Use of Sheet Piles to Control Contaminant Transport through the Soil

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Abstract: In the present work an attempt is conducted to study the control of contaminant transport through porous medium by using sheet piles. The regional contaminated groundwater flow field in two dimensions is studied numerically using the method of finite elements. The equations of contaminant transport through advection, diffusion, dispersion, and adsorption are combined with the groundwater flow equations to obtain the contaminant distribution as a function of soil, contaminant and fluid properties. The influence of installing a vertical sheet pile on the rate of contaminant transport is studied for different penetration depths of the sheet piles. Design charts are presented to quantify the effects of the sheet pile wall on the hydraulic control of the groundwater flow field. From the charts, the sheet pile depth can be selected according to the needed condition. This process can be useful in the preliminary design works which may reflect the influence on the cost estimate of the used dewatering complementary remedial system.

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1. Introduction

Wheat (*Triticum aestivum* L.) is the most Recent years have witnessed gradual increase in environmental hazards in such a way that threatens development plans in the future. Groundwater contamination has great impacts on the environment as it is used for variety of purposes (Domestic, Agricultural, and Industrial). The quality problem becomes the limiting factor in the development and use of water resources. Thus, it is important to identify sources of contamination and methods of its control.

Physical techniques are used to control (stop, contain, restrict, limit, or redirect) contaminant transport through porous medium. Impermeable medium can be used to control the contaminant transport. These may be grout curtains, or sheet piles.

1. Literature Review

In 1987, Bear and Verruijt [2], demonstrated the effect of the internal friction and the inertial effects of fluid, if compared to effect of fluid-solid interface can be neglected. They had used this assumption in addition to the assumption of saturated, two phases flow (single fluid and soil) to generalize Darcy's law into three-dimensional flow in porous medium by using the continuum approach.

Bennethum, and Giorgi (1997) [3], developed a Forchheimer equation for two-phase flow. Domain of study was composed of two immiscible fluids and isotropic swelling porous medium. They presented two equations for no-thermal and thermal effects.

In 2005, Anderson [7], presented a new Dupuit model, where he added new parameters to eliminate global errors in mathematical model of groundwater- surface water interaction in head and discharge. Surface water affects flow in aquifer, as surface water transforms aquifer flow from horizontal flow to horizontal and vertical flow. Consequently, new parameters are added to adopt the Dupuit approximation. Anderson chosen an idealized domain of groundwater flow. The flow in the domain is two-dimensional, steady, and confined in an infinite strip of homogeneous isotropic soil media, while surface water is in direct connection. The new Dupuit model includes two parameters. First, the resistance of stream to vertical flow beneath surface water body. Second, a new hydraulic conductivity beneath the surface water body.

In 2006, Bayer, and Finkel [1], presented a comparison between pump-and-treat and funnel-and-gate systems, as typical active and passive groundwater remediation technologies. The funnel-and-gate systems are an existing case, in the former manufactured gas plant site of the city of Karlsruhe in Southern Germany, while pump-and-treat system is hypothetical.

In the year 2000, a funnel-and-gate systems (FGS) was installed down gradient of approximately 200 m thick plume emanating from the former manufactured gas plant site of the city of Karlsruhe in the Rhine valley, Germany.

In 2006, Anderson, and Mesa [6,11], investigated the effect of vertical barrier walls or /

and well on the hydraulic control of contaminated groundwater. They used impermeable circular arc wall with finite length where the centre of curvature is downstream the arc. The domain is infinite and homogenous and the flow is steady and uniform. They found that the barrier wall created two stagnation points in the field one is in up gradient side and the other one is in down gradient side. At every stagnation point there exists a region of low discharge at interior side of curvature; there is large region of low discharge. The region of low discharge may be used to slow the movement of contamination. The rate of advective contamination transport can be significantly reduced when the wall placed up gradient of contaminant source rather than down gradient, where it reduces the plume width. Combination effect of a barrier wall with well decrease the discharge required to hydraulically control, time of contamination treatment, and cost over life time.

They developed explicit analytical expressions for the hydraulic head and the discharge vector for steady, shallow groundwater flow past an impermeable barrier embedded in a regional groundwater flow in the presence of multiple discharge and recharge wells. They presented design charts quantifying the effects of the barrier wall on the hydraulic control of the groundwater flow field and estimating the change in head across a barrier.

