Stability of abandoned pit slopes - how groundwater and lake water control may support safety while flooding

Ershad Ud Dowlah Pahlowan, Anika Braun, and Tomas Manuel Fernandez-Steeger

Department of Engineering Geology, Technische Universität Berlin, Berlin, Germany

1.Introduction

As Europe progresses towards decarbonization, renewable energy plays a pivotal role, with its rapid growth essential for reducing carbon emissions. In the context of the contemporary energy landscape, a pioneering energy storage approach has been developed: converting disused open-pit mines into extensive pumped-hydropower storage (PHS) facilities. This method involves pumping water upwards during times of low energy demand and then releasing it to generate electricity during high demand periods (Fig.1), akin to the operation of conventional hydropower stations

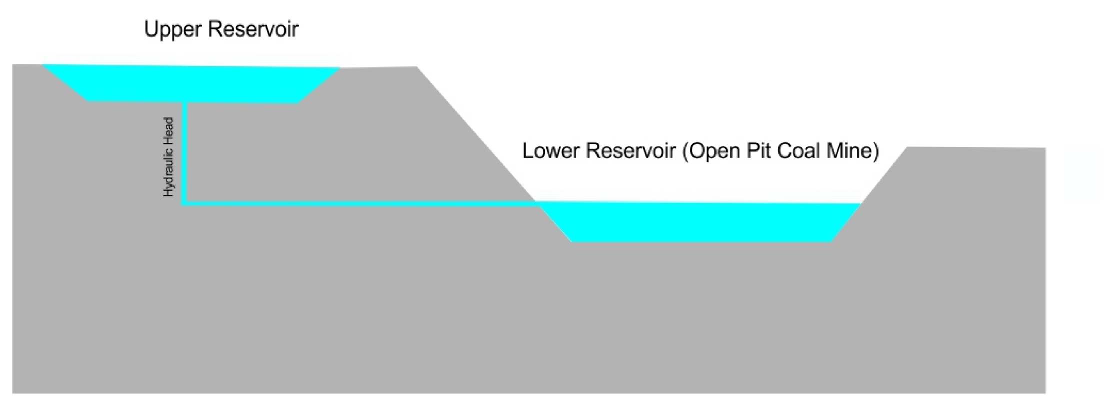

Fig. 1: A conceptual diagram of pumped-hydropower storage (PHS) on abandoned open pit coal mine.

Research Question: How can we manage the initial mine pit flooding to establish the lower reservoir while ensuring slope stability under changing water pressures?

- **Challenge 1:** Addressing geotechnical challenges related to mine slope stability during the initial flooding of the mine (Fig. 2)

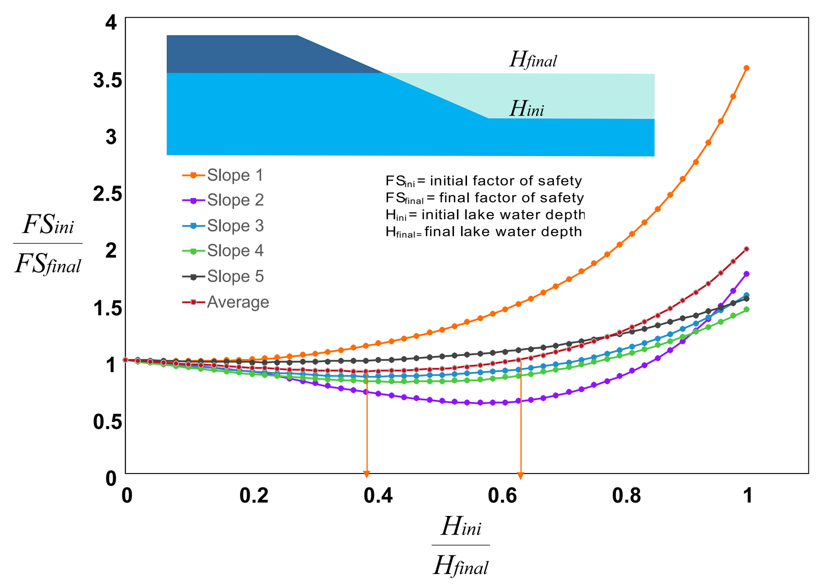

Fig. 2: Fluctuations in water levels affect the slope stability (FS) of a pit lake.

- **Initial Safety Drop:** Sharp decrease in FS during the initial stage.
- **Lowest FS Point:** Occurs at 36% of target depth.
- **Stability Recovery:** Improves to 63% of final depth.
- **Enhancement Measures:** Stability enhanced by raising water level and reducing Hydraulic Head for PHS.

