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"Experimental study of phreatic surface for earth dam with filter"

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ملخص البحث:

يهدف هذا البحث إلى دراسة سطح الضغط الحر للتسرب غير المستقر فى سد ترابى على قاعدة غير منفذة مزود بمرشح وهو الذى يتحكم فى حركة المياه داخل جسم السد. تم إستخدام نموذج الرمل فى التجارب المعملية حيث تم تزويد نموذج السد الرملى بثلاث أنواع من المرشحات وهم المرشح الأفقى والمرشح الرأسى والمرشح الذيلى فى ثلاث أماكن مختلفة بخصائص مختلفة. فى كل مرة يتم تعيين سطح الضغط الحر ومقارنته بسطح الضغط الحر للسد بدون مرشح (الحالة العامة). وأوضحت النتائج أن تزويد السد الترابى المتجانس بمرشح له تأثير واضح على سطح الضغط الحر حيث أنه كلما قلت المسافة بين موضع المرشح وبداية الميل الامامى للسد ابتعد سطح الضغط الحر عن الإصطدام بمؤخرة السد وهو المطلوب.كما أوضحت النتائج أيضا أن زيادة سمك المرشح الأفقى وكذلك زاوية ميل المرشح الرأسى والذيلى عند نفس موضع المرشح لهم نفس التأثير على سطح الضغط الحر.

Abstract

This investigation concerns to study the free water surface (the phreatic line) of the unconfined steady flow through a homogenous earth dam based on an impervious base provided with three types of filter which control the water movement through the earth dam through the sand mode. The sand model runs are carried out with horizontal, vertical and toe filter on three different locations and properties. For each run the phreatic line is determined by using piezometers. Then all cases are compared with the case of earth dam without filter (the original case). The results showed that the phreatic line of a homogeneous earth dam with filter has a clear effect by decreasing the distance of filter position and the dam inlet. Increasing the thickness of horizontal filter, the angle of vertical filter and the angel of toe filter at the same location has the same effect on the phreatic line. The distance between the dam inlet and the start filter position (a/L) has an effect on the phreatic line which clears by decreasing this distance, the phreatic line becomes so far away from the downstream side of the earth dam.

Keywords: Seepage, earth dam, phreatic line, horizontal filter, vertical filter, toe filter.

Introduction

Filters for earth dams were designed specifically to control the seepage through the dam and prevent internal soil movement, that causes great danger with the time may lead to the earth dam failure, so filters in embankment dam should be designed correct and high accurate way to control the phreatic surface. Therefore, researchers studied empirical, graphical and recently numerical methods. Numerical models are used to make acceptable approximations for the Laplace equation in complex flow conditions. The methods of numerical solution, such as finite element [1, 2, 3, 4, 5 and 6] finite difference [7], finite volume [8] and boundary element [9], were used to analyze the phenomenon of seepage through earth dams. Irzooki [10], developed a hybrid solution (velocity hodograph- viscous flow analog) in order to determine the slope of the inflection point of the free surface for flow through an earth dam with horizontal under drain. Irzooki and Jamel [11] studied the characteristics of phreatic line of seepage through homogenous earth dam with and without horizontal filter using Hele-Shaw model. Irzooki [12] investigated the computer program SEEP/W (which is a sub-program of Geo-Studio) to find a new equation for computing the quantity of seepage through homogenous earth dam with horizontal toe drain. Moayeri [13] studied inverse hodograph and conformal mapping to obtain the most accurate analytical solution for seepage through trapezoidal dams taking into account the effect of the inflection point on the free surface. Hathoot [14] used image method to study seepage through an earth dam with a horizontal filter. The earth dam was homogeneous, isotropic and resting on an impervious base. Cabral [15] studied only dams without drainage system, and presented a new BEM formulation using cubic B-splines, which provides continuity till the second derivative of the potential head. Neuman [16] presented an improved finite element approach to the problem of steady state seepage with a free surface by combining the regular Finite Element Method (FEM) with a minimization function for the difference between inflow and outflow seepage through the dam. Abdrabbo [17] used the BEM with constant elements to study the present problem. He suggested different positions for the exit point of the free surface with the drain. According to the author, there is no previous trial to analysis our problem that is determining the location of the free surface and its exact exit point using the BEM. Abdel-Gawad [18] applied the Boundary Element Method (BEM) for Laplace’s equation to solve the problem of seepage through earth dams underlined by horizontal filter, and used linear elements to discretize the boundary of the flow domain. Also, he presented a novel idea to assure convergence of the unknown free surface to the correct one. Jong-Wook [19] proved that with the application of a digital filter which filters out rainfall-induced infiltration into a downstream shell from a measured seepage flow through two large rock-fill dams would make analyzing the seepage behavior of dams more effective. This paper study the seepage surface (the phreatic line) through earth dam provided with horizontal drain, also study the effect of horizontal filter location and thickness on the phreatic line shape. This Experimental work focused on a homogenous earth dam provided with horizontal filter. Determine the phreatic line position, and the exit point of the phreatic surface. It is a necessary step to complete the design of the earth dam. The Laplace equation that governs water seepage cannot be solved analytically, except for cases with very simple and special boundary conditions.

