

SLOPE STABILITY AND SEEPAGE ANALYSIS OF EARTH DAMS USING NUMERICAL MODELS: A CASE STUDY, EGYPTHager N. Zaied¹, Ezzat E. Gomma², Mustafa E. Rawy³, Emad A.M. Osman⁴¹Research Student at Civil Engineering, Civil Eng. Dept, Faculty of Engineering, Minia University, Egypt²Lecturer of Hydraulic and Irrigation Engineering, Civil Eng. Dept, Faculty of Engineering, Minia University, Egypt³Associate Professor of Hydraulic and Irrigation Engineering, Civil Eng. Dept, Faculty of Engineering, Minia University, Egypt⁴Professor of Geotechnical and Foundations Engineering, Civil Eng. Dept, Faculty of Engineering, Minia University, Egypt**ABSTRACT**

The stability of the dams is critical due to the huge damage of construction and killing people in case of failure happened. The dam stability is component of slope stability and seepage. Many methods were developed to assess the factor of safety (FOS) of the dams especially in the seepage conditions. Numerical method is one of the most common used method in studying both seepage and stability analysis of the dams. In this research, two finite element soft wares (PLAXIS 2D V8.6 and SLIDE V6 seepage model) were used for investigating the seepage effect on the dam body and to investigate the effect of using different soft wares on results[5] [8]. Factor of safety was calculated using limit equilibrium method (SLIDE) and numerical reduction method (PLAXIS) during steady-state (seepage analysis) and the results were compared with the theoretical state. The results show the flow net contours, pore pressure shading, deformations, distribution of total head and discharge values for case study.

KEYWORDS:

Numerical modelling, Stability, Seepage, PLAXIS, Earth Dams.

INTRODUCTION

Earth dams is a crucial structure for humans and there failure caused catastrophic. The important factors in earth dams design are flow calculation, seepage, and stability analysis after construction. The stability of the dams mainly depends on its geometry, material properties, and subjected forces [9] [10]. Earth-dams can be homogeneous or zoned which consists of many type of soil with different hydraulic conductivities. Excessive seepage causes a real problem in dams. The excess pore water pressure can be increased in rapid draw down cases. There are many method developed to calculate the seepage in the dams like analytical and numerical methods. Analytical methods have been previously used to evaluate seepage and analyze seepage control methods in earth dams [2] [3].

Numerical model is a strong tool which used to investigate the seepage through dams. There are many geotechnical soft wares developed based on finite element analysis to calculate the factor of safety of dams slope with and without coupling with seepage analysis. Various soft wares were used in the analysis of earth dams and discussed their advantages and limitations [6]. The finite element method was used to solve the governing equations of flow through earth dams considering a case study of Al-Adhaim dam which consists of zoned embankment [4].

2D numerical model was conducted to investigate the seepage and stability analysis of Koga main dam using PLAXIS 2D and concluded that the downstream slope is critical during end of construction and steady state seepage and upstream is critical in rapid drawdown analysis[12]. Geostudio (SEEP/W) software was used to study stability and seepage analysis in Hub dam[1].

In this research, two well known, finite element programs were used (PLAXIS 8.6 and SLIDE6.0 seepage model), for investigating the seepage effect on the dam body as well as studying the stability of earth dams. As an application of the model, the study was implemented on a real case in Upper Egypt (Esna earth dam).

Verification Model (MANDALI earth dam constructed in, Iraq 1987)

Mandali dam is located in Harran Wadi, Diyala, Iraq as shown in Figure.1. The foundations of soil beds consist of gravel and shell. The length of the dam is about 1316 m, and maximum 14 m height. The shell layers content poorly graded gravel. The core has available clay materials at the site [7]. Figure 2 shows cross-section of the dam. The

soil properties of the dam component and the foundation soils are shown in table 1. Mohamed Soliman carried out a 2D model using Geostudio to study the seepage and the stability of the dam. [11]



Fig.1. Mandali Dam location.[11]

OBJECTIVES

2D models using SLIDE 6.0 and PLAXIS 8.6 were performed to compare their results with Mohamed's model. Sensitivity analysis were performed to choose the mesh size. Very fine mesh size was chosen. The boundary was chosen based on fixing the lateral movement in left and right sides $U_x = 0$ and fixing the lateral and vertical movement in bottom boundary $U_x=U_y=0$. The stage of construction was taken into consideration the gravity loading in initial case. Steady state analysis was used in our cases.

RESULTS AND DISCUSSION

The three Finite Element models: GeoStudio, PLAXIS and Slide were used in this analysis and the results of all the three models are shown.

The total head

For all models 1, 2, and 3 are shown in figures 3-5. The maximum head value was 32.5m in all cases and the minimum head value was 22. The three models have almost the same 2D shading contours. Slide and Geostudio are also helping us to plot the flow line in the with the equipotential line. They also provide a good deal of distribution and values for the flow lines. PLAXIS 8.6 and slide models give a good agreement values compared to Geostudio.

The pore pressure

For all models 1, 2, and 3 are shown in figures 6-8. The values of the pore pressure range from 0KPa and increase with increasing depth below the water table. The Factor of safety was obtained based on stress reduction method (Plaxis) or limit equilibrium (Slide and Geostudio).