In 2008, Mesa, and Anderson [5], developed mathematical model for steady groundwater flow near a vertical impermeable arc shaped barrier wall and multiple wells. Their model did not explicitly include distant boundary conditions to represent real aquifer features such as streams, lakes, or rock outcrops. The effect of the distant aquifer features on local flow field is represented by a combination of uniform flow from infinity and a constant areal recharge rate. The flow domain extended to infinity. They developed an explicit closed form solution to the boundary value problem using the analytic element method. They used the result to investigate the effect of areal recharge and vertical barrier on capture zone envelopes of the pumping wells down gradient, reduction in discharge, and time required for treatment. They found that the vertical barrier wall minimize pumping rate required to isolate a given plume which increases, when the aquifer is subjected to areal recharge.

2. Numerical solution of the problem

There are many numerical solution methods such as Finite Differences (FDM), Finite Elements (FEM), Boundary Elements (BEM), and Total Variation Diminishing Method (TVD)

The FEM is an effective numerical technique because of its numerous applied fields such as groundwater flow, multiphase flow, and mass flow through pours medium. It is flexible in simulation and introduce accurate.

In the present study, Geo-Studio 2004 software is used. It consists of two modules. The first module (SEEP/W) is the flow module, which computes the water levels, and piezometeric heads. The second module (CTRAN/W) is the transport module, which uses the data from the flow module to determine advective displacement, additional diffusion through dispersion, and chemical transformation.

The Objective of the present study is to use of sheet pile to control contaminant transport through the soil. Process of control contaminant transport is process of contain or redirect of contaminant transport to cretin direction or position for a period of time.

The flow is considered to be unsteady, two-dimensional in a homogeneous isotropic porous media. An impermeable vertical sheet pile is embedded to depth d in the domain as illustrated in Fig1.

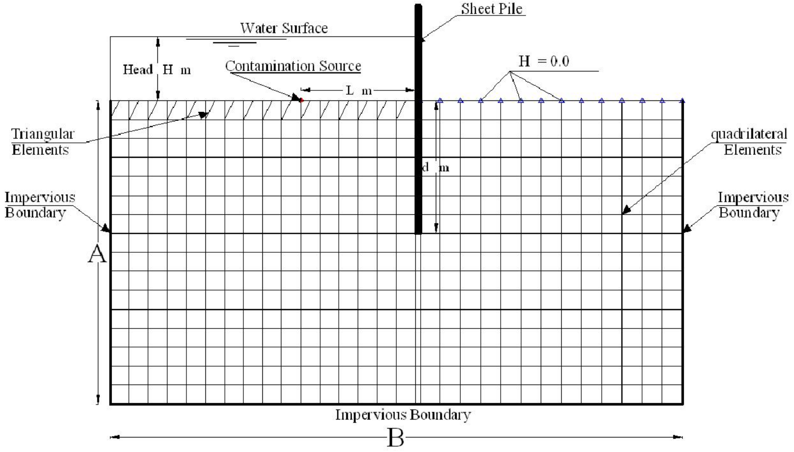

Figure (1): Model dimension and boundary conditions

The pressure head on the top soil surface is taken to be H and 0 at the left hand side (LHS) and the right hand side (RHS) of the sheet pile respectively. The other three sides of the rectangular model area are assumed to be impermeable.

Despite the fact that the results are presented in dimensionless form, it is found important to refer to the actual dimensions used in the work. The domain under study has a dimension A = 32.0 m as a depth and B = 60 m long with thickness 1.0 m. The volumetric water content equals 0.50 m^3. The dispersivity equals to 100 mm and molecular coefficient is set to zero. Hydraulic conductivity equals to 5×10^{-7} m/sec. The sheet pile is located at distance 32.0 m from left side with depth d m.

The time step sequence consists of 100 steps. The time step sequence starts with an increment of 100 seconds. Time starts by Zero sec end by 7.884×10^{8} sec.

Table 1 summaries the variables used to analysis in numerical model.

Table 1. Parameters used in the Numerical Model.

Parameters	Value
Model Dimension	2D
Hydraulic Conductivity (K)	5×10^{-7} m/sec
Kx / Ky	1.0
Initial Head Difference Across Sheet Pile (H)	1,2,3,4,5 m
Porosity (n)	0.50
Storage coefficient (S)	0.0
Aquifer Dispersivity (D)	2 m^2/sec
Longitudinal Dispersivity / Transverse	1.0
Time (t)	1,5,10,15,20

3. Results and Analysis

For certain values of head difference (H), hydraulic conductivity (K), distance between contamination source from sheet pile (L), and time (t), sheet pile depth is determined by iteration which give a 5% of concentration arrives downstream the sheet pile. Then, the solution is repeated for different values of head difference, hydraulic conductivity, distance between contamination source from sheet pile, and time as summarized in Table 1.

From the numerical solution of computer programs SEEP/W and CTRAN/W the following results also can be obtained the total head distributions, and distributions of contamination at any time.