1- Experimental work

Experimental work was carried out using the sand model in the Soil Mechanics Laboratory, Faculty of Benha Engineering, Benha University, Egypt. The sand model tank was with 195 cm length, 70 cm depth and 30 cm width as shown in Photo (1). The earth dam model with 96 cm length, 25 cm depth, and the same width of the tank, it made from wetted sand as shown in Fig.(1). The filter was made from felt and used gravel to increase the filter's volume. The piezometers and their position were shown in Fig.(2). The upstream water level was kept 20 cm and the downstream was kept dry. Horizontal, vertical and toe filter was located on three different position a1, a2 and a3 were shown in Fig.(3). The relative thickness of horizontal filter was changed three times in each location and the angle of vertical or toe filter too were shown in Fig.(4), Fig.(5) and Fig.(6). After reaching steady state in all experimental runs, piezometric heads were measured. Finally, drawing the phreatic line inside the earth dam body by the result of the relation between the ratio of piezometer head (h) and the upstream water depth (h_w), and the ratio of piezometer position (x) and the tank length (L).

Photo (1): General view for sand model.

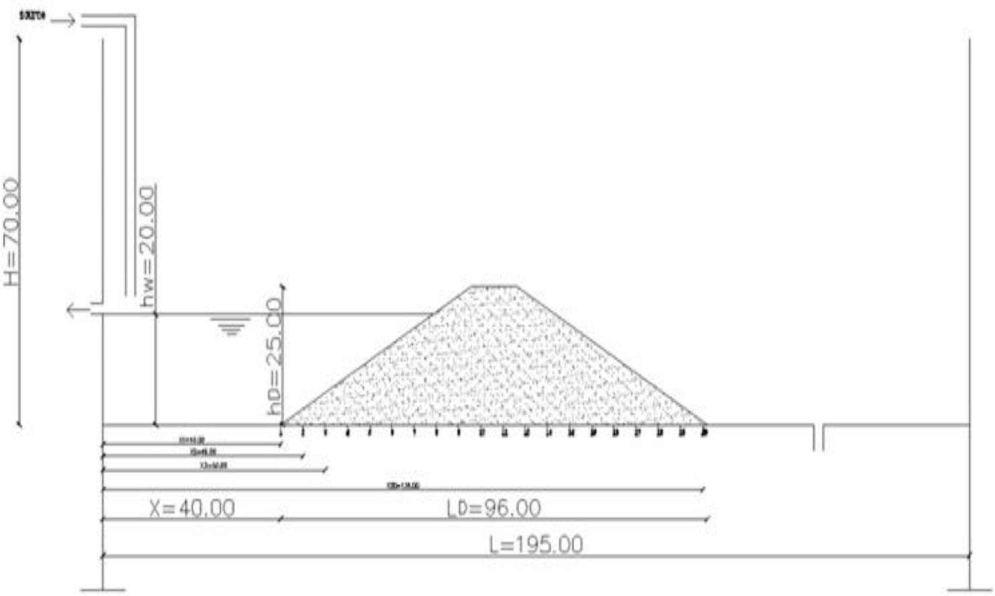

Fig. (1): General view for sand model.

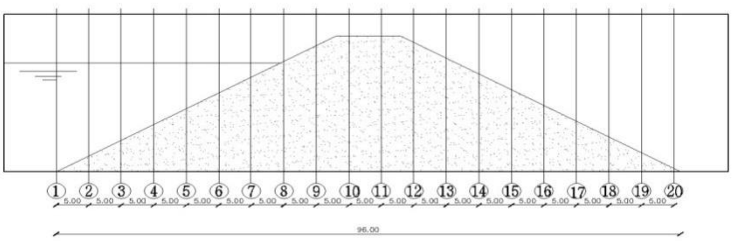

Fig. (2): Piezometers positions.

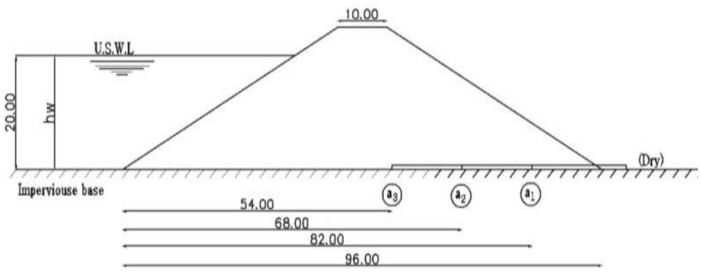

Fig. (3): Earth dam model with horizontal filter in different location.

