UNSATURATED GROUNDWDATER FLOW TO OPEN DRAINS

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ABSTRACT

Drains are constructed far enough below the cultivated land to allow for a phreatic ground water level below the plant root zone. The soil permeability and rate of infiltration play the major role in a determination of the required drain dimensions. In the case of clayey soil, the unsaturated zone that overlays the groundwater free surface is reatively thick. The rate of seepage from the unsaturated zone to the drain is considerably high. In the meantime, calculating the seepage rates towards drains, using the available seepage theories, generally neglects the part supplied by the unsaturated zone. In this work, a numerical model is adopted to simulate the flow that takes place through a multilayered porous media towards a system of parallel open drains. The calculations are made for variable number of layers and different soil anisotropy conditions. The results are presented in a graphical form. The graphs correlate on one hand the drain total depth water, depth, bottom width, side slopes as well as the distance between the drains and on the other hand, the number of soil layers, the thickness of each layer together with soil hydraulic such as permeability and anisotropy conditions.

Keywords: Drains, unsaturated flow, free surface, seepage, anisotropy.

INTRODUCTION

The soil with low permeability values needs a deep drain network in order to keep the groundwater surface at the required level. The voids in the soil zone between the ground level and the free groundwater surface are usually occupied by air and water with varying ratios. The water content and hydraulic conductivity are highly dependent on the pore pressure values.

The rate of seepage towards the drains from the region below the groundwater free surface does not always represent the dominant portion of the flow. In the periods following the irrigation processes, usually considerable amount of water seeps to the drains through the unsaturated soil zone.

It is remarkable that the available literature related to drain design is either very complicated and difficult to be used in practice or based on theory that does not take into consideration the seepage through the unsaturated zone[1]. This may be the reason behind the fact that most drains are over dimensioned as they take a high factor of safety to make up for that.

In this work, a general mathematical model is built with the aim of producing, simple to use curves to determine the drain dimensions for different soil conditions. In the analyses, the fluid flow rate through both the saturated and unsaturated soil regions is considered.

MODEL DESCRIPTION

A number of parallel trapezoidal drains is assumed to be existing in a multilayered soil with thickness d_1, d_2, etc. The distance between the drains centerlines is L, while their depth and bottom width are b and d, respectively. The drain sides make an angle with the horizontal whose tangent equals s. At a depth D below the ground surface, a totally impermeable layer is assumed to underlay the permeable soil layers. The water bearing soil layers may be anisotropic. In Figure 1, the drain and soil dimensions are illustrated.

In the analyses, four types of soil are considered, namely, clayey, silty, sandy and well graded soils. The relations between the pore pressure and hydraulic conductivity for the chosen soil types are assumed to follow the corresponding curves shown in Figure 2. The study domain is assumed to be consisting

