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Effect of Intermediate Sheet Piles in Non-Homogenous Soil on Seepage Properties Under Hydraulic Structure Using SEEP/W Program

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Abstract

The seepage through a permeable soil under hydraulic structure exerts uplift pressure and may carry soil particles there by leads to piping. This paper concerns to study the effect of using intermediate sheet pile under the apron of hydraulic structure besides the upstream and downstream piles rest on non-homogeneous soil layer. This configuration aim to show how it affect the uplift pressure, exit gradient and seepage discharge at toe of hydraulic structure by using computer program SEEP/W Package.

From the software test carried out two cases, first case using two sheet pile one at the upstream and the other at the downstream, then compare its results with the second case when the sheet pile at upstream, downstream and intermediate pile introduced Also for each run the quantity of uplift pressure, exit gradient and discharge at toe of hydraulic structure were determined to develop an empirical equations. Also, the results have been verify with artificial neural network (ANN), this verification shown good agreement between them.

Keywords: Uplift pressure, Exit gradient, Discharge, SEEP/W, ANN, Non-homogenous soil.

تأثير استخدام ركيزة وسطية في تربة غير متجانسة على خصائص التسرب تحت المنشأ الهيدروليكي باستخدام البرنامج الحاسوبي SEEP/W

الخلاصة

تسرب المياه في التربة النفاذة تحت المنشأ الهيدروليكي يولد ضغط اصعاد والذي يؤدي الى حمل دقائق التربة والذي يؤدي الى حدوث ظاهرة الانبوبية. هذا البحث يهدف لدراسة تأثير استخدام ركيزة في المنتصف بالإضافة الى الركيزتين اللتين هما في مقدم ومؤخر المنشأ وذلك في تربة غير متجانسة على قيم ضغط الاصعاد وتدرج المخرج والتصريف الخارج عند مؤخر المنشأ الهيدروليكي باستخدام برنامج SEEP/W.

باستخدام البرنامج تم اجراء حالتين من التحليل، الحالة الاولى كانت باستخدام ركيزتين احدهما في المقدم والاخرى في مؤخر المنشأ، ثم مقارنتها مع الحالة الثانية الناتجة عن استخدام ثلاث ركائز (في مقدم ومؤخر ووسط) المنشأ على خصائص التسرب. لكل تجربة تم قياس مقدار ضغط الاصعاد وتدرج المخرج والتصريف عند مؤخر المنشأ الهيدروليكي وبذلك تم استخراج معادلات رياضية لإيجاد هذه القيم. كذلك تم التحقق من نتائج البرنامج باستخدام الشبكة العصبية الصناعية، ومن خلالها اوجد ان مقدار التقارب بالنتائج كان بشكل كبير.

الدالة الكلمات: ضغط الاصعاد، تدرج المخرج، التصريف، SEEP/W، الشبكة العصبية الاصطناعية، تربة غير متجانسة.

Nomenclature

α = Angle of last sheet pile.
β = Angle of intermediate sheet pile.
B = Distance between two sheet pile (L).
d_1 = Depth of first sheet pile (L).
d_2 = Depth of second sheet pile (L).

d_3 = Depth of intermediate sheet pile (L).
H = Upstream head (L).
i= Exit gradient (L/L).
kx = Hydraulic conductivity of soil in X direction (L/T).
ky = Hydraulic conductivity of soil in Y direction (L/T).
P= Uplift pressure head (L).
q = Discharge (L^3/T/L).
θ = Angle of first sheet pile.

Introduction

The stability of earth structures and natural deposits is dependent not only upon the static properties of the soil but also the forces produced by water as it seeps through the pores. As an aid to engineer judgment in the design of earth structures or the stabilization of earth deposits, the engineer should be talented to estimate through analyses, the magnitude of seepage forces and pressures and the quantities of water flowing through the soil.

Farouk and Smith, studied the design of hydraulic structures with two intermediate filters located anywhere between two end cutoffs of a flat floor[1].

Mohsen, studied seepage with nonlinear permeability by least square FEM[2].

Al-Delewy et al., studied the optimum design of control devices for safe seepage under hydraulic structures by finite-element method which used to evaluate seepage through porous media below hydraulic structures with blanket, filter trench as seepage control devices[3].

Arslan and Mohammad used investigational for pizometric head under hydraulic structures for upstream, intermediate and downstream sheet piles inclination[4].

Alsenousi and Mohamed studied the effects of soil foundation features and inclined cutoffs on seepage beneath hydraulic structures Using conformal analysis, electrical analog models empirical formulas, experimental works using physical as well as numerical models[5].

Kumar studied experimentally different forms of seepage stream under the sheet pile through model perform seepage analysis of bulkheads[6].

Baghalian and Nazari predicted the uplift pressure under the diversion dam using artificial neural network[7].

Jain studied the finite depth seepage below flat overall with end cutoffs and a downstream step by way of design curves for uplift pressure at key points[8].

Ijam obtained an analytical solution for seepage flow below a dam with inclined cutoff set anywhere along the base of the dam. The derivative equations have been used for calculation of hydraulic gradient along the downstream bed and for the pressure at key points[9].

Azizi et al. studied the Weep Hole and Cut-off Effect in Decreasing of Uplift Pressure (Case Study: Yusefk and Mahabad Diversion Dam) by simulation it in SEEP/W software[10].

Mansuri et al. studied the effect of location and angle of cutoff Wall on uplift pressure in change dam by compares the adeptness of cutoff wall for some design parameters in an supposed diversion dam cross-section[11].

Khalili and Amiri studied the effects of blanket, drains and cutoff wall on reducing uplift pressure, exit gradient, and seepage under hydraulic structures for different inclined angles of cutoff walls[12].

Kramer studied piping in transient conditions analysis of time-dependent erosion under dikes[13].

