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Research paper

Influence of Cavity Under Hydraulic Structures on Seepage Characteristics

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Abstract

Cavities under hydraulic structures have a significant influence on the stability of these structures. This study depends on (SEEP/W) software for a hydraulic structure model with an upstream sheet pile. Thus, different results are obtaining for discharge, uplift pressure and exit gradient. For the output a dimensional analysis is perform to study the effect of these variables. Also (SPSS), where special equations are obtaining for seepage discharge, uplift pressure and exit gradient has a coefficient of determination and correlation (0.9, 0.89, 0.8) respectively. The effect of the presence of the cavities on seepage properties whenever the location of the cavity before the sheet pile increased its effect on the discharge and uplift pressure in contrast to the exit gradient where cavity approaching the end of the structure that is increasing its impact on the exit gradient. Also decrease the depth of the cavity from ground increase its impact on the characteristics of seepage, as well as the greater coefficient of permeability and the diameter of the cavitation will increase seepage properties. Also shows that when comparing the state of the presence of cavity with the absence of it, different behaviors with different characteristics of seepage will appear at different percentage.

Keywords: *Cavity, Exit Gradient, SEEP/W, Seepage, Uplift Pressure.*

1. Introduction

The existence of cavities may adversely affect the stability of submerged surfaces. At present there is no widely accepted method for analyzing the stability of the system of reduction and for the development of such an analytical method. Studies have been conducted to analyze the effect of cavity on the stability of hydraulic structures. Jamel, (2017), the research was based on the (SEEP/W) program to study the seepage properties of soil with layers on different sheet piles and then to verify the results using artificial neural network Where observed difference less than 2% ,5% and 6% for seepage, exit gradient and uplift pressure respectively with (ANN). [(1)] Shayan and Tokaldany (2015), using upstream blankets used to reduce leakage, uplift pressure and exit gradient under hydraulic structures. It was developed on a laboratory model, and a large number of different sheet piles angles, the length of the upstream blankets, and different locations of the drains were simulated within the mathematical model. [(2)] Alghazali and Alnealy (2015), detect equipotential lines and flow lines under the hydraulic structure containing a cutoff at different angles to find the best angle and location of the cutoff that achieved the least characteristic of seepage, where concluded that using inclined downstream cutoff increasing structre safety against the piping. [(3)] Maatooq et al. (2014), laboratory study of sandy soil containing cavity to show the effect of location and diameter of the cavity on the amount of seepage over time and the form of flow lines, then established an equation for seepage, and the importance of cavity on seepage properties. [(4)] Mansuri et al., (2014), studied the effect of the cutoff on the uplift pressure and finding its efficiency, which showed reducing in uplift pressure [(5)] Mansuri et al., (2014), prevent piping by using cutoff with different displacements and various angles of inclination to minimize the uplift pressure, where results showed reduse in uplift pressure values [(6)] El-Jumaily and AL-Bakry, (2013), depending on the method of finite volume and the use of rectangular elements, the seepage was analyzed under the hydraulic structure which contains sheet piles at the toe or heel of it, the assessment showed adjacent results [(7)] Ahmed, (2013), investigated the confined flow under hydraulic structures, where the hydraulic conductivity of the soil is considered as a three-dimensional arbitrary field, where the results showed isotropic condition [(8)] Obead, (2013), used finite element model for steady and two dimensional flow analyses under the base of the structure with cut off wall to control leakage. Also used for this purpose is a computer program in (Fortran 90) to find seepage proparties behind the cutoff wall, which led to a good consensus with previous studies [(9)] Rafiezadeha and Astiani, (2012), A computer analysis program has been developed for seepage of differentiated media based on the boundary element method to show the ability and accuracy of the mathematical model to solve various types of applied three-dimensional seepage problems that ascend in engineering practice. [(10)] Ashraf, (2011), developing finite element method configurations of sheet pile under the hydraulic structure. Also suggests that two-dimensional analysis of seepage problems such as exit gradient and uplift pressure for hydraulic structures. [(11)] Bereslavskii et al., (2011), studied the problems that related to flow with unidentified limits under hydraulic construction, using the two-dimensional steady state of the non-compressed liquid in accordance with the Darcy law in isotropic soils, results showed that the effect of the physical limits of models was perfected. [(12)] Khassaf et al., (2009), using SEEP/W the distribution of pressure, seepage and exit gradient under the Diyala weir foundation was studied. [(13)]

The current study depends on the use of Geo-Studio through (SEEP/W), where the study is carried out using a hydraulic structure with sheet pile at upstream for the following purposes:

1. Base on the outline of data for three different types of non-homogenous soils, three heights of upstream heads and the presence of different positions of three vertical depths of the cavity for three different diameters of these cavities, estimate the amount of seepage discharge, uplift pressure and exit gradient.

2. Drawing relationships that represent the effect of the different variables of the soil under the hydraulic structure, location of the cavity, on the properties of seepage and find percentages of the amount of different effects.

3. Find mathematical equations to calculate the amount of seepage discharge, uplift pressure and exit gradient.

4. Comparisons between the effect of the presence of these cavities and their absence within the soil on the properties of seepage below the hydraulic structure.

1.1. Geo-Studio Program

Geo-Studio is a main program for several sub- programs, and the program used in this mathematical analysis study is one of these sub-programs: SEEP/W, which is an analytical model that can mathematically represent physical processes for the flow of water through the intermediate parts. The SEEP/W tools are effectively used for the intended purpose and it's an effective tool for complex numerical analysis. As these tools have been introduced in Geo-Studio, the geometry of the model is defined within the program as a network form meshing, where the model is divide automatically, advance and sufficient to represent the behavior well understand physical processes and also enabled to understand the modeling of saturated and unsaturated flow.

The mesh has no concern that its across multiple areas or the boundary conditions and material properties will disappear once the mesh partition is changed, since any mesh partition change it is easy to change the size of the grid (Global Edge Size) and the number of segments along a specific area or by direct insertion of the edge measure. Where the current study divides the soil below the hydraulic structure into specific elements and the form of division into quadratic forms and triangle, where the number of Elements are (6510), and the number of points that surround each division (Nodes) are (6666) nodes, while the size of edges (0.4 m) as shown in figure (1).

