Research Article

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The effect of cutoff angle on the head pressure underneath dams constructed on soils having rectangular void

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Abstract: In this research, a hydraulic model is used to find the effect of the cutoff angle and dimensions of the void in the soil on the head pressure and leakage under the dam, and finding the best angle and size of the void will have a positive effect. The model was designed with a cutoff that can be moved in three angles (45°, 90° and 135°) in the center of the dam and three ratios of void dimensions (width of the void (W)/the dam width (b) = 0, 0.34 and 0.69) were taken. Head pressure was measured using a piezometer installed in the front of the model. When the flow reached the balance, leakage and pressure head were measured. From the results, it was observed that the lowest head pressure value occurs when the angle is 90° and the void ratio is 0.69. The principles of dimensional analysis and non-linear regression by using IBM SPSS 19 were used to find an empirical formula for the computation of the head pressure depending on the angle of the cutoff and the size of the void.

Keywords: head pressure, cutoff angle, rectangle void, leakage

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1 Introduction

Dams are probably the most important hydraulic structure built on the river. Dams have played an important role in flood control, municipal, water supplies and other fields [1]. Water is the most important factor in most of the dam stability analyses. Pore water in soil can strongly influence the physical interaction among soil grains. Changes in pore pressures can directly impact the effective stresses, which in turn affect both the behavior of soil. Therefore, analysis of pore fluid seepage plays an important role in the solution of many hydraulic structure problems [2]. The groundwater flow depends on the type of flow, the soil media, and the boundary conditions. Seepage of water is one of the major problems, which has effect on hydraulic structures [3]. The water flow puts pressure on the base of the dam as well as the sedimentary deposits and limestone rock decompose and lag many voids that affect the value of the head pressure and the amount of leakage. The volume of water with time, uplift pressure generated underneath the base of hydraulic structure, exist gradient at downstream side changes with different location and inclination of cutoff wall [4]. Alghazali and Alnealy [4] studied the effect of the cutoff inclination angle on exit gradient, factor of safety, uplift pressure and quantity of seepage through single-layer soil foundation underneath hydraulic structure. Jamel [5] studied the effect of using upstream and downstream sheet piles in double soil layer on the seepage and uplift pressure exit gradient at toe of hydraulic structure using computer program SEEP/W software. Maatooq and Abdulhasan [6] developed a formula for the determination of start time of seepage when single cavity presence at a specific location within the homogenous soil under a hydraulic structure. The investigation aims to observe the effect of cavity locations and size on the start time of seepage. Rasool et al. [7] presented a new method to estimate the uplift pressures at key points by performing sub-surface flow analysis using the Analysis system (ANSYS)

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software. In previous research, the effect of cutoff angle and cavitation in soil at the same time on the amount of leakage was not studied, so the main objective of this research is to study the effect of cutoff angle and dimension of rectangle void on head pressure and quantity of leakage.

2 Materials and methods

In this section, the materials used in the manufacture of the model are mentioned. It also describes the method of conducting experiments.

2.1 Laboratory model

The experimental work was conducted in the manufactured laboratory model. Figure 1 shows the model. It consists of three parts, the middle part of the soil was placed while external parts used as reservoirs for upstream and downstream levels. The sides of the model (in the width direction) contain slots at different levels in order to allow for the flow of water through the soil. Steel dam with a length of 145 mm and a height of 150 mm was manufactured, with rectangular plastic cutoff (height = 100 mm) embedded within a soil. The dam was installed in the hydraulic model and the cutoff was fixed at the center in order to be influential on head pressure of the heel and toe of the dam with the possibility of moving it. The voids were prepared by placing a rectangular steel tube after perforating holes at 3 mm in their bodies to allow water flow. Two different lengths have been used to represent the size of void, L = 50 mm and 100 mm, at constant width W = 100 mm. The void model is shown in Figure 2. The void is placed at the center of the soil during compaction process. Many piezometers were placed at different locations (A, C, G, E and F) for obtaining the results; two points were taken in the upstream side (A, C) and in the downstream side (E, F), and one under the sheet pile (G). These piezometers are connected to the model through an aluminum pipe containing holes in the same way as mentioned in the previous research [2]. Figure 3 illustrates a diagram of the piezometers and angles.