Abbood et al. studied the optimum dimensions of hydraulic structures foundation and protections using combined genetic algorithm using artificial Neural Network, also the Geo-studios software used to analyze 1200 different cases[14].

Alnealy and Alghazali, (2015), studied seepage under hydraulic structures using slide program then they had present a distribution curves of uplift pressure along the floor as well as the distribution of exit gradient at downstream[15].

In this study and in order to provide the required safety for both piping and uplift pressure due to exit gradient, the designers usually provide sheet pile at the upstream and the downstream sides of the hydraulic structures foundation for non-homogenously the intermediate sheet pile being necessary. By using SEEP/W, and depends on software program SPSS-19 Statistics, equations will provide information on the amount uplift pressure head, exit gradient and seepage discharge at toe of hydraulics structure then verify these results by using an artificial neural network (ANN).

Procedure of Design Setup

For the purpose of running SEEP/W model tests, the two cases carried out, the first case using two sheet pile one on the upstream and the other on downstream, while in the second case using three sheet pile at upstream, downstream and intermediate, for each case four different values for each variable, were used these are angle of Upstream sheet pile (θ=90°, 10°, 20° and 30°), angel of downstream sheet pile (α=90°, 10°, 20° and 30°), angel of intermediate sheet pile (β= 90°, 10°, 20°, and 30°), soil permeability ratio (Kx/Ky= 0.1, 0.5, 2 and 5), with constant upstream head 5m and distance between sheet piles 25m, depth of first, last and intermediate sheet piles are (d_1=3.5m), (d_2=2.5m), (d_3=3m) respectively. so the overall runs were carried out for the first case 64 runs, and for second case 255 runs. For each run determine the amount of the uplift pressure head, exit gradient and discharge at toe of hydraulic structure. Figure (1) shows designation for first and second cases.

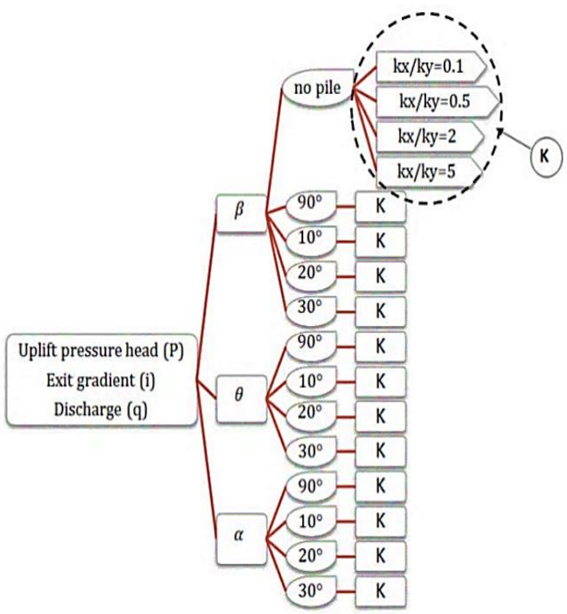

Fig. 1. Tests for first and second group

Design Variables

The variation of uplift pressure, exit gradient and discharge under the hydraulic structure, depends on the same parameter influences these are:

$$\begin{pmatrix} P \\ i \\ q \end{pmatrix} = f\left(d_1, d_2, d_3, H, b, \theta, \alpha, \beta, \frac{Kx}{Ky}\right) \quad (1)$$

In order to develop an empirical equations to determine the uplift pressure, exit gradient and discharge at the toe of hydraulic structure the above equations simplest as shown below without taking the effect of some variables that was widely studied by pervious researcher:

$$\begin{pmatrix} P \\ i \\ q \end{pmatrix} = f\left(\theta, \alpha, \beta, \frac{Kx}{Ky}\right) \quad (2)$$

Figure (2) illustrates the possible variables that can be affect the uplift pressure, exit gradient and discharge at toe of hydraulic structure.

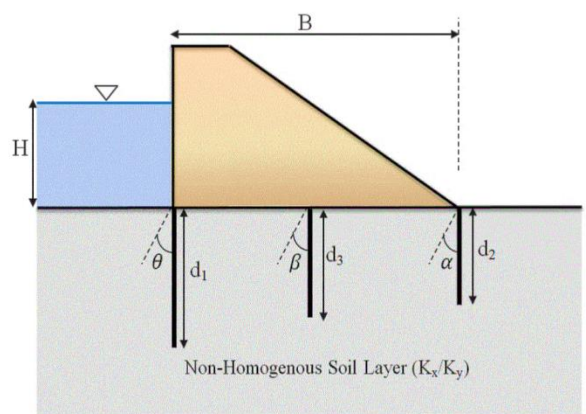

Fig. 2a. The general section study

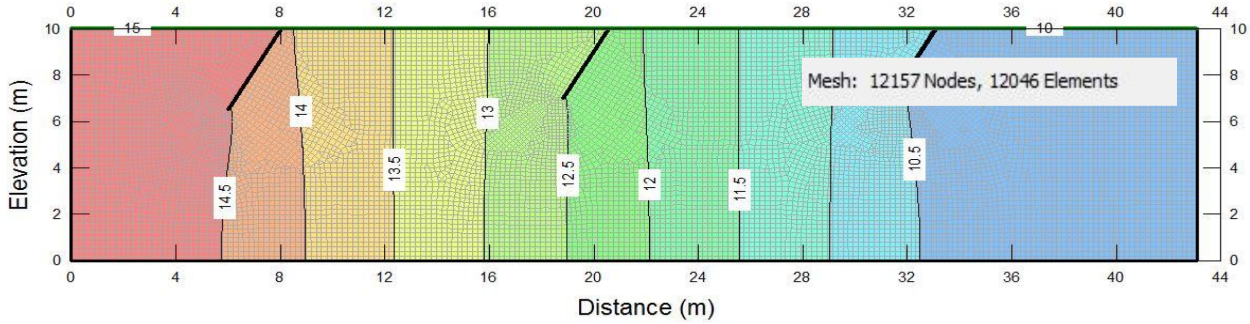

Fig. 2b. The general section of three sheet pile in non-homogenous soil layer

Results and Discussion

Relationship Between the Variables without Using Intermediate Sheet Pile

Using SEEP/W data, the following relations between the variables for cases without intermediate sheet pile comparing with cases having three sheet piles as shown in the left side of the Equation (2) with the variables in the right side of the above equations were obtained.