- **Challenge 2:** Maintaining an efficient hydraulic head in PHS systems, particularly when the elevation difference between the upper and lower reservoirs is minimal.

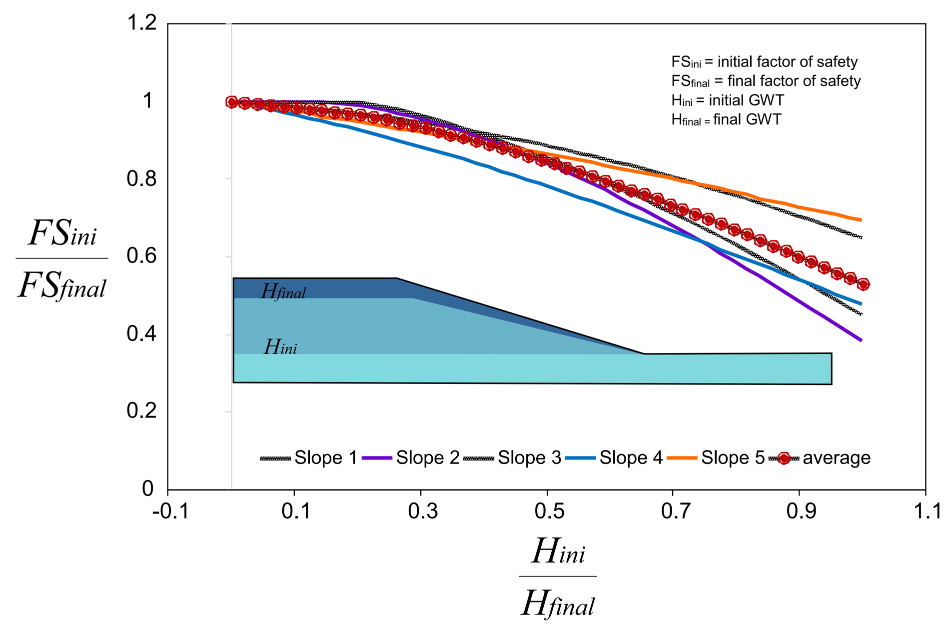

Fig.3: Fluctuations in groundwater levels affect the slope stability (FS) of a pit lake.

- **Initial FS Decline: FS** begins with a gradual decrease.
- **Impact of GWT Increase:** As the GWT rises, FS reduces to 53% of its original level.
- **Threshold Effect:** After surpassing the 53% threshold of final hydraulic head, FS drops sharply to 38%.
- **Water Level Elevation Impact:** Raising the water level further decreases the FS of the slope and the Hydraulic Head for PHS.

2.Methodology

Limit Equilibrium Methods are utilized to assess the stability of slopes, offering a measure that compares the driving forces to the resisting forces along the shear surface of the slope (Fig.4).

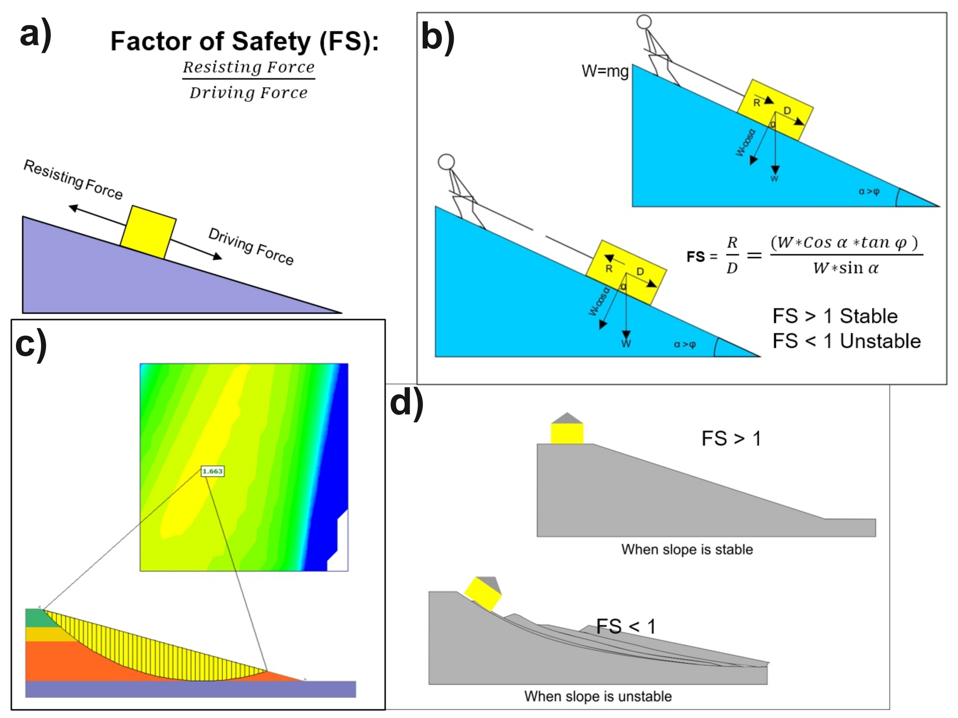

Fig. 4: Calculating Slope Stability: A Methodical Approach.