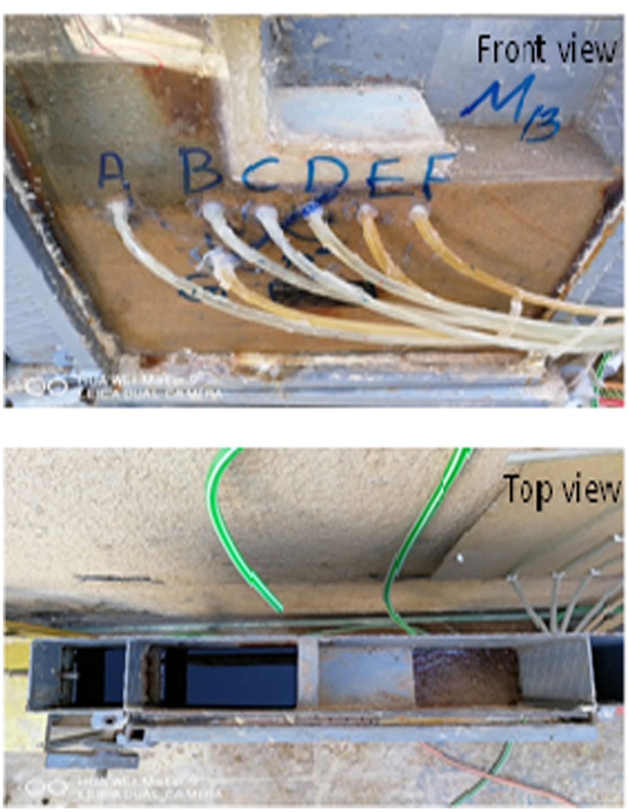

Figure 1: Images of laboratory model.

2.2 Soil used

According to the laboratory results of sieve analysis and unified soil classification system for the experimental soil sample used in this study, it is classified as well graded sand (S_w). The results of Standard Proctor test and Constant Head test for soil are shown in Table 1.

In the center of the model in the longitudinal and transverse direction was for all model tests, the soil used are complete by mixing dry soil with water in percent

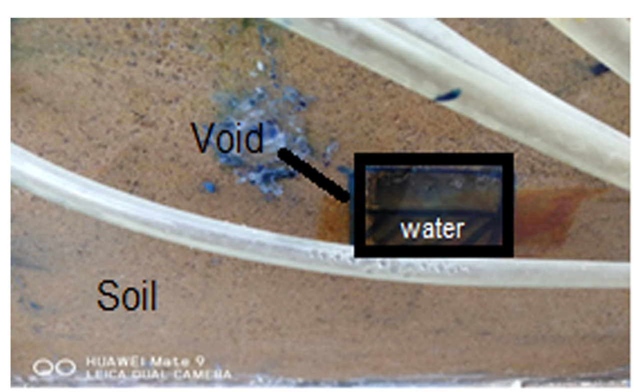

Figure 2: Image of void model.

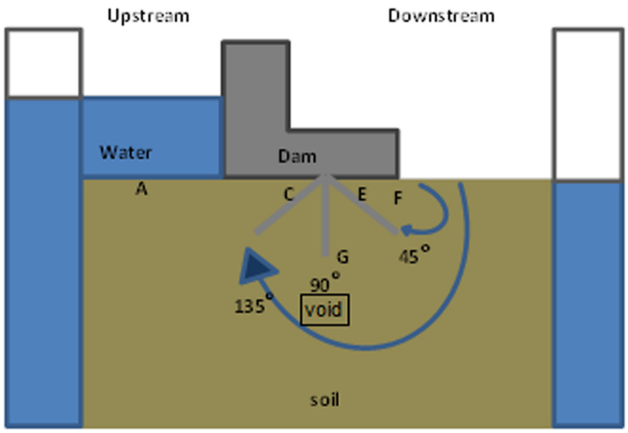

Figure 3: A diagram of the piezometers and angles.

