Experimental Analysis of Seepage Flow under Small Hydraulic Structure with Two Inclined Cutoffs

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Abstract:-

In the present investigation, an experimental work by using physical model and numerical model by using Geo-studio software were done to test the effect of using two inclined sheet piles one located at the upstream and the other at the downstream side of the structure through a pervious soils beneath hydraulic structures. Also, it has been studied through this investigation, the effect of cutoffs inclination angle on exit gradient and uplift pressure head under hydraulic structure. Different cases were analyzed by using Geo-studio model by taking different direction of inclination of the sheet piles. Further investigation of the effects of using these inclined cutoffs with different hydraulic conductivity ratio (Kr =Kx/Ky) and various orientation of soil ellipsoid was also carried out. The results obtained from the experimental analysis were found to be comparable with that obtained from numerical model for the seepage flow, the exit gradient variation and the uplift pressure distribution. It has been concluded that when the inclination of both the upstream and the downstream cutoffs are in the adverse direction of the inclination of the soil ellipsoid, a significant reduction in uplift head is obtained, but no considerable change in the hydraulic gradient along the downstream bed.

Keywords: Inclined cutoff, Hydraulic structures, Geo-Studio, Uplift Pressure, Exit Gradient, Factor of Safety.

1. Introduction

Historically, batter piles (inclined piles) were used to resist lateral forces and inclined forces specially in water front structures. The forces on these structures are axial loads due to self-weight of a superstructure. However, due to poor performance in recent time, plumb piles (vertical piles) are now the system of choice. Nevertheless, there are situations where batter piles are desirable, for example, where the new structure has to be compatible with an existing batter pile structure or has high service-level lateral loading conditions such as ship mooring [7]. In addition, certain difficulties might be experienced in driving the sheet piles vertically downwards [10]. Most of the earlier studies were concerned only with one embedded inclined sheet pile. However, limited literature is available concerning the use of two inclined sheet piles. The calculated exit gradient values, flow rates, and uplift pressure were proved to be affected by changing the slope angle of the sheet pile and varying the soil conditions. Recently, an attempt was made to study the effect of using two inclined cutoffs; one located at the upstream and the other at the downstream of the hydraulic structure; on the exit gradient and the uplift pressure head under hydraulic structure experimentally as well as by using the finite element method. A model was prepared to compute the piezometric head distribution for different flow conditions and soil characteristics. The calculated exit gradient values, flow rates, and uplift pressure were shown to be affected by changing the slope angle of the sheet pile and varying the soil and flow conditions.

Limited literature is available for seepage through pervious medium beneath hydraulic structures with inclined cut-offs as a control device.

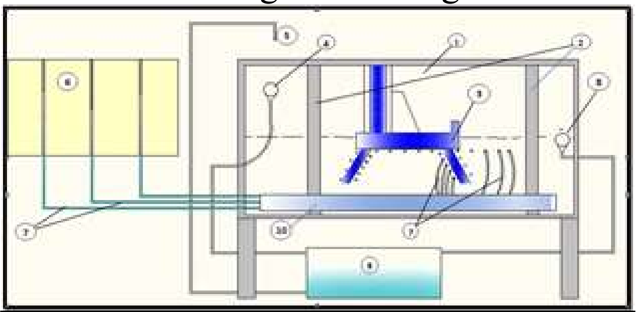
The distribution of uplift pressure under weirs with a single sheet pile inclined to the floor has been determined. This problem was investigated by electrical analogy method [10]. The static and cyclic lateral responses of vertical and batter piles have been studied based on a newly developed nonlinear finite element code using hyperbolic and modified hyperbolic relations to represent the nonlinear behavior of soil [9]. A two dimensional finite element model have been developed to analyze seepage flow beneath a dam with an inclined sheet pile. The effects of inclined cutoffs, permeability ratio and foundation soil depth on the exit gradient, uplift pressure and flow rate have been studied [3]. The exit gradient variation along the downstream side for an inclined sheet pile has been obtained using analytical solution. The solution was developed using the Schwarz-Christoffel transformation. Results indicate that the exit gradient is decreased as the angle is increased.. Moreover when the angle of inclination more that 90o the protection length decreases with the angle of inclination increase [4]. An electrolytic tank has been used to study the effect of using a perforated blanket downstream the aprons of heading –up structures on the safety against piping [1]. An experimental and theoretical study has been conducted for a pizometric head distribution under hydraulic structures to test the effect of upstream, intermediate and downstream sheet piles inclination, and then the optimum case of the uplift pressure reduction was found [6]. An analytical solution has been used to obtained seepage flow below a dam structure with inclined cutoff located anywhere along the base of the dam. The results reveal that the pressure is reduced when the inclination of the cutoff is towards the downstream side of the dam [8]. The effect of cut-off inclination angle on exit gradient and uplift pressure head under hydraulic structure have been investigated. The optimum location and angle of inclination of cut-off have been also determined. This problem is solved using the finite element method by using (ANSYS 11.0) [2].

Since numerous numerical models have been developed for prediction of seepage flow under these structures and have been rarely verified by experimental data, application of some experimental methods for this purpose is vital. The first objective of the present experimental investigation is aimed at fulfilling this requirement and the second objective is to verify the validity of the existing numerical methods in designing seepage control measures for hydraulic structures constructed on alluvial foundations.

To fulfill this objective, the general cases underneath the floor of the hydraulic structure were studied by using the (GEO-SLOP, SEEP/W 2007 version 7.10 build 4143).

Finally, the results obtained from the GEO-SLOP software were compared with the results obtained from the experimental model. Further investigation of the effects of using two inclined cutoffs with various soil properties and various orientation of soil ellipsoid was also carried out.