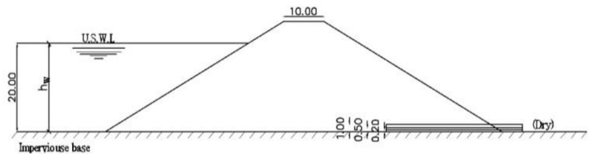

Fig. (4): Earth dam model with horizontal filter in different thickness in each location.

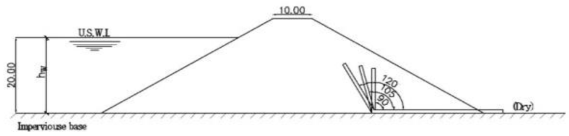

Fig.(5): Earth dam model with vertical filter in different angel in each location.

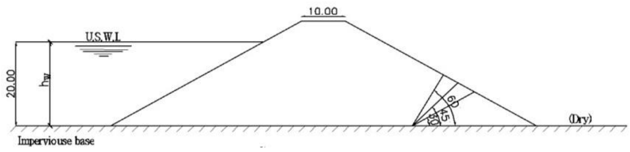

Fig.(6): Earth dam model with toe filter in different angel in each location.

2- Dimensional analysis

The dimensional analysis method for the experimental parameters were applied, the different variables affecting the seepage surface through a homogenous earth dam provided with horizontal filter can be expressed as a function of the following independent variables:

$\frac{h}{hw}$ = f (L, x, L_d, H_d, b_d, θ, a, t, ∝, β, h_w, h, V, Q, ρ_s, D_{50})…................(1)

Applying the Buckingham theorem with (ρs, V, h_w) as repeating variables Eq. (1) can be written in dimensionless form as following;

$\frac{h}{hw} = f\left(\frac{L}{hw}, \frac{x}{hw}, \frac{Ld}{hw}, \frac{Hd}{hw}, \frac{bd}{hw}, \theta, \frac{a}{hw}, \frac{t}{hw}, \propto, \beta, \frac{h}{hw}, \frac{Q}{V\ hw2}, \frac{D_{50}}{L}\right)$ .... (2)

Hence, ($\frac{D_{50}}{hw}$), Q were kept constant, Eq. (2) is reduced to

$$\frac{h}{hw} = f\left(\frac{L}{hw}, \frac{x}{hw}, \frac{Ld}{hw}, \frac{Hd}{hw}, \frac{bd}{hw}, \theta, \frac{a}{hw}, \frac{t}{hw}, \propto, \beta\right) \qquad (3)$$

Where:

Characteristics	Unit	Characteristics	Unit
L: Sand Model length	L	x: Position of piezometer	L
L_d: Embankment length	L	H_d: Embankment height	L
b_d: Embankment crest width	L	θ: Embankment angle in upstream and downstream	-
a: Location of filter	L	t: Thickness of horizontal filter	L
∝: Angle of vertical filter	-	β: Angle of toe filter	-
h_w: Upstream water depth	L	h: Piezometer head	L
V: Velocity of flow	LT^{-1}	Q: Discharge of flow	L^3T^{-1}
ρ_s: Density of water	ML^{-3}	D_{50}: Medium particle diameter	L

3- Analysis and discussion:

3-1 Effect of horizontal filter on seepage surface of a homogeneous earth dam

The effect of horizontal filter thickness on the phreatic line shape inside the earth dam is shown in Fig. (7) to Fig. (9), and from Fig. (10) to Fig. (12) illustrate effect of horizontal filter location on the phreatic line shape inside the earth dam for cases of a homogeneous earth dam with horizontal filter at locations a_1=0.42, a_2=0.35, and a_3=0.28 with different relative thicknesses t_1=0.01, t_2=0.025, and t_3=0.05. From these figures, it notes that, the seepage surface of earth dam with horizontal filter for all locations and relative thicknesses was lower than the seepage surface of earth dam without filter. The thickness of horizontal filter at the same position has no effect on the phreatic line.

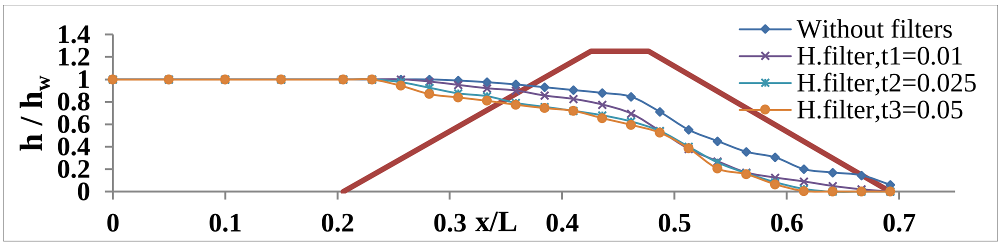

Fig.(7): Comparing phreatic surface of earth dam model provided with horizontal filter for different relative thicknesses at relative location (0.42) with the original case.

