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# Analysis of upstream slope stability during rapid drawdown - Sidi Abdelli dam as a case study

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**Abstract:** Many factors, including soil permeability and mechanical properties, upstream side slope, drawdown ratio, and drawdown rate, influence the stability of an earth dam during sudden drawdown. This paper investigates the influence of rapid drawdown on earth dam upstream slope stability and its role in the change of pore water pressure at different locations and factor of safety of the upstream slope. To achieve the aim of this study, the Sidi Abdelli dam was taken as a case study by using the Geo-SLOPE/W program based on the limit equilibrium method. The results show that the pore water pressures are very low at the toe of the dam and then increase as the initiation of pore water dissipation from the dam and then decrease as the elevation, as well, the velocity vectors start to exit from the upstream side, the possible seepage face is on the upstream side. As well as, the factor of safety of the upstream slip surface decrease with the initiation of rapid drawdown, the upstream slope is no in a safe stability condition. But, after 13 days the factor of safety increases above value 1.00, that is means the upstream slope will be in a safe condition.



## 1 Introduction

The soil parameters, geometry, and force applied both internally and externally determine the stability of any slope. Pore water pressure and surface water pressure represent the internal and external forces that influence slope stability, respectively. During the operation of the dam, the water level in the reservoir must always be changed; this operation will have an impact on the upstream face's stability.

The reduction of water in the reservoir has two effects: a change in internal pore water pressure and a reduction in the external hydrostatic pressure's ability to stabilize. Using finite element and limit equilibrium methods, Zomorodian and Abodollahzadeh (2010) investigated the effect of horizontal drains on the upstream slope of earth fill dams during rapid drawdown. The changing pore water pressure, outpouring seepage flow, and safety factor were all examined. Using the SEEP/W software, the amount of water leakage and seepage in the dam was investigated, as well as the static slope stability analysis using the SLOPE/W software. Berilgen (2007) investigated slope stability during drawdown based on soil permeability, rate of drawdown, and drawdown ratio, and found that the rate at which pore water falls has a significant impact on slope stability during drawdown, as well as the magnitude of displacement developed in the sloped soil mass. Fattah et al. (2015) studied the behavior of an earth dam during rapid drawdown of water in the reservoir and came to the conclusion that the factor of safety against dam slope sliding decreases slightly within a short period after the start of rapid drawdown of water from the dam reservoir,

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then the factor of safety increases the effective stresses in the soil, thus increasing shear strength of the soil behavior of the Khasa-Chai Dam during the drawdown operation, taking into account the dam's new construction. The phreatic line falls nearly at the same position in both cases, according to the drawdown conditions. Furthermore, in both cases, the upstream slip surface's factor of safety exceeds (1.0), indicating that the upstream slope is in a safe condition during water drawdown. Recently, (Bhutto et al. 2020) studied the slow and rapid drawdown of a rainfed embankment dam by using finite element method. They found the safety of the dam was satisfactory when the reservoir was lowered at the quick rate for a depth of 10m, 20m, 30m respectively. As well, the stability of the dam was also found satisfactory even though the reservoir was lowered at a rate of 0.25m/day for a depth of 55m.

(Alfatlawi et al. 2020) Evaluated of the upstream slope stability of earth dams based on drawdown conditions - Khassa Chai Dam. They concluded the stability of the slope during drawdown is highly impacted by how fast its pore water pressure dissipates. As well as, minimum F.S. was achieved within 10 hr in the case of a 1-day water drawdown, with the F.S. reduced by 60.66%. (Azadi et al. 2022) Analyzed the stability analysis of earth-fill dams under rapid drawdown and transient flow conditions used to prepare stability analysis charts by conducting coupled finite-element numerical and analytical limit equilibrium procedures. They found decreasing the permeability of the core's material, despite preventing seepage, the instability risk of the upstream slope as a result of rapid drawdown intensifies.

In this paper, the rapid drawdown condition is investigated by the Geo-SLOPE/W program for reservoir water of Sidi Abdelli dam. The stability of slope the upstream dam is traced during the rapid drawdown.