Figure (3) shows the relationship between the angle of last sheet pile with the uplift pressure head (P) at toe of hydraulic with boundary conditions of constant angle of first sheet pile (θ), constant depth of all piles under taken, with constant permeability ratio (Kx/Ky). From this figure it can be shown the high effect of using intermediate sheet pile on the magnitude of the uplift pressure head. Also it shown that (P) decreases with increasing (α) but when reach to (α=90°) the uplift pressure increase. Also by using intermediate sheet pile with ($\beta = 10°$ or $90°$) beside the first and last sheet piles the uplift pressure head decreases by approximately 8%, 5%, 2.8% and 2.2% for permeability ratio (Kx/Ky) 0.1, 0.5, 2 and 5 respectively. But when use intermediate sheet pile with ($\beta = 20°$) the uplift pressure head decreases by approximately 7.5%, 4.8%, 3% and 2.3% for permeability ratio (Kx/Ky) 0.1, 0.5, 2 and 5 respectively, and when use intermediate sheet pile with ($\beta = 30°$) the uplift pressure head decreases by approximately 7%, 4.7%, 3.1% and 2.5% for permeability ratio (Kx/Ky) 0.1, 0.5, 2 and 5 respectively. So from above results the maximum uplift pressure head when used intermediate sheet pile with angle ($\beta = 10°$) at (kx/ky=5), while the minimum uplift pressure head when used intermediate sheet pile with angle ($\beta = 10°$) at (kx/ky=0.1).

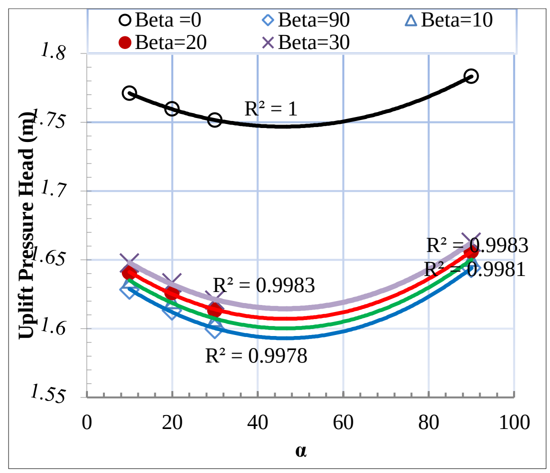

Fig.3. Relationship between (α) and uplift pressure head at ($\theta = 90°$), Kx/Ky=0.1

Figure (4) shows the relationship between the angle of last sheet pile with the exit gradient at toe of hydraulic structure (i) with boundary conditions of constant angle of first sheet pile (θ), constant depth of all piles under taken, with constant permeability ratio (Kx/Ky). From this figure it can be shown that (i) increases with increasing (α) but when reach to (α=90°) the exit gradient decrease, also when use intermediate sheet pile with ($\beta = 10°, 20°, 30°, 90°$) beside the first and last sheet piles the exit gradient decreases by approximately 4.7% for permeability ratio (Kx/Ky=0.1, but for permeability ratio (Kx/Ky=0.5) decreases about 3%, 5%, 7% and 9% when ($\alpha = 90°, 10°, 20°, 30°$) respectively, also for permeability ratio

(Kx/Ky=2) was decreases about 3%, 7%, 11% and 13% when $(\alpha = 90°, 10°, 20°, 30°)$ respectively, and for permeability ratio (Kx/Ky=5) decreases about 2%, 10%, 11% and 17% when $(\alpha = 90°, 10°, 20°, 30°)$. So from above the maximum exit gradient is by using any intermediate angle with last sheet pile at angle $(\alpha = 90°)$ for (kx/ky=5), while the minimum exit gradient when use any intermediate angle with last sheet pile at angle $(\alpha = 30°)$ for (kx/ky=5).

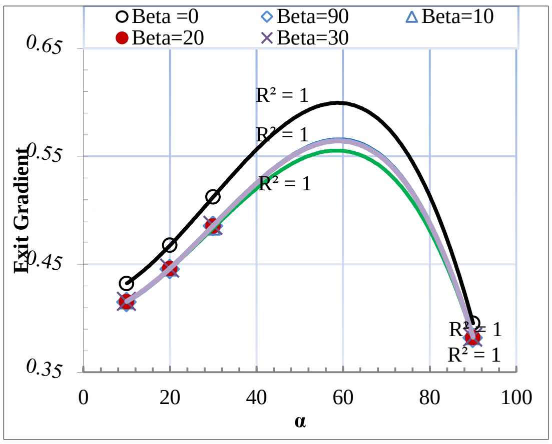

Fig. 4. Relationship between (α) and exit gradient at $(\theta = 90°)$, Kx/Ky=0.1