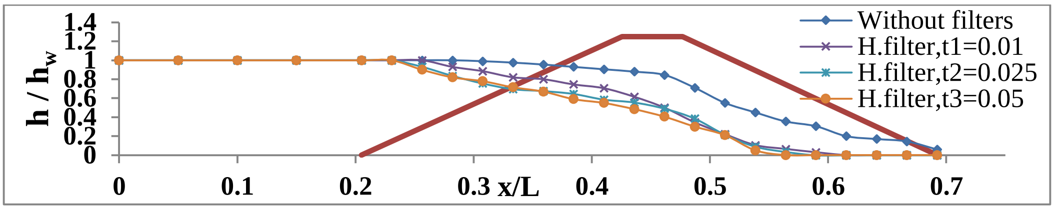

Fig.(8): Comparing phreatic surface of earth dam model provided with horizontal filter for different relative thicknesses at relative location (0.35) with the original case.

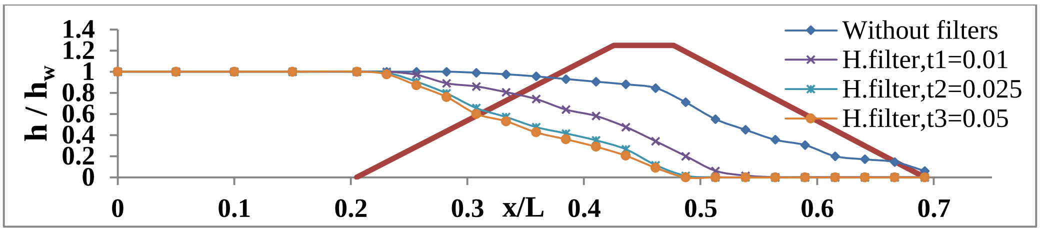

Fig.(9): Comparing phreatic surface of earth dam model with horizontal filter for different relative thicknesses at relative location (0.28) with the original case.

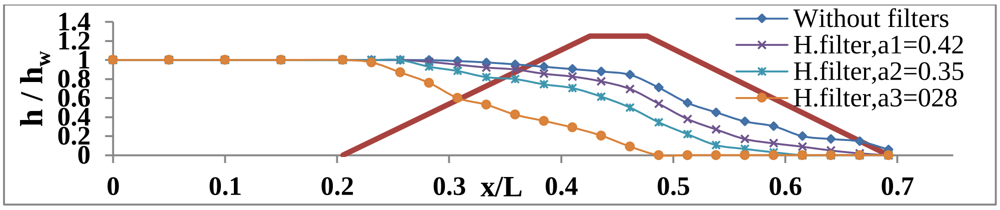

Fig.(10): Comparing phreatic surface of earth dam model provided with horizontal filter for relative thickness (0.01) at relative locations (0.42, 0.35, 0.28) with the original case.

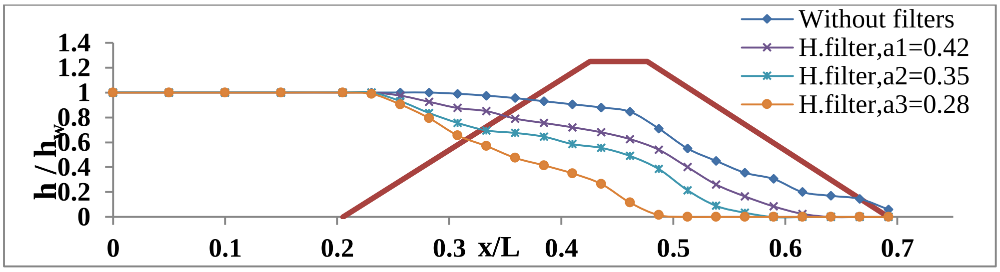

Fig.(11): Comparing phreatic surface of earth dam model provided with horizontal filter for relative thickness (0.025) at relative locations (0.42, 0.35, 0.28) with the original case.

