The Effect of inclined intermediate Sheet Pile on Seepage Properties Under Hydraulic Structure Using SEEP/W Program

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Abstract. This paper is intended to study the effect of using incline intermediate sheet pile and finding the effect of change for its angle, besides the upstream and downstream piles rest in homogeneous soil layer on the seepage, uplift pressure exit gradient at toe of hydraulic structure using computer program SEEP/W software. From the software test carried out many cases, in beginning, finding the best distance between the three sheet piles then finding the best depth of three sheet piles finally using the angle for incline intermediate sheet pile (θ =30,45,60,90,120,135,150) degree in three cases for first and last sheet piles when the angle of them (θ =30,60,90)degree. 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. Depended on the software program tests were carried out with three different value of each following parameter: upstream sheet pile depth, downstream sheet pile depth, intermediate sheet pile depth, upstream sheet pile angle, downstream sheet pile angle and four different value of distance between the sheet piles, then it carried out with seven different value of intermediate sheet pile angle, all of them with using constant upstream head and permeability for soil layer.

Keywords: Uplift pressure, Exit gradient, Discharge, Intermediate pile, SEEP/W.

1. Introduction
Hydraulic structures are using to control the flow of water are subjected to seepage under the hydraulic structures adversely affects the safety of the structure resulting in its failure. So, the seepage under hydraulic structures can be considered as one of the most important critical problems in the hydraulic structures safety. The seepage phenomenon (uplift pressure - flow rate - exit gradient of hydraulic structures) is one of the main causes of failure or collapse of hydraulic structures, so it has been reduced using sheet piles under floor of hydraulic structures. For the SEEP/W, it is a finite element software product that design both saturated and unsaturated flow and simulate the actual physical process of water flowing through a particulate medium [1]. Swamee et al., investigate the affectivity of multiple sheet piles in weir design [2]. Irzooiki study the effect of the inclined piles of hydraulic installations on the lift pressure under the structures by using the defined difference method with the relaxation technique in computer programs [3]. Arslan & Mohammad used the experimental and the theoretical study for a pizometric head distribution under the hydraulic structures for upstream, intermediate and downstream sheet piles inclination [4]. Ali study the effect of middle sheet pile on a uplift pressure under hydraulic structure by the finite difference method with the relaxation technique [5]. Teah & Alghazali study the analysis of seepage under hydraulic structures using slide program through single and multi-layers soils and its effect on structures with inclined cut-off at
downstream, at upstream, and at both of them [6]. Rasool study effect of mutual interference piles on seepage properties under hydraulic structures by using finite elements program ANSYS and verify with the practical results L-SAYED [7]. Jamel research the result of using intermediate sheet piles under the hydraulic structure apron in addition to upstream and downstream piles on non-homogeneous soil layer by using computer program SEEP/W Package and verify with artificial neural network (ANN) [8]. Abbood et al. study an experimental work by using physical model and numerical model by using Geo-studio software were done to test the effect of using two inclined sheet piles one located at the upstream and the other at the downstream side of the structure through a pervious soils beneath hydraulic structures [9]. Talukdar & Dey study the results of using multiple the sheet piles of different lengths positioned at different distances from the upstream and downstream of a homogeneous earthen dam on the element of seepage and analyze it by using a finite Element modeling in GeoStudio 2007 program using the SEEP/W module [10]. Arshad & Babar investigate and Estimate Using SEEP/W Model and Artificial Neural Network, the Seepage Discharge Through Homogenous Earth Dam with Core, depending on field notes for seepage study, maximum seepage velocity and exit gradient through and under body and earth dam (Case Study: Hub Dam - Pakistan) [11]. Nassralla & Rabea study the effect of sheet pile on seepage characteristics under the hydraulic structure floor through soil consists of two layers by experimentally (Sand Model) and Numerically (Geo-Studio SEEP/W Model) [12]. Irzooki study the quantity of seepage through homogenous earth dam with horizontal toe drain by the computer software program SEEP/W to Research the result of using double soil layer upstream and downstream sheet pile on discharge, uplift pressure and exit gradient at the toe of hydraulic structure [14]. L. Saleh study the exit gradient of seepage under a concrete dam provided with two sheet piles. The results of this study obtained from SEEP/W model were then used to create two neural artificial network (ANN) models [15]. Jassim & Abdulrazzaq study seepage through Al - Wand dam was analyze by using SEEP/W model [16]. Teah & Alghazali study flow net and analyze seepage flow through different porous soil foundation underneath a hydraulic structure by physical model (seepage tank) and Compare of the physical model results with the resulted by Finite element method software (SLIDE 5.0) model [17]. Al Siaede study the stability and safety of small weirs (Teeb weir) using SEEP/W and SIGMA/W packages [18]. 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, the downstream sides of the hydraulic structures foundation for homogenously the intermediate sheet pile being necessary. By using SEEP/W will provide information on the amount uplift pressure head, exit gradient and seepage discharge at toe of hydraulics structure.

