SLOPE STABILITY AND SEEPAGE ANALYSIS OF HOMOGENOUS EARTHEN DAM

Abdullah Homayan Al-Harbi　　Rayan Mohammed Al-Mutairi

Supervised by Dr. Zafar Mahmood

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ABSTRACT

Dams are delicate constructions, so they must be carefully planned according to specific criteria, including the dam's geometry and materials. Assessment of seepage and slope stability were carried out on a homogeneous earth dam. The stability of a 12-m high homogeneous earth dam during the reservoir fill and rapid drawdown under static and dynamic loading conditions was examined. This study was performed using the Rocscience package Slide. The study was carried out on two models: (i) dam with chimney drain, and (ii) dam with blanket drain. Both static and pseudo-dynamic analyses were performed. The sensitivity analysis carried out for the stability of the dam under steadystate conditions shows that friction angle is a more sensitive parameter than cohesion and unit weight. Probabilistic analyses show that the probability of failure on the downstream side is high while deterministic analysis shows them satisfactory. It is concluded dam with a chimney filter is better than a dam with a blanket filter.

PROBLEM STATEMENT

The stability of an earth dam is critical during the first reservoir fill and also during the quick drawdown conditions. The dam attains steady-state seepage conditions after a considerable time after reservoir filling. The stability of upstream and downstream slopes is also critical during the first reservoir fill. During the rapid drawdown conditions, the excess-pore pressure may cause the instability of upstream slopes. Therefore, first reservoir fill and rapid drawdown analyses are an important part of a dam design.

OBJECTIVES

- To carry out the steady-state and transient seepage analysis of homogeneous earth dam;
- To study the behavior of homogeneous earth dam during the reservoir fill and draw down analysis;
- To study slope stability of homogeneous earth dam during reservoir fill and drawdown analysis; and
- To perform a parametric study to investigate the effect of permeability and dam slopes on the overall performance of the homogeneous earth dam.

METHODOLOGY

This study of homogeneous earthen dam stability is based on two analyses, seepage analysis, and slope stability analysis, which provide a thorough understanding of how the earthen dam is stable in a variety of conditions. The following are the details of these two analyses: For one-dimensional flow problems, Darcy's law is used.

Darcy's Law states that: $q = kiA$

Laplace's equation is the partial differential equation that describes seepage through a heterogeneous, anisotropic soil in two dimensions:

The equation for transient analysis: $\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t}$

The equation for steady-state analysis: $\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = 0$

Ordinary Method of Slices methods It works by cutting a possible sliding mass into many vertical slices, these methods determine the factor of safety (FS): $F_s = \frac{\sum_{n=1}^{n=p}(c'\Delta L_n + W_n \cos\alpha_n \tan\phi')}{\sum_{n=1}^{n=p}(W_n \sin\alpha_n)}$

COMPARISON OF TWO MODELS IN STATIC LOADING CONDITIONS

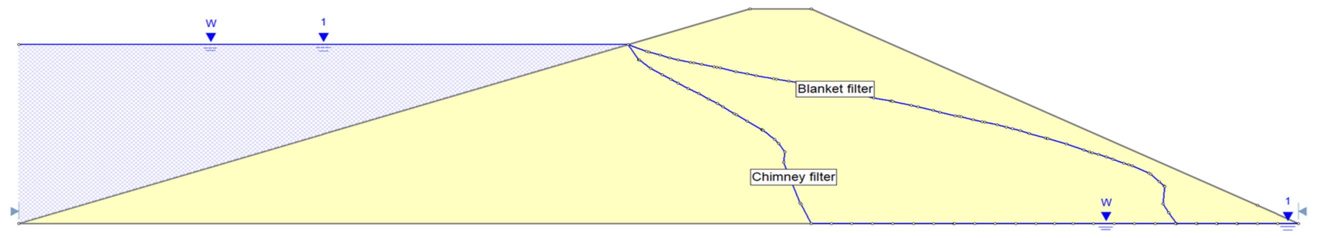

Figure 1: Comparison between both models in phreatic line.