Experimental Setup Laboratory experiment were conducted in a tank of 2 m long, 0.5m width and 1m height. The bottom and sidewalls of this tank were made of Acrylic of (8mm) thickness. Fig.1 shows a schematic representation of the experimental equipment and the other facilities, such as: water supply system, joints and connectors, blanket and sheet pile elements, recirculation tank, submerged pump, piezometer tubes and discharge measuring device.



1-Seepage Tank (Acrylic) 2-Iron Frame 3-Superstructure 4-Overflow 5-Inlet House 6-Piezometers Boards 7- Piezometers 8-Outlet 9-Sump Tank provided with submerged pump 10-Plastic Cover for Piezometers

Fig. 1 Schematic diagram of experimental setup

The seepage tank was fixed on proper steel frame such as iron angles and channel sections. Fig. 2 shows the details of the steel frame.

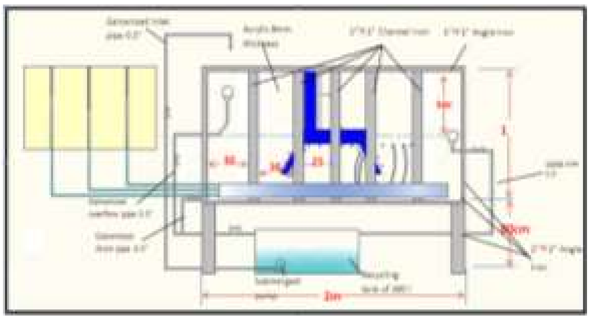


Fig. 2 Detail of the steel frame of the experimental setup

The seepage tank is depicted in Fig.3. In fact before any experiment was conducted, the tank was filled with water and kept for a period of 48 hours with all possible outlets closed, and was found that no changing in the level of the water in the tank.

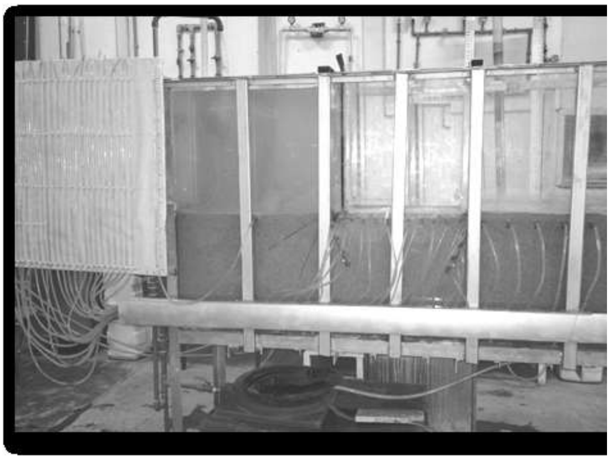


Fig.3 General Setup of the experimental work

The soil chosen for the experiment consists of sieved sand with the sieve analysis shown in Fig. 4. The bottom of the tank was filled with this material to a depth of 50 cm. Using Darcy's Law, the following single phase permeability for fine sand was calculated:

K= 42.3 m/day Fine Sand

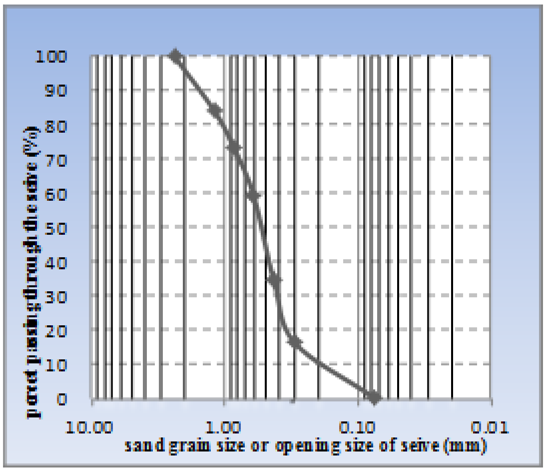


Fig. 4 Sieve analysis curve for fine sand

Acrylic walls were used to build the body of the superstructure which consists of two parts. The first part simulated as foundation of a structure (60 cm long × 50 cm wide) (Fig. 5). This base is connected with the upstream and downstream cutoffs by gluing rubber strips. These strips allow free movement for the cutoffs to achieve different inclinations with the horizontal base. The contact area between the cutoffs and the tank walls was sealed with the aid of the rubber glued (silicone) to avoid water leakage through it.

It has been noticed that after running the model, the sand settled down to a level less than the level of the base of the structure, and that might affect the piezometers reading. Therefore to avoid that, an opining of 20× 20 cm was made on the base of the superstructure to refill the seepage tank with sand specially at the area under the structure. This opening could be closed again by a small sheet of Acrylic using silicone as shown in Fig.5. The other part of the superstructure is an Acrylic gate. This gate consists of vertical rectangular of Acrylic sheet, 52cm in height, 50 cm in width and 6mm thickness with an additional element of triangular sheet for supporting purpose. Those two sheets fixed together by sort of adhesion solution (chloroform). The both edge of the vertical plate (gate) covered with rubber strips such as this plate moves as a slide inside a housing made from Acrylic strips which were fixed at the internal side walls of the seepage tank and also at the base of the superstructure using chloroform and silicon.

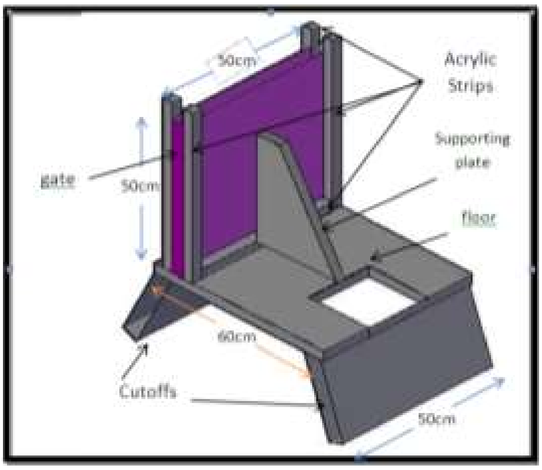


Fig.5 Schematic diagram of superstructure

31 piezometers were placed at the right side of the tank at different locations under the superstructure and along the sheet piles. These piezometers are from clear and flexible Acrylic tube and are connected to seepage tank through a copper pipe (which is usually used for air-conditioning units). The copper pipes are punctured along the length from its bottom side and then well covered with a piece of pad tissue serving as a semi permeable membrane to prevent the movement of sand particles inside the tube. All these piezometers were fixed at drilled holes each of (6.5 mm) and sealed with silicone at the contact area with the basin to ensure proper waterproofing.