2. The Procedure of Design Setup

The object of the SEEP/W model test is to use three different values for each variable effect on the properties of the seepage, which are up stream sheet pile depth(first sheet pile), downstream sheet pile depth(third sheet piles) \((L1=2,3,4)\text{m}\), intermediate sheet pile depth(second sheet pile) \((L2=3,4,5)\text{m}\), the distance between first and third sheet pile \(=25\text{ m}\), the distance between first and second sheet piles \((b=5,10,15,20)\text{m}\), angle of first and third sheet pile \((1=\theta=30,60,90)\text{ degree}\), angle of intermediate sheet pile \((30,45,60,90,120,135\text{ and }150)\text{ degree}\). For constant up stream head \((4.5)\text{ m}\) and permeability of soil \((k=10^{-6})\text{ m/sec}\). The overall runs are \((1136)\text{ runs}\). The quantity of inflow discharge exit gradient and uplift pressure at the toe of the hydraulic structure are calculated for each run. The classification for a study group is seen in Figure 1.

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3. Design Variables

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

\[
\begin{pmatrix}
\frac{P}{i}
\end{pmatrix} = f(L1, L2, L3, H, b, \theta 1, \theta 2, \theta 3, k)
\]  

(1)

The probable variables that can influence uplift pressure, exit gradient and discharge of the hydraulic structure at a toe are shown in Figure 2.
4. Results and Discussion

4.1. Effect The distance of intermediate sheet pile on the variables

In beginning, the following relationships between the variables for cases by using seep/w data with change of site and the distance between the intermediate sheet pile and the terminal sheet piles. Figure 3, shows the relationship of the distance (b (m)) between the first sheet pile and intermediate sheet pile to up lift pressure (P (kPa)) at toe with boundary conditions of constant angle three sheet piles (θ 1, θ 2, θ 3=90º) with constant permeability factor (0.0001 m/sec). When the second sheet pile have 3m as length and it on the site at (5m,20m) from the first sheet pile the value of pressure is low and when second sheet pile at (10m,15m) from the first sheet pile the value of pressure will increase. And when the length of piles is 4m, the result of pressure will increase as (0.051, 0.06, 0.065, 0.058)% to site of intermediate pile as (5, 10, 15, 20) m. while the pile have length 5m the percent of increase in pressure value as (0.11, 0.14, 0.13, 0.12)%. Finally, that mean the hydraulic pressure value decrease when the site of intermediate near the terminal pile and increase when it near the middle of structure.
Figure 4, shows the relationship of the distance (b (m)) between the first sheet pile and intermediate sheet pile with exit gradient at toe with a boundary conditions of a constant angle three sheet piles (θ 1,θ 2,θ 3=90º) with constant permeability factor(0.0001m/sec). When the second sheet pile have 5m as length and it on the site at (5,10,15,20)m from the first sheet pile the value of exit gradient is low and decrease gradually when the second pile become farther. And when the length of piles is 4m, the result of exit gradient will increase as (2.99,3.43,2.89,3.73)% to site of intermediate pile as (5 ,10,15,20) m while the pile have length 3m the percent of exit gradient value increase as (5.25,6,5.8,7.13)%). Finally, that mean the exit value decrease when the site of intermediate far from the begging of structure and increase when the site of intermediate near the begging of structure.