The safety factor was determined on the full geometry in two cases: without seepage and with seepage analysis. The factor of safety of the Slide model without taking into account the seepage is 2.03 which greater than 1.5, which means that it is safe. This value is almost equal to the value of Geostudio model that is equal to 2.15. The factor of safety in seepage analysis decreased to 1.87. This value is still higher than 1.5, and the dam is still safe. Slide agrees with Geostudio on the calculation of safety factor because the factor of safety of Geostudio was 1.95.[11]

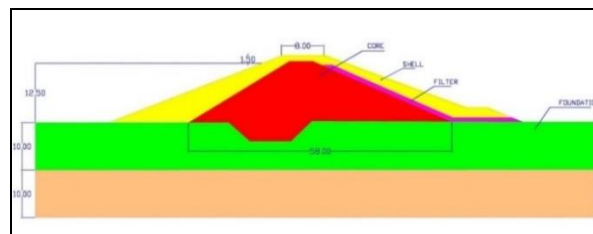


Fig.2. Cross-sectional of the Mandali Dam, Iraq

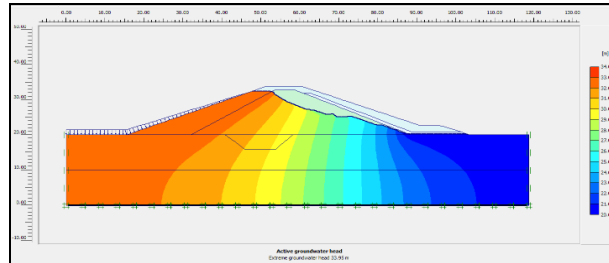


Fig.3. Water head variations, PLAXIS 8.6 model

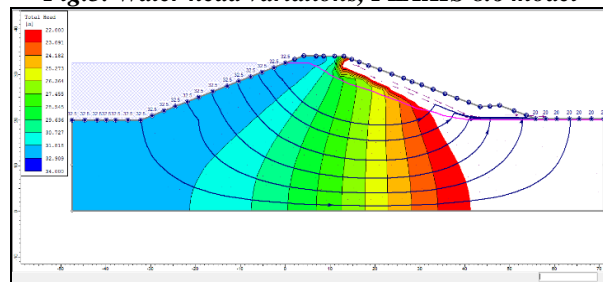


Fig.4. Water head and flow lines distribution, SLIDE 6.0 model

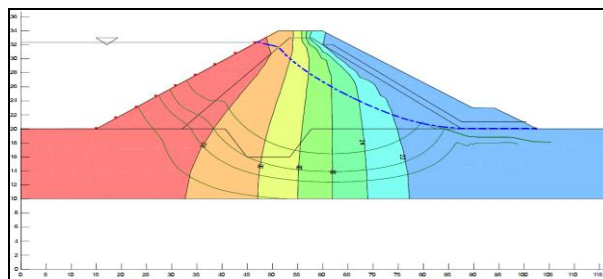


Fig.5. Water head and flow lines distribution, Geostudio model [11]