The figures from 2 through 6 present the correlation between depths of sheet pile with time at different position of sheet pile to contamination source in dimensionless form. Those figures show that, with increase both of time and head difference, the required depth of sheet pile to control contamination transport increase. In these figures, the dimensionless sheet pile depth is obtained by dividing its actual depth by the soil layer thickness (A) while the dimensionless time equals the actual time divided by 20 years.

The total head distribution in the soil for head difference equalling 2.0 m is illustrated in Fig. 7, while, Fig. 8 shows the distribution of contamination at time 15.0 years where depth of sheet pile equal to 13.40m. Depth of sheet pile is determined at time when 5% of contamination arrives at behind sheet pile. Distance between contamination source and sheet pile equal to 6.0 m.

The result of numerical model which presented in figures from 2 through 6 shows that the depth of sheet pile required to retained contamination in upstream of sheet pile increases with time, also increase with head difference and hydraulic conductivity. Depth of sheet pile decrease with increase distance between sheet pile and contamination source.

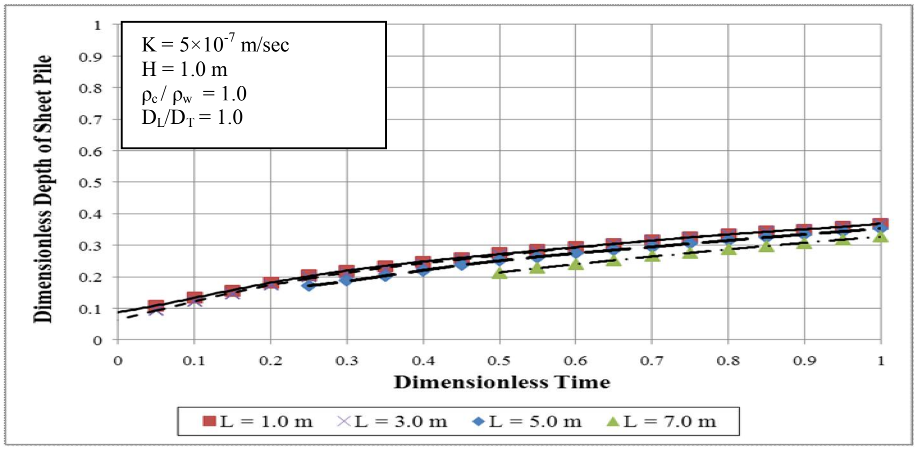

Figure 2. Correlation between Dimensionless Depth of Sheet Pile and Dimensionless time (H=1.0 m)

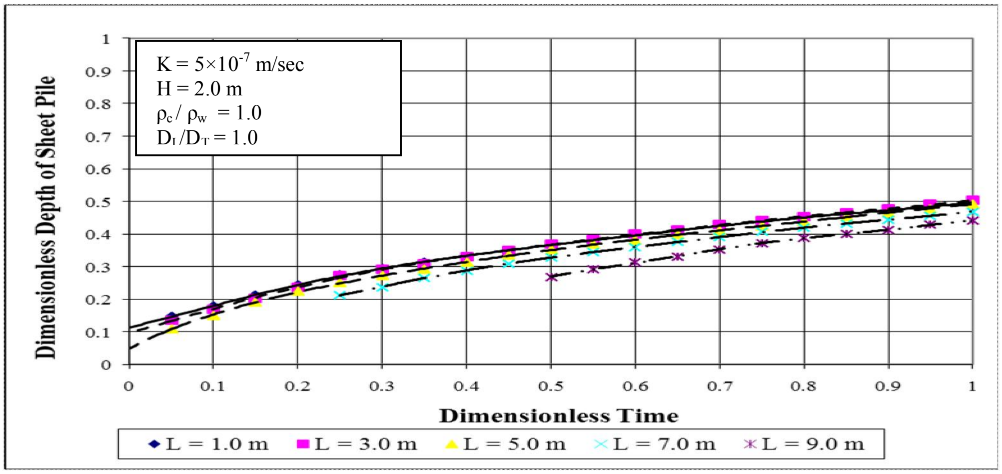

Fig. 3. Correlation between Dimensionless Depth of Sheet Pile and Dimensionless time (H=2.0 m)

