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Control of Contaminant transport through Different Horizontal Layered Soil Using Sheet Pile.

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Control of contaminant transport through different horizontal layered soil using sheet pile

التحكم في انتقال الملوثات خلال طبقات التربة الأفقية المختلفة باستخدام ستارة لوحية

M.M.A. Shaeshaa, *M.B.A. Khadr*, *M.A. El-Enany* and I.M.H. Rashwan

KEYWORDS:
Contaminants, groundwater, different layered soil, horizontal layers of the soil, sheet pile and finite element.

الملخص العربي: **- في الدراسة الحالية تم استخدام الحل العددي لدراسة استخدام ستارة لوحية للتحكم في انتقال الملوثات خلال طبقات التربة المختلفة. العناصر التي تم دراستها عبارة عن (أعماق مختلفة للستارة اللوحية - المسافة بين الستارة اللوحية ومصدر التلوث - الضاغط - معاملات النفاذية لطبقات التربة المختلفة) وقد تلاحظ تأثر كفاءة الستارة اللوحية بترتيب التربة ذات الطبقات الأفقية المختلفة ومعامل النفاذية في عملية انتقال الملوثات. كما تم تقييم العمق الفعال للستارة اللوحية العمودية ذات النفاذية المختلفة عن طريق إعداد جداول تصميمية لا بعدية كمرجع استرشادي لتحسين الأداء الهيدروليكي للتحكم في انتقال الملوثات. وتظهر النتائج أن وقت انتقال الملوث يزداد بانخفاض الضاغط وبزيادة معامل النفاذية للطبقة السفلية. أيضا يعتمد تأثير معامل النفاذية للطبقة السفلية على وقت وصول الملوث على أي عمق للستارة في حالة ما تكون المسافة كبيرة بين مصدر التلوث وموقع الستارة. كما إن زيادة عمق الستارة اللوحية لا يكون فعالا على وقت وصول الملوث لسطح التربة خلف الستارة اللوحية في حالة ارتفاع النفاذية للطبقة العليا والطبقة السفلية. ولإعطاء تأثير كبير على انتقال الملوثات في حالة ما يكون معامل النفاذية للطبقة السفلية يساوي أو يزيد عن 0.001 سم / ثانية يجب ان تخترق الستارة اللوحية الطبقة السفلية بعمق كبير نسبيا بسبب كون الطبقة ذات نفاذية عالية.**

***Abstract*—** **the present study investigates numerically the using of vertical sheet pile to control contaminant transport through different horizontal layered soil. Two finite element software SEEP/W and CTRAN/W are used to study the regional contaminated porous field numerically. The considered parameters are different depths of sheet pile, distance between sheet pile and point source of contamination, head between upstream and downstream of the sheet pile and coefficients of permeability for horizontal layered soils. The efficiency of the sheet pile is affected by arranging the horizontal layered soil and their hydraulic conductivity in the process of contaminant transport and treatment. The effective depth of vertical sheet pile with different permeability is evaluated by preparing dimensionless designed charts as a guide reference for improving the hydraulic performance of the remedial system. The results show that the arrival time increases for decreasing the head difference between upstream and downstream of the sheet pile and with increasing the coefficient of permeability of the lower layer. In addition, the effect of coefficient of permeability for the lower layer on the arrival time is dependent on any depth of sheet pile for large distance between the contamination point source and the sheet pile. Increasing the sheet pile depth has no effect on the elapsed arrival time for the higher permeability of the upper and the lower layer at any distance between the sheet pile and the contamination point source. The sheet pile must be deeply embedded in the lower layer to give a great effect on contamination transport for the value of the coefficient of**

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permeability of the lower layer equal to or higher than 1×10-3 cm/sec because of being highly permeable.

I. INTRODUCTION

GROUNWATER contamination is one of the most major problem around the world, because of using the groundwater as an important source for municipalities, agriculture and industry. The contaminants can reach the aquifers by several means such as infiltration of polluted surface water through the soil and direct flow through wells that were built incorrectly make it a conduit for contamination. It is very difficult to restore the groundwater quality to its original status. Therefore, knowing contamination sources, contaminant transport techniques and properties of porous medium are important to predict how to minimize the contaminant transport through porous medium.

