EMPTY DRAIN AND THE WATER LEVEL AT MIDWAY BETWEEN THE DRAINS. ASPECTS REGARDING MANAGEMENT

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ABSTRACT Standing water above drains as a result of a submerged drain outlet, promotes flow conditions so that there is a smaller rise in the water table height at midway between the drains. This case has been studied through theoretical analyses by van Deemter (1950); Childs (1958), Kirkham(1958); Santos-Júnior (1971); Wesseling (1979) an Gammal et al (1995). In this paper the numerical results from DRENAFEM software package simulator are compared with the theoretical analysis of Santos-Júnior (1971). The software uses a finite element analysis to solve the Richard’s equation. Several simulations were performed with a small drain radius, and with a back pressure in the drain outlet to achieve a high entrance resistance and promote the rise of the water table at midway between the drains. With the standing water above the drains, the theoretical and numerical results show a rise in the water table height which is smaller than the drain outlet pressure. This paper demonstrates how the software can be used to simulate the behavior of a water table under controlled drainage to determine the water table’s position in situations with no analytical solutions, such as hydraulic conductivity anisotropy or in non-homogeneous soils with several layers.

Keywords: Drainage, controlled drainage, numerical simulation.

INTRODUCTION

Loss of Hydraulic pressure in the drain is an important factor in a sub-surface drainage system’s performance. This pressure loss is a function of two factors: the drain geometry and the type and quantity of the filter used in the drain (Dierickx, 1999). Davenport and Skaggs (1990) have confirmed that about 50% of the entrance resistance occurs at the drain due to its small holes, which is why addition of a filter or envelop, reduces this entrance resistance by increasing the effective radius of the drain (Bentley, 1991). The spacing of the drains is greatly influenced by the drain radius, the number and nature of holes and the type of the filter. Numeric simulations show that the use of a geo-textile or gravel as filter make it possible to increase the spacing of the drains without changing their behavior, in variable regime, from the water table (Skaggs and Tang, 1979).
This loss of pressure results in a non-elliptical water table, with the consequent expected change of hydraulic potential, especially at the midway between drains and in the drain flow. Controlling the position of the water table becomes more complicated with high pressure loss at the drains. (Chescheur et al., 1992).

Classical analytical equations for determining the spacing of the drains use the concept of an ideal drain and the line of the water table is a perfect ellipse which passes through the center of the drain. The pressure loss that occurs from convergence of the current around the drain is considered by using the equivalent layer introduced by Hooghoudt, to reduce the distance between the impermeable layer and the drain, which makes the drainage basically horizontal, virtually. The major shortcoming of this procedure is the fact that this pressure loss only considers the space between the drain and the impermeable layer, and does not apply if there is pressure above the vertical plane of the drain. Skaggs (1991) developed a numeric model that takes into consideration the radial pressure loss in cases where the drain is found totally surrounded by saturated soil. Simply combining the Hooghoudt equation and the radial flux also provides satisfactory results with regard to determining the drain flow in non-ideal drainage situations. (Fipps e Skaggs, 1991).

Presence of this pressure at the vertical plane of the drain can also be a result of its submergence, which leads to its functioning under a positive interior pressure. As a consequence, the usual elliptical shape of the water table changes.

The relationship between the drain flow and the height and shape of the water table has been demonstrated by Bouarfa e Zimmer (2000) through spatial integration of the Boussinesq equation in variable regime. The authors state that the shape of the water table depends on the simple combination of geometric factors of the system with hydraulic conductivity and porosity. They introduce an analytic expression for quick characterization of the shape of the water table and determination of the drain flow.

This article aims at simulating the behavior of the water table when the drains are not under pressure at the outlet and/or do not undergo a reduction in their effective radius. The classical theory is compared with simulations that were performed using a DRENAFEM model (Castanheira, 2009).

**MATERIAL AND METHODS**

Figure 1 provides a schematic presentation of the concept of the drainage system in a plane drainage section, perpendicular to the direction of the drain. The soil is considered as plane with a impermeable layer at a relatively shallow depth. Subsurface drainage is carried out by pipe drains, placed at the same height, away from the impermeable layer, and with a spacing $L$ between them. The flux density $q$ is constant and uniform. For simplicity, it was considered that there is no evapotranspiration and deep percolation and that the excess soil surface water is removed instantaneously.
Figure 1 – The concept of the drainage model and the respective variables

Infiltration and later percolation along the profile, as well as the rate water is removed by the drains, promote dislocation of the water table. Considering the impermeable layer as the point of reference, in a homogeneous profile, the water table reaches a maximum height ($H_m$) at midway between the drains and a minimum height next to the drains ($H_d$). In the case of ideal non-submersed drains, $H_d$ coincides with the distance of the drain from the impermeable layer.