## 2 Materials and methods

### 2.1 Location of Sidi Abdelli dam

Instead of Lambert coordinates, the Sidi Abdelli dam is located in the north-west of Algeria, on the Isser wadi north of the village of Sidi Abdelli and upstream of the town of Bensakrane, 37 km from the town of Tlemcen. It is a 60-meter-high earth dam with a central core. The selected cross section's crest elevation was 665m throughout the dam's length, while the ground elevation level was 340m. Figure 1 depicts the dimensions of selected cross sections.

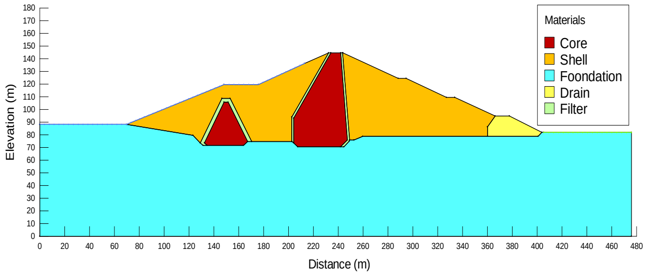


**Fig 1.** Cross section of the Sidi Abdelli dam.

**Table 1** show that the parameters of Dam soils (COBA 1981).

| Parameters | Shell | Clay core | Foundation | Filter | Drain | Unites |
|---|---|---|---|---|---|---|
| **Poid volumique (ɣsat)** | 22 | 18 | 22 | 21 | 22.5 | kN/m$^2$ |
| **Module de young (E)** | 4.5*10 | 1.7*10 | 4*10 | 1.8*10 | 5*10 | kN/m$^2$ |
| **Coefficient de poisson (v)** | 0.2 | 0.33 | 0.3 | 0.3 | 0.3 | --- |
| **Cohésion (c)** | 10 | 17 | 15 | 12 | 0 | kN/m$^2$ |
| **Angle de frottement (ø)** | 30 | 15 | 35 | 23 | 40 | o |
| **Permeability** | $10^{-5}$ | $10^{-9}$ | $10^{-5}$ | $10^{-4}$ | $10^{-2}$ | m/s |

### 2.2 Computer program

To create a numerical model for the analysis of slope stability using Geo-Slope software (2012), in the first case the initial stage of steady-state when the reservoir is at normal level, and in the second case the rapid drawdown of water from the reservoir when the dam is at normal natural reservoir level.

The water is drawn from the reservoir from a height of 45 meters up to the tower intake point, which is 88 meters above the dam toe.

According to the toe drain discharge and the reservoir storage quantity, the time required to draw down the reservoir was estimated to be 30 days.

The dissipation of pore water pressure was measured until (30 days). The shortcut steps for dealing with Geoslope/W is shown in Fig. 2.

The generation of a finite element model is activated when a geometry model is created in the Slope /W 2D program. A test was performed to adjust the mesh according to the desired accuracy before beginning the modeling of the dam in the various cases to be treated. The mesh of the dam was depicted in Figure 3.

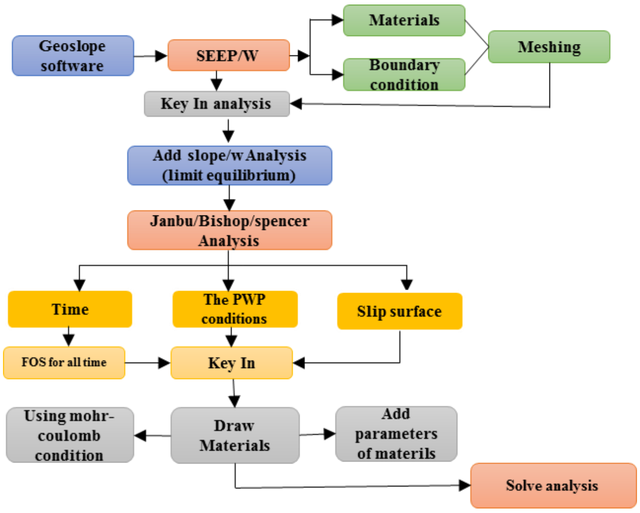


**Fig 2.** Geoslope/W software chart.

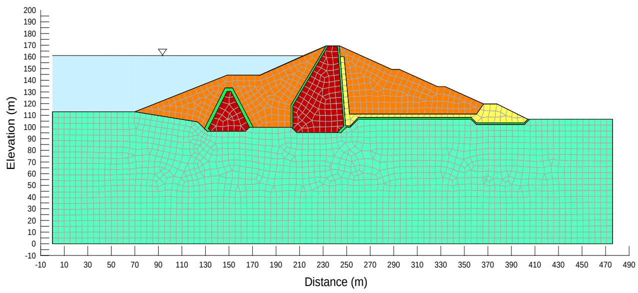


**Fig 3.** Finite element mesh of the dam.

## 2.3 Analysis of slope stability theory

Limit equilibrium analysis methods have been used to compute embankment slope stability to solve geotechnical engineering problems for many years.

