Numerical Simulation of Effect of Drain Pipe in Uplift Force, Exit Hydraulic Gradient and Seepage in Gravity Dams

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ABSTRACT: In this study, the effects of diameter and location of drain pipes in uplift force, exit hydraulic gradient and seepage in the foundation of gravity dams are investigated. For this purpose, the SEEP/W software as a subgroup of Geo-Studio software is implemented and the foundation of a gravity dam is simulated. The results showed that the existence of drain pipes under the gravity dam reduce 4, 6, and 9 times of uplift force, exit hydraulic gradient and seepage, respectively. Installation of two drain pipes with 0.25L distance from each other and in the depth of 0.26D near the dam heel presents a more suitable position with respect to uplift force reduction (D is the pervious foundation depth). Also, by defining the best position for the location of drain pipes, it was observed that drainage pipes in these situations reduce 41-67% in the volume of the studied dam and increase the safety factor up to 2 to 3 times against the dam overturning. It is also found that the drainage pipe diameter has less effect on the uplift force, exit hydraulic gradient and seepage and is controlled by the rules of the executive. For validation, the numerical method used in this study was compared with the laboratory method by others and a suitable match was observed.

1- Introduction

One of the major factors in dam destruction is seepage from dams and subsequent increase in uplift force. All dams and water retention structures are exposed to water passing through the foundation, sides and sometimes their bodies. So that, the water in the dam reservoir, at any moment, tends to seepage through the dam and at the junction of the dam body with the foundation. In addition, water tends to seeps from the pores in the foundation soil and appear downstream of the dam. This flow causes performing a force from down to up in the dam's body, so-called uplift force [1]. The exit hydraulic gradient is also the most important design criterion for the safety factor compared to the piping of the foundation. One of the measures used to reduce the uplift force and also to reduce the exit hydraulic gradient is the creation of cut-off walls [2]. Mansouri and Salmasi [3] studied the effect of horizontal drainage and cut-off walls on seepage and uplift pressure in homogeneous earth dam using numerical simulation. The results showed that increasing the length of the horizontal drain increases the rate of seepage and exit hydraulic gradient. The seepage from the dam is also reduced by increasing the depth of the cut-off wall. The installation of the cut-off wall in the middle of the foundation leads to a 19.68% reduction in the hydraulic gradient relative to the installation of the cut-off

on upstream. Azizi et al. [4] studied the influence of the weep holes and cut-off on the uplift pressure in the stilling basin of a diversion dam. The results showed that the upstream cut-off wall with a depth of 8 meters reduced the uplift force by about 63% and the exit hydraulic gradient decreased by 79% compared to the non-cut-off wall state. In the present study, the best position of the drain pipe is determined for minimum uplift force, exit hydraulic gradient and seepage. Also, the safety factor against overturning of the non-drain mode and the effect of drains construction on the reduction of the gravity dam volume is determined and all cases are compared with the non-drain mode.

2- Material and Methods

In the present study, for numerical simulation, seep/w software is used to simulate the porous soil environment by finite element method [5]. Figure 1 shows the geometrical cross-section of the gravity dam and the position of the drain pipes located in the dam foundation with the parameters studied. Table 1 shows the range of dimensionless parameters changes in the present study. Also, N is the number of drains.

In this study, the numerical model was simulated separately by changing the diameter and dimensionless parameter L/H while the drains were embedded in the coordinates ab, ac, ad, …, ij. In order to compare the effect of drains pipe location