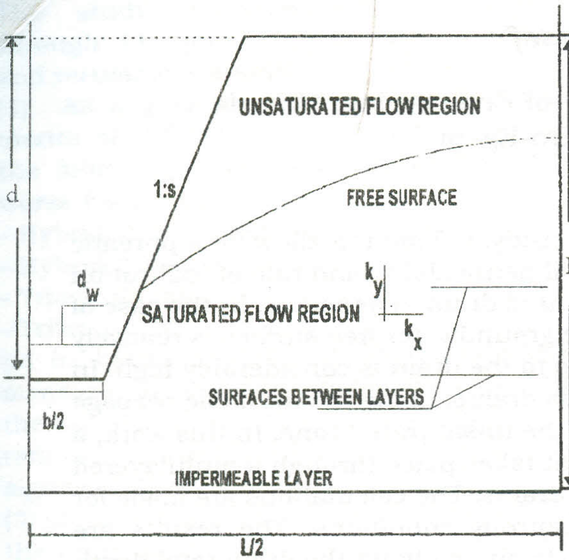

Figure 1 Physical model description

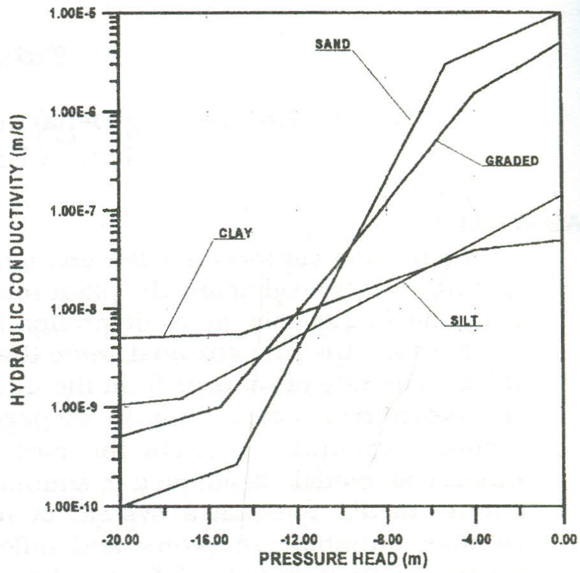

Figure 2 Relations between hydraulic conductivity and pressure head

of two regions separated by a free groundwater surface that is not known in advance. The flow in the region below the free surface follows the equations of flow through saturated porous media [2, 3], while that in the upper part of the region is treated as a flow through soil with partial saturation [4, 5]. Combining the equation of continuity and Darcy's equation for two dimenional anisotropic flow through saturated porous media leads to the following differential equation [6]:

$$(\delta/\delta x).(k_x\delta h/\delta x)+(\delta/\delta y).(k_y\delta h/\delta y)+W=S\delta h/\delta t \quad (1)$$

in which:

x and y are the cartesian coordinates, k_x and k_y are the hydraulic conductivity in the x and y directions, respectively, W is the source or sink rate term, S is the storativity of the aquifer and his total head.

On the impermeable boundary, the velocity component perpendicular to its surface vanishes. The value of h is constant on the drain bottom and on its sides below the water table while on the seepage surface above the water level, the pressure is taken to be atmospheric and hence, h=y. The free surface is assumed also to have an atmospheric pressure.

In the unsaturated zone, the water content and hydraulic conductivity vary as functions of the pore water pressure p. The application of the continuity and Darcy's equations lead to following relation [7]:

$$(\delta/\delta x).[k_x(p)\delta h/\delta x]+(\delta/\delta y).[k_y(p)\delta h/\delta y]=\delta\Theta(p)/\delta(t) \quad (2)$$

where :

p= γ(h-y), γ equals the specific weight of the fluid and Θ is the water content.

The solution is conducted of the boundary value problem for two different types of boundary conditions on the ground surface. In the first case, a constant atmospheric pressure is assumed, while in the second a known uniform rate of infiltration or evaporation is assumed to be taking place.

The method of finite elements is used in model construction[8,9]. The elements are chosen generally rectangular in shape with 8 nodes and an integral order equals 9. Around the drain sides, triangular elements with 6 nodes an integral order equals 3 are used.

RESULTS AND ANALYSES

The model is applied for the different cases that cover most situations and conditions that meet the designers of open drains. The calculations are conducted for different values of the effective parameters within the practical ranges.

The number of water varying formations can have any value between 1 and 4. The relation between the hydraulic conductivity and water pressure in each layer is assumed to be represented by one of the adopted 4 curves. The thickness of different layers is changed from one meter to infinite length. The relations d/D, b/D and d_w/d take values between 0.00 and 1.00. The drain side slope s is changed from 1.0° to 90°. The distance between the drains L varies between 0.00 and infinity.

The model is used to calculate the rate of seepage to the drain through both the saturated and unsaturated zones. Also the velocity flow vectors as well as the shapes of the interface between the two zones and the lines of equal total head h are determined.

In Figure 3 an example of the graphical part of the model results is presented. It represents the case of a drain with d/D=0.40, b/D=0.20 and L/D=3.20. The drain lies in a clayey soil which is underlined by sand whose thickness is 1.5 times that of the clay layer.

The figure includes the equipotential lines, velocity and the free surface. The effect of drain depth and water depth in drain on the total amount of seepage is presented in a group of figures. Each of these figures is drawn for certain constant values of other factors. Figure 4 is an example of these figures. It gives in a dimensionless form for the rate of seepage for different d and d_w values for an isotropic single layer with drain width b=0.00, side slope $s \rightarrow \infty$ and distance between drains L= 3.20D.

