Parametric study to evaluate critical core thickness for stability of earth and rockfill dams

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ABSTRACT

In earth and rockfill dams, a designer can design different sections of a dam depending upon the availability of fine and coarse grained materials near the site. To arrive an economical dam section, it is necessary to choose a core thickness which results in steepest side slopes and minimum earth work. A parametric study was undertaken to evaluate the critical core thickness within which a core does not effect stability of upstream slope (u/s) and downstream slope (d/s) of earth and rockfill dams. An earth and rockfill dam section of 180m height, with flat base and strong foundation without berms, was chosen as a base section for analysis. Stability analysis was take-up for three conditions, namely, End-of-Construction (EOC), Steady-State-Seepage (SSS) and Rapid-Draw-Down (RDD) with various parameters under static condition to determine the factor of safety (FoS) of the dam using standard available software. The critical core thickness (for vertical core) was identified, as the thickness beyond which the FOS of outer slopes of the dam decreased progressively. The following were the parameters that were varied for each of these three conditions: core thickness of vertical core, relative strength of core to shell, height of dam, pore water pressure ratio, r_u and drawdown levels. From this parametric study, three zones were identified in which location of a vertical core has different influence on the stability of the u/s and d/s slopes of a dam; no effect, some effect or significant effect. Thus, this study is useful for identifying the optimal zone for positioning a vertical core in an earth and rockfill dam.

Keywords: core; shell; thickness; strength parameters

1 INTRODUCTION

In earth and rochfill dams, imperviousness and stability is provided by core and shell respectively. Depending upon the availability of materials, one can opt for different sections of dam having thin or thick vertical core. From the stability consideration of outer slopes, it is important to arrive at optimal thickness of core. Since the core material has lower strength as compared to shell material, therefore steepness of the outer slopes depends upon the relative strength of core and shell. A precise understanding of how and when the thickness of core influences the outer slopes of dam is useful for the designer to decide the thickness to be adopted for providing steep outer slopes. This would lead to economical dam section by saving in the cost of earthwork. The present paper delineates three zones of dam in which location of core can effect stability by different magnitudes, which affects the stability of outer slopes in an earth and rockfill dam.

2 OBJECTIVE

The objective of the study was to identify the thickness of core beyond which the core causes a decrease in the factor of safety of dam slopes. This thickness is designated as ‘critical thickness’. A parametric study was carried out to estimate the influence of different core thicknesses on stability of outer slopes for different range of design parameters. The study was undertaken under EOC, SSS and RDD condition. The study reveals three different zones in which core thickness affects the stability of slopes.

3 PARAMETRIC STUDY

A dam section of height 180m with flat base and founded on strong foundation was selected for the present study. A simplified dam section adopted is shown in Figure 1. The parameters adopted in the present study are:

Shell materials:
$c' = 0$ kN/m², $\phi = 42°$ (for EOC, SSS and RDD)
Core material:
$c' = 50$ kN/m², $\phi = 42°$ (for EOC)
$c' = 0$kN/m², $\phi = 42°$ (for SSS and RDD)

Parametric studies on the following parameters were carried out for:

a. Thickness of core: Starting from 25% of dam height to full base width
b. Relative strength of core to shell: $\phi'_{core} = 24°$ (constant), $\phi'_{shell} = 30°, 42°, 54°$
c. EOC pore water pressure: $r_u = 0, 0.25, 0.50, 0.75$
d. Levels of drawdown: (H/4, H/2, 34/4)
e. Height of dam: (180m and 45m)

Base case was taken as: $c'_{core} = 50$kPa, $\phi'_{core} = 24°$, $c'_{shell} = 0$kPa $\phi'_{shell} = 42°$, $r_u = 0.5$

Stability analysis was carried out using Bishop’s simplified method using SLIDE 5.0 software. Parametric study was carried out for downstream slope under EOC and SSS conditions while for the upstream slope EOC and RDD conditions were analyzed.