![Figure 4](image1.png)

**Figure 4.** The relation between the exit gradient and the distance of the intermediate pile.

![Figure 5](image2.png)

**Figure 5.** The relation between the discharge and the distance of the intermediate pile.

Figure 5, shows the relationship of the distance (b (m)) between the first sheet pile and intermediate sheet pile against a discharge at toe with a constant angle three sheet piles (θ 1,θ 2,θ 3=90º) as a boundary conditions with constant permeability factor(0.0001m/sec). When the second sheet pile have 5m as length and it on the site at (5,10,15,20)m from the first sheet pile the value of discharge is low and decrease gradually when the second pile become farther from begging of hydraulic structure. And when the length of piles is 4m, the result of discharge will increase as (3.23 , 3.1, 2.36, 2.4)% to site of intermediate pile as (5 ,10,15,20) m while the pile have length 3m the percent of discharge value as (4.67,6.22,5.5,8.7)%). Finally that mean the discharge value decrease when the site of intermediate far from the begging of structure and increase when the site of intermediate near from the begging of structure. Although the difference of the
sheet pile lengths but the site of intermediate sheet pile at 20 m as best site for seepage properties. So, from above results, the best site of intermediate sheet pile at 20 m in design model.

4.2. Effect the lengths of intermediate sheet pile and the terminal sheet pile on the variables

4.2.1. Effect length first sheet pile

The following relationships between \((P, q, i)\) were obtained from the SEEP/W outcomes.

![Figure 6](image1.png)

Figure 6. The relation between the up-lift pressure and the depth of first pile.

Figure 6, shows a relation for the depth of first pile \((L1(m))\) with the pressure at a toe in a constant angle three sheet piles \((\theta 1,\theta 2,\theta 3=90^\circ)\) and constant permeability factor and the distance between first sheet pile and intermediate sheet pile \((b= 20 \text{ m})\) as boundary conditions. It can be seen from this figure that the pressure will decrease with increasing of depth for piles. When the first pile that have depth =2 m, the pressure was high value and when the length of first pile =3m the value of pressure decrease by approximately \((0.14\%)\). Finally, when depth of first pile =4m the value of discharge decreases by approximately \((0.28\%)\).

![Figure 7](image2.png)

Figure 7. The relation between the exit gradient and the depth of first pile.
Figure 7, illustrates the relation of a depth for first pile (L1(m)) to a exit gradient toe of hydraulic in boundary conditions of a constant angle three sheet piles (θ 1,θ 2,θ 3=90º) taken with constant permeability factor. It can be seen from this figure that the pressure will decrease with the rise of depth for piles. When the first pile that have depth =2 m, the pressure was high value and when the length of first pile =3m the value of exit decrease by approximately (3.23%). Finally, when depth of first pile =4m the value of exit decrease by approximately (7.36%).

Figure 8, describes the relation of the depth of first pile (L1(m)) to the discharge downstream hydraulic structure (q) with a boundary conditions of constant angle three sheet piles (θ 1,θ 2,θ 3=90º) with constant permeability factor and the distance between first sheet pile and intermediate sheet pile (b= 20 m). From this figure it can be illustrate that a discharge reduces with rising of depth for piles. When the first pile that have depth =2 m, the discharge was high value and when the length of first pile =3m the value of discharge decrease by approximately (3.122%). Finally, when depth of first pile =4m the value of discharge decreases by approximately (12.812%). That is meaning, when the first sheet pile have a greater of the length from the length of the two sheet piles others (intermediate and last sheet piles), the effect on the drainage values becomes very clear, and this explains the length of the path of the water molecule as it travels within the net flow from the begging to the end of the line at toe point. From the results, the length of first sheet pile have inverse relation with seepage properties. So, the best long form (2m,3m,4m) for first sheet pile for design in the model was 4m.