Figure (5) shows the relationship between the angle of last sheet pile with the discharge exit at toe of hydraulic structure (q) with boundary conditions of constant angle of first sheet pile (θ), depth of first, intermediate constant depth of all piles under taken, with constant permeability ratio (Kx/Ky). From this figure it can be shown that (q) increases with increasing (α) but when reach to (α=90°) the discharge decrease, so when use intermediate sheet pile with $(\beta = 10°, 20°, 30°, 90°)$ beside the first and last sheet piles, the discharge decreases by approximately 4.8% for permeability ratio (Kx/Ky=0.1), also for permeability ratio (Kx/Ky=0.5) decreases about 5%, 6%, 9% and 3% when $(\alpha = 90°, 10°, 20°, 30°)$ respectively, for permeability ratio (Kx/Ky=2) decreases about 4% when $(\alpha = 90°)$ and increases 2.5% when $(\alpha = 10°, 20°, 30°)$, for permeability ratio (Kx/Ky=5) decreases about 2.2% when $(\alpha = 90°)$, and increases 2.2%, 6.7% and 1.5% at $(\alpha = 10°, 20°, 30°)$ respectively. So from above results the maximum discharge when used last sheet pile with angle $(\alpha = 20°)$ at (kx/ky=5), while the minimum discharge when used last sheet pile with angle $(\alpha = 90°)$ at (kx/ky=0.5) with any intermediate sheet pile angle.

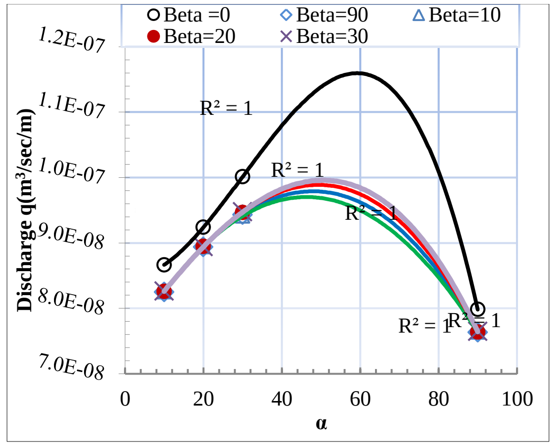

Fig. 5. Relationship between (α) and discharge at $(\theta = 90°)$, Kx/Ky=0.1

Relationship Between the Variables with Using Intermediate Sheet Pile

From the results SEEP/W, the following relations between (P, q, i) were obtained. Figure (6) shows the relationship between the angle of last sheet pile with the uplift pressure head (P) at toe of hydraulic structure for some models of three sheet piles in non-homogenous soil layer. The boundary conditions are constant angle of first and intermediate sheet pile (θ, β), constant depth of all sheet piles under taken, four different ratio of permeability (Kx/Ky) above used. From this figure it can be shown that the uplift pressure head increases with increasing (α) but when reach to $(\alpha = 90°)$ the uplift pressure decrease. The uplift pressure head decreases by approximately 0.95% when decreases the angle $(\alpha = 90°)$ to $(\alpha = 10°)$, and decreases by approximately 0.92% when decreases the angle $(\alpha = 90°)$ to $(\alpha = 20°)$, decreases by approximately 0.85% when decreases the angle $(\alpha = 90°)$ to $(\alpha = 30°)$. Also, the figure show that the uplift pressure head decreases with increasing the soil permeability ratio which decrease approximate about 20.5% when increases the permeability ratio from 0.1 to 0.5, decrease approximate about 30% when increases the permeability ratio from 0.5 to 2, decrease approximate about 25% when increases the permeability ratio from 2 to 5.

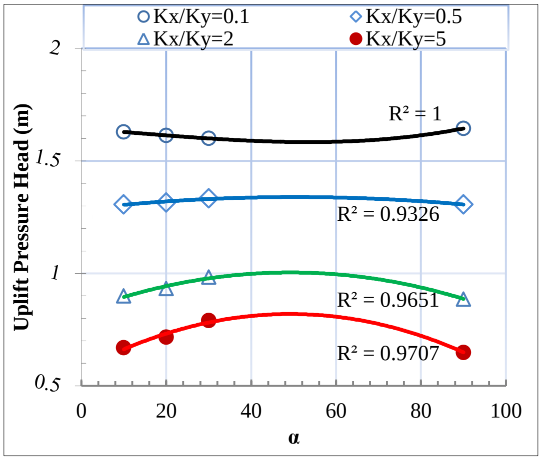

Fig. 6. Relationship between (α) and uplift pressure head at $(\theta = 90°, \beta = 90°)$

Figure (7) shows the relationship between the angle of first sheet pile with the uplift pressure head (P) at toe of hydraulic structure. The boundary conditions of constant angle of last and intermediate sheet pile (α, β), constant depth of all piles under taken, with four different ratio of permeability (Kx/Ky) have used. From this figure it can be shown that the uplift pressure head decreases with increasing (θ) but when reach to $(\theta = 90°)$ the uplift pressure increase. The uplift pressure head decreases by approximately 2% when decreases the angle $(\theta = 90°)$ to $(\theta = 10°)$, and decreases by approximately 2.3% when decreases the angle $(\theta = 90°)$ to $(\theta = 20°)$, decreases by approximately 3% when decreases the angle $(\theta = 90°)$ to $(\theta = 30°)$.

Figure (8) shows the relationship between the angle of intermediate sheet pile with the uplift pressure head (P) at toe of hydraulic structure for some models of three sheet piles in non-homogenous soil layer with boundary conditions of constant angle of first and last sheet pile (θ, α) constant depth of all piles under taken, four different ratio of permeability (Kx/Ky) have used. From this figure it can be shown the low effect of (β), and the uplift pressure head increases with increasing (β), The uplift pressure head increases by approximately 0.38% when decreases the angle $(\beta = 90°)$ to $(\beta = 10°)$, and increases by approximately 0.35% when decreases the angle $(\beta = 90°)$ to $(\beta = 20°)$, increases by approximately 0.4% when decreases the angle $(\beta = 90°)$ to $(\beta = 30°)$. Also, the figure show that the uplift pressure head decreases with increasing the soil permeability ratio.

