

PAPER • OPEN ACCESS

Safety evaluation of the chamrga earth dam. a seepage deformation, and stability analysis with GeoStudio

To cite this article: Ali A. Aldulaimi 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **664** 012075

View the [article online](#) for updates and enhancements.

You may also like

- [Evaluation of the upstream slope stability of earth dams based on drawdown conditions - Khassa Chai Dam: a case study](#)

Thair J M Alfatlawi, Yahyea K. Al-temimi and Zeena M. Alomari

- [Demonstration of the Separation of Actinides from Lanthanides By Electrolysis with in-Situ Voltammetry](#)

Melissa A. Rose, Javier Figueroa, James L Willit et al.

- [Assessing the Stability of Poor Drainage Soil Slopes Under the Combined Effect of Water Level Drawdown and Rainfall](#)

Libin Tang, Ling Wang and Wengang Zhang



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Safety evaluation of the chamrga earth dam. a seepage deformation, and stability analysis with GeoStudio

Ali A. Aldulaimi ¹

¹ *Ph.D. Student*, Technical University of Civil Engineering Bucharest, Romania, Bucharest

aliengpro77@gmail.com

Abstract. Drawdowns and filling may cause instability in slopes without adequate levels of protection against failure. In this paper, a numerical approach utilizing the finite element method (FEM) was employed to examine the seepage and slope stability of a typical earth-fill dam. Finite element software (GEOSTUDIO 2012) was used to carry out both steady-state and transient seepage analyses on Chamrga earth Dam in Iraq to study the seepage and upstream slope stability during normal water level, filling stage and drawdown conditions for two scenarios. To include water levels during the filling and drawdown variable linear water heads with time were identified as boundary states in the transient seepage analysis. The quantity and direction of water flux, existing gradient, and safety factor were calculated for all scenarios. The results revealed that the stability of the slope during drawdown is highly impacted by how fast its pore water pressure dissipates.

1 Introduction

Dams can be classified in number of ways but they are mostly classified based on either their function such as storage dams, diversion dams, detention dams, debris dams and coffer dams or based on their design and structure such as gravity dams, buttress dams, arch dams, rock-fill dams and earth dams. In this study, this search will focus on earth dams. Since earth, dams are the most widely spread type of dams in the world; its stability is one of the major concerns in dams engineering [1]. Recently, computer based numerical models are used to check the stability of earth dams and to simulate the effects of all the parameters that play a role in its safety. The materials used in constructing an earth dam are one of these important parameters. Thus, they are considered as the main subject of the study. (T. Hnang), used an efficient finite element procedure to identify the steady state flow free surface through an earth dam for evaluating the pressure distribution within the embankment. The seepage forces on each element in the finite element mesh can be determined for stability analysis, [2]. (A. Khalil), also used 2D finite element analyses to simulate pore-water pressure development by Geo-Studio software for saturated and unsaturated conditions analysis in Chamrga earth dam using SLOPE/W software to evaluate slope stability of the dam. Analyses for each state and each slope with Morgenstern-Price method and finite element stress method are calculated so that the minimum safety factor in each of these methods is considered as a safety factor of slope stability. The two approaches of slope stability analyses, one based on Morgenstern-Price method and the other on the finite element stress method are widely used in geotechnical engineering, [3]. (S. Athani), have introduced the results of stability analysis of an earth dam using finite element method. Stability study has brought out the importance of considering the coupled effects on the overall stability of the earth dam. It is concluded that the coupled analysis is a



prerequisite for the design and performance evaluation of the earth dam under all conditions of seepage and stability, [4].

2 Seepage Analysis

Seepages from a reservoir created by an earth dam may take place through the earthfall body, through foundation ground and through the dam abutments, [5]. The analysis of the seepage phenomenon is a requirement for the assessment of safety and operational utility of the dam because:

- I. Allows the evaluation of the water loss from the reservoir and of the efficiency of the water tightening provisions of the design.
 - a. Defines the seepage forces that must be included in the stability analysis of the dam slopes.
- II. Allows the quantitative evaluation of the actual hydraulic gradients and the identification of potential piping risks.

The main purpose of the seepage analysis is to establish the position of the line of seepage (the interface between the saturated and unsaturated zones of the dam) and of the flow net in the saturated zone, [5].

3 Stability Analysis

Structural analyses serve two purposes for the design of earth dams: first insure that the dam will be stable during construction, during normal operating conditions, and during possible earthquake loading conditions; and second, to ensure that the deformations during construction, normal operation, or earthquakes will not be excessive, [5].

4 Case Study - Chamrga Dam

The Chamrga Dam is an earth dam located in the north of Iraq on the seasonal river Chamrga, total length 257m with a maximum storage of 1,620,000 m³ and about 17.5-meter height with the crest elevation at 658 m.a.s.l level. The crest width is 6 m and there are slopes 2% to both upstream and downstream directions. The crest of the dam is designed to carry normal car vehicle traffic. The upstream face of the dam has a slope of 1:2.5, as shown in figure 1. The upper downstream slope of the dam has 1:2 with a 4-meter berm. While in the lower part, the downstream slope will be flattened to 1:2.5. The foundation soil of the dam site in general comprises of Upper Bakhtiari formation. It consists of a mixture of sand and gravel with some fines.

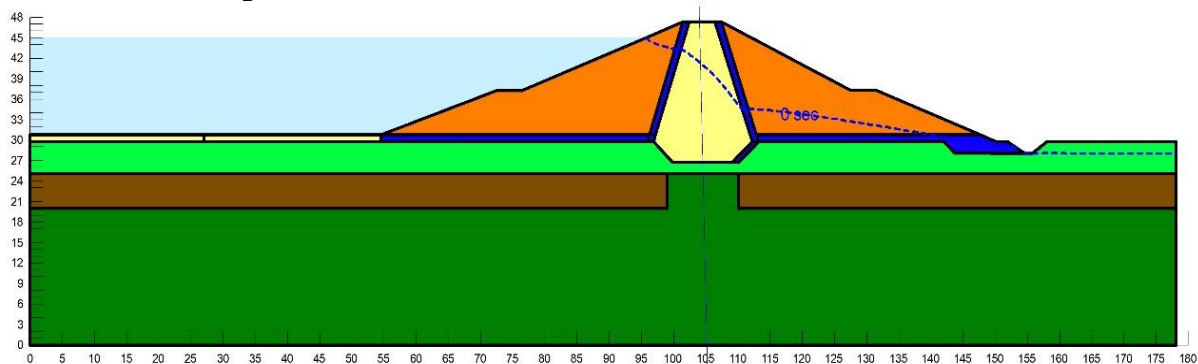


Figure 1. Chamrga dam actual design.

cofferdam with the crest elevation at 648m m.a.s.l will be performed upstream of the concrete plinth. The crest width is 4m. The upstream and downstream face slopes are 1:2.75. The cofferdam body will be constructed from clayey silt soil. During the dam erection the river discharge, if any, is diverted through a steel pipe that is an upstream extension of the bottom outlet. Before the filling of the reservoir the cofferdam will be demolished, and the diversion pipe removed.

4.1 Material Properties

The properties of the material used in the construction of the dam can be summarized in Table 1.

Table 1. Material Properties of Chamrga dam.

Ref. No.	Material	Color code	k (m/s)	γ (kN/m ³)	c (kPa)	ϕ (o)
1	Dam body fill		2. exp-05	19	15	38
2	Drainage layer		5. exp-04	17	0	33
3	Sediment		1. exp-04	21	5	39
4	Claystone layer		1. exp-06	23	20	40
5	Conglomerates		5. exp-05	21	5	40
6	Clay blanket		1. exp-07	16	20	20

4.2 Simulation and modeling in GeoStudio

The numerical analysis in this report has been made based on models and simulations carried out in the computer software GeoStudio. GeoStudio widely used computer software for geotechnical and earth science problem modeling. SEEP/W, SIGMA/W and SLOPE/W, which are tools within GeoStudio, [6] were used in order to analyze the given construction design of the dam embankment in this research.

