Journal of Structural Engineering and Geotechnics,

7 (1), 31- 45 , Winter 2017

Studying the Effect of Horizontal Drains on Stability of Heterogeneous and Homogeneous Earth Dams during Rapid Drawdown Condition

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Received 12 August 2016, Accepted 25 October 2016

Abstract

One of the main concerns to design earth dam is the stability of the upstream slope of the earth dam in phase of rapid drawdown. Confined pore water pressure reduces the effective stress in this mode, so possibility of the instability and slippage will be increased. The main goal of this research is to investigate changes in the pore water pressure by using horizontal drains in upstream slope of the earth dams and the improvement in case of the factor of safety. In this study, firstly, the homogeneous and heterogeneous modes of the earth dam are considered and then rapid drawdown mode are modeled in two upstream slope modes without the horizontal drain and with the upstream slope including up to seven horizontal drains. These two modes are modeled by using GEOSTUDIO software. According to the obtained results, improvement by horizontal drains leads to increase in dissipation of pore water pressure and also increase the stability of the safety factor of the upstream slope up to 24% for homogeneous dams and 17% for heterogeneous dams. Practical equations were also presented to show the relation between the numbers of horizontal drains, the factor of safety and the pore water pressure. In order to study the influence of the horizontal drains on the upstream slope of the earth dams during the rapid drawdown condition, Molasadra earth dam geometry is used both in the modes of homogenous and heterogeneous dam. Molasadra dam and power station is located in about 13 kilometers of southwest of Sadeh county, around of Eghlid town in the north of Fars province in Iran.

Keywords: Homogeneous Earth Dam, Heterogeneous Earth Dam, Horizontal Drains, Rapid Drawdown, Slope Stability Analysis.

1. Introduction

Not only the dam itself is a relatively expensive project, but it also contains various economic aspects such as power production, flood control, irrigation and so on. Dam failure is a disaster, because it does not only cause economic damages, but also it may cause casualties and destruction of nature. Regarding the importance of dams, engineers have done a lot of studies about this field for several decades. Stability is the most important discussion in studying earth dams. One of the dangerous factors for earth dams is drop in water level of reservoir phenomena which may lead to serious damages. Some of observed samples which had related to destruction of earth dam that is always happening due to drop reservoir water level are included as a Hilarious dam in south of California and Walter Bolden Dam in Alabama [1]. After filling the dam reservoir with water and during its exploitation when water penetrates into the body of dam, any rapid or slow drawdown of water level may lead to slippage in upstream slope. If for any reason, for example earthquake, appearance of big and sudden cracks, disruption of arch phenomena, flood and withdrawal of water for various uses etc., water level of an earth dam is reduced quickly but water level in the core does not

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follow water level of reservoir, this phenomena is called rapid drawdown sudden fall. As a result of depletion and falling water level in reservoir, hydrostatic pressure, which is exist in external surface of upstream slope when reservoir is full, is dissipated while its balanced hydrostatic pressure is still available in internal body of dam. The remaining pore water pressure is one of the most important factors which causes danger of slide in upstream slope [2].There are generally two groups of researchers who have worked on the stability of embankment dams in rapid drawdown condition. Lowe and Karafiath (1980) and Baker et al. (1993) belong to the first group, who assumed the undrained shear strength behavior in the embankment dam [3, 4]. On the other hand, Svano and Nordal (1987), Wright and Duncan (1987), Lane and Griffiths (2000), Duncan and Wright (2005), Malekpour et al. (2012) and Berilgen (2007) are in the second group, who investigated the effect of rapid drawdown on the stability of an embankment dam[1,5-9]. They applied drained shear strength parameters. Lane and Griffiths (2000) have studied rapid drawdown phenomena by using finite element method [7]. In this research, they investigated modes of rapid drawdown in full reservoir, rapid drawdown in semi-full reservoir and also slow draw down by using software they had coded based on finite elements method. These researchers compared their results with Morgenstern (1963) results and diagram by using finite element sanalysis and observed that obtained results of these two methods were compatible in both rapid drawdown and the slow drawdown of reservoir [10]. Berilgen (2007) analyze rapid drawdown phenomena and its effect on the stability of slope by finite element method [1]. He considered effective factors in this analysis such as soil permeability coefficient, the ratio of reservoir drawdown, the speed of reservoir drawdown, slope and other characteristics of the slope material. He mentioned that in this analysis, the soil is considered as a two-phase environment with elastoplastic behavior. Bergen has also mentioned the effects of external forces such as volumetric forces and the effects of seepage turbulent water flow. Based on results of this analysis, it has determined that permeability coefficient has more effect on the behavior of soil slope in comparison with the rate of drawdown. Generally, one can say that by less permeability rate and more rapid drawdown rate, the observed behavior trends toward complete rapid drawdown. Pinyol et al. (2008) have recorded pore water pressure in rapid drawdown condition in different parts of one earth dam. Some concepts were discussed in a qualitative way and investigated in more details in combined examples with a different hypothesis. [11]

Different methods are suggested in order to control pore water pressure that is resulted from reservoir drawdown that each of these methods is used according to available materials and transportation or building costs. The preparation of horizontal drains in upstream slope of earth dams is one of the most effective methods [12]. Tasoji (2010) studied the influence of horizontal drains on the improvement of stability of upstream slope of Heterogeneous earth dam during the rapid drawdown. Also, different parameters are considered for analysis such as permeability, number, length and width of drains, the height of placing drains and vertical distance between them. The results have shown that influence of drain's length on outlet discharge of upstream slope in steady state and rapid drawdown, output gradient of core and dam stability was more than the width of drains. By considering the less vertical distance between drains, the stability of upstream slope will have improved and a factor of safety values has increased. But where it isn't possible to place a drain in short distances, it is better to use drains with more length and less vertical distance [13]. Komakpanah and Arabnajafi (2010) studied the influence of horizontal drain in the stability of heterogeneous earth dam and analyzing shear stress during rapid drawdown with ABAQUS software. The results showed that range of shear stress in the dam core with a horizontal drain in upstream increased up to 300kpa. The maximum amount of this stresses in the dam core without a drain in upstream is 250kpa. The maximum amount of shear stress in dam observed in adjacent areas of the upstream oblique drain and in dam without an upstream drain in adjacent areas of downstream oblique drains [14]. Moharrami et al (2014) studied the performance of the horizontal drains in upstream slope of earth dams on the dam stability during rapid drawdown conditions. The results demonstrated that the stability of the upstream slope during rapid drawdown conditions increases by increasing in the number of drains [15]. Salmasi and Mansuri (2013) studied the efficiency of the use of horizontal drains in reducing the adverse effects of seepage at an assumed homogeneous earth dam. Results showed that the existing of the filter nearer the upstream side results in higher seepage losses and an increment in the required filter length [16]. Fan et al. (2016) show that the Xiaochatou