3.Results

- **Method Focus:** Control the head difference between lake water and groundwater to maintain mine slope stability during PHS operations.
- **Approach Evaluation:** Two distinct methods are evaluated for managing the head difference (Fig.4 and Fig.5).
- **Stability Analysis Tool:** Utilize the Limit Equilibrium Method (LEM) to assess slope stability at various flooding stages.

Reservoir Filling Approch 1:

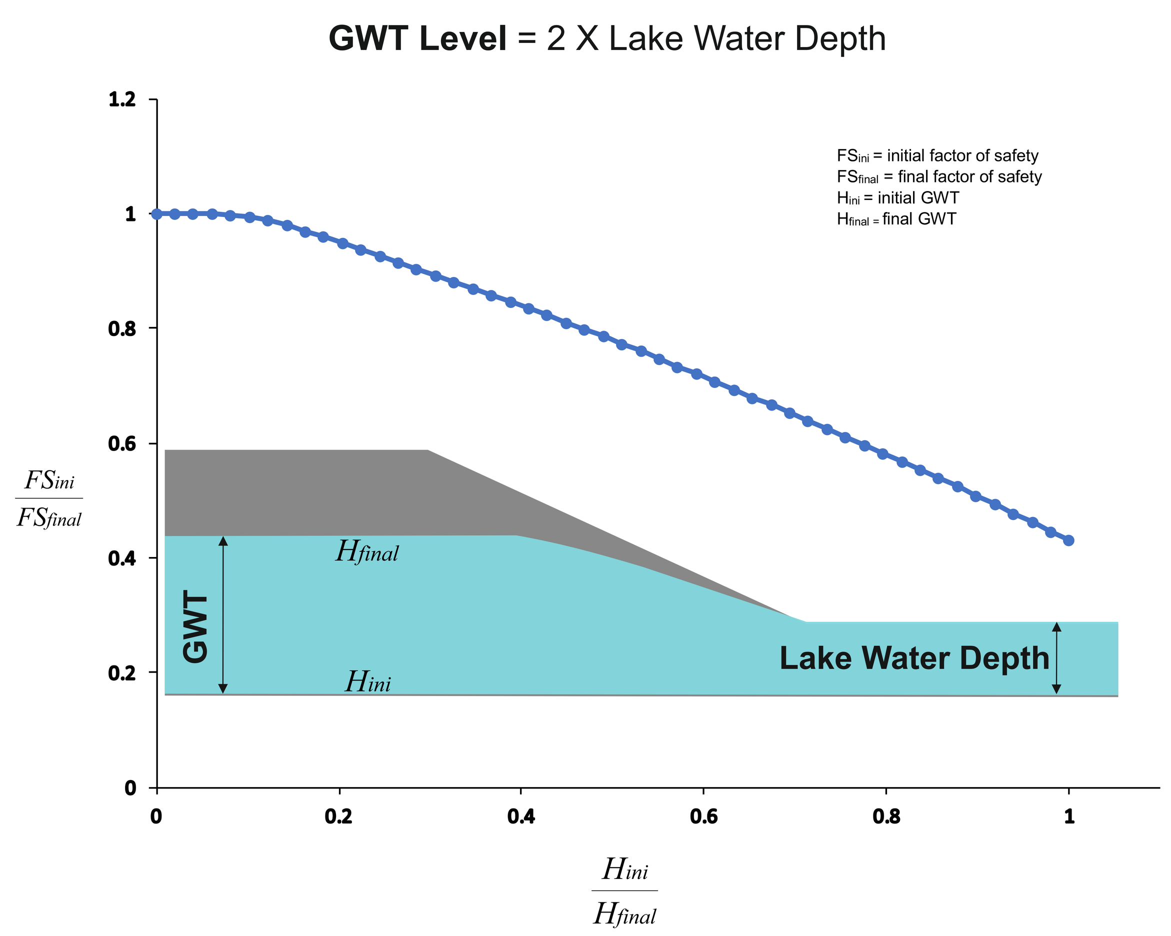

Fig.4: Approach 1, the increase in GWT levels impacts the slope stability of the pit lake.

