Slope Stability of Earthen Dams under Extreme Weather Events in a Changing Climate

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1. Background

Numerous cases of slope failure in earthen dams are reported, many of which have been attributed to hydraulic or seepage failure (Bhaskar et al., 2022).

The core of an earth dam is a crucial factor in reducing seepage potential. Homogeneous earth dams lack this feature, making them more susceptible to piping compared to non-homogeneous types (Kalateh & Kheiry, 2023).

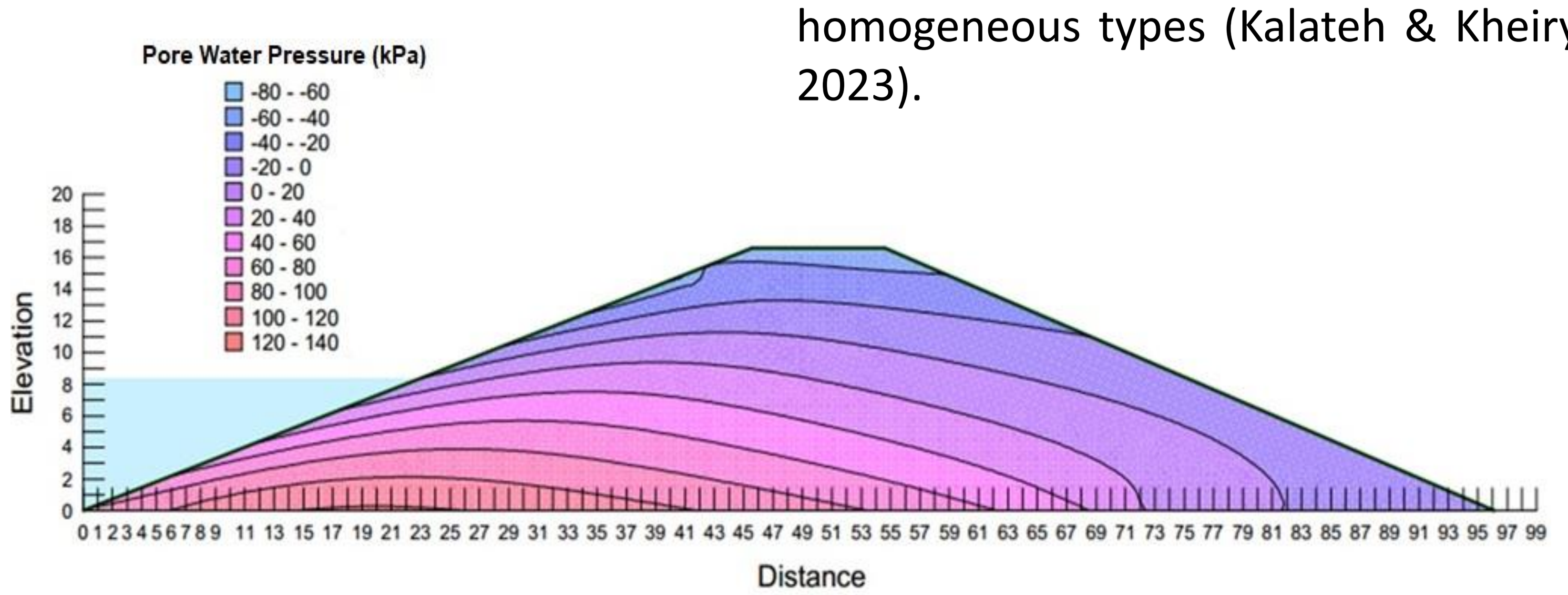

Figure 1. Pore water pressure in a homogeneous earthen dam during rapid drawdown.

Floods and droughts have profound impacts on a wide range of sectors such as water, agriculture, energy production, infrastructure, and ecosystem health. Despite the potential for rapid transitions between floods and droughts to result in greater economic and environmental impacts compared to each event in isolation, these two extremes have traditionally been studied separately (Rezvani et al., 2023).