Landslide, which is a complex landslide containing a shallow slide mass, middle slide mass, and deep slide mass, is extremely sensitive to the rapid drawdown of the water level, by using centrifugal model test. The centrifuge tests show that the shallow slide mass will fail and that the middle slide mass will suffer a large displacement after a rapid decrease in the reservoir water level. [17]. Friedland et al. compare the Duncan et al. (1990) three-stage methodology [18] for analyzing rapid drawdown scenarios to a combined transient seepage and slope stability analysis. Traditional limit equilibrium methods will be utilized in the slope stability analysis and the accommodation of saturated and unsaturated pore-water pressures has been considered [19]. They have been illustrated scenarios under which the Duncan methodology produces similar results to the results of a more rigorous analysis. Fattah et al. (2015) simulated the rapid draw condition on the Dau Tieng reservoir in Tay Ninh province in Southern Vietnam as a case study, by means of finite element software. They found that 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 [20]. Zomorodian and Abdollahzadeh (2012) discussed the effect of horizontal drains on upstream slope of earth fill dams during rapid drawdown using finite elements and limit equilibrium methods. They showed that in the case of rapid drawdown, which represents the most critical condition, it is assumed that the pore water pressure within the embankment continues to reflect the original water level. The lag of the phreatic line depends on factors such as permeability of soils, drawdown rate, drawdown ratio and slope gradient [21]. Fattah et al. studied flow and stability of Al-Wand earth dam during the rapid drawdown of water in the reservoir [22]. Al-Wand dam in Iraq has been chosen for analysis for the original period of emptying the dam reservoir and emergency periods. They found that when the reservoir is rapidly emptied and water is drawn down, pore water pressures in the dam body are decreased in two ways: the first way is through slow dissipation of pore water pressure due to drainage, and there is an immediate elastic effect due to the removal of the total or partial water head. During rapid draw down, the pore water pressure at all points within the dam body decreases linearly which indicates that steady state flow takes place. Kirra et al. investigated the seepage and slope stability analysis of Mandali earth dam in Iraq [23]. The results of their analysis confirm the safety of Manali dam against combined seepage and slope stability under all cases of operation. The case of rapid drawdown is the most critical operating case; compared to other cases of operation. Zhou et al. studied the reservoir landslides and its hazard effects for the hydropower station [24]. They found that, for the hazard prevention of reservoir landslides, firstly, the traffic route should be changed and moved to higher elevations, and should be stay away from the reservoir bank; secondly, resident live near the reservoir bank can be relocated in advance, preferably not in the reservoir area; thirdly, to develop a reasonable operation scheme for the water level of reservoir, the large and frequent fluctuation of water level should be avoided, especially for the rapid drawdown of water level. Tung et al. analyzed the stability of the earth embankments subjected to natural cyclic processes [25]. The study analyzed the stability of an 8 m height embankment in the Gosaba region of Sundarban considering a 2m wide earth filled berm at 6m from the bottom of varying clay core thickness under the transient groundwater flow. Sun et al. showed the effects of an increase in reservoir drawdown rate on bank slope stability in a case study at the Three Gorges Reservoir of China [26]. They found that, (a) safety factor decreases about 14% as the reservoir level drops with rate of 0.6 m/d and about 16% with rate of 1.2 m/d at the fall of reservoir water level 30.0 m; (b) an increase in the drawdown rate of the Three Gorges Reservoir from 0.6 m/d to 1.2 m/d is unfavorable for the stability of the slope that extends into the water, but the extent of the decrease in safety factors resulting from this increase in rate is not significant. Pan and Dias performed three-dimensional stability of a slope subjected to seepage [27]. The influence of soil properties, 3D slope geometry, and anisotropic permeability is discussed in this work. Numerical results show that the 3D effect is important for B/H ratios lower than 10.0, beyond which the two-dimensional (2D) plane-strain analysis can be used for a 3D slope, and that a larger horizontal permeability with respect to the vertical one is a favorable factor for the slope stability. The main goal of this research is to study the influence of horizontal drains on improving stability of upstream slope in homogenous and heterogeneous earth dams. Although these drains cause improvement in stability of earth slope by dissipating extra pore water pressure, but on the other hand leads to increase in seepage, so it should be designed and use carefully.

2. Materialsand Methods

Granular soils and fine-grained soils show different behaviors according to pore water pressure in triaxial phase, so it is necessary to have a correct understanding of their behavior in different conditions in order to make proper modeling. Three modes are considered for an earth dam: 1- at the end of construction and before impoundment, 2- in impoundment condition and steady state, 3- the rapid drawdown of the reservoir or water level condition. In the mode of the end of construction, until the dam does not have impoundment and there is no water and therefore pore water pressure does not appear in the soil, the soil is unconsolidated undrained. In the second mode, if the dam impoundment and has the steady seepage condition, so the soil will drain and consolidated by pore water pressure dissipation so the soil is in CD (consolidated drained) mode. In the third mode, if the condition of rapid drawdown happens, due to the existence of water in the soil, the consolidation happens but rapid drawdown of pore water pressure does not dissipate and the soil does not drainage. So the CU condition (consolidated un drained) is rolled to this mode. As mentioned earlier, after filling the dam reservoir, water seeped into the dam body and any slow or rapid drawdown in reservoir height will have leads to seepage in upstream slope. In this mode, a rapid drawdown in reservoir water height is faster than that pore water pressure in body or base of dam can dissipate it. The phreatic line in dam body is placed above reservoir water level and drainage cannot dissipate pore water pressure with the same speed that water pressure in the reservoir is decreased.