Table 1: Physical properties of soil

Dry unit weight (kN/m^3)	Optimum moisture content (%)	Hydraulic conductivity (m/s)
16.94	5.7	6.84×10^{-5}

agreeing to optimum water content, then spreading the soil inside the middle part of the model for several layers. Each layer is compacted to a unit weight equal to the maximum dry unit weight. The compaction process was selected to produce homogeneous sample.

2.3 The experimental procedures

1. Install the model in a balanced way, then place the soil in the middle part and compact. The void is placed in the required position during the compaction process, and the compaction continues until the final height is achieved.
2. Feed the water to the model through upstream part until the water level reached the overflow holes (the high 112.5 mm above soil).
3. After reaching steady-state flow, record the reading of the piezometric head of all installed piezometers. The process of measuring the head pressure is done by calculating the height of the water in the piezometric installed next to the model on a vertical wooden board and starts at the same level.
4. Measure the leak of drained water collected from the downstream part by using the volumetric method.
5. The cutoff is fixed in the center of the dam with the possibility of moving it at any angle. The cutoff is fixed at the angle with the silicon material, and the compaction process is completed. Repeat the steps (1–4) to find the best angle and void size to give less value of head pressure and quantity of leakage.

The steps of the test contain three groups. Each group takes the angle of a specific cutoff and takes three tests once without void and others with a void in a certain distance, and Table 2 shows the parameters taken for each test.

2.4 Dimensional analysis

In this study, there are ten variables shown in equation (1) having an effect on a head pressure as the following functional relationship:

$$h = f(q, H, L, L_w, W, b, \theta, \theta°, \rho, k), \quad (1)$$

where q is the quantity of the leakage ($L^3 T^{-1}$), H is the water level in upstream zone (L), L is the length of flow to limit point (L), L_w is the length of flow (L), W is the width of the void (L), b is the dam width (L), θ is the inclination of cutoff (°), $\theta°$ is the standard angle (90°), ρ is the density of the water (ML^{-3}) and k is the hydraulic conductivity (LT^{-1}).

According to Buckingham's theorem, the functional relationship may be written as:

$$h/H = f(q/(k \cdot H), L/L_w, W/b, \theta/\theta°). \quad (2)$$

3 Discussion of the results

Herein, the discussion of the results for soil is according to the following parameters:

1. Effect of the cutoff angle on the head pressure and leakage

   The angle of the cutoff (90°) has been tested by observing the effect of the different angle ratios ($\theta/90° = 0.5$, 1 and 1.5) on the head pressure for the three width

