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Effect of Uplift Pressure under Hydraulic Structure Founded on Isotropic and Anisotropic Soil

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ABSTRACT:
In this research, "Slide" program was used to analyze seepage flow under the hydraulic structure through isotropic and anisotropic soils and its effect on structures with cut-off at downstream, at upstream, and at both of them. The distribution curves of uplift pressure along the floor had been reached at downstream for different degrees of anisotropy from the horizontal axis. The effects of anisotropy on uplift pressure . The analysis process depends on a finite element method. Eight-noded quadratic elements to represent the porous media. The maximum values of uplift pressure under the structure with cut-off at downstream are seen at 180˚, and 0˚ inclination angles and the minimum values are seen at 90˚ inclination angle, the maximum values of uplift pressure under the structure with cut-off at upstream are at 90˚ inclination angle and the minimum values are at 180˚, and 0˚ angles, and the maximum values of uplift pressure under the structure with cut-off at upstream and downstream are at 90˚ inclination angle and the minimum values are at 180˚, and 0˚ inclination angles but the relationship is reversed after x=0.5. The quantity of seepage in downstream side of the structure with a cut-off at downstream was 0.546 m^3 /day, at upstream was 0.396 m^3 /day, and at both of them was 0.501 m^3 /day. The quantity of seepage for anisotropic soils was calculated for all cases.

KEYWORDS:pressure head,uplift pressure, seepage, isotropic soil and anisotropic soil.

1. INTRODUCTION:

Hydraulic structures asconcrete dams, weirs,culvert, gates, retaining walls…etc. are founded on impervious soil or pervious soil. The difference in water level between upstream and downstream through the hydraulic structure results in water seepage through the soil under the hydraulic structure. anothermethodscalculationslike mathematical solutions, electrical solutions, flow models, fragments methods, and numerical methods [4].

2. SEEPAGE ANALYSIS:

The effect of seepage through soil requires calculation of uplift pressure under the structure. The uplift pressure is one of the important points that are consider to the safety and stability of hydraulic structures. It refers to the pressure of the water seepage under the structure that pushes the floor to up direction. The piping cavities are been due to water seepage across salt soil (e.g. gypsum salts). these cavities due to salts that weaken the soil of the hydraulic structure foundation. The isotropic soil, the values of hydraulic conductivity are equal in all directions. In anisotropic soil, they not equal with different in direction. In this research, the effect of anisotropy of soil under the hydraulic structures with sheet pile at downstream, at upstream, and at both of them on the uplift pressure are studied.

The flow across a saturated soil is given by Darcy's law:

$$V_s = K \quad i \tag{1}$$

Where:

V_s = Velocity through porous media

K = Hydraulic conductivity

i = Hydraulic gradient = $\frac{-dh}{dl}$

h = Piezometric head

l = Distance along the flow line

Darcy's law is valid when Reynolds number is taken equal to or less than unity, or

$$\text{Re} = \frac{VD\,°}{«} \leq 1 \quad (2)$$

Where

Re = Reynolds number.

V = Discharge velocity.

D = Average of diameter of soil particles.

° = Density of fluid, and

« = Dynamic viscosity

Fortunately, most of practical seepage flow under dam is laminar (*Re‹1*) [3].

3. THE ANISOTROPY SOIL AND ISOTROPY:

If an *x y* coordinates is the coordinate Direction , the hydraulic conductivity values in the directions is specified as Kx, and Ky, another point or any point(x, y) an isotropic caseis $Kx = Ky$, an anisotropic caseis$Kx \neq Ky$.

4. THE HYDRAULIC CONDUCTIVITY:

The conductivity in the two dimensional cases Is in the maximum and minimum values along the axes, are principal axis. Other directions through the domain of hydraulic conductivity are between the principal values are given[3] with the principal values making the major and minor axis. the flow under hydraulic structures at anisotropic soil foundation, where the flow is in the (x, y) coordinate axes makes an angle β with the principal axes of conductivity of the soil, the coordinate system points(μ, λ) is consider the principal axes of hydraulic conductivity,hydraulic conductivity and axis rotationis shown in figure (1).

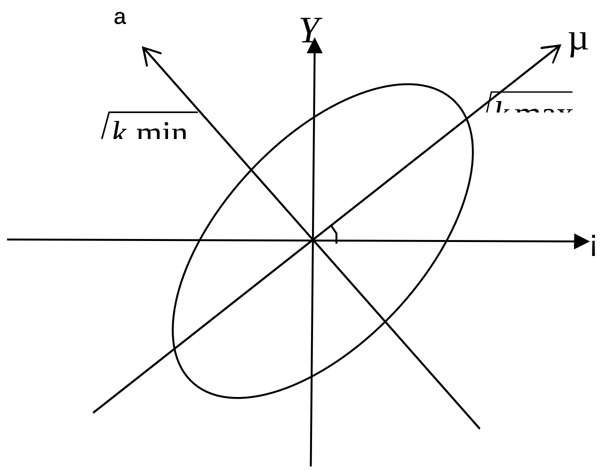

Fig.(1) Hydraulic conductivity and axis rotation,[5].

5. EQUATION OF FLOW:

The analysis of the seepage velocity through soilin the law of Darcy for Two-dimensional flow are [2]:

$$u = -k_x \frac{\partial H}{\partial x} \qquad (3)$$

$$v = -k_y \frac{\partial H}{\partial y} \qquad (4)$$

where:

u, v = Velocity components in the horizontal x direction, and*vertical y* direction.

k_x , k_y= Hydraulic conductivity in the *x*- and *y* directions. The continuity equation for two-dimensional of flow is following:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (5)$$

Substitute the law of Darcy, eq.(3-3), in eq.(3-4) gets the following:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) = 0 \qquad (6)$$

For a homogenous and isotropic soil, the hydraulic conductivity is equal in all the directions, is:

$k_x = k_y = k$

Thus, eq.(3-5) is:

$$\frac{\partial^2 H}{\partial x^2} + \frac{\partial^2 H}{\partial y^2} = 0 \qquad (7)$$

The continuity equation for seepage flow in anisotropic soil is[1]:

$$\frac{\partial}{\partial x} q_x + \frac{\partial}{\partial y} q_y = 0 \qquad (8)$$

Where:

q_x , and q_y are seepage fluxes in *x* and *y* direction respectively and are given in equation (8).

6. SLIDE PROGRAM:

Slide V.5.0 is a finite element based analysis of seepage , for saturated/unsaturated, steady flow conditions,the seepage analysis by slideis shown in figure (2).