4.3 Dam model and material parameters

The CAD drawing of the Chamrga dam was translated into GeoStudio. Regions were created and material layers were assigned to each region according to the embankment design. In the beginning of the modelling process simple or estimated material parameters were used as input data. This was according to directions from GeoStudio instructions, [6]. And the purpose was to verify that the models worked properly. When the models were verified to similar studies, the accurate material parameters were substituted into the model in order to refine the analysis. Material parameters used in the simulations will be presented in the SEEP/W, SIGMA/W and SLOPE/W sections, [7].

4.4 Simulated scenarios

There are three scenarios have use in this research, these scenarios illustrated in the following:

4.4.1 Scenario 1.

In this scenario the current situation represented the original cross section without additions with clay core and clay blanket for 55 m extend in upstream reservoir has been used, as shown in figure1.

Max water level in upstream (h=15.5m) at elevation 655.5 MASL and in downstream (h=0) at elevation 640.00 MASL, the nodes at the bottom and lateral of the dam foundation for each model are considered with zero-flux condition.

4.4.2 Scenario 2.

inclined core and the upstream clay blanket connected to the water tightening system of the dam (clay core) extend in upstream reservoir as shown in figure 2.

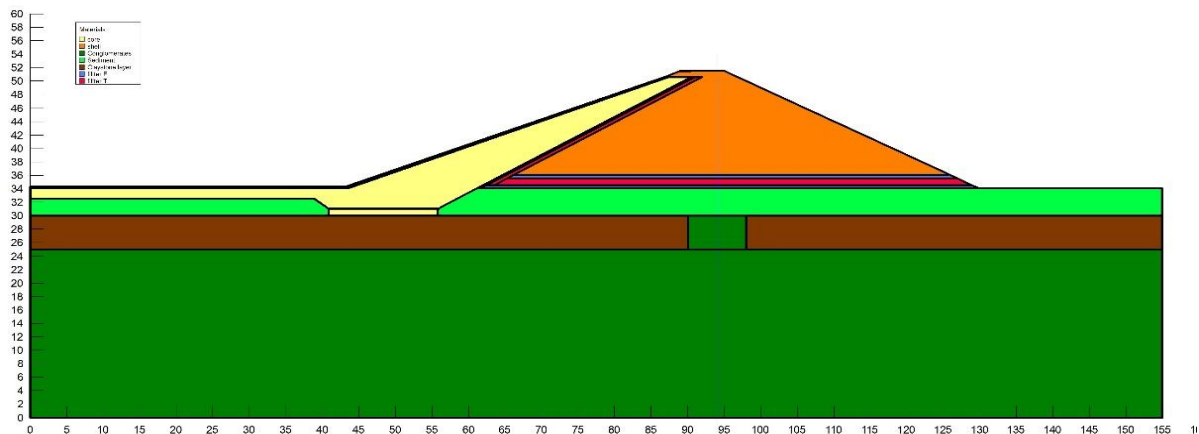


Figure 2. scenario 2.

with Every scenario were simulated and analyzed for deferent operating conditions. The Normal, filling stage and drawdown.

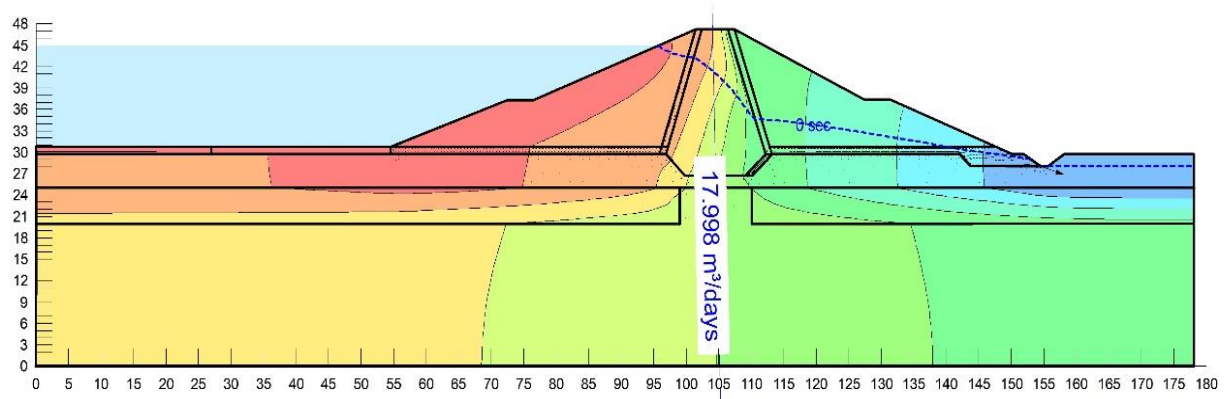
5 Results

The results from the simulations are presented divided into the different simulations that has been conducted. The results are presented in the same order as they were conducted starting with the seepage analysis in SEEP/W. The seepage analysis was conducted to provide data to the load, deformation and Coupled analysis done in SIGMA/W and also the analysis is done in SLOPE/W since it is using data from SIGMA/W. The results that SIGMA/W and SLOPE/W are using from SEEP/W are pore water pressure, seepage velocity, volumetric water content, etc.

5.1 Seepage analysis

5.1.1 steady-state Analysis.

The results of water flux, seepage velocity and exit gradient for two scenarios are presented in Figure 3,4. presents the computed contour map of pore water pressure distribution and the flow line through chamrga Dam at the initial steady-state seepage.



A

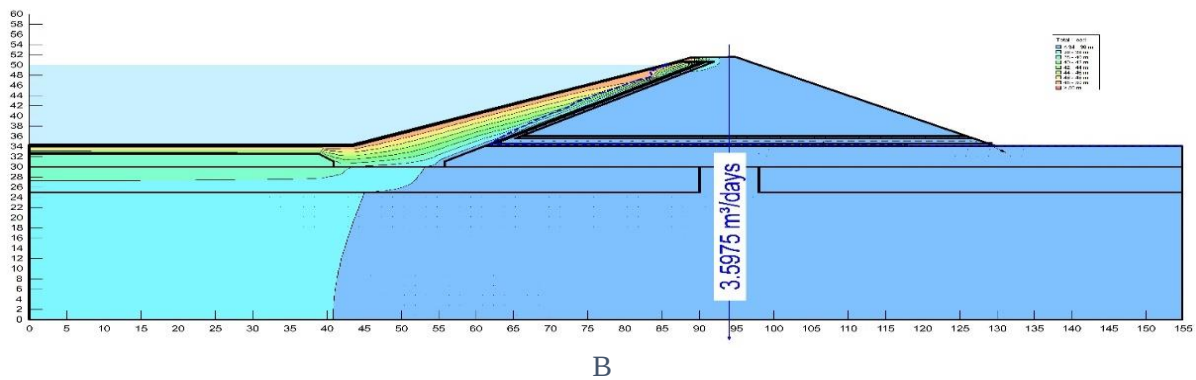


Figure 3. A, B, Total hydraulic head in the dam, in meters. This shows that the total head on the right is larger than the total head on the left. The total head difference creates a water flow from the right to the left.