Objectives:

1. **Analyze the behavior of the safety factor during flood-drought transitions.**
2. **Establish the correlation between the rate and the safety factor in flood-drought transitions.**

References

Bhaskar, P., Puppala, A., & Boluk, B. (2022). Influence of Unsaturated Hydraulic Properties on Transient Seepage and Stability Analysis of an Earthen Dam. *Int. J. Geomech*, *22*(7), 1–12. https://doi.org/10.1061/(ASCE)GM.1943-5622.0002414

Kalateh, F., & Kheiry, M. (2023). A Review of Stochastic Analysis of the Seepage Through Earth Dams with a Focus on the Application of Monte Carlo Simulation. *Archives of Computational Methods in Engineering*, *0123456789*. https://doi.org/10.1007/s11831-023-09972-3

Rezvani, R., Rahimimovaghar, M., Na, W., & Najafi, M. R. (2023). Accelerated lagged compound floods and droughts in northwest North America under 1 . 5 ∘ C − 4 ∘ C global warming levels. *Journal of Hydrology Journal*, *624*(July). https://doi.org/https://doi.org/10.1016/j.jhydrol.2023.129906

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2. Study Case

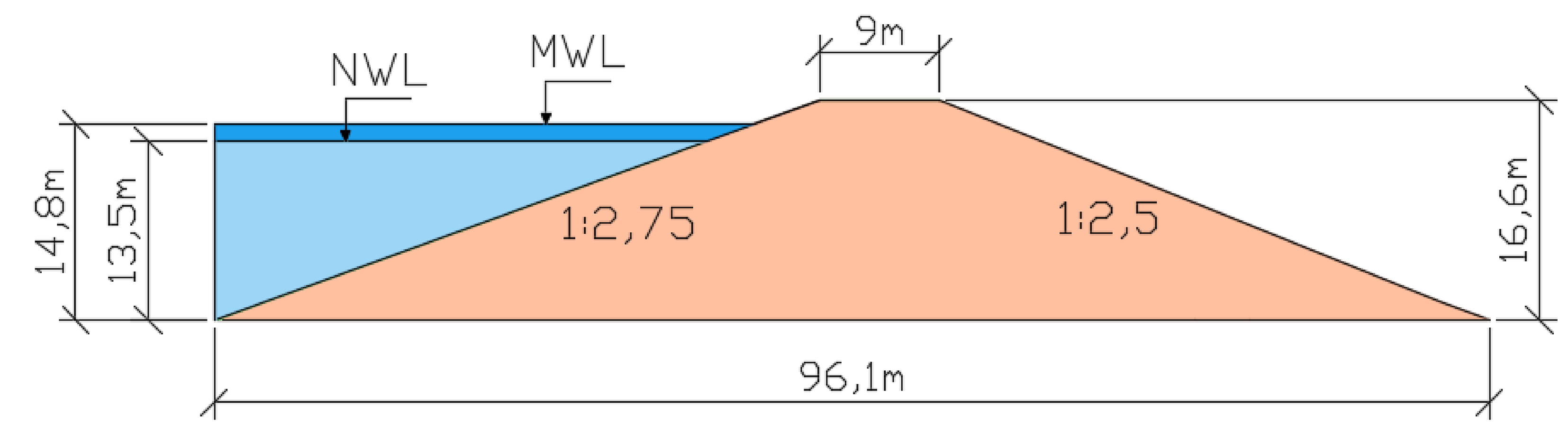

Figure 2. Geometry for homogeneous earthen dam with water levels (NWL: Normal Water Level; MWL: Maximum Water Level)

Table 1. Geotechnical parameters of soil

Specific weight (kN/m³)	Cohesion (kPa)	Friction angle (°)	Permeability (m/s)	VWC	Mv (kPa^{-1})	kx/ky
18,83	19,60	20,0	1,00E-08	0,361	8,50E-05	0,0833