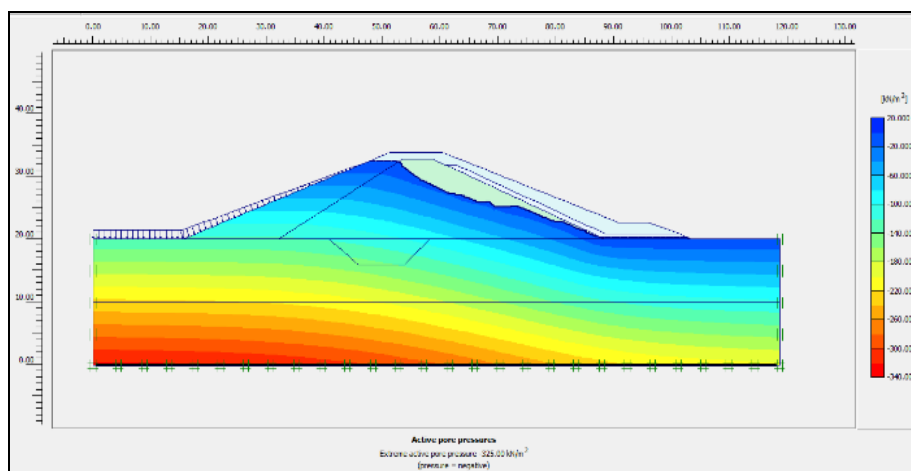


Fig.6. Pore water pressure variation, PLAXIS 8.6 model

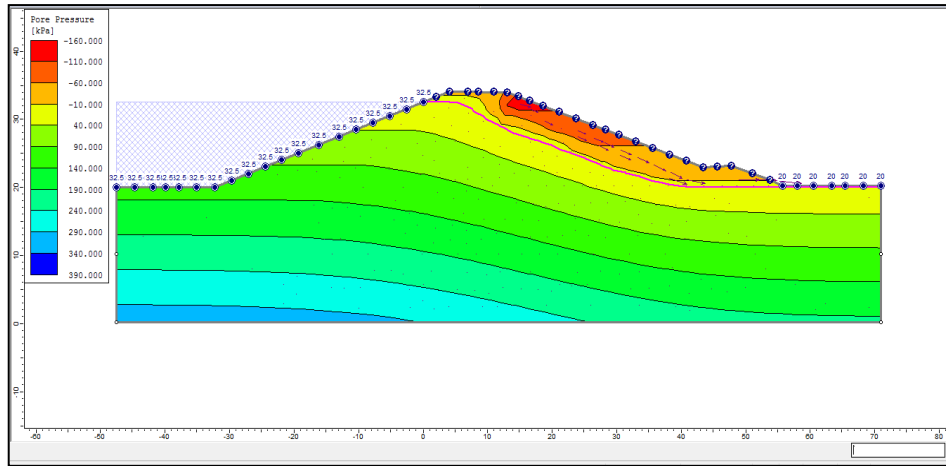


Fig.7. Pore water pressure variation SLIDE 6.0 model

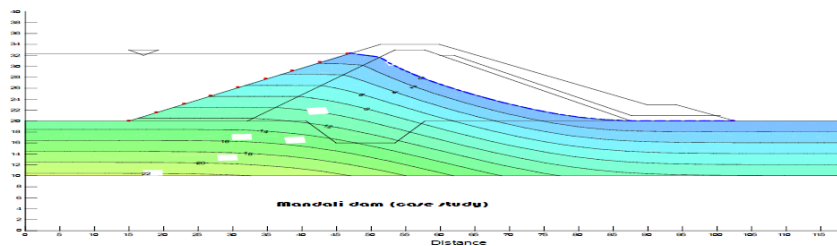


Fig.8.Pore water pressure variation, Geostudio model [11]

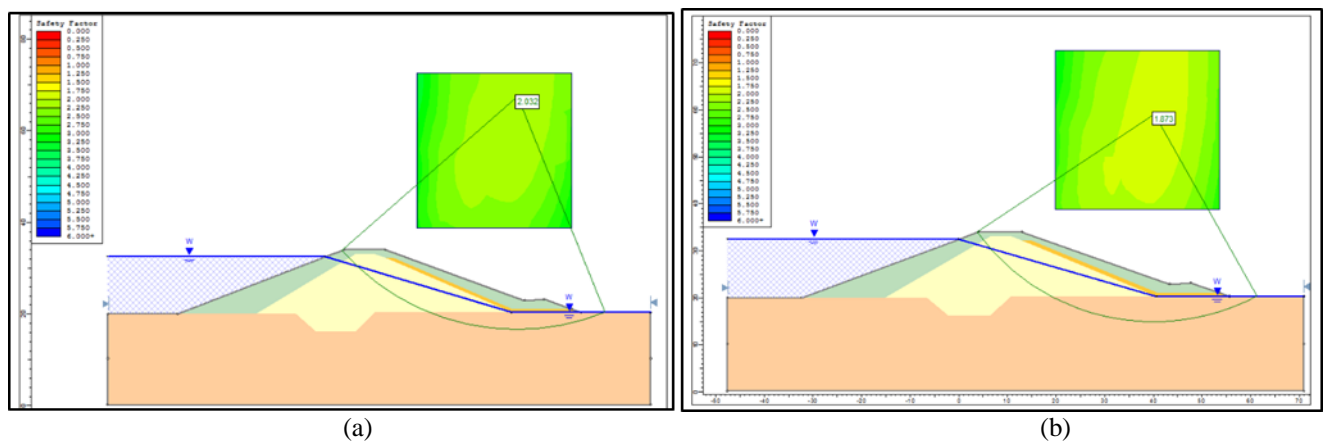


Fig. 9. The factor of safety (a) without seepage and (b) with seepage, SLIDE 6.0 model

Table 1. Soil properties of the Mandili Dam, Iraq

Soil type	Shell (sandy soil)	Clay core (very stiff clay)	foundation
Bulkdensity (γ) (KPa)	21	19.2	22
The angle of internal friction (Φ_0)	40	15	18
Cohesion(c) (KPa)	0	40	45
Permeability(k) (m/sec)	$1.37 \cdot 10^{-5}$	$9.88 \cdot 10^{-9}$	10^{-8}

Case study (Esna Dam)

Earth and rockfill dam is located in Upper Egypt. The dam height is 19.5m, with a dam crest width of 15 m as shown in Figure 10. The upstream slope is 1V:3H and the downstream slope is 1V:3H. A diaphragm wall is surrounded by Pit run sand and gravel for centre dense and crown zone, the upstream zone from hydraulic medium-fine sand and stream cutting dike from rockfill. The soil properties of the dam component and the foundation soils are shown in Table 2. The upstream maximum water level is 79m and minimum water level for downstream is 71m respectively. 2D numerical model was used by PLAXIS 8.6 and SLIDE 6.0. The numerical models were carried out to investigate the stability and seepage behavior of the dam. The finite element model of the cross-section of the dam is shown in Figures 11 and 12. The cross section of the dam was used in this model. The geometry was taken into consideration the model boundary effect and the conduct wide model was used in this case. The default standard fixtures in Plaxis were selected for generation of boundary outermost vertical, left, right foundation boundary and horizontal displacements were set to zero ($U_x=0$). Both horizontal and vertical displacements were set to zero ($U_x=U_y=0$). The element type was chosen as triangular elements. The mesh sensitivity was examined in the choice of mesh size. Several different meshes were tested. The selected fine meshes are shown in Figure (11and12). Both PLAXIS 8.6 and SLIDE 6.0 soft wares were used to simulate seepage analysis in study case. The results in this study include: Total Head, pore Water pressure, Flow Net and the discharging value in the dam body.

