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Deflection range of water in heterogeneous permeable media

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Abstract

Knowledge of mode of transport of fluid in soil is the basis for soil environmental engineering especially in transport of contaminants in groundwater. The study investigates the possible minimum and maximum angle of deflection of water through media of different porosities for the purpose of environmental pollution control. An established equation which relates angle of deflection with porosity ratio was used to determined angle of deflection. The minimum and maximum deflection angles were found to be 17.8^0 and 53.5^0 respectively for sands with porosity ranging from 0.25-0.42, while for sands categorized under fine and medium, the maximum angle of deflection was found to be 69.1^0.

Keywords: porosity ratio, deflection angle, volume flux, inlet pipe, outlet pipe.

1.0 Introduction

Laboratory experiments on layered heterogeneous porous media (otherwise known as intermediate scale experiments, or ISEs) have been increasingly relied upon by hydro-geologists for the study of saturated and unsaturated groundwater system [1]. Among the many ongoing applications of ISEs is the study of fluid flow and transport of conservative solutes in correlated permeability fields.

Deflection is easily understood on the laboratory scale. However, the deflection observed in real subsurface soils and rock is much larger than that measured in the laboratory [2]. In fact it is very difficult to predict deflection in real geological material. Moreover, experiments to measure deflection in the field are time consuming because groundwater often moves as slowly as a few centimeter per day.

Indiscriminate construction of sewage tank or septic tank in homes without considering the effect of flow of contaminated fluid to the source of water supply is one of the major environmental pollutions in most urban areas. A broader focus in soil Physics research and more emphasis on soil physical properties and processes in an environmental engineering perspective is needed to provide the necessary solution to this problem.

The link between angle of deflection of fluid and nature of porous media (selective material) is of great practical importance in controlling environmental pollution. The flow of fluids in porous permeable mediums has been studied by many investigators with varying degrees of success. Darcy's law describes the situation very well for many flow systems in which the medium is homogeneous and the pores are relatively small, such as flow of water in a sandstone or in a filter bed [3-6].

However if the fluid flows through two or more media of different permeability, even though each medium is of the same permeability in all directions and from point to point, the law no longer holds in its simple from and the

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patterns of flow vis-à -vis deflection of fluid through these media must be examined [7].

It is the objective of the present work to determine the minimum and maximum deflection angles when there is a flow through layers of porous media of different porosities. This will be of help in designing a seepage control to prevent contaminated fluid from reaching the source of water in homes.

2.0 Theoretical Background

Fig.1 shows the case when the porosity of soil 2 (ϕ_2) is greater than the porosity of soil 1 (ϕ_1). The flow lines get deflected away from the normal after crossing the interface. The phenomenon of deflection of the flow lines is somewhat similar to refraction of light rays from a dense medium to a sparse medium [2, 8].

Angle α is the angle which the flow line in soil 1 makes with the interface, β is the angle which the flow line in soil 2 makes with the interface, and θ is the angle which the flow line in soil 2 makes with the normal (angle of deflection). l_1 and l_2 are the distances travel by fluid in soil 1 and soil 2 respectively

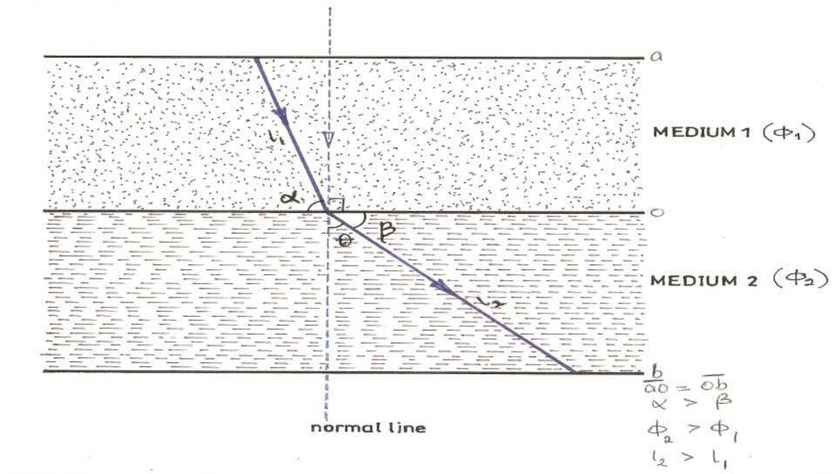


Fig. 1: Fluid flow in non-homogeneous soil mass [2].