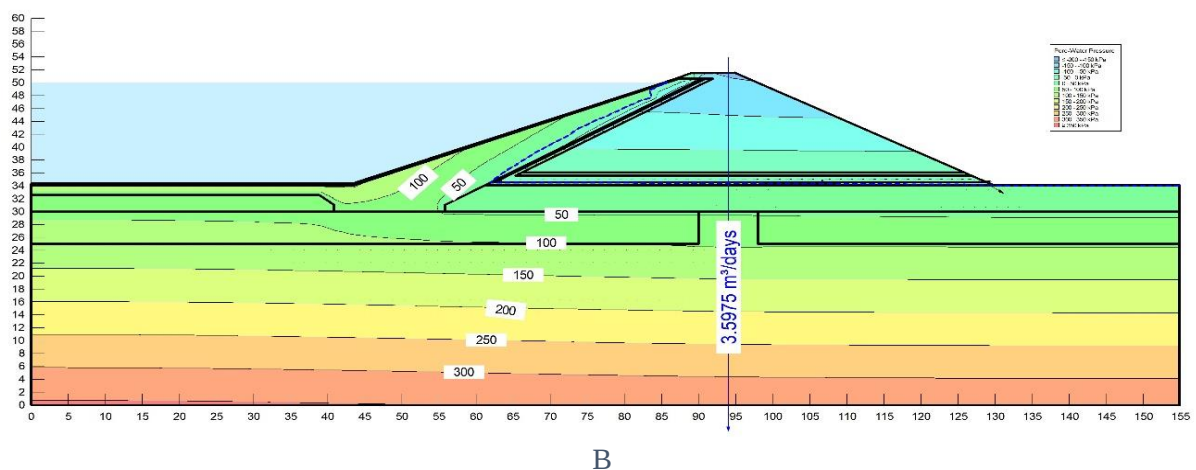
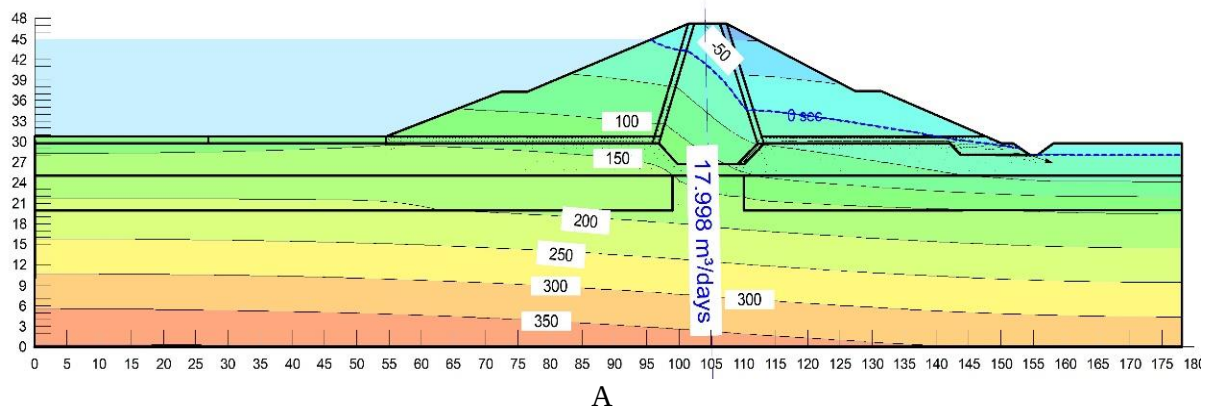


Figure 4. A, B, Pore-water pressure in the dam, in kPa. The phreatic surface is shown as the thick blue line, which is also the iso-line where the porewater pressure is zero. The pore-water pressure is negative above the phreatic surface and positive below the phreatic surface.

- Summary

The results from simulations in SEEP/W for two scenarios under steady state are summarized in table 2.

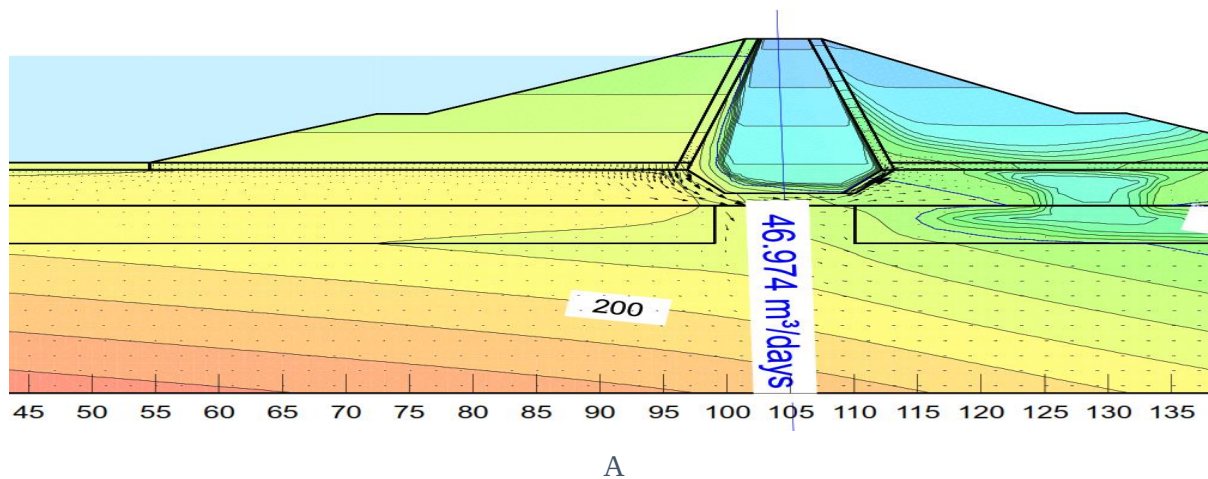
Table 2. seepage analysis steady state.

No.	Scenarios	Operation condition	Max. seepage Velocity V_{max} [m/s]	Tot. flux at center Q [m ³ /s]	Exit gradient Toe downstream
1	Actual cross section	Normal W. L	3.85×10^{-4}	2.08×10^{-4}	0.84
2	inclined core	Normal W. L	2.65×10^{-5}	4.15×10^{-5}	0.005

5.1.2 Transient analysis.

A. Filling stage in 9 days

During reservoir filling, the pore-water pressures in the upstream shell and the core increase with the increasing water level, but there is almost no change in the downstream shell. Because the conductivity of the core is about 4 orders of magnitude lower than that of the shell, the phreatic line exits the back of the core at a very low level and shows little change with the increasing water level. The distributions of the pore-water pressure in the dam in three scenarios 1, 2, are almost identical when the reservoir water level rises to the normal water level as show in figure 5. It can be concluded that the construction and filling processes have little effect on the final distribution of pore-water pressure in the dam as show in figure 6.



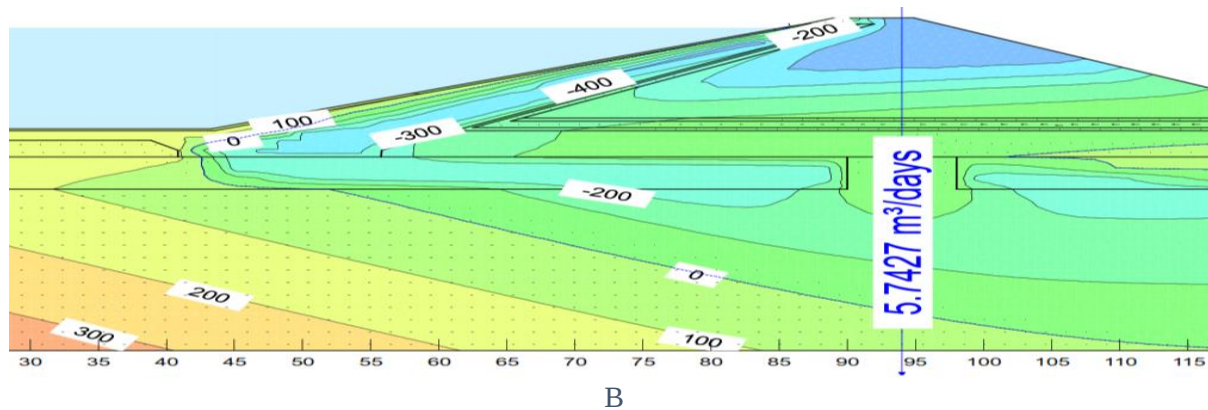


Figure 5. A, B pore water pressure developed in the core of the dam in three scenarios.