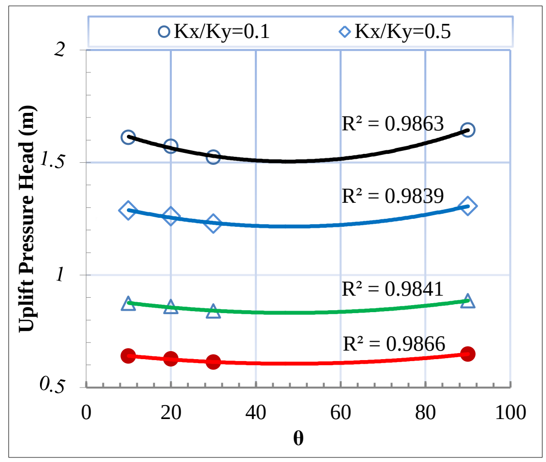

Fig. 7. Relationship between (θ) and uplift pressure head at $(\alpha = 90°, \beta = 90°)$

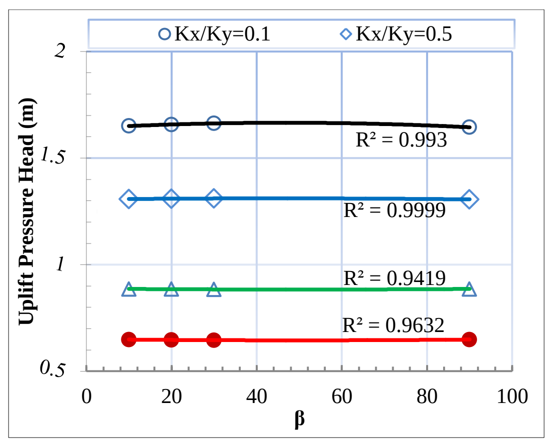

Fig. 8. Relationship between (β) and uplift pressure head at $(\theta = 90°, \alpha = 90°)$

Figure (9) shows the relationship between the angle of last sheet pile with the exit gradient at toe of hydraulic structure (i). The boundary conditions are constant angle of first and intermediate sheet pile (θ, β), constant depth of all piles under taken, four different ratio of permeability (Kx/Ky) have used. From this figure it can be shown that the exit gradient increases with increasing (α) but when reach to (α = 90°) the exit gradient decrease. The exit gradient increases by approximately 7.9% when decreases the angle (α = 90°) to (α = 10°), and increases by approximately 6.8% when decreases the angle (α = 90°) to (α = 20°), increases by approximately 8.2% when decreases the angle (α = 90°) to (α = 30°). Also, the figure show that the exit gradient decreases with increasing the soil permeability ratio which decrease approximate about 30% when increases the permeability ratio from 0.1 to 0.5, decrease approximate about 34% when increases the permeability ratio from 0.5 to 2, decrease approximate about 26% when increases the permeability ratio from 2 to 5.

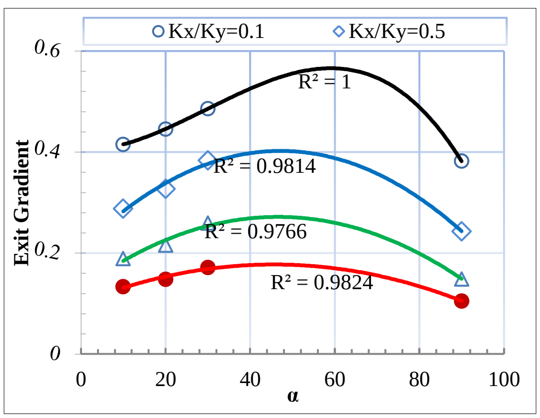

Fig. 9. Relationship between (α) and exit gradient at (θ = 90°, β = 90°)

Figure (10) shows the relationship between the angle of first sheet pile with the exit gradient at toe of hydraulic structure (i). The boundary conditions are constant angle of last and intermediate sheet pile (α, β), constant depth of all sheet piles under taken, four different ratio of permeability (Kx/Ky) have used. From this figure it can be shown that the exit gradient decreases with increasing (θ) but when reach to (θ = 90°) the exit gradient increase. The exit gradient decreases by approximately 2% when decreases the angle (θ = 90°) to (θ = 10°), and decreases by approximately 2.4% when decreases the angle (θ = 90°) to (θ = 20°), decreases by approximately 3.1% when decreases the angle (θ = 90°) to (θ = 30°).

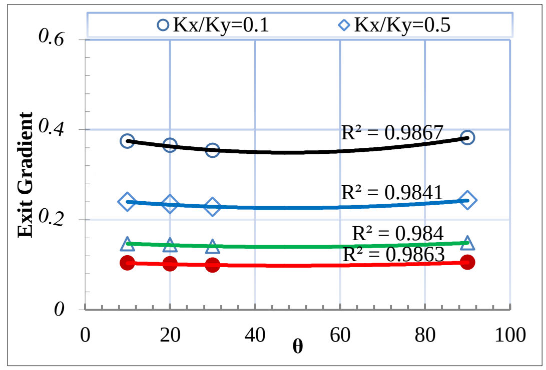

Fig. 10. Relationship between (θ) and exit gradient at (α = 90°, β = 90°)

Figure (11) shows the relationship between the angle of intermediate sheet pile with the exit gradient at toe of hydraulic structure (i). The boundary conditions are constant angle of first and last sheet pile (θ, α), constant depth of all piles under taken, four different ratio of permeability (Kx/Ky). From this figure it can be shown the low effect of (β). The exit gradient decreases with increasing (β), exit gradient increases by approximately 0.05% when decreases the angle (β = 90°) to (β = 10°), and increases by approximately 0.047% when decreases the angle (β = 90°) to (β = 20°), increases by approximately 0.067% when decreases the angle (β = 90°) to (β = 30°). Also, the figure show that the exit gradient decreases with increasing the soil permeability ratio.