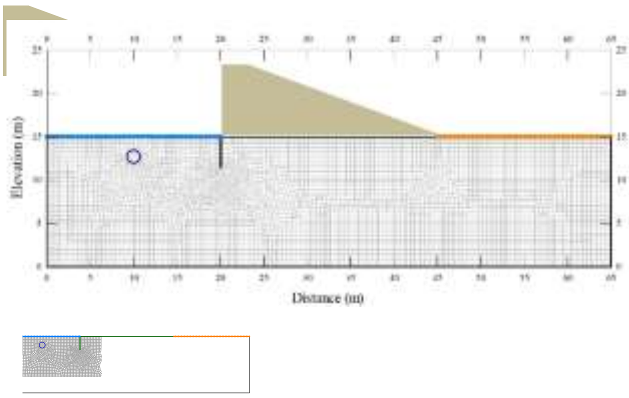

Fig. 1: The division of the grid elements identified below the hydraulic structure**.**

1.2. The Numerical Models

One of the factors influencing the seepage properties below the hydraulic structure with sheet pile is the cavity. The present study is based on the effect of the different variables on the seepage characteristics in the case of the presence of the cavity and the absence of it. Figure (2) shows the variables affecting the amount of seepage discharge, exit gradient and uplift pressure in this study.

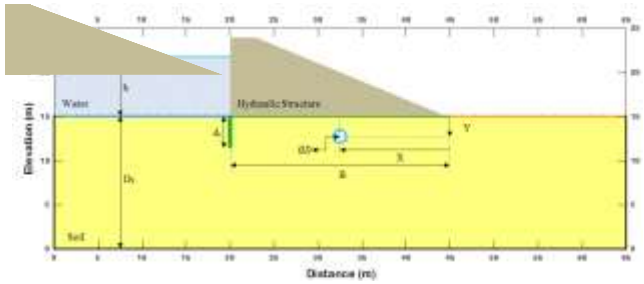

Fig. 2: Diagram of the hydraulic structure used in the study**.**

The tests are carry out using six horizontal distances from the center of the cavity to the downstream structure (X). For each value of the distance (X= 40, 35, 27, 23, 12.5, 4.5) m three depths of cavities are use from the base of the hydraulic structure (Y =1.5, 3.5, 5 m), three diameters of cavity (D= 0.2 , 0.4 , 0.8m), and three values of the permeability coefficient ($K = \left(\frac{K_y}{K_x}\right)$ = 0.5, 1, 2). When the soil permeability in the horizontal direction (Kx), and the soil permeability in the vertical direction (Ky), the width of the base structure (B=25m). Horizontal distance from the upstream structure to the upstream sheet pile (L=20m). Depth to impervious layer (Ds= 15m). The depth of the upstream sheet pile (d_1=3.5m). See equation (1).

$$\begin{pmatrix} q \\ p \\ i \end{pmatrix} = f(X, Y, D, h, kx, ky, B, L, Ds, d_1) \quad (1)$$

Figure (3) shows a diagram of the tests carried out for one model of horizontal distance and the same path is repeated several times (six times). Thus, (486 tests) are conduct in the (SEEP/W) program based on all variables of the current study. The number of models without cavity are nine models in which the upstream head changes (3.5, 4.5, 5.5 m) and three values for permeability coefficient ($K = \frac{ky}{kx}$) (0.5, 1, 2), for the same constants for pervious case, as shows in equation (2).

$$\begin{pmatrix} q \\ p \\ i \end{pmatrix} = f(h, kx, ky, B, L, Ds, d_1) \quad c \quad (2)$$

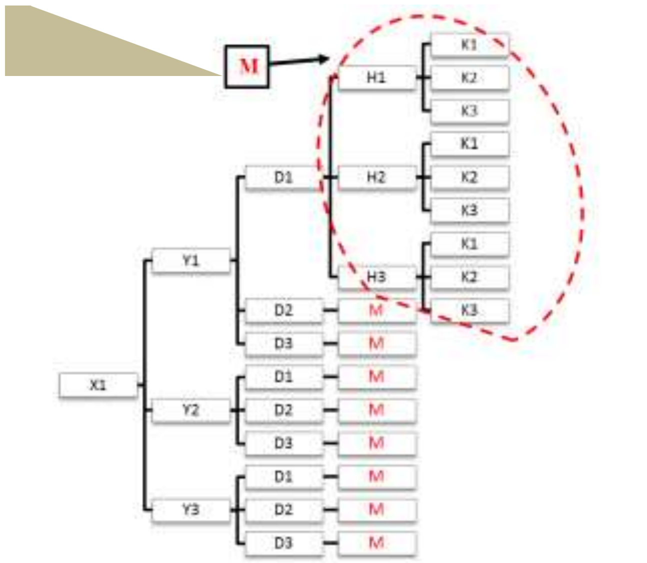

Fig. 3 : Outline of the tests complete in the present study (for one model only)**..**

1.3. Dimensional Analysis

A dimensional analysis in which it is possible to drive relatives that connects the physical quantities to a logical correlation commensurate with the properties of these quantities, so that the result of this correlation is a set of nonlinear numbers. These numbers are associations between these quantities. Dimensional analysis is a way to discover and derive laws through which it is possible to analyze how physical quantities affect different experiments. Base on the theory of dimensional analysis to find the non-dimensional variable that affect the seepage discharge (q), exit gradient (i) and the uplift pressure (P) with the effect of cavity. Depending on the (л theory), the non-dimensional variable shows in equation (3).

$$\begin{pmatrix} \frac{q}{k_x Y} \\ \frac{P}{Y} \\ i \end{pmatrix} = f\left(\frac{x}{Y}, \frac{D}{Y}, \frac{h}{Y}, \left[K = \frac{ky}{kx}\right], \frac{B}{Y}, \frac{L}{Y}, \frac{Ds}{Y}, \frac{d_1}{Y}\right) \quad (3)$$

2. Results and Discussion

2.1. Factors Effecting on Seepage Properties

The effect of the variables shown in the left part of the equation (3) with each value of the variables in the left part of the same equation is study in order to determine the effect of cavity on the variables of discharge, the uplift pressure and exit gradient.

2.1.1. Effect of the Variable $\left(\frac{X}{Y}\right)$ on the Values of $\left(\frac{q}{k_x Y}\right)$, $\left(\frac{P}{Y}\right)$ and (i).

