Effect of Porosity and Hydraulic Conductivity Coefficient on Contamination Penetration Depth in Soils

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Abstract

After industrial revolution, growing development of industries facing human societies with environmental pollution problems. Soil as a major component of environment and site of human activities is subjected to pollutants. A large number of studies in this field within recent years demonstrate the importance of this subject. Effects of soil geotechnical properties is the key point laid behind understanding contaminant transport in soils. Therefore, in this paper by simulating contaminant transport effect of porosity and hydraulic conductivity coefficient studied. Results illustrate: increase in porosity reduces contaminated zone and reduction in hydraulic conductivity coefficient reduce contaminated zone non-linearly. Simulations results demonstrate hydraulic conductivity is more effective in comparison with porosity and by considering porosity effect on hydraulic conductivity coefficient, porosity increase has not significant effect on polluted zone in fine-grained soils but reduces polluted zone in granular soils. Also porosity incensement, decrease penetration depth linearly and increment in hydraulic conductivity coefficient increase penetration depth exponentially.

INTRODUCTION

Numerous studies on contamination migration modeling into porous media were performed [1], Hochmuth and Sunada, [1], Osborne and Sykes, [2], Rajapaska, [15], Ryan and cohen, [3], Rahman and Lewis, [4], Van Geel and Roy, [5], Sharma and Mohamed, [6], Lenhard et al., [7], Henry and Smith, [8], Javadi and Najar, [9] and Kartha and Srivastava, [10]. Most studies in this field have been carried out in present behavioral model and there has been little discussion about soil properties effect on contamination migration. Therefore, in this paper effects of porosity and hydraulic conductivity coefficient were investigated. Rowe and Booker, [11], Badv, [12] and Sharma and Reddy, [13] researches show advection-diffusion equation has good compliance with experimental results. Hence in this research governing equation was solved by finite element method (FEM) and after verifying by experimental results effects of porosity and hydraulic conductivity coefficient were studied.

Bellow equation, shows general form of governing equation.

\[
\left( \theta + \rho_d \right) \frac{\partial C}{\partial t} = \theta D \frac{\partial^2 C}{\partial x^2} - V \frac{\partial C}{\partial x} - \lambda C - \lambda S \rho_d
\]

Where:

- \( \theta \) = porosity
- \( \rho_d \) = dry specific unit weight
- \( C \) = contamination concentration
- \( D \) = hydrodynamic diffusion coefficient
- \( V \) = Darcy velocity
- \( S \) = adsorbed contamination in unit weight of soil
- \( \lambda \) = Decay coefficient

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MATERIALS AND METHODS

Verification:
To verify numerical model, experiment which was done by Kamon et al., 2004[17] modelled and results compared with each other. Comparison of results show proper compliance. Figure 1 shows schematic view of experimental model. Used parameters in numerical model are equal to reported values in reference presented in table 1. Visual observations and numerical results for 1, 4 and 7 hours after infiltration are presented in figures 2 to 4 respectively.

Fig. 1: schematic diagram of experimental model[17]

Table 1: physical properties of materials

<table>
<thead>
<tr>
<th>parameter</th>
<th>units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic conductivity of Silica sand</td>
<td>m/s</td>
<td>2.33E-5</td>
</tr>
<tr>
<td>Hydraulic conductivity of Toyoura sand</td>
<td>m/s</td>
<td>1.45E-4</td>
</tr>
<tr>
<td>Porosity of Silica sand</td>
<td>---</td>
<td>0.72</td>
</tr>
<tr>
<td>Porosity of Toyoura sand</td>
<td>---</td>
<td>0.62</td>
</tr>
<tr>
<td>Contamination Flux</td>
<td>m/s</td>
<td>1E-6</td>
</tr>
<tr>
<td>Time</td>
<td>h</td>
<td>1, 4 and 7</td>
</tr>
<tr>
<td>Longitudinal dispersivity coefficient</td>
<td>m</td>
<td>0.2</td>
</tr>
<tr>
<td>Transverse dispersivity coefficient</td>
<td>m</td>
<td>0.1</td>
</tr>
<tr>
<td>Diffusion coefficient</td>
<td>m²/s</td>
<td>1E-7</td>
</tr>
<tr>
<td>Contamination relative density</td>
<td>---</td>
<td>1.54</td>
</tr>
</tbody>
</table>