SLOPE/W calculates the factor of safety against failure using the theory of limit equilibrium for moments and forces.

The factor of safety (FoS) is the amount by which the soil shear strength should be reduced to place the soil mass in a limited equilibrium condition alongside a chosen slip surface. (SLOPE/W, 2012).

$$FoS = \Sigma Sresisting / \Sigma Smobilised \tag{1}$$

Different limit equilibrium methods, such as Bishop (1955), Morgenstern-Price (Morgenstern and Price, 1965), Janbu (1968) and Spencer (1967) method, were used in this study to analyze the upstream slope of the earth dam during rapid drawdown conditions.

## 3 Results and Discussion

For slope stability analysis, several limit equilibrium methods were used, including Bishop, Janbu, Morgenstern-Price, and Spencer.

All of these techniques were used to run the finite element program SLOPE/W, which is based on the assumption of rapid drawdown to the dam's reservoir water.

### 3.1 Pore water pressure

Pore water pressures are high at the toe of the upstream slope before rapid drawdown, and they decrease with elevation until they are below zero for points above the piezometric line, as shown in Figs. 4(a) and 4(b).

The pore water pressures are very low at the toe of the dam after rapid drawdown, then increase as pore water pressure dissipation from the dam begins, and then decrease as elevation rises, as shown in Fig. 5.

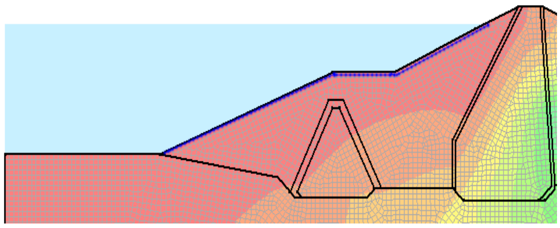

**Fig 4(a).** pore pressure line of the upstream side.

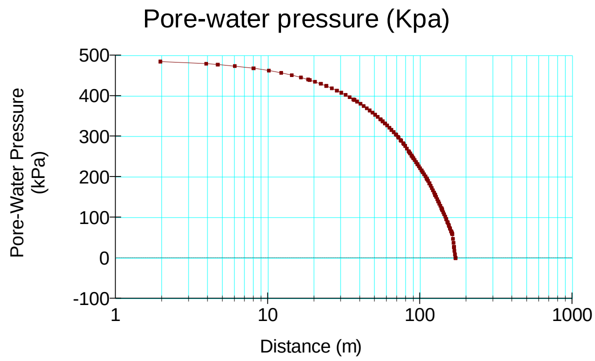


**Fig 4.** Pore water pressures across the slip surface before the initiation of rapid drawdown.

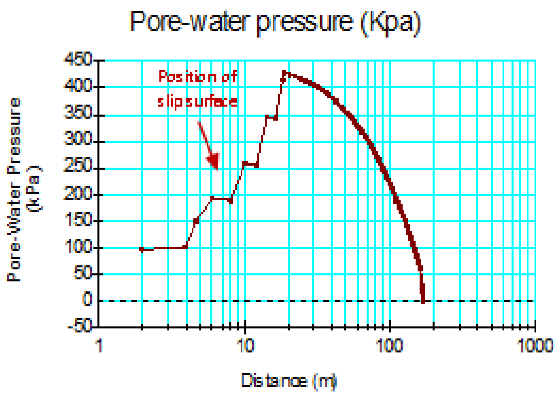


**Fig 5.** Pore water pressure across the slip surface after (30 days) rapid drawdown.

### 3.2 Rapid drawdown condition

This condition's exact mechanism is as follows:

It is assumed that the reservoir has been filled to a sufficiently high level with water for a sufficiently long time that the dam's fill material has been fully saturated and a steady seepage has been established.