Bowles [8] used trench and gate remediation system to isolate the areas having issues due to releases of multiple contaminant and economize the repetitive cost of cleanup process. In addition, the configuration of open gate make easy routine repair and minimizes operating cost. Simon [15] used the permeable reactive barriers for groundwater remediation by eliminating the organic and inorganic pollutants from groundwater. The results show that large-scale application is feasible and the reactive barriers will treated successfully.

Bayer et al [7] studied the combination between pump-and-treat system with vertical barriers such as slurry walls or sheet piles for reducing the pumping rate required. The system was a suitable mean to decrease predicted pumping rates. In addition, the total costs having a significant savings by using the barriers. Anderson [2] suggested an alternate Dupuit model for groundwater and surface water interaction to eliminate global errors in head and discharge. It was recommended that Dupuit model could be very exact when used in problems consisting regions of concentrated vertical flow.

Anderson [3] used a combination of a vertical barrier wall and extraction wells to examine the hydraulic containment plumes. An analytic solution was used to illustrate the effects of open barrier wall on the seepage. The impermeable circular arc wall was used with finite length where the center of curvature was downstream the arc. Harte [13] applied two numerical models to simulate the low permeability barriers. The first one was depended on representing the hydraulic characteristics of the barrier directly on grid cells. In the second one, the values of hydraulic conductivity were modified for using grid having more of coarser.

Basha et al [6] used GEOSTUDIO 2004 as a numerical model to control the contaminant transport through the soil by using vertical sheet pile. It was considered two-dimensional flow in a homogeneous single layer of porous media. The contamination source was applied as a point source with constant rate at different distances from the sheet pile with different depths of sheet pile were studied. Daood [5] applied numerical model that use the finite element package of GEOSTUDIO 2007 to simulate steady state or transient solute movement. The problem under study having change in groundwater level in different seasons due to leachate migration from landfill site through saturated and unsaturated horizontal layered soils.

Anand et al [1] studied a model having two-dimensional with physical processes involving advection, dispersion, diffusion and interaction between the solution and the soil solids. The used model is GEOSTUDIO for the FEM to simulate the contaminant transport through porous media. The numerical solution will provide a better alternative to the modeling of contaminant transport compared to the analytical solutions for complex boundary conditions. Eltarabily [9 and 10] used a numerical model GEOSTUIO 2007 software to investigate the effect of sheet piles on phosphate transport through the layered soil and fertilizers as a line source from nitrate through the sand.

Isabel [14] applied the vertical barriers as a containment system using Jet grouting and pre-grouting of bedrock to separate the contaminants when are moving through the pervious bedrock due to active chemical facilities. The vertical barriers of low permeability can be built-up using a variety of techniques to control the contaminant of groundwater. Asaad et al [4] investigated double sheet piles to control the contaminant transport through single layer of porous medium. Two software (MODFLOW and MT3DMS) were applied as numerical models. Different distance between two sheet piles were investigated. The contaminant source was a line source under variable head.

The main purpose of this research is to study the effect of using vertical sheet pile to control the contaminant transport through the horizontal layered soil having different permeability. Different depths of sheet pile (d), head difference (ΔH) and different distances between the sheet pile and the contamination point source (L) are studied for reducing the arrival time of the contaminant transport to the soil surface downstream of sheet pile.

II. NUMERICAL SOLUTION

GEOSTUDIO 2007 software was applied in the present study to simulate steady state or transient solute movement in a groundwater system in saturated horizontal layered soils. The modules that are used in this work are two finite element programs. The first module (SEEP/W) is the flow module, which computes the piezometric heads. The second module (CTRAN/W) is the transport module, which uses the data from the flow module to determine advective displacement and dispersion process in the soil.

The domain has dimensions 80.0m long, 40.0m depth and 1.0m width with impervious boundary for bottom, left and right sides. The upper layer having depth (D_1) equals 10.0m with hydraulic conductivity (K_1) and the lower layer having depth (D_2) equals 30.0m with hydraulic conductivity (K_2). The mesh is divided into square elements and the dimensions are chosen 0.5m × 0.5m. A vertical sheet pile with thickness 0.25m is embedded at different depths (d) and located at distance 40.0m from the left impervious boundary of the domain as shown in Fig. 1. The model runs to simulate 20 years, and the number of steps equals 500. For all runs, the arrival time of the contamination with 5.0% of the initial concentration to the soil surface downstream of the sheet pile is determined at different depths of sheet pile and head difference between upstream and downstream of sheet pile ΔH.