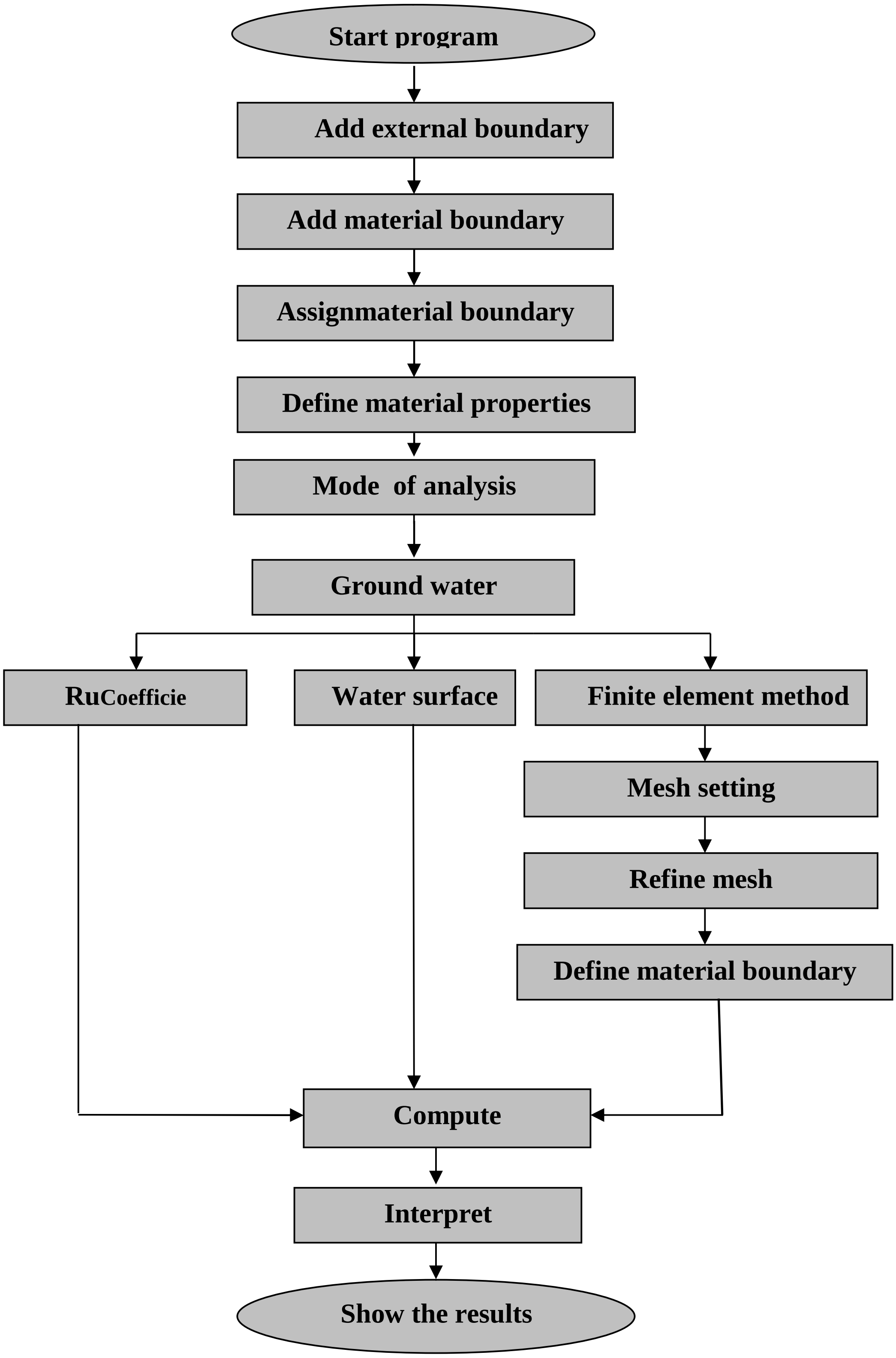

Fig. (2) The seepage analysis by slide program [6].

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7. HYDRAULIC STRUCTURE WITH CUT-OFF AT DOWNSTREAM:

The effect of parametric on the uplift pressure under hydraulic structure, are divided like the following:

1. Geometry parameters (difference of soil, location of cut-off).
2. Physical parameters (change in degree of anisotropy).

Quantity of seepage in downstream side for isotropic soil and flow vector is shown in figure (3),and the dimension of the problemis shown in figure(4).

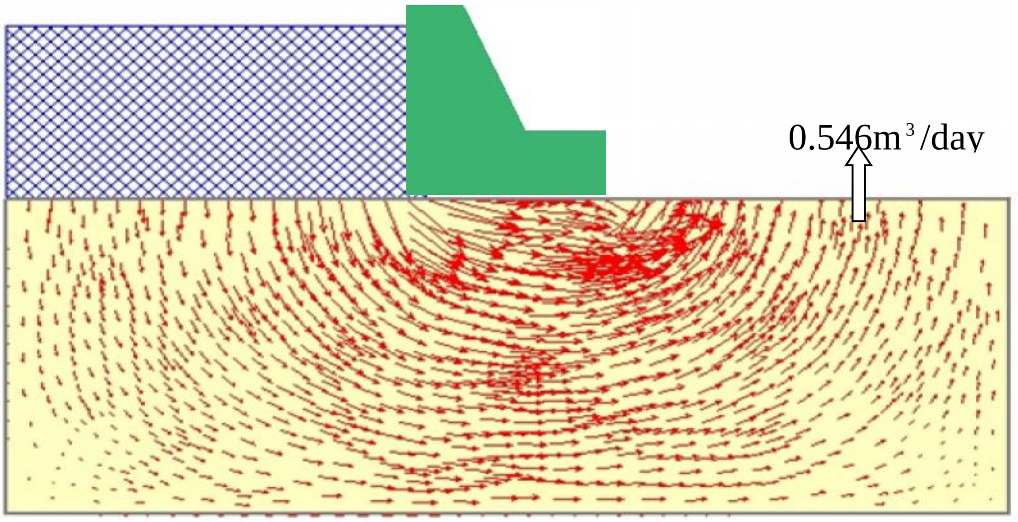

Fig. (3) Quantity of seepage in downstream side for isotropic soil and flow vector.

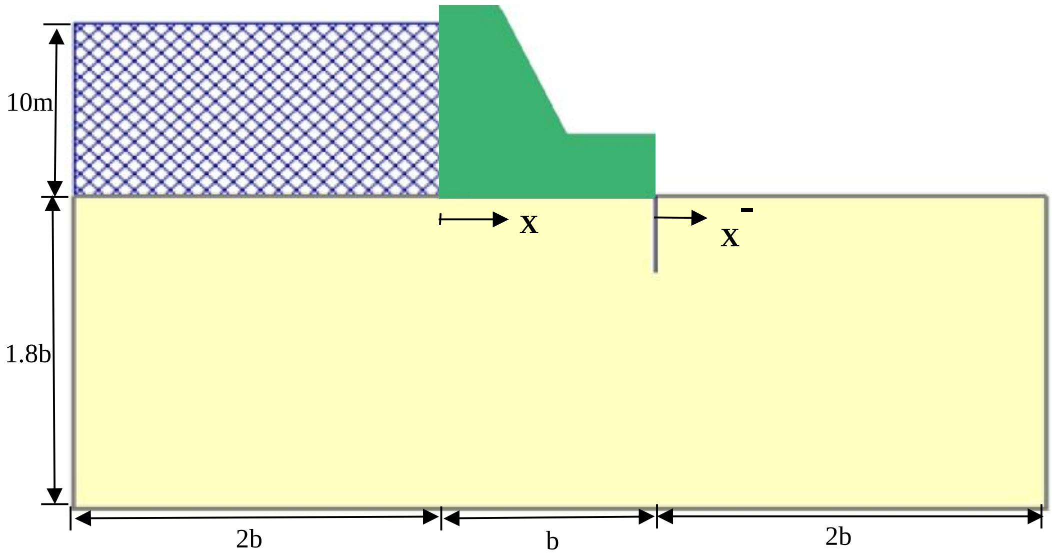

Fig.(4) Dimension of the problem

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7-1 INCLINATION ANGLEEFFECT AND DEGREE OF ANISOTROPY SOIL:

The distribution of uplift pressure under the retaining structure for different anisotropic angles at different inclination angles (45˚,90˚,135˚, and 180˚) are shown in Figures(5),(6),(7),and(8) respectively. It has been found that at 180˚ angle, the distribution of uplift pressure increased with increasing the degree of anisotropy. In regard to the 90˚ and 135˚ angles, the values of uplift pressure decrease with increase in degree of anisotropy. In contrast, the distribution of uplift pressure for 45˚ angle increased with increasing permeability until x/b = 0.5, then decreased with increasing permeability.