If the reservoir is rapidly depleted at this point, the flow direction is reversed, causing instability in the earth dam's upstream slope.

There is no discernible change in the water content of the saturated soil within the dam due to the low permeability, while the water pressure acting on the upstream slope at "full reservoir" state is reduced.

### 3.3 Velocity of seepage

As the water velocity vectors move from the reservoir towards the downstream face before the start of drawdown, the potential seepage face will be on the downstream face of the dam. In Fig 6.

When the water in the reservoir begins to rapidly drain, the water velocity vectors begin to exit from the upstream side, making the upstream side the most likely seepage face in Fig 7.

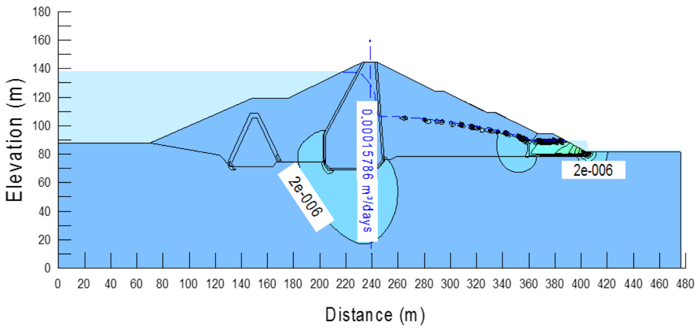


**Fig 6.** Phreatic line, velocity vectors and flow rate quantity before the initiation of rapid drawdown.

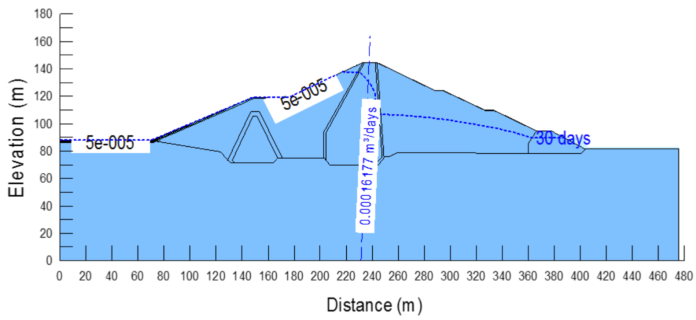


**Fig 7.** Phreatic line, velocity vectors and flow rate quantity after 30 days rapid drawdown.

### 3.4 Factor of safety

As the water level in the reservoir is rapidly lowered, the factor of safety decreases; however, as the pore water pressure dissipates, the factor of safety gradually increases.

On the first days, the minimum factor of safety during rapid drawdown falls below the value of (1), but after 13 days, the factor of safety rises, indicating that the slope will be at a safe level when water is drawn from the reservoir using different Janbu, Spencer, and Bishop methods with a Morgenstern-Price method.