The seepage tank is provided with some equipment in order to control the water levels and the flow measurements. Two funnels were used in the seepage tank for this purpose one at the upstream side and the other at the downstream side of the structure. The upstream funnel was fixed on the ruler by a screw-bolt in such away; it can be adjusted to get different upstream heads. The ruler was placed and fixed at the internal wall of the upstream side by fixing screw.

The downstream funnel was covered with a semi permeable membrane to prevent movement of sand particles in the direction of the drained water. This funnel was fixed at the downstream side of the seepage tank to a depth of 0.5 m (sand depth) in order to get the downstream head equal to zero.

A volumetric method was employed to measure the seepage flow discharge. Upstream water heads were 300, 350, and 450 mm above the flume bed, while the downstream water level was kept at zero. The superstructure itself was assumed as being impermeable with a height of 500 mm above the flume bed which gives a 1:1 ratio with respect to foundation thickness. All experimental conditions are summarized in table 1. These experiments were carried out to measure the uplift pressure under the \;;kl-/lk--;superstructure and the exit gradient along the downstream side of the superstructure for each scenario mentioned in table 1.

Table 1. Experimental conditions for different scenarios investigated for D=10m, B=12m and H=6m.

Experimental scenarios	S_1 (m)	S_2 (m)	θ_1	θ_2
1	4	4	65^o	65^o
2	4	4	65^o	115^o

3	4	4	115°	65°
4	4	4	115°	115°
5	3	3	65°	65°
6	2	3	65°	115°
7	2	4	115°	65°
8	4	2	115°	115°
9	3	2	65°	65°
10	4	2	65°	115°
11	1	2	115°	65°
12	2	1	115°	115°

1. The Geo-studio Model

The Finite element method was used to analyze the general case study shown in Fig.1 using the Geo-studio program (GEO-SLOP, SEEP/W 2007 version 7.10 build 4143). The hydraulic structure is illustrated in Fig. 6.

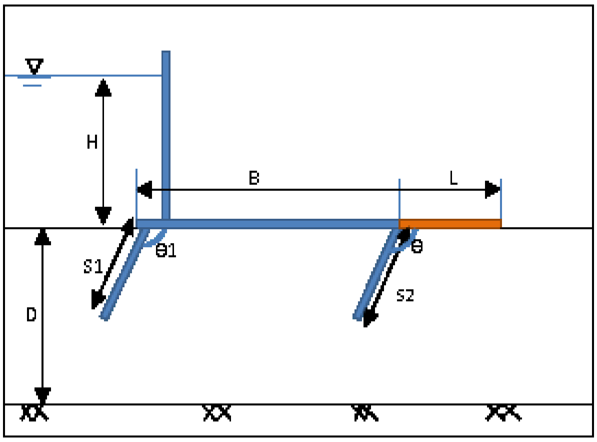


Fig. 6 the variables involved in the problem

This weir was taken to study multi cases of the seepage, where H=Head difference between upstream and downstream the structure, B=Length of the apron, L= Length of downstream protection, S_1=Depth of upstream cutoff, S_2=Depth of downstream cutoff, D=Depth of impervious layer, Θ_1=Angle of orientation of upstream cutoff, Θ_2= Angle of orientation of downstream cutoff.

The problem in Fig. 6 shows the hydraulic structure resting on a pervious homogeneous isotropic or anisotropic soil of depth (10)m and hydraulic conductivity $4.899*10^{-4}$ m/s. The problem was simulated for penetration depth (3m) of upstream and downstream sheet piles of the hydraulic structure with different inclination (60°, 65°, 70°, 80°, 90°, 100°, 110° , 115° , 120° and 130°). The length of the modeled zone was 40 m and length of floor of the structure (12)m were simulated. The steady seepage flow occurs due to differential head (10)m between the upstream and the downstream sides of the structure.

After drawing the problem, a mesh is required that places the junctions or the nodes at the points corresponding to those at which piezometer reading were taken in the seepage tank model. The elements used are square and triangular. The total number of nodes was 1743 and the total number of elements was 1625. A 2D simulation was performed for multi-different cases. For each case the program solves the seepage equation of the steady-state flow. The values of exit gradient, seepage flow beneath the structure, and the uplift pressure under the structure were calculated.

Fig. 7 shows the structure for one of the cases with the discretization process. This figure shows also the uplift Pressure Distribution beneath the Structure, flow lines and equipotential lines.

Fig. 8 shows the distribution of the exit gradient along the downstream side of the structure.

