INTERRUPTION OF SEEPAGE FROM A CANAL TOWARDS A LAKE

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ABSTRACT

The paper presents numerical solutions of interruption of two-dimensional flow from a trapezoidal canal towards a lake, through a layer of semi-pervious homogeneous isotropic soil which overlies an impermeable bed of soil. The flow from the canal towards the lake was interrupted by a freely permeable layer with finite thickness. Practically, this finite layer may be constructed by means of perforated pipes placed at a specified depth under the lake and the canal. The well known boundary element technique was applied. The results indicated that, a completely different dynamic pattern of flow has been occurred, when the freely permeable layer was introduced to interrupt the flow towards the lake.

INTRODUCTION

Generally in river valleys, which are usually agricultural valleys, the soil profile is formed of a top alluvial clay deposit of finite thickness, which is a semi-pervious layer, overlying either impermeable layer of rock or highly permeable layer of sand and gravel of finite thickness. Usually irrigation canals are excavated in these valleys in a way that the water level in these canals are higher than those in drains and lakes nearby, thus seepage flow takes place from these canals towards the drains and lakes. Therefore, such construction of these canals through the agricultural land, certainly, spoils these lands due to the rise of the ground water level accomplished by the seepage flow. Thus it becomes necessary to lower the ground water table, in the agricultural land and this can be done by different ways. One of these ways is to construct embedded drains under the canal and the lake, using perforated pipes enclosed by sand filter. Therefore the prediction of seepage from these canals is an important practical problem since, it can be considered as a vital factor in planning and constructing new agricultural areas.

The problems of seepage from open canals have attracted the attention of many research workers since 1960. Among these research workers, Hammad [1] used two steps of conformal mapping for computing the seepage flow, under gravity, from a system of parallel, identical and equally spaced canals through a semi-pervious clay layer of finite thickness underlain by a freely permeable layer of sand or gravel (aquifer), in which the piezometric head is very near the canal water level. In 1963, El-Nimr [2] reported an analytical solution, through conformal mapping, for calculating the seepage discharge from the above system of canals considering the aquifer to act as a drain. Also, Hathoot [3] derived a formula for calculating the seepage discharge from the above system of canals.

An approximate analytical solution for seepage from trenches was obtained by El-Nimr and Street [4] in which the formulae for the quantity of seepage and the free water surface were reported. Hathoot [5], derived a simple discharge formula for calculating the discharge from a canal through a semi-pervious layer towards a free permeable one.

It is obvious that most of these research workers implied the conformal mapping technique. Nevertheless no attention was directed for studying the interaction effect between a canal and a lake or drain nearby, when a freely permeable aquifer is located at a shallow depth under the beds of canal and lake. This may be due to the complexity of the problem in which no rigorous theoretical closed form solution can be, easily, obtained.

The available literature showed that, the boundary element method was applied successfully for analysing the potential problems, for instant, Brebbia [6], Banerjee and Butterfield [7], Abdrabbo [8,9,10], and Chang [11]. In this work, the boundary element technique was adopted, for the analysis of the problem.

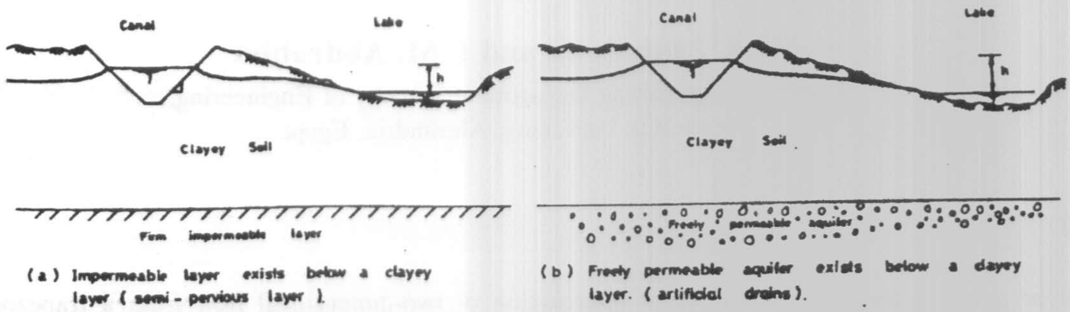