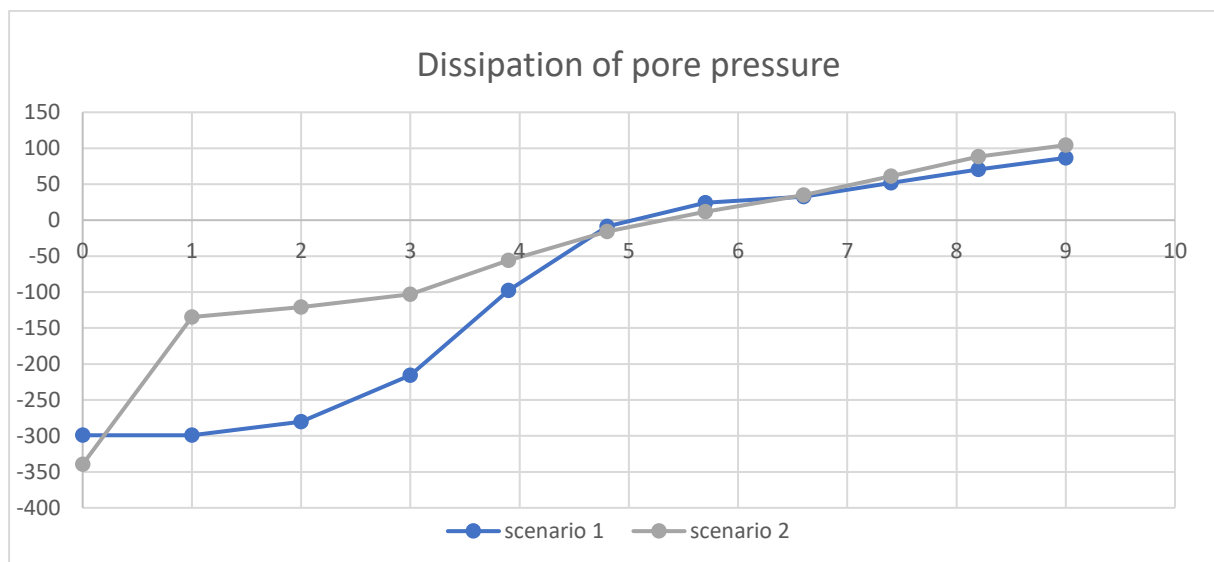


Figure 6. developed of pore water pressure in the core of dam.

B. Drawdown in 1 day.

The exact mechanism of this condition is as follows: It is assumed that the reservoir has been filled with water at a high level for a sufficiently long time so that the fill material of the dam is fully saturated and steady seepage established. If the reservoir is drawn down rapidly at this stage, the direction of flow is reversed, causing instability in the upstream slope of the earth dam. The most critical condition of sudden drawdown means that while the water pressure acting on the upstream slope at the “full reservoir” condition is removed, there is no appreciable change in the water content of the saturated soil within the dam because of the low permeability. Pore water pressure in the dam’s body during rapid drawdown seems not to change very much at all drawdown levels. Even when the water is almost empty, pore water pressure in the dam’s body is still high because the phreatic line does not drop. The lag of the phreatic line depends on four factors: permeability coefficient of the dam fills, drawdown rate, pore active volume, and upstream slope gradient [1]. Before rapid drawdown, the pore water pressures are high at the toe of the upstream slope and decrease with elevation until they are below the value of zero for those points that exist above the piezometric line. After drawdown, the pore water pressures are very low at the toe of the embankment and then increase as the initiation of pore water dissipation from the embankment and then decrease as the elevation increases as presents in Figure 7,8.

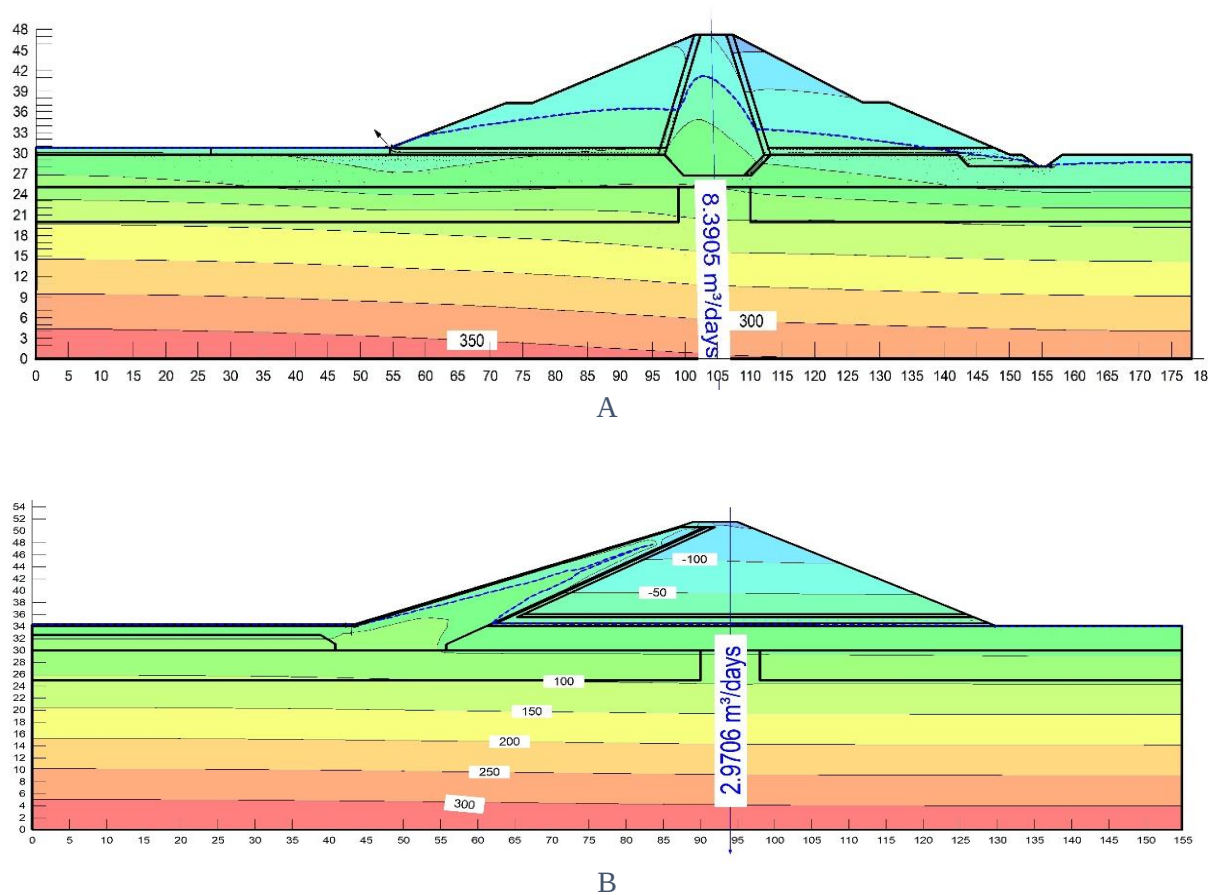


Figure 7 .pore water pressure distribution in the body of the end of a 1day of drawdown.