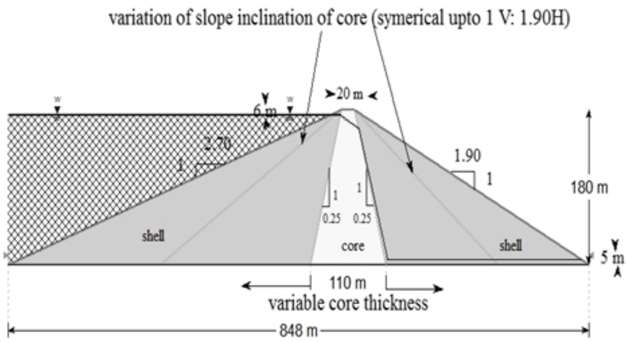

Fig. 1. Simplified section of 180m high earth and rockfill dam

4. IDENTIFICATION OF CRITICAL CORE THICKNESS

Identification of critical core thickness was carried out under three conditions, EOC. SSS (for d/s slope) and RDD (for u/s slope) Figure 2 (base case) shows that for variation of thickness of vertical core from 25% to 100% of dam height, FoS remains constant for the downstream slope and has a value of 1·71 for EOC and SSS conditions. When the thickness of the core is increased beyond 100% of dam height, it is observed that effect of core comes into play and hence the factor of safety starts decreasing. This thickness is termed as critical core thickness. Similarly for RDD for a vertical core thickness up to 150% of dam height, FoS remains constant having value of about 2·45 and then it starts decreasing.

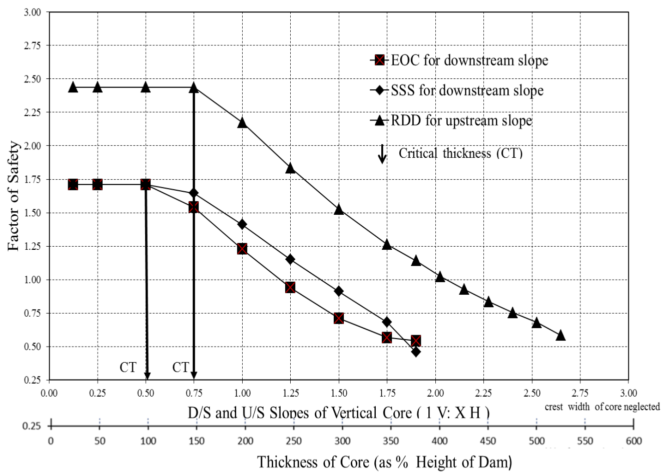

Fig. 2 Identification of critical thickness under EOC. SSS and RDD conditions

5. INFLUENCE OF RELATIVE STRENGTH OF CORE TO SHELL

Influence of relative strength of core to shell was carried out under three conditions, EOC. SSS (for d/s slope) and RDD (for u/s slope). It is evident from figure 3 (base case) that for EOC condition when the thickness of core is small, the influence on stability of outer slopes begins early (100% of dam height) for large difference in relative strength of core to shell (i.e. when the core is much weaker in comparison to shell: $\phi'_{core} = 24°$ and $\phi'_{shell} = 54°$). However when the relative strength difference is low (i.e. $\phi'_{core} = 24°$ and $\phi'_{shell} = 30°$), the FoS starts to decrease only after the core thickness exceeds 150% of dam height. A similar trend is observed for SSS and RDD conditions.

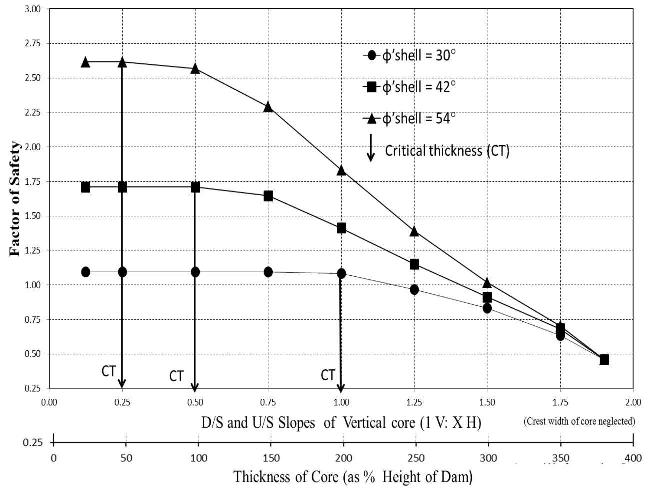

Fig. 3 Influence of relative strength on critical core thickness for EOC condition

6. INFLUENCE OF HEIGHT OF DAM

Influence of height of dam was carried out under three conditions, EOC. SSS (for d/s slope) and RDD (for u/s slope). Under EOC condition, Figure 4 (base case) depicts variation of FoS with change in core thickness for dam heights of 180m and 45m. It is observed that the FoS decreases when the thickness of the vertical core exceeds 100% of dam height for both heights of the dam. The decrease in the FoS beyond critical thickness is larger for the higher dams because the influence of cohesion intercept on stability is smaller for large height of slopes. The critical thickness for both heights is 100% of dam height. It is further confirmed from Figure 5 that under SSS and RDD conditions the dam height has no influence on the critical core thickness.