Some factors that influence on slide and slip of slope act as degenerative processes in a slow and impalpable way (these factors result from the geological condition of the area and some of them cause fast and sudden rupture). Generally, increasing shear stress more than shear strength in failure surface can be considered as the main reason of failure in slope surface. Therefore, calculation of slope stability in failure surface is in fact known as a comparison between driving forces and resistance forces. Common methods for review slopes that can divide into two following groups: 1- limits equilibrium method 2- finite element methods. Limit equilibrium methods themselves divided into several groups. In all of these methods, the desired slip surface divided into two parts and the forces acting on each part are studied. Since a two-dimensional continues domain is statically indeterminate, it needs an extra assumption to compare shearing strength and driving force and calculate the factor of safety on slip surface. In fact, the difference between different limit equilibrium methods is related to the hypothesis that was considered for determining the desired system. Considering a cylindrical slip surface is a widely uses assumption for studying the stability of slopes because it is easy to calculate and practically near to experimental observations. Between limit equilibrium methods, it could be mentioned to Fellenius or Sweden method, Taylor method, Bishop Method, Spenser method, Morgenstern method and so on [28]. Generally, in limit equilibrium method, which is only based on the force balance, a factor of safety is very sensitive to the selected direction of inter slice forces. Finite Element method in studying slopes factor of safety could be divided into two parts. A- The method of assuming a circular slip surface and or desired one. B- The method of reducing soil strength parameters.

The software is needed for modeling must have a capability of two-dimensional analyses of steady and unsteady state flows in porous media and can perform two-dimensional stability analyses of soil slopes. Since GEOSTUDIO software is capable of doing above-mentioned numerical analysis in a comprehensive and precise way, so it is used here.

This software is one of GEOSTUDIO programs which have an ability to analyze two-dimensional slopes stability. This software is used limit equilibrium method in order to do stability analysis. In this program, soil behavior is modeled by Mohr-Coulomb relations. This software also has the ability of modeling structural elements such as piles, geotextile, and anchors. After doing these stability analyses and obtaining a factor of safety, at least it can show slip surface and other related unknowns.

SLOPE/W solves two factors of safety equations; one equation satisfies force equilibrium and the other moment equilibrium. All the commonly used methods of slices can be visualized as special cases of the General Limit Equilibrium (GLE) solution. The theory of the finite element Stress method is presented as an alternative to the limit equilibrium stability analysis. This method computes the stability factor of a slope based on the stress state in the soil obtained from a finite element stress analysis. Finally, the theory of probabilistic slope stability using the Monte Carlo method is also presented.

The GLE formulation is based on two factors of safety equations and allows for a range of inter-slice shear-normal force assumptions. One equation gives the factor of safety with respect to moment equilibrium (1), while the other equation gives the factor of safety with respect to horizontal force equilibrium (2). The idea of using two factors of safety equations follows from the work of Spencer (1967) [29].

The GLE factor of safety equation (3) with respect to moment equilibrium is:

(1)

$$F_m = \frac{\sum\left(C' \cdot \beta \cdot R + \left(N - u \cdot \beta\right) R \cdot \tan\phi'\right)}{\sum W_X - \sum N \cdot f \pm \sum D \cdot d}$$

The factor of safety equation (4) with respect to horizontal force equilibrium is:

(2)

$$F_f = \frac{\sum\left(C' \cdot \beta \cdot cos\,\alpha + \left(N - u \cdot \beta\right) tan\phi' cos\,\alpha\right)}{\sum N \cdot sin\,\alpha - \sum D \cdot cos\,\omega}$$

The terms in the equations are:
C' = effective cohesion
Ø' = effective friction angle
U = pore-water pressure
N = slice base normal force
W = slice weight
D = concentrated node load
R, x, f, d = geometric parameters
α = inclination of slice base
One of the key variables in both equations is N, the normal at the base of each slice. This equation is obtained by the summation of vertical forces. Vertical force equilibrium is consequently satisfied. In equation (3) form, the base normal is defined as:

(3)

$$N = \frac{W + \left(X_R - X_L\right) - \dfrac{C' \cdot \beta \cdot sin\alpha + u \cdot \beta \cdot sin\alpha \cdot tan\phi'}{F}}{cos\alpha + \dfrac{sin\alpha \cdot tan\phi'}{F}}$$

F is equal to F_m, when N is substituted into the moment factor of the safety equation and F is equal to F_1 when N is substituted into the force factor of safety equation. An important node to note here is that the slice base normal is dependent on the inter-slice shear forces and on either side of a slice. The slice base normal force is consequently different for the various methods, depending on how each method deals with the inter-slice shear forces [28].
The inter slice shear forces in the GLE method are handled with an equation proposed by Morgenstern and Price (1965) [30]. The equation is:

(4)

$$X = E \cdot \lambda \cdot f(x)$$

Where, f(x), is a function, λ is the percentage (in decimal form) of the function used, E is the inter-slice normal force and X is the inter-slice shear force.

3. Dam Geometry and Numerical Modeling

In order to study the influence of horizontal drains on upstream slope of the earth dams during rapid drawdown condition, Molasadra earth dam geometry has been used both in the mode of the homogenous and heterogeneous dam. Molasadra dam and power station are located in about 60 kilometers in upstream of Doroodzan dam and about 13 kilometers of southwest of Sadeh county, around of Eghlid town in the north of Fars province. This earth structure locates 125 km away from northwest of Shiraz. Power station of this dam is located about 4 km away from Molasadra dam. Table1 show technical specifications of Molasadra dam and figure 1 shows a typical section of the dam and zonation. Also, parameters related to different materials of the dam have been mentioned in Table 2.
After drawing dam geometry in a homogenous and heterogeneous state, at first the dam was studied without considering horizontal drain in the condition of steady state and its stability and factor of safety have been investigated. In the steady state model, a section of earth dam analyzed when the water level is at its maximum, normal and minimum situations. Then, a safety factor of dam stability was studied under the condition of rapid drawdown without considering horizontal drain. At first water level has been drawn with the hypothesis of flood condition in maximum allowed water depth (M.W.l=144) and then during the rapid drawdown, it has been transmitted from this level to normal level and other levels. Then, by assuming drawdown rate of 1.92 meters per day, the water level was dropped to next levels.