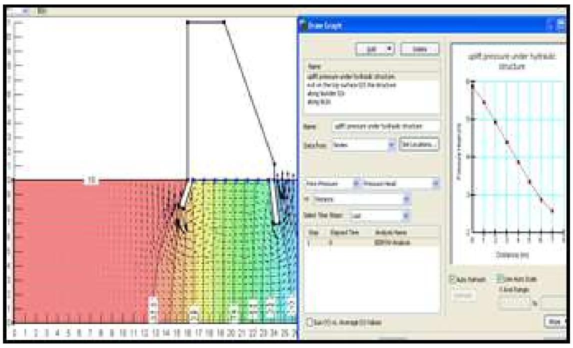


Fig. 7 Uplift pressure distribution beneath the structure, flow lines and equipotential lines. (The zero distance in the distribution figure refer to the left point of the dam base)

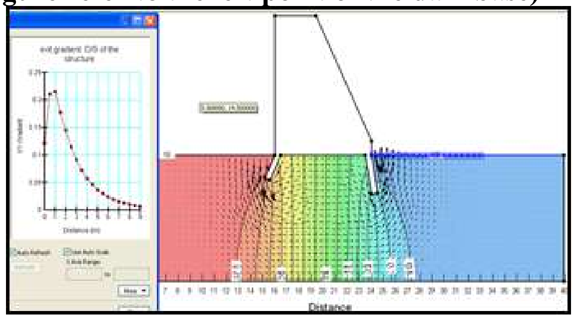


Fig. 8 Distribution of the Exit Gradient along the Downstream Side. (The zero distance in the distribution figure refer to the right point of the dam base)

2. Comparison of Experimental Results and Geo-studio Results

The experimental scenarios that have mentioned previously in table 1, were conducted in order to measure the piezometric head at different location; under the superstructure, along the inclined cutoffs and at the downstream side of the superstructure. In order to compare the experimental results with the results obtained using Geo-studio model, the measuring pressure head should be obtained in prototype scale using the scale ratio of 1:20. The results show high agreement in behavior for both pressure cells theoretically and measured. Table 2 shows the comparisons of the pressure head between the experiment cases and the Geo-studio model. The results show that the difference between the calculated pressures head and the measured one for range between (2.96% - 18.61%).

Table 2. Comparison Between the Geo –studio Model with the Physical Model for the Case Number 4 (S_1=4m , S_2=4m , θ_1=115^o , θ_2=115^o , H=7m , K_r=1.35, D=10m, B=12m) (the scale ratio =1:20)

point position	Piezometer No.	Experimental scale			Experimental model in Prototype Scale				Geo-studio model	Difference %
		X (cm)	Y (cm)	Piezometer Reading (cm)	X (m)	Y (m)	Piezometric head (m)	Pressure head (m)	Pressure head (m)	
	1	40	47	86.3	8	9.4	17.26	7.86	7.45	5.22
along U/S sheetpile	a	68	43	80.8	13.6	8.6	16.16	7.56	8.562776	-13.26
	2	63	32	78.8	12.6	6.4	15.76	9.36	9.020054	3.63
	3	65	38	78.5	13	7.6	15.7	8.1	7.54777	6.82

	4	63	39	73.5	12.6	7.8	14.7	6.9	6.342038	8.09
	5	65	44	72	13	8.8	14.4	5.6	5.160455	7.85
under hydraulic structure	6	75	50	71.6	15	10	14.32	4.32	4.105581	4.96
	7	80	50	70.35	16	10	14.07	4.07	3.949698	2.96
	8	85	50	69.5	17	10	13.9	3.9	3.765136	3.46
	9	90	50	68.9	18	10	13.78	3.78	3.567418	5.62
	10	95	50	67.9	19	10	13.58	3.58	3.366101	5.97
	11	105	50	67.3	21	10	13.46	3.46	3.169194	8.40
	12	110	50	66.15	22	10	13.23	3.23	2.985849	7.56
	13	115	50	65.1	23	10	13.02	3.02	2.828624	6.34
	14	120	50	64.2	24	10	12.84	2.84	2.714176	4.43
	15	125	50	64.05	25	10	12.81	2.81	2.655617	5.49
along D/S sheetpile	16	126	45	63.9	25.2	9	12.78	3.78	3.537655	6.41
	17	124	41	64.1	24.8	8.2	12.82	4.62	4.40021	4.76
	18	122	37	65.5	24.4	7.4	13.1	5.7	5.199617	8.78
	19	120	33	66.15	24	6.6	13.23	6.63	5.747954	13.30
for exit gradient measurement	20	130	48	50.7	26	9.6	10.14	0.54	0.729832	8.14
	21	140	48	50.4	28	9.6	10.08	0.48	0.585901	6.25
	22	150	48	50.3	30	9.6	10.06	0.46	0.560778	18.61
	23	160	48	50.2	32	9.6	10.04	0.44	0.541604	16.75
	24	170	48	50.14	34	9.6	10.028	0.428	0.52967	15.16

Another comparison was conducted between the seepage flow obtained using Geo-studio model with the one obtained from the seepage tank model. The result shows an acceptable agreement between the calculated results and the measured one for the seepage flow with maximum difference -13.72%. The data are listed in Table 3.

Table 3. Comparison of Seepage Flow Between the Geo –studio Model with the Physical Model