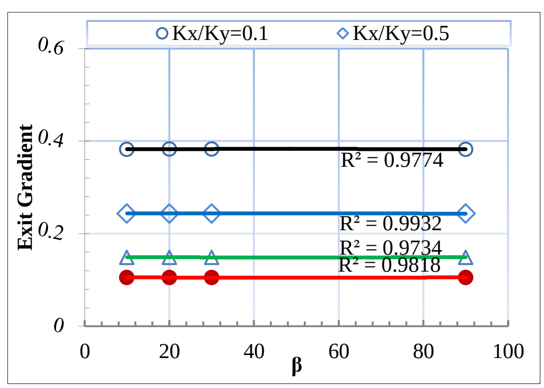

Fig. 11. Relationship between (β) and exit gradient at (θ = 90°, α = 90°)

Figure (12) shows the relationship between the angle of last sheet pile with the discharge seepage at toe of hydraulic structure (q). The boundary conditions are constant angle of first and intermediate sheet pile (θ, β), constant depth of all piles under taken, four different ratio permeability (Kx/Ky) have used. From this figure it can be shown that the discharge increases with increasing (α) but when reach to $(\alpha = 90°)$ the discharge decrease. Discharge increases by approximately 7.4% when decreases the angle $(\alpha = 90°)$ to $(\alpha = 10°)$, and increases by approximately 7.7% when decreases the angle $(\alpha = 90°)$ to $(\alpha = 20°)$, increases by approximately 5.2% when decreases the angle $(\alpha = 90°)$ to $(\alpha = 30°)$. Also, the figure show that the seepage discharge decreases with decreasing the soil permeability ratio which increase approximate about 72% when increases the permeability ratio from 0.1 to 0.5, increase approximate about 62% when increases the permeability ratio from 0.5 to 2, increase approximate about 42% when increases the permeability ratio from 2 to 5.

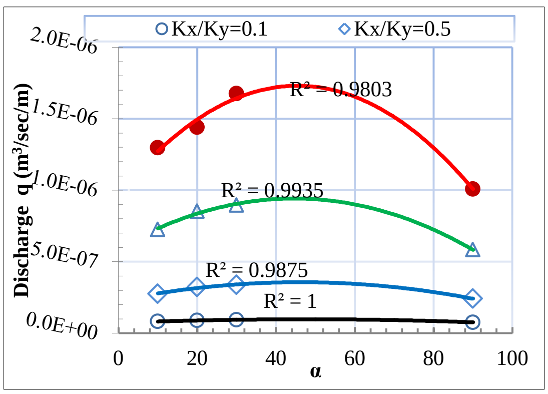

Fig. 12. Relationship between (α) and discharge at $(\theta = 90°, \beta = 90°)$

Figure (13) shows the relationship between the angle of first sheet pile with the seepage discharge at toe of hydraulic structure (q). The boundary conditions of constant angle of last and intermediate sheet pile (α, β), constant depth of all piles under taken, four different ratio of permeability (Kx/Ky) have used. From this figure it can be shown that the discharge decreases with increasing (θ) but when reach to $(\theta = 90°)$ the discharge increase. Discharge decreases by approximately 2% when decreases the angle $(\theta = 90°)$ to $(\theta = 10°)$, and decreases by approximately 2.4% when decreases the angle $(\theta = 90°)$ to $(\theta = 20°)$, decreases by approximately 3% when decreases the angle $(\theta = 90°)$ to $(\theta = 30°)$. Also shown that the discharge decreases with decreasing soil permeability ratio.

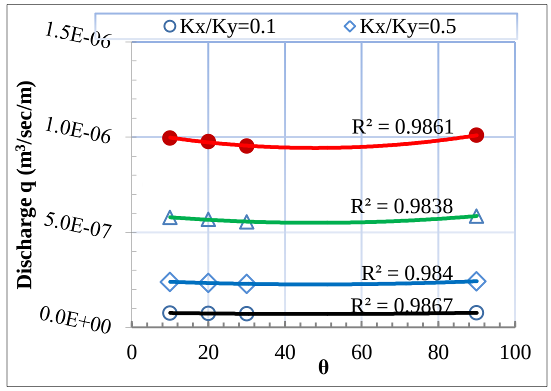

Fig. 13. Relationship between (θ) and discharge at $(\alpha = 90°, \beta = 90°)$

Figure (14) shows the relationship between the angle of intermediate sheet pile with the seepage discharge at toe of hydraulic structure (q). The boundary conditions are constant angle of first and last sheet pile (θ, α), constant depth of all piles under taken, four different ratio of permeability (Kx/Ky) have used. From this figure it can be shown the low effect of (β), and the discharge increases with increasing (β). Discharge increases by approximately 0.05% when decreases the angle $(\beta = 90°)$ to $(\beta = 10°)$, and increases by approximately 0.046% when decreases the angle $(\beta = 90°)$ to $(\beta = 20°)$, increases by approximately 0.058% when decreases the angle $(\beta = 90°)$ to $(\beta = 30°)$.