From the figure, the flow through the unsaturated zone decreases with the increase of drain water depth while the flow in

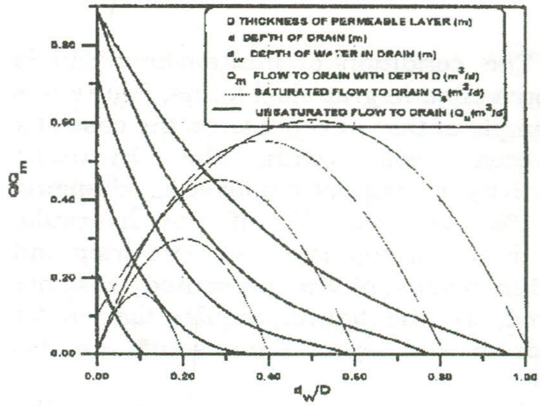

Figure 4 Seepage rate for different drain and water depths

the saturated zone increases from zero for d_w =0.0 to a maximum value at a point that is dependent on drain depth, and afterwards decreases gradually to become zero again for d_w/d=1.00. Figures that contain the effect of the drain side slope on seepage values are also prepared. A sample from these is referred to by Figure 5.

The figure contains the flow rate for different side slope for a drain with the following dimensions, b/d= 0.20, d_w/d= 0.50 and L=3.20D. From the figure, it can be deduced that the flow rate in both saturated and unsaturated zones is inversely proportional to s. Also from the figure, it can be noticed that the discharge in the saturated zone increases as d/D decreases while the flow in the unsaturated zone is almost unaffected by changing d/D for The same d and s.

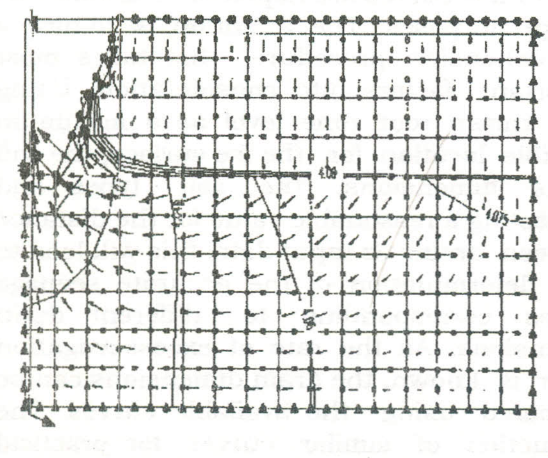

Figure 3 An example of graphical presentation of model results

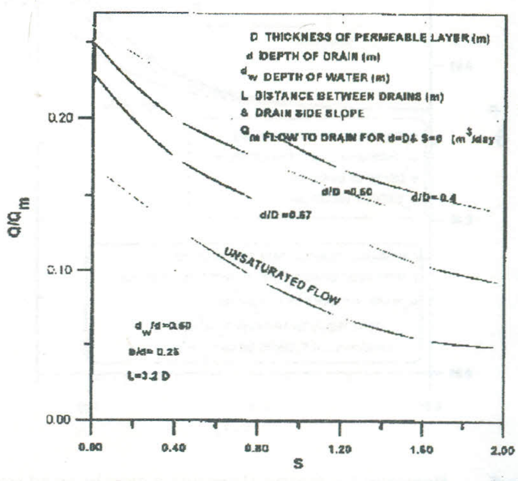

Figure 5 Effect of drain side slope on seepage rates

The condition of multilayered soil is also presented in graphical forms. Figure 6 is an example of that. It represents the case of a two-layered soil with the hydraulic conductivity of the bottom layer k_2 changing from 1% to 200 % of the hydraulic conductivity of top layer k_1. The drain and layer dimensions of the presented case are indicated in the figure. Similar figures for other drain and layers dimensions are also available.

As it can be easily observed from the figure, the flow in the unsaturated zone is mainly dependent on the upper layer properties while that in the saturated zone inceases with the increase of k_2 and D_2 for the same k_1 and D_1 values. Here, D_1 and D_2 are the thickness of the top and bottom layers respectively.

The influence of soil anisotropy is illustrated by Figure 7. It is one of the available figures that correlate the ratio between the horizontal and vertical hydraulic conductivity k_r with the rate of seepage for different drain water depths.

The curves in the figure can be used to calculate the discharge rates in the saturated and unsaturated zones for different k_r, and d_w values. It is clear that the discharge increases with increase of k_r.