Table 2 Properties of Soil in case study (Dam geotechnical report)

Material & Zones (Dam geotechnical report)	(v) (KN/m ²)	(E) (KN/m ²)	(k) (m/sec)	(Φ _o)	(c) (KN/m ²)	(γ) (KN/m ³)
Silt stone	0.3	1×10 ⁵	1×10 ⁻⁶	34	100	20
Lower sand	0.3	3×10 ⁴	5×10 ⁻⁴	35	1.0	21
Upper sand	0.3	2.2×10 ⁴	1×10 ⁻⁴	33	1.0	20
Upstream zone	0.25	1.12×10 ⁴	8×10 ⁻⁵	35	2.5	16
Dense zone	0.3	3.5×10 ⁴	6×10 ⁻⁶	39	1.0	20
Crown zone	0.35	3.5×10 ⁴	3×10 ⁻⁶	42	1.0	22
Cutting dike & Rip rap	0.3	4×10 ⁴	1×10 ⁻⁵	38	3.5	21
Diaphragm wall	0.3	2×10 ⁵	5×10 ⁻⁸	0	100	20
Zone(10)	0.3	3.5×10 ⁴	5×10 ⁻⁶	39	1.0	20

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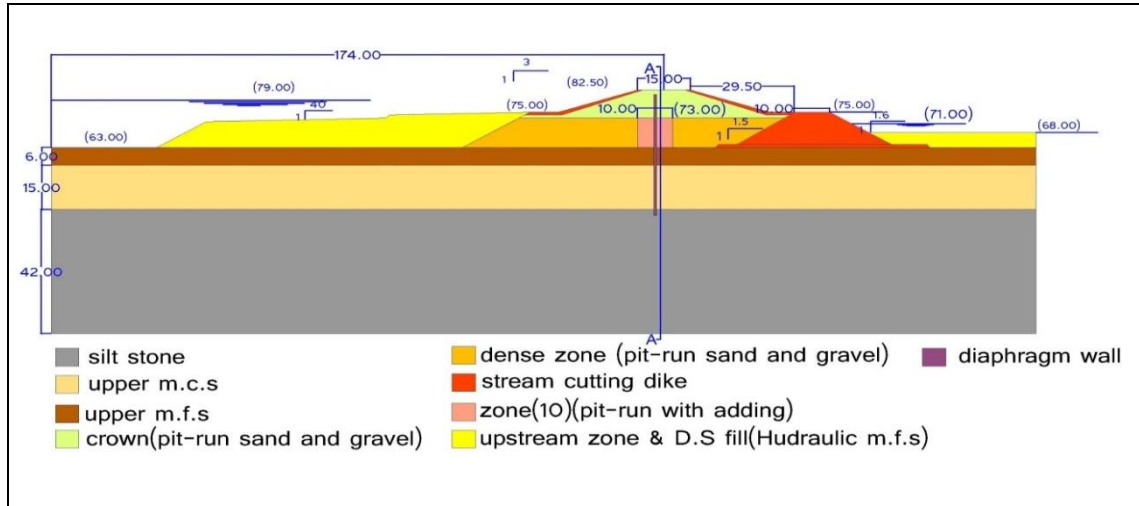


Figure 10. Dam cross-section and dimensions (Dam geotechnical report)

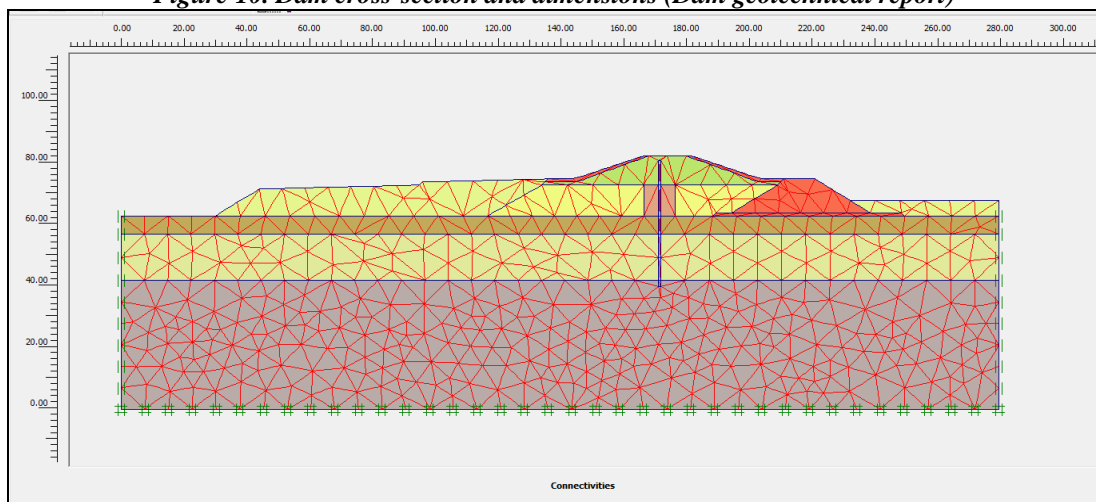


Figure 11: D numerical model geometry (PLAXIS 8.6)