No of Experiment	head (m)	Physical model				Geo-studio model	Difference %
		Collected volume of water (liter)	Time (sec)	Seepage $(m^3/s)/0.5m * 10^{-5}$	Seepage $(m^3/s)*10^{-5}$	Seepage $(m^3/s) *10^{-5}$	
1	6	1	31	3.2258	6.45	6.9533	-7.77615
	7	1	25	4	8	8.1122	-1.4025
	9	1	21	4.7619	9.52	10.43	-9.515
2	6	1	28	3.5714	7.14	7.583	-6.162
	7	1	24	4.1667	8.33	8.8468	-6.1616
	9	1	19	5.2632	10.5	11.374	-8.053
3	6	1	30	3.3333	6.67	6.4634	3.049
	7	1	26	3.8462	7.69	7.5406	1.9722
	9	1	20	5	10	9.6951	3.049
4	6	1	31	3.2258	6.45	6.9669	-7.98695
	7	1	25	4	8	8.128	-1.6
	9	1	21	4.7619	9.52	10.45	-9.725
5	6	1	27	3.7037	7.41	7.7238	-4.2713
	7	1	22	4.5455	9.09	9.0111	0.8779
	9	1	19	5.2632	10.5	11.586	-10.067
6	6	1	23	4.3478	8.7	8.6929	0.03165
	7	1	20	5	10	10.142	-1.42
	9	1	17	5.8824	11.8	13.039	-10.8315
7	6	1	27	3.7037	7.41	7.2803	1.71595
	7	1	25	4	8	8.4937	-6.17125
	9	1	20	5	10	10.92	-9.2
8	6	1	26	3.8462	7.69	7.5702	1.5874
	7	1	23	4.3478	8.7	8.592	1.192
	9	1	18	5.5556	11.1	11.047	0.577
9	6	1	25	4	8	8.347	-4.3375
	7	1	22	4.5455	9.09	9.738	-7.118
	9	1	17	5.8824	11.8	12.52	-6.42
10	6	1	25	4	8	8.261	-3.2625
	7	1	22	4.5455	9.09	9.637	-6.007
	9	1	18	5.5556	11.1	12.39	-11.51
11	6	1	26	3.8462	7.69	8.7477	-13.7201
	7	1	21	4.7619	9.52	10.206	-7.163
	9	1	17	5.8824	11.8	13.122	-11.537
12	6	1	25	4	8	8.34	-4.25
	7	1	22	4.5455	9.09	9.73	-7.03
	9	1	18	5.5556	11.1	12.51	-12.59

Fig. 9 and Fig. 10 represent the comparison of the uplift pressure distribution under the structure and exit gradient variation along the downstream side of the structure versus the distance, respectively. Through these two figures
the obtained results; by Geo-studio model compared with the measured one using physical model. The figures show high agreement between calculated results and measured ones for both the uplift pressure distribution and the exit gradient variation.

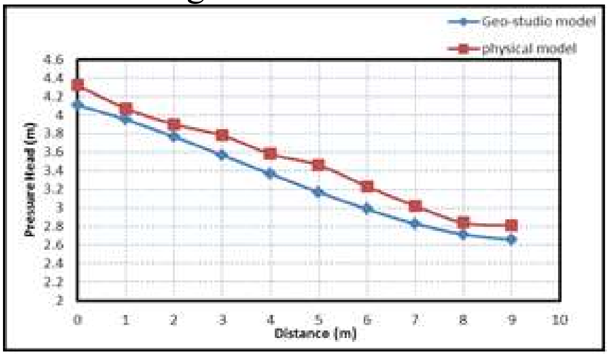


Fig. 9 Comparison of the uplift pressure distribution under the structure between the experimental results and the geo-studio model results for the experiment No.4 (S_1=4m , S_2=4m , Θ_1=115^o , Θ_2=115^o , H=7 m , K_r=1.35, D=10m, B=12m)

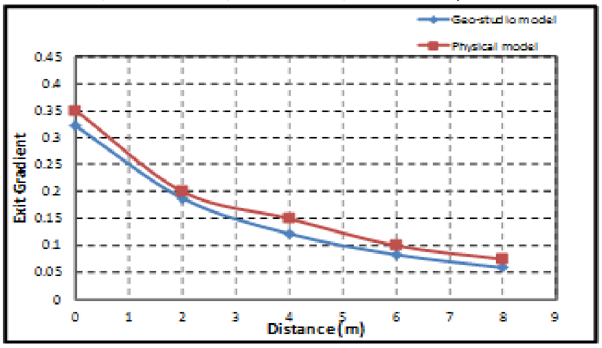


Fig. 10 Comparison of exit gradient variations downstream of the structure between the experimental results and the geo-studio model results for the experiment No.4, (S_1=4m , S_2=4m , Θ_1=115^o , Θ_2=115^o , H=7 m , K_r=1.35, D=10m, B=12m)

3. Effects of the Inclined Cutoffs

In order to study the effect of using an inclined cutoff (either upstream or downstream cutoff), either on uplift pressure on the foundation of the structure or on exit gradient downstream of the structure, some cases where chosen to be analyzed by using Geo-studio modeling. For a given upstream head (H), depth of impervious layer (D), width of foundation (B) and depths the upstream and the downstream cutoffs (S_1, S_2), different angle of orientation of the upstream and downstream cutoffs (Θ_1, Θ_2), the hydraulic conductivity ratio ($K_r = K_x/K_y$) and the orientation of soil ellipsoid were simulated (Alfa). The following mentioned curves have been obtained for H=10m, S_1= S_2=3m, B=12m and D=10m.

Fig. 11 and Fig. 12 show the uplift pressure distributions and the exit gradient variation respectively, changing over various orientations of the downstream cutoffs at various angles of inclination, namely 60^o, 70^o, 80^o, 90^o, 100^o, 110^o, 115^o, 120^o and 130^o. These simulations have been carried out for K_r equal to 1 and with vertical upstream cutoff. As shown in the above figures, a high values for exit gradient are developed if the cut-off is inclined towards the upstream side (Θ_2 is greater than 90°), and the uplift head reduces as Θ_2 becomes greater than 90°. On the other hand, when Θ_2 decreases towards the downstream ($\Theta \leq 90$) the exit gradient decreases while the uplift pressure increases.

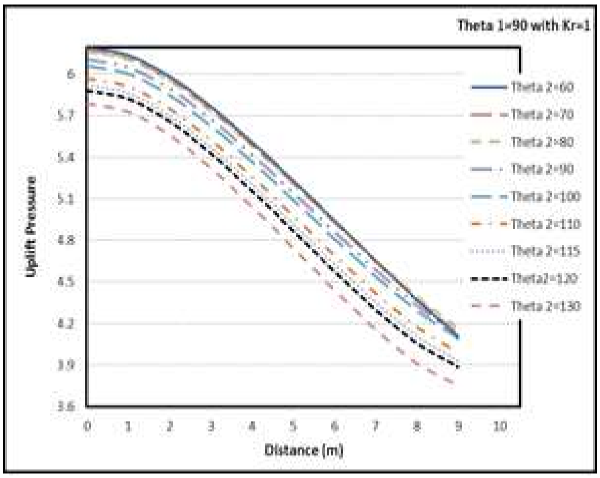


Fig. 11 Variation of uplift pressure under hydraulic structure with different inclination (Θ_2) of the downstream cutoff with K_r=1.