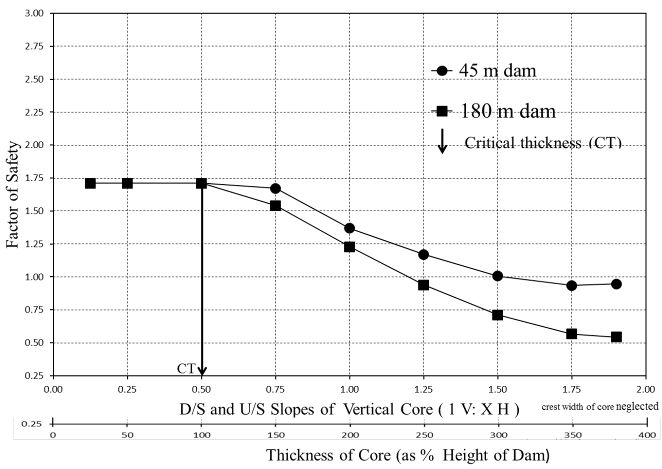

Fig. 4 Influence of height of dam on critical core thickness for EOC condition

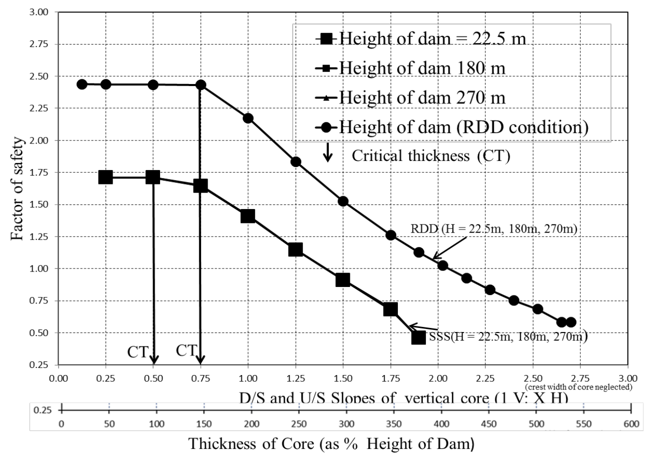

Fig. 5 Influence of height of dam on critical core thickness for SSS and RDD condition

7. INFLUENCE OF END-OF-CONSTRUCTION PORE WATER PRESSURE RATIO (DOWNSTREAM SLOPE)

Figure 6 (base case) depicts how under EOC condition thickness of the core under different pore water pressure ratios affects the stability of the downstream slope. It is observed that for variation of r_u from 0 to 0·75, the FoS decreases when the core thickness values exceed critical values. As the value of pore water pressure increases, strength of core material decreases and hence this results in decrease in FoS at a smaller core thickness. While for highest value of r_u the FoS begins to decline after the thickness of the vertical core exceeds 50% of dam height, in contrast, for $r_u = 0$, the critical core thickness is observed to be as high as 150% of dam height.

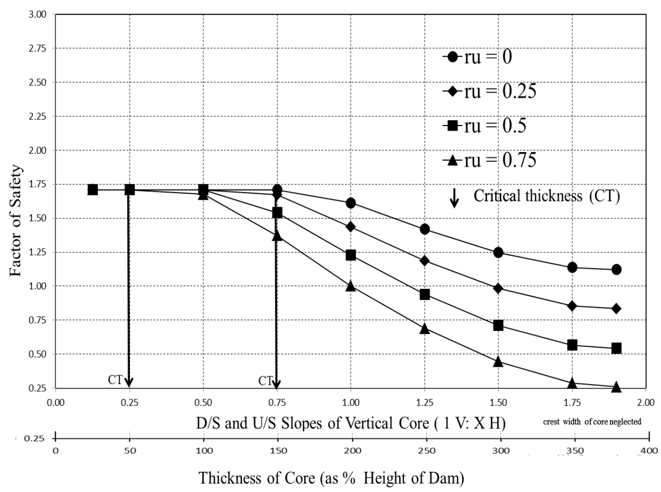

Fig. 6 Influence of pore water pressure ratio, 'r_u' on critical core thickness for EOC condition

8. INFLUENCE OF DRAWDOWN LEVELS (H_{dd}) UNDER RAPID-DRAW-DOWN CONDITION (UPSTREAM SLOPE)

Figure 7 (base case) depicts that for different drawdown levels from H/4 to 3H/4 there is no change in the FoS of U/s of the dam with increase in core thickness. This critical core thickness is 150% and is not affected by drawdown levels.

