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The Impact of Horizontal Drainage on Persistent Leakage of Non-Homogeneous Soil Dam Body

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ABSTRACT: The leaking water flow from the soil dam body lead to transport of its materials that this issue causes internal corrosion and create piping phenomenon in the dam body. To avoid causing this phenomenon, the drainage plan in the downstream of the dam body is necessary. In this paper, the flow leakage of Jaghnab soil dam by using the seep w software based on finite element method have been calculated and the effect of horizontal drainage dimensions on the amount of leakage flow from the dam body has been investigated and evaluated. The result shows that in the non-homogeneous dam, by increasing the length and the thickness of horizontal drainage, the amount of leakage flow increases too. But the effect of the horizontal drainage length in increasing of leakage flow compared to its thickness is significant. In addition, in the dam shell dissimilar condition when kx>ky, the effect of length and thickness parameters of horizontal drainage for the discharge of the drainage water is reduced.

Keywords: Horizontal Drainage, Non-homogeneous Dam, Leakage Flow, Finite Element

INTRODUCTION

Soil dam as one of the most important soil structures is usually subjected to instability due to increase or decrease in the level of water tank. This structure is built by using local materials and in order to control and store runoff (Rahimi 2007). Homogenous soil dam is one of the types of structures that usually are made from a one type of fine materials with high water- holding capacity. In this structure, by reducing in the level of water tank, the hydrostatic pressure due to the weight of the water on the upstream slope which is the factor of maintaining stability in the upstream slope, decreases. However, the pore water pressure in the body requires more time to depreciation (Hajian and Salami 2005). In all soil dams, existence of drainage is unavoidable and usually it doesn't bring damages. But if the condition is appropriate for soil corrosion, it caused leaching of it in conducive areas and if it didn't ban at the beginning of the occurrence of corrosion, it leads to destruction of the dam. Researches showed that approximately the 30 percent of dams have been destroyed due to the leakage. In the soil dams, three different process cause internal corrosion phenomenon which include progressive corrosion toward the upstream body, concentrated leakage and saturation of the dam material (Baher Talari and Hosseinzadeh Dalir, 2002). Horizontal drainage as a recharging system of drainage water of the dams with average height is common. Because lowering the leakage line, keeps the downstream slope from piping risk. By reducing the elevation of leakage line, the volume of saturation part of the dam material is also confronted with decreasing. Thus a large part of the dam material have been in a state of non-saturation and the possibility of occurrence of the internal corrosion caused by high energy of leakage flow is decreased. This issue has a positive role in supplying structure stability. Thus, by increasing the efficiency of drainage system, the possibility of dams building with larger dimensions has provided (William et al., 2008). Some of the observed cases related to destroying of soil dams due to drop of tank water include Pilarcitos dam in the south of San Francisco and Walter Boudin dam in Alabama (Berilgen 2007). In general, two different approaches have been taken by researchers to determine the pore water pressure after drop in the level of water in the tank, during which some researchers consider drained behavior and some other consider non-drained behavior for soil dam. The researchers who have examined the slops stability in the non- drained condition can be mentioned to Lowo and Karafiat (1980), biker et al. (1993) and engineering association of American army (2003).

Sedghi asl et al. (2010) investigated the effect of optimized condition of dam curtain in the leakage reduction and flow velocity in an underwater structure using numerical model and concluded that the best place for controlling leakage and under washing are the hill and toe of the dam. Ghobadian et al. (2009) studied the effects of the drainage and dam wall on a under pressure force and output gradient from under water structures using finite element method. Belghasem and Abdolrahman (2008) found that the existence of horizontal drainage for improvement of the performance of homogenous soil dam and mechanical and hydraulic stability is very important. Amir Malek pour et al. studied thickness variations of horizontal drainage on the shape of leakage free level and

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amount of leakage flow. In comprehensive study done by Foster et al. (2000) and Fel et al. (2003), it determined that internal corrosion was the most important factor that effect on destruction of soil dams.

The purpose of this study was to investigate the effect of length and thickness of horizontal drainage on the amount of leakage flow from the body of non-homogenous soil dam. For this purpose, as an example, Jaghnab soil dam was modeled by using seep/w software and the effect of the different dimensions of drainage in this dam on amount of leakage flow have been investigated.

Important issues in this research are:

a) Theoretical analysis of leakage for Jaghnab non-homogenous dam using finite element analysis with seep w software in two cases of with and without drainage.

b) Study the effect of dissimilarity of dam shell materials on amount of leakage flow

Given that in practice, due to slamming the soil of all dams dissimilarly and permeability of x direction of dam materials is multiple of y direction, by applying these conditions in the present research, we can have a closer look on the performance of drainage for controlling the drain flow in the soil dam. Also, because it may be very difficult to access the drainage material in the construction place of the actual structure and the costs of transition from remote borrow resources is significant and furthermore in the absence of appropriate performance of drainage system, it is impossible to repair, investigation of appropriate dimensions for establishment of these materials in the body of soil dam can lead to economic savings and enhancement of performance of constructed structure.

