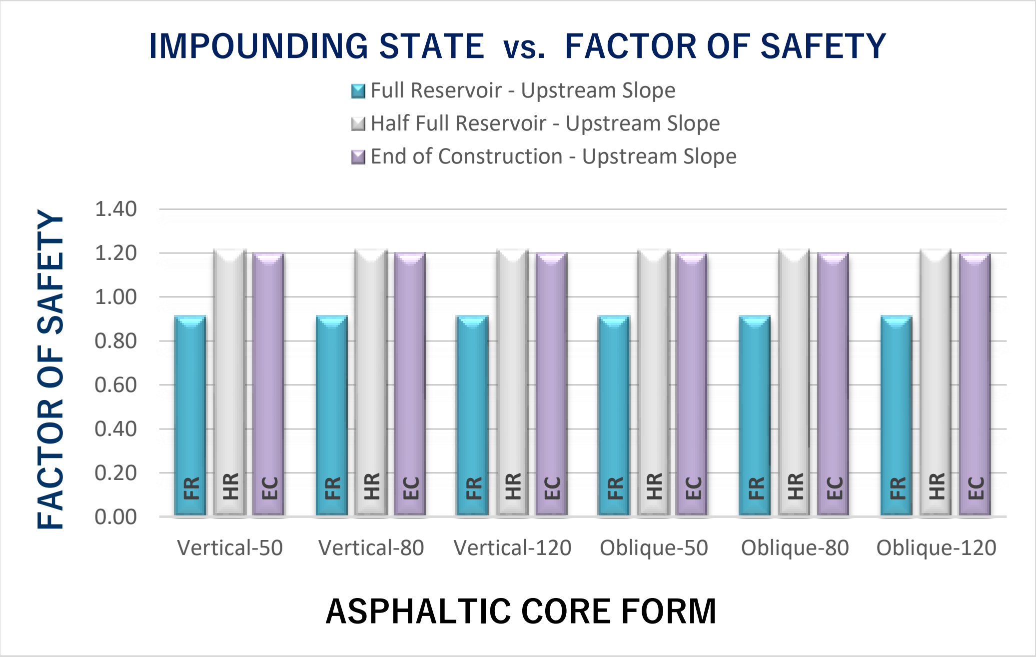


Figure 14. FOS comparison chart for different core forms vs. impounding states.

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