Table1. Specification of Molasadra dam

Dam Specification	Title
Heterogeneous Dam with impermeable core	Type
72 m	Height
630 m	Crest Length
440 million/m^3	Reservoir volume
Free without gate	Type of Spillway
3400 m^3/s	Probable Maximum Flood (PMF)

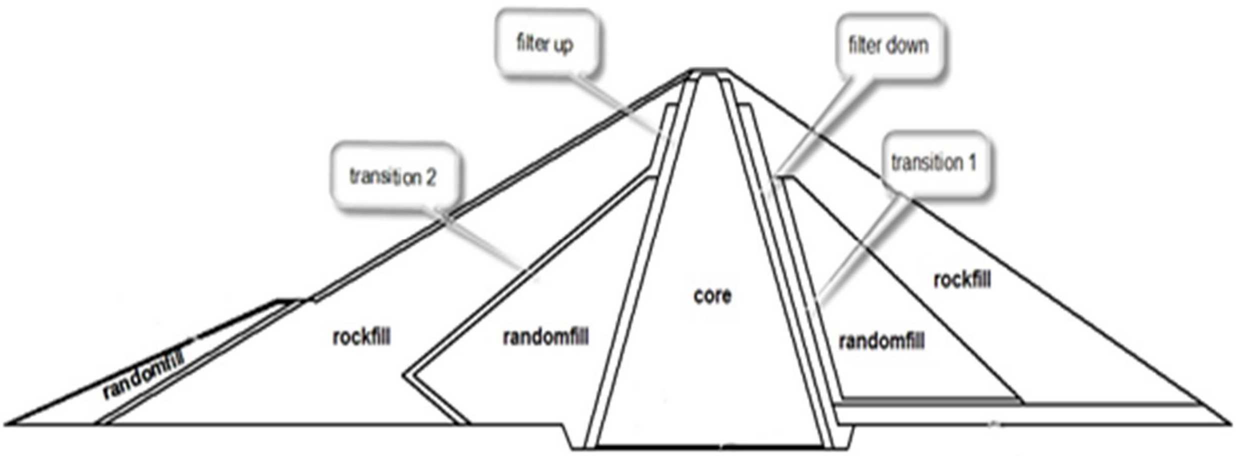

Figure 1. Type Section of the dam and how zoning

Table 2. Parameters of Dam Materials

Parameter	Internal Angle (Degree)	Saturation unit Weight (kN/m^3)	moist unit weight(kN/m^3)	Cohesion (kPa)
Core	10	21	20.3	100
Rock fill shell	46	21	19	50
Random Fill shell	24	22	21	60
Filter	35	20	18.5	50
Transition Zone 1	37	21	19	50
Transition Zone 2	38	21	21	50
Foundation	46	26	24	2100
Drain	32	21	20	5

In the next step in upstream of the dam, horizontal drains considered by 2 meters width, 5 meters of drains distance and drain length of 0.5L. L has been defined as a percentage of the horizontal distance between slope surface and the core of the dam. It is necessary to mention that horizontal drains have been placed in 7 modes in homogenous and heterogeneous dams. In the first mode one drain has been considered, in the second mode two drains have been utilized and so on, finally in the seventh mode 7 drains have been embedded. At the end, the influence of placing drains on improving the stability of upstream slope studied by Spencer and Morgenstern-Price method. Cross section of heterogeneous dam considering seven horizontal drains has been shown in figure 2.

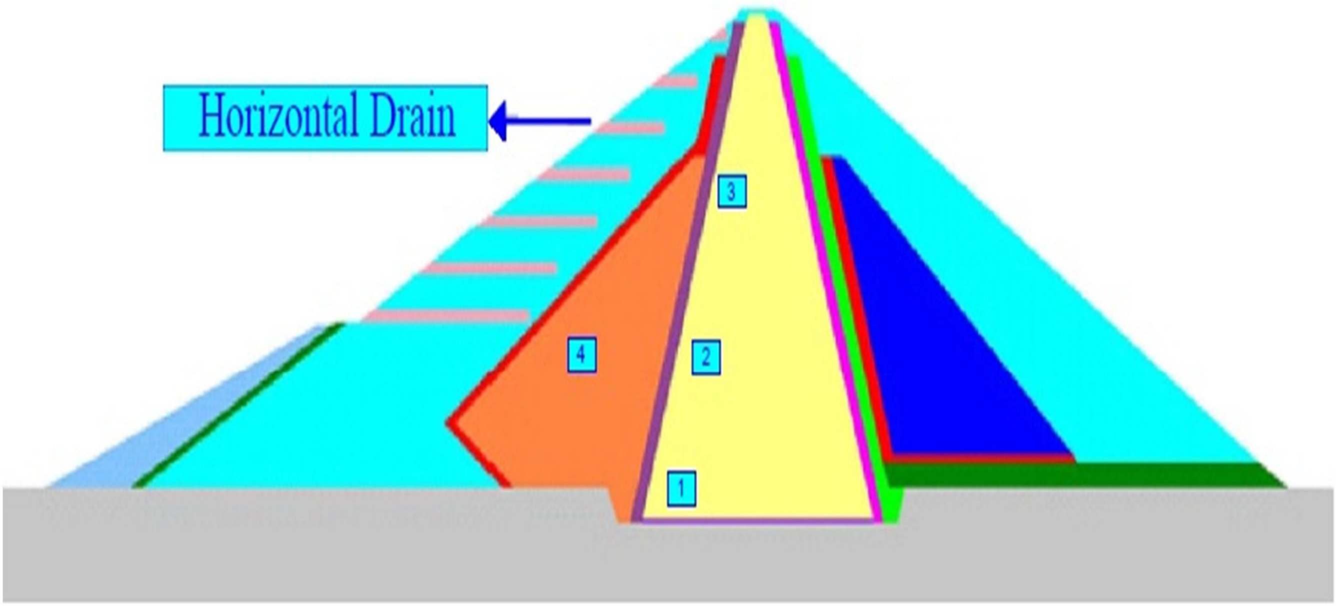

Figure 2. Cross section of heterogeneous dam by considering seven horizontal drains[13].

4.Results and Discussion

4.1. Slope stability investigation in steady state mode

Tables 3 and 4 respectively show amounts of a factor of safety of upstream slope of homogenous and heterogeneous dams without considering rapid drawdown and horizontal drain and by mentioning steady state condition in the maximum (M.W.L), normal (N.W.L) and minimum (M.W.L) surfaces of the water level. Also, figures 3 and 4 indicate slip surfaces and amounts of a factor of safety in the condition of normal water level for the homogenous and heterogeneous dam. According to tables 3 and 4, a factor of safety has determined values in the condition of steady state in two studied modes.