MATERIAL AND METHOD

The governing equations

For finding the governing equations of water flow in a porous environment, a small and saturation element with dimensions of dx, dy is considered and the flow velocity along the x, y respectively vx, vy are considered. By ignoring the volumetric changes of the element caused by different factors such as changes in effective stress and writing the law of mass conservation, the pure amount of input flow to element is equal to:

$$q_{net} = q_x + q_y + Q.dA = \left(-\frac{\partial v_x}{\partial x} - \frac{\partial v_y}{\partial y} + Q \right).dA \qquad \textbf{(1)}$$

Where q is amount of pure flow in dual directions and Q is amount of production flow rate per unit of element area. By using the relations of the rate of water mass changes in the soil element and the rate of soil element volumetric moisture percent changes and the law of mass conservation, we have:

$$-\frac{\partial v_x}{\partial x} - \frac{\partial v_y}{\partial y} + Q = \frac{d\theta}{dt} \qquad \textbf{(2)}$$

Equation (2) is called a differential equation of flow continuity. By combining Darcy relation and differential equation of flow continuity, differential equation of leakage is obtained.

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y} \right) + Q = \frac{d\theta}{dt} \qquad \textbf{(3)}$$

By entering the specific storage coefficient in equation (3), we have:

$$\bar{\nabla}.(C.\nabla h) + Q = m_w.\gamma_w.\frac{dh}{dt} \qquad \textbf{(4)}$$

Equation (4) is the leakage equation where the operator $\bar{\nabla}$ and C are the permibility matrix. Since in steady flows, the value of h doesn't change with time, the leakage equation becomes simple as follows:

$$\bar{\nabla}.(C.\nabla h) + Q = 0 \qquad \textbf{(5)}$$

Finite element method is one of the most powerful methods in numerical solution of differential equations, including the equation of leakage problem that nowadays has many applications in engineering. In this method, the problem area is divided into a limited number of component and by assuming an approximate solution for the differential equation and minimizing the difference between actual and approximate solution of the problem (minimizing the energy of system), the differential equation is converted into integral form and unknown values in the specific points called nodes are obtained. By using the interpolation functions or shape functions and substituting in the derivative of differential equation of leakage and applying the boundary conditions, the matrix form of the equation of leakage will be obtained.

$$[K]\{H\} + [M]\{H\}_t = \{Q\} \qquad \textbf{(6)}$$

Equation (6) is a general equation of leakage in finite element method. Because in steady analyses $\{H\}_t = 0$, equation (6) becomes simple as follows:

$$[K]\{H\} = \{Q\} \qquad \textbf{(7)}$$

The above matrixes are calculated with numerical integration methods. With calculating the above matrixes, applying the boundary conditions and solving the system of equations, baraby values at the desired points of network nodes are obtained.

Analysis method and assumptions

Jaghnab storage dam which is a dam out of the main stream is to collect and store the water of the Tea Karandagh River in non-agricultural seasons to supply the water of the large parts of the lands of village of Jaghnab in Kosar city of environs of Ardabil province. The total height of Jaghnab soil dam is calculated 23 meters from the bottom of the river. The crest width of the dam is considered 7 meters. The value of permeability coefficient of the dam shell for core and foundation is 10^{-3} and $5\,x\,10^{-7}$, respectively. The geometric dimentions of jghnab dam is shown in Figure 1.

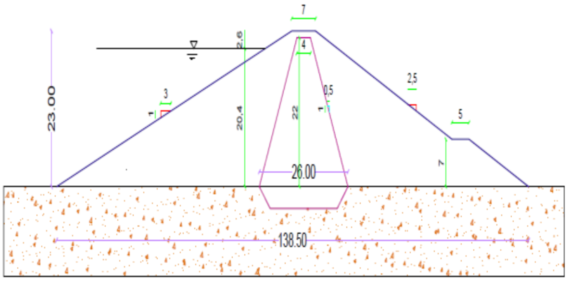

Figure 1. Geometric dimensions of Jaghnab dam

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In this research, the results of leakage analysis of Jaghnab dam are presented in two options.

a) The option of homogenous and dissimilar dam with horizontal drainage

b) The option of non-homogenous dam with the core which its thickness is 26 meters at the bottom and horizontal drainage.

To perform the leakage analysis, the analysis was performed by assuming the maximum height of water (difference in upstream and downstream water levels) in order to obtained the most modal similarity to the real from the point of leakage and parameters of horizontal drainage in the downstream of related dam. In order to leakage analysis of the body of Jaghnab soil dam, the seep w subprogram of Geo-studio 2004 was used. In fact, this program solves the leakage equation with finite difference method.