Figures (4), (5) and (6) show the effect of the ratio between the distance from which center of cavity far from the end of the structure to the depth of the existence of this cavity from the bed level of structure $\left(\frac{X}{Y}\right)$, with the variables of discharge $\left(\frac{q}{k_x Y}\right)$, uplift pressure $\left(\frac{P}{Y}\right)$ and exit gradient (i) respectively, for three different values for cavity depth (Y) in values (1.5, 3.5, 5 m), and by changing the values of the horizontal distance of the cavity from the end of the structure (X), when the values of the permeability factor (K), the cavity diameter (D) and the height of upstream water level (h) are constant. From the figures (4), (5) and (6), it is noted that by increasing the value of (X) and demonstrated (Y), the amount of seepage and uplift pressure decreases and leads to an increase in the amount of the exit gradient. It is also note that for most cases the greatest values of seepage discharge and uplift pressure are when the site of the cavity after the sheet pile (near the downstream structure), while the lowest values of these characteristics are when the location of the cavity before the sheet pile, it is the opposite of what is observe for the exit gradient, where the greatest value of it when the site of cavity before the sheet pile, and the lowest value of the exit gradient when the location of the cavity after the sheet pile (near downstream structure). Figure (4) shows that the ratio of the drop in the amount of discharge when changing the horizontal position of the cavity from the greatest value of it before the sheet pile to a lower value after the sheet pile is about (42%) for each of the three different cases of cavity depths (Y = 1.5, 3.5, 5) m. Figure (5) shows the amount of change in a drop of uplift pressure when the position of the cavity change from the highest value of it before the sheet pile to a lower value after the sheet pile is about (3%) for the depth of the cavity (Y = 1.5, 3.5m), and about (23%) for its depth (y = 5m). Figure (6) shows the increase in the exit gradient at the change of the cavity location from the maximum value of it after the sheet pile to its lowest value by about (38.8%) for each of the cavities locate at depths (Y = 1.5, 3.5 m), and about (10.2%) for the cavity of the depth (Y = 5m). Dischare results showed good agreement with Maatooq[4].

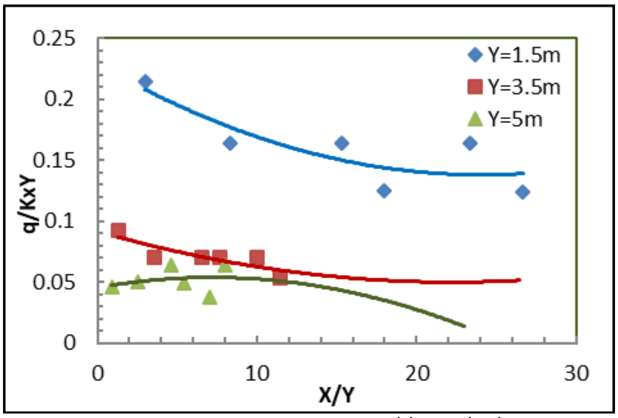

Fig. 4: The relationship between $\left(\frac{X}{Y}\right)$ and $\left(\frac{q}{k_x Y}\right)$.

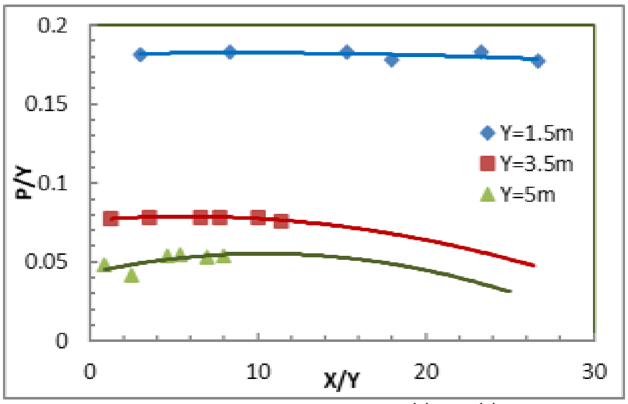

Fig. 5: The relationship between $\left(\frac{X}{Y}\right)$ and $\left(\frac{P}{Y}\right)$.

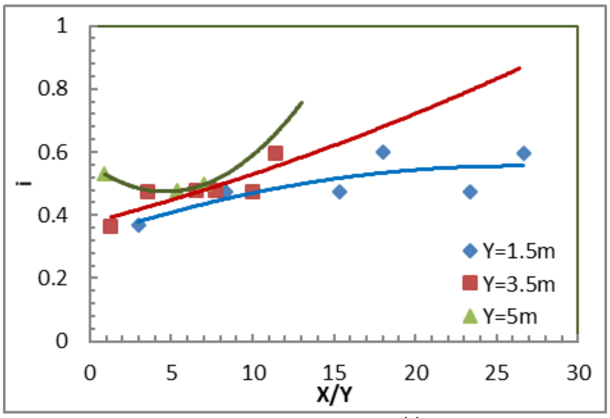

Fig. 6: The relationship between $\left(\frac{x}{y}\right)$ and (**i**).

2.1.2. Effect of the Variable $\left(\frac{D}{Y}\right)$ on the Values of $\left(\frac{q}{k_x Y}\right)$, $\left(\frac{P}{Y}\right)$ and (i) for Different (X) Value.

Figures (7), (8) and (9) show the effect of the ratio between the diameter of the cavity (D) and the depth of the cavity from bed of structure $\left(\frac{D}{Y}\right)$ on the variability of discharge $\left(\frac{q}{k_x Y}\right)$, the variable of uplift pressure $\left(\frac{P}{Y}\right)$ and the exit gradient (i) respectively, for different values of the horizontal distance of the cavity from end of the structure (X) and diameter of cavity (D), for values of the permeability coefficient (K), the upstream head (h) and the depth of cavity (Y) are constant. From the figures above, it is note that for most of the results, increasing the diameter of the cavity (D) and the constancy of (Y) will increase the amount of discharge, uplift pressure and exit gradient. It is note from figure (7) that the amount of variation in discharge when changing the value of the cavity diameter from (0.8m) to (0.2m) with cavity location at a distance (35m) drop by about (0.07%), While at (X = 40m) is (0.14%), also its value at (X = 27m) is (1.24%) and (X = 4.5m) it is (1.89%), and thus the highest value of seepage discharge drops when (X = 4.5m). The change between the highest and the lowest discharge value is at (D = 0.2m) and the distance (X = 4.5m) is (26.87%). Figure (8) shows the amount of change in the uplift pressure when the value of the cavity diameter changes from (0.8m) to (0.2m) when the cavity position at a distance (X = 35m) is about (0.06%), While its value at (X = 40m) is (0.14%), also its value at (x = 27m) is (1.24%), and at (X = 4.5m) is (0.65%). While the amount of change between the highest value of uplift pressure at cavity diameter (0.8m) and the distance (X = 40m) with the lowest value of the uplift pressure at the diameter of the cavity (0.2m) and the distance (X = 4.5m) is (22%).