Table 2: The parameters of test

Group number		*W* (cm)		*θ*
1	0	5	10	45°
2	0	5	10	90°
3	0	5	10	135°

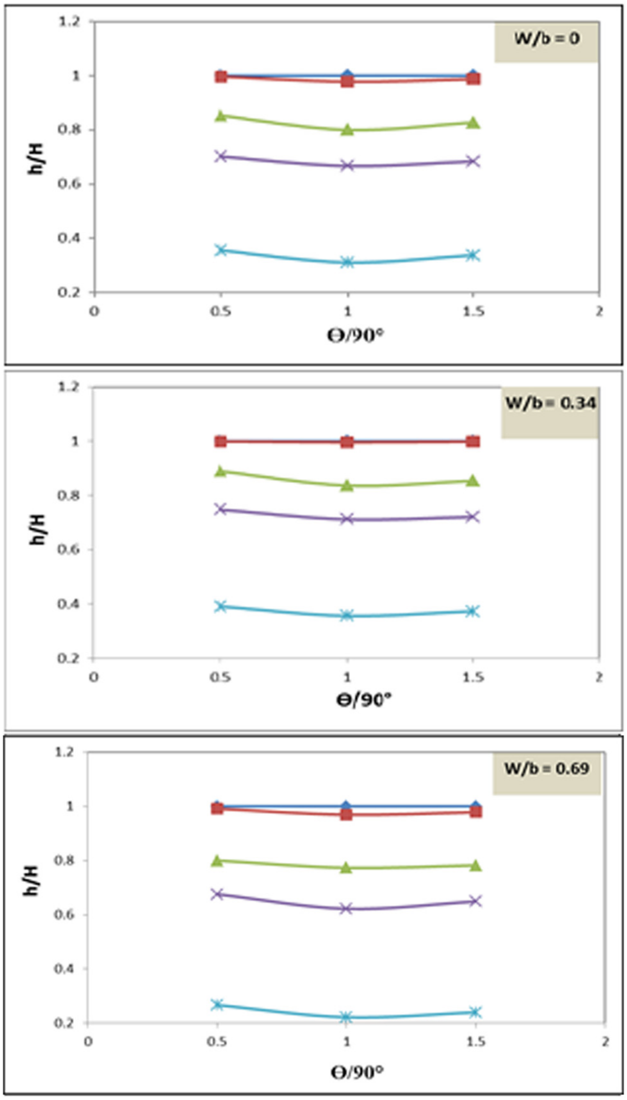

Figure 4: Effect of cutoff angle on head pressure for different points at flow line.

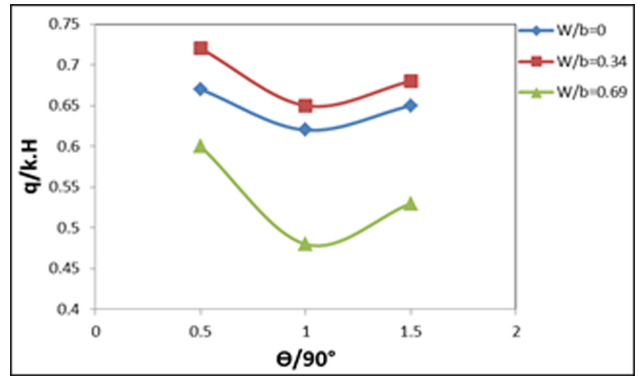

Figure 5: Effect of cutoff angle on leakage for different width ratios W/b.

ratios undertaken (W/b = 0, 0.34 and 0.69). Figures 4 and 5 illustrate this effect. The following conclusions can be observed:

(a) The pattern of decreasing and increasing the head ratio (h/H) with increasing angle ratio ($\theta/90° = 0.5$) is the same for all models imposed.

(b) In all experiments, it can be observed that, at an angle ratio ($\theta/90° = 0.5$), the highest influence was recorded. And at ($\theta/90° = 1$), the minimum influence was observed by further decreases in head pressure.

(c) Note that the ratio of angle ($\theta/90° = 1$) gives the lowest percentage of leakage due to the length of the water flow, and the highest value is at the angle ratio of ($\theta/90° = 0.5$) because of the short runway water flow. The researchers in ref. [4] found that the minimum value of uplift pressure was obtained when the cutoff used in upstream part of hydraulic structure with an angle of inclination ($\theta = 45°$) without the presence of cavitation.

2. Effect of void width on the head pressure and leakage

Figure 6 shows that above the higher value of the head pressure ratio at the ratio of width ($W/b = 0.34$) but the situation reflected at the ratio of the width of ($W/b = 0.69$). The same pattern of increase and decrease is observed for every angle.

Note from Figures 7 and 8 that the cutoff angle and void width affect the head pressure readings for the same points. The minimum leakage value is at the width ratios ($W/b = 0.69$) because the void acts as a reservoir for water, and this automatically reduces the pressure on the dam while the situation is reflected at the ratio of width ($W/b = 0.34$) because the void only reduces the flow path without water storage.

$$\frac{h}{H} = 0.063*\frac{q}{k*H} - 0.014*\frac{\theta}{90°} + 0.014*\frac{W}{b} + \frac{-567.91 + 2890.7*\frac{L}{L_w} - 2018.071*\left(\frac{L}{L_w}\right)^2}{2160.781*\left(\frac{L}{L_w}\right)^2}. \quad (3)$$

Figure 9 shows a well-accepted correlation between predicted and observed head ratios. The accuracy between the predicted and observed ratios is 53%.