Fig. 2: contamination transport after 1 hour infiltration
RESULTS AND DISCUSSION

Effect of porosity:
As obvious in governing equation contamination transport is under porosity and hydraulic conductivity effect. Due to corresponding of porosity and hydraulic conductivity effects of these parameters cannot be studied independently. Therefore, in first step for specific porosity 4 different hydraulic conductivity coefficient considered. Table 2 presents porosity and hydraulic conductivity coefficient values which are considered in analyses.

<table>
<thead>
<tr>
<th>Porosity</th>
<th>hydraulic conductivity coefficient (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>1E-4</td>
</tr>
<tr>
<td>0.4</td>
<td>1E-5</td>
</tr>
<tr>
<td>0.5</td>
<td>1E-6</td>
</tr>
<tr>
<td>0.6</td>
<td>1E-7</td>
</tr>
<tr>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

Trend of contamination penetration depth relative to porosity for 1, 4 and 7 days after infiltration into soil media are shown in figures 5 to 7 respectively. It is apparent from these figures that at specific time increase of porosity caused reduction in penetration depth. Regression of curves shows depth of penetration for specific hydraulic conductivity coefficient at fixed time can be defined as a linear function. In other words, order of porosity in contamination transport is one. Shadnia and Vafaeyan express that less porosity and high saturation degree are reasons of maximum oil penetration in clayey sand that are in good agreement with obtained results[16]. Also comparing curves for different hydraulic conductivity coefficients indicate that effects of porosity reduced by hydraulic conductivity coefficient reduction. Reason of this can be more sensitivity to hydraulic conductivity coefficient.
Effect of hydraulic conductivity coefficient:
As mentioned in previous section, considering porosity and hydraulic conductivity independent does not provide good results. However, to investigate hydraulic conductivity effects, values presented in table 2 for each porosity were considered. Depth of penetration based on absolute value of hydraulic conductivity coefficient logarithm showed in figures 8 to 10 for same times as porosity effect. The reason of using logarithm is that hydraulic conductivity coefficients are too small and absolute value used to make logarithm value positive.
Fig. 8: penetration depth-hydraulic conductivity coefficient after 1 day

Fig. 9: penetration depth-hydraulic conductivity coefficient after 4 day

Fig. 10: penetration depth-hydraulic conductivity coefficient after 7 day

From figures 6 to 8 we can see that by reduction in hydraulic conductivity coefficient, penetration depth reduce with sharp slope at first and followed by mild gradient. This trend holds true for all porosity values. This fact and negligible differences for specific hydraulic conductivity indicate effect of porosity on hydraulic conductivity coefficient can be ignored.

Effect of porosity and hydraulic conductivity coefficient:

To study effect of porosity and hydraulic conductivity coefficient dependently, hydraulic conductivity coefficient increased intellectually. For this purpose, empirical equations for hydraulic conductivity coefficient based on porosity provided by Carmen and Taylor used.

Results showed in figure 11. From this figure it can be concluded that, by porosity increment in granular soils, penetration depth reduced but in fine-grained soils this increment has not significant effect. Nevertheless these analyses does not rule out previous results.
Conclusion:
Contamination transport simulation into soil media indicates followed results.
- Penetration depth of contaminant reduces by porosity increase.
- Effect of porosity on contamination transport reduces by hydraulic conductivity coefficient reduction.
- Effect of porosity in contrast, hydraulic conductivity coefficient is negligible.
- Effect of hydraulic conductivity coefficient on penetration depth is nonlinear and can defined as an exponential function.
- Porosity increase and hydraulic conductivity coefficient increase due to this, in fine-grained soils has negligible effect on penetration depth but in granular soils reduces penetration depth.

REFERENCES