ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Behavior of an Earth Dam during Rapid Drawdown of Water in Reservoir – Case Study

Mohammed Y. Fattah[(1)] , Hasan A. Omran[(2)], Mohammed A. Hassan[(3)]

1. Professor, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq,
2. Assistant Professor, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.
3. Former graduate student, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

Manuscript Info

Manuscript History:

Received: 15 August 2015
Final Accepted: 22 September 2015
Published Online: October 2015

Key words:

Rapid drawdown, finite element method, Geostudio 2007, slope stability.

***Corresponding Author**

Mohammed Y. Fattah

Abstract

In this study, the finite element method is used to study seepage through the body of an earthfill dam. For this purpose, the software Geostudio 2007 is used through its subprograms SEEP/W and SLOPE/W. The water levels on the upstream and downstream sides, the properties of materials and boundary conditions of the dam were input variables and the water flux and pore water pressure were the target outputs. The Dau Tieng reservoir, which is located in Tay Ninh province in Southern Vietnam was analyzed as a case study. The rapid drawdown is simulated by means of the staged construction mode.

It was concluded that the factor of safety against sliding of the dam slopes decreases slightly within the short period after the start of rapid draw down of water in the reservoir, 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. The saturated weight of the slope produces the shearing stresses while the shearing resistance is decreased considerably because of the development of the pore water pressures which do not dissipate rapidly.

When the stability of a zoned earth dam is examined during rapid draw down under different water levels in the reservoir, the insufficient stability may occur in the upstream slope as soon as the water is lower than the drawdown level of 1/3 of the dam height. It can be explained that the water load has disappeared during rapid drawdown and the hydrodynamic pressure creates the tensile-downward forces, resulting in a decrease of the shear resistance of the upstream slope. Besides, there is no supporting pressure to resist against mobilizing of the upstream slope.

INTRODUCTION

The drawdown is known as one of the most dangerous conditions for the upstream slope. When the countervailing upstream water pressure has disappeared, it causes a danger to the upstream slope. The upstream shell cannot keep peace under the hydrodynamic pressure due to rapid drawdown. Soils inside the dam body remain saturated and seepage commences from it towards the upstream slope. Seepage and hydrodynamic pressures create downward forces acting on the upstream slope. Those are adverse to the stability and create a critical condition to the upstream slope (Tran, 2004).

At the rapid drawdown of the reservoir, the pore water pressure will be reduced slowly due to small permeability of the soil, thus there are two methods to solve this issue, the first method, the usage of horizontal filters in the upstream reaching the core of the dam to absorb the pore water pressure. The second method is by the usage of vertical filters parallel to the dam core to the upstream side to absorb the water and returning them to the reservoir to reduce the pore water pressure ,therefore, the interior soil stress will be dissipated which will lead to increase the safety factor.

When the phreatic line (free surface) falls slowly or remains almost at the same position, it is considered as ‘rapid’ drawdown. The lag of the phreatic line or the rate of drawdown depends on four factors: permeability coefficient of the dam fills, drawdown rate, pore active volume, and upstream slope gradient. The case in which the water has to be quickly lowered for the special purpose of rehabilitation, or material of the dam slope is impermeable so the phreatic line does not fall so much even if this drawdown has lasted for several months, is a common problem in the reality (Abadjiev, 1994).

The rapid drawdown condition occurs when a slope that is used to retain water experiences a rapid (sudden) lowering of the water level and the internal pore pressures in the slope cannot reduce fast enough (Khassaf et al., 2013).

Zomorodian and Abodollahzadeh (2010) investigated the effect of horizontal drains on upstream slope of earth fill dams during rapid drawdown using finite elements and limit equilibrium methods. Changing of pore water pressure, outpouring seepage flow and factor of safety were inspected. The amount of water leakage and seepage in the dam was investigated by using the SEEP/W software and the static slope stability analysis by using the SLOPE/W software.

Noori and Ismaeel (2011) stated that seepage can cause weakening in the earth dam structure, followed by a sudden failure due to piping or sloughing. For this purpose, a finite element method through a computer program, named SEEP2D, was used to determine the free surface seepage line, the quantity of seepage through the dam, the pore water pressure distribution, the total head measurements and the effect of anisotropy of the core materials of Duhok zoned earth dam. First, the accuracy of the program was tested via the data of experimental dam and the results showed an acceptable accuracy of the program. The effect of the ratio of the permeability in the horizontal direction to that in the vertical direction (kx/ky) on seepage was tested and results indicated an increase in seepage quantity as this ratio increased. The stability of Duhok zoned earth dam was analyzed using a slope stability computer program, named STABIL2.3. The slope stability analysis results showed that the factor of safety decreases with the increase of kx/ky ratio. The analysis of the results of this study showed that Duhok zoned earth dam is safe against the danger of piping and slope sloughing under the present operation levels.

Chugh (2013) examined the stability of a circular earth dam for radial cracking potential and static slope stability using continuum mechanics-based three-dimensional numerical models. Comparisons of numerical model results for a circular water tank with vertical walls and different radii with their analytical counterparts are included to support the validity of the ideas and their implementation in the continuum mechanics-based computer program used. Effects of sloping wall faces and Poisson’s ratio on computed deformations and stresses are also included. The same numerical models were used to assess stability of a circular dam in terms of factor of safety and associated failure surface. Three-dimensional slope stability analysis results were compared with continuum based two-dimensional slope stability analysis results to assess the magnitude of 3D effects. Example problems are included to illustrate the use of ideas presented.

Seepage analysis of earth dams is one of the major interesting points in geotechnical engineering. The amount of water seeping through and under an earth dam together with the distribution of the water pressure can be estimated by using the theory of flow through porous media which is one of the most valuable analytical tools available to the engineer. Fattah et el. (2014) utilized the finite element method to solve the governing equations of flow through earth dams. The computer program Geo-Slope was used in the analysis through its sub-program named SEEP/W. Eight node isoparametric elements were used to model the dam and its foundation, while mapped infinite elements are used to model the problem boundaries. A case study was considered to be Al-Adhaim dam in Iraq which consists of zoned embankment 3.1 km long. The dam at its actual design was analyzed using the program SEEP/W. Then several analyses were carried out to study the control of seepage in the dam through studying the effect of several parameters including the permeability of the shell material and the presence of impervious core and its location and thickness. It was concluded that the presence of clay core has an important effect on decreasing the exit gradient, which may increase in the order of 300% when the core does not exist and the factor of safety may be critical when the water level in the reservoir is at 143.5 m. The sloping core of Al-Adhaim dam is the best design for core than other choices since it permits the lowest values of seepage and provides the lowest exit gradients.

The need to study the slope stability of earthfill dams during drawdown is necessary and imperative not only for the existing dams, but also for the design and construction other earthfill dam projects in the region. In this paper, the rapid drawdown condition is investigated by the finite element method for Dau Tieng reservoir dam. The stability of the dam slopes is traced during the change in water level.