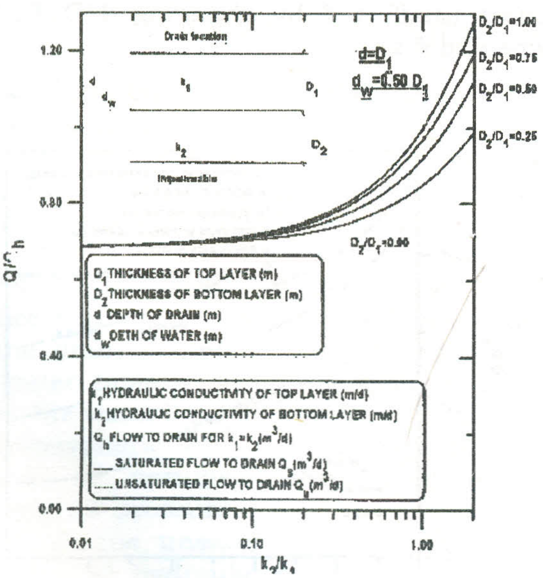

Figure 6 Seepage to drains through a two layered soil

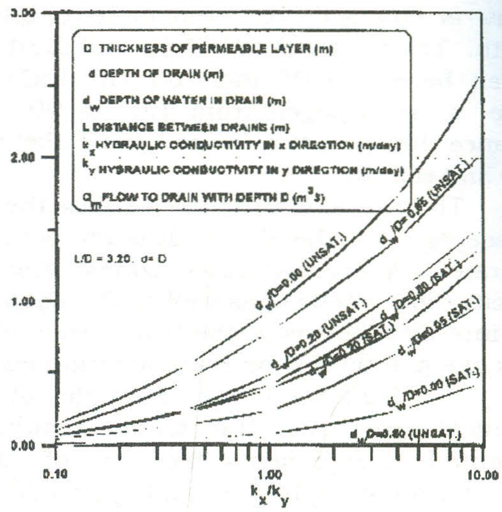

Figure 7 Effect of soil anisotropy on seepage to drains

CONCLUSIONS

The model results can be used to determine the expected rate of water to be collected by drains with reasonable accuracy. Calculations are made for a wide range of drain dimensions. Four different types of soils are considered such that any soil type can be approximated by one of these types.

The number of soil layers can be as high as 4. It is thought that this number satisfies most practical purposes as the effect of deep layers is more or less negligible. Moreover, in case of stratified very thin soil layers, it is always possible to combine more than one layer in the analyses taking average values for the soil parameters.

The results which are presented in easy to use curves are hoped to be of value for design purposes. The intention is to have a comprehensive procedure that takes most important factors into consideration. Using the known root zone level as a maximum possible location for the fee surface, the soil layers dimensions, the soil types and suggesting a reasonable value for the distance between drains as input data, this will lead to the determination of the accurate seepage values corresponding to different drain dimensions. As the rate of excess irrigation water is known, the drain dimensions can be estimated using the available curves. The production of similar curves for practical ranges of drains and aquifer dimensions can be used as a base for an economic design.

REEERENCES

[1] P.S Huyakorn, and G.F Pinder, Computational Methods in Subsurface Flow, Academic Press INC, New York, 1983

[2] J. Bear, A. Rndverruijt, Modeling Groundwater Flow And Pollution, Reedier Publishing Company, pp27-117, 1987

[3] M.A. Celia, Boutoulas, E.T. and P. Binning, "Numerical Methods for Nonlinear flow in porous media", Proceedings of the Eighth International Conference on Computational Methods in Water Resources, pp. 145-149, Venice, Italy, 1990

[4] R. Ababou, "Numerical Analysis of Nonlinear Unsaturated Flow Equations", Proceedings of the Eighth International Conference on Computational Methods in Water Resources, pp. 151-159, Venice, Italy,1990.

[5] D.R. Hampton, "A method to Fit the Hydraulic curves in Models of Flow in Unsaturated Soils", Proceedings of the eighth International Conference on Computational Methods in Water Resources, pp. 175-179,Venice, Italy, 990

[6] W.E Culham, and S. Varga, "Nunerical Methods for Time-Dependent Nonlinear Boundary Value Problems", Soc. of Pet. Eng.J.11,pp.374-388, 1971

[7] S.P. Neumann, "Saturated-Unsaturated Seepage by Finite Elements", J. Hydr. Div. Asce, HY12, vol. 99, pp. 2233-2250, 1973

[8] O.C. Zienkiwicz, "Finite Elements method", Third edition, McGraw Hill, 1977

[9] A.B. Gureghian, "A Two-Dimensional Finite Element Solution for the Saturated-Unsaturated Flow with Application to Flow Through Ditch-Drained Soils", J. Hydrol, vol. 50, pp. 333-353, 1981