4.2.2. Effect of length of intermediate sheet pile

Figure 9, illustrates the relation between a depth of intermediate pile (L2(m)) to pressure at toe of hydraulic with boundary conditions of constant angular for three sheet piles (θ 1,θ 2,θ 3=90º) with constant permeability factor and the distance between first sheet pile and intermediate sheet pile (b= 20 m). It can be seen from this figure that the pressure would rise with increasing of depth for piles. When the second pile that have depth =3 m, the pressure was low value and when the length of second pile =4m the value of pressure increase by approximately (0.06%). Finally, when depth of second pile =5m the value of pressure...
increases by approximately (0.14%). This indicates the increasing in length of intermediate sheet pile have little effect on pressure.

**Figure 9.** The relation between the uplift pressure and the depth of intermediate pile.

**Figure 10.** The relation between the exit gradient and the depth of intermediate pile.

Figure 10, indicates the relation of the depth of first pile (L1(m)) with the exit gradient with constant angle three sheet piles (θ 1,θ 2,θ 3=90º) taken and constant permeability factor as boundary conditions. It can be seen from this figure that an exit gradient will reduce with rising of depth for piles. When the second pile that have depth = 3m, the exit was high value and when the length of second pile = 4m the value of exit decrease by approximately (3.21%). Finally, when depth of second pile = 5m the value of exit decrease by approximately (7.64%), that mean the length of intermediate sheet pile have inverse relationship with exit gradient.
Figure 11. The relation between the discharge and the depth of intermediate pile.

From Figure 11, the relation will be illustrated the depth of second pile (L2(m)) to discharge of the downstream hydraulic structure (q) with the boundary conditions of the constant angle three sheet piles (θ1, θ2, θ3=90º) with constant permeability factor and the distance between first sheet pile and intermediate sheet pile (b= 20 m). This figure show the discharge reduce with rising of depth for piles. When the second pile that have depth =3 m, the discharge was high value and when the length of second pile =4m the value of discharge decrease by approximately (4.77%). finally, when depth of second pile =5m the value of discharge decreases by approximately (6%). This explains the effect of increasing the length of the intermediate sheet pile on the discharge value, and it is evident that when the path length of the water molecule increases, it will negatively affect the drainage values (decrease), which is what the designer needs during the design. That indicate the length of intermediate sheet pile have inverse relation with the discharge value. For design model, the best length for intermediate sheet pile is 5m.

4.2.3. Effect of length of last sheet pile

Figure 12 illustrated the relation of the depth of first pile (L3(m)) with the pressure with boundary conditions of constant angle. Three sheet piles (θ1, θ2, θ3=90º) with constant permeability factor and the distance between first sheet pile and intermediate sheet pile (b= 20 m). In the figure show that a pressure will reduce with rising of depth of piles. When a third pile that have depth =2 m, the pressure was high value and when the length of third pile =3m the value of pressure increase by approximately (0.1%). Finally, when depth of third pile =4m the value of pressure increases by approximately (0.214%). This indicates the increasing in length of third sheet pile have little effect on value of pressure.
Figure 12. The relation between the uplift pressure and the depth of third sheet pile.

Figure 13. The relation between the exit gradient and the depth of third sheet pile.

Figure 13, illustrates the relation of the depth for first pile (L3(m)) to exit gradient with boundary conditions of the constant angle three sheet piles (θ 1,θ 2,θ 3=90º) taken with constant permeability facto. The figure illustrate the reduce of the exit gradient with rising of depth for piles . When the third pile that have depth =2 m, the pressure was high value and when the length of third pile =3m the value of pressure decrease by approximately (4.87%). finally, when depth of third pile =4m the value of pressure decreases by approximately (7.54 %). So, the third sheet pile have inverse relationship with value of pressure.
Figure 14. The relation between the discharge and the depth of third sheet pile.

Figure 14, illustrates the relation between the depth of third pile ($L_3(\text{m})$) to the discharge ($q$) with boundary conditions of the constant angle three sheet piles ($\theta_1, \theta_2, \theta_3 = 90^\circ$) with constant permeability factor and the distance between first sheet pile and intermediate sheet pile ($b = 20 \text{ m}$). In this figure it can be seen that the discharge reduces with increasing of depth piles. When the third pile that have depth = 2 m, the discharge was high value and when the length of third pile = 3 m, the value of discharge decrease by approximately (0.82%). Finally, when depth of third pile = 4 m, the value of discharge decreases by approximately (2.67%). From the results, Seepage properties have inverse relationship with the length for all sheet piles in most cases. So the best length of sheet piles for design model are ($L_1 = 4 \text{ m}, L_2 = 5 \text{ m}, L_3 = 4 \text{ m}$).

