International Journal of Engineering & Technology, 7 (4.37) (2018) 17-21

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Slope Stability of an Earth Dam during Drawdown Conditions (KHASA-CHAI Dam) as a Case Study

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Abstract

Aiming in this research was to have a clear view about the behavior of Khasa-Chai Dam during the draw down action taking into consideration the newly built of this dam which was filling during the time of this article, the upstream slope was investigated by taking drawdown of the water from the reservoir. This dam is consists of the zoned embankment with a total length of (2.36 km) with an upstream slope (1v:3h) and downstream slope (1v:2h). Slope stability was investigated during the drawdown of the water from the reservoir by considering the water in the reservoir to be at maximum water level and by taking two cases during the rapid and slow drawdown. SLOPE/W which is a sub program from Geo-Slope software was used in association with SEEP/W software to find the factor of safety of the upstream slip surface during the drawdown conditions. It was noticed from the drawdown conditions that the phreatic line falls almost at the same position for both cases. Also for both cases the factor of safety of the upstream slip surface falls above the value of (1.0) and that is mean the upstream slope is in a safe condition when the water drawdown. The exit gradient and the rate of flow at the downstream face decrease with time as the water in the reservoir drawdown which means the factor of safety against boiling increases with time.

Keywords: *Slope Stability analysis; Embankment Dams; Finite Elements; Khasa-Chai Dam; Drawdown conditions.*

1. Introduction

The stability of any slope depends on its soil properties, geometry and the forces that subjected to the slope internally and externally. Pore water pressure and the surface water pressure represents an example for the internal and external forces that act on the slope stability, Fattah, 2015. During the operation of the dam it always requires to change the water level in the reservoir, this action will affect the stability of the upstream face. The reduction of water in the reservoir has two effects:

•A change in the internal pore water pressure.

•A reduction to the stabilizing of external hydrostatic pressure.

This two action depends on the rate of draw down and on the hydraulic conductivity and the rate of compressibility of the slope materials. Two cases were studied here to find the effect of drawdown on the stability of KHASA-CHAI Dam upstream slope: a)The first case is the rapid drawdown by fast draw of the water from the reservoir when the dam is at maximum natural reservoir level. b) The second case is the slow drawdown by slow draw the water from the reservoir during a time sequence when the dam is at maximum natural reservoir

level. The rapid draw down condition usually happened when the slope that is used to retain water experience a sudden lowering of the water in the reservoir and the internal pore water pressures in the slope cannot reduce fast enough Khassaf, et al., 2013. The case studied here by totally pull the water from the reservoir when the water in the reservoir is at normal storage level (spillway top level) which is at elevation (491 m), the water drawn from the reservoir from height (45.17 m) till the tower intake point which is (17.17 m) height from the dam toe. The time required for the reservoir to be drawn down was taken to be (20 days) according to the toe drain discharge and the reservoir storage quantity. The pore water pressure dissipation was measured till (60 days). The slow drawdown case was studied by totally pull the water from the reservoir, the water in the reservoir was taken to be at the level of (45.17 m) and the time required for the reservoir to draw was taken to be at a sequence and to be empty in (40 days). The dissipation of pore water pressure was measured till (60 days). Tran, 2004. Studied the effect of rapid drawdown condition on Dau Tien

2. Materials and Methods

Main dam for two cases before and after rehabilitation using limit equilibrium and finite element methods were checked. The rapid drawdown is simulated by means the water level in the reservoir is lowered quickly into six steps. The maximum water level is lowered from (28 m) to (25 m) at the first time then lowered (5 m) in the following drawdown. Changes the behavior of stress-strain, pore pressure, failure mechanism, and a factor of safety for the slope of the upstream are investigated. Then he concluded that the stability of the upstream slope is gradually decreased but still in the stable during rapid drawdown condition. Berilgen, 2007. Made an investigation of slope stability during drawdown depending on the soil permeability, drawdown rate, and drawdown ratio, considering the nonlinear material and loading conditions. Because during the rapid drawdown there will be a decrease in slop stability which may lead to instability in slopes that do not have enough level of safety against failure. He concluded that the stability of a slope is greatly influenced during drawdown by how fast its pore water falls, the magnitude of displacements developed in the soil mass of slope is considerably affected by its hydraulic conductivity and the rate of drawdown. Zomorodian, and Abodollahzadeh, 2010. Studied the effect of rapid drawdown conditions on the stability of an earth fill dams using finite elements and limit equilibrium methods. They discuss the effect of using horizontal drains on the upstream slope during the rapid drawdown. They found that the outflow in case of presence of drains is much more than the case where there is no drain in upstream slope so they play an important role in expelling the outflow and making the equipotential lines tend to become horizontal. Also, the existence of drains has a great effect on the factor of safety of the upstream slope during drawdown condition.