By geometry, if $ao = ob$ and $\alpha > \beta$ which implies that $l_2 > l_1$

l_1 = distance travel by fluid in soil1 of porosity ϕ_1

l_2 = distance travel by fluid in soil 2 porosity ϕ_2

α = angle between fluid flow line in soil 1 and the interface

β = angle between fluid flow line in soil 2 and the interface

θ = angle of deflection from the normal in soil 2

It has been [9] established that angle of deflection θ is related to porosity ratio ψ by equation

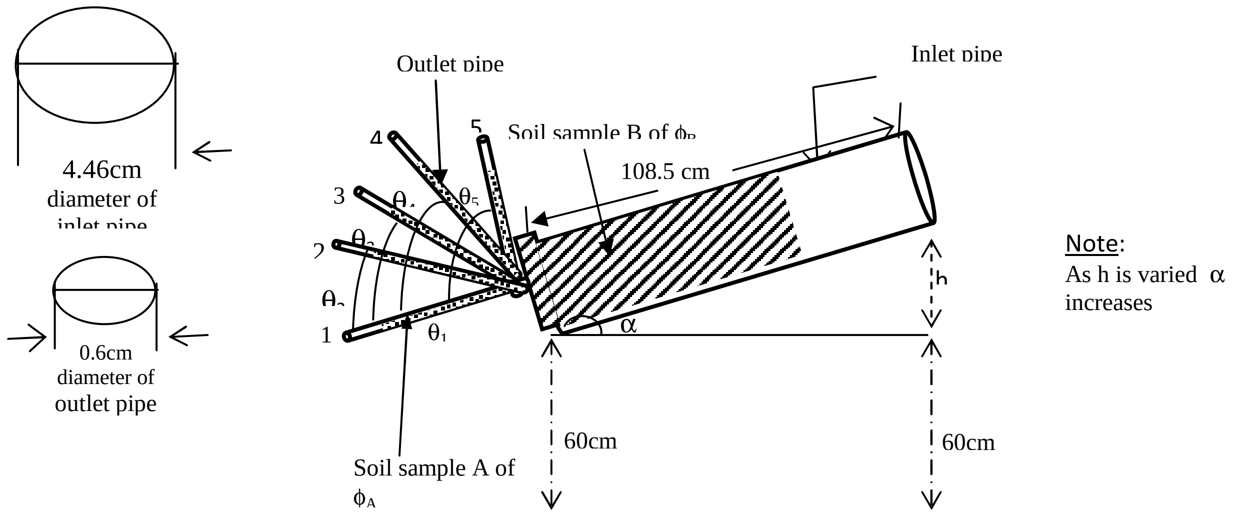
$$\cos\theta = n\psi, \qquad (\psi = \phi_1/\phi_2) \tag{1}$$

Equation (1) shows the relationship between angle of deflection θ and porosity ratio (ψ) of the soils 1 and 2. This implies that as porosity of the soil 2 (ϕ_2) increases relatively to porosity of soil 1, porosity ratio (ψ) decreases; and as the porosity ratio decreases, the angle of deflection, θ increases. This is true because cosine of angle θ decreases with increasing angle θ.

3.0 Model Configuration

A simplified two- dimensional model is used, shown in Fig.2.The inlet pipe is 1.085 m long with diameter 4.66 x 10^{-2} m of inlet pipe while each of the outlet pipes has diameter of 6 x 10^{-3} m. The outlet pipes were joined to the centre of the circular plastic plate on the end of the inlet pipe at different angles θ of 0^0, 20^0, 50^0, 70^0 and 90^0 from the normal. The inlet pipe was filled with a sample of a particular porosity while the outlet pipes were filled with another sample of different porosity.

The volume of water discharged from each outlet for a period of 60 seconds was measured directly with measuring cylinder. The volume flux q or specific discharge from each outlet for each case was then computed from the volumetric flow rate Q by dividing it with the cross-sectional area 2.83×10^{-5} m^2 of the outlet pipe. The equation obtained from this modeling is now used in this work.



θ_1 = 0^0 to the normal
θ_2 = 20^0 "
θ_3 = 50^0 "
θ_4 = 70^0 "
θ_5 = 90^0 "

α = angle of inclination. $\alpha = 0^0, 5^0, 10^0, 15^0$ and 20^0

Figure.2: Schematic model configuration [9]

4.0 Results

Table 1 presents the porosities for sample A, B, C, D, and E as determined in the laboratory by volumetric approach. The porosities ranged from 0.250 to 0.420. Sample E has the highest value while A has the lowest value.

Tables 1: Porosities of the samples

S/No	Sample	Porosity
1	A	0.250
2	B	0.333
3	C	0.364
4	D	0.400
5	E	0.420

Table 2**: Porosity ratios of the media and their respective deflection angle.**

Porosity ratio Ψ	Deflection angle θ/degree
0.9523	17.8
0.9148	23.8
0.9100	24.5
0.8667	29.9
0.8325	33.6
0.7929	37.5
0.7508	41.3
0.6868	46.6
0.6250	51.3
0.5952	53.5