Case Study - Dau Tieng Dam

The Dau Tieng reservoir, which is located in Tay Ninh province in Southern Vietnam, with 1350 hectares of water surface and 1450 m^3 of water, is the biggest reservoir in Veitnam. The main dam is a homogeneous earthfill with a height of 31 m above ground, a crest of 10 m, and a length of 1100 m. The slope inclination varies from 1: 3 to 1: 4.5 upstream and from 1: 3 to 1: 4 downstream. The subsoil contains two soft soil layers having about 9 m, and sand layers at the deeper level. The fills of sandy-silty clay do not have very high shear strength. Moreover, its permeability is not low enough to totally intercept the seepage through the dam.

The Dau Tieng reservoir was built in three years from 1981 to 1984 and has been put in service since 1984-1985. Many parts of the water work, after 15 years in operation, have been downgraded and damaged. The dam slopes were suspected to be not stable enough because the shear strength of the fills was not very high. The downstream drains were too few, so erosion might occur. Therefore, the main dam had to be repaired in 1999. Figure 1 describes a general cross-section of the dam before and after treatment by constructing a cut-off wall (0.6 m wide and 33 m high) in the dam's body and stabilizing berms in the downstream slope (Tran, 2004).

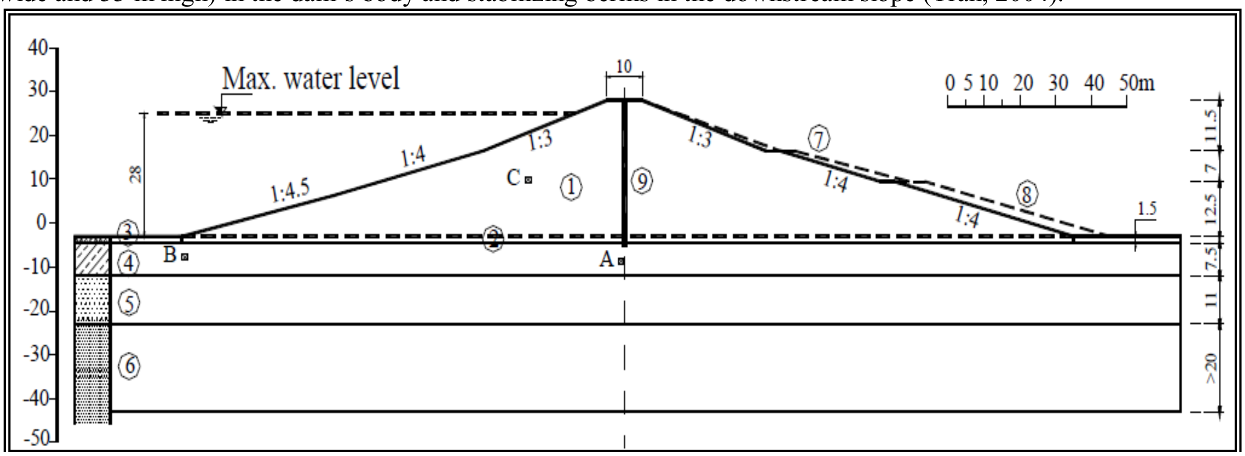

Figure 1 General cross-section of the Dau Tieng main dam, and simulation of five-stage construction and selected points for analysis (Tran, 2004).

(1) Sandy-silty clay, (2) excavation and backfill, (3) Top soil of silt and fine sand (layer 1), (4) Sandy clay (layer 2), (5) Medium sand (layer 3), (6) Fine sand (layer 4), (7) Shoulder berm of silty clay (after rehabilitation), (8) Toe berm of coarse gravel, cobblestones, and clay (after rehabilitation), (9) Cut-off wall of 0.6 m wide (after rehabilitation).

The rapid drawdown is simulated by means of the staged construction mode. The water level in the reservoir is supposed to lower quickly into six steps. The maximum water level (from L = 28 m) is lowered in 3 m (to L = 25 m) at the first step, and then equally in 5 m for each following drawdown. The phreatic line is assumed to remain at its initial position during drawdown.

The drained behavior of the soil materials is employed for the analysis of rapid drawdown because the dam has been put into operation for a long time. Three points (A at the middle of the soft soil layer, B at the upstream toe, and C at the middle shoulder of the upstream slope) are typically chosen for the analysis Figure (1). The input parameters of the soils and cut-off wall properties are shown in Table 1.

Table 1: The properties of Dau Tieng dam (after Tran, 2004).

Material	k (m/sec)	γ (kN/m^2)	c (kN/m^2)	□□, degree
Sandy-silty clay	$5*10^{-7}$	21	20	24
Sandy clay	10^{-8}	19	14	14
Medium sand	$5*10^{-6}$	19.5	2	26
Find sand	$2*10^{-6}$	20	3	29
Clay (shoulder berm)	$5*10^{-8}$	20	-----	-----
Gravel, cobblestone and clay	$1*10^{-4}$	22	-----	-----

Computer Program

Geostudio software is one of geotechnical programs that is based on the finite element and can consider analysis like stress-strain, seepage, slope stability, dynamic analysis and also fast water drop in reservoir.

SEEP/W is Part of the GeoStudio suite of engineering analysis applications, SEEP/W is a 2-D, finite element software program for analyzing ground water and excess pore-water pressure dissipation problems in a porous media. The comprehensive nature of the program enables analyses ranging from simple, saturated, steady state problems to sophisticated, saturated and unsaturated, time dependent problems. Good quality output graphics allow a visual display of equipotential lines and flow paths, and contours can be plotted for a number of properties/results such as pore pressures, seepage velocities, and gradients. As with most seepage analysis programs, computations include flow quantities and uplift pressures at selected locations in the model (Engemoen, 2014).

Results of Analysis

Pore water pressure

When the phreatic line (free surface) falls rapidly almost at the same position, it is considered as rapid drawdown. The lag of the phreatic line or the rate of drawdown depends on four factors: permeability coefficient of the dam fills, drawdown rate, pore active volume, and upstream slope gradient. The case in which the water has to be quickly lowered for the special purpose of rehabilitation, or material of the dam slope is impermeable so the phreatic line does not fall so much even if this drawdown has lasted for several months, is a common problem in the reality (Abadjiev, 1994).

II- Failure mechanism

When the water in the reservoir is at the maximum level, the potential failure surface dominantly takes place in the downstream slope at the highest danger degree.

Soils in the dam tend to displace to the downstream slope as seen in Figures 2 and 3. Since the water level commences to lower, soils change to move from the upstream to the upstream slope. The potential slip surface or failure mechanism changes to occur in the upstream slope. When the water just passes the level of ½ h (where h is the dam height), the upstream slope is dominant to be destabilized to the downstream one. The potential mechanism of collapse occurs in the upstream and moves from the dam crest to ground as described in Figures 2 and 3.