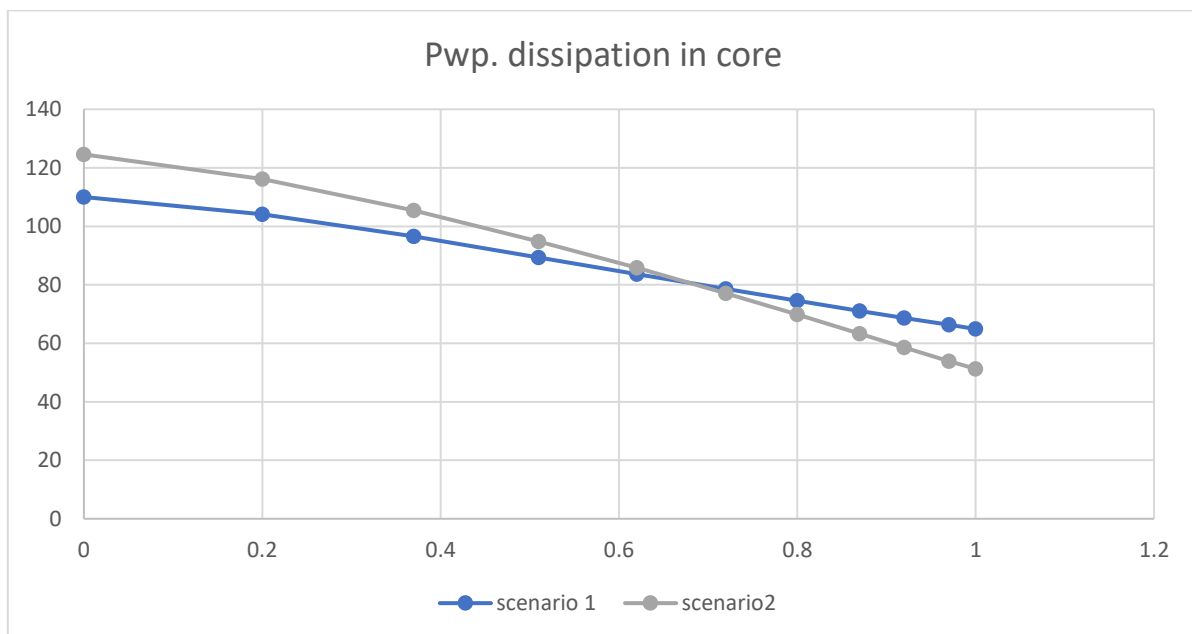


Figure 8. pore water pressure Dissipation in core of dam.

- Summary

The results from simulations in SEEP/W transient analysis during the drawdown in 1 day are summarized in table 3.

Table 3. Drawdown 1 day for three scenarios.

No.	Scenario	Operation condition	Max. seepage Velocity Vmax [m/s]	Tot. flux at center Q [m3/s]	Exit gradient Toe upstream at end of 1 day.
1	Actual cross section	Drawdown /1day	2.93×10^{-4}	9.7×10^{-5}	1.9
2	inclined core	Drawdown /1day	3×10^{-4}	8.88×10^{-5}	0.005

5.2 Coupled Stress-Pore Pressure Analysis

In this analysis, the seepage analysis is solved independently of the volume change analysis, [7]. The incremental change in pore-water pressures from the seepage solutions are used at each load step in the stress-deformation calculation in order to determine the change in effective stresses. in a couple analysis, we look for change in total stress as well as changes in pore water pressure, seep/w analysis doesn't consider a change in total stress.

The result from the load and deformation analysis that has been conducted for the scenarios 1,2 the two scenarios has been simulated during drawdown conditions in 1 day. as shows in figure 9. the total stress distribution, the shear stress, and the total displacement in the dam.

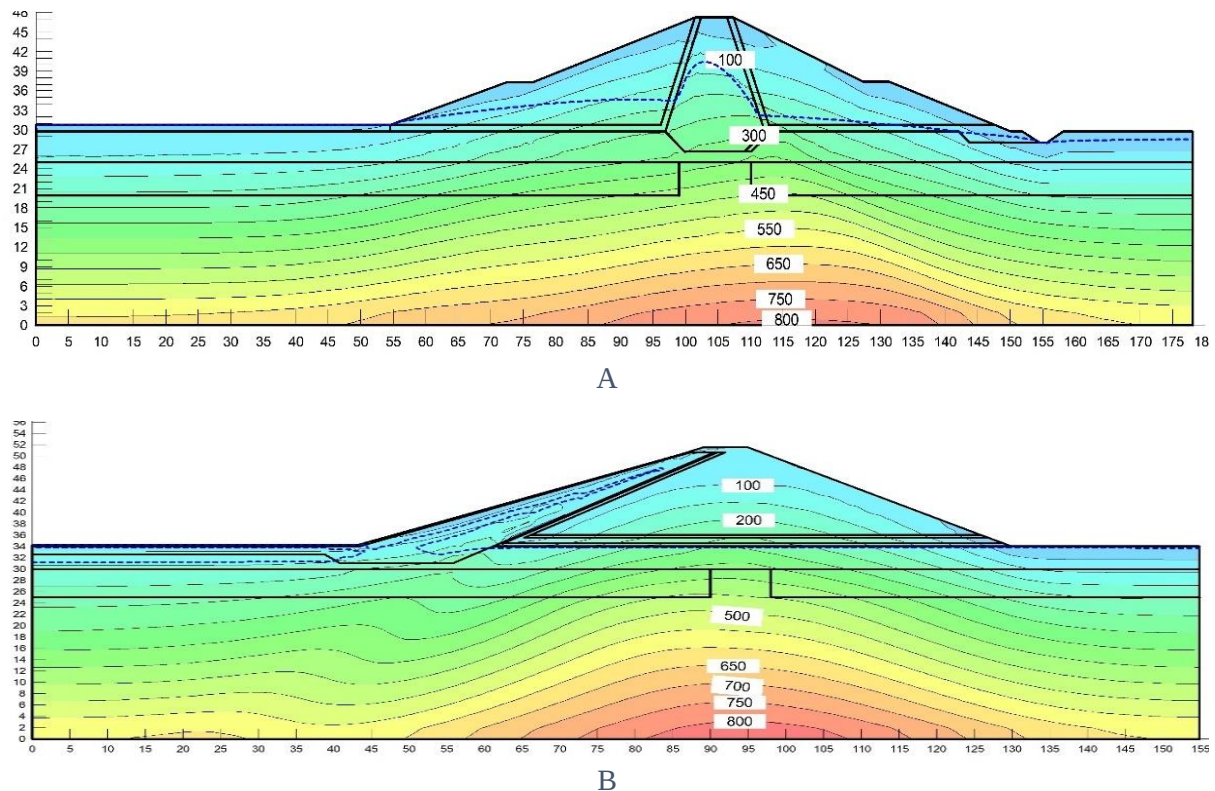


Figure 9 .A,B. Total stress in kPa, in the dam. The total stress is the lowest on top of the dam (zero), then it increases in the middle of the dam as well as when the dam elevation decreases.

Figure 10 shows the movement of the soil particles and the deformed shape after the reservoir is suddenly drawdown in 1 day. As seen in Figure 10, the seepage force causes movement of the soil particles in the direction of flow towards the reservoir. This causes a settlement at the dam crest and a swelling of the soil on the upstream face. The highest displacement value is concentrated near the water level after the drawdown, while it decreases gradually toward the foundation surface on both the upstream and the downstream sides. the magnitude of the soil movement reaches the maximum level as soon as the drawdown process is completed.