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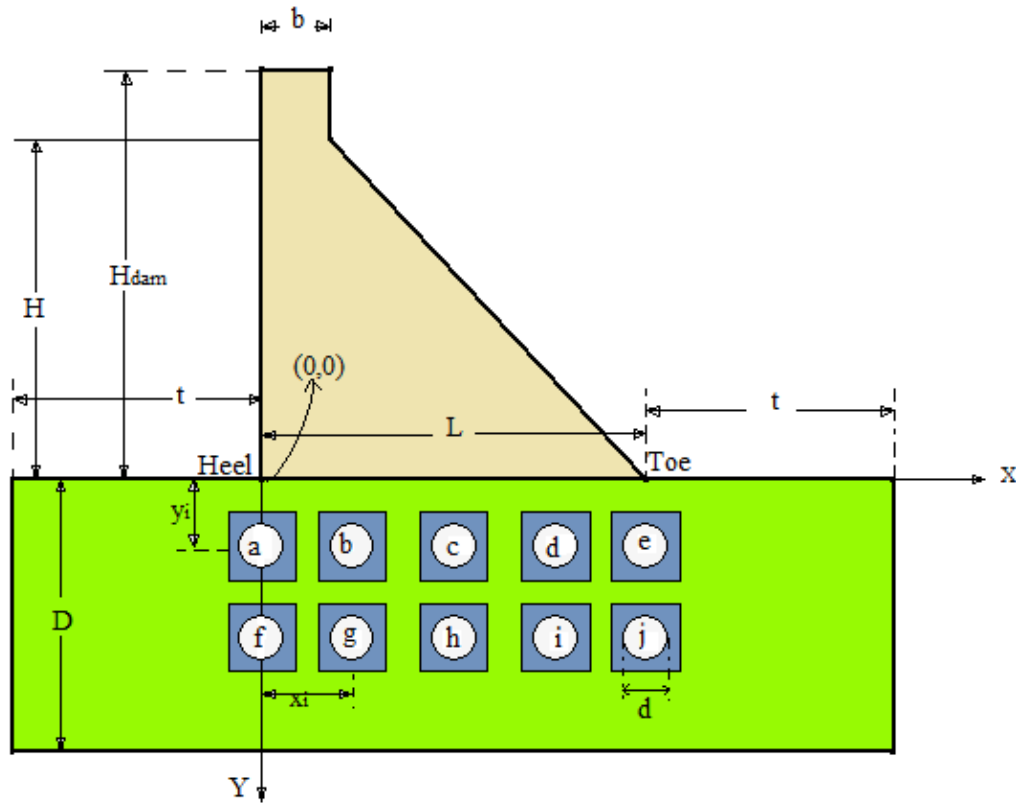
Fig. 1. Two-dimensional view of the gravity dam and its foundation in the present study

Table 1. Range of dimensionless parameters changes in the present study

L/H	0.8	1	1.2	1.5	---
d/D	0.003	0.006	0.01	---	---
N	2	---	---	---	---
(x_i, y_i) (m,m)	a=(0,5) f=(0,8)	b=(15,5) g=(15,8)	c=(30.75,5) h=(30.75,8)	d=(45,5) i=(45,8)	e=(61.5,5) j=(61.5,8)

and drains size on the uplift force, exit hydraulic gradient and seepage, the model was simulated for non-drain mode for different (L/H). For numerical simulation, the boundary conditions at the upstream and downstream of the gravity dam are defined as the water behind the reservoir and water height in tail-water as the compressive head. It should be noted that due to the lack of water at downstream of the dam, the boundary condition is considered as a zero hydraulic head. Also, for horizontal drainage under gravity dam, the hydraulic head is considered as zero pressure. The foundation materials of the gravity dam are considered as a homogeneous porous and isotropic environment with a hydraulic conductivity of 0.0002 m/s. In this study, the drain pipe is located inside the filter on the side of 30 cm, which hydraulic conductivity is 100 times the hydraulic conductivity of the soil in the foundation.

3- Results and discussion
After solving the problem governing equation with the specified boundary conditions, the results of these models can be extracted.