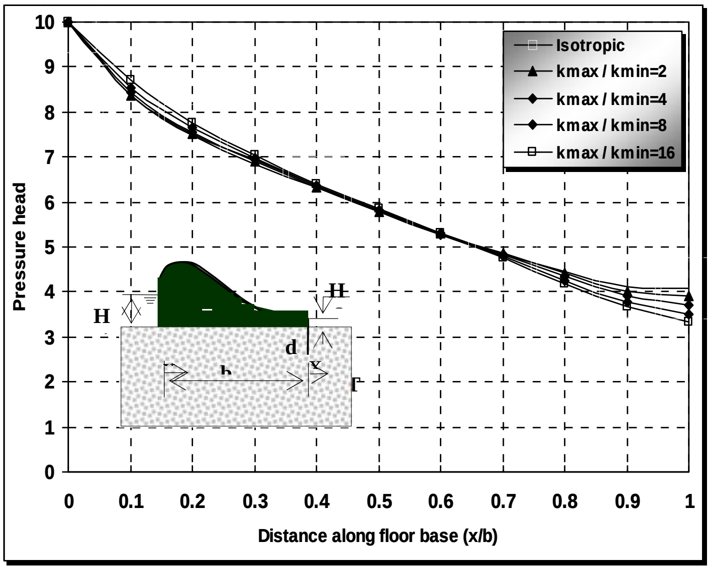

Fig.(5) Uplift pressure distribution under hydraulic structure with D/S cut-off in anisotropic

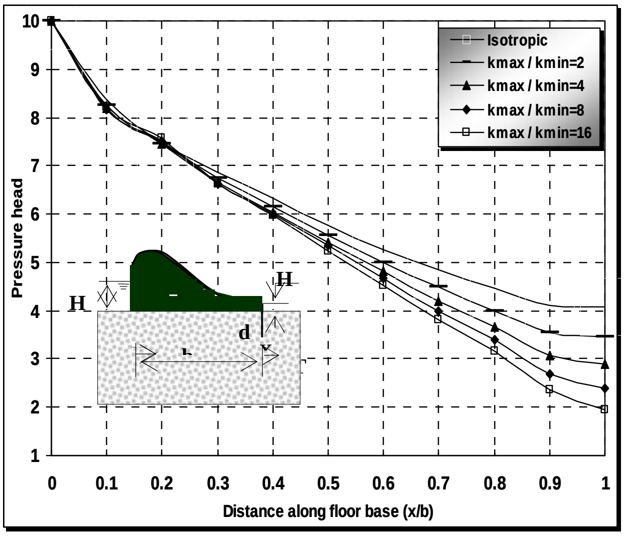

Fig.(6) Uplift pressure distribution under hydraulic structure with D/S cut-off in anisotropic

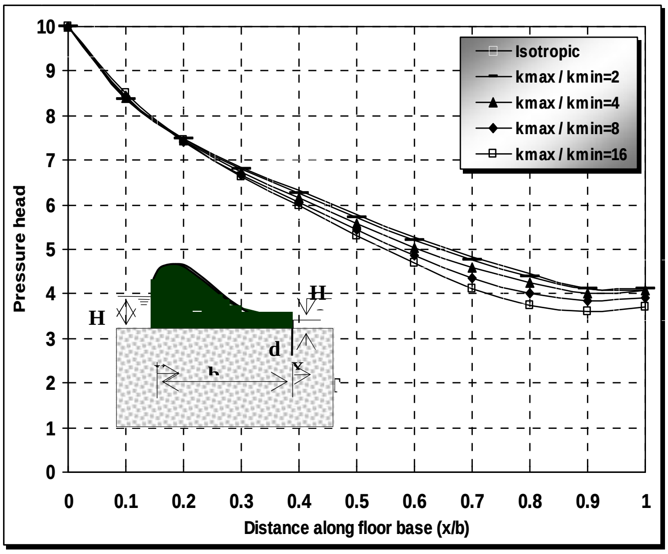

Fig.(7) Uplift pressure distribution under hydraulic structure with D/S cut-off in anisotropic

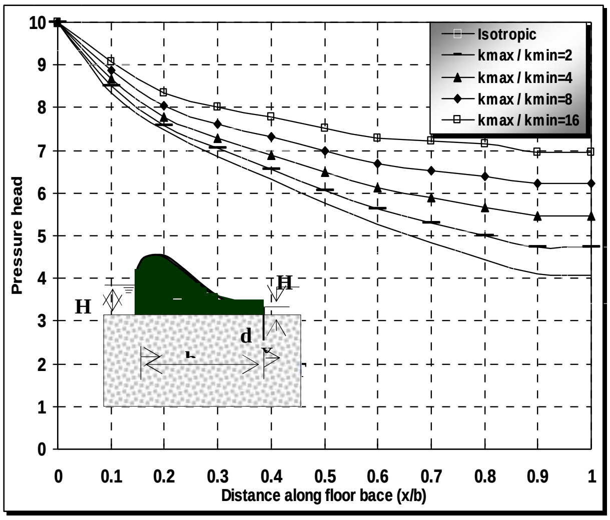

Fig.(8) Uplift pressure distribution under hydraulic structure with D/S cut-off in anisotropic soil at

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The distribution of uplift pressure under the hydraulic structure for different inclination angles and different degrees of anisotropy (2,and 4) are shown in Figures(9),and (10) respectively. It can be seen from these figures, that the distribution values of uplift pressure are maximum at 180˚,and 0˚ degree angles which are greater than the values of uplift pressure for isotropic soil. This is attributed to the relatively large hydraulic conductivity causing increase in uplift pressure. It is also noticed that the values of uplift pressure were minimum at 90˚ angle. This is due to the fact that the hydraulic conductivity is small along the floor which cause large head losses in that direction.The uplift pressure values of 45˚ angle are greater than the uplift pressure values of 75˚ angle, as the stream lines are inclined more toward the structure floor when the angle is 45˚ causing greater values for uplift pressure. Likewise, 115˚ and 135˚ have the same effect.