CASE STUDY: KHASA-CHAI Dam: This multipurpose project is a zoned embankment dam Fig. 1. The right side of it located at Coordinates (E 452041, N 3934306) and the left side of it located at coordinates (E 452441, N 3933254) the dam constructed on the river KHASA-CHAI Dam, the seasonal tributary of Zaghaitun River, which is in turn flowing into Al-Adhaim dam reservoir about (10 km) northeast of Kirkuk near Kuchuk village. The KHASA-CHAI Dam was built in 5 years from 2009-2014 with a height of (58 m) and the total length of (2.36 km). Zoned earth dam with silty clay core dam was constructed for which a lake would be developed and used as a reservoir with active and dead storages of (80 and 5.15 Mm^3) respectively. The dam contains many instruments for monitoring and inspection to be sure that the dam will be in a safe condition during the operation periods, this instruments will be responsible for observing the settlement, deformation, movement, the total earth pressure and the pore water pressure inside the dam body.

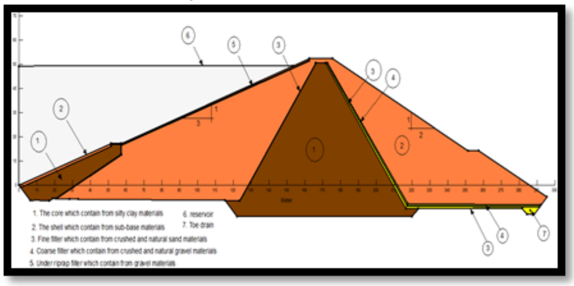

Fig. 1: Cross section of the dam

Computer Program

SLOPE/W software was used in associated with SEEP/W software to draw the effect of drawdown on slope stability, pore water pressures dissipation and velocity vector contours. SLOPE/W software can use pore water pressure from SEEP/W software. The use of finite element computed pore water pressures in SLOPE/W make this software possible to deal with highly irregular saturated and unsaturated conditions in stability analysis. 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. The shortcut steps for dealing with SLOPE/W is shown in Fig. 2.

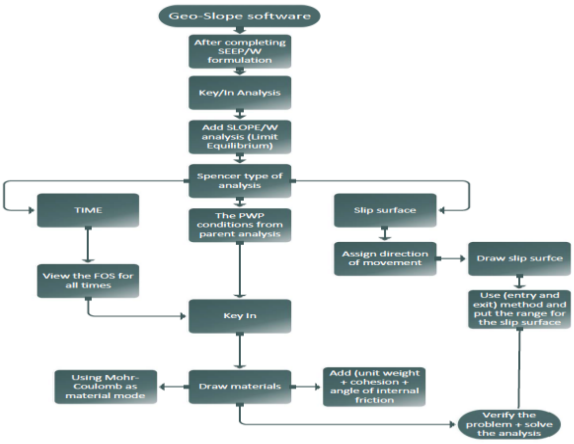

Fig. 2: SLOPE/W flow chart

Rapid Drawdown Conditions 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 “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. The shortcut steps for dealing with rapid drawdown is presents in Fig. 3.