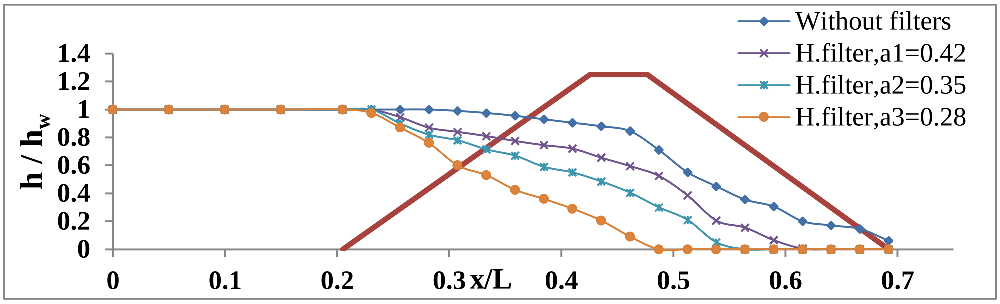

Fig.(12): Comparing phreatic surface of earth dam model provided with horizontal filter for relative thickness (0.05) at relative locations (0.42, 0.35, 0.28) with the original case.

3-2 Effect of vertical filter on seepage surface of a homogeneous earth dam

Figs. (13) through (15) highlight effect of the angle of vertical filter on the phreatic line shape inside the earth dam and Fig. (16) to Fig. (18) shows effect of vertical filter location on the phreatic line shape inside the earth dam for cases of a homogeneous earth dam with vertical filter at relative locations (0.42, 0.35, 0.28) with different angel (90°, 105°, 120°). from the previous results, the seepage surface of earth dam with vertical filter for all locations and angels was lower than the seepage surface of earth dam without filter. The angel of vertical filter at the same position has the same effect on the phreatic line.

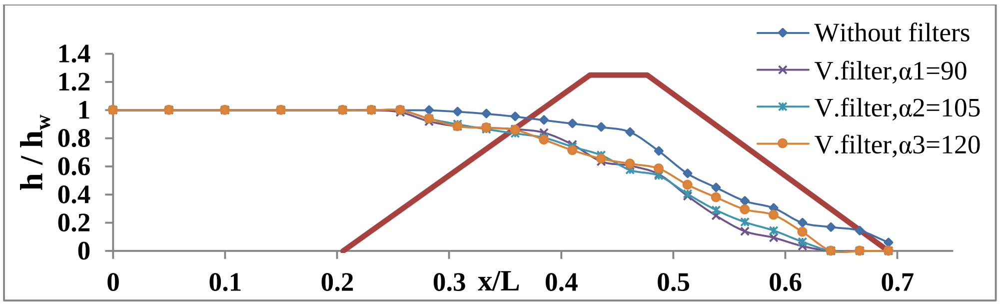

Fig.(13): Comparing phreatic surface of earth dam model with vertical filter for angles (90°, 105°, 120°) at relative location (0.42) with original case.

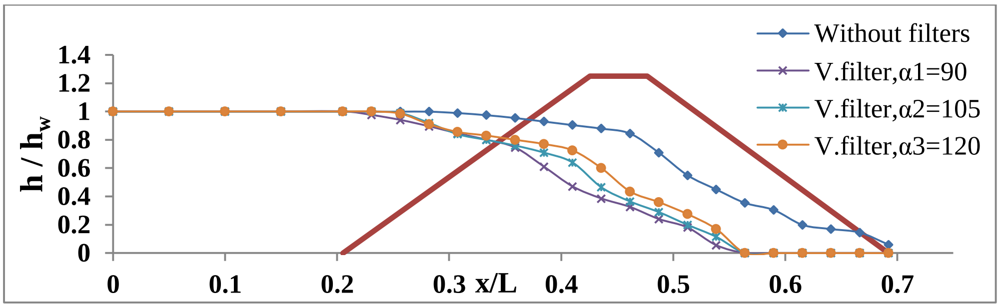

Fig.(14): Comparing phreatic surface of earth dam model with vertical filter for angles (90°, 105°, 120°) at relative location (0.35) with original case.

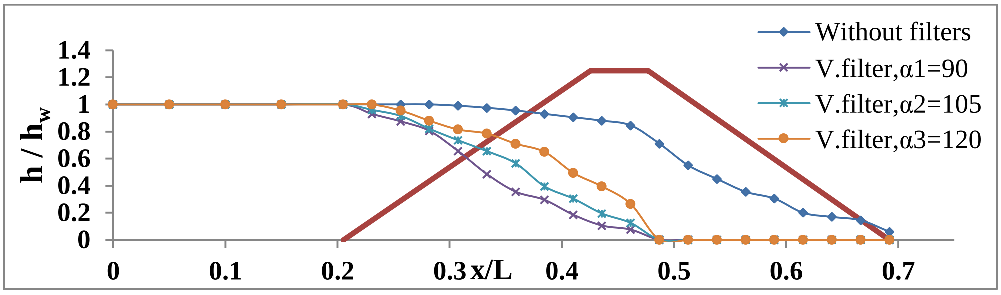

Fig.(15): Comparing phreatic surface of earth dam model with vertical filter for angles (90°, 105°, 120°) at relative location (0.28) with original case.