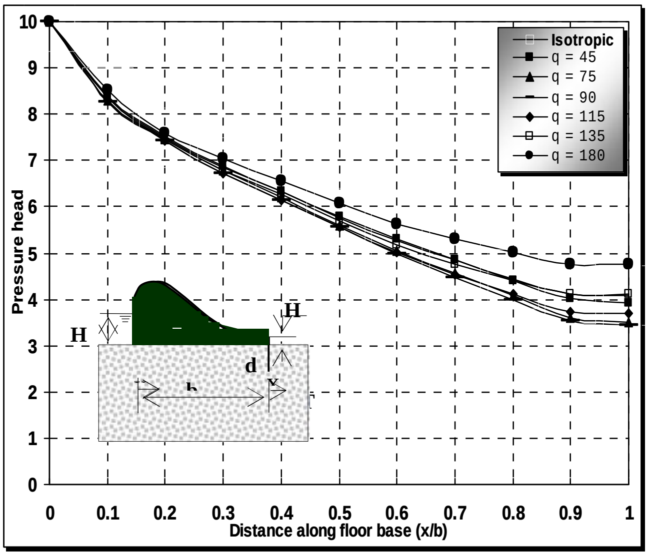

Fig.(9) Uplift pressure distribution under hydraulic structure with D/S cut-off in anisotropic soil at (kmax/kmin=2).

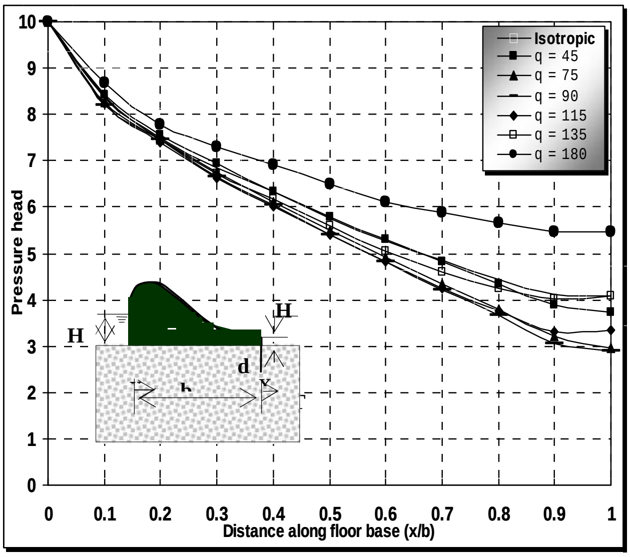

Fig.(10) Uplift pressure distribution under hydraulic structure with D/S cut-off in anisotropic soil at (kmax/kmin=4).

7-2 EFFECT OF LOCATION OF CUT-OFF ON UPLIFT PRESSURE:

Figure(11) illustrates the distribution of uplift pressure under the floor base of the hydraulic structure for different locations of the cut-off. When the cut-off is at upstream, uplift pressure decreases due to increasing head loss from increasing length of creep whenever the cut-off is far away from upstream, uplift pressure values increase.

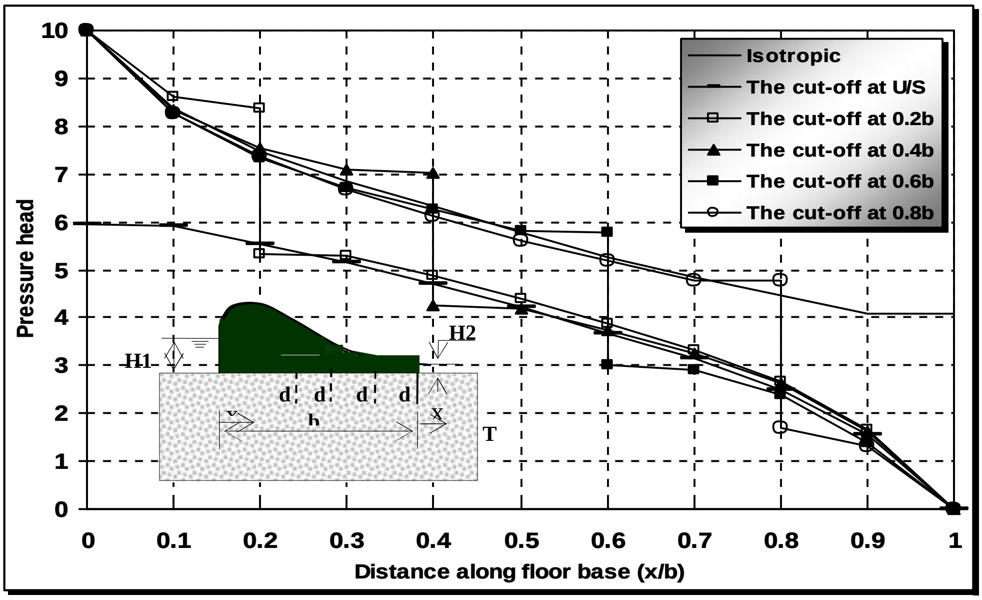

Fig.(11) Uplift pressure distribution under hydraulic structure with various locations of cut-off in isotropic soil

Table(1) Results of Quantity of Seepage ($m^3/s/m$) for Different kmax/kmin and Constant Valueof Inclination Angle for (45, 90, 135, 180)

θ \ kmax/kmin	2	4	8	16
45	4.307E-06	2.814E-06	1.765E-06	1.065E-06
90	3.957E-06	2.371E-06	1.375E-06	0.775E-06
135	4.443E-06	2.990E-06	1.928E-06	1.195E-06
180	4.757E-06	3.356E-06	2.244E-06	1.440E-06

8. RETAINING STRUCTURE WITH CUT-OFF AT UPSTREAM

The quantity of seepage for hydraulic structures with cut-off at upstream as shown in figure(12)

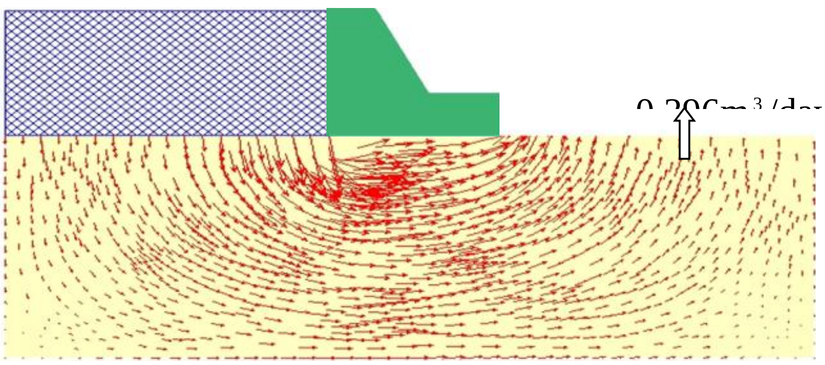

Fig. (12) Quantity of seepage in downstream side for isotropic soil and flow vector.

The distribution of uplift pressure for retaining structure for different degrees of anisotropy and different inclination angles (45˚, 90˚, 135˚, and 180˚) are shown inFigures (13), (14), (15), and (16) respectively. It is found that for 180 angle, the distribution values of uplift pressure decrease with increasing anisotropy from those of isotropic soil.It is found that the uplift pressure values for the angles (45˚, 90˚, and 135˚) increase when the anisotropy increases. This explained the fact that stream lines move in the direction of the structure floor as the anisotropy increases causing greater values of the uplift pressure.