- **Factor of Safety Reduction:** Decreases to 56% of the original value.
- **Groundwater Table Increase:** Rises by 140 m.
- **Lake Water Level Increase:** Elevates by 70 m.
- **Onset of Factor of Safety Decline:** Occurs after a 17 m rise in lake water level.
- **Slope Stability Concern:** Initiates after a 125 m increase in groundwater table.
- **Groundwater Management:** Requires existing pumping operations to continue in order to control GWT.

Reservoir Filling Approch 2:

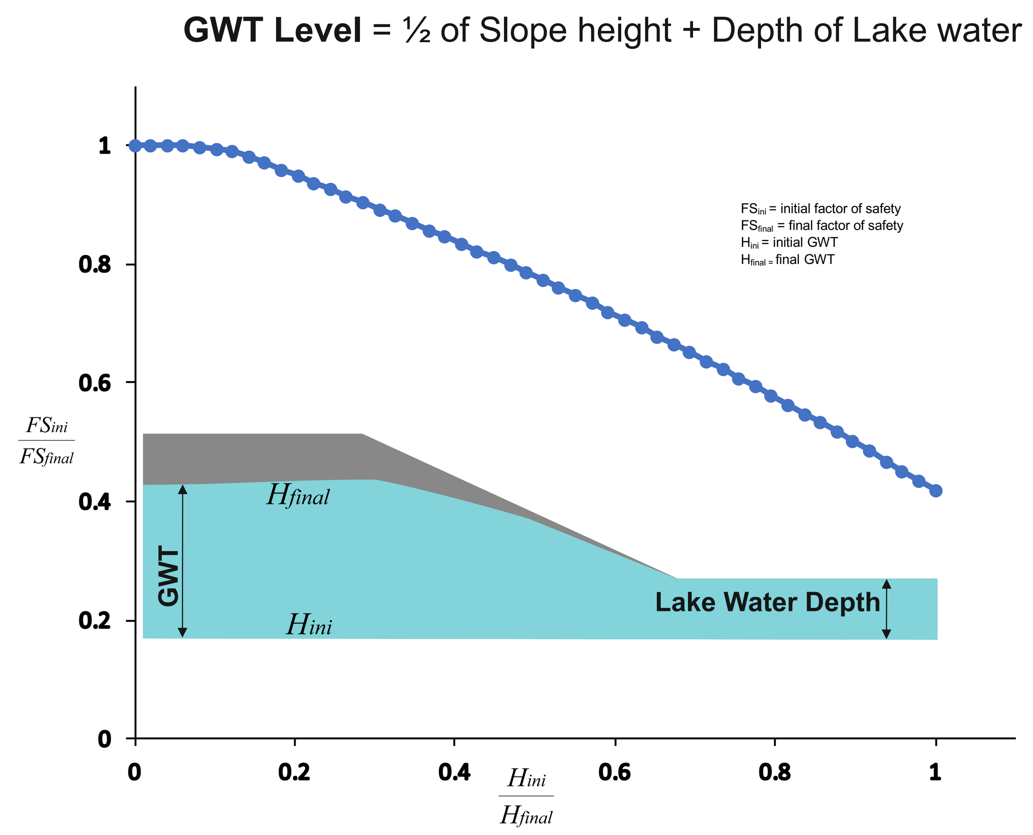

Fig.5: Approach 2, the increase in GWT levels impacts the slope stability of the pit lake.

- **Factor of Safety Reduction:** Decreases to 58% of the original value.
- **Groundwater Table Increase:** Rises by 152 m.
- **Lake Water Level Increase:** Elevates by 70 m.
- **Onset of Factor of Safety Decline:** Occurs after a 15 m rise in lake water level.
- **Slope Stability Concern:** Initiates after a 136-meter increase in groundwater table.
- **Groundwater Management:** Requires existing pumping operations to continue in order to control GWT.

4.Conclusion

Regardless of whether the Limit Equilibrium Method or the Finite Element Method is used, the methods applied are distinct from each other. A controlled rise of the groundwater table is essential for maintaining slope stability. In comparative terms, Approach 2 proves to be more effective. It ensures a gradual increase in groundwater levels and provides enhanced safety for the slope, marrying precision in hydrogeological management with geotechnical assurance.

Contact: Ershad Ud Dowlah Pahlowan
E-Mail: pahlowan@tu-berlin.de
Phone: +49 30 314-70929
ResearchGate: Ershad-Pahlowan

Abstract:

Department of Engineering Geology
https://www.tu.berlin/en/ingenieurgeologie

Technische Universität Berlin

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