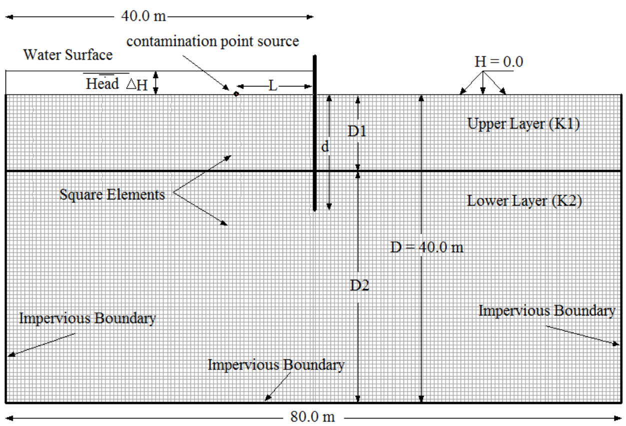

Fig. 1. Model dimensions and boundary condition.

III. Results and Analysis

The results of two modules SEEP/W and CTRAN/W show the distributions of the total head, and the contamination distributions for any time. The considered parameters are summarized in Table I, which used in the numerical model. Fig. 2 illustrates the distribution of contamination by using CTRAN/W module after arrival time of about 14.0 years at L=10.0m, H=3.0m and d=15.0m for coefficients of permeability K_1 and K_2 equal 5.0×10^{-5} cm/sec and 5.0×10^{-4} cm/sec; respectively.

TABLE I
Considered Parameters in the Numerical Model

Parameters	Value
Model dimension	2 D
Depth of upper layer D_1 m	10.0
Depth of lower layer D_2 m	30.0
Depth of sheet pile d m	2, 5, 7, 10, 15, 20, 25, 30, 35 and 38
Coefficient of permeability K_1 and K_2 cm/sec	5×10^{-5}, 1×10^{-4}, 5×10^{-4} and 1×10^{-3}
Kx / Ky	1.0
Head difference (ΔH) m	1, 2, 3 and 4
Distance between sheet pile and contaminant point source L m	2, 4, 6 and 8
Longitudinal dispersivity D_L / Transverse dispersivity D_T	10.0
Volumetric water content m^3/m^3	0.5

Fig. 3 presents the correlation between depth of sheet pile (d) with the arrival time of contaminant from upstream to soil surface downstream of sheet pile (t) at head equal to 2.0m, distance L=8.0m, $K_1=5.0\times10^{-4}$ cm/sec and different values for K_2 that equal to 1.0×10^{-3}, 1.0×10^{-4} and 5.0×10^{-5} cm/sec. There are variations between the values of the arrival time of the contaminant for the different values of coefficient permeability. The reference elapsed arrival time is referred to be 20 years for all the numerical runs.

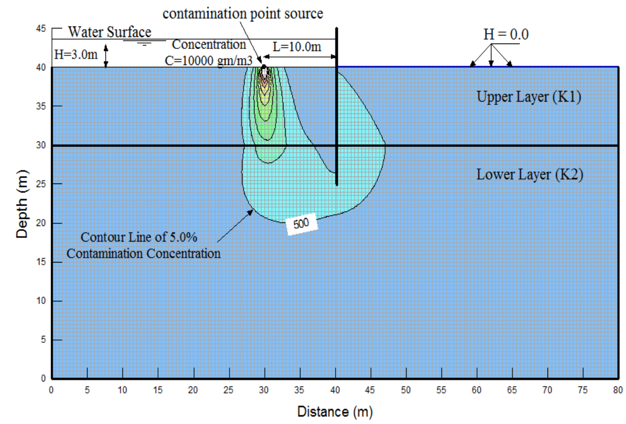

Fig. 2. Contaminant concentration after arrival time of about 14.0 years.

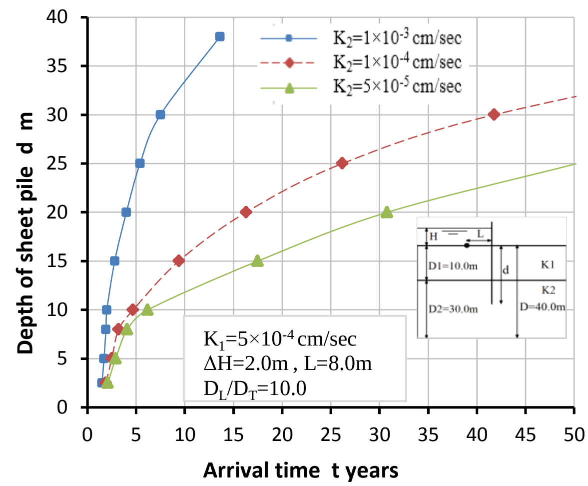

Fig. 3. Relationship between depth of sheet pile and the arrival time for different permeability for the lower layer.