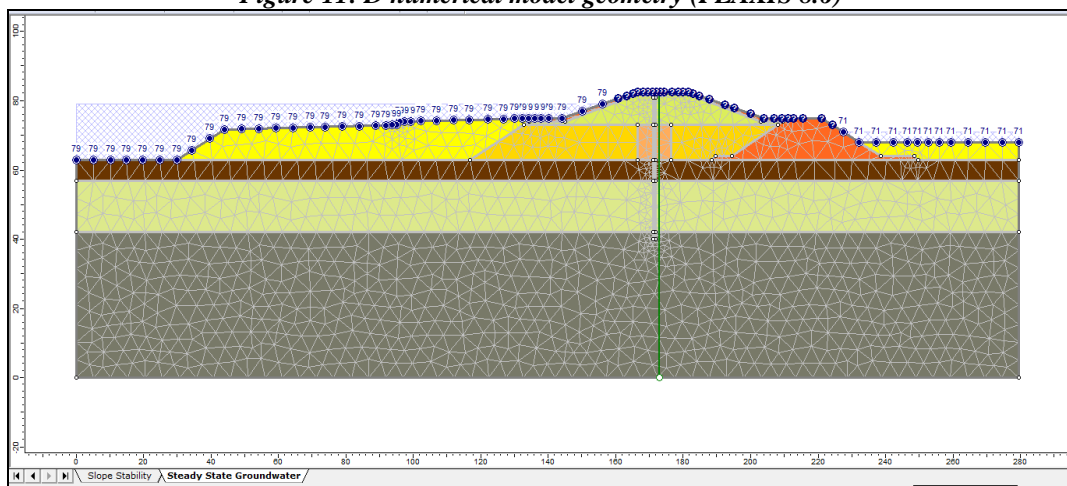


Figure 12. 2D model geometry SLIDE 6.0

Seepage analysis

In order to investigate the dam state, Plaxis and Slide were conducted. The results such as total head, pore water pressure, flow net and the discharge value in the dam body were compared in different soft wares.

Total head

The maximum total head was 79 m and the minimum value was 71m. Figures (13 and 14) show the total head 2D shading contours for both models. It is clear that the head was dissipated through the dam due to the using of the diaphragm wall. The headlines represent equipotential line in flow net. The sheet pile dissipates the water head energy. The head was high byong the sheet pile (upstream level) and decreased gradually beneath the sheet pile. The total head decreases with water seepage distance movement. Figure 13 represent PLAXIS results and Figure 14 shows the SLIDE results. The flow under the sheet pile equal 2.13m³/day, Figure 14. The head also dissipated through the dam body.

Pore pressure

The flow lines show pore pressure in coloured shading contours. The maximum pore pressure was 800kPa and the minimum value was 0kPa. Figures 15 and 16 show the 2D pore pressure shading contours for both models. It is clear that the pressure was dissipated through the dam due to the using of the diaphragm wall. The pressure decreases with water seepage movement. The existing of the diaphragm wall causes a sudden drop in the flow line as it is clear in the figures. i.e. that the sheet pile causes a dissipation of water energy. PLAXIS and SLIDE give a good agreement of the calculation of pore pressure inside the dam cross section.

Flow net and Discharge value

The flow net was shown as a result of Slide model in Figure 17, which the PLAXIS model cannot produce, so SLIDE model was used to obtain this output. A section was taken during calculation. The result was 2.13m³/day for Slide and 2.1 m³/day for PLAXIS as shown in Figures (16 and 18).

Stability analysis

The assessment of the slope stability gives a good indicator that there is no failure will be happened. Bishop, Spencer and Janbu methods were used in Slide to calculate the value of the safety factor. PLAXIS model are used to calculate the minimum factor of safety using numerical model as shown in Figure 21. The calculated factor of safety values are presented in Table 3. Figure 19 shows the factor of safety of the dam after construction (without seepage condition) by using SLIDE with Bishop's method. The Factor of safety was 2.14. The factor of safety decreased to 1.69 after starting the steady state case as shown in Figure 20 and equal 1.65 by PLAXIS as shown in Figure 21 . The reduction of factor of safety shows the important of using the numerical models in the calculation of seepage and factor of safety.

The results show that the dam is safe in steady state case, i.e. this dam is safe in terms of stability.

Table 3. The factor of safety of case study dam

Method State	Bishop	Spencer	Janbu
End of construction	2.14	2.14	2.09
Steady state	1.69	1.69	1.65