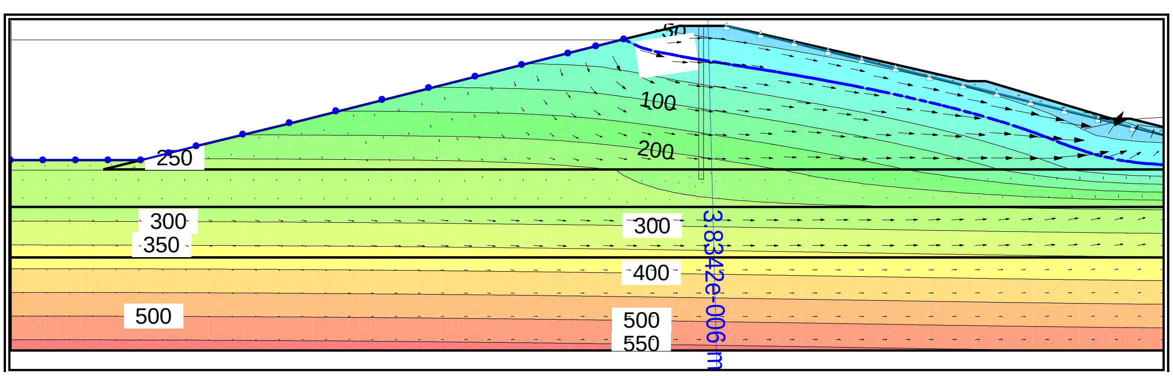

Figure 2: Pore water pressure (kPa), velocity vectors and water flux before rapid drawdown for Dau Tieng dam.

The insufficient stability may occur in the upstream slope as soon as the water is lower than the drawdown level of 1/3 h. It can be explained that the water load has disappeared during rapid drawdown and the hydrodynamic pressure creates the tensile-downward forces, resulting in a decrease of the shear resistance of the upstream slope. Besides, there is no supporting pressure to resist against mobilizing of the upstream slope, and the high negative pore water pressure remains in the dam slopes as the result of soil saturated, reducing the effective shear resistance of the upstream slope.

When the reservoir is rapidly evacuated and drawn down, pore water pressures in the dam body are reduced in two ways. There is a slower dissipation of pore pressure due to drainage and there is an immediate elastic effect due to the removal of the total or partial water load.

The exact mechanism of this phenomenon is as follows: It is assumed that the reservoir has been maintained 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 at this stage, the direction of flow is reversed, causing instability in the upstream slope of the earth dam. The "instantaneous" drawdown is a hypothetical condition that is assumed and pore pressures along the sliding surface are determined by inspection of "instantaneous" pore water pressure at different points in the finite element mesh. The most critical condition of sudden drawdown means that while the water pressure acting on the upstream slope at "full reservoir" condition is removed, there is no appreciable change in the water content of the saturated soil within the dam.

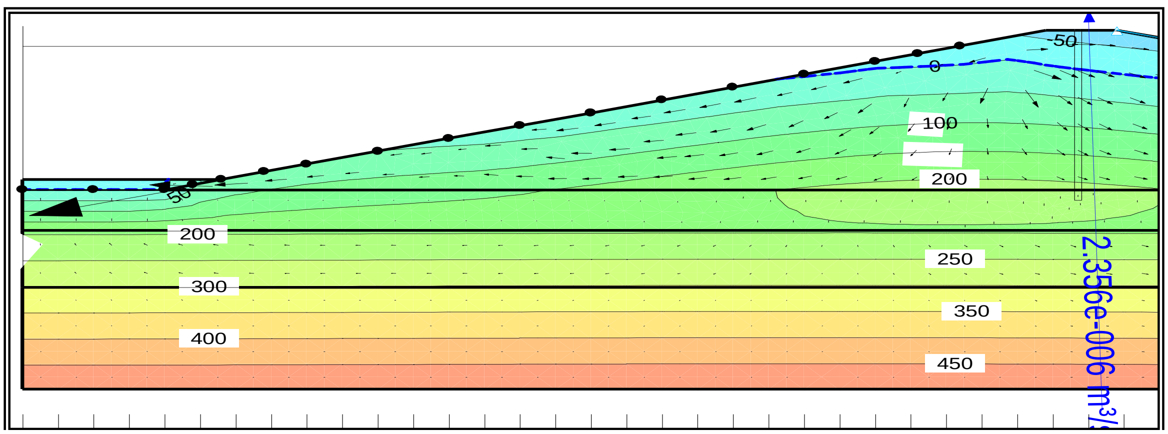

Figure 3: Pore water pressure (kPa), velocity vectors and water flux after rapid draw down for Dau Tieng dam.

Figures 4 and 5 illustrate Dau Tieng dam before and after analysis with the Program SEEP/W with the presence of cut off wall.

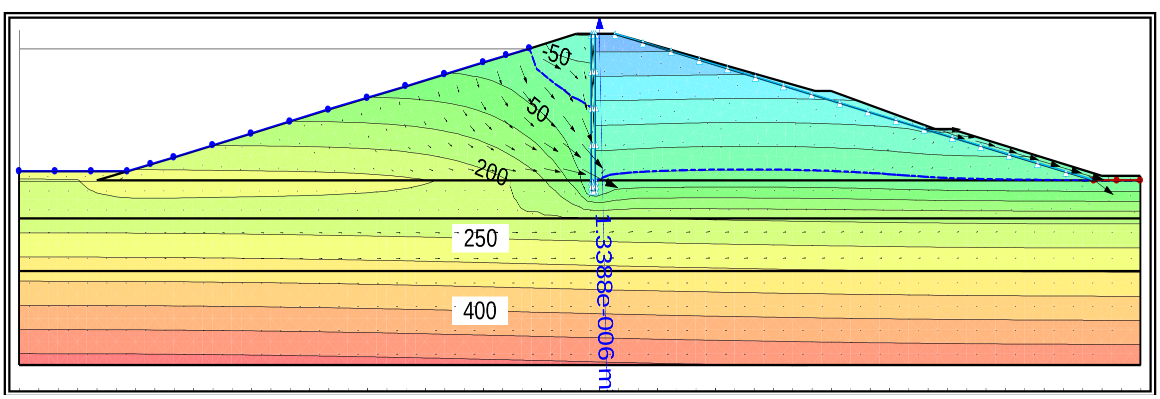

Figure 4: Dau Tieng dam with cut off wall after analysis with the Program SEEP/W before drawdown.