Considering a section of drainage perpendicular to the direction of the drains, from the drain to midway between the drains, with the origin of the axis at a vertical point that crosses the drain, the following boundary conditions were established:

$$
\begin{align*}
  x = 0, & h = H_d \\
  x = \frac{L}{2}, & h = H_m
\end{align*}
$$

(1)

Considering $Q_f$ as the uniform flow through a straight section of the drainage per unit width, and assuming that the soil surface and the impermeable layer are horizontal and plane, and that the drains are parallel, equidistant and at the same height, then:

$$
Q_f = -K_s h \frac{\partial h}{\partial x}
$$

(2)

which can be rearranged and written as:

$$
\frac{\partial h}{\partial x} = -\frac{Q_f}{K_s h}
$$

(3)

On the other hand $\frac{\partial Q_f}{\partial x} = -v_z$, where $v_z$ is the vertical component of the velocity of infiltration. Supposing $v_z$ to be constant with $x$, and integrating, the result is:
making \( q=-v_z \), with \( q \) in this case being the flux through the water table per unit surface, positive from up to down, and \( c \) as the integration constant.

In any drainage situation, in permanent regime, the uniform flux \( q \) that crosses the soil surface is equal to the value of the flux that crosses the water table. Accepting that the movement is exclusively vertical in the non-saturated area, this flux is also numerically equal to a medium flux, defined by the quotient between the flow in the drain and the area of the horizontal section of drainage.

Integrating (2) within the limits (1), substituting \( Q_f \) by (4), and separating the variables gives:

\[
K_s \int_{H_d}^{H_m} h \, dh = q \int_0^L x \, dx
\]  

which, when integrated, gives:

\[
H_m^2 = q \left( \frac{L}{2} \right)^2 + H_d^2
\]  

or, in another format, to allow the use of dimensionless variables:

\[
\left( \frac{H_m}{L/2} \right)^2 = \left( \frac{H_d}{L/2} \right)^2 + \frac{q}{K_s}
\]  

Theoretical analysis shows that the rise of the water table at midway between the drains has the same magnitude as the vertical rise in the drain. However, there is an exception to this general rule when the drain is under external pressure. Application of an external pressure at the drain outlet creates a positive pressure within the drain and consequently leads to a rise in the level of the water table. In addition, it alters the shape of the water table, reducing its curvature in the direction of the drain and its height at midway between the drains, which, when measured from the external pressure plane, has decreased with the increase in the external pressure (Santos-Júnior, 1971).

Graphic representation of eq (7), is shown in Figure 2, where each curve translates the relationship \( H_m/0.5L \) on the x-axis and \( q/K_s \) on the y-axis for the value of \( H_d/0.5L \) equal to 0 at the base of the curve.

The figure demonstrates that as \( H_d \) increases the relationship curves \( H_m/0.5L \), tend to become more vertical, that is, with \( L \) remaining constant, and with an increase in \( H_d \), the
value of $H_m$ does not increase in the same proportion, and the difference between them becomes increasingly less. This behavior leads to the conclusion that the water table tends to acquire a plane form with the increase in external hydraulic pressure at the drain (situation of submersed drain), while its height at midway between the drains does not rise in the same proportion as the height of the vertical plane of the drain.

In fact, if $h'_m$ and $h'_d$ are considered as the heights of the water table measured above the plane of external pressure, respectively at midway between the drains and at the vertical plane of the drains, then:

\[ H_m - H_d = h'_m - h'_d \]  \hspace{1cm} (8)

or

\[ h'_m = (H_m - H_d) + h'_d \]  \hspace{1cm} (9)

Therefore, $h'_d$ does not depend on external pressure on the drain as proven by Santos-Júnior (1971) experimentally. Therefore, according to eq.(9), a reduction in $(h'_m - h'_d)$ will lead to a reduction in $h'_m$.

Figure 2 – Family of the curves of equation 5.10

Mathematical model description
A two dimensional saturated-unsaturated Galerkin finite element numerical model was used to predict the water table height between parallel drains. A user friendly software (DRENAFEM) was developed, for calculating the distance between the drains and the water table height at midway between the drains. The software also makes it possible to determine variations of the total head throughout the entire geometric space and, consequently, design flow nets with stream lines and equipotentials. In addition, the numerical drain outflow can also be determined.

If we were to admit, without a great margin of error, that the water and the soil are incompressible and that there is no change of mass, that there are no thermal gradients in the soil and that the law of Darcy is valid in all the domain of the flow, then the general flow equation or Richard’s equation can be written in the following way:

\[ C(\psi) \frac{\partial \psi}{\partial t} = \nabla (K(\psi) \nabla (z + \psi)) \]  

(10)

where \( K(\psi) \) is the unsaturated hydraulic conductivity (m.day\(^{-1}\)), \( C(\psi) \) is the soil water capacity (m\(^{-1}\)), \( \frac{\partial \psi}{\partial t} \) represents the slope of the curve of moisture retention in the soil, \( \psi \) is the pressure potential related to water weight (m), \( z \) is the gravitational potential (m) and \( t \) is the time (days).