Figs. from 4 to 13 present groups of charts about the relationship between dimensionless depths of sheet pile d^* and d_1^* with the dimensionless elapsed arrival time of contaminant from upstream to downstream of the sheet pile at the soil surface t^*. Where: d^* is the ratio between depth of the sheet pile d and the total depth of the layers D, d_1^* is the ratio between depth of the sheet pile d and depth of the upper layer D_1 and t^* is the ratio between the elapsed arrival time and the reference elapsed arrival time which equals 20 years.

For smaller value of L as shown in Fig. 4, it is observed that differences of t^* in case of d^* equal or less than 25% are very small compared with the corresponding values of d^* more than 25% for considered values of K_2, where the value of t^* increased by 205%, 215% and 220% for $K_2=1\times10^{-3}$, 5×10^{-4} and 1×10^{-4} cm/sec; respectively when d^* increased from 10% to 25%. While for d^* increased from 25% to 45%, the value of t^* increased by 104%, 110% and 180% for $K_2=1\times10^{-3}$, 5×10^{-4} and 1×10^{-4} cm/sec; respectively. It is denoted that the effect of d^* on value of t^* is dependent on value of K_2 in case the sheet pile penetrates it. For large values of L, the value of d^* has more significant effect on the value of t^* for considered values of K_2 with or without the sheet pile penetrates the lower layer.

Also for the considered values of L which equal to 2.0 and 8.0m as shown in Figs. 4 and 5, it is noticed that differences of t^* and d^* in case of $K_2=1\times10^{-3}$ and 5×10^{-4}cm/sec are small compared with the corresponding values in cases of $K_2=5\times10^{-4}$ and 1×10^{-4}cm/sec, where the maximum values of d^* for $K_2=1\times10^{-3}$, 5×10^{-4} and 1×10^{-4}cm/sec range from 53% to 68%, 49% to 63% and 33% to 48%; respectively. This means that the high value of K_2 has less effect on the value of t^* and d^* compared with the corresponding smaller value of K_2. Increasing the value of L from 2.0m to 8.0m for Figs. 4 and 5 at d^* equals 30% causes an increasing in value of t^* by 86%, 97% and 102% for $K_2=1\times10^{-3}$, 5×10^{-4} and 1×10^{-4}cm/sec; respectively. This means that the effect of the distance L on the value of t^* is slightly dependent on value of K_2. Increasing d^* from 10% to 30% leads to increase the value of t^* about 320% and 28% for L=2.0 and 8.0m; respectively for all considered values of K_2. It is signified that the effect of d^* on value of t^* is highly dependent on the distance L.

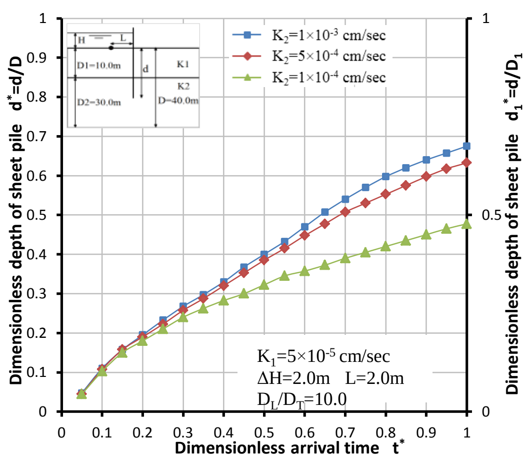

Fig. 4. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for different permeability for the lower layer.

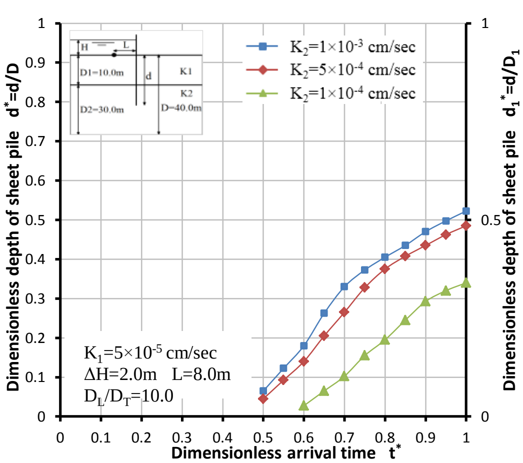

Fig. 5. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for different permeability for the lower layer.