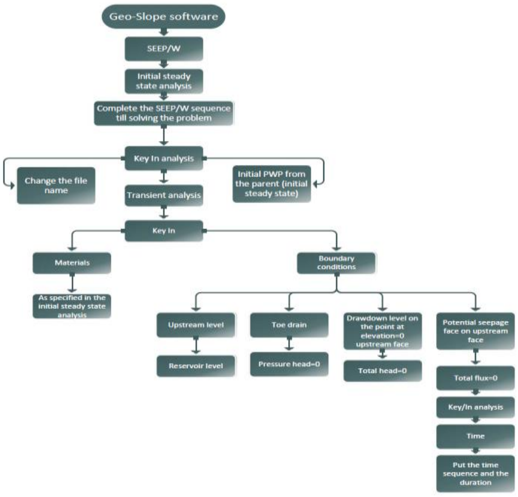

Fig. 3: Rapid drawdown flow chart

Pore water pressure: 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 Abadjiev, 1994. 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 that points that exists above the piezometric line as presents in Fig. 4. 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 Fig. 5.

Potential seepage face: Before the initiation of drawdown, the potential seepage face (failure face) was on the downstream face as the water velocity vectors move from the reservoir towards the downstream face Fig. 6. When the water in the reservoir starts to drawdown, the water velocity vectors starts to exit from the upstream face, and the potential seepage face will be the upstream face Fig. 7.

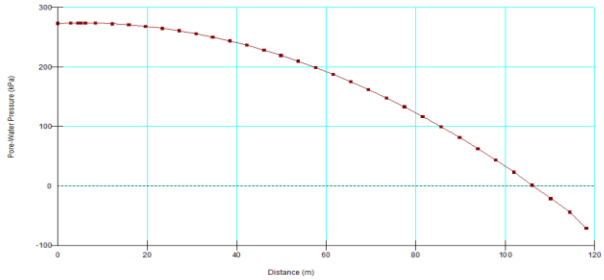

Fig. 4: Pore water pressures across the slip surface before the initiation of rapid drawdown condition

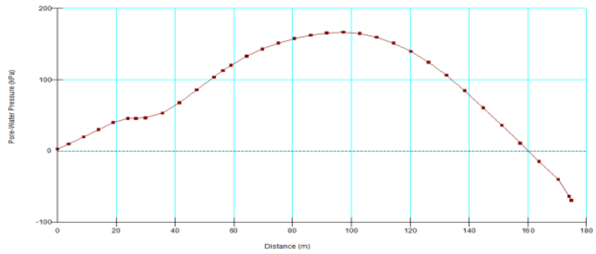

Fig.5: Pore water pressure across the slip surface after (60 days) rapid drawdown

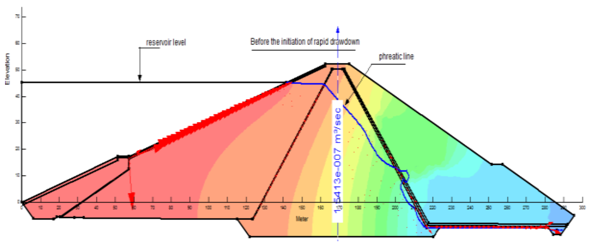

Fig. 6: Phreatic line, velocity vectors and flux suction quantity before the initiation of rapid drawdown

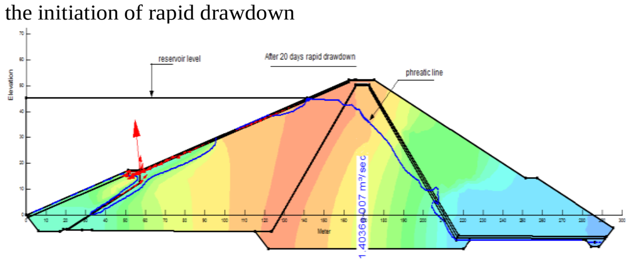

Fig.7: Phreatic line, velocity vectors and flux suction quantity after 20 days rapid drawdown

Factor of safety: The factor of safety is decrease as the initiation of drawdown as the water level quickly lowered from the reservoir then the factor of safety gradually increase as the dissipation of the pore water pressure proceed as presents in Fig. 8. The minimum factor of safety during rapid drawdown falls above the value of (1.0) that is mean the slope will be at the safe condition when the water is drawn from the reservoir in (20 days). Figs. 9-11 present the factor of safety for different time intervals. Table 1 Presents the factor of safety by using different methods for different time intervals.