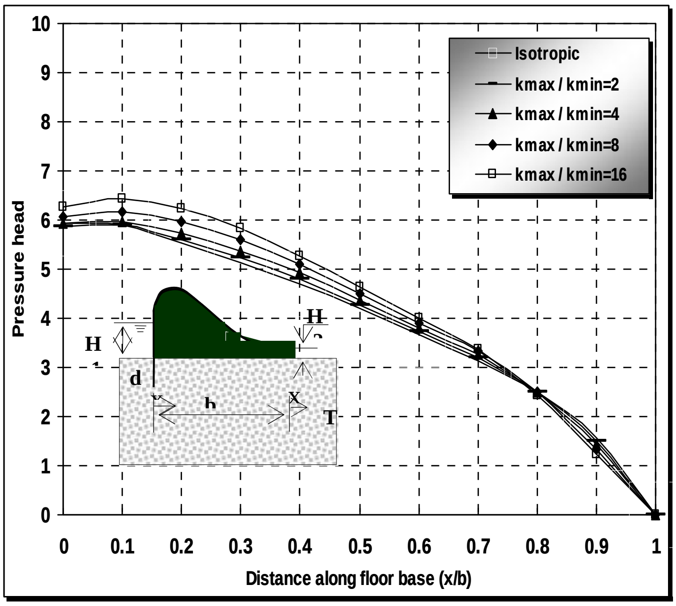

Fig. (13) Uplift pressure distribution under hydraulic structure with U/S cut-off in anisotropic soil at

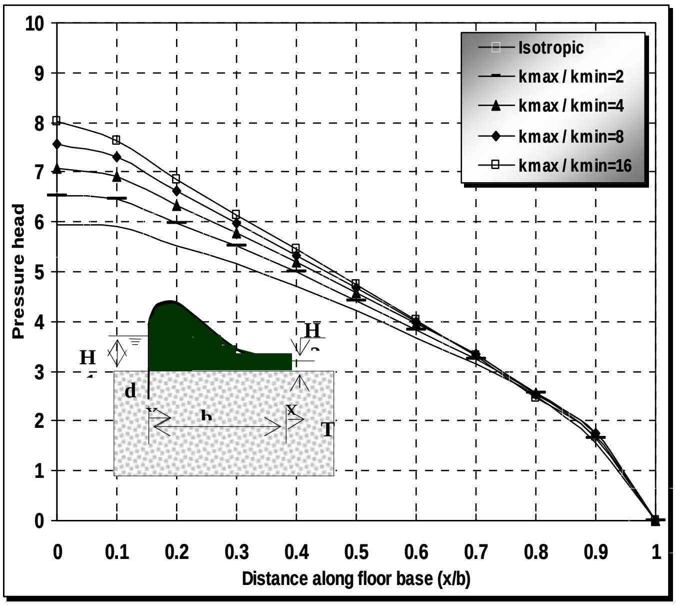

Fig. (14) Uplift pressure distribution under hydraulic structure with U/S cut-off in anisotropic soil at (ϴ=90)

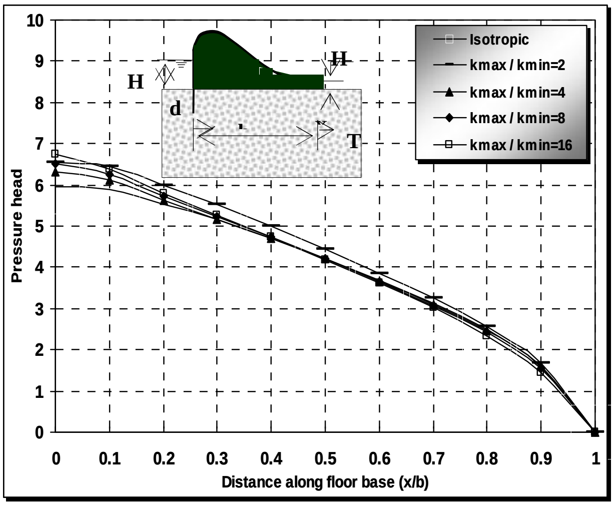

Fig. (15) Uplift pressure distribution under hydraulic structure with U/S cut-off in anisotropic soil at (ϴ=135)

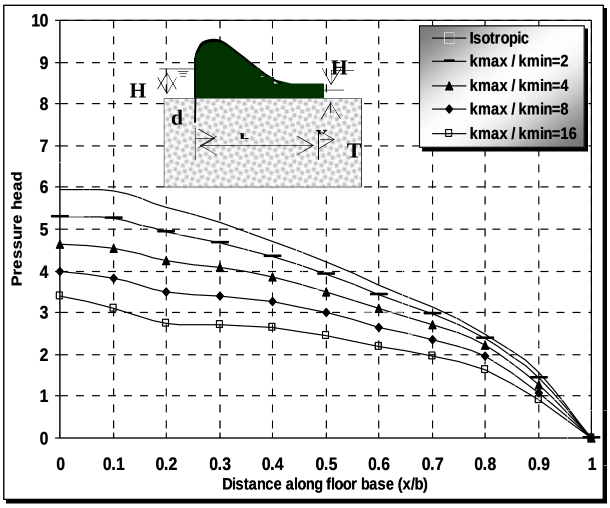

Fig. (16) Uplift pressure distribution under hydraulic structure with U/S cut-off in anisotropic soil at (ϴ=180)

Figures(17)and (18) illustrate the distribution of uplift pressure under the structure for different inclination angles andfor two different degrees of anisotropy (2, and 4) respectively. It can be seen that the values of uplift pressure for 180˚ angle is lower than uplift pressure values of isotropic soil, since the hydraulic conductivity will be smaller along the cut-off causing major reduction in head lossesof that direction.For 90˚ angle, the uplift pressure values will be maximum and so greater than the uplift pressure values of isotropic soil, because conductivity is greater in the direction of the cut-off causing minor reduction in head losses in that direction and consequently high values of uplift pressure.It is realized that the values of uplift pressure for angles less than 180˚ angle will be greater than the values of uplift pressure for isotropic soil. This is due to the stream lines which approach toward the structure floor causing increase in the uplift pressure values.

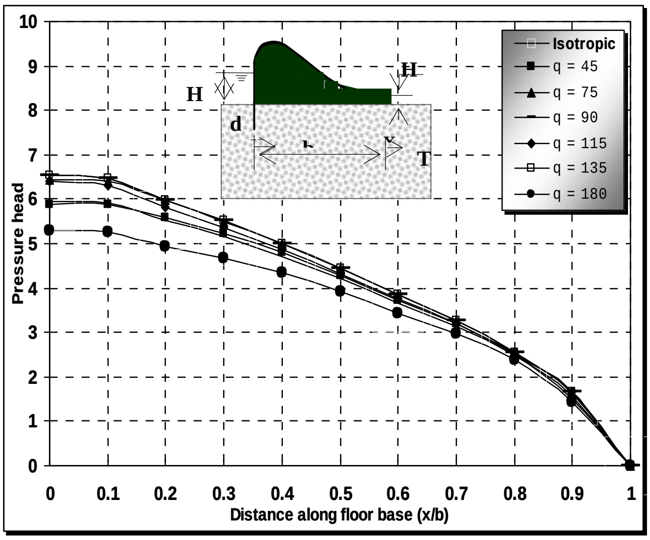

Fig. (17) Uplift pressure distribution underhydraulicstructure with U/S cut-off in anisotropic soil at (kmax/kmin=2).