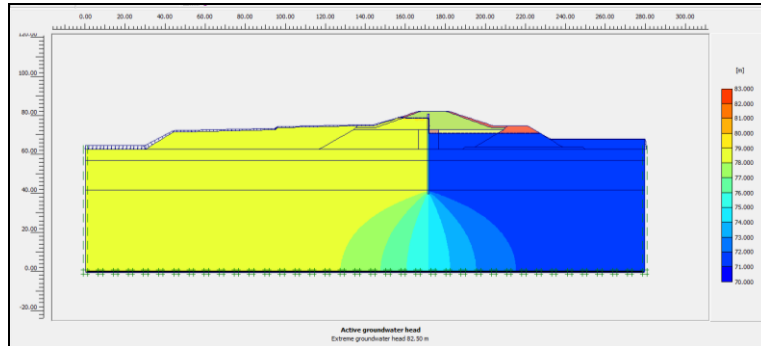


Figure 13. 2D coloured shading of total head – PLAXIS 8.6

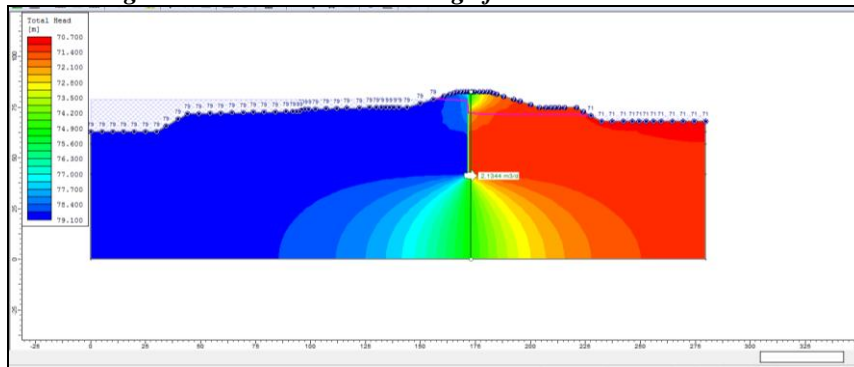


Figure 14. 2D coloured shading of total head – SLIDE 6.0

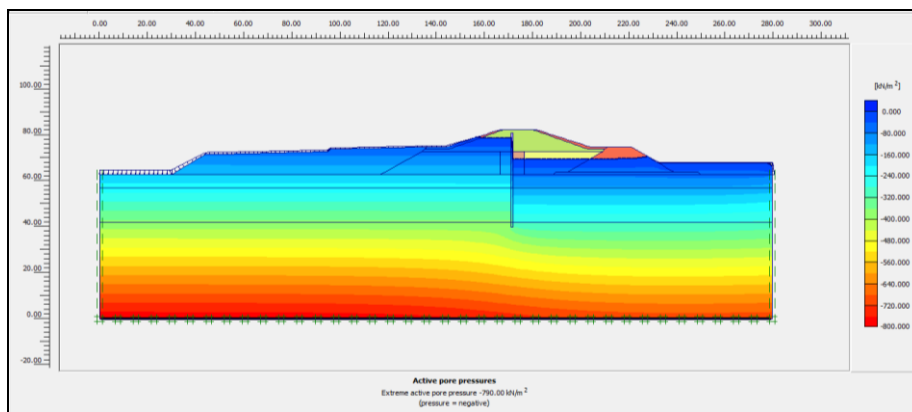


Figure 15. 2D coloured shading of flow line (pore pressure) – PLAXIS 8.6

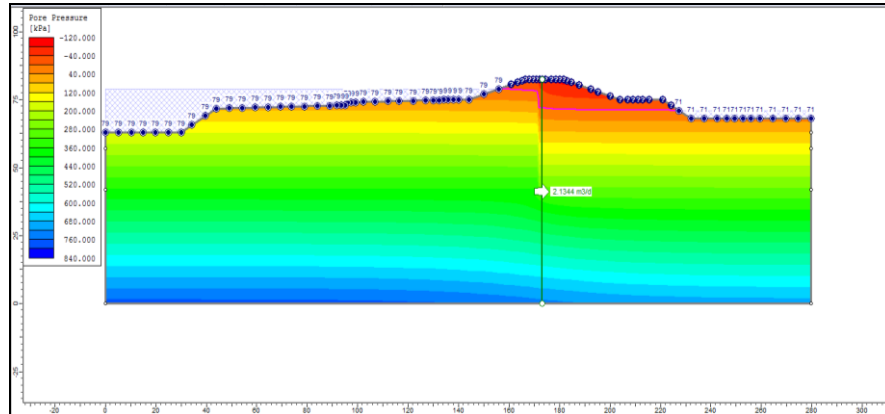