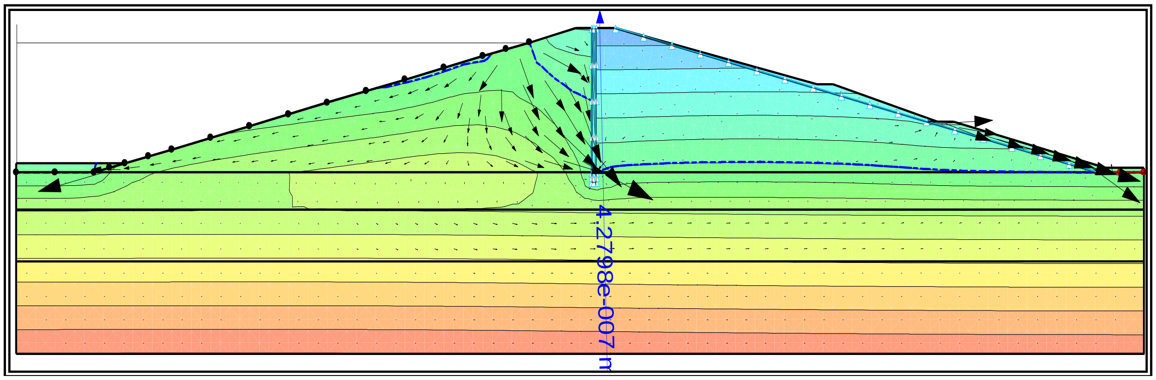

Figure 5: Dau Tieng dam with cut off wall after analysis with the Program SEEP/W after drawdown.

III- Factor of safety

The results of slope stability analysis; factor of safety (F.S) of the upstream slope before rehabilitation (without cut-off wall and stabilizing berms) are plotted in Figures 6 and 7 for different ratios of ΔH/h. Bishop's simplified method of analysis is adopted in this study.

The interesting results shown in Table 2 and Figure 8 indicate that the F.S decreases dramatically from the beginning of drawdown to the level of 1/3 h. When ΔH = 1/3 h, the value of F.S = 1.46 which can be considered nearly minimum. The differences of F.S are not so great in the range of drawdown lower than 1/3 h, roughly constant F.S = (1.297 - 1.46). The value of F.S decreases approximately 22% at the drawdown level of 1/3 h and nearly 49% at the full emptying of reservoir.

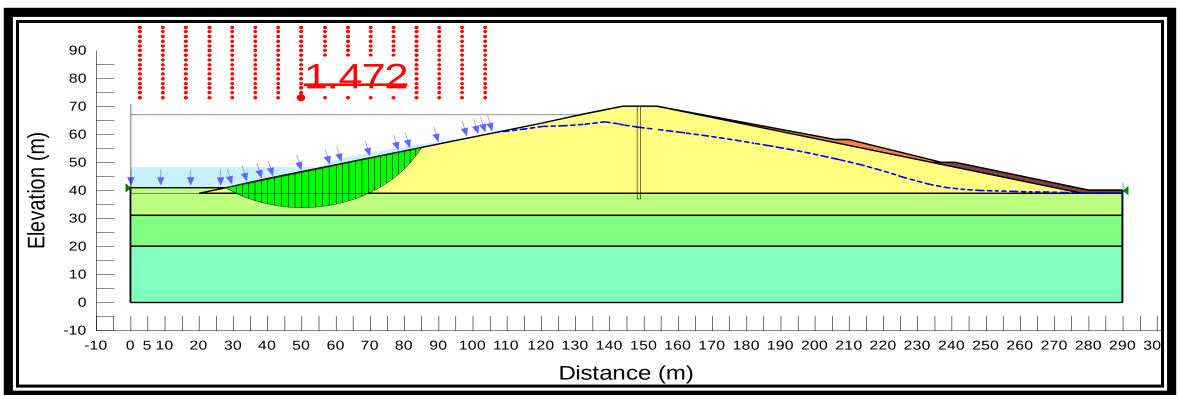

Figure 6: Slope stability using Bishop's method at water table 10 m in Dau Tieng dam without cut off wall.

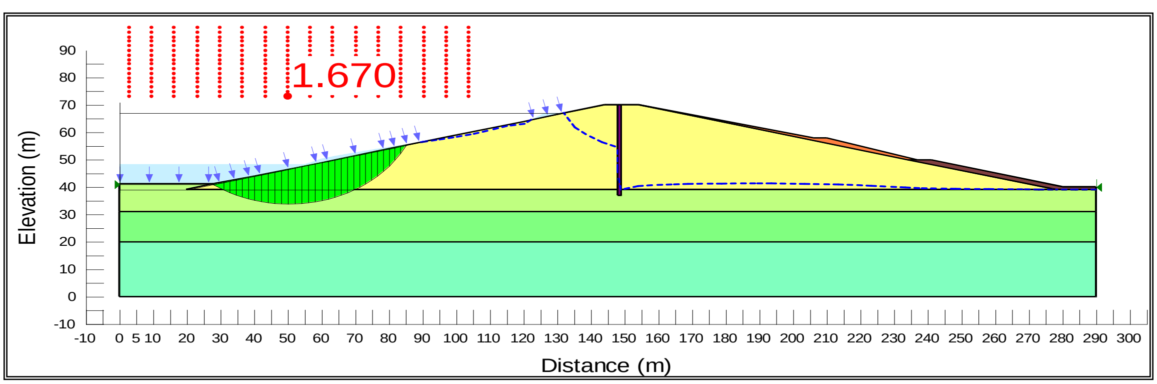

Figure 7: Slope stability using Bishop's method at water table 10 m in Dau Tieng dam with cut off wall.

Table 2: Factor of safety values using Bishop's method compared with the values of Tran (2004) for the dam without cut off wall.

ΔH/h	Bishop's method	Tran (2004)
1	2.57	2.1987
0.893	2.578	2.08
0.7143	2.11	1.98
0.5357	1.876	1.82
0.357	1.472	1.5
0.1786	1.198	1.29
0	1.297	1.22

The results of F.S of the upstream slope after the rehabilitation (with cut-off wall and stabilizing berms) are prsented in Table 3 and Figure 9 for different ratios of ΔH/h. The value of F.S is equal to 1.52 at the drawdown level of 1/3h and 1.229 at the emptying.