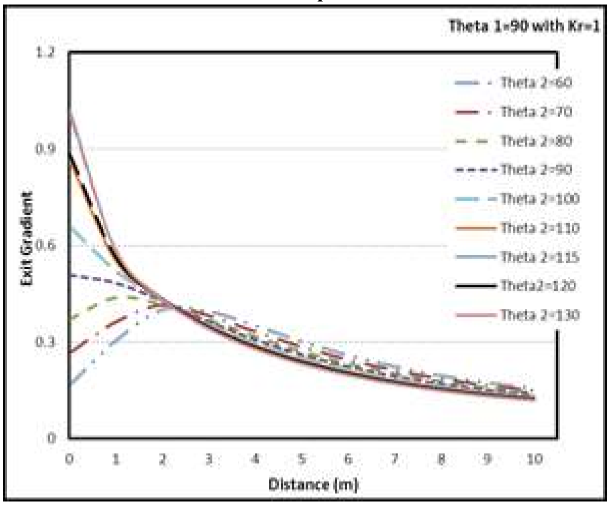


Fig.12 Variation of exit gradient for a hydraulic structure with different inclination (Θ_2) of the downstream cutoff with K_r=1.

Fig. 13 and Fig. 14 show the uplift pressure distributions and the exit gradient variation respectively, changing over various orientations of the upstream cutoffs at various angle of inclination of the upstream cutoff, namely, 80°, 90°, 100° and 115°. While for the downstream cutoffs, the angle of orientations is equal to 90°. The above mentioned curves have been obtained for soil permeability ratio (k_x/k_y) equal to 1. These figures show that the exit gradient does not show any marked change with change of inclination of the upstream cutoff. But, the uplift pressure distribution along the floor shows a little change. However the uplift pressure decreases slightly when Θ_1 is greater than 90°.

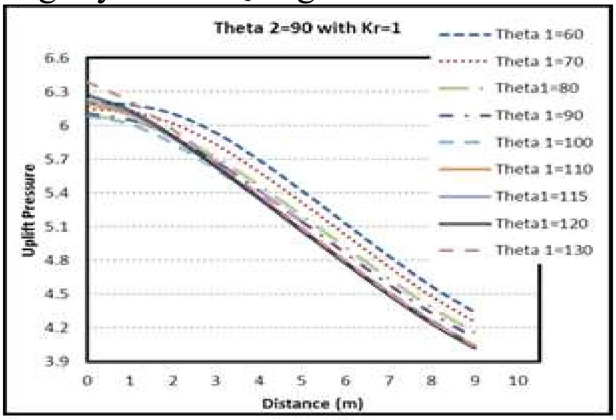


Fig. 13 Variation of uplift pressure under hydraulic structure with different inclination (Θ_1) of the upstream cutoff with K_r=1.

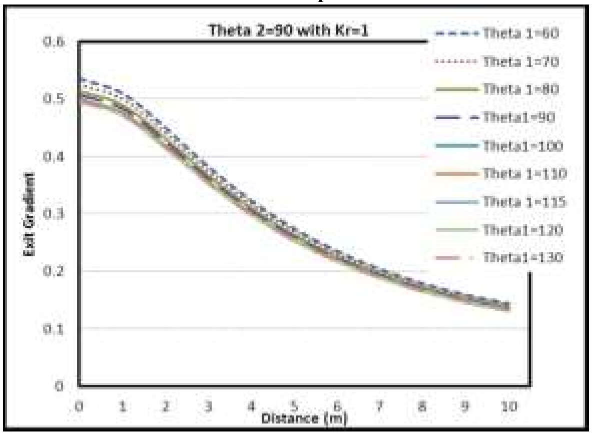


Fig. 14 Variation of exit gradient for a hydraulic structure with different inclination (Θ_1) of the upstream cutoff with K_r=1.

The similar curves have been obtained for the same dimensions mentioned above but by changing the inclination of both the upstream and downstream cutoffs. Fig. 15 and Fig. 16 show the uplift pressure distributions and the exit gradient variation respectively, changing over various orientations of the upstream and downstream cutoffs. From these figures, the following remarks can be distinguished:

1. When the upstream cutoff inclined towards the downstream side (Θ_1 is less than 90°) and the downstream cutoff inclined towards the upstream side (Θ_2 is greater than 90°), the developed exit gradient was higher than that of vertical cutoffs. On the other hand a considerable decrement was noticed for the uplift head when compared with that of vertical cutoffs.

2. When the upstream cutoff inclined towards the upstream side (Θ_1 is greater than 90°) and the downstream cutoff inclined towards the downstream side (Θ_2 is less than 90°), the maximum value of exit gradient was reduced. While, the rest values of exit gradient toward the downstream side, were found to be higher than that of vertical cutoffs. Thus, a longer protection needed for the downstream side of the structure to overcome the high exit values. Moreover, no dramatic change was observed with respect of the uplift head compared with the case of vertical cutoffs.

3. When the upstream cutoff inclined towards the upstream side (Θ_1 is greater than 90°) and the downstream cutoff inclined towards the upstream side (Θ_2 is greater than 90°), the maximum value of exit gradient was increased. While, no change was noticed for the rest values of exit gradient along the downstream distance compared with that of vertical cutoffs. Thus, no increment in protection needed for the downstream. However, a significant reduction in the uplift head is obtained for this case.

4. When the upstream cutoff inclined towards the downstream side (Θ_1 is less than 90°) and the downstream cutoff inclined towards the downstream side (Θ_2 is less than 90°), a high exit gradient and a high uplift head were obtained compared with the vertical cutoffs case.