RESULTS AND DISCUSSION

Numeric simulations were performed using submersed drains to confirm the presented theory. Three situations were tested for the same \( q/K \) ratio; drains with 0.1m, 0.2m head, and no head pressure. A Dirichlet boundary was applied at the drain nodes with the respective desired value for exterior pressure. Figure 2 shows the behavior of the flow at midway of the drain (\( h_m \)) and in the vertical plane of the drain (\( h_r \)), for the three mentioned situations.
Figure 2 – Variable regime. Variation of $h_r$ and $h_m$ with time, subject to 0.1 m, 0.2 m and no external pressure, in initially saturated soil. Simulation was carried out for $L=30$ m, $K=1$ m day$^{-1}$, with impermeable layer at a 4 m depth, drain at a 1 m depth, with the following VG parameters: $n=1.09$, $\theta_s=0.36$ m$^3$m$^{-3}$, $\theta_r=0.07$ m$^3$m$^{-3}$ e $\alpha=0.5$ m$^{-1}$, $q=0.005$ m day$^{-1}$ and a 0.05 m drain radius.

The simulations demonstrate that the difference between these two pressures decreases with the increase in the external pressure and that the flow at the vertical plane of the drains does not approach the exact height of submersion, remaining slightly higher than the value applied at the drain. This fact is probably due to the non-ideal behavior of the drain for the Vimoke adjustment used in the test. However, this difference does not seem to be very important in demonstrating the point being studies. The behavior of the water table height shows that subjecting the drain to an external pressure leads to a general rise in the water table height. However, for the same density of flux it also leads to a decrease in the difference ($H_m-H_0$) and the value of $h'_m$, according to equation 9. Thus, under equal conditions, installation of drains below the water plane of collecting ditches leads to a lowering of the level of the water table at midway between the drains.

This fact is based on the drainage conditions. The drain working under pressure, saturates the soil around it, which according to El-Gammal et al. (1995), provides a more favorable condition for drainage, because it improves the extent of radial drainage around the drain, and thus creates lower water table levels than those initially expected.

The use of this observation is important in controlled drainage situations or in subterranean irrigations, as management of submersion heights of the drains is important when these are higher than the water table, or alternatively, in soil depths that are not saturated.
Correct management of this pressure allows for watering a larger amount of the soil, namely, in areas closer to the drains, without causing a large rise in the water table height, at midway between the drains.

Figure 3 shows the reduction that is observed in the difference between \( H_m \) and \( H_d \) as the exterior pressure above the drain level increases. The results were obtained with numeric simulations of DRENAFEM model, for no exterior pressure and 0.1 m, 0.2 m, and 0.3 m exterior pressures.

The values of \( h_m \) and \( h_r \) were numerically determined in permanent events for different ratios of \( q/K_s \). As the external flow increases the reduction in the ratio of \( (H_m - H_d)/0.5L \) can be noted for a not very large increase in \( H_d/0.5L \). The decreasing segments corresponding to values of \( (H_m - H_d) \), indicate the fact that \( H_m \) reaches the soil surface and remains constant, but the value of \( H_d \) continues to rise, leading to a decrease in the \( (H_m - H_d) \) difference.

CONCLUSION

The submersed drain’s behavior was simulated and it was observed that the effect of an external pressure at the drain output leads to a rise in the water table at midway between the drains, at a lower magnitude than the applied flow.

This is important, as it makes it possible to select deeper drains, at the planning stage, without the need to increase the depth of the rest of the trench. At the same time, it ensuring a higher water table height between the drain and the midway between the drains creates better conditions for the plants, due to the generalized rise of the saturated

Figure 3 – Variation of \( H_m \) and \( H_d \), for the drains with 0 m, 0.1 m, 0.2 m, 0.3 m, external flows with \( q/K \).
zone, without compromising the depth of the non-saturated (drained) area, especially the area located above the drain. On the other hand, instead of placing the drains at a lower elevation, the base of the trenches can be dug at a higher elevation, reducing the costs of the project and ensuring submersion of the drains with controlled flows through management of the water plane in the trench.

REFERENCES


CHESCHEUR, G.M., MURUGABOOPATHI,C; SKAGGS, R.W; SUSANTO, R.H.; EVANS, R.O.. 1992. Modeling water table control systems with high head losses near the drain. in Drainage and water table control. Proc. of sixth international drainage control. ASAE. 38:45.