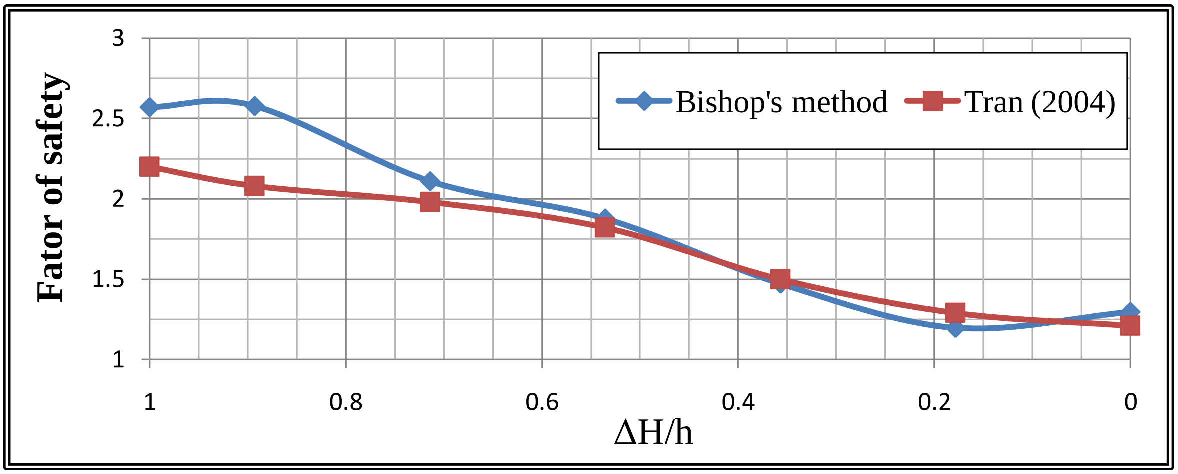

Figure 8: Factor of safety using Bishop's method compared with the values of Tran (2004) without cut off wall.

Table 3: Factor of safety values using Bishop's method compared with the values of Tran (2004) for the dam with cut off wall.

ΔH/h	Bishop's method	Tran (2004)
1	2.41	2.31
0.893	2.409	2.252
0.7143	2.235	2.298
0.5357	1.909	1.97
0.357	1.67	1.62
0.1786	1.34	1.369
0	1.229	1.27

where ΔH: the elevation of water during drawdown, h is the dam height = 31m

The value of F.S decreases by about 19% at the drawdown level of 1/3h and around 49% at the emptying. It can be inferred that the results of two cases (dam without and with cut off wall) are almost similar and the difference is very small. The presence of the cut-off wall dose not affect considerably the F.S value of the upstream slope during rapid drawdown.

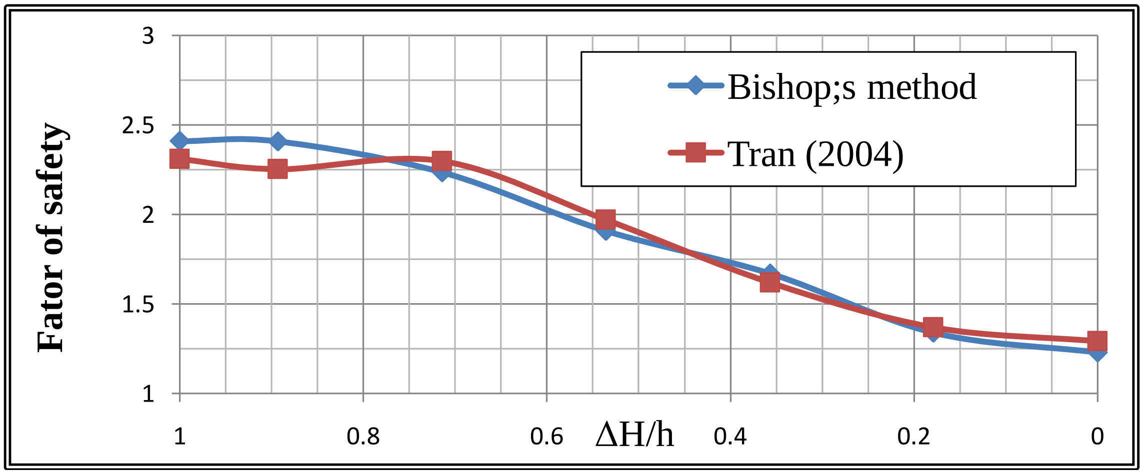

Figure 9: Factor of safety using Bishop's method compared with the values of Tran (2004) of the dam with cut-off wall.

In the initial stages of drawdown, the increased weight of the slope has a proportionally greater destabilizing effect than the increased frictional strength. At the lower levels of drawdown, the increased frictional strength starts to have a greater influence than the increased weight.

Using the Programs SEEP/W and SLOPE/W, Dau Tieng dam has been analyzed using Bishop's method in addition to Morgenstern-Price and Janbu methods. The results of analysis are shown in Figures 10 to 15. A comparison between the three methods with Tran's results is shown in Tables 4 and 5 and Figures 16 and 17.

Figures 16 and 17 reveal that for both cases; with cut off or without cut off wall, Bishop and Morgenstern-Price methods results approximately mach and Janbu's method always gives lower values for factor of safety. It can be noticed that there is a little difference between the results calculated by the Program GEO-Studio, 2007 and the solution of Tran (2004) for Dau Tieng dam for factor of safety.

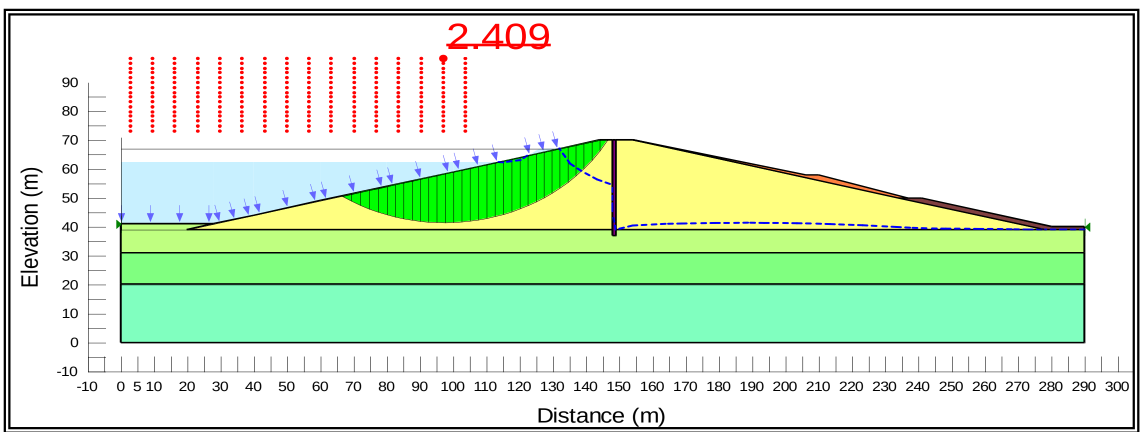

Figure 10: Slope stability using Bishop's method at water level 25 m in Dau Tieng dam with cut off wall.