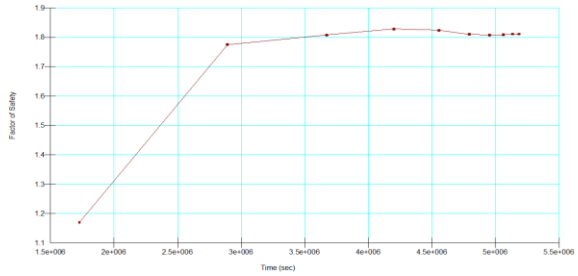

Fig. 8: Relationship between the factor of safety and the time for each upstream slip surface when the reservoir is drawdown rapidly.

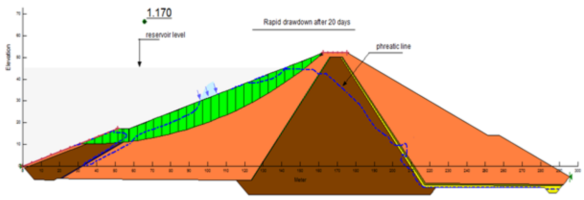

Fig. 9: Slip surface and factor of safety after 20 days when the dam is drawdown rapidly.

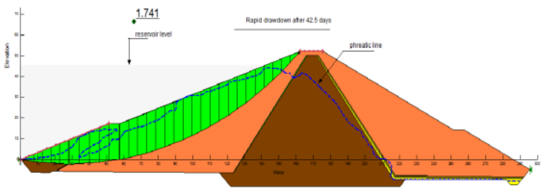

Fig. 10: Slip surface and factor of safety after 42.5 days when the dam is drawdown rapidly.

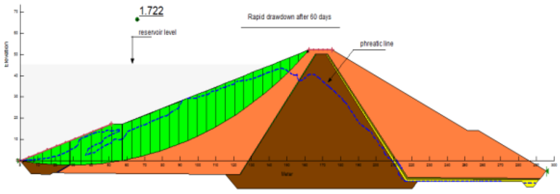

Fig. 11: Slip surface and factor of safety after 60 days when the dam is drawdown rapidly.

Slow Drawdown Conditions: 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. Then a hydraulic boundary function was done to the upstream face as presents in Fig. 12. The shortcut steps for dealing with rapid drawdown is presents in Fig. 13.

Table 1: Factor of safety results by using different methods for KHASA Dam

Times (day)	Methods for calculating the factor of safety			
	Spencer	Janbu	Bishop	Ordinary
20	1.170	1.153	1.169	1.133
33.5	1.739	1.657	1.741	1.616
42.5	1.741	1.661	1.743	1.621
49	1.746	1.667	1.748	1.628
52.7	1.746	1.667	1.748	1.628
55.5	1.734	1.656	1.736	1.617
57	1.728	1.651	1.730	1.612
58.6	1.726	1.650	1.729	1.611
59.4	1.727	1.650	1.729	1.612
60	1.722	1.646	1.724	1.608

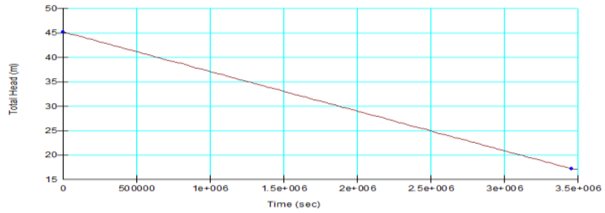

Fig. 12: Relationship between the total head and the time required to empty the reservoir by the slow drawdown

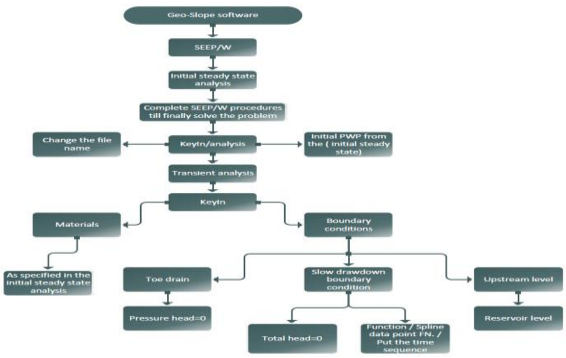

Fig.13: Slow drawdown flow chart Pore water pressure

Like the situation during the rapid drawdown the pore water pressure in the dam's body during rapid drawdown seems not to change very much at all drawdown levels. The low permeability of the dams' soils play an important role in the low dissipation of pore pressure Fig. 14 presents the pore water pressure dissipation after 60 days.