Figures 2 and 3 are shown the geometric model used in the two options analysis of the Jaghnab dam. Finite element network in the analysis of cross-max of this option of dam has 2198 nodes and 2082 element which can be seen in the following figures.

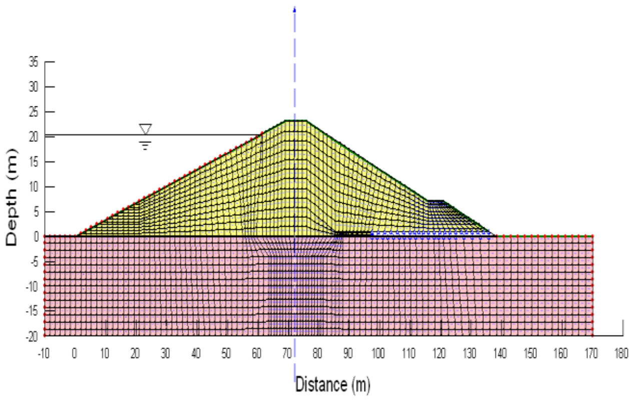

Figure 2. Sample of element classified of homogenous soil dam with horizontal drainage

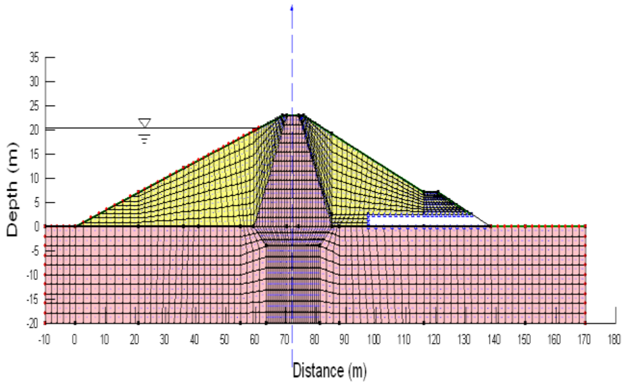

Figure 3. Sample of element classified of non-homogenous soil dam with the core which its thickness is 26 meters at the bottom with horizontal drainage

Leakage analysis of homogenous and similar dam with horizontal drainage

To analysis and evaluate of the results, Jaghnab soil dam has been assumed as a homogenous soil dam without core at first and obtain the flow rate passing through the middle of the core by using seep w software. In this section, our variables are length and thickness of horizontal drainage. Thus, the length of drainage is assumed within 0.5h to 2.5h (h: height of the tank water), the thickness of drainage is assumed 1 to 4 meters and we note the flow rate passing through the middle of the core. The flow rate passing through the middle of the dam for the permeability case $k_x=k_y$ are shown in Table 1.

Table 1. Flow rate passing through the core for homogenous dam case with similar shell according to (m^3/s)

Thickness of drainage (meter)			Length of drainage (meter)		
	0.5h	1h	1.5h	2h	2.5h
1	$3.77*10^{-5}$	$4.67*10^{-5}$	$5.61*10^{-5}$	$6.79*10^{-5}$	$8.42*10^{-5}$
2	$3.78*10^{-5}$	$4.72*10^{-5}$	$5.66*10^{-5}$	$6.84*10^{-5}$	$8.47*10^{-5}$
3	$3.80*10^{-5}$	$4.76*10^{-5}$	$5.70*10^{-5}$	$6.89*10^{-5}$	$8.49*10^{-5}$
4	$3.84*10^{-5}$	$4.78*10^{-5}$	$5.74*10^{-5}$	$6.92*10^{-5}$	$8.52*10^{-5}$

After providing the relevant datas, we draw the relationship between the datas as the curve visible in Figure 4 by using matlab software.

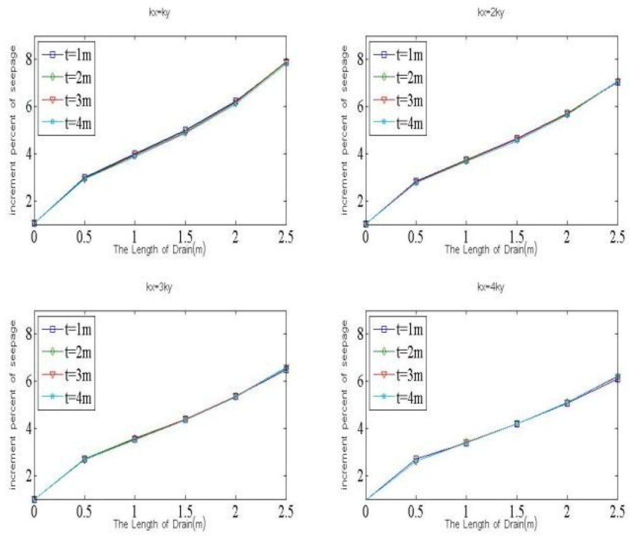

Figure 4. The relationship between the length of horizontal drainage and leakage flow rate increasing percent for different thickness of drainage in the homogenous soil dam