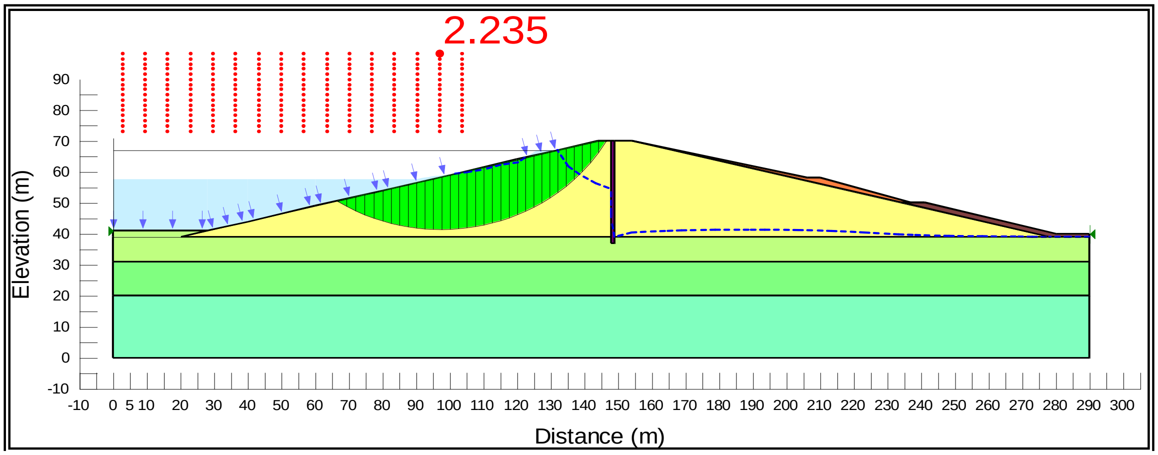

Figure 11: Slope stability using Bishop's method at water level 20 m in Dau Tieng dam with cut off wall.

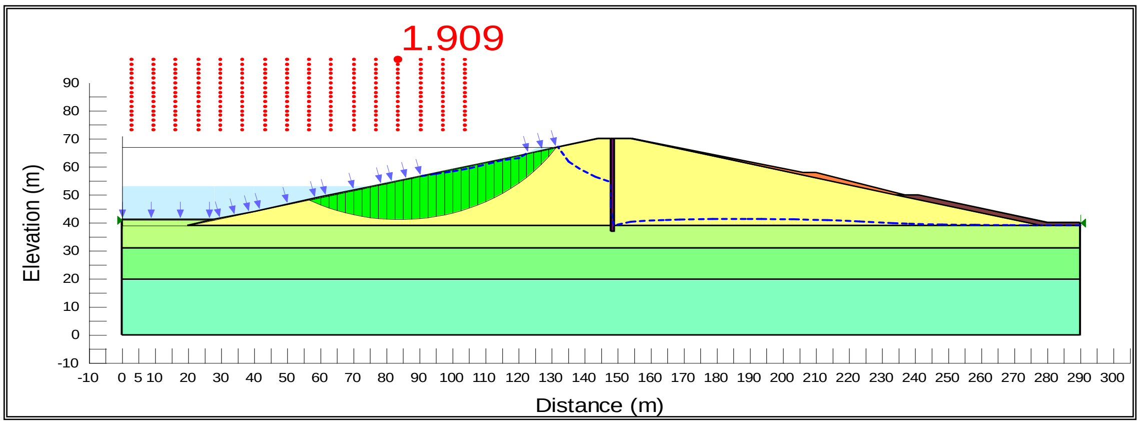

Figure 12: Slope stability using Bishop's method at water level 15 m in Dau Tieng dam with cut off wall.

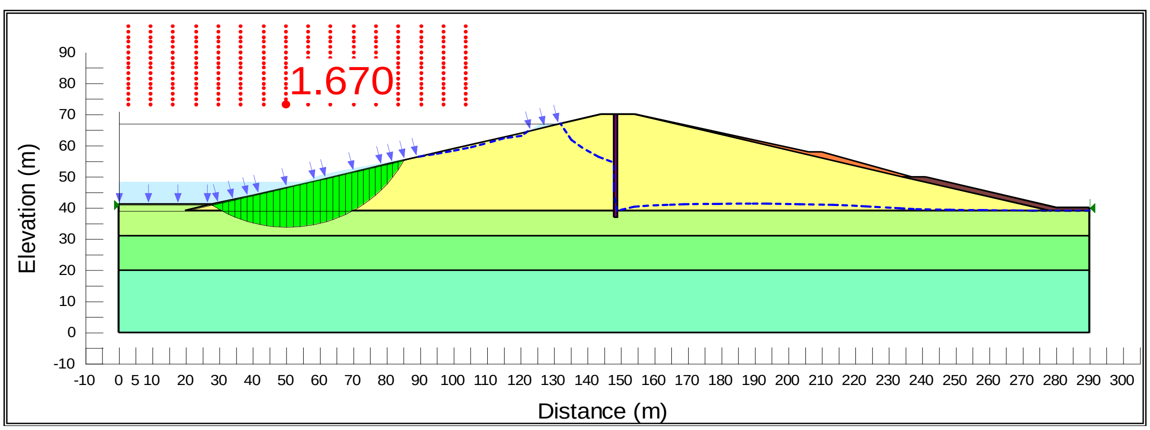

Figure 13: Slope stability using Bishop's method at water level 10 m in Dau Tieng dam with cut off wall.

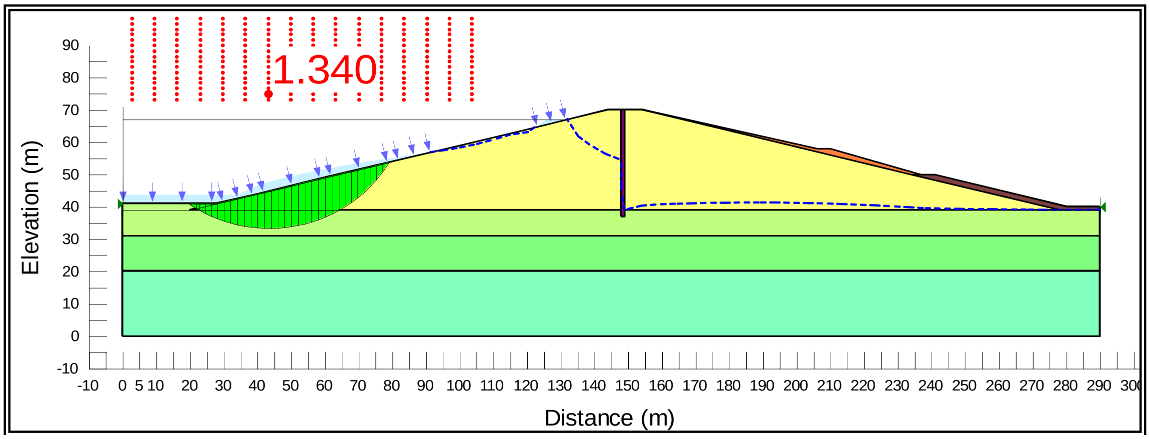

Figure 14: Slope stability using Bishop's method at water level 5 m in Dau Tieng dam with cut off wall.