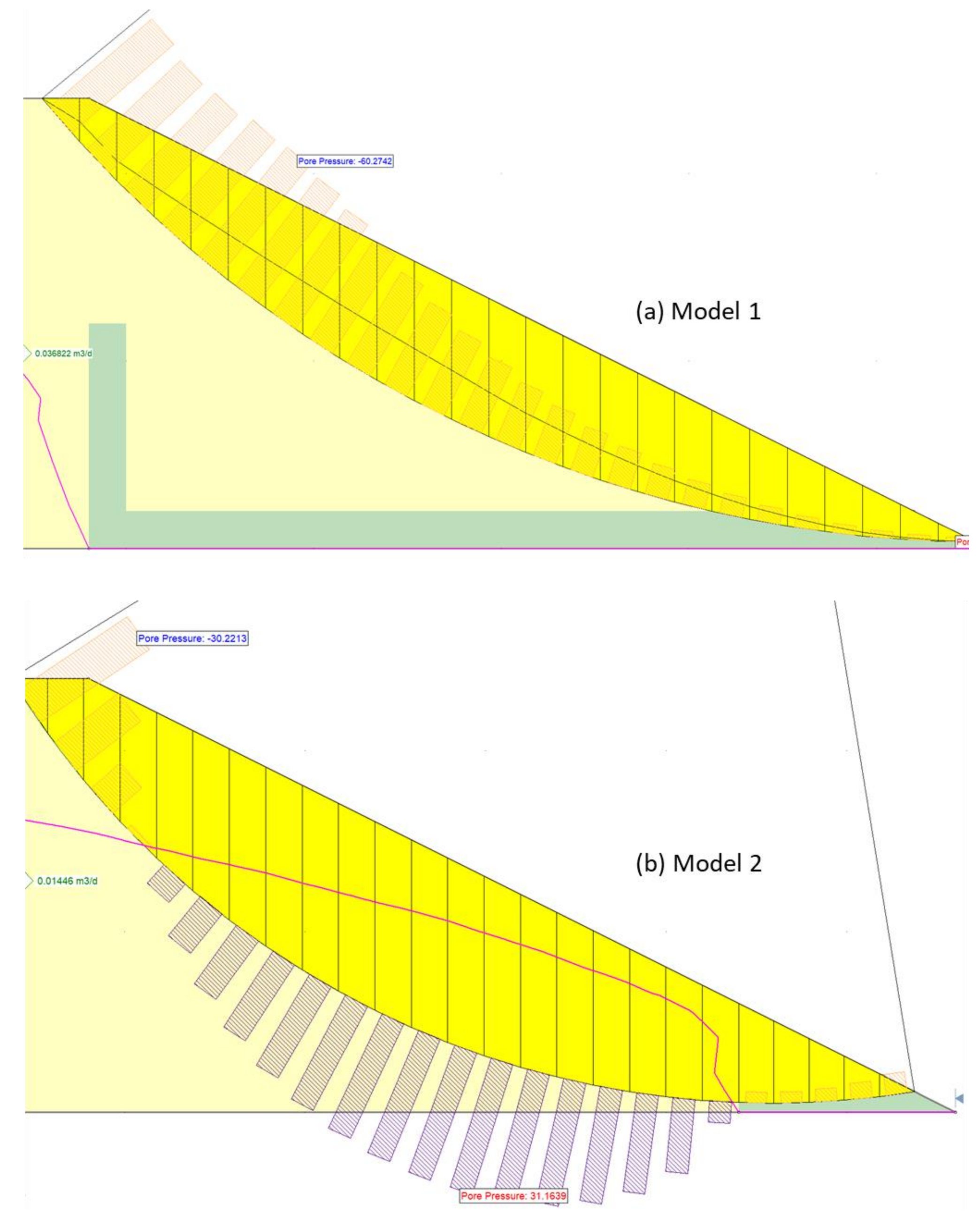

Figure 2: Distribution of pore pressure on the downstream side for both models.

STABILITY OF THE DAM AT THE END OF CONSTRUCTION

Model	Static loading		Seismic loading ($\frac{a}{g} = 0.05$)	
	U/S	D/S	U/S	D/S
1	2.196	1.566	1.881	1.398
2	2.196	1.566	1.881	1.398

STABILITY OF DAM IN STEADY-STATE CONDITION

Model	Static		Seismic (a/g=0.05)	
	U/S	D/S	U/S	D/S
1	2.641	1.570	1.877	1.398
2	2.458	1.300	1.83	1.118