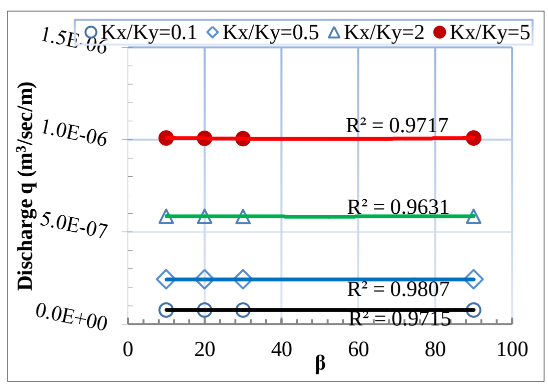

Fig. 14. Relationship between (β) and discharge at (θ=90°,α=90°)

Equations for the Uplift Pressure Head, Exit Gradient and Discharge at Toe of the structure

By substituting approximately two thirds of the SEEP/W results for the cases using three sheet piles in software program SPSS-19 Statistics, it will be get the following equations which used to determine the quantity of uplift pressure head, exit gradient and discharge at toe of hydraulic structure in non-homogenous soil.

$$P = \frac{1.007 * \theta^{0.0094}}{\beta^{0.002165} \quad \alpha^{0.00011396}\left(\frac{K_x}{K_y}\right)^{0.196}}$$ (R^2=0.95),

(Pearson correlation=0.938) ………….. (3)

$$i = \frac{0.263 * \beta^{0.007} \quad \theta^{0.009}}{\alpha^{0.054}\left(\frac{K_x}{K_y}\right)^{0.261}}$$ (R^2=0.879),

(Pearson correlation=0.975) …………….(4)

$$q = \frac{0.5894 * 10^{-6} * \beta^{0.008} \quad \theta^{0.008}\left(\frac{K_x}{K_y}\right)^{0.652}}{\alpha^{0.092}}$$

(R^2=0.94), (Pearson correlation=0.970) ...(5)

Figures 15, 16, 17 show the comparison between the remaining one third results of the uplift pressure, exit gradient and discharge respectively by SEEP/W runs and the results by suggested equations (3, 4 and 5) using the same characteristics and geometry boundary conditions. The figures above show good agreement between the results.

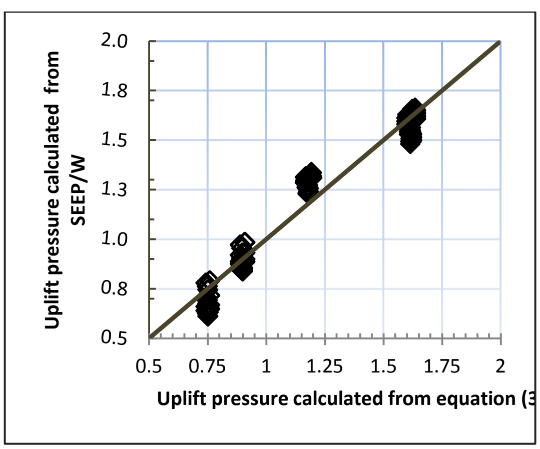

Fig. 15. Comparison between the calculated uplift pressure from the equation (3) and measuring from SEEP/W model

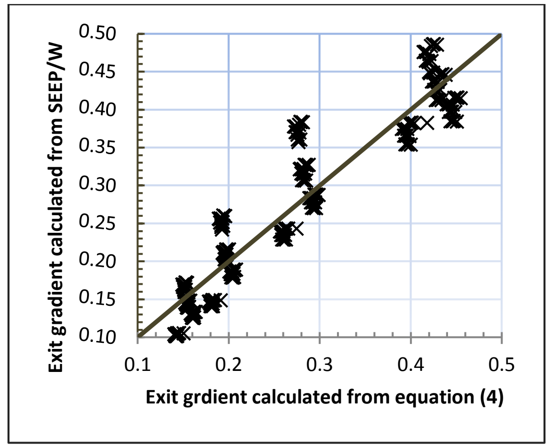

Fig. 16. Comparison between the calculated exit gradient from the equation (4) and measuring from SEEP/W model

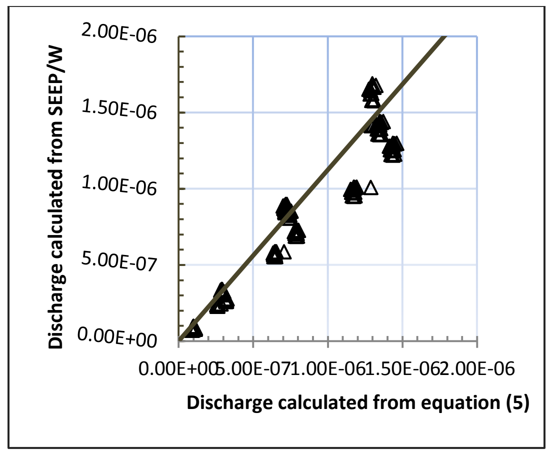

Fig. 17. Comparison between the calculated discharge from the equation (5) and measuring from SEEP/W model

Verification SEEP/W Results by ANN

Artificial Neural Network (ANN) operates by creating connections between many different processing elements, each analogous to a single neuron in a biological brain. These neurons may be physically constructed or simulated by a digital computer. Each neuron takes many input signals, then, based on an internal weighting system, produces a single output signal that's typically sent as input to another neuron.

After trials with several ANN architectures were made a Multilayer Perceptron (MLP), ANN model with one hidden layers was used due to its accurate results compared to others.

Figures 18, 19, 20 shows good agreement between SEEP/W and ANN (MLP) results.

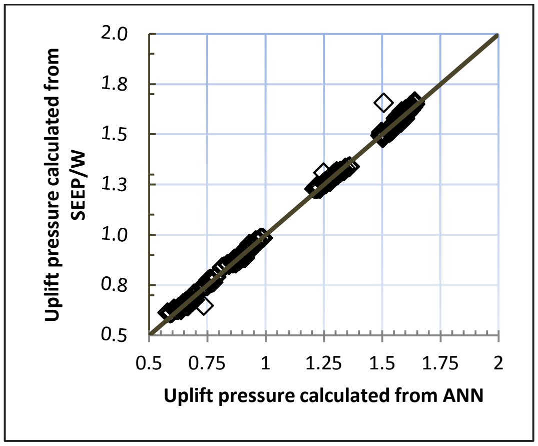

Fig. 18. Comparison between the calculated uplift pressure by SEEP/W model and ANN results