A non-linear regression analysis is represented by the following equation by using IBM SPSS 19 program to estimate the correlation between the different dimensionless parameters indicated in equation (2), and the correlation coefficient for the development equation is 0.89, and its expression is as follows:

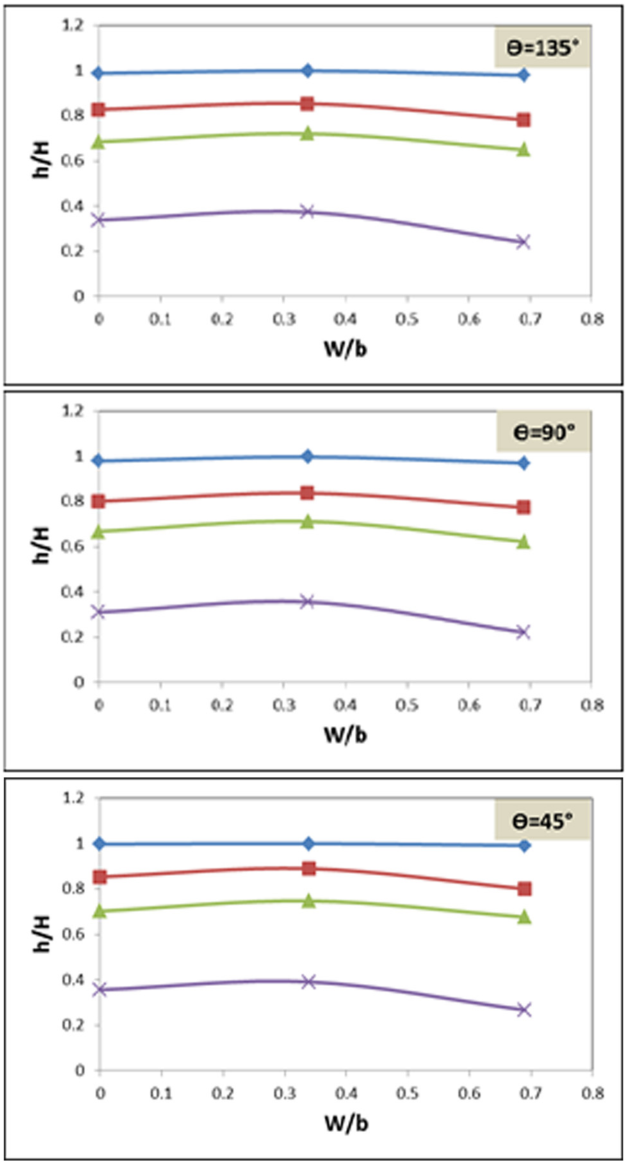

Figure 6: Influence of void width on head pressure of the points for three angles of cutoff.