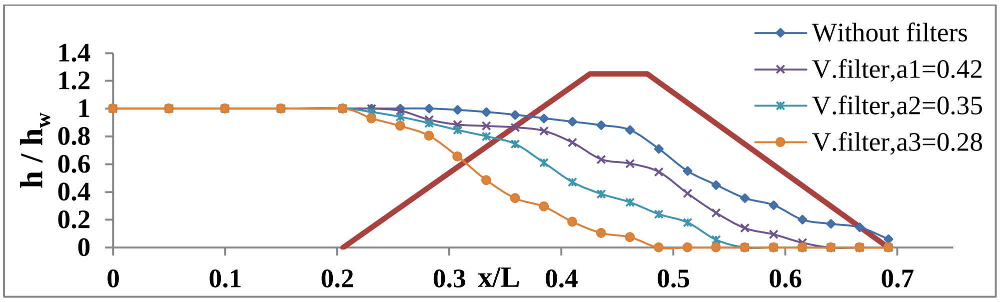

Fig.(16): Comparing phreatic surface of earth dam model with vertical filter for angle (90°) at relative locations (0.42, 0.35, 0.28) with original case.

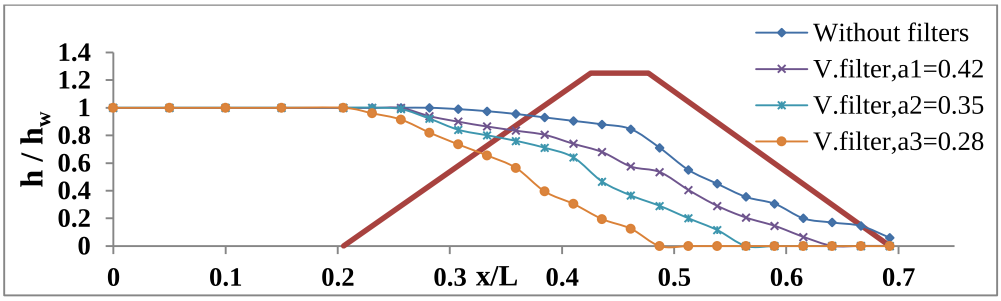

Fig.(17) Comparing phreatic surface of earth dam model with vertical filter for angle (105°) at relative locations (0.42, 0.35, 0.28) with original case.

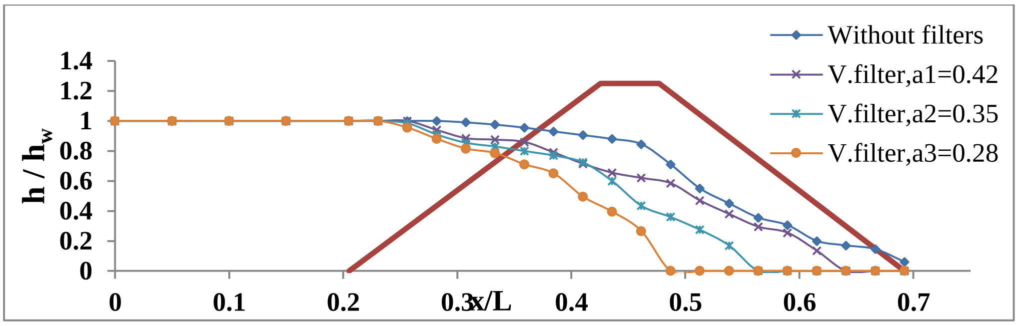

Fig.(18) Comparing phreatic surface of earth dam model with vertical filter for angle (120°) at relative locations (0.42, 0.35, 0.28) with original case.

3-3 Effect of toe filter on seepage surface of a homogeneous earth dam

Figs. (19) through (21) present effect of the angle of Toe filter on the phreatic line shape inside the earth dam, and Fig. (22) to Fig. (24) shows effect of toe filter location on the phreatic line shape inside the earth dam for cases of a homogeneous earth dam with toe filter at relative locations (0.42, 0.35, 0.28) with different angel (30˚, 45˚, 60˚) cm. the results from this figures illustrates that the seepage surface of earth dam with toe filter for all locations and angles was lower than the seepage surface of earth dam without filter. The angel of toe filter at the same position has the same effect on the phreatic line.