Table 3. Values of factor of safety stability of upstream slope for heterogeneous dam in steady state condition

Water Level	Max. W. L	Norm. W. L	Min. W. L
Factor of Safety	2.665	2.518	2.049

Table 4. Values of factor of safety of upstream slope for homogeneous dam in steady state condition

Water Level	Max. W. L	N.W.L	Min. W. L
Factor of Safety	3.988	3.848	3.047

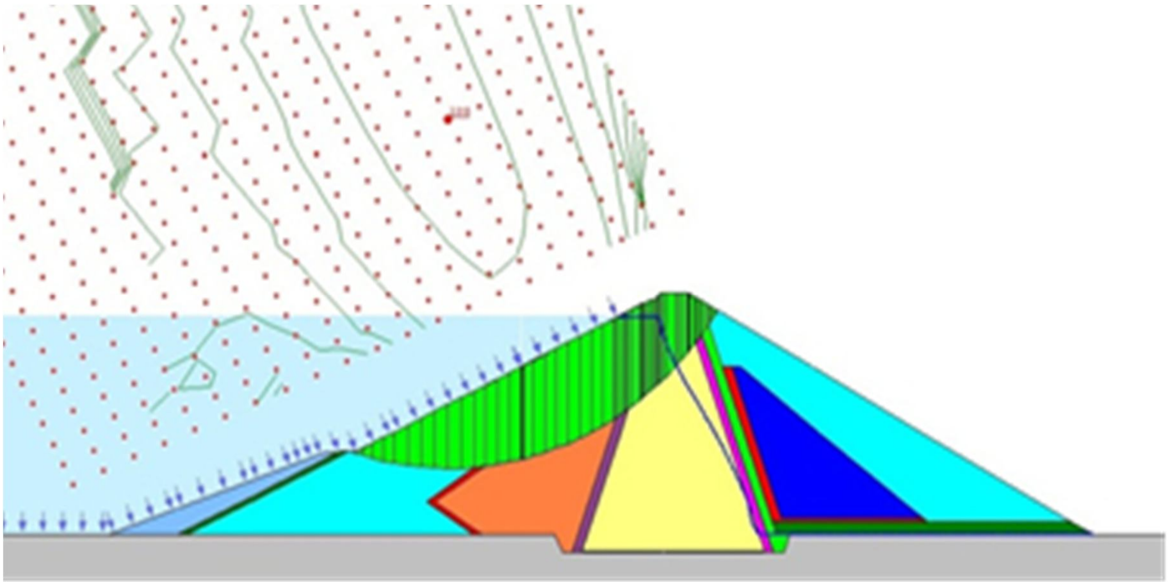

Figure 3. Slip surface and factor of safety in N.W.L condition of heterogeneous dam

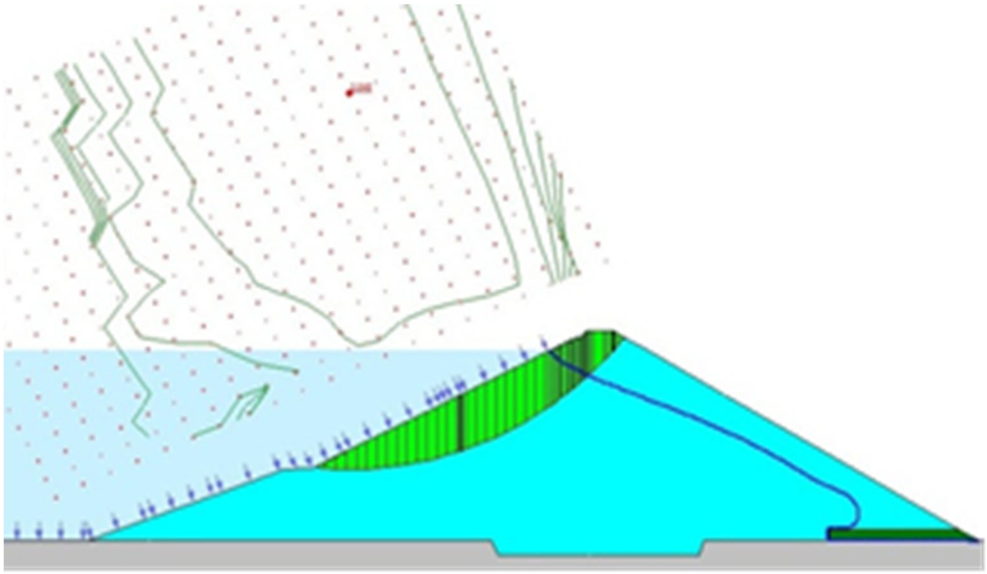

Figure 4. Slip surface and factor of safety in N.W.L condition of homogenous dam

4. 2. Studying the slope stability in rapid drawdown condition without considering horizontal drain

Tables 5 and 6 show the values of stability factor of safety for an upstream slope of a homogenous and heterogeneous dam with considering rapid drawdown and without a horizontal drain. The drawdown rate in this condition is 1.92 m. It should be noted that factor of safety in these modes has been calculated by using the Morgenstern-Price method and Spenser method. Also, figure 5 shows a sample of the heterogeneous dam during rapid drawdown condition without considering horizontal drain. According to figure 5, in rapid drawdown condition, the phreatic line was placed upper than the water level of the reservoir and so drainage cannot dissipate pore water pressure, in coordination with decreasing rate of water level in the reservoir especially in the core. It is necessary to mention that homogenous dam consists of materials with permeability, 10-4 cm/s, in comparison with the heterogeneous dam, which has a core with a permeability of 10-7 cm/s. So, the homogenous dam has more drainage capability and it can dissipate created pore water pressure which produced from rapid drawdown phenomena and as a result has a higher factor of safety. Also, while values of Spenser method analysis is very close to Morgenstern-Price method results and static equilibrium equations are satisfied completely in Spenser method, so in rest parts of the study, Spenser method has been utilized.