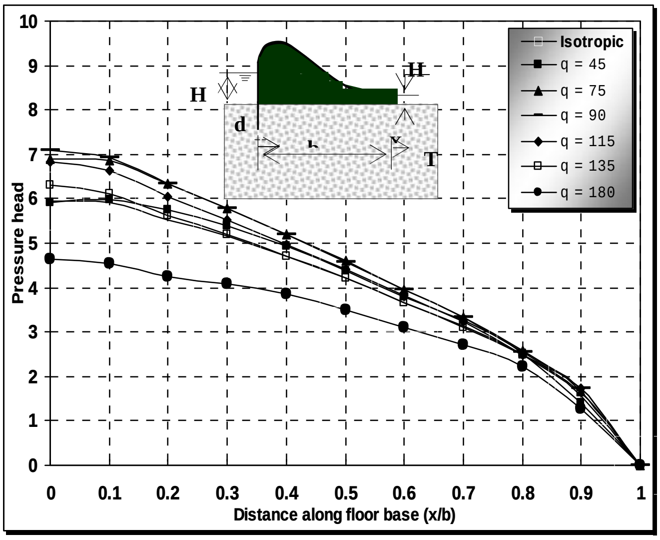

Fig.(18) Uplift pressure distribution under hydraulic structure with U/S cut-off in anisotropic soil at (kmax/kmin=4).

Table(2) Results of Quantity of Seepage ($m^3/s/m$) for Different kmax/kmin and Constant Value of Inclination Angle for (45, 90, 135, 180)

θ \ kmax/kmin	2	4	8	16
45	3.532E-06	2.234E-06	1.316E-06	0.7123E-06
90	3.235E-06	1.880E-06	1.040E-06	0.544E-06
135	3.717E-06	2.505E-06	1.616E-06	1.001E-06
180	3.986E-06	2.805E-06	1.860E-06	1.182E-06

9. RETAINING STRUCTURE WITH CUT-OFFS AT UPSTREAM AND DOWNSTREAM

The quantity of seepage is 0.501m is shown in figure(19)

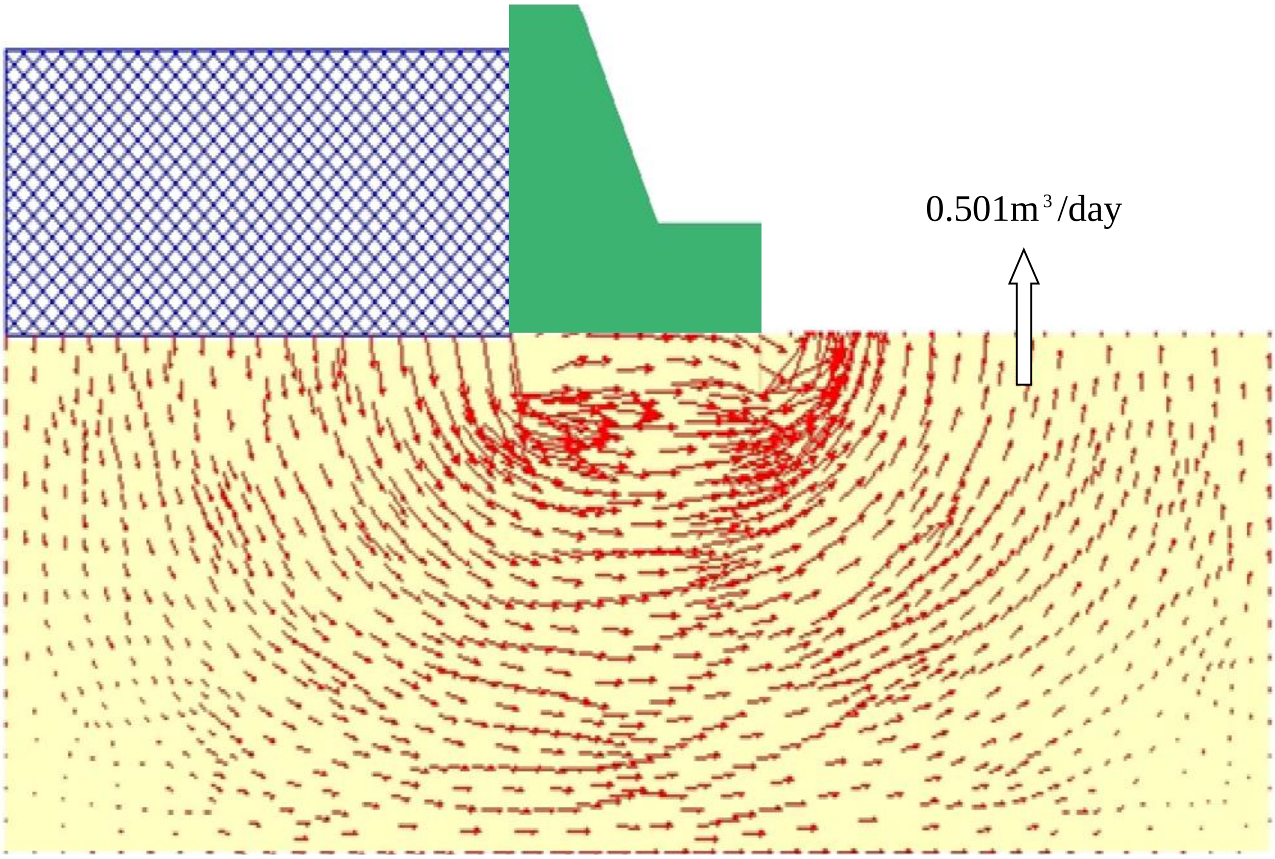

Fig. (19) Quantity of seepage in downstream side for isotropic soil and flow vector.

The distribution of uplift pressure under the retaining structure with upstream and downstream cut-offs for different degrees of anisotropy and different inclination angles (45˚,90˚,135˚, and 180˚) are shown in Figures(20),(21),(22),and(23) respectively. It is found that the distribution curves of the uplift pressure meet in one point because of the combined effect of the cut-offs that change the physical characteristics of the flow through the porous medium. The meeting point is changing from one case to another depending on the value of the inclination angle and the degree of anisotropy.It can be seen from figure (23) that at 180˚ angle, the meeting point will be when x/b = 0.5, and the distribution of uplift pressure before the meeting point decrease with increasing anisotropy. In contrast, they increase with increasing anisotropy after the meeting point.Figure (22) illustrates that at 135˚ angle, the meeting point will be happened when x/b = 0.2, and the distribution of uplift pressure before the meeting point increase and after the meeting point decreases with increasing degree of anisotropy.Figure (21) shows that at 90˚ angle, the meeting point will be occured when x/b = 0.5. The values of uplift pressure before the meeting point increase with increasing degree of anisotropy, while after the meeting point the uplift pressure values decrease with increasing of anisotropy.Figure (20) shows that when the inclination angle is 45˚, the meeting point will be at x/b = 0.85. The values of uplift pressure increase before the meeting point and thereafter decrease.