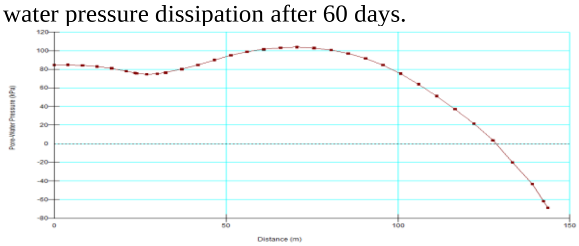

Fig. 14: Pore water pressure across the slip surface after (60 days).

Potential seepage face: Like the situation during the rapid drawdown, before drawdown condition, the potential seepage face is on the downstream face after the initiation of drawdown the seepage velocity vectors move towards the upstream face where it becomes the potential seepage face as for shown in Figs. 15-17. The quantity of flow inside the dam body decrease with the time as the water drawn from the reservoir. Also the exit gradient on the downstream face decrease with time intervals.

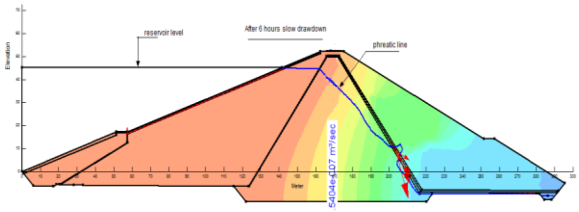

Fig.15: Phreatic line, velocity vectors and flux suction quantity after 6 hours slow drawdown.

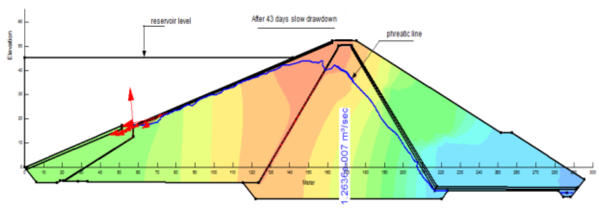

Fig. 16: Phreatic line, velocity vectors and flux suction quantity after 43 days slow drawdown.

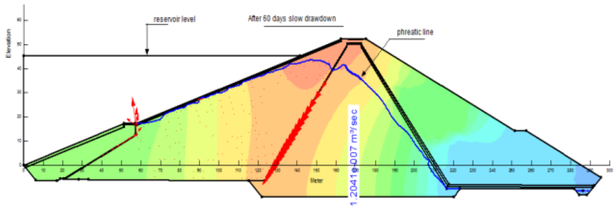

Fig.17: Phreatic line, velocity vectors and flux suction quantity after 60 days slow drawdown.

Factor of safety: The factor of safety gradually decreases 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 as presents in Fig. 18. The minimum factor of safety during slow drawdown falls above the value of (1.0) that's mean the slope will be at the safe condition when the water drawdown from the reservoir in (40 days). Figs. 19-21 present the factor of safety for different time intervals. Table 2 Presents the factor of safety by using different methods for different time intervals.

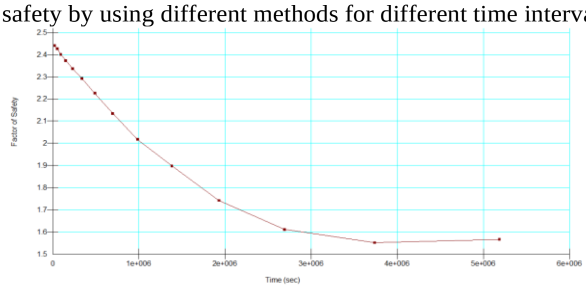

Fig.18: Relationship between the factor of safety and the time for each upstream slip surface when the reservoir is drawdown slowly.