Table5. Values of Stability factor of safety for upstream slope of heterogeneous dam during rapid drawdown condition without considering drain

	Morgenstern - price	Spencer
Factor of Safety without Considering Drain	1.316	1.3

Table6. Values of stability factor of safety for upstream slope of homogenous dam during rapid drawdown condition without considering drain

	Morgenstern - price	Spencer
Factor of Safety without Considering Drain	1.802	1.805

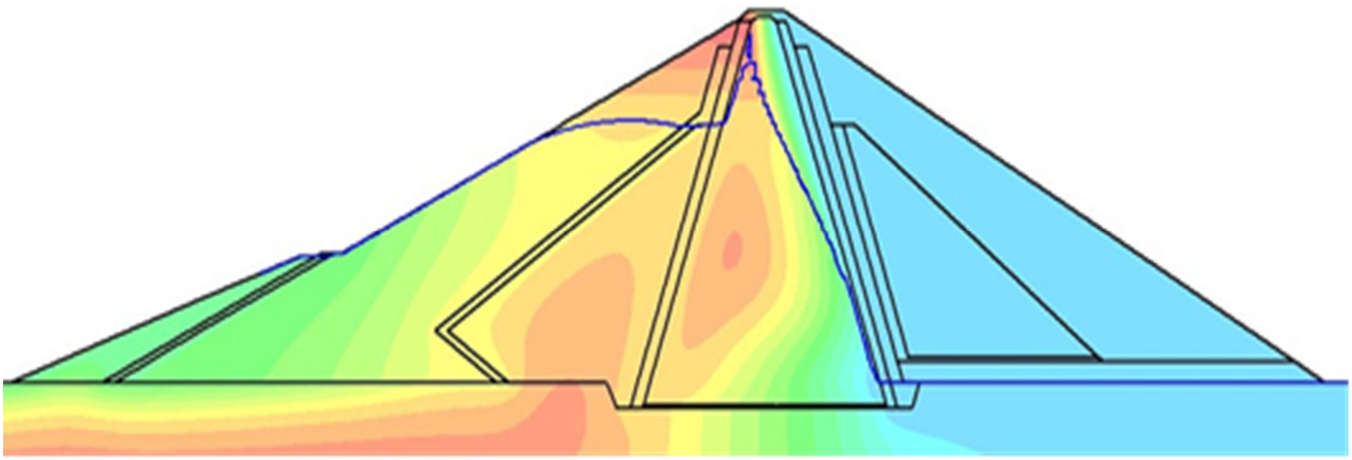

Figure 5. A sample of analyzing heterogeneous dam in condition of rapid drawdown without considering horizontal drain

4. 3. Studying slope stability during rapid drawdown condition with considering horizontal drains

Figures 6 and 7 show the values of stability factor of safety ratio for the upstream slope of homogenous and heterogeneous dams by considering rapid drawdown condition in seven different modes of placing horizontal drains. In these diagrams, SF* is a factor of safety of without drain mode and SF is a factor of safety for other seven studied modes.

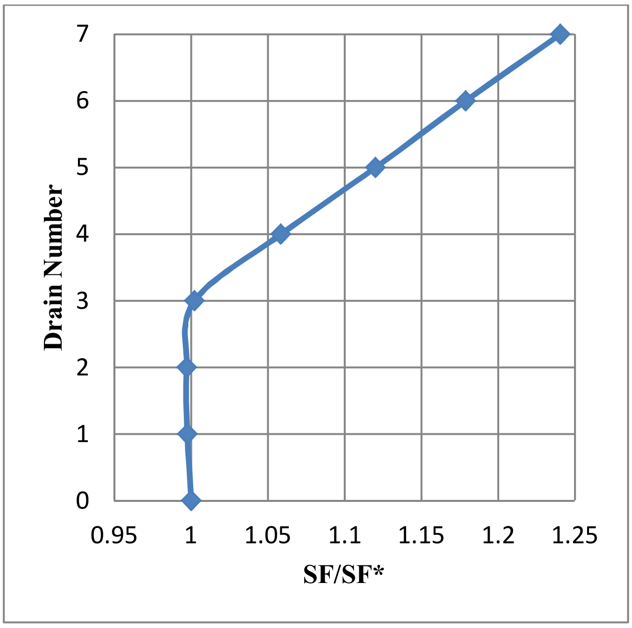

Figure 6. Variation of factor of safety in homogenous dam versus numbers of horizontal drains

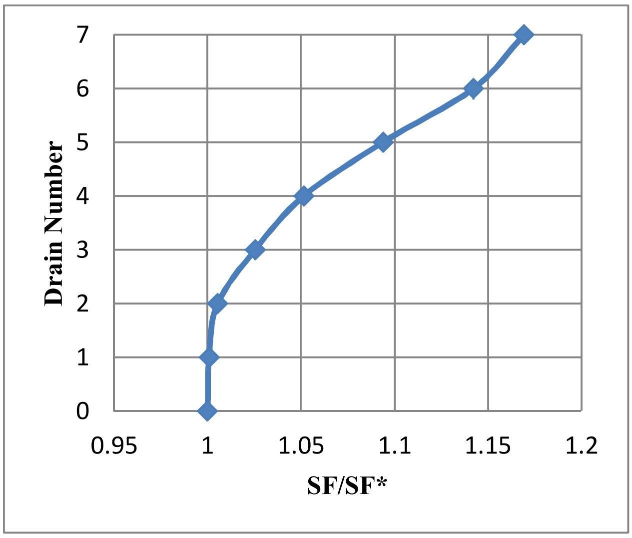

Figure 7. Variation of factor of safety for heterogeneous dam in modes of various numbers of horizontal drains

Figure 7 shows Variation of factor of safety for heterogeneous dam in modes of various numbers of horizontal drains.

In homogenous dam:

$$N_d = -46.364\left(\frac{SF}{SF^*}\right)^2 + 123.99\left(\frac{SF}{SF^*}\right) - 75.572 \quad (5)$$

In heterogeneous dam:

(6)

$$N_d = -113.45(\frac{SF}{SF^*})^2 + 277.09(\frac{SF}{SF^*}) - 162.16$$

In which, Nd is number of horizontal drains.