3.1. Influence Of Lateral Walls Distance
To eliminate the effect of lateral boundaries in the numerical model on the results, the ratio of these walls distance from the dam body to the water height behind the dam (t/H) was considered as equal to 0.25, 0.5, 0.8, 1, 1.3, 1.5, 1.75, 2, 2.5. According to the results, in all modeling cases, the distance of the lateral boundaries from the concrete body of the dam was considered 2 times the maximum upstream water height.
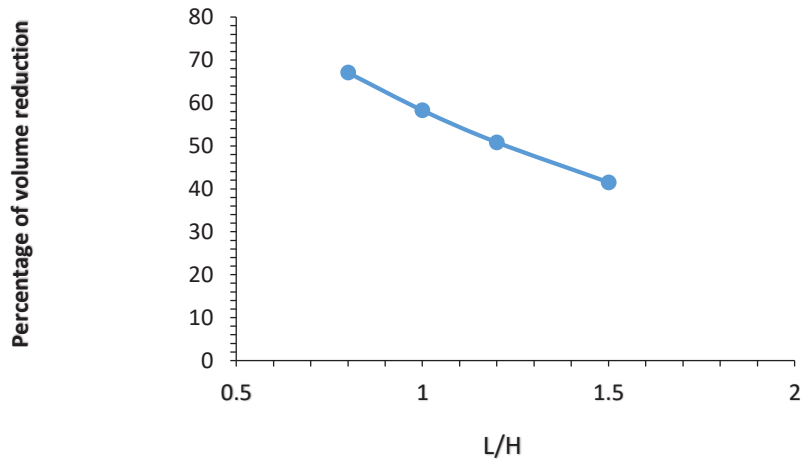
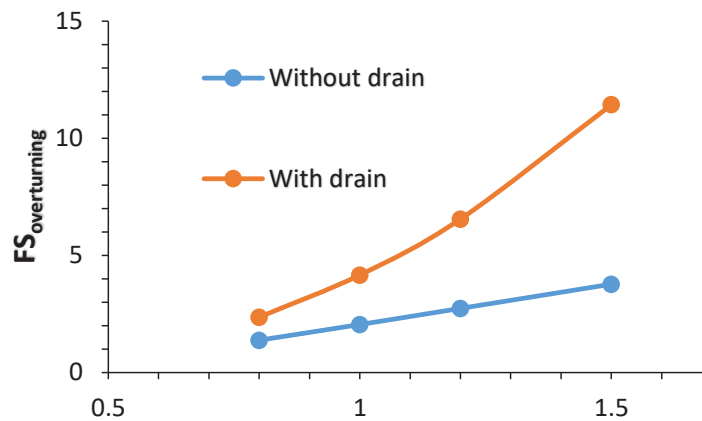**Fig. 2. The effect of L/H on structural volume reduction**

Fig. 3. Effect of L/H on safety factor against overturning with and without drains

3.2. Effect Of Drain Diameter

According to the studies conducted, it was found that drains diameter change had little effect on the uplift force, exit hydraulic gradient and seepage; therefore, changing this case is subject to executive considerations.

3.3. Effect Of Drain Position

According to studies, it is observed that by changing the drain position under the gravity dam, the ratio of the uplift force in the drain mode to the non-drain mode (U/U_0), when the drain is simultaneously in the f and g positions, it has the lowest value. It is also observed that by changing the drain position under the gravity dam, when the drains are simultaneously in positions h and d, the lowest amount of exit hydraulic gradient occurs. Similarly, it is observed that the least seepage of the dam occurs when the drains are in positions h and g simultaneously. Also, with increasing L/H ratio (reduction of upstream water depth), the maximum reduction of U/U_0, exit hydraulic gradient and seepage happens at these points.

3.4. Effect Of Drain Presence On Gravity Dam Volume And Safety Factor Against Overturning

Placing drain in specified positions to reduce uplift force, Figures 2 and 3 were plotted to reduce the volume and increase the safety factor against overturning. According to Figures 2 and 3, it can be concluded that the drain embedded under the gravity dam reduces the dam volume and increases the safety factor against overturning.

4- Conclusions

The results showed that the existence of drain pipes under the gravity dam reduces the uplift force, exit hydraulic gradient and seepage. It was also found that the choice of drain pipe diameter had less impact on the uplift force, the exit hydraulic gradient and seepage and was subject to construction considerations. Determining the best position for drain pipes, it was found that the application of drain pipes in these situations reduces the volume of the dam by 41 to 67 percent and increases of 2 to 3 times the safety factor against overturning of the structure. The results of this study are in good fit with the experimental work of other researchers.

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