In Fig. 6 for small value of L, it is noticed that differences values of t^* in case of d^* more than 25% are high compared with the corresponding values of d^* equal or less than 25% for considered values of K_2, where the value of t^* increased from 7% to 14%, 7% to 14% and 8% to 22% for $K_2=1\times10^{-3}$, 5×10^{-4} and 5×10^{-5}cm/sec; respectively when d^* increased from 15% to 25%. While for d^* increased from 25% to 45%, the value of t^* increased from 14% to 30%, 14% to 35% and 22% to 96% for $K_2=1\times10^{-3}$, 5×10^{-4} and 5×10^{-5} cm/sec; respectively. This means that the effect of d^* on value of t^* is dependent on value of K_2 especially the small values in case the sheet pile penetrates it. For high value of L, the effect of d^* on value of t^* is significantly dependent on values of K_2 when the sheet pile penetrates the upper or the lower layer.

Figs. 6 and 7 show that decreasing the value of distance L from 8.0m to 2.0m at d^* equals 30% causes an increasing in value of t^* by 51%, 52% and 54% for $K_2=1\times10^{-3}$, 5×10^{-4} and 5×10^{-5}cm/sec; respectively. This denotes that the effect of distance L on the value of t^* is slightly dependent on value of K_2. For changing the value of the distance L from 2.0m to 8.0m, the maximum values of d^* for $K_2=1\times10^{-3}$, 5×10^{-4} and 5×10^{-5} cm/sec are in the range from 78% to 83%, 70% to 79% and 34% to 46%; respectively. This concludes that the lower value of K_2 has significant effect on the value of t^* and d^* compared with the corresponding high values of K_2. Increasing d^* from 15% to 30% leads to increase the value of t^* about 160% for $K_2=1\times10^{-3}$, 5×10^{-4}cm/sec and 310% for $K_2=5\times10^{-5}$cm/sec at L=2.0m and about 20% for $K_2=1\times10^{-3}$, 5×10^{-4} cm/sec and 70% for $K_2=5\times10^{-5}$cm/sec at L=8.0m. It is signified that the values of d^* has more significant effect on the value of t^* with increasing the distance L.

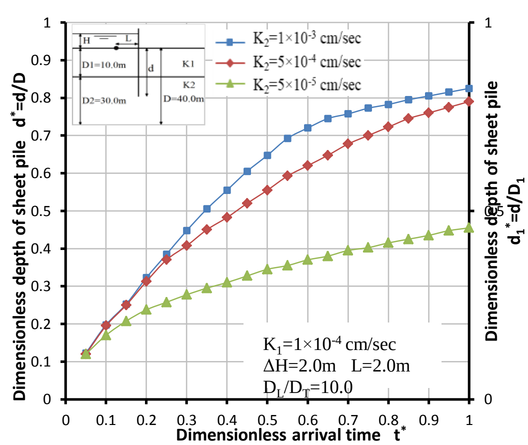

Fig. 6. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for different permeability for the lower layer.

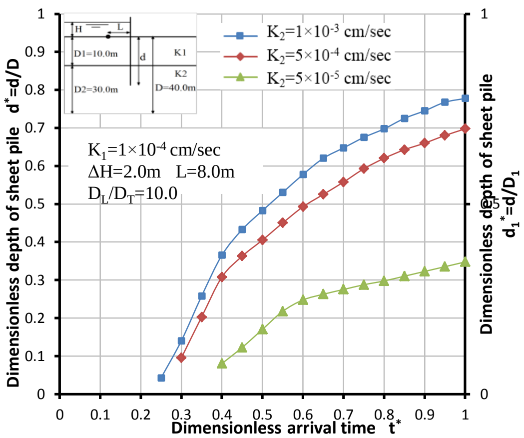

Fig. 7. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for different permeability for the lower layer.