Figure (9) shows the change in the exit gradient when changing the cavity diameter from (0.8m) to (0.2m) at a distance (X = 35m) about (44.93%), While its value when (X = 40m) is (0.4%), also (X = 27m) is (1.25%), and at (X = 4.5m) is (1.73%), Thus the greatest change is when (X = 35m). The difference between the highest value of the exit gradient when (D = 0.8m) and (X = 4.5m) with the lowest value of the exit gradient when (D = 0.2m) and (X = 35m) is (74.63%). Dischare results showed good agreement with Maatooq[4].

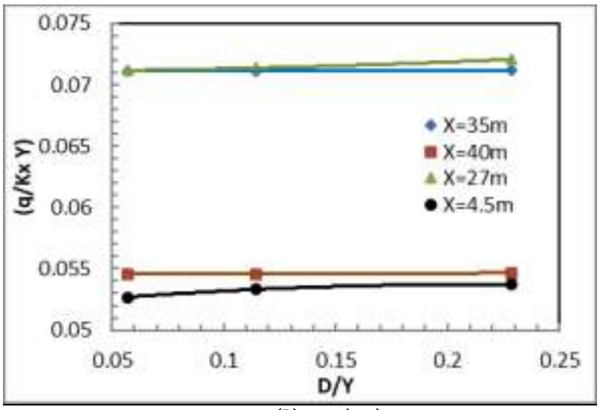

Fig. 7 : The relationship between $\left(\frac{D}{Y}\right)$ and $\left(\frac{q}{k_x Y}\right)$ for different values of (X).

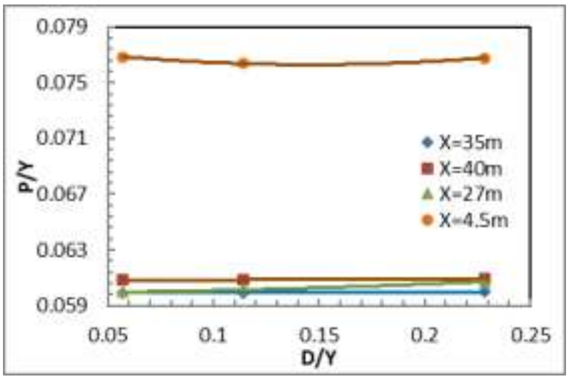

Fig. 8 : The relationship between $\left(\frac{D}{Y}\right)$ and $\left(\frac{P}{Y}\right)$ for different values of (X).

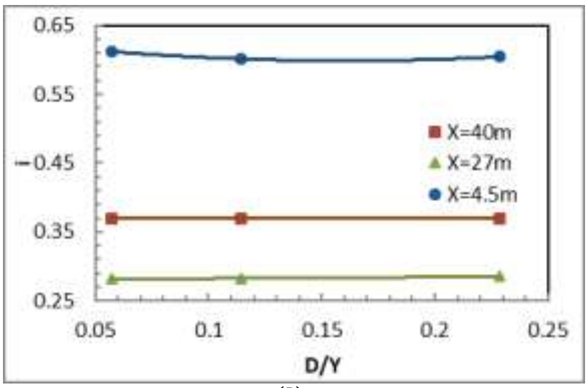

Fig. 9 : The relationship between $\left(\frac{D}{Y}\right)$ and $(\mathbf{i})$ for different values of (X).

2.1.3. Effect of the Variable $\left(\frac{D}{Y}\right)$ on the Values of $\left(\frac{q}{k_x Y}\right)$, $\left(\frac{P}{Y}\right)$ and $(\mathbf{i})$ for Different (Y) Values.

Figures (10), (11), and (12) show the effect of the ratio between the diameter of the cavity (D) and the depth of it from the bed level of structure $\left(\frac{D}{Y}\right)$ on the variability of discharge $\left(\frac{q}{k_x Y}\right)$ and $\left(\frac{P}{Y}\right)$ variable and exit gradient (i) respectively, for different values of the depth (Y) (1.5, 3.5 and 5m), with constant values for the horizontal distance of cavity (X), the upstream head (h), the permeability ratio (K), and cavity diameter (D). From the above figures, it is note that for most of the results, by increasing the diameter of the cavity (D) and stability of (Y), leads to an increase in the amount of the discharge and the uplift pressure and exit gradient. It is also note from these figures that the percentage of change for increasing in seepage discharge, uplift pressure and the exit gradient (2.23%) when the value of the cavity diameter changes from (D = 0.2m) to (D = 0.8m) and when the depth of the cavity (Y = 1.5m), Also when the depth of the cavity (3.5m) the percentage of the increase in discharge, uplift pressure and the exit gradient is (1.5%), and in depth of (5m) the percentage of increase up to (1%). While the increase in discharge, uplift pressure and the exit gradient between the lowest value occurs when (D=0.2m, Y=5m) and the highest value at (Y=1.5m, D=0.8m) are (61.4%), (69.8%) and (22.13%) respectively. Dischare results showed good agreement with Maatooq[4].

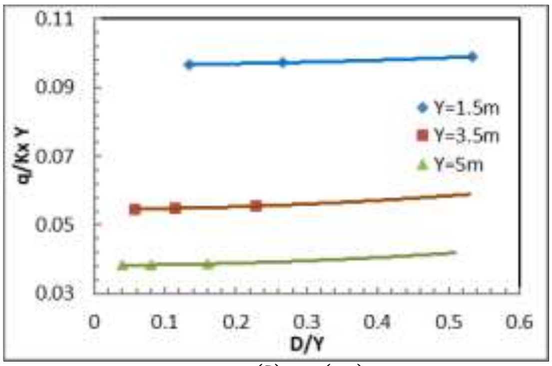

Fig. 10 : The relationship between $\left(\frac{D}{Y}\right)$ and $\left(\frac{q}{k_x Y}\right)$ for different values of (Y).