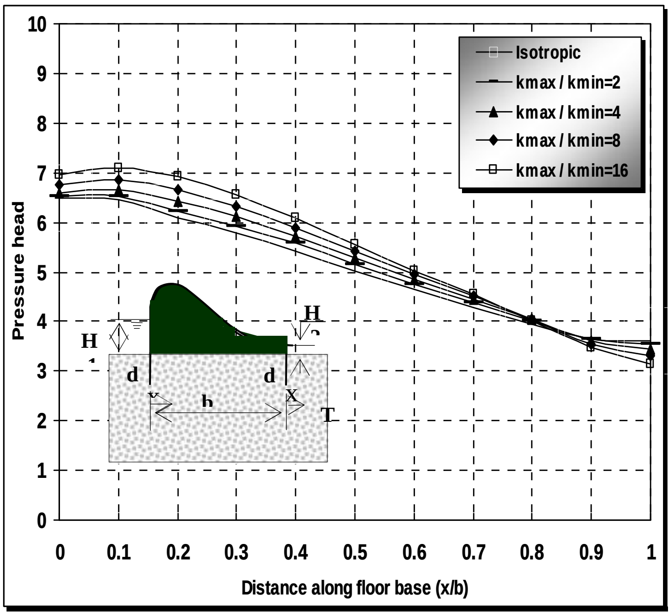

Fig. (20) Uplift pressure distribution under hydraulic structure with U/D cut-offs in anisotropic soil at (ϴ=45).

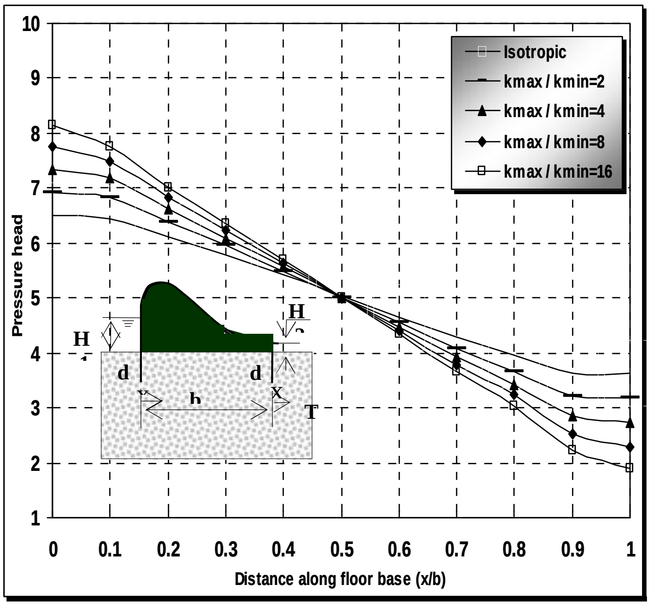

Fig. (21) Uplift pressure distribution under hydraulic structure with U/D cut-offs in anisotropic soil at (ϴ=90).

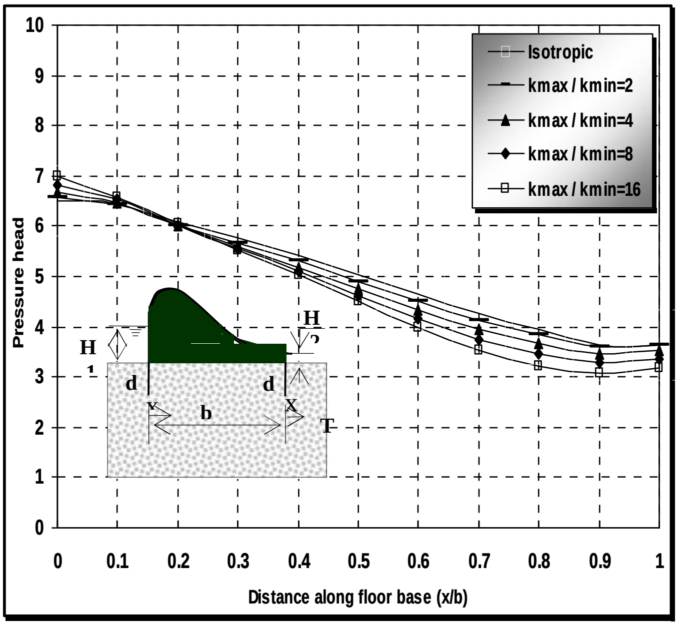

Fig. (22) Uplift pressure distribution under hydraulic structure with U/D cut-offs in anisotropic soil at (ϴ=135).

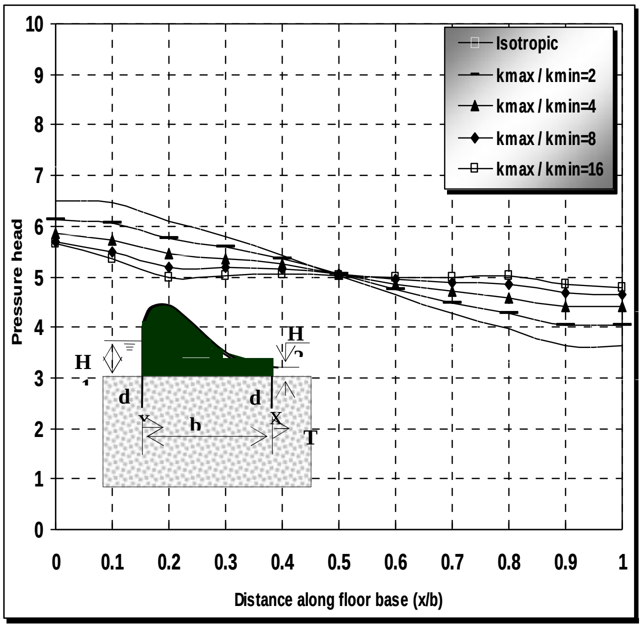

Fig.(23) Uplift pressure distribution under hydraulic structure with U/D cut-offs in anisotropic soil at (ϴ=180).

Figures(24),and (25) illustrate the distribution of uplift pressure under the hydraulic structure with cut-off at upstream and downstream for different inclination angles andfor different degrees of anisotropy (2, and 4) respectively.It can be seen that at 180˚ angle, the uplift pressure values are smaller than those of isotropic soil till x/b = 0.5, thereafter they are greater. In contrast, at 90˚ angle, the values are greater than those of isotropic soil till x/b = 0.5, thereafter smaller.The values of uplift pressure at 45˚ angle are a little bit higher than those of isotropic soil, while those at 75˚ angle are greater than those of isotropic soil and those seen in 45˚ angle. The same thing is noticed in 115˚ and 135˚ angles.