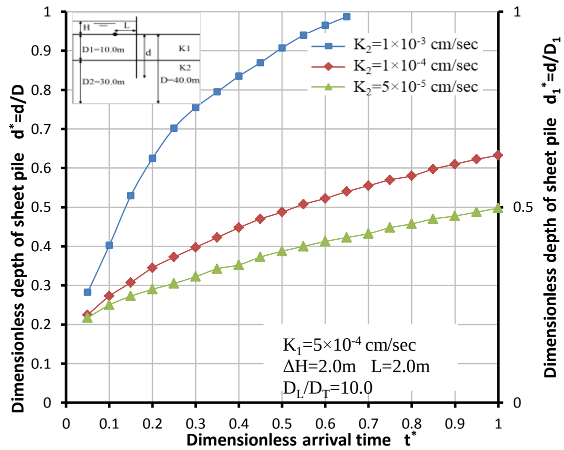

Fig. 8. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for different permeability for the lower layer.

Figs. 8 and 9 show that decreasing the value of L from 8.0m to 2.0m at d^* equals 35% leads to decrease the value of t^* by 5%, 20% and 40% for $K_2=1\times10^{-3}$, 1×10^{-4} and 5×10^{-5}cm/sec; respectively. This concludes that the effect of the distance L on the value of t^* is dependent on the small value of K_2. For the considered values of L=2.0 and 8.0m, it is observed that the difference in the values of t^* and d^* in case of $K_2=1\times10^{-4}$ and 5×10^{-5}cm/sec are small compared with the corresponding values of $K_2=1\times10^{-3}$ and 1×10^{-4}cm/sec. Increasing d^* from 30% to 50% leads to increase the value of t^* about 7% and 39% for $K_2=1\times10^{-3}$ and 1×10^{-4} cm/sec; respectively for L=2.0m and about 8% and 48% for $K_2=1\times10^{-3}$ and 1×10^{-4}cm/sec; respectively for L=8.0m. This means that the effect of d^* on value of t^* is significantly dependent on the distance L.

Also from Figs. 8 and 9, it is noticed that the difference in the values of t^* in case $K_2=1\times10^{-3}$ and 1×10^{-4}cm/sec are high compared with the corresponding values of $K_2=1\times10^{-4}$ and 5×10^{-5}cm/sec. It is found that the value of t^* increased about 220% for K_2 is in the range from 1×10^{-3} cm/sec to 1×10^{-4} cm/sec and increases about 85% for K_2 is in the range from 1×10^{-4} cm/sec to 5×10^{-5} cm/sec for d^* equals 40%. This means that the effect of d^* on the value of t^* is extremely dependent on value of K_2. For higher value of K_2, the effect of increasing the depth of sheet pile into the upper layer has no effect on value of t^*. But for lower value of K_2, the effect of increasing the depth of sheet pile into the upper layer has less effect on value of t^* and increased with increasing the sheet pile depth in the lower layer.

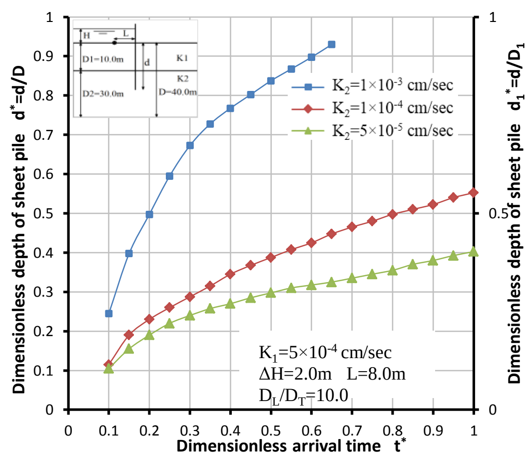

Fig. 9. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for different permeability for the lower layer.

Figs. 10 and 11 show that increasing the value of d^* leads to increase the value of t^* for all values of K_2. For $K_2=5\times10^{-4}$ cm/sec, it is clear that differences values of t^* in case of ΔH=4.0, 3.0 and 2.0m are small compared with the corresponding values of ΔH=1.0m, where from Fig. 11 for d^* equals 40%, the values of t^* are 21%, 27%, 40% and 81% for H=4.0, 3.0, 2.0 and 1.0m; respectively. This means that the effect of high values of ΔH on values of t^* are more than the corresponding values of smaller value of ΔH. For increasing value of d^* from 15% to 40% as shown in Fig. 11, the values of t^* are increased by 82%, 93%, 90% and 100% for H=4.0, 3.0, 2.0 and 1.0m; respectively. This denotes that the effect of d^* on the value of t^* is slightly dependent on value of ΔH.