SENSITIVITY ANALYSIS

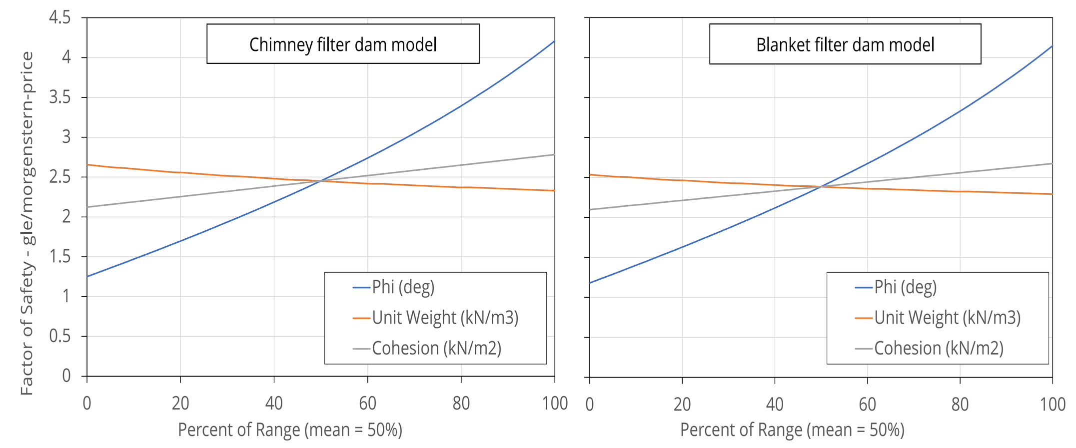

Figure 3: Sensitivity analysis.

PROBABILISTIC ANALYSIS

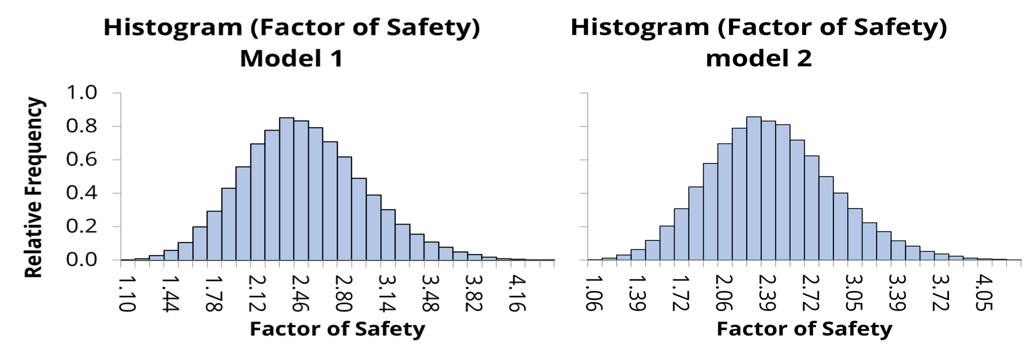

Figure 4: Normal distribution for the factor of safety.

Summary for probabilistic analysis.

Model	FS(Deterministic)	FS(Mean)	β	Remarks
U/S side				
1	2.448	2.484	3.10	$\beta = 3$ means failure of 1 in 1000
2	2.385	2.416	2.97	
D/S side				
1	1.568	1.590	2.22	$\beta = 2.22$ means failure of 1 in 100
2	1.264	1.279	1.37	$\beta = 1.37$ means failure of 9 in 100