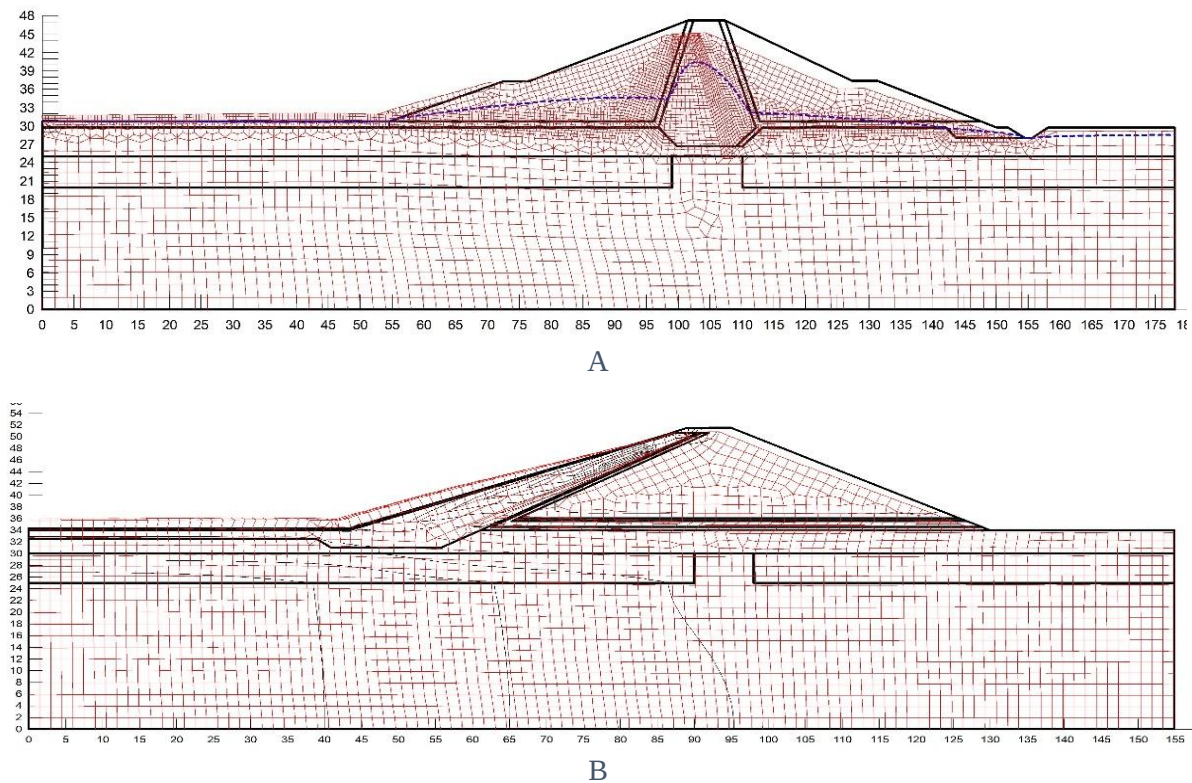


Figure 10. Deformed shape after the reservoir is suddenly drawdown.

- Smarmy

The results of simulations in SIGMA/W are summarized in table 4.

Table 4 .max shear stress, max total stress, and displacement of scenarios.

No.	Scenario	Operation condition	Max. shear Stress [kPa]	Max. Total stress [kPa]	Max. Total displ. [m]
1	Actual cross section	Drawdown /1day	51.21	810.95	0.485
2	inclined core	Drawdown /1day	60.26	837.57	0.474

From couple analysis obtained the pore water pressure less than in seep/w analysis as shown in figure 11, because of removing the weight of water and doing a couple analysis, there is the tendency for a

slight amount of rebound of the soil and this tendency for the rebound has an effect on pore water pressure response and the result is slightly lower in pore water pressure.

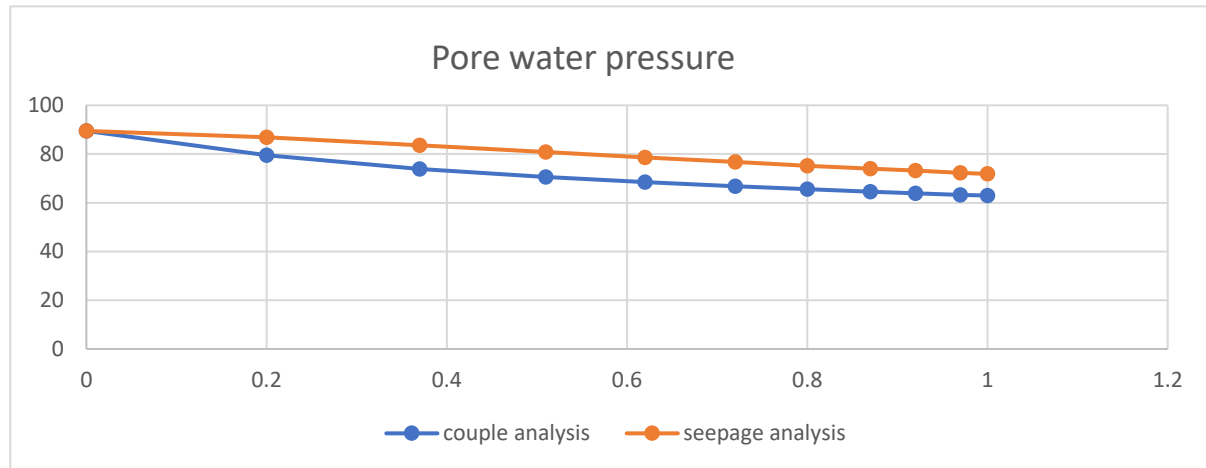


Figure 11. Pore water pressure in couple analysis and seep/w analysis.

5.3 Stability Analysis

To assess upstream dam slope stability, the limit equilibrium (slice technique) analysis of slope stability depending on FEM is used. Results can be obtained from the application of (Morgenstern-price) techniques. The factor of safety gradually decreases as water in the reservoir decrease until all the water in the reservoir drawdown then the factor of safety increase as the pore water dissipation from the embankment. The minimum factor of safety during slow drawdown falls above the value of (1.0) that's mean the slope will be at safe condition when the water drawdown from the reservoir in (1 day).

5.3.1 Scenario 1.

calculating the factor of safety for different time intervals by using Morgenstern-price techniques from couple analysis and seepage analysis.as show in figure 12,13 and 14.

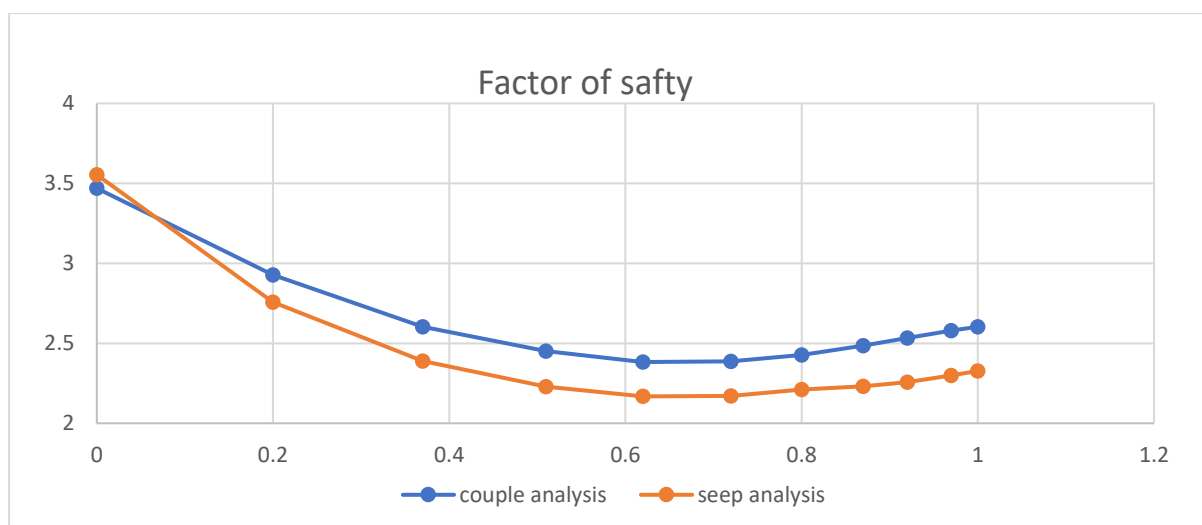


Figure 12. Factor of Safety for two analysis scenario 1.