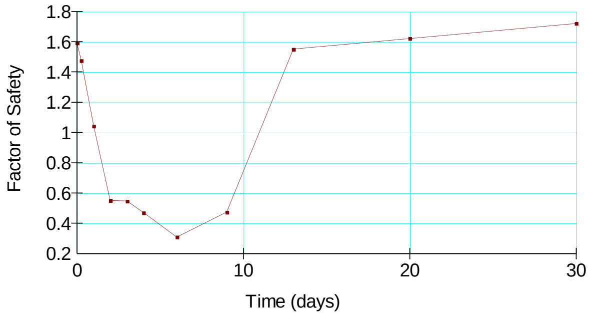


**Fig 8.** Relationship between the factor of safety and the time for upstream slip surface (spencer method).

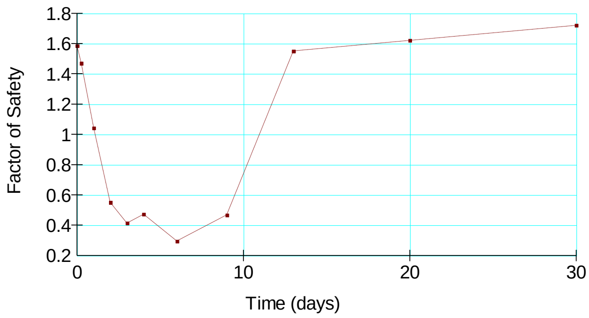


**Fig 9.** Relationship between the factor of safety and the time for upstream slip surface (Morgenstern-Price method).

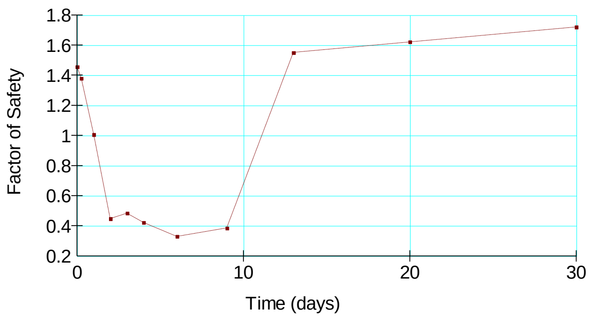


**Fig 10.** Relationship between the factor of safety and the time for upstream slip surface (Janbu method).

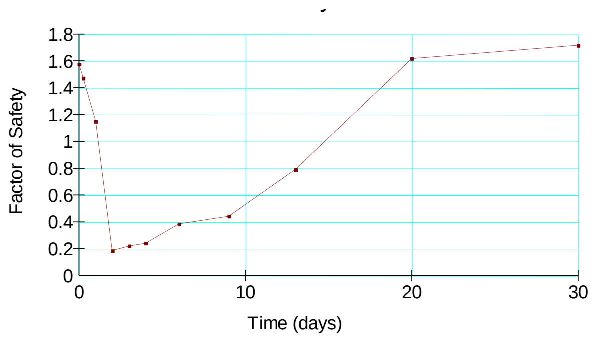


**Fig 11.** Relationship between the factor of safety and the time for upstream slip surface (Bishop method).

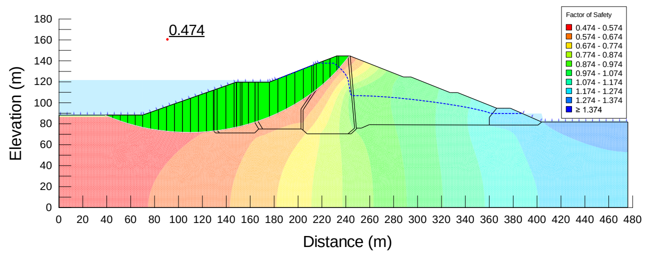


**Fig 12.** Slip surface and factor of safety after 9 days when the dam is drawdown rapidly (Method of spencer).

Fig 13 Presents the factor of safety by using different methods for different time intervals.

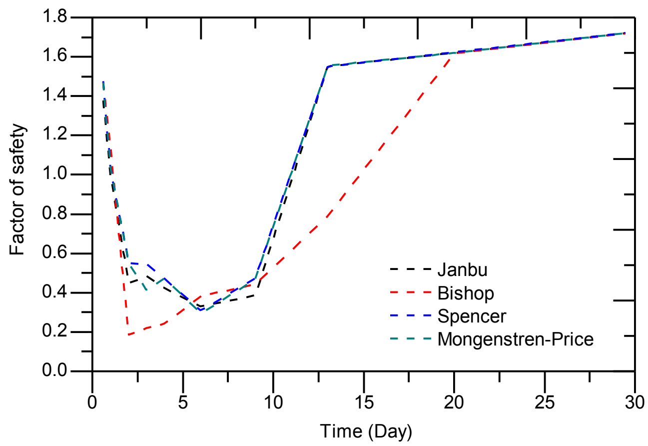


**Fig 13** Factor of safety results by using different methods.

## 4 Conclusion

The study of the drawdown condition of this earthen dam and its stability during the drawdown process has been investigated. During rapid drawdown, the phreatic line falls almost at the same position. The safety factor against slipping of the dam slope decreases during the rapid retreat at the beginning of the rapid drawdown of water after 9 days is less than (1.00), which means that the upstream slope will be in unsafe positions during the rapid drawdown. Then it starts to increase above (1.00) after 13 days to the safety position. This occurs due to the dissipation of excess pore water pressure over time which leads to an increase in effective stresses in the soil and thus an increase in shear strength. When the reservoir decreases rapidly the pressure of the pore water in the dam decreases.

## Acknowledgments

No conflict in this article.

## Disclosures

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