STABILITY OF DAM IN DRAWDOWN CONDITION

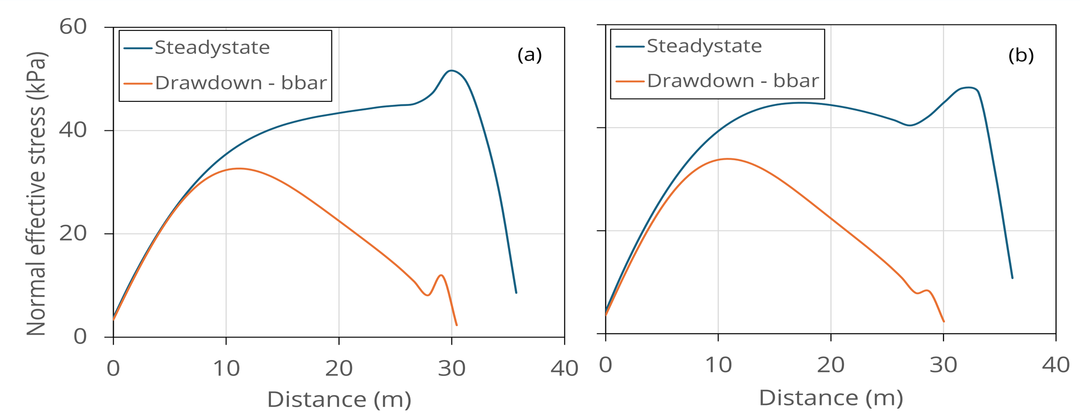

Figure 5: Comparison of normal vertical effective stress at the base of each slice for steadystate and drawdown conditions for (a) model 1 and (b) model 2.

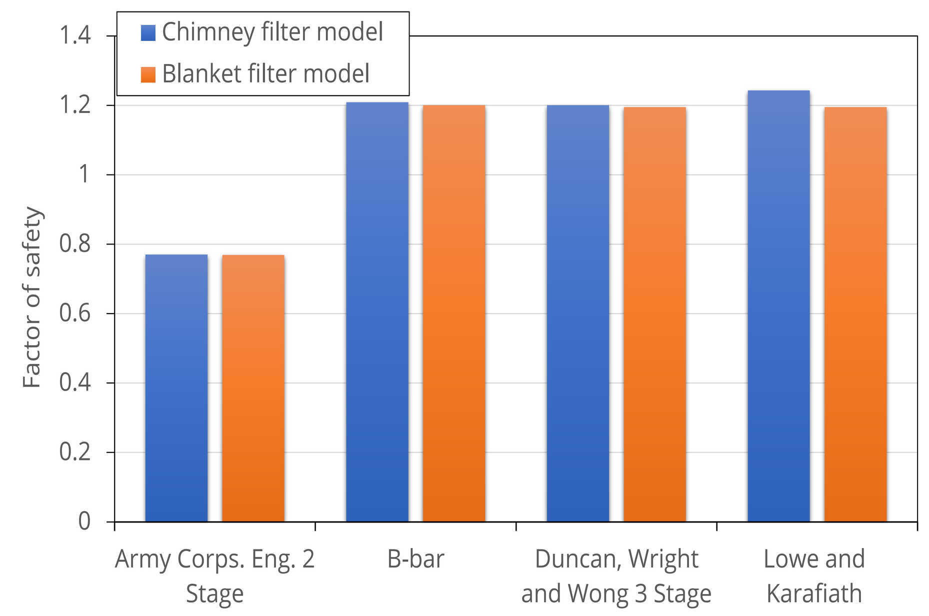

Figure 6: Comparison between methods.