Figure 16. 2D coloured shading of flow line (pore pressure) – SLIDE V6

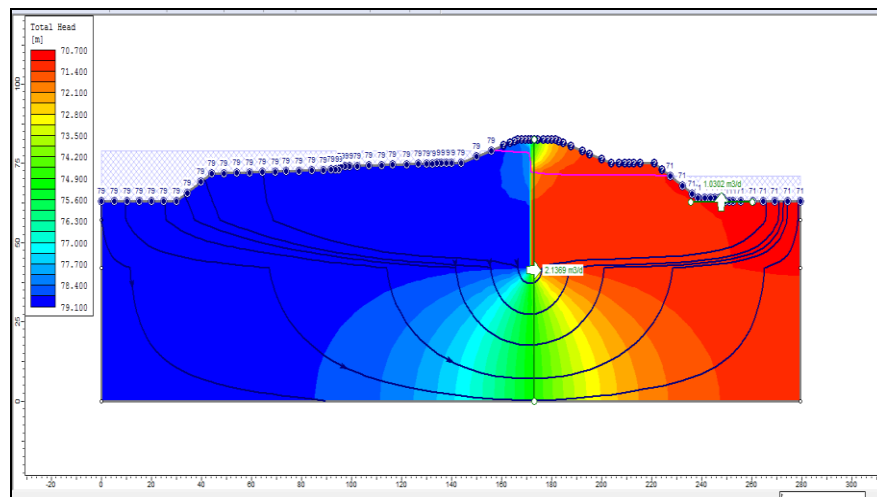


Figure 17. 2D coloured shading of flow net and discharge – SLIDE 6.0

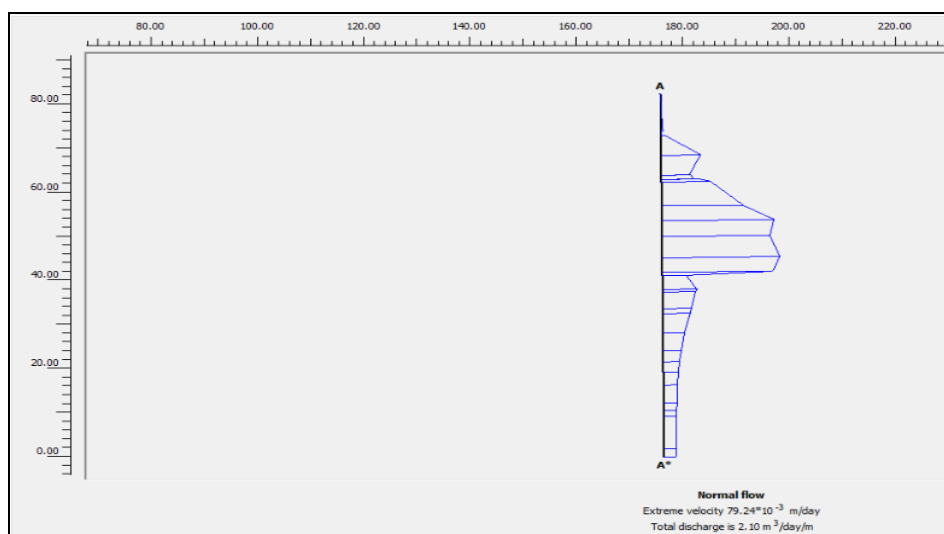


Figure 18. Cross-section of discharge values – PLAXIS 8.6

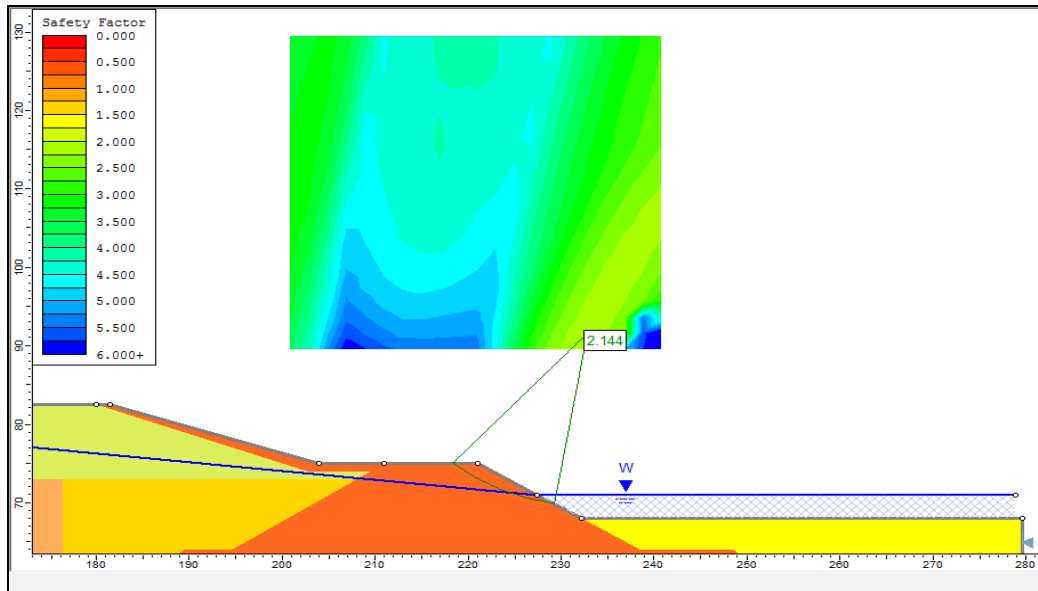


Figure 19. Factor of safety downstream, Bishop's method, non seepage case– SLIDE 6.0