4.2.4. Effect the angle intermediate sheet pile and the terminal sheet pile on The Variables

Figure 15. Relation of intermediate sheet pile angle to the uplift pressure

Figure 15, illustrates the relation between the angle of intermediate sheet pile and the uplift pressure ($P$) at toe of hydraulic structure with boundary conditions of constant angle of first and last sheet pile ($\theta_1, \theta_3 = 90^\circ$), constant depth of all piles $L_1 = 4 \text{ m}, L_2 = 5 \text{ m}, L_3 = 4 \text{ m}$, with distance between first and second pile = 20 m, ratio of permeability under taken have used. The figure illustrate at first case, the angle of first and last sheet pile is perpendicular ($\theta_1, \theta_3 = 90^\circ$) the least effect occurs on pressure value at angle $150^\circ$. 
In second case (angle for terminal sheet piles ($\theta_1, \theta_3 = 60^o$)) the pressure value decrease by approximately (0.85%) and the best intermediate sheet pile angle is $150^o$. The last case, angle for terminal sheet piles ($\theta_1, \theta_3 = 30^o$) the pressure value decrease by approximately (1.53%) and the best intermediate sheet pile angle is $150^o$ too.

**Figure 16.** Relation of intermediate sheet pile angle with the exit gradient

Figure 16, show the relation of angle of intermediate sheet pile to exit gradient. From this figure the best effect is noted that reduces the boiling state at toe of hydraulic structure when the angle of terminal sheet piles is perpendicular, and the best angle of intermediate sheet pile is $135^o$ counterclockwise. At second case, the angle of terminal sheet piles is $30^o$, the exit gradient increase approximately (7.45%) and the large value reach at the intermediate angle = $30^o$. Finally the percent increase approximately (11.5%) when the terminal angle become $60^o$. The largest value of exit at $\theta_2 = 30^o$.

**Figure 17.** Relation of intermediate sheet pile angle with the discharge

Figure 17 shows that when the terminal angles = $90^o$, the large value of the intermediate angle affects to increase the amount of drainage at $\theta_2 = 135^o$, and the value of the intermediate angle that reduces the amount of drainage $\theta_2 = 120^o$. When the terminal angles reach to $30^o$ counterclockwise, the effect on the drainage increases approximately (10.86%). When the terminal angle = $60^o$ counterclockwise, the drainage value decreases approximately (7.04%).
5. Conclusion
Of the studied cases, we can conclude that:

1. When the distance between first and intermediate sheet pile is the bigger of the distance of the intermediate and third sheet pile will reduce the properties of the seepage (P, q, i).
2. When the increase the depth of the sheet piles due to reduce the properties of the seepage (P, q, i).
3. The minimum value of the uplift pressure when the angle of intermediate sheet pile at 150° counterclockwise.
4. The minimum value of the exit gradient when the angle of intermediate sheet pile at 135° counterclockwise.
5. The minimum value of the discharge when the angle of intermediate sheet pile at 120° counterclockwise.
6. The minimum value of exit gradient when the angles of the three sheet pile at 60° counterclockwise.
7. The maximum value of the uplift pressure when the angles of the three sheet pile at 30° counterclockwise.
8. When the distance between the first and intermediate sheet pile is increased, the exit gradient decreases and the uplift pressure decreases.

6. Recommendations
From the results obtained from applying the coordinates to the program, it was found that the best distance between the first and intermediate sheet pile is (20 m) and the best lengths for the three sheet piles in a row are (4, 5, 4 m) and the best rotation angles for the third sheet piles in a row is (60 degrees). Follows:

• Study the effect of increasing thickness of the sheet piles on exit gradient and lift pressure.
• Add a filter, which is composed of layers of aggregate with different gradations, to reduce the uplift pressure and the gradient of the outlet and study its effect.

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