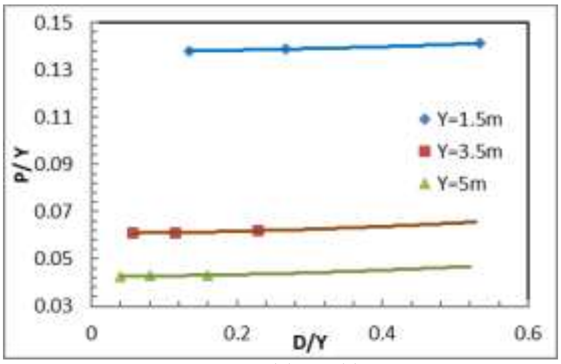

Fig. 11: The relationship between $\left(\frac{D}{Y}\right)$ and $\left(\frac{P}{Y}\right)$ for different values of (Y).

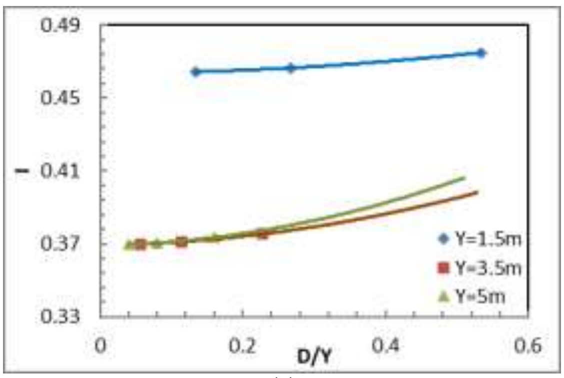

Fig. 12 : The relationship between $\left(\frac{D}{Y}\right)$ and $(\mathbf{i})$ for different values of (Y).

2.1.4. Effect of the Variable $\left(\frac{h}{Y}\right)$ on the Values of $\left(\frac{q}{k_x Y}\right)$, $\left(\frac{P}{Y}\right)$ and $(\mathbf{i})$.

Figures (13), (14), (15) show the effect of the ratio between the upstream head (h) and the depth of the cavity from the bed level of structure $\left(\frac{h}{Y}\right)$ on variables of discharge $\left(\frac{q}{KxY}\right)$ and the variable $\left(\frac{P}{Y}\right)$ and exit gradient (i) respectively, for different values of the permeability coefficient (K) and the upstream head value (h), at constant horizontal distance of the cavity (X), depth of the cavity (Y) and cavity diameter (D). From the above figures, it is note that for most of the results, with the increase of the upstream head (h) and the confirmation of cavity diameter (D), all seepage discharges, uplift pressure and exit gradient are increasing. Figure (13) shows that the amount of variation in discharge when the upstream head change from (3.5m) to (5.5m) at the rate of permeability (K= 0.5, K= 1, K= 2) has an increase of (36.3%), While the difference in discharge between the lowest value occurred when (h=3.5m) and permeability coefficient (k = 0.5) with the highest value at (h = 5.5m) and (K = 2) is an increase of (62.9%). Figure (14) shows that the amount of change in uplift pressure from upstream head (h = 3.5m) to (h = 5.5m) at the permeability ratio (K = 0.5) has an increase of (18.1%), while the amount of change in uplift pressure from (h=3.5) to (h = 5.5m) at the permeability ratio (K = 1, K = 2) increase by (36.3%), while the amount of change between the least value for uplift pressure is when (h = 3.5m) and (K = 0.5) and the highest value when (h = 5.5m) and (K = 2) is (37.3%). Figure (15) shows the amount of change in the exit gradient at (h = 3.5m, 4.5m, 5.5m) and the permeability ratio (K = 0.5, 1, 2), has an increase in the exit gradient (36.36%). While the amount of change between the lowest value when the upstream head Water (h = 3.5m) and (K = 0.5) and the highest value (h = 5.5m) and (K = 2) has an increase of (61.39%). It is note through the values that the effect of upstream head is on the discharge and the exit gradient is clear at different rates of permeability and has little effect on the uplift pressure.

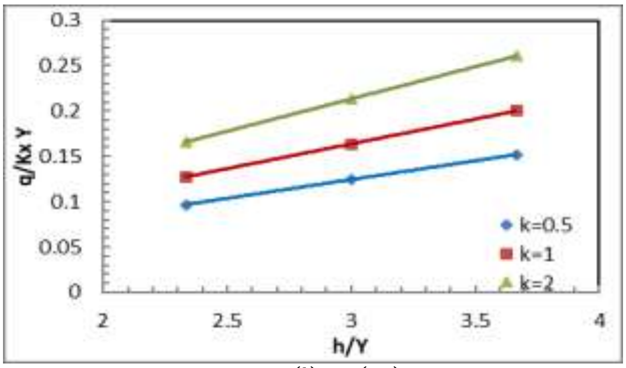

Fig. 13 : The relationship between $\left(\frac{h}{Y}\right)$ and $\left(\frac{q}{k_x Y}\right)$ for different values of (K).

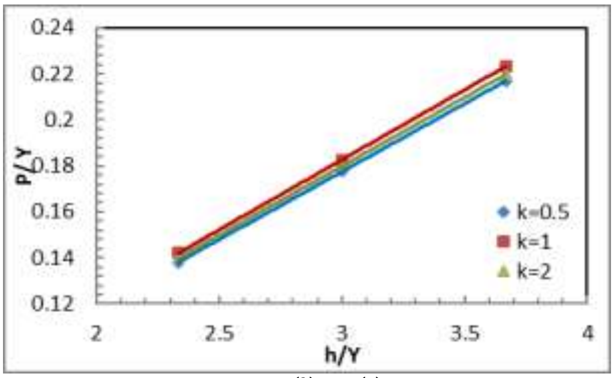

Fig. 14: The relationship between $\left(\frac{h}{Y}\right)$ and $\left(\frac{P}{Y}\right)$ for different values of (K).