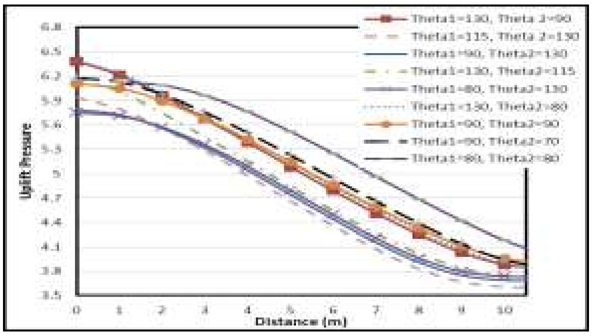


Fig. 15 Variation of uplift pressure under hydraulic structure with different inclination (Θ_1) of the U/S cutoff and different inclination (Θ_2) of the D/S cutoff with K_r=1.

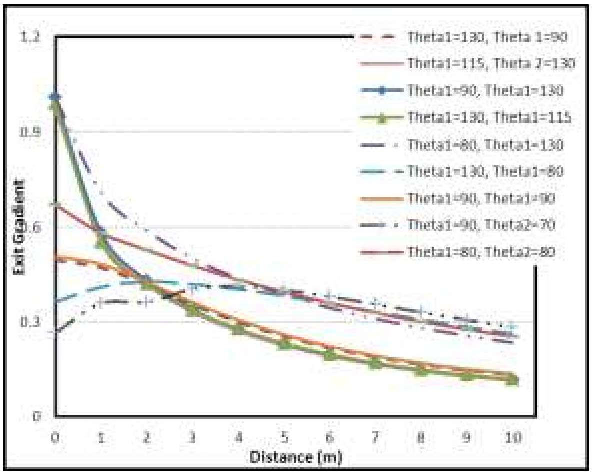


Fig. 16 Variation of exit gradient for a hydraulic structure with different inclination (Θ_1) of the U/S cutoff and different inclination (Θ_2) of the D/S cutoff with K_r=1.

The similar analysis was done for the same dimensions of the structure but for different soil properties, namely, K_r=4 and orientation of soil ellipsoid (α=45^o). Fig. 17 and Fig. 18 show the distribution of the uplift pressure and variation of exit gradient respectively. Obtaining these curves, the following rules can be observed:

1. When the inclination of both the upstream and the downstream cutoffs are in the same direction of the inclination of the soil ellipsoid, a high exit gradient and a high uplift head were developed.

2. When the inclination of both the upstream and the downstream cutoffs are in the adverse direction of the inclination of the soil ellipsoid, A significant reduction in uplift head is obtained, but no considerable change in the hydraulic gradient along the downstream bed.

3. These figures indicate that the value of Θ_1 had considerable effect on decreasing the uplift pressure, especially when increasing the value of Θ_1 from (90^o to 120^o). While the value of Θ_2 has no effect on reducing the hydraulic gradient.

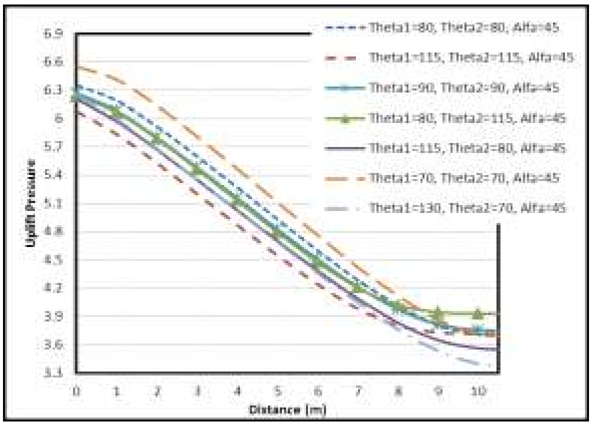


Fig. 17 Variation of uplift pressure under hydraulic structure with different inclination (Θ_1) of the upstream cutoff and different inclination (Θ_2) of the downstream cutoff with K_r=4 and α=45^o

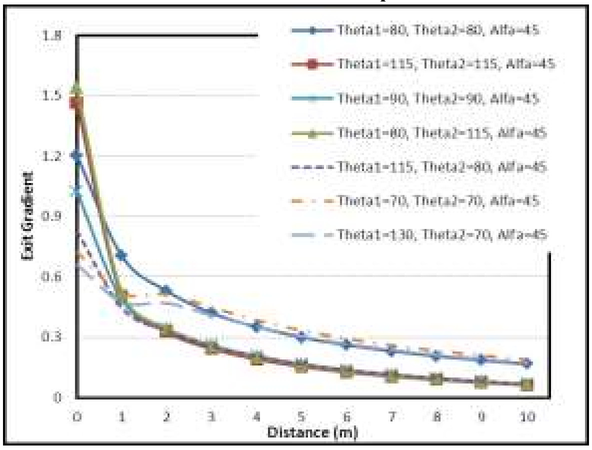


Fig. 18 Variation of exit gradient for a hydraulic structure with different inclination (Θ_1) of the upstream cutoff and different inclination (Θ_2) of the downstream cutoff with K_r=4 and α=45^o.