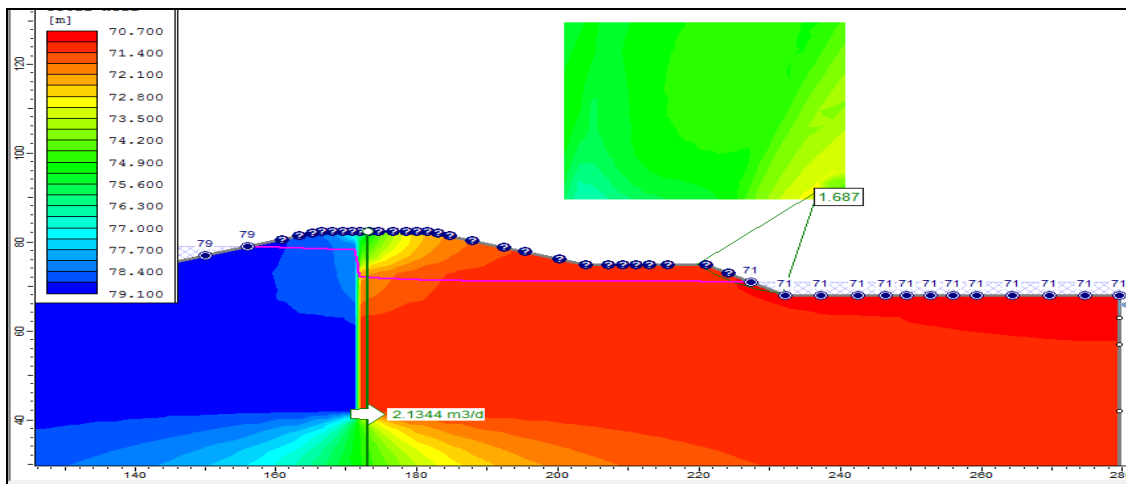


Figure 20. factor of safety downstream, Bishop's method, seepage case– SLIDE 6.0

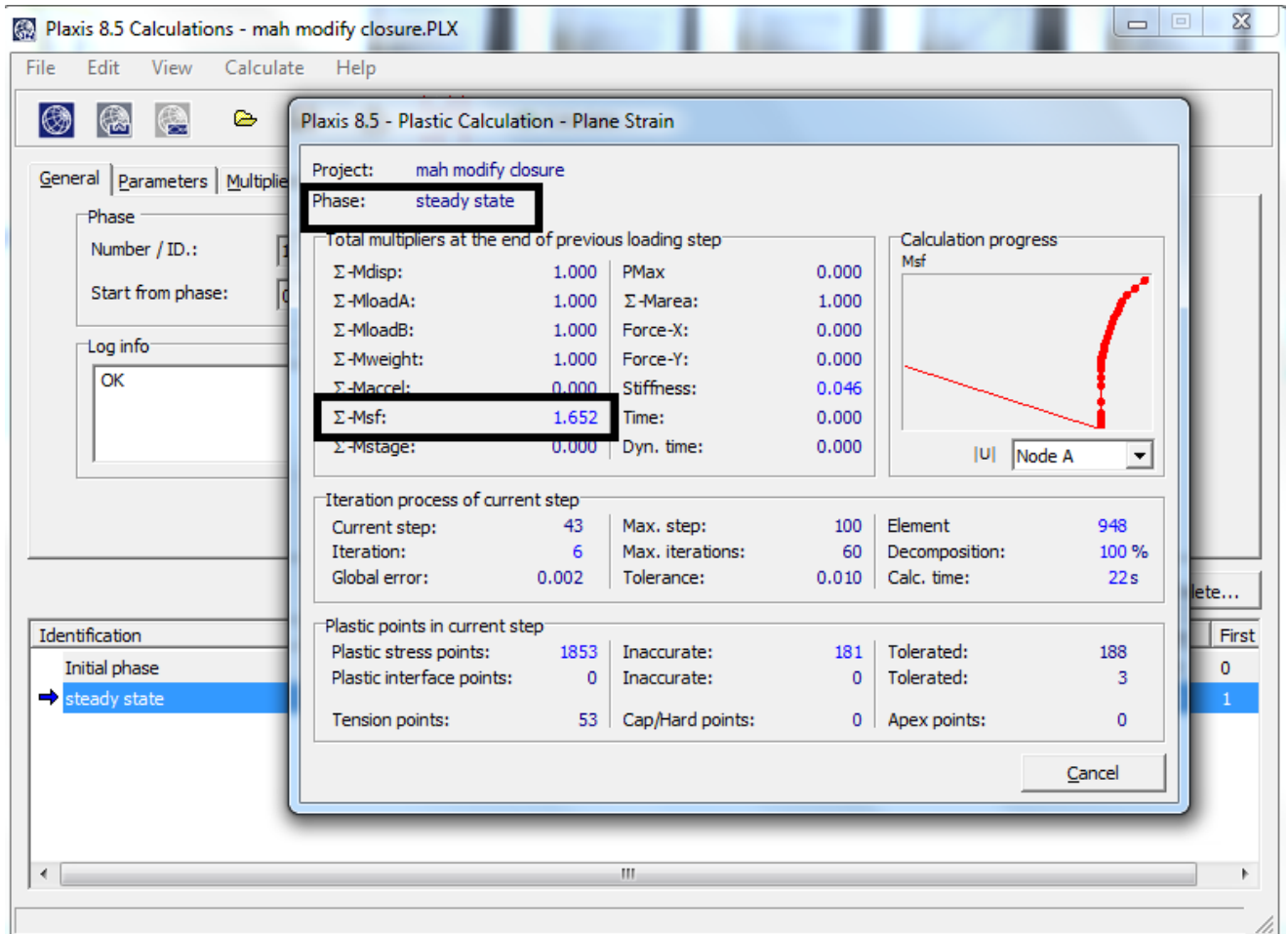


Figure 21. Factor of safety, steady state, – PLAXIS 8.6

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CONCLUSION

This study was focused on investigating the dam seepage behavior and the stability analysis. This study was performed by using 2D numerical models using PLAXIS 8.6 and SLIDE 6.0. On the basis of the results obtained, the following can be concluded:

1. PLAXIS, SLIDE and Geostudio give a good agreement in water head, pore pressure, discharge, and the stability analysis.
2. In the seepage analysis, the factor of safety for stability of the dam is lower than that without a seepage analysis.
3. In seepage case, the downstream always a critical section in stability analysis.
4. In the limit equilibrium method, the factor of safety change depends on the method type, so it is better to conduct several methods and choose the lower value.
5. The diaphragm wall beneath the dam works on disturbing water head and reducing its value in the downstream section.

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