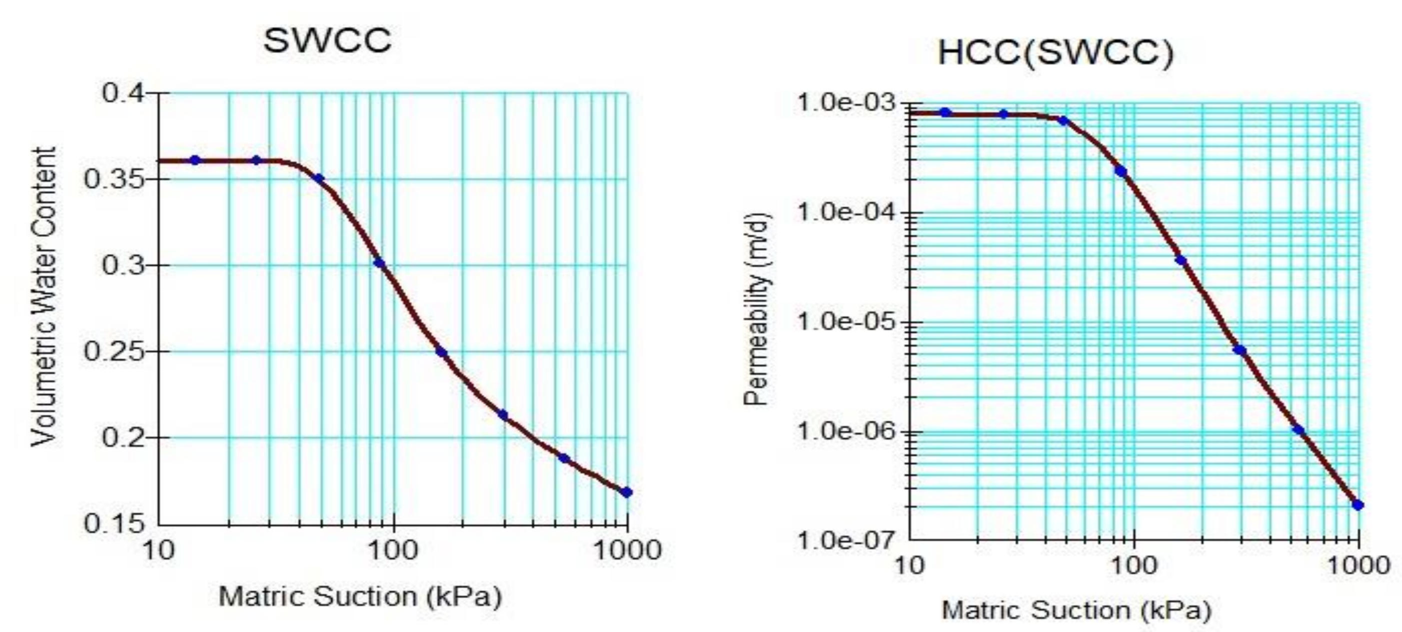

Figure 3. Characteristic curves (SWCC) and hydraulic conductivity curves (HCC) for soil.

Based on the study developed by Rezvani et al. (2023), the following duration times are proposed for the base period and different global warming levels.

Table 2. Duration of each event

	Duration (days)			
	Flood	Transition	Drought	Total
Base period	14	114	102	230
1,5°C	14	75	78	167
2°C	13	63	64	140
3°C	14	50	62	126

Additionally, three velocity rates for flooding and drought were included. In this way it is possible to analyze the effect of this variable on the SF.

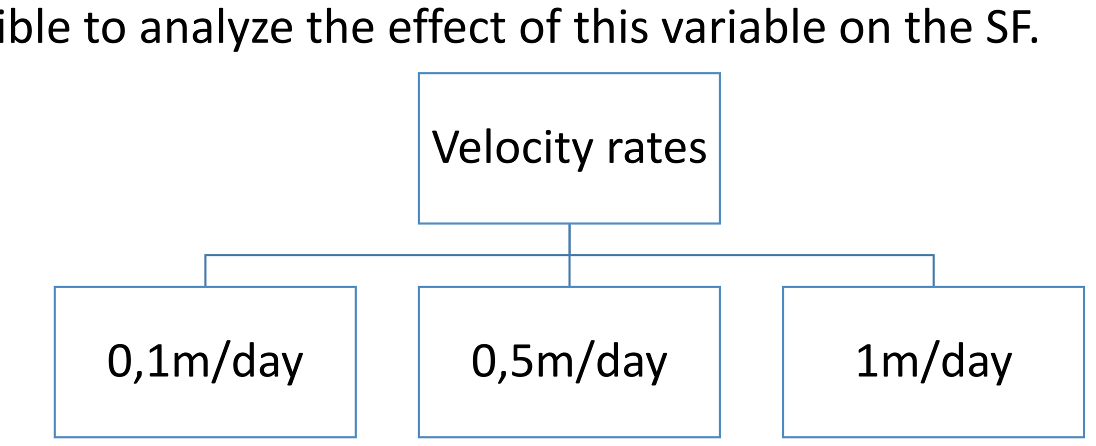

Figure 4. Velocity rates for flood and drought process.