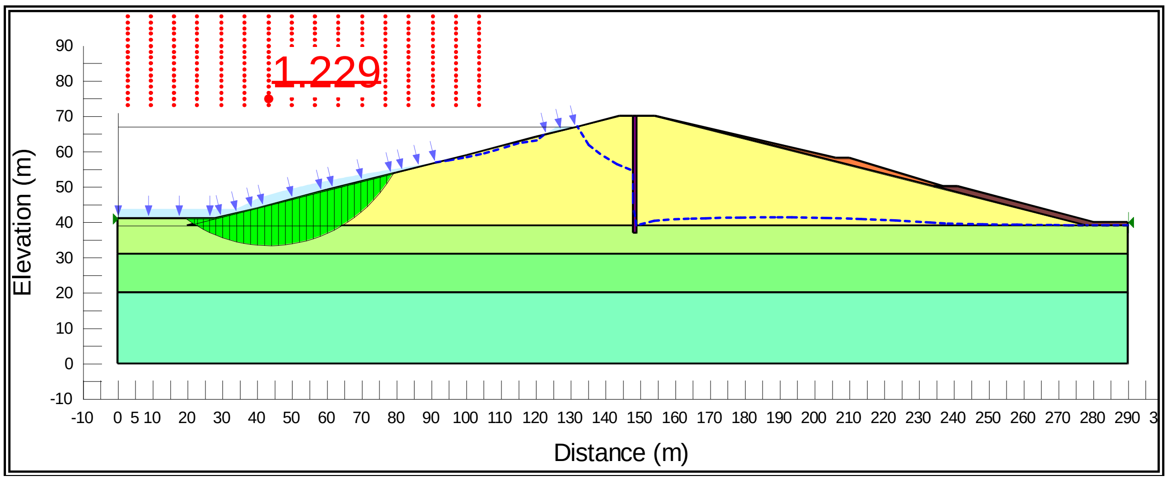

Figure 15: Slope stability using Bishop's method at water level 0 m in Dau Tieng dam with cut off wall.

The saturated weight of the slope produces the shearing stresses while the shearing resistance is decreased considerably because of the development of the pore water pressures which do not dissipate rapidly (Gopal and Rao, 2005).

Table 4: Factor of safety values using Bishop's method, Morgenstern-Price's method and Janbu's method for Dau Tieng dam (with cut off wall).

ΔH/h	Bishop's method	Morgenstern-Price method	Janbu method	Tran (2004)
1	2.57	2.578	2.25	2.1987
0.893	2.578	2.58	2.249	2.08
0.7143	2.11	2.113	1.86	1.98
0.5357	1.876	1.88	1.68	1.82
0.357	1.472	1.459	1.311	1.5
0.1786	1.198	1.191	1.11	1.29
0	1.297	1.294	1.245	1.21

Table 5: Factor of safety values using Bishop's method, Morgenstern-Price's method and Janbu's method for Dau Tieng dam (without cut off wall).

ΔH/h	Bishop's method	Morgenstern-Price method	Janbu method	Tran (2004)
1	2.41	2.448	2.41	2.31
0.893	2.409	2.447	2.409	2.252
0.7143	2.235	2.237	1.983	2.298
0.5357	1.909	1.912	1.714	1.97
0.357	1.67	1.655	1.478	1.62
0.1786	1.34	1.331	1.229	1.369
0	1.229	1.236	1.342	1.291

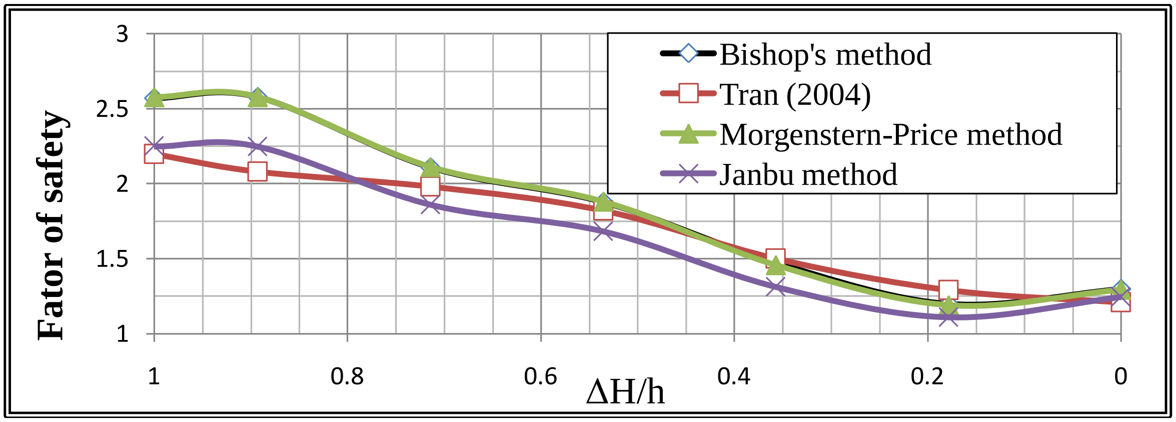

Figure 16: Factor of safety using different methods compared with the values of Tran (2004) for the dam without cut off wall.

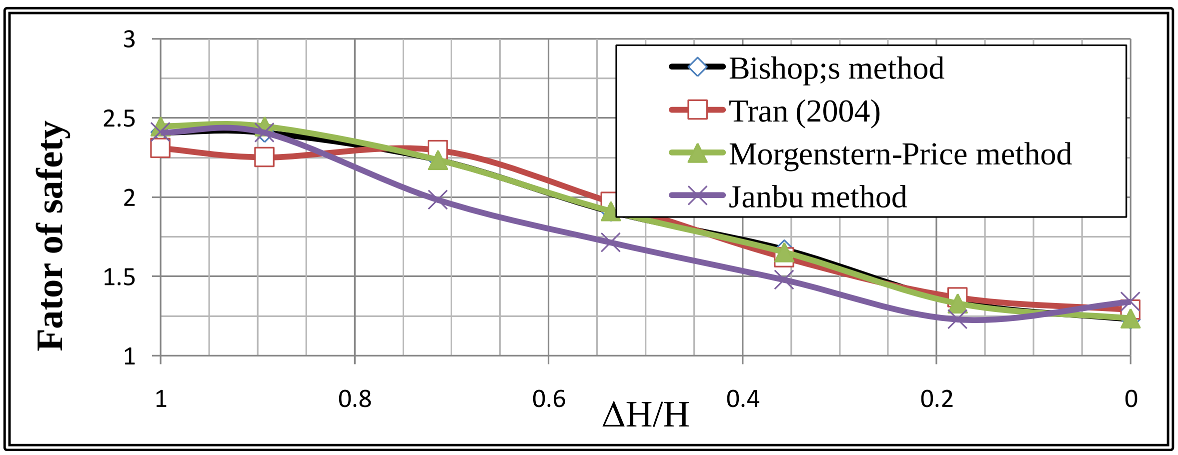

Figure 17: Factor of safety using different methods compared with the values of Tran (2004) for the dam with cut off wall.