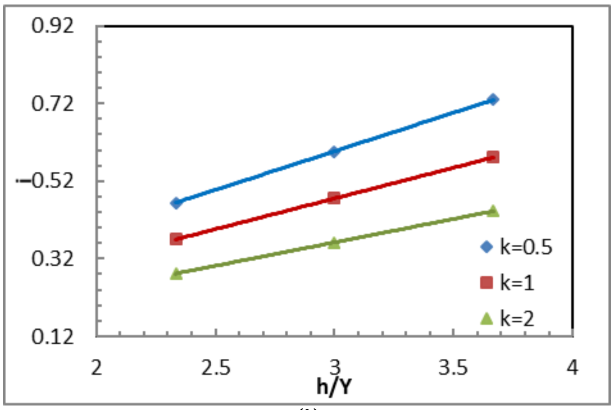

Fig. 15 : The relationship between $\left(\frac{h}{Y}\right)$ and $(\mathbf{i})$ for different values of (K).

2.1.5. Effect of the Variable $(\mathbf{K})$ on the Values of $\left(\frac{q}{k_x Y}\right)$, $\left(\frac{P}{Y}\right)$ and $(\mathbf{i})$.

Figure (16) shows the relationship between the discharge variable $\left(\frac{q}{KxY}\right)$ on permeability ratio (K) for three different values of upstream head (h) and constant values of (X=40m, Y=3.5m, D=0.2m), which shows that with an increase in the value of (K) the amount of discharge decreases. This means when $\left(\frac{KY}{KX}\right)$ increases the vertical permeability for horizontal permeability while maintaining that the vertical permeability is less than the horizontal permeability to (Kx = Ky) in value, then begins to behave in opposite path, the discharge starts increase when the ratio of $\left(\frac{Ky}{Kx}\right)$increases, this means increasing the vertical to horizontal while maintaining that the vertical permeability is higher than horizontal. In addition, it is note that increasing the value of the upstream head leads to increase the amount of discharge, where the ratio of variability between the highest value and the value of discharge at a height of upstream head equal to (3.5m) is (62.9%). Also, when the upstream head is equal to (4.5m) the highest discharge value is at (K=0.5), This value starts to decrease when the ratio increases to a certain extent and the discharge value starts to increase due to the effect of the vertical permeability. The variance of the highest value of discharge and the lowest value at a height of (4.5m) for upstream head is (25.1%), and the difference between the highest value and the lowest value of discharge at the upstream head of (5.5m) is (24.1%). The difference between the highest value of the discharge and the lowest value of it for the three upstream heads is (51.16%). Figure (17) shows the relationship between uplift pressure$\left(\frac{P}{Y}\right)$ and the ratio of permeability (K) to different upstream head. When the upstream head is (3.5m), the highest uplift pressure value is when the permeability ratio is equal to (0.5). When the upstream heads are equal to (4.5m) and (5.5m), the uplift pressure value is as low as possible at a permeability rate of (0.5), but its value is higher at a permeability rate of (2). The difference between the highest value and the lowest uplift pressure value at (4.5 m) and (5.5 m) are (23.4%) and (19.4%) respectively, as well as the difference between the highest value and the lowest value of uplift pressure at three upstream heads (38.2%). In figure (18) the exit gradient (i) shows behavior is different from the uplift pressure and discharge with the ratio of permeability when the upstream head changes. The exit gradient value is greatest when permeability ratio (1) at upstream heads (4.5m) and (5.5m), where the variance between the highest value and the lowest value of the exit gradient at upstream heads (3.5, 4.5 and 5.5) are (20.3%), (52.75%), and (50.3%) respectively. The variance between the highest and lowest values for the three upstream heads equal to (61.34%).

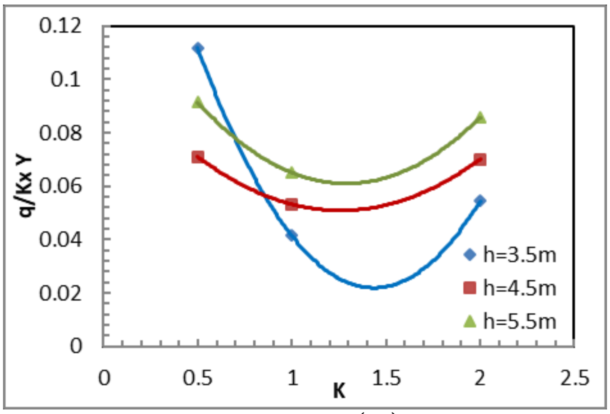

Fig. 16 : The relationship between (**K**) and $\left(\frac{q}{k_x Y}\right)$ for different values of (h).

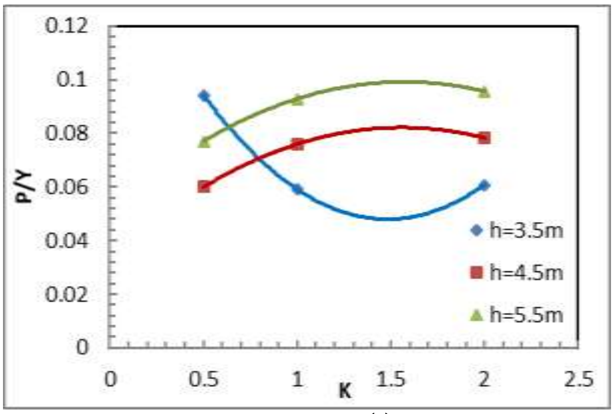

Fig. 17 : The relationship between (**K**) and $\left(\frac{P}{Y}\right)$ for different values of (h).

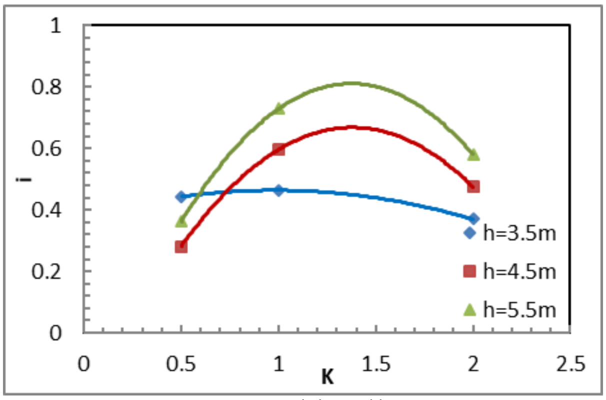

Fig. 18 : The relationship between (**K**) and (**i**) for different values of (h).