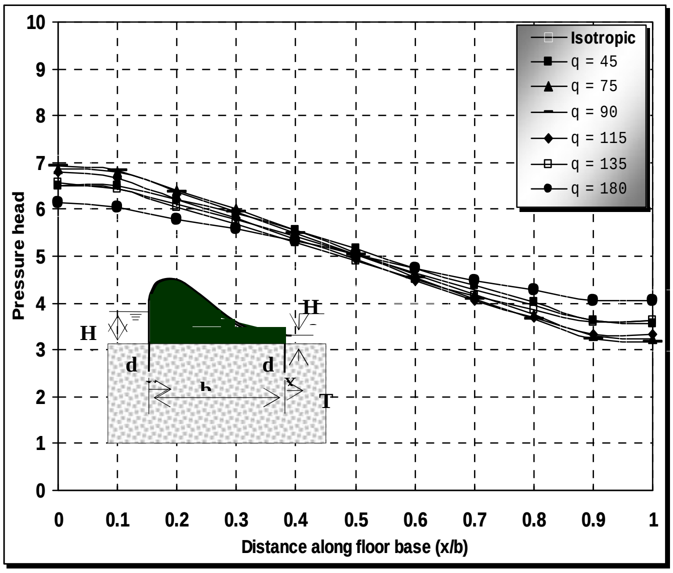

Fig. (24) Uplift pressure distribution under hydraulic structure with U/D cut-offs in anisotropic soil at (kmax/kmin=2).

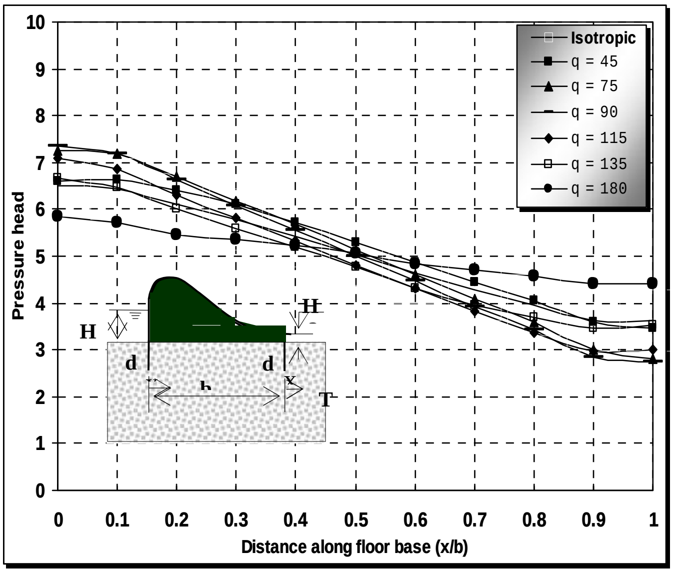

Fig. (25) Uplift pressure distribution under hydraulic structure with U/D cut-offs in anisotropic soil at (kmax/kmin=4).

9-1 EFFECT OF DEPTH OF CUT-OFFS ON UPLIFT PRESSURE:

The effect of depth is changing in cut-off at upstream from depth in cut-off at downstream on uplift pressurewhichis shown inFigures(26).It can be seen that when the depth of cut-off at upstream is greater than that at downstream.

Table(3) Results of Quantity of Seepage ($m^3/s/m$) for Different kmax/kmin and Constant Value of Inclination Angle for (45, 90, 135, 180).

θ \ kmax/kmin	2	4	8	16
45	4.014E-06	2.660E-06	1.687E-06	1.026E-06
90	3.683E-06	2.232E-06	1.307E-06	0.744E-06
135	4.016E-06	2.663E-06	1.692E-06	1.032E-06
180	4.289E-06	2.958E-06	1.927E-06	1.208E-06

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10.CONCLUSIONS:

The following conclusions are reached at the end of this study:

1. The values of uplift pressure under structure with cut-off at downstream at 180˚, and 0˚ angles will be a maximum and greater than those of isotropic soil. In contrast, they are minimum at 90˚ angle, and they are smaller than those of isotropic soil.

2. The maximum distribution of uplift pressure under the structure with cut-off at upstream will be at 90˚ angle, and they are greater than those of isotropic soil. The smallest values are seen at 180˚ angle, however they are smaller than those of isotropic soil.

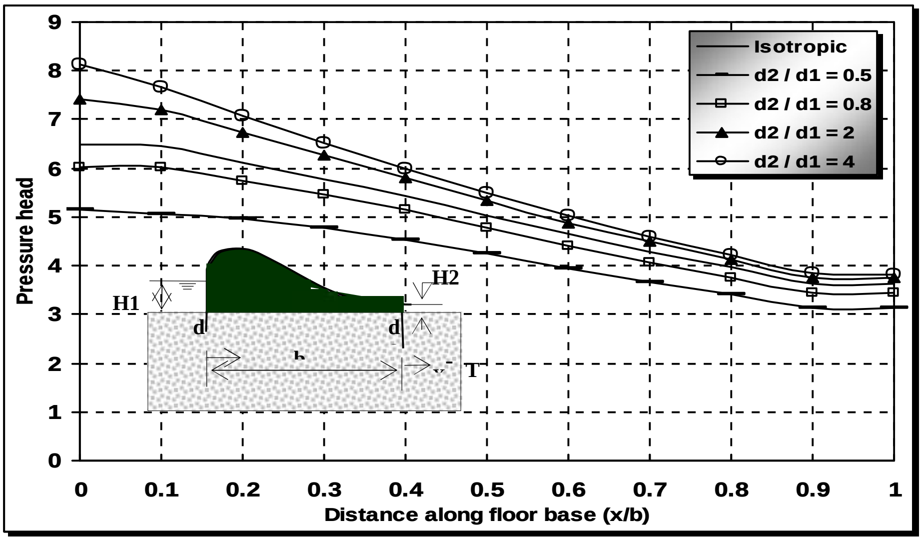

Fig. (26) Uplift pressure distribution under retaining structure withU/D cut-offs in isotropic soil for various d2/d1

3. The values of uplift pressure under the structure with cut-off at downstream at 180˚ angle increased by increasing anisotropy, while at 90˚, and 135˚ angles, they decreased by increasing anisotropy. In contrast, they increase by increasing anisotropy till x/b = 0.5, thereafter decrease in case of 45˚ angle.

4. The values of uplift pressure under the structure with cut-off at upstream at 180˚, and 0˚ angles decrease by increasing anisotropy, while they increase in other angles.

5. The distribution of uplift pressure for the structure with cut-offs at upstream and downstream meet in one point and the position of this point depends on the degree of anisotropy and the inclination angle at 180˚, and 0˚ angle, the values of uplift pressure before the meeting point decreased by increasing anisotropy while after the meeting point, the increase by increasing anisotropy. In regards to the other angles, the values of uplift pressure before the meeting point increase by increasing anisotropy, and thereafter decrease will happen by increasing anisotropy.

6. The distribution of uplift pressure under the structure with cut-offs at upstream and downstream will be minimum at 180˚, and 0˚ angles. The values are smaller than those of isotropic soil before the meeting point, and greater after the meeting point. The maximum values will be at 90˚ angle, and these before the meeting point are greater than those of uplift pressure for isotropic soil, while after the meeting point, they are smaller than those of isotropic soil.

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