3. Results

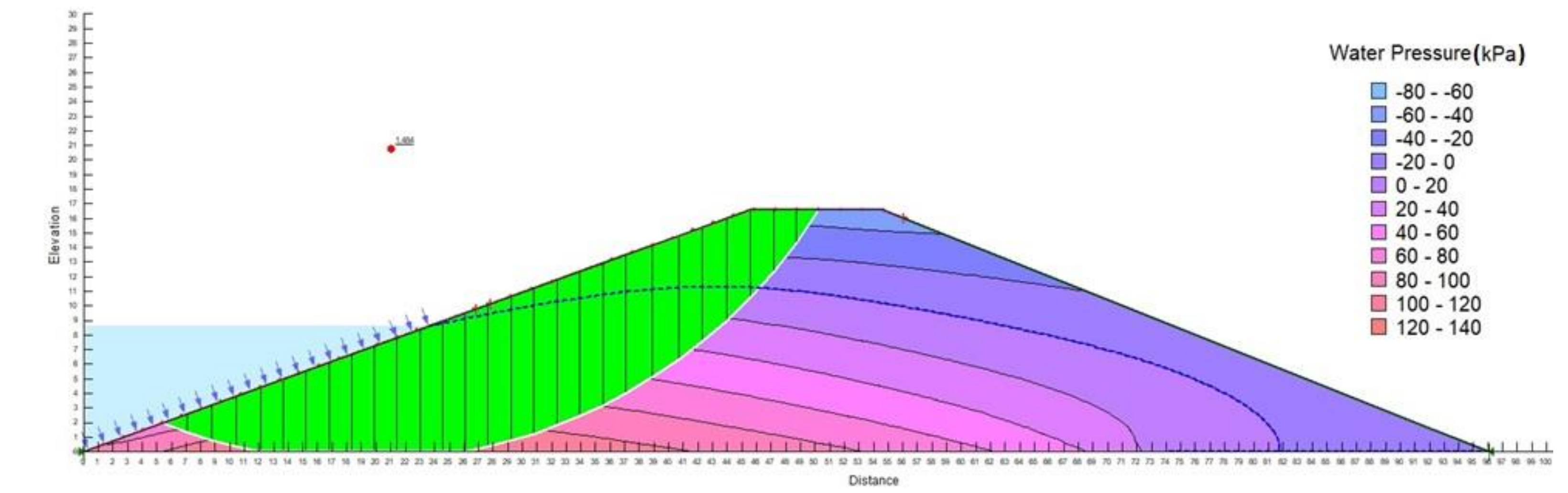

Figure 5. Proposed failure surface and pore pressures generated at the end of the drought.