As shown in the figures 6 and 7, a factor of safety increases gradually by placing more drains. Low values of a factor of safety in modes of a dam with up to 3 horizontal drains indicate un drained behavior in the area of the upstream slope. Also, in modes of the dam with 4 and 5 horizontal drains, the slope of curve increases which is showed the gradual occurrence of drained behavior in upstream slope. It means that by decreasing water level in the reservoir, the drainage ability to dissipate extra pore water pressure increases. And as a result, it may cause to increase the factor of safety. In the mode of the dam with 7 drains, by increasing drawdown of water level in the reservoir, all drains have been balanced pore water pressure well and then a factor of safety is increased. As observed in Figures 6 and 7, the rate of the increase of the curve slope in the modes of 6 and 7 drains were more than other conditions due to making more desirable drainage condition and avoid more dissipation of pore water pressure.

4. 4. Study of pore water pressure under condition of rapid drawdown - in different modes

One of the effects of having the horizontal drain in the upstream slope of the dam is the fact that it tends equipotential and flow lines to horizontal mode and nearly vertical mode respectively. It causes to drain rock fill, therefore the drains may increase dissipated pore water pressure and shear strength. According to these facts stability of the upstream slope is satisfied. Figures 8 and 9 show these changes. In following, the influence of drains in the dissipation of pore water pressure in four selected areas which have placed in different levels in upstream of dam core, has been shown in figures 10 and 11 respectively for homogeneous and heterogeneous dams. As seen a change of pore water pressure value for node3 that is placed in level 2097 in upstream dam core level and node 4 that is placed in level 2075 out of the core in rock fill shell of the dam is more than the other two nodes. Node 3 was placed at a higher level in comparison with two other nodes and according to figure 4 is closer to upstream horizontal drains. Node 4 in the heterogeneous dam was placed in rock fill shell area with more permeability coefficient than the core and also located close to the upstream horizontal drain. So, in the heterogeneous dam, the value of dissipated pore water pressure in node 4 is higher than node 3, nodes 1 and 2. Also, in homogeneous dam dissipation of pore water pressure in node 3 is more than node 4 because of being closer to upstream horizontal drain. Therefore, pore water pressure in nodes 3 and 4 has been dissipated more and free drainage condition is dominated. Also, according to figures 10 and 11, the pore water pressure in nodes 1 and 2 is less than pore water pressure in node 3 when a horizontal drain has been placed in a dam upstream. This process is due to placing these two nodes in the lower level and more influence of downstream horizontal, in comparison with a single horizontal drain in a dam upstream. Gradually, by increasing the number of horizontal drains in a dam upstream, the influence of downstream horizontal drain in the dissipation of pore water pressure is decreased, so that in the mode of 7 horizontal drains in upstream, the maximum amount of pore water pressure is dissipated. In the following, some obtained equations from figures 10 and 11, have been presented.