The cut-off wall seems not to resist any failure in the upstream shell. The water load in the reservoir plays an important role in resisting the potential failure and in increasing the stability of the upstream slope.

To illustrate the effect of the cut off wall on the quantity of seepage through the body of dam, the case of 7 days of drawdown for the reservoir of the dam has been studied and the results are shown in Table (6) and Figure (18).

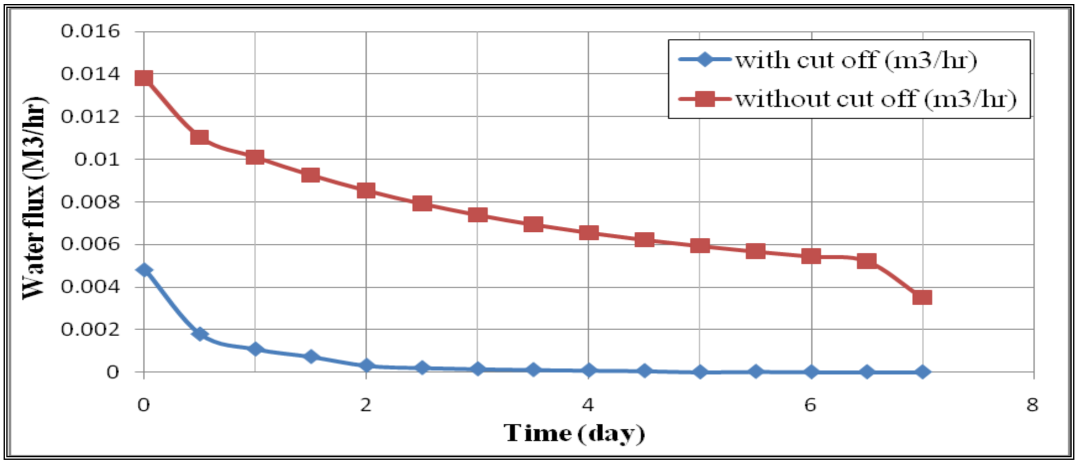

Figure (18) Water flux with time during drawdown of 7 days in the reservoir of Dau Tieng dam (with and without cut-off wall).

From Figure (18), it can be noticed the cut-off has a major effect on the seepage quantity, there is also decrease of flow rate with time.

Table (6) Values of water flux with time during rapid drawdown of 7 days in the reservoir of Dau Tieng dam.

Time (day)	with cut off (m^3/hr)	without cut off (m^3/hr)
0	4.82×10^{-3}	1.38×10^{-2}
0.5	1.79×10^{-3}	1.10×10^{-2}
1	1.08×10^{-3}	1.01×10^{-2}
1.5	7.29 x 10-4	9.26×10^{-3}
2	3.11×10^{-4}	8.53×10^{-3}
2.5	2.06×10^{-4}	7.91×10^{-3}
3	1.50×10^{-4}	7.39×10^{-3}
3.5	1.13×10^{-4}	6.94×10^{-3}
4	8.52×10^{-5}	6.55×10^{-3}
4.5	6.10×10^{-5}	6.22×10^{-3}
5	4.27×10^{-6}	5.93×10^{-3}
5.5	2.71×10^{-5}	5.67×10^{-3}
6	1.17×10^{-5}	5.44×10^{-3}
6.5	8.20×10^{-6}	5.22×10^{-3}
7	6.21×10^{-6}	3.50×10^{-3}

Conclusions:

1. The rate of flow at the dam downstream decreases with time; this decrease is caused by rapid flow of water caused by emptying the reservoir in a short period. Generally, the water flux decreases linearly with time and with water level in the reservoir which indicates that the rate of flow in the whole body of the dam shows almost uniform change.
2. The factor of safety against sliding of the dam slopes decreases slightly within the short period after the start of rapid draw down of water in the reservoir, 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. The saturated weight of the slope produces the shearing stresses while the shearing resistance is decreased considerably because of the development of the pore water pressures which do not dissipate rapidly.

3. When the stability of a zoned earth dam is examined during rapid draw down under different water levels in the reservoir, the insufficient stability may occur in the upstream slope as soon as the water is lower than the drawdown level of 1/3 of the dam height. It can be explained that the water load has disappeared during rapid drawdown and the hydrodynamic pressure creates the tensile-downward forces, resulting in a decrease of the shear resistance of the upstream slope. Besides, there is no supporting pressure to resist against mobilizing of the upstream slope.

References:

- Abadjiev, C. B., (1994). “Safety Assessment and Stability Improvement of the Upstream Slope of Earth Dams”, Proc. of the 18th ICOLD Congress. Durban, South Africa. Vol. 1, Q. 68, R. 20, pp. 261-273.
- Chugh, A. K., (2013). “Stability Assessment of a Circular Earth Dam”, International Journal for Numerical and Analytical Methods in Geomechanics, DOI: 10.1002/nag.2163, Vol. 37, 17, pp. 2833–2859.
- Engemoen, B., (2014) “Embankment Dams”, U.S. Department of Interior Bureau of Reclamation 2014, DS-13(8) - 4.1, Phase 4 (Final) January 2014 Chapter 8: Seepage.
- Fattah, M. Y., Al-Labban, S. N. Y., Salman, F. A., (2014), “Seepage Analysis of a Zoned Earth Dam by Finite Elements”, International Journal of Civil Engineering and Technology (IJCIET), Volume 5, Issue 8, August (2014), pp. 128-139, IAEME: www.iaeme.com/ijciet.asp.
- Gopal, R, Rao, A.S.R., (2005). “Basic and Applied Soil Mechanics”, New Age International (P) Ltd. Publishers. ISBN: 81-224-1223-8, pp. 758.
- Khassaf, S. I., Abdoul- Hameed, M. R., Shams Al-deen, N.N., (2013). “Slope Stability Analysis under Rapid Drawdown Condition and Siesmic Loads of Earth Dam (Case Study: Mandali Dam)”, International Journal of Innovative Research in Science, Engineering and Technology, Vol.2, Issue 12, pp. 7114-7118.
- Noori, B.M.A., Ismaeel, K. S., (2011). “Evaluation of Seepage and Stability of Duhok Dam”, Al-Rafidain Engineering Vol.19, No.1, pp. 42-58.
- Tran, X. T. (2004). “Stability Problems of an Earthfill Dam in Rapid Drawdown Condition”, Ph.D. Dissertation, Slovak University of Technology.
- Zomorodian, S. M. A., Abodollahzadeh, S. M., (2010). ”Effect of Horizontal Drains on Upstream Slope Stability During Rapid Drawdown Condition”, International Journal of Geology, Vol. 4, 4, pp. 85-90.