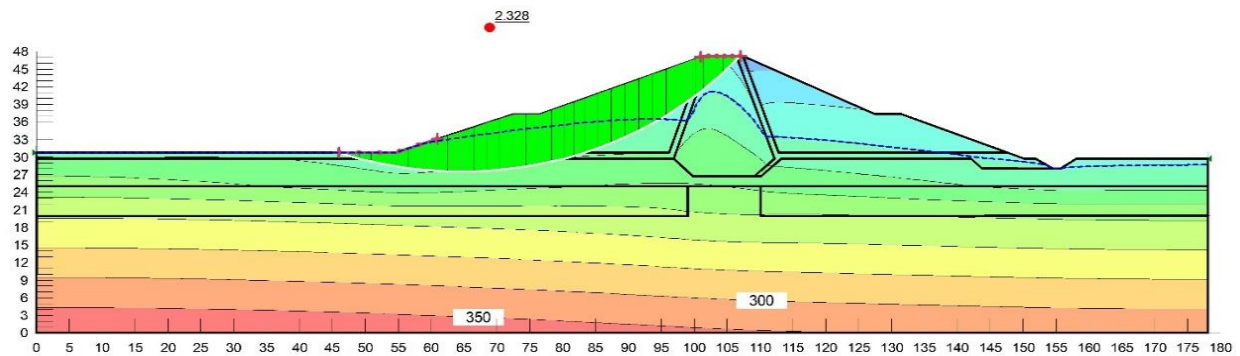


Figure 13. Slip surface and factor of safety for scenario 1 after 1 day when the dam is drawdown rapidly from seep analysis only.

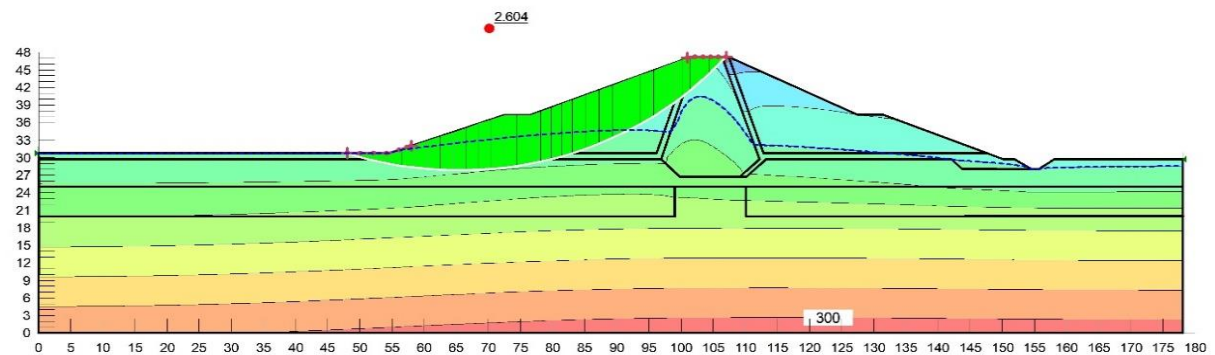


Figure 14. Slip surface and factor of safety for scenario 1 after 1 day when the dam is drawdown rapidly from couple analysis.

5.3.2 Scenario 2.

calculating the factor of safety for different time intervals by using Morgenstern-price techniques from couple analysis and seepage analysis as show in figure 15,16 and 17 .

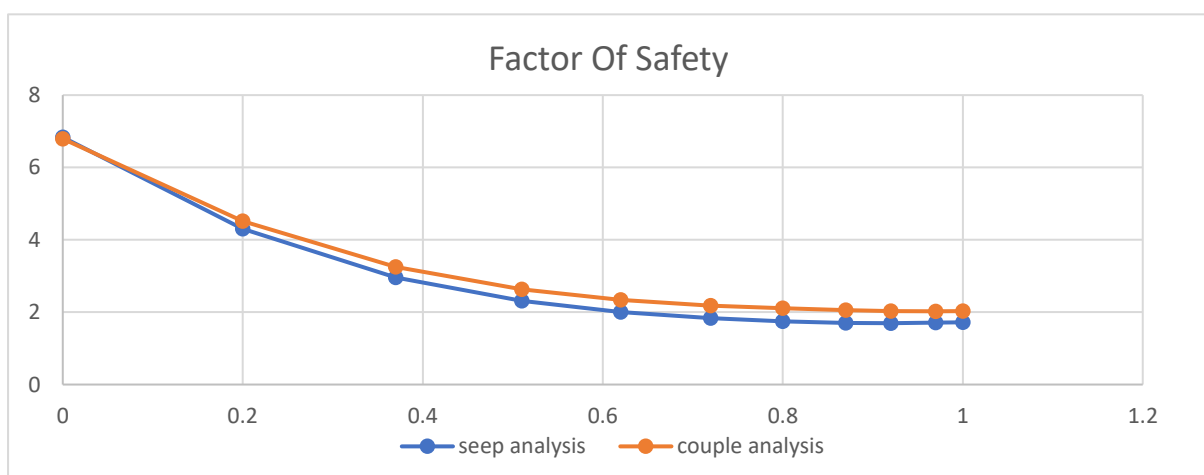


Figure 15. Factor of Safety for two analysis scenario 2.

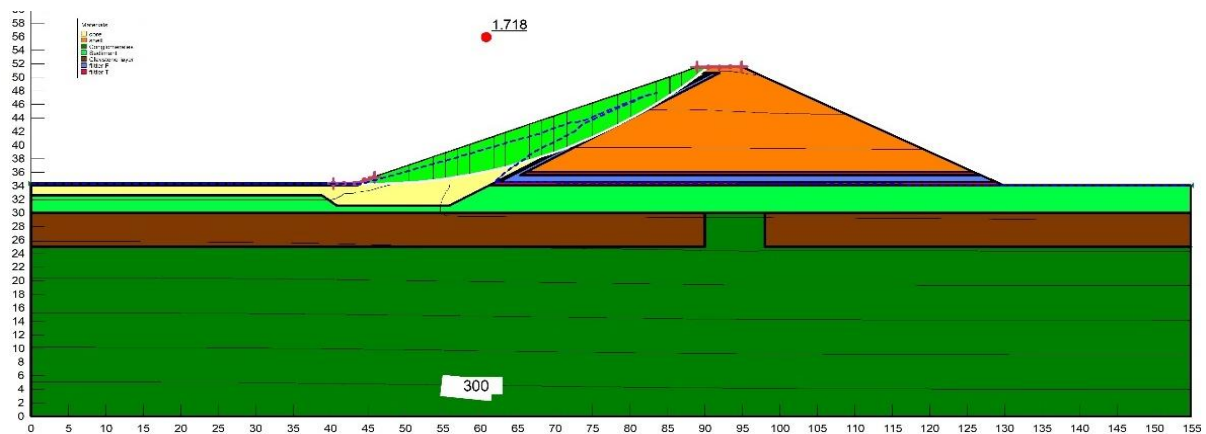


Figure 16. Slip surface and factor of safety for scenario 2 after 1 day when the dam is drawdown rapidly from seep analysis only.