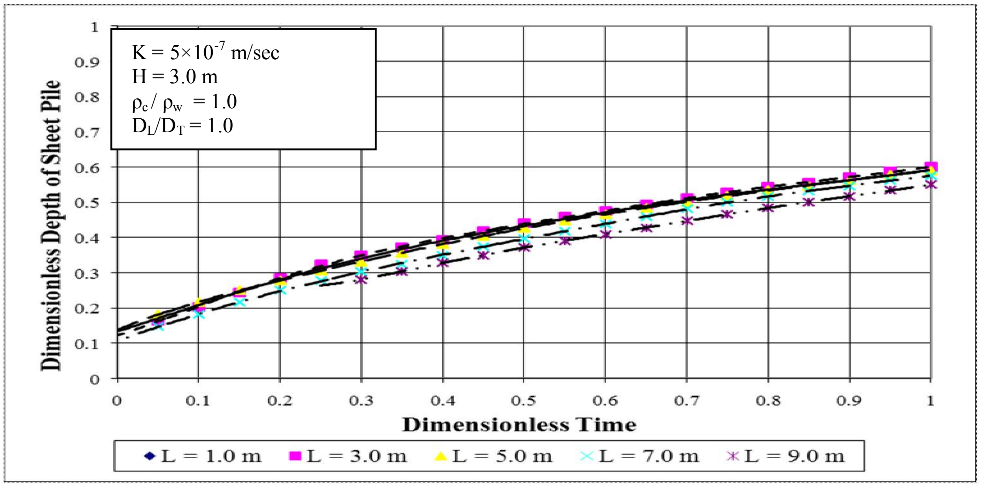

Figure 4. Correlation between Dimensionless Depth of Sheet Pile and Dimensionless time (H=3.0 m)

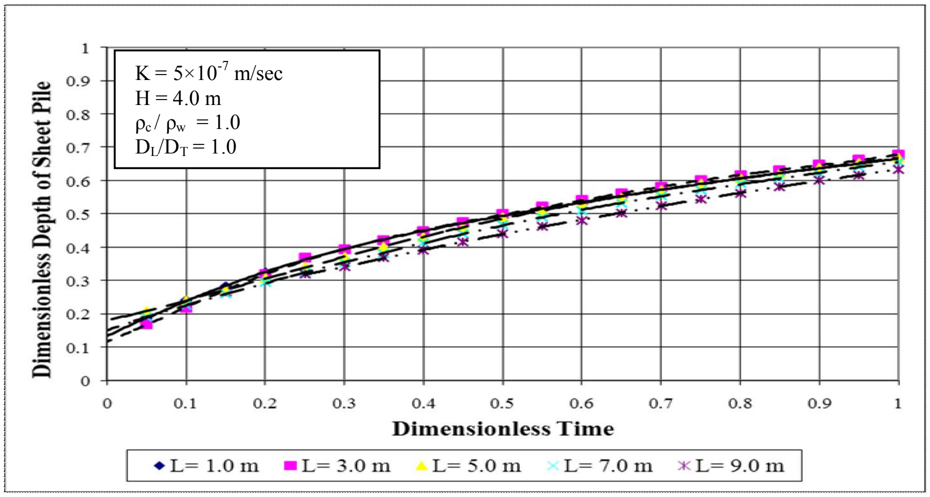

Figure 5. Correlation between Dimensionless Depth of Sheet Pile and Dimensionless time (H=4.0 m)

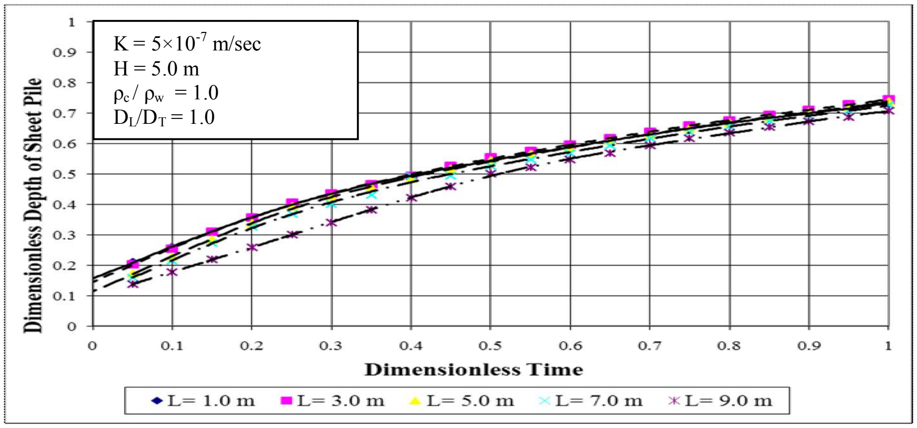

Figure 6. Correlation between Dimensionless Depth of Sheet Pile and Dimensionless time (H=5.0 m)