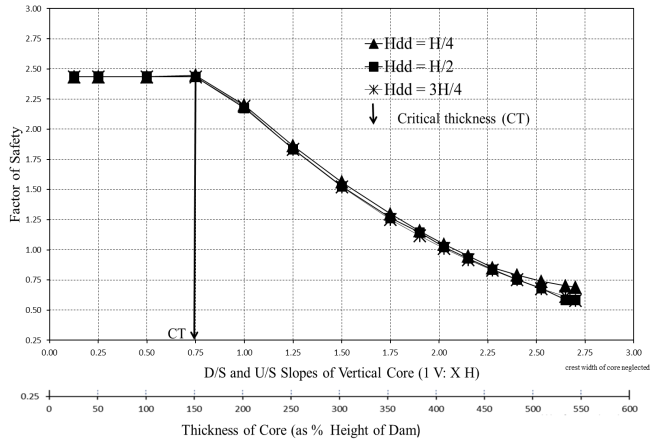

Fig. 7 Influence of drawdown levels on critical core thickness

9 THREE ZONES

Table 1 presents the values of critical thickness of vertical core beyond which factor of safety decreases for U/s and D/s slopes of the dam for all cases studied. Figure 8 depicts three zones based on results of parametric study. If a core is placed within Zone I it will not affect the stability of U/s and D/s slopes. If the core slopes reach Zone III, the FoS will be reduced. Zone II is a transition zone in which the influence depends on relative strength properties of core to shell material as well as r_u.

Zone I = Core position in this zone has no influence on FOS of outer slope

Zone II = Core position in this zone may or may not cause decrease in FOS of outer slope

Zone III = Core position in this zone causes FOS of outer slope to decrease

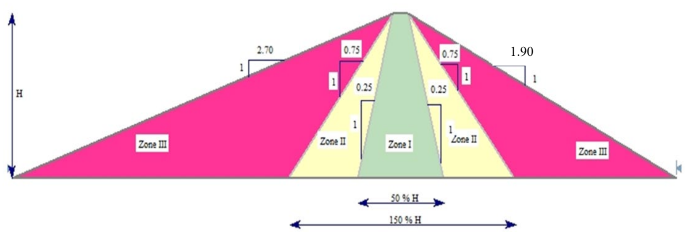

Figure 8 Location of vertical core in different zones affecting stability of slopes of earth and rockfill dam

10. CONCLUSION

This parametric study on the stability of an earth and rockfil dam identifies three zones in which vertical core will have different influence on stability of the dam. Depending upon the design parameters of construction materials, a designer can locate the core of the dam in an optimal zone so that the slopes are both safe and economical.

Table 1 Critical thickness of vertical core beyond which factor of safety decreases for upstream and downstream slopes of the dam

Condition →	EOC	SSS	RDD	EOC		SSS	RDD
↓ Range of Parameters				Critical Core Thickness as % of height of dam		Critical Core Thickness as % of height of dam	
				Upstream slope	Downstream slope	Downstream slope	Upstream slope
Pore Water Pressure Parameters							
$r_{u\ core}$	0	-	-	200	150	-	-
	0.25			150	100		
	0.50			150	100		
	0.75			100	50		
$r_{u\ Shell}$	0	-					
Relative strength parameters							
ϕ'_{core}	24°	24°	24°				
ϕ'_{shell}	30°	30°	30°	150	150	150	150
	42°	42°	42°	150	100	100	150
	54°	54°	54°	100	50	50	100
SSR*	0.77	0.77	0.77				
	0.49	0.49	0.49				
	0.32	0.32	0.32				
Height of dam							
	45 m	45 m	45 m	150	100	100	150
	180 m	180 m	180 m	150	100	100	150
Depth of drawdown level				-		-	
-			H_{dd} = H/4	-		-	150
			H_{dd} = H/2	-		-	150
			H_{dd} = 3H/4	-		-	150

*SSR = Shear Strength Ratio = $\tan\phi'_{core} / \tan\phi'_{shell}$

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