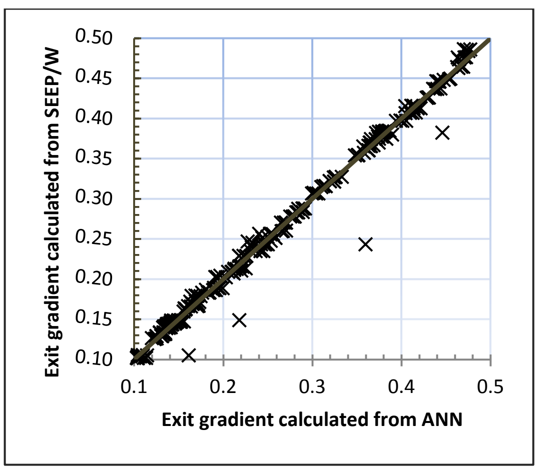

Fig. 19. Comparison between the calculated exit gradient by SEEP/W model and ANN results

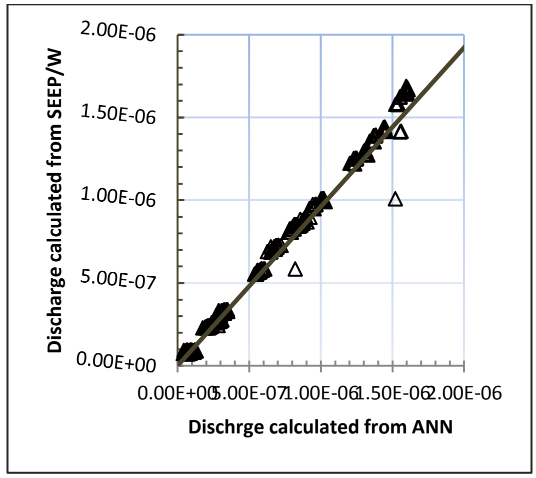

Fig. 20. Comparison between the calculated discharge by SEEP/W model and ANN results

Tables (1), (2) and (3) show depended on ANN results for uplift pressure, exit gradient and seepage under hydraulic structure the importance of each variable in equation (2) on behave of the magnitude uplift pressure, exit gradient and discharge respectively. Also it was show the high effect of permeability ratio on these results and the lower effect was at intermediate sheet pile angle for the case of using three sheet piles.

Table 1. Independent variable importance for uplift pressure head using three sheet piles

variable	Importance	Normalized Importance
β	.016	1.9%
θ	.072	8.5%
α	.071	8.4%
Kx/Ky	.842	100.0%

Table 2. Independent variable importance for exit gradient using three sheet piles

variable	Importance	Normalized Importance
β	.027	4.0%
θ	.053	7.8%
α	.234	34.2%
Kx/Ky	.685	100.0%

Table 3. Independent variable importance for discharge using three sheet piles

variable	Importance	Normalized Importance
β	.018	2.3%
θ	.033	4.2%
α	.166	21.2%
Kx/Ky	.784	100.0%

Conclusions

In this paper, the SEEP/W model was used to simulate the uplift pressure head, exit gradient and discharge at toe of hydraulic structure in non-homogenous soil in to case: first case by using two sheet piles, which shown:

1- The high effect of using intermediate sheet pile on the magnitude of the uplift pressure head, and (P) decreases with increasing (α) but when reach to (α=90°) the uplift pressure increase. The maximum uplift pressure head was used intermediate sheet pile with angle ($\beta = 10°$) at (kx/ky=5), while the minimum uplift pressure head when used intermediate sheet pile with angle ($\beta = 10°$) at (kx/ky=0.1).

2- (i) increases with increasing (α) but when reach to (α=90°) the exit gradient decrease. The maximum exit gradient was when used last sheet pile with angle ($\alpha = 90°$) at (kx/ky=5), while the minimum exit gradient when used last sheet pile with angle ($\alpha = 30°$) at (kx/ky=5).

3- (q) increases with increasing (α) but when reach to (α=90°). The maximum discharge when used last sheet pile with angle ($\alpha = 20°$) at (kx/ky=5), while the minimum discharge when used last sheet pile with angle ($\alpha = 90°$) at (kx/ky=0.5).

The second case by using three sheet piles, which shown:

1- The maximum decreases in uplift pressure head by approximately 0.95% when decreases the angle ($\alpha = 90°$) to ($\alpha = 10°$).

2- The maximum decreases in uplift pressure head was approximately 3% when decreases the angle ($\theta = 90°$) to ($\theta = 30°$).

3- The maximum increasing in uplift pressure head approximately 0.4% when decreases the angle ($\beta = 90°$) to ($\beta = 30°$).

4- The maximum increasing in exit gradient approximately 8.2% when decreases the angle ($\alpha = 90°$) to ($\alpha = 30°$). Also exit gradient decreases with increasing the soil permeability ratio.

5- The maximum decreasing in exit gradient was approximately 3.1% when decreases the angle ($\theta = 90°$) to ($\theta = 30°$).

6- The maximum increasing in exit gradient was approximately 0.067% when decreases the angle ($\beta = 90°$) to ($\beta = 30°$).

7- The maximum discharge increasing approximately 7.7% when decreases the angle ($\alpha = 90°$) to ($\alpha = 20°$).

8- The maximum decreasing in discharge was approximately 3% when decreases the angle ($\theta = 90°$) to ($\theta = 30°$).

9- The maximum increasing in discharge was approximately 0.058% when decreases the angle ($\beta = 90°$) to ($\beta = 30°$).

Depended on the SEEP/W results developed equations to determine the uplift pressure head, exit gradient and discharge at toe of hydraulic structure.

When verify the SEEP/W and ANN results it was shown good agreement. Also show the high effect of permeability ratio on these results and the lower effect was at intermediate sheet pile angle.

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