The effect of increasing the orientation value of soil ellipsoid (α) was also investigated for a structure has the same dimensions as above and provided with two inclined cutoffs but with K_r=4 and α=90°. Fig. 19 and Fig. 20 show the uplift head and exit gradient variation respectively. Results shown by Fig. 19 indicates that the distribution curve of the uplift head became flatter; started with a lower head value but ended with a higher head value; when compared with the previous case of (α=45°). While the exit gradient started with a maximum value and then it decreases slightly with distance as it goes to infinity at the ending point, as presented in Fig. 20. This trend have been observed for any inclination values of either upstream or downstream cutoffs

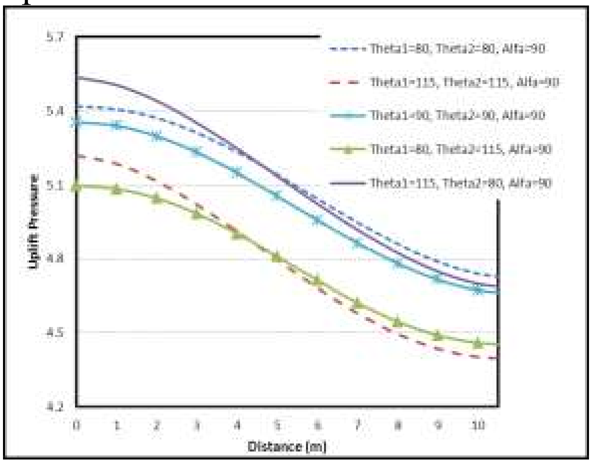


Fig. 19 Variation of uplift pressure under hydraulic structure with different inclination (Θ_1) of the upstream cutoff and different inclination (Θ_2) of the downstream cutoff with K_r=4 and α=90°.

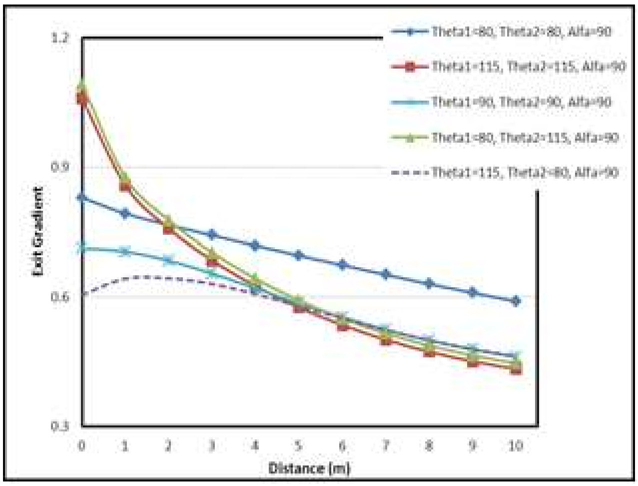


Fig. 20 Variation of exit gradient for a hydraulic structure with different inclination (Θ_1) of the upstream cutoff and different inclination (Θ_2) of the downstream cutoff with K_r=4 and α=90°.

4. Conclusions

From the present work, the following conclusions could be obtained:

1) The seepage flows obtained from the Geo-studio model were found to be comparable with the measured steady-state seepage flow by the seepage tank.
2) When the uplift pressure distribution under the hydraulic structure that obtained by Geo-studio model was compared with that measured from the seepage tank model, it was seen a good compatibility with a maximum percentage difference of (18.61%). The same conclusion was drawn for the comparison of the exit gradient variation downstream the hydraulic structure.
3) For K_r=1, using upstream and downstream cutoffs, both inclined

toward the upstream side will contribute in reducing the uplift pressure under the floor of the structure, thus the volume of structure required to satisfy the safety against uplift pressure will also reduce. A similar trend is observed for the case of soil properties (K_r=4 and α=45°) when using upstream and downstream cutoffs both inclined toward the upstream side in the direction adverse to the orientation of soil ellipsoid.

4) The analysis of the case (K_r=4 and α=45°) indicates that the value of inclination of the upstream cutoff has considerable effect on decreasing the uplift pressure, especially from a value of (90° to 120°).
5) When α increases to a value of 90°, this contribute in reducing the uplift head , especially when both Θ_1 and Θ_2 inclined toward the upstream side. While the exit gradient started with a maximum value and then it decreases slightly with distance as it goes to infinity. This trend has been obtained nearly for any value of inclination of upstream and downstream cutoffs.

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تحليل مختبري للتسرب تحت منشأ هيدروليكي صغير مزود بجدران قاطعة مائلة

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الخلاصة:-

الخلاصة: تناول هذا البحث دراسة عملية باستخدام نموذج مختبري بالاضافة الى موديل عددي باستخدام برنامج ال (Geo-studio) لاستقصاء تأثيراستخدام ركيزتين صفائحية (Sheet piles) مائلتين احدى الركيزتين موضوعة في مقدم منشأ هيدروليكي والاخرى في مؤخرهذا المنشأ المقام على تربة نفاذة. كما تم دراسة تأثير استخدام تلك الركائز على اختلافات تدرج الخروج للمنشأ وعلى توزيع ضغط الاصعاد اسفل تلك المنشأت. تم تحليل حالات مختلفة لقيم مختلفة لمتغيرات الادخال على سبيل المثال تغيير الزوايا وتغيير أوضاع الميلان للركائز الصفائحية في مقدم ومؤخر المنشأ الهيدروليكي بأستخدام نموذج (Geo-studio). تم دراسة تأثير ميلان الركائز لمختلف نسب تباين الموصلية الهيدروليكية(Kr=Kx/Ky) ولزوايا ميل مختلفة للموصلية الهيدروليكية عن المحور الرئيسي (Alfa). تم مقارنة نتائج الحالات الماثلة للنموذج الفيزيائي ونموذج الـ(Geo-studio) واظهرت النتائج بأن هناك توافق بينهما لتدفق التسرب وتوزيع الضغط واختلافات تدرج الخروج للمنشأ. بينت النتائج انه عندما يكون اتجاه ميلان كلا الركيزتين الموجودة في مقدم ومؤخر المنشأ الهيدروليكي في اتجاه معاكس لاتجاة زاوية ميل الموصلية الهيدروليكية عن المحور الرئيسي ينتج انخفاض ملحوظ بقيم ضغط الاصعاد لكن لم يلاحظ تغيير كبير في قيم تدرج الخروج على طول ارضية مؤخر المنشأ..