2.2. Mathematical Equations to Find the Amount of Seepage Discharge, Uplift Pressure and Exit Gradient.

Base on the statistical package for social sciences (SPSS), which is an integrated computer package for data entry and analysis because it contains most of the statistical tests and its great ability to process data. Therefore, (70%) of the data extracted by (SEEP/W) to determine the mathematical equations for finding the values of the seepage discharge, uplift pressure and exit gradient as shown in equations (4), (5) and (6), respectively.

$$q = 0.112 K_x Y * \left(\frac{X}{Y}\right)^{-0.001} * \left(\frac{D}{Y}\right)^{0.016} * \left(\frac{h}{Y}\right)^{0.718} * (K)^{0.099} * \left(\frac{B}{Y}\right)^{0.23} * \left(\frac{L}{Y}\right)^{0.239} * \left(\frac{Ds}{Y}\right)^{-1.01} * \left(\frac{d1}{Y}\right)^{0.827} \quad .(4)$$

$$P = 0.224Y * \left(\frac{X}{Y}\right)^{0.002} * \left(\frac{D}{Y}\right)^{-0.017} * \left(\frac{h}{Y}\right)^{0.721} * (K)^{0.004} * \left(\frac{B}{Y}\right)^{0.207} * \left(\frac{L}{Y}\right)^{-0.761} * \left(\frac{Ds}{Y}\right)^{-0.256} * \left(\frac{d1}{Y}\right)^{1.127} \quad ..(5)$$

$$i = 0.191 - 0.00024X - 0.000198Y + 0.00594D + 0.0686h - 0.0152K \quad (6)$$

Statistical parameters are used to prove that these equations are complied with (SPSS) where the coefficient of determination (R^2) for both the discharge and uplift pressure equations (4) and (5) are (0.89) and (0.9) respectively, while the coefficient of correlation (R) for the calculation of the exit gradient in equation (6) is (R = 0.8), which show high accuracy and very good result for the efficiency of these equations. In addition to the statistical criteria, the above equations are verifying by applying (30%) of the remaining results in these equations. Figures (19), (20) and (21) extracted from the (SEEP/W) results and the results obtain from the propose equations for seepage discharge, uplift pressure and exit gradient respectively. The above figures show great convergence of results for most cases and this can be considered that mathematical equations proposed in the study with high efficiency.

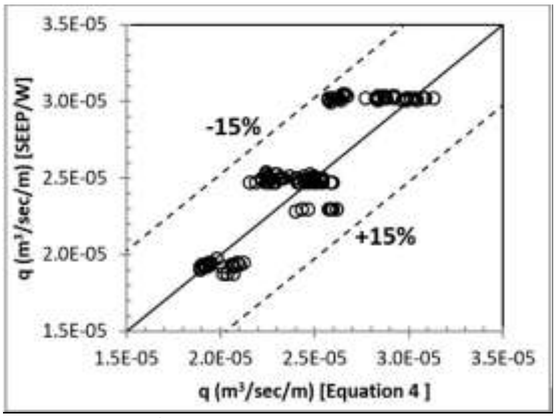

Fig. 19 : Comparison of the seepage discharge values determine by the propose equation (4) with the current study and determine by SEEP/W, for (30%) of the randomized results.

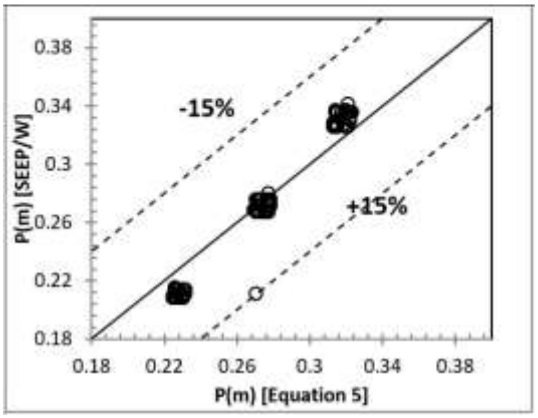

Fig. 20 : Figure (20): Comparison of the uplift pressure values determine by the propose equation (5) with the current study and determine by SEEP/W, for (30%) of the randomized results.

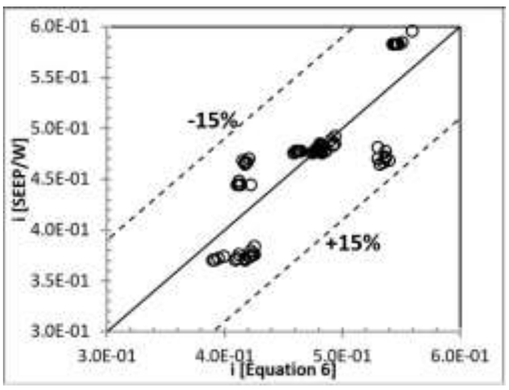

Fig. 21 : Comparison of the exit gradient values determine by the propose equation (6) with the current study and determine by SEEP/W, for (30%) of the randomized results.

2.3. Comparison of the Effect of the Presence and Disappearance of Cavity on Seepage Characteristics.

By comparing the effect of the presence of cavitation in the soil with the absence of these cavities, it is observing that behaviors are similar to most, as follows

2.3.1. Comparison of the Effect of the Presence and Disappearance of Cavity on Seepage Discharge.

Table (1) shows the percentage of discharge values for the condition of the presence of cavity compared to disappearance of cavity on it, which shows an increase in this percentage as a ratio for most cases due to the influence of the permeability, upstream head and distance (X) and depth (Y). Figures (22), (23), and (24) show model of the difference between the results of the presence and absence of the cavity on discharge values, the uplift pressure and exit gradient respectively.

Table 1: shows the percentage of discharge values for the condition of the presence of cavity compared to disappearance of cavity on it.