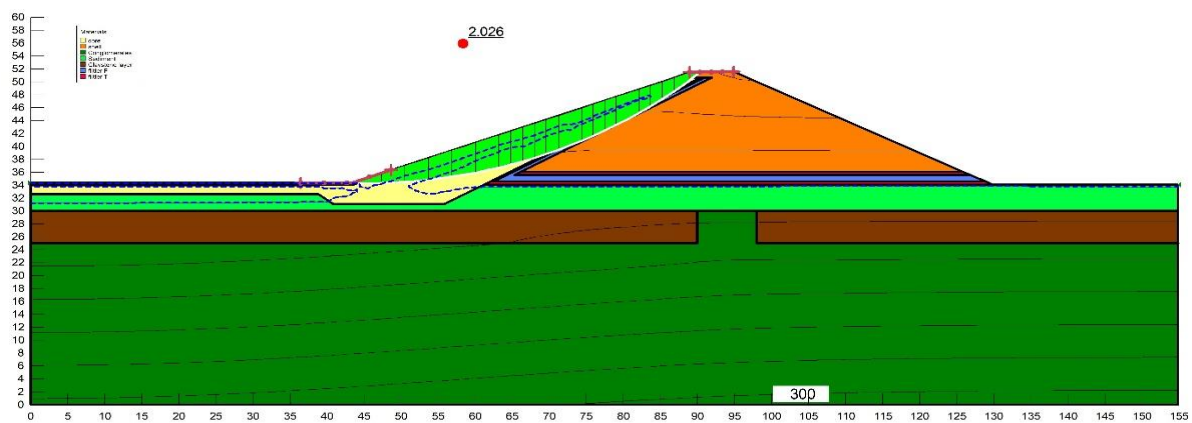


Figure 17. Slip surface and factor of safety for scenario 2 after 1 day when the dam is drawdown rapidly from couple analysis.

- Summary

Factor of safety results by using Morgenstern-price techniques for two scenarios regarding seepage analysis only and couple analysis.as shown in table 5. And the factor of safety for two scenarios as seep analysis only is shown in figure 18.

Table 5. Factor of safety for two scenarios.

Scenario	Operation condition	F.S from seep analysis only	F.S from couple analysis
1	Drawdown 1 day	2.328	2.604
2	Drawdown 1 day	1.718	2.026

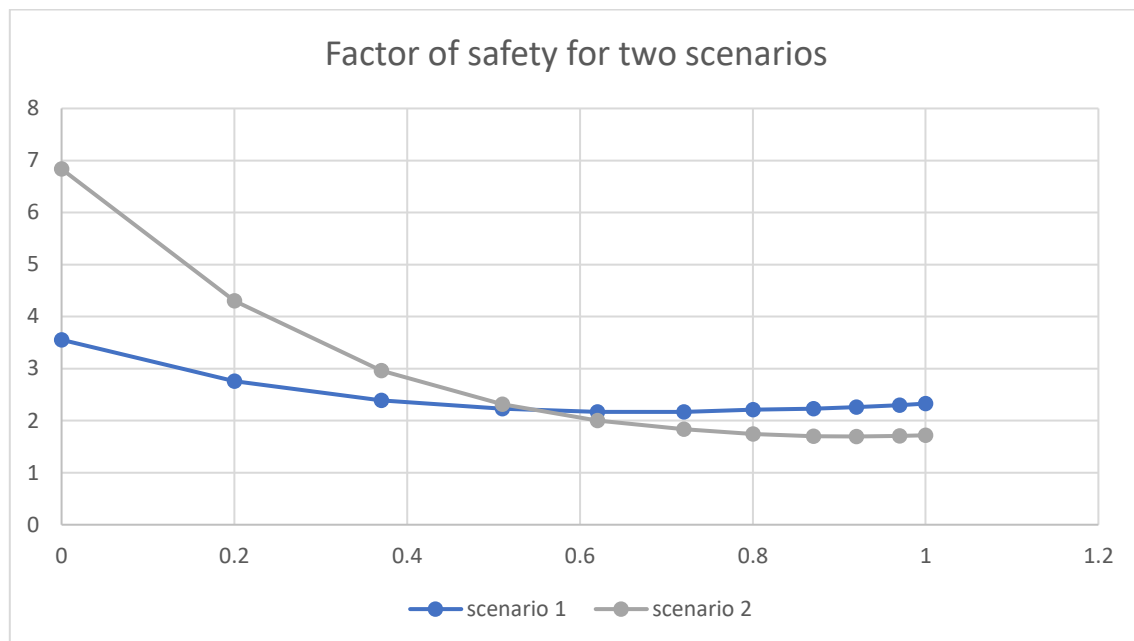


Figure 18. Factor of safety for two scenarios.

6 Conclusion

- From the seepage analysis under steady-state condition, scenario 2 (inclined core) is the optimum scenario results obtain the total flux 2.65×10^{-5} m/s, the seepage velocity 4.15×10^{-5} m/s, and exit gradient in the toe of downstream 0.005.
- During the filling stage at 9 days, the pore water pressure develop in the core of the dam is rapid in scenario 2 from -350kpa to +100.
- During the drawdown, in 1 day the dissipation of pore water pressure in the core of the dam in scenario 2 (inclined core) is the optimum that ranges from 125 kpa to 50 kpa
- During Coupled Stress-Pore Pressure Analysis obtained the maximum shear stress 60.26 kpa, maximum total stress 837.57 kpa and the XY total displacement 0.474 are in scenario 2 (inclined core)
- In couple analysis consider the change in total stress as well as the change in pore water pressure.
- The factor of safety against sliding of the dam slope during rapid drawdown decreases within the start of rapid drawdown of water then starts to increase. This is caused by dissipation of excess pore water pressure with time which leads to increase the effective stresses in the soil and hence increase its shear strength.
- When the reservoir rapidly drawdown the pore water pressures in the dam are reduced in two ways: there is an immediate elastic effect by the removal of the water head from the reservoir and a slow dissipation of pore water pressure from the dam body by drainage.
- During the drawdown, the minimum factor of safety falls above the value of (1.0) for two scenarios which means the upstream slope will be in a safe condition during the rapid drawdown sequences.
- During slow drawdown the factor of safety gradually decrease as water in the reservoir decrease until all the water in the reservoir drawn down then the factor of safety increase as the pore water dissipation from the embankment.
- For all scenarios obtained factor of safety from two analysis 1- seepage analysis only and 2- couple analysis that's FS. in couple analysis little be larger than from seepage analysis.

7 References

- [1] C. Abadjiev, "Safety Assessment and Stability Improvement of the Upstream Slope of Earth Dams," in *Proc. Of the 18th ICOLD Congress*, Durban, South Africa, 1994.
- [2] T. Hnang, *Stability Analysis of an Earth Dam under Steady State Seepage*, Republic of China: Elsevier, 1996.
- [3] A. Khalil, "Numerical Modeling of Pore Water Pressure Development within a Thin Clay Core in an Earth Dam," *Al-Rafdain Engineering*, pp. 93-109, 2012.
- [4] S. Athani, "Seepage and Stability Analyses of Earth Dam Using Finite Element Method," in *Coastal and Ocean Eng*, India, 2015.
- [5] D. STEMATIU, *Embankment Dams*, BUCURESTI, 2006.
- [6] GEO-SLOPE, *Stability Modeling with SLOPE/W*, Alberta- Canada: An Engineering Methodology, 2012.
- [7] L. GEO-SLOPE International, *Stress-Deformation Modeling with SIGMA/W*, Canada: An Engineering Methodology, 2009..