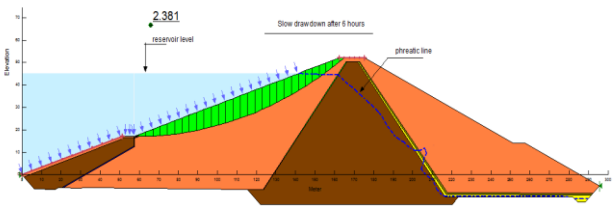

Fig. 19: Slip surface and factor of safety after 6 hours when the dam is drawdown slowly.

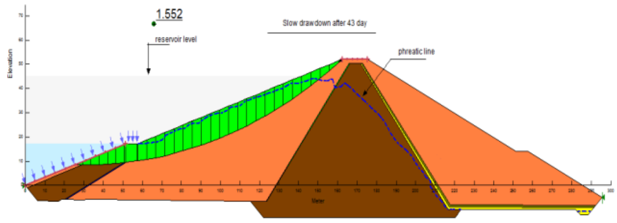

Fig. 20: Slip surface and factor of safety after 43 days when the dam is drawdown slowly.

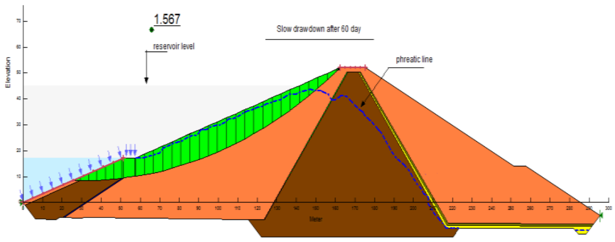

Fig. 21: Slip surface and factor of safety after 60 days when the dam is drawdown slowly.

Table 2: Factor of safety results by using different methods for KHASA Dam

Times (day)	Methods for calculating the factor of safety			
	Spencer	Janbu	Bishop	Ordinary
0.25	2.381	2.319	2.380	2.181
1	2.330	2.267	2.328	2.135

2.64	2.247	2.184	2.245	2.063
4	2.191	2.128	2.189	2.015
5.65	2.112	2.051	2.110	1.948
8	2.004	1.945	2.002	1.856
16	1.757	1.708	1.753	1.652
31	1.546	1.515	1.544	1.495
43	1.552	1.521	1.556	1.493
60	1.567	1.537	1.571	1.510

3. Conclusion

Studying draw down cases for this Dam was concluded the stability of this Dam for future draw down works. During rapid drawdown and slow drawdown the phreatic line falls almost at the same position. The lag of the phreatic line depends on four factors: the permeability coefficient of the dam fills, drawdown rate, active pore volume, and upstream slope gradient. The factor of safety value after (20 days) rapid drawdown equal to (1.170), this value more than (1.0) which means that the upstream slope will be at safe situations during the rapid drawdown Figure 8.

The factor of safety against sliding of the dam slope during rapid drawdown decreases within the start of a 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 slow dissipation of pore water pressure from the dam body by drainage. During the slow drawdown, the minimum factor of safety falls above the value of (1.0) which means the upstream slope will be in a safe condition during the slow drawdown sequences Figure 18. During the slow drawdown the factor of safety gradually decreases 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. Before drawdown of the water from the reservoir the pore water pressures are high at the toe of the upstream slope and decrease with elevation until they are equal to zero for that points that exists above the piezometric line. After drawdown of the water from the reservoir, 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. During rapid and slow drawdown the rate of flow through the dam body decrease with time, the decreasing in the flow depend on the time that required to drawdown the reservoir. Generally, during the rapid drawdown, the water flux decrease fast relating to slow drawdown as the water in the reservoir fast drawdown. The exit gradient at the downstream face decrease during the slow and rapid drawdown, the decrease period depends on the time required for the reservoir to be empty, which means the factor of safety against boiling increases. Generally the exit gradient decreases fast during rapid drawdown than slow drawdown.

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