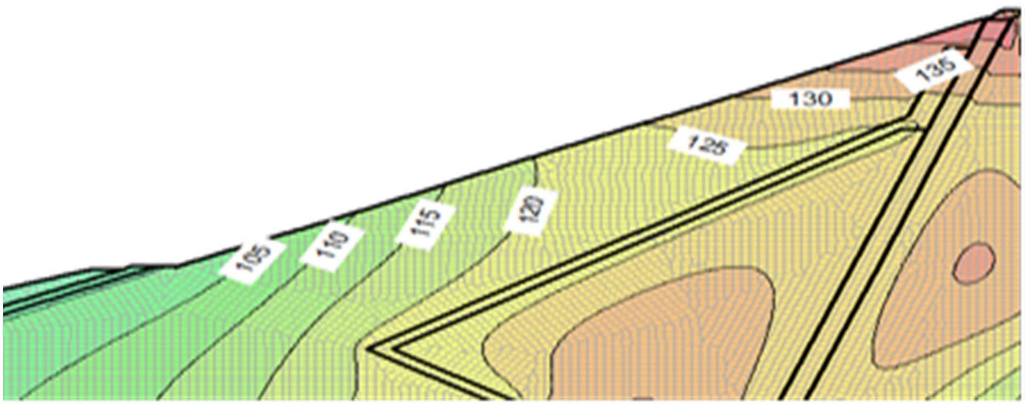

Figure 8. Equipotential line in the upstream dam slope without horizontal drains

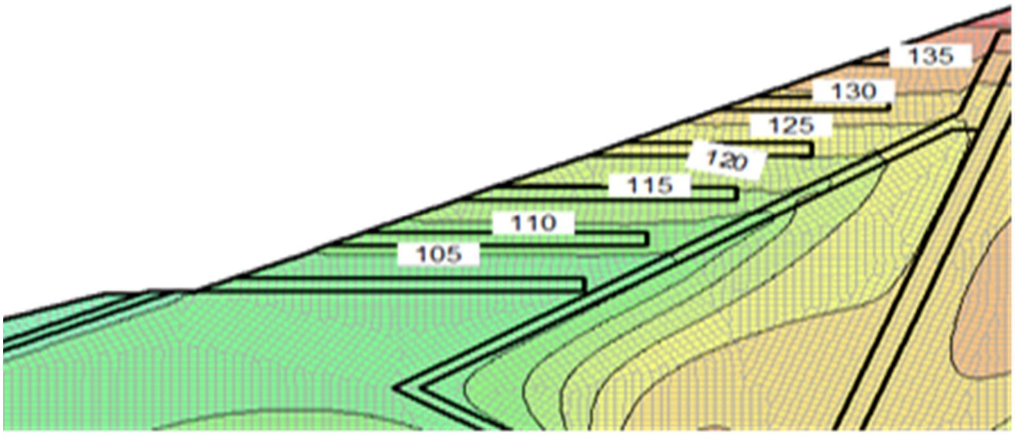

Figure 9. Equipotential line in the upstream dam slope with 6 horizontal drains

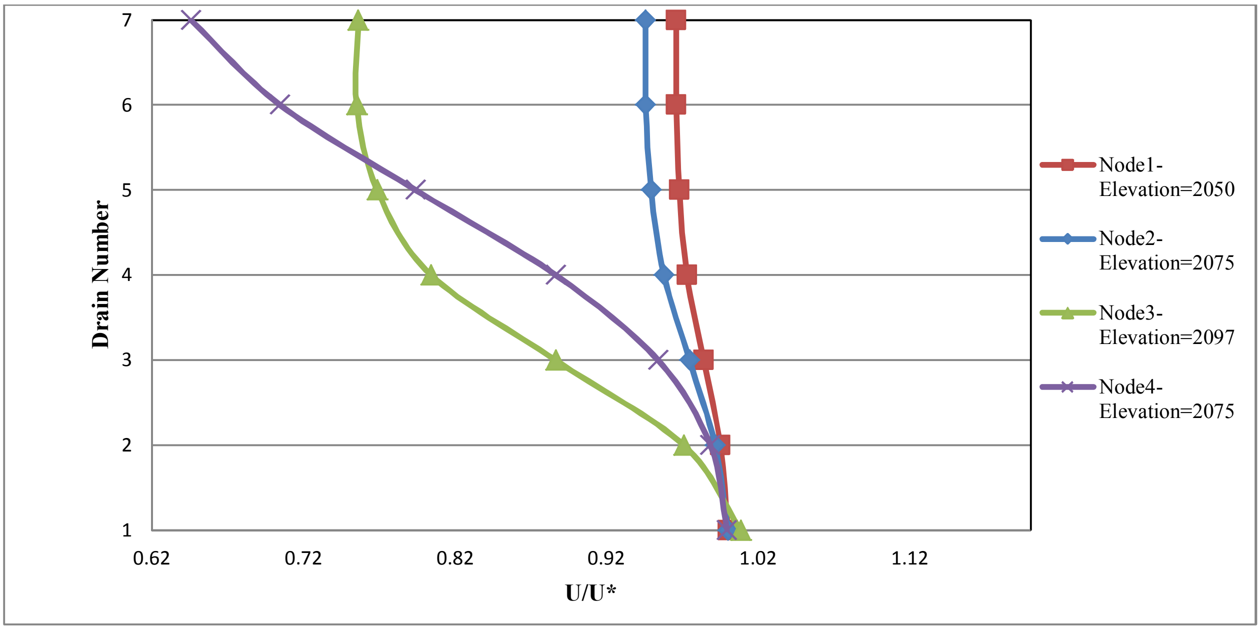

Figure 10. Variation of pore water pressure in three different levels during rapid drawdown condition in heterogeneous dam

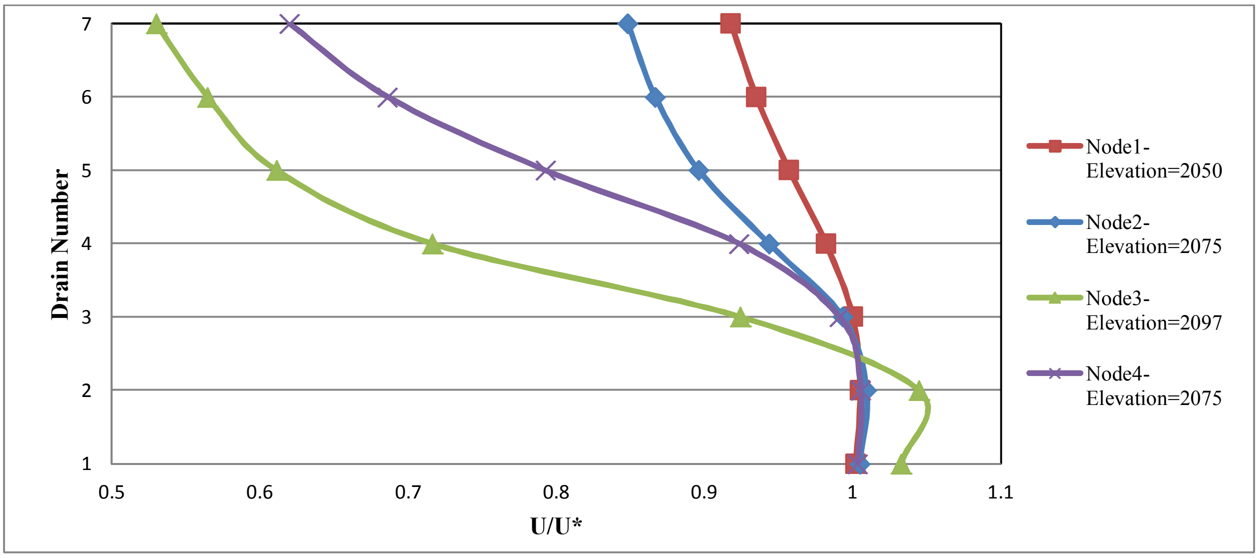

Figure 11. Variation of pore water pressure in three different levels during rapid drawdown condition in homogeneous dam

Equations 7 to 14, illustrate the relation between the drain numbers and the pore water pressure both in the homogenous and heterogeneous dams.

In heterogeneous dam:

(7)

$$N_d = -318.62(\frac{U}{U^*})^2 + 555.35(\frac{U}{U^*}) - 234.48$$

(8)

$$N_d = -6.474(\frac{U}{U^*})^2 + 18.89(\frac{U}{U^*}) - 27.42$$

(9)

$$N_d = -18.59(\frac{U}{U^*})^2 + 17.88(\frac{U}{U^*}) - 2.79$$

(10)

$$N_d = -10.31(\frac{U}{U^*})^2 + 25.78(\frac{U}{U^*}) - 17.35$$

In homogeneous dam:

(11)

$$N_d = -3053.3(\frac{U}{U^*})^2 - 6141.5(\frac{U}{U^*}) - 3089.6$$

(12)

$$N_d = -1153.4(\frac{U}{U^*})^2 - 2332.7(\frac{U}{U^*}) - 1180.6$$

(13)

$$N_d = -56.05(\frac{U}{U^*})^2 - 117.48(\frac{U}{U^*}) - 62.82$$

(14)

$$N_d = -21.87(\frac{U}{U^*})^2 - 21.317(\frac{U}{U^*}) - 2.107$$

In which U and U* is defined as pore water pressure in each node of dams with and without any horizontal drains, respectively.

5. Conclusions

Comparing the obtained results of the accomplished study in the current research, it can be concluded that placing the horizontal drains in dam upstream causes to improve the stability of the safety factor. Also, it was observed that during the rapid drawdown condition with seven horizontal drains in the dam upstream up to 24.04 percentages in the homogeneous dam and up to 17.19 percentages in the heterogeneous dam, the stability factor of safety is increased. Furthermore, it is shown that drains which placed in lower levels, have more effects in the upstream slope in the passing discharge during the rapid drawdown condition and dissipation amount of the pore water. This matter is caused to increase the value of the factor of safety and finally improve the stability of upstream crust.

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