With a little contemplation on the above diagrams, it can be seen that by increasing the length of horizontal drainage, the value of leakage flow is also increased. In addition, the value of leakage flow rate increases with increasing the thickness of drainage. But the effect of the thickness of horizontal drainage in increasing of the leakage flow rate compared to the length of drainage is very low and this indicates that the length of horizontal drainage compared to the thickness of drainage is more effective in increasing of the leakage flow.

In the dissimilar environment, the thickness effect is more likely to drop. By increasing the permeability coefficient of x direction of shell materials than y direction, leakage flow decreases. As in the case kx=4ky, almost the thickness variations becomes ineffective on the leakage flow rate curve. In the distance between 0.5h to

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2.5h (h: height of the tank water), the curve slop becomes high which indicates that the drainage performance in this distance improved.

Leakage analysis of non-homogenous dam with dissimilar shell and horizontal drainage at the downstream of the dam

In this section, horizontal drainage with different thicknesses in the range of zero length (without drainage) to the downstream shell length (the length equal to the length of the downstream shell of the dam) to control the steady leakage flow was investigated in order to evaluate the relationship between the length and thickness of horizontal drainage with the value of leakage flow in the dam.

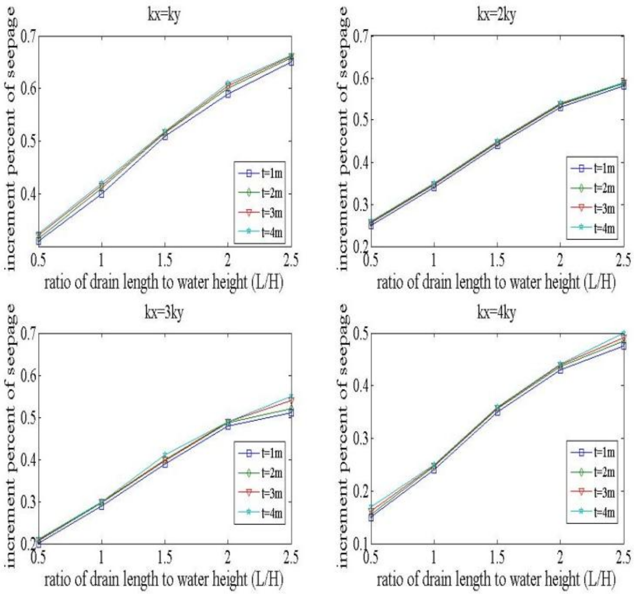

Figure 5. The relationship between the length of horizontal drainage and the flow rate increasing percent for different thickness of drainage in the non-homogenous soil dam with dissimilar shell

The result of numerical analysis showed that in the non-homogenous dam, by increasing the length or thickness of the horizontal drainage, the value of leakage flow increases too. But the effect of the length of drainage in increasing of the leakage flow rate compared to the thickness of drainage is significant (Fig 5).

This issue becomes more pronounced when the same dam as it's homogenous and without core has been studied. The ability of discharging the drainage leakage flow rate in non-homogenous dam is less than homogenous dam. Because in non-homogenous dam the greatest flow drops occurs virtually in the core of the dam and the effect of the drainage in discharge of leakage flow is trimmed. In dissimilar conditions for dam shell, due to the difference between horizontal and vertical direction permeability of materials, performance of stable length and thickness of the horizontal drainage in increasing the leakage flow rate decreases. So the influence of length and thickness parameters of horizontal drainage to discharge the drainage water in dissimilar conditions is lower than similar conditions. Therefore, to maintain the efficiency of horizontal drainage in dissimilar conditions with the same efficiency that acts in the similar conditions, it is recommended that the length and thickness of horizontal drainage in dissimilar condition is more selected.

CONCLUSION

After performing the analysis, the following results were obtained on the Jaghnab dam sample:

1. In the non-homogenous dam, with increasing the length or thickness of the horizontal drainage, the value of leakage flow also increases.

2. The effect of the length of the horizontal drainage in increasing the leakage flow rate is greater than its thickness.

3. The horizontal drainage with constant cross section can increase the leakage flow rate in the homogenous dam more than the nucleate non-homogenous dam.

4. The efficiency of horizontal drainage with constant dimensions in dam shell dissimilar conditions (kx>ky) is less than similar conditions (kx=ky). Therefore, to maintain the efficiency of the drainage in dissimilar condition (kx>ky), we should choose the greater drainage dimensions (length and thickness).

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