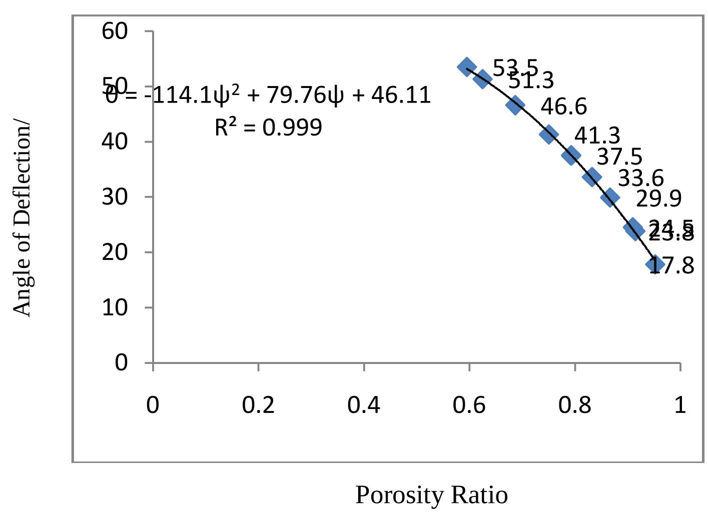


Fig.3: Plot of deflection angle against porosity ratio

Table 2 presents the ten different porosity ratio obtained from the five samples and their respective deflection angle as determined from already established equation. The porosity ratio ranged from 0.5952 (ϕ_1/ϕ_5) to 0.9523 (ϕ_4/ϕ_5). Fig. 3 shows the relationship curve fitting between angle of deflection and the porosity ratio with correlation coefficient of 0.99. Thus, if water flows through layers of sand of different porosities with porosity ratio, ψ, the preferred direction of flow at angle, θ in the second layer could be obtained with this equation as shown on the graph.

5.0 Discussion

The established equation, $\cos\theta = n\psi$ was used to determined angle of deflection θ, where n is taken as 1, as determined for correlation between theoretical and empirical equation [9]. The aim of this work is to determine the possible minimum and maximum angles of deflection of water in permeable aquifer. From the set of porous material (sands) used, the minimum and maximum angle of deflection were found to be 17.8^0 and 53.5^0 respectively. These angles could not be taken as the generalized value for all sand because of experimental limitation. For a specific case, sand categorized under fine and medium, with porosity ranges from 0.25-0.44 (ψ = 0.5682) [10], the angle of deflection will be 69.1^0.This could be taken as real case, and this value is closer to the maximum boundary deflection angle,90^0 which could be obtained if porosity ratio ψ is zero. However, porosity ratio of zero could not be achieved for any permeable medium except for impermeable media. On other hand, when porosity ratio is 1, angle of deflection 0^0 will be obtained. This minimum boundary condition could be considered as a case for a homogeneous aquifer. However, homogeneous aquifer is not possible in real case. It is usually assumed for easier modeling.

6.0 Conclusion

From these results, it is reasonable to conclude that a stratified porous media of a known porosity ratio can be used to control the flow direction of contaminated fluid. This can be done by backfilling the excavated region between the source of water and contaminant with stratified porous media (or layered soils) of known porosities. However, for the set of porous material (sands) used in this work, the minimum and maximum angle of deflection were found to be 17.8^0 and 53.5^0 respectively, while for sands categorized under fine and medium, with porosity ranges from 0.25-0.44 (ψ = 0.5682), the maximum angle of deflection will be 69.1^0.

References

[1] Silliman, S.E., L. Zheng and P. Conwell, 1998. The use of Laboratory Experiments for the study of conservation solute transport in heterogonous Porous media. *Hydrogeology Journal*, 6, 166 – 177.
[2] Cedergreen, H.R., 1976. Seepage, Drainage and Flownets (New York: Willey Interscience Publication).
[3] Stearn, N.D., 1927. Laboratory tests on Physical Properties of water bearing materials. *Geological survey water supply paper* 596, 121- 176
[4] Meinzer, O.E. and V.C. Fishel, 1934. Test of Permeability with low hydraulic gradients. Trans. America Geophysical Union, 15, 405 – 409.
[5] Crawford, F.W and G.M. Hoover, 1966. Flow of fluids through Porous mediums. *Journal of Geophysical Research*, vol. 71, No. 12, 2911-2917.
[6] Popoola O. I., Adegoke J.A. and Alabi O.O., 2007. A laboratory study of Effect of Porosity on the deviation from Darcy's Law in Saturated Porous Media. *Research Journal of Applied Sciences* Vol. 2, No.8, 892 – 899.
[7] Swartzendruber D.,1962. Water flow through a soil profile as affected by the least permeable layer. *Journal of Geophysical Research*, vol. 65, No. 6, 4037 – 4042
[8] Arora, K. R. 2009. Soil mechanics and foundation Engineering. (Geotechnical 7th Engineering) Edition. Standard publishers distributors, Delhi.
[9] Popoola O. I., Adegoke J.A. and Alabi O.O., 2011.Modelling the flow of water in stratified layers of sand. *Journal of the Nigerian Association of Mathematical Physics* vol. 18: 119 – 130.
[10] Freeze R.A. and Cherry J. A., 1979. Groundwater. Prentice - Hall, Inc. Englewood Cliffs, N.J. pp. 604