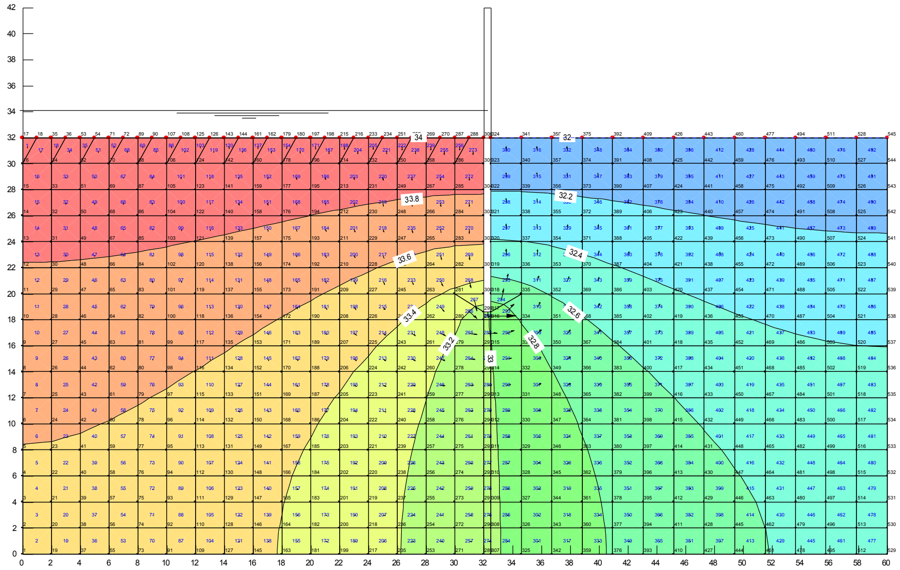

Figure 6. Total Head Distribution at Head Difference 2.0m and K = 5×10^{-7} m/sec

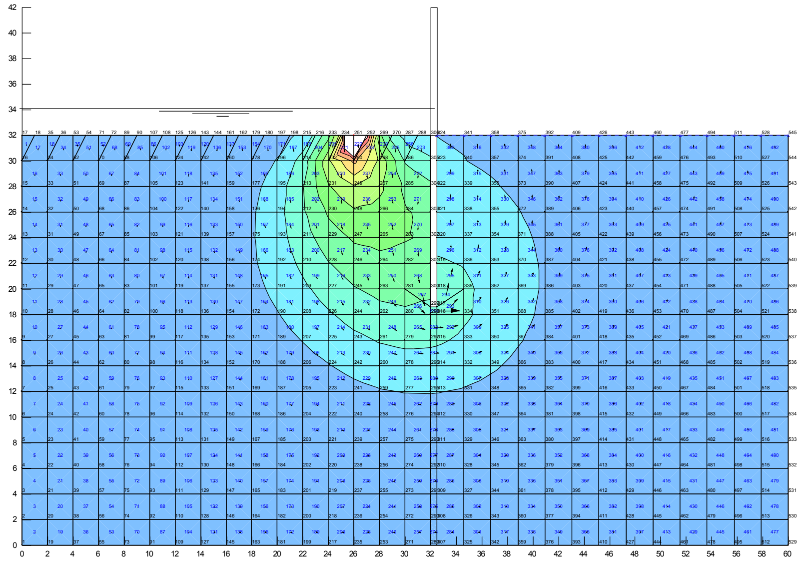

Figure 7. Contamination Concentration and Distribution at H = 2.0 m and t = 15.0 years

Conclusions

Vertical Sheet Pile could be used as an effective system to control the spread of contaminants in the subsurface soil.

It is found that the hydraulic conductivity plays the major role as far as the efficiency of the sheet piles as a remediation mean of contaminant transport through porous media.

Tools in the form of dimensionless graphs are presented in order to aid engineers in the rough determination of the proper sheet pile dimensions necessary to reach the required accepted contaminant distribution at different times.

Based on this study, the impermeable subsurface vertical Sheet Pile can be placed as close to a contaminant source or the leading edge of the contaminant plume (recharge).

This study has shown that existence of the impermeable subsurface vertical Sheet Pile gained a time delay due to placing Sheet Pile down gradient of contaminant source.

Also, the study has shown that the existence of the vertical sheet pile causes an increase in the concentration of contamination below the lower edge of sheet pile.

For hydraulic conductivity less than 1×10^{-8} m/sec the aquifer is considered to be impermeable. Existence of sheet pile hasn't any significant effect on contamination transport due to slowly movement of groundwater.

For hydraulic conductivity higher than 1×10^{-5} m/sec, the aquifer is considered to be highly permeable. In this case, existence of sheet pile has a great effect on contamination transport. It must be keyed into impervious layer; because of contamination is rabidly transport from upstream to downstream of sheet pile.

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