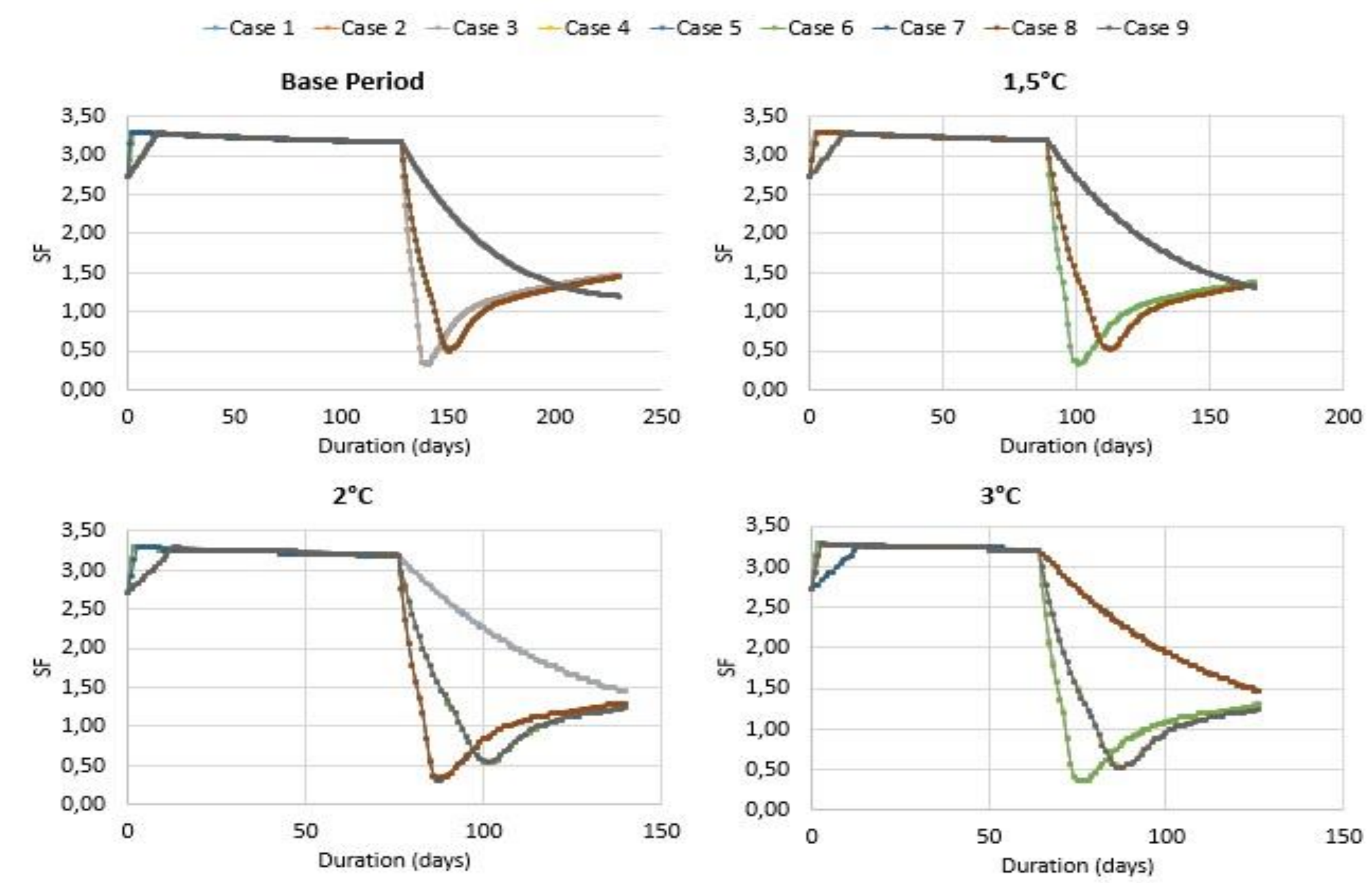

Figure 6. Behavior of the SF for the different cases analyzed.

Figure 6 shows that for some of the cases evaluated, the values overlap in the graphs, because the behavior of the Factor of Safety is very similar.

5. Conclusions & Future work

The behavior of the Factor of Safety (FS) during extreme flood-drought transitions indicates that the most critical scenario for slope stability is during drought. As flooding occurs, the FS improves for all projected scenarios due to increased pore pressures within the embankment. Subsequently, during the transition phase, these pore pressures typically stabilize. However, this situation is later affected when the reservoir level begins to decrease. This leads to an increase in stress along the upper streamline, as the pore pressures do not dissipate rapidly enough, resulting in a reduction in FS in all cases. The correlation between speed and flood-drought phenomena is evident. For velocity of 0.5m/day and 1m/day, the FS during drought experiences a sharp decline, causing it to fall below the safety threshold of 1, which is typically set to ensure stability. Additionally, when considering the projected climate change scenarios, where the total duration of flood-drought transition is reduced, so is the time at which the minimum FS is reached.