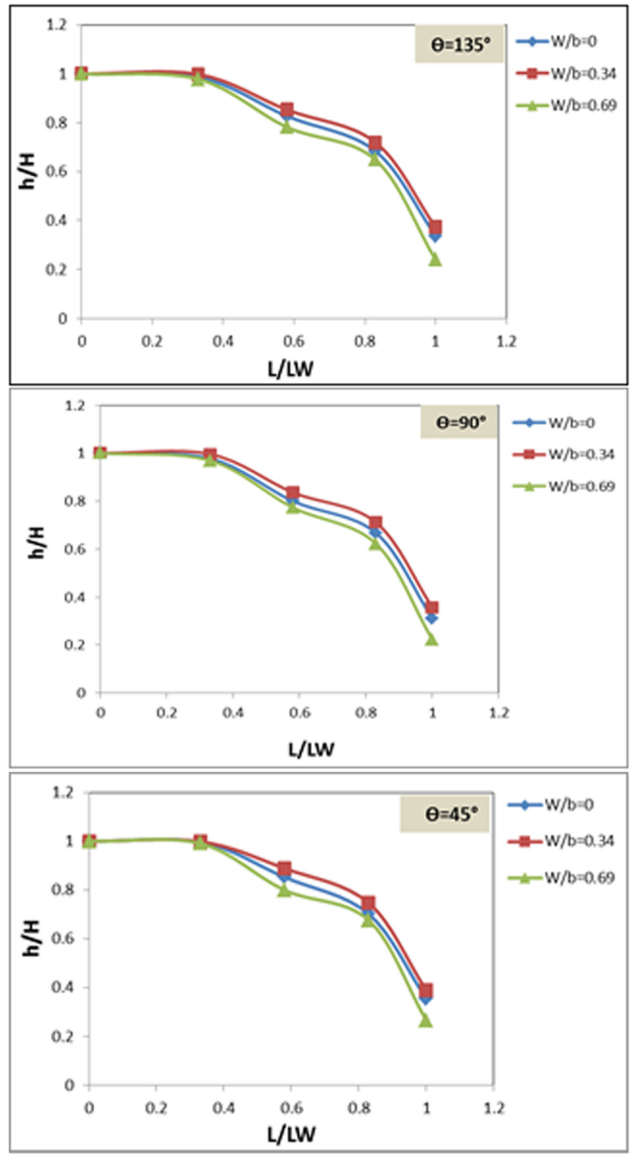

Figure 7: Change in the head pressure for different points under the dam.

4 Conclusion

1. The lower head pressure (h/H) value on the bottom of the dam occurs when the cutoff is vertical ($\theta/90° = 1$), but the highest value is when the cutoff is angled at ($\theta/90° = 0.5$) for different points along flow line.
2. The minimum amount of leakage is at ($\theta/90° = 1$) and increases when the cutoff tends toward the toe or heel of the dam for different width ratios.
3. When the cutoff is tilted toward the toe, the flow of the water decreases, leading to increased leakage, which increases pressure on the dam.

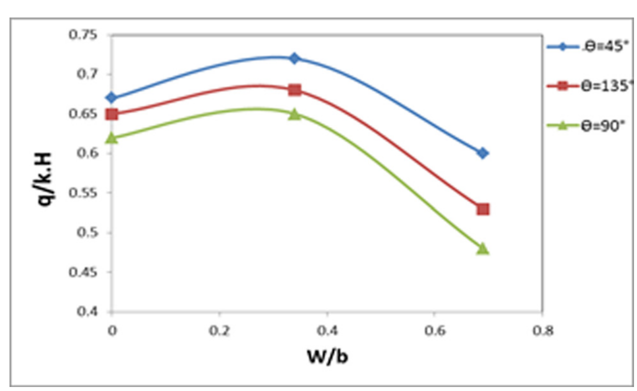

Figure 8: Effect of void width on leakage for cutoff angles.

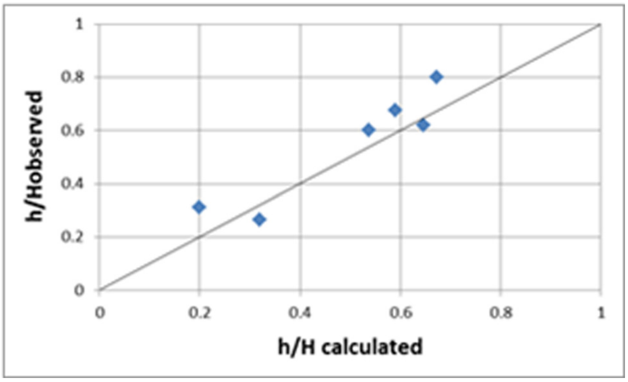

Figure 9: Correlation of the head pressure.

4. The head pressure ratio (h/H) decreases with increasing length ratios (L/L_w). The same pattern is observed for all angles.
5. From the results it was observed that the most effective angle in reducing the leakage is 90°, where the amount of leakage decreases according to the general case ($W/b = 0$) by 22.2% at the ratio of the void width of $W/b = 0.69$ and increases at a ratio of the void width of $W/b = 0.34$ by 5.56%. When the amount of leakage decreases, the head pressure for points under the dam decreases for all angles and width ratios used.
6. By using the Buckingham π-theory method as a dimensional analysis concept and non-linear regression analysis by using IBM SPSS 19 program, an empirical formula advanced for computing the head pressure change with cutoff angle under the dam.

Conflict of interest: The authors state no conflict of interest.

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