Also for Figs 10 and 11, increasing K_2 from 5×10^{-5} cm/sec to 5×10^{-4} cm/sec has a clear differences in the values of t^*, where the value of t^* decreases by 38%, 36%, 34% and 33% for ΔH=4.0, 3.0, 2.0 and 1.0m; respectively for d^* equals 25%. This means that the effect of ΔH on value of t^* is significantly dependent on K_2 for smaller values of K_2. For decreasing ΔH by 75%, the change in the value of t^* for d^* equal 20% and

45% are about 300% for $K_2=5\times10^{-4}$ cm/sec. This means that the effect of ΔH on value of t^* is extremely dependent on value of d^*. For $K_2=5\times10^{-5}$ cm/sec, it is noticed that increasing the depth of the sheet pile into the upper layer has a great effect on the value of t^* and not needed to increase the depth of sheet pile to the lower layer for the low value of ΔH which equals 1.0m.

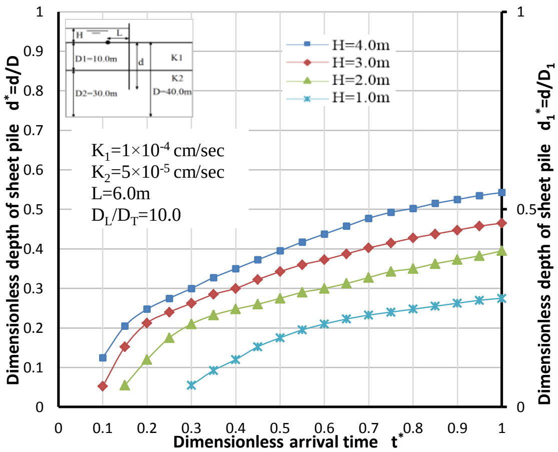

Fig. 10. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for head difference.

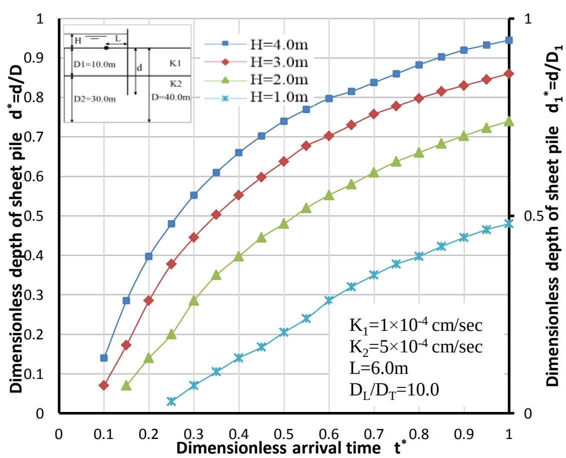

Fig. 11. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for head difference.

From Fig. 13, for increasing the value of d^* from 25% to 40%, the values of t^* are increased by 14%, 18%, 27% and 56% for ΔH=4.0, 3.0, 2.0 and 1.0m; respectively. This clear that the effect of d^* on value of t^* is extremely dependent on value of ΔH. For $K_2=1\times10^{-3}$ cm/sec, the differences values of t^* in case of ΔH=4.0, 3.0 and 2.0m are small compared with the corresponding values of ΔH=1.0m, where from Fig. 12 for d^* equals 60%, the values of t^* are 11%, 14%, 22% and 43% for ΔH=4.0, 3.0, 2.0 and 1.0m; respectively. This denotes that the effect of higher values of ΔH on values of t^* are more than the corresponding values of smaller value of ΔH.

From Figs. 12 and 13 for $K_2=1\times10^{-3}$cm/sec, it is noticed that increasing the depth of the sheet pile into the lower layer has a weak effect on the value on t^* due to be the upper and the lower layer have high permeability, where the values of t^* for d^* equal 80% are 21%, 28%, 42% and 82%; respectively. Increasing value of K_2 from 1×10^{-4}cm/sec to 1×10^{-3}cm/sec has an obvious differences in the values of t^*, where the value of t^* decreases by 72%, 72%, 62% and 62% for ΔH=4.0, 3.0, 2.0 and 1.0m; respectively for d^* equals 40%. This means that the effect of H on value of t^* is significantly dependent on the value of K_2. For decreasing ΔH by 75%, the change in the value of t^* for d^* equal 25% and 40% are about 420% and 300%; respectively for $K_2=1\times10^{-4}$cm/sec. This means that the effect of ΔH on value of t^* is extremely dependent on value of d^*.