STABILITY OF THE DAM IN TRANSIENT CONDITION

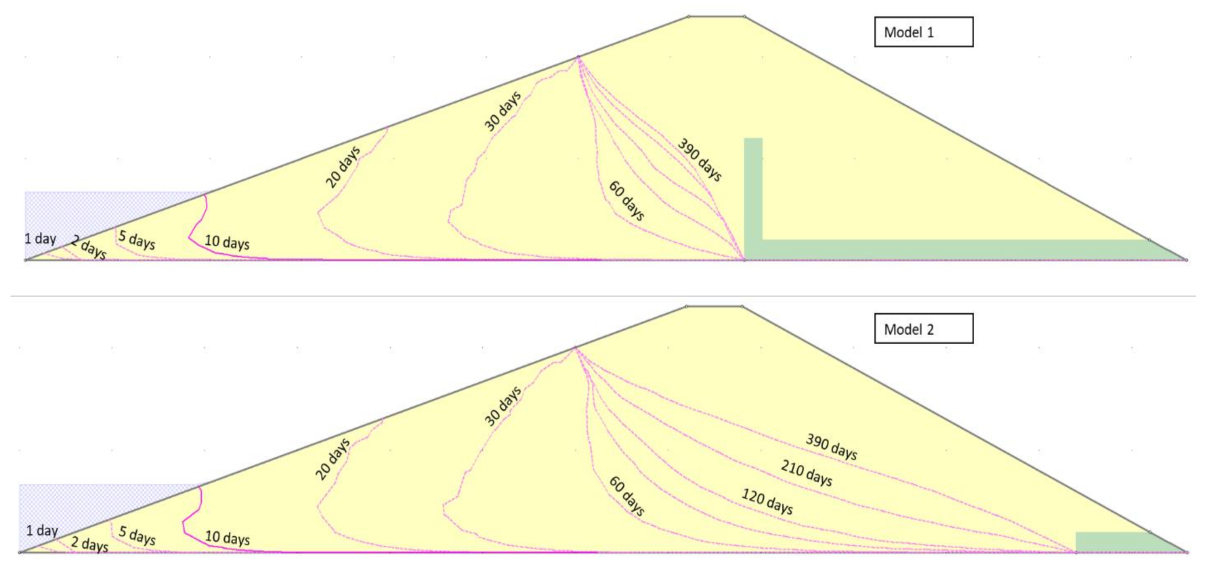

Figure 7: The evolution of the phreatic line during reservoir filling.

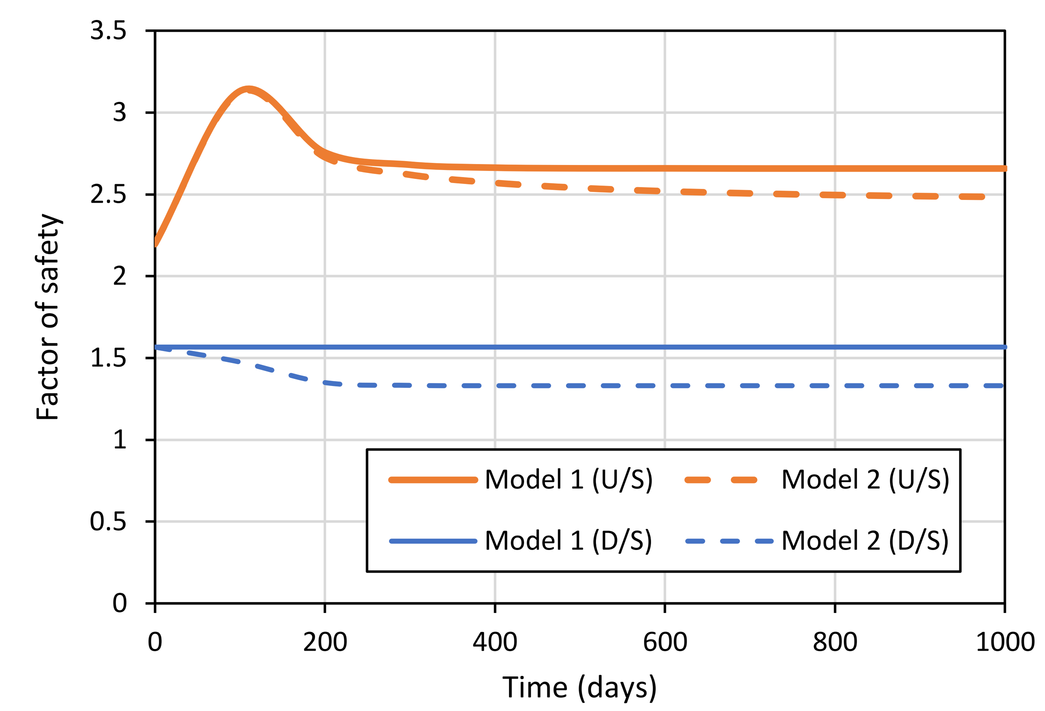

Figure 8: Change in Factor of safety through the time for both models upstream and downstream.

CONCLUSIONS

- The factor of safety at the end of construction for both upstream and downstream sides for both dam models under static and dynamic loading conditions is above the minimum factor of safety as required by USACE (EM 1110-2-1902).
- In steadystate analysis under static loading conditions, the factor of safety for both models on the upstream side is more than the recommended value of 1.5. However, the factor of safety downstream of model 2 is less than the recommended value of 1.5. The downstream factor of safety can be improved by increasing the length of the filter, or by changing the downstream side slopes.
- Sensitivity analysis carried out during steadystate conditions indicates that the friction angle has a higher influence on the safety factor.
- Rapid drawdown analysis is carried out using four different methods reported in the literature. It has been observed that in drawdown analysis, all methods give the factor of safety more than the critical value (i.e., FS ≥1.1) except the Army Corps of Engineers method, which is more conservative than the other methods.
- In the end, we can observe that the dam with a chimney filter provides more safety than the dam with a blanket filter because it has the ability to keep the phreatic line far from the downstream side more than the blanket filter.