Unit Discharge (%)	y (m)	x (m)	K
+ 0.08-0.005	1.5 3.5	35	
	5	35	
	1.5	40	
	3.5	40	
	5	40	
	1.5	27	
-30	5	12.5	2
	3.5	23	
	5	23	
	1.5	4.5	
	3.5	4.5	
	5	4.5	
	1.5	12.5	
+ 1.35-0.09	3.5	12.5	
	5	12.5	
+ 62-0.04	All Positions of Cavities		0.5
+ 51.2-0.015	All Positions of Cavities		1

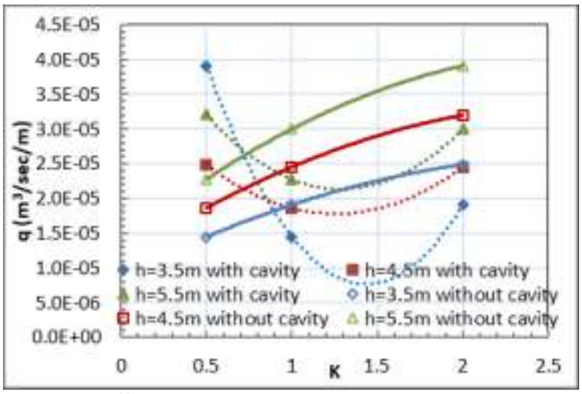

Fig. 22 : The difference in the seepage discharge results between the state of presence and absence of cavtation.

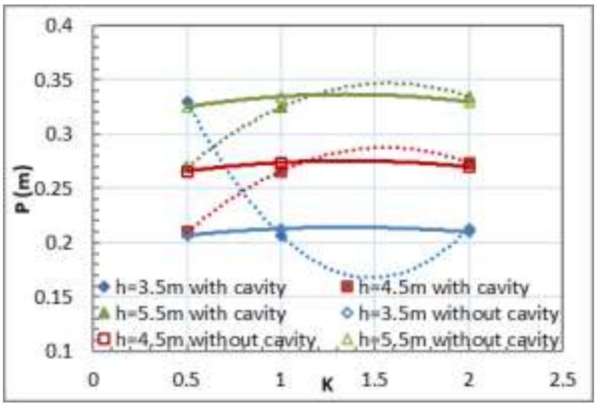

Fig. 23 : The difference in the uplift pressure results between the state of presence and absence of cavtation.

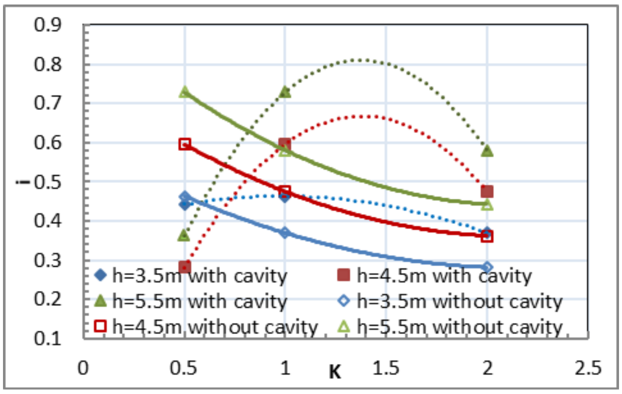

Fig. 24 : The difference in the exit gradient results between the state of presence and absence of cavtation.

2.3.2. Comparison of the effect of the presence and disappearance of cavity on uplift pressure.

It is note that the results obtain for each of the uplift pressure in the case of the presence of cavity and the absence of a cavity under the same conditions of upstream head, permeability ratio (K=0.5) and the depth of the sheet pile, there is an increase in the amount of uplift pressure in the case of cavity by (38-0.03%) compare with the absence of cavities. For soil with (K=1), there is an increase in the uplift pressure in the case of cavity by (29.2-0.01%) compare with the absence of cavities. For soil with (K=2), there is an increase in the uplift pressure in the case of cavity by (23.56-0.00095%) compare with the absence of cavities.

2.3.3. Comparison of the effect of the presence and disappearance of cavity on exit gradient.

Table (2) shows the percentage of exit gradient values for the condition of the presence of cavity compared to disappearance of cavity on it, which shows in most cases an increase in percentage ratio due to the influence of the permeability factors, upstream head, horizontal distance (X) and cavity depth (Y).

Table 2: shows the percentage of exit gradient values for the condition of the presence of cavity compared to disappearance of cavity on it.

Exit Gradient (%)	y (m)	x (m)	K
+ 0.55-0.03	1.5		
	3.5	35	
	5		
- 4.75	1.5		
	3.5	40	
	5		
	1.5		
	3.5	27	
+ 20-0.05	5		0.5
	1.5		
	3.5	12.5	
	5		
+ 1.23-0.15	1.5		
	3.5	23	
	5		
- 63-21	1.5		
	3.5	4.5	
	5		
+ 38.4-0.04	All Positions of Cavities		1
+ 53-0.05	All Positions of Cavities		2

3. Conclusions

Through the analytical analysis in the (SEEP/W) program to demonstrate the effect of the cavity on the seepage characteristics below the hydraulic structure, the following conclusions are reach:

1. By changing the ratio of the permeability coefficient (0.5 to 1.5) with the presence of the cavity lead to a decrease in the discharge values, and change (1.5 to 2) it is observing increase in discharge to different upstream head.

2. The variable permeability coefficient (0.5 to 2) leads to an increase in the values of the uplift pressure in most cases with the presence of the cavity.

3. Increasing the permeability coefficient from (0.5-1.5) with different upstream head lead to a gradual increase in the values (i) but with the persistence of the permeability coefficient (1.5-2) lead to reduce (i), with the presence of the cavity.

4. With the presence of the cavity show that the increase in upstream head lead to increase in the values of the discharge, uplift pressure and exit gradient.

5. Increasing the distance (X) leads to reduction both values of the discharge, uplift pressure, and increasing in exit gradient.

6. The increase in diameter of the cavity will affect the increase the seepage properties and this effect is less than the effect of the coefficient of permeability and upstream head.

7. Develop empirical equations for seepage discharge, uplift pressure and exit gradient have a coefficient of determination and correlation (0.8 ,0.89 ,0.9) respectively.

8. The behavior of variables of this study in the case of the cavity comparable to the absence of a cavity under hydraulic structure shows variation in the results, where there are increasing and decrease behavior for the different cases.

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