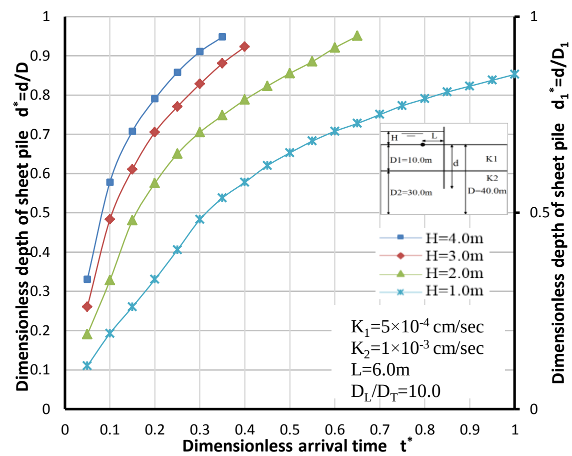

Fig. 12. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for head difference.

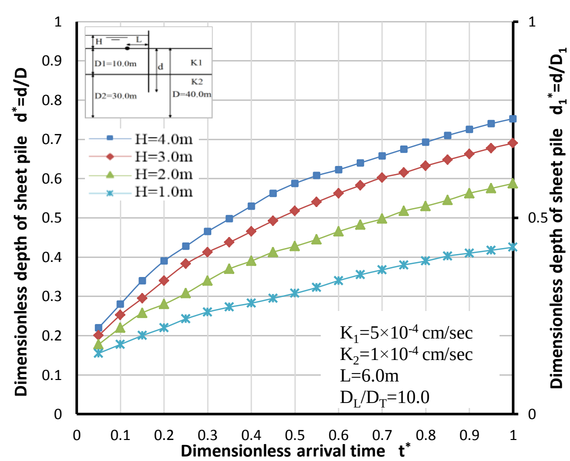

Fig. 13. Relationship between dimensionless depth of sheet pile and dimensionless arrival time for head difference.

IV. CONCLUSIONS

The general conclusions based on the present study could be drawn as follow:

1) The arrangement of layers of the soil and their hydraulic conductivity affect the efficiency of sheet piles in the

process of contaminant transport.

2) Dimensionless designed charts are prepared as a guide reference for determining the effective depth of vertical sheet pile with different permeability to improve the hydraulic performance of the remedial system.
3) The effect of distance between sheet pile and the contamination point source on the elapsed arrival time of contamination independent on the ratio between coefficient of permeability of the upper and the lower layer. However, it is dependent on the values of them.
4) The large depths of the sheet pile must be selected for decreasing the arrival time of the contaminant for higher values of the head.
5) For smaller distance between the contamination point source and the sheet pile, the value of coefficient of permeability for the lower layer has less effect on the elapsed arrival time for smaller depth of sheet pile. But, the effect increases by increasing the depth of the sheet pile.
6) For large distance between the contamination point source and the sheet pile, the effect of depth of sheet pile on the elapsed arrival time has a significant effect when the sheet pile penetrates the lower or the upper layer.
7) For the constant depth of sheet pile, increasing distance between the contamination and the sheet pile leads to increase the elapsed arrival time.
8) For higher value of coefficient of permeability of the upper and the lower layer, increasing the depth of sheet pile has less effect on the arrival time at any distance between the sheet pile and the contamination point source.
9) Increasing the depth of the sheet pile into the lower layer has a weak effect on the value on the elapsed arrival time for the higher value of permeability for the upper and the lower layer.
10) The elapsed arrival time is affected by the head for smaller permeability of the lower layer, but slightly dependent on higher value.
11) The change of permeability of the lower layer causes suddenly changing in the elapsed arrival time of the contaminant, when the sheet pile depth penetrates in this layer or approaching from this layer.
12) Penetrating of the sheet pile inside the lower layer of coefficient of permeability ranging from 5×10^{-5}cm/sec to 1×10^{-3}cm/s gives a great impact on arrival time and distribution of the contamination through the soil.
13) For hydraulic conductivity equal or higher than 1×10^{-3} cm/sec, the soil is considered highly permeable. Therefore, existence of sheet pile has a great effect on contamination transport. However, it must be deeply embedded in the soil.
14) For hydraulic conductivity less than 1×10^{-6}cm/sec, the aquifer is considered impermeable. Existence of sheet piles has no effect on contamination transport due to slowly moving groundwater.

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