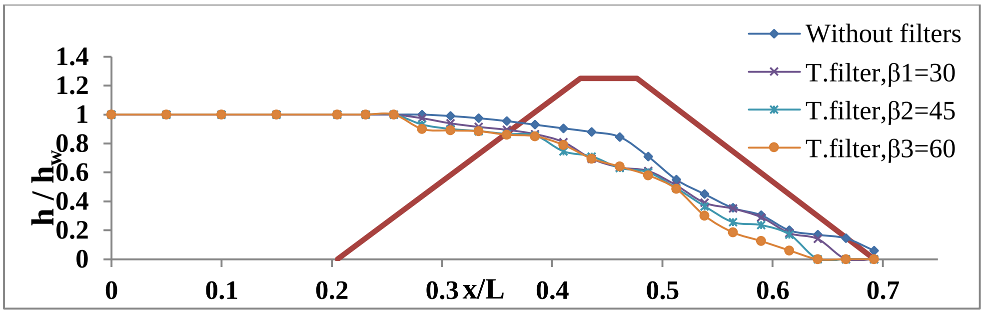

Fig.(19): Comparing phreatic surface of earth dam model with toe filter for angles (30º, 45º, 60º) at relative location (0.42) with original case.

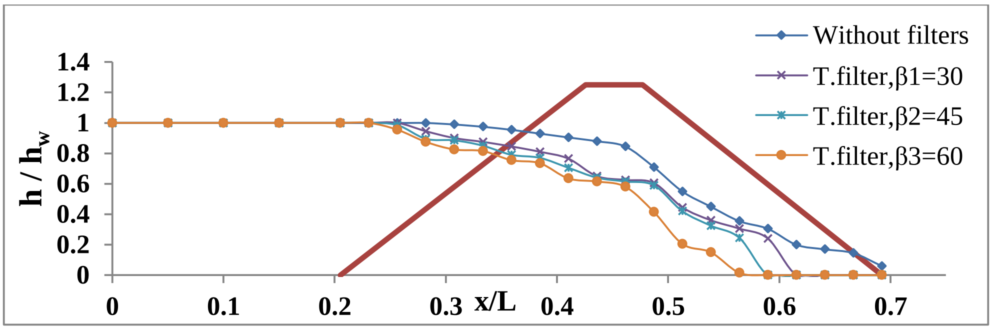

Fig.(20): Comparing phreatic surface of earth dam model with toe filter for angles (30º, 45º, 60º) at relative location (0.35) with original case.

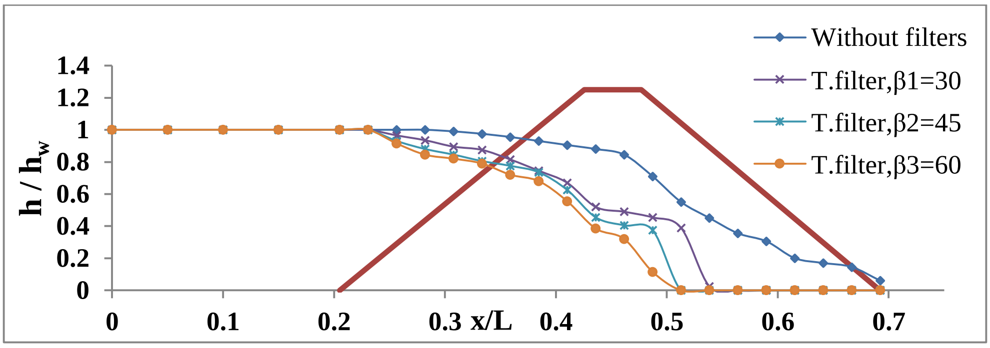

Fig.(21): Comparing phreatic surface of earth dam model with toe filter for angles (30º, 45º, 60º) at relative location (0.28) with original case.

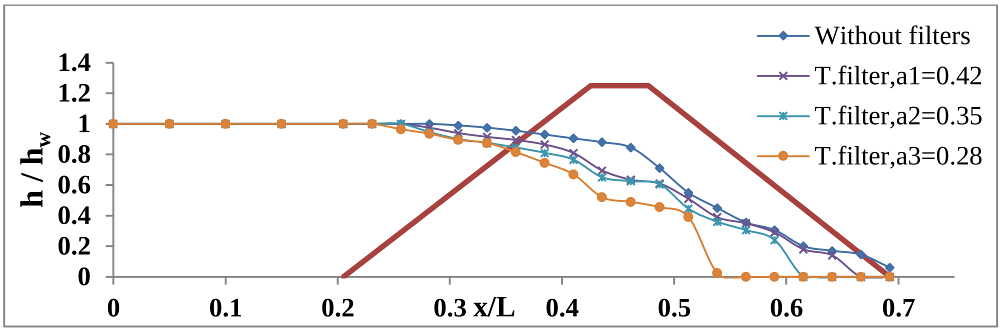

Fig.(22): Comparing phreatic surface of earth dam model with toe filter for angle (30°) at relative locations (0.42, 0.35, 0.28) with original case.

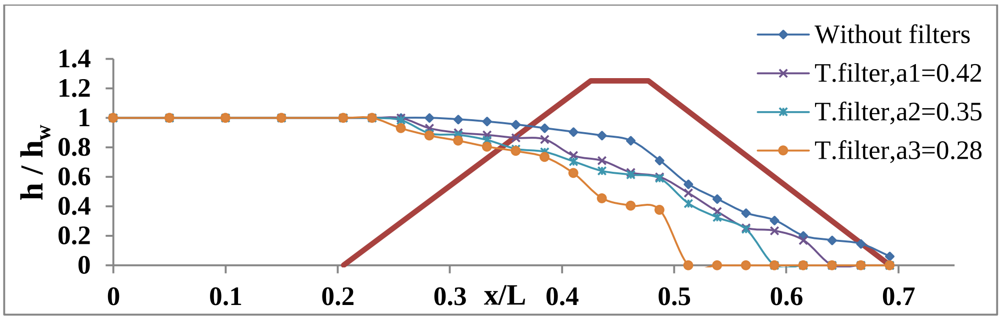

Fig.(23): Comparing phreatic surface of earth dam model with toe filter for angle (45°) at relative locations (0.42, 0.35, 0.28) with original case.

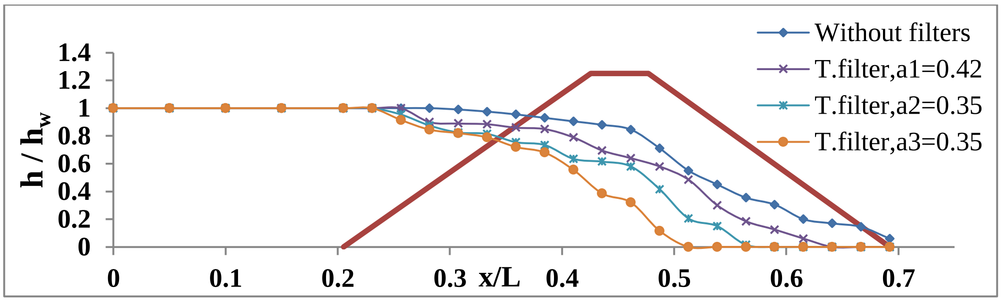

Fig.(24): Comparing phreatic surface of earth dam model with toe filter for angle (60°) at relative locations (0.42, 0.35, 0.28) with original case.

From all the above comparisons it is clear that the best relative location for the all types of filter inside the earth dam is a3=0.28, it means that the lower relative distance between the dam inlet and the filter position gives better results for the phreatic line inside the earth dam body. And therefore, the phreatic surface is far away from the downstream slope of the earth dam, which is required.

By comparing the best of all locations and properties of three types of filter horizontal, vertical, and to as shown in Fig.(25).

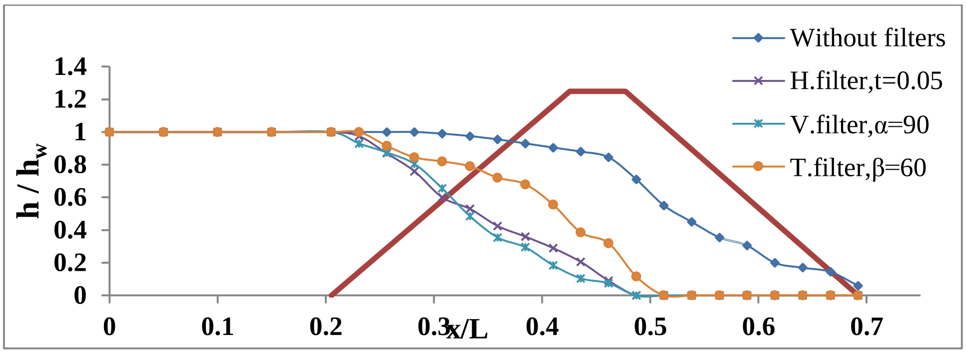

Fig.(25) Comparing the best phreatic surface of earth dam model with horizontal, vertical, and toe filter at the best relative location (0.28) with original case.

From the last comparing, it showed that horizontal and vertical filter give the lower and farther phreatic surface inside the earth dam body than toe filter. From this results, the best type of filters used in experimental work in this research is horizontal filter because it achieves the required purpose, and more economic also.

4- Conclusions

According to this study the obtained results and their discussions, the following conclusions can be summarized as follows:

1. Decreasing the distance between the dam inlet face and the filter position lead to decreasing free water surface for the same cross section of an earth dam.
2. Decreasing the distance between the dam inlet face and the filter position lead to increasing the seepage flow rate for the same cross section of an earth dam.
3. Effect of horizontal filter thickness on phreatic surface at same position gives the same effect.
4. Effect of vertical filter angle on phreatic surface at same position gives the same effect.
5. Effect of toe filter angle on phreatic surface at same position gives the same effect.
6. Best type of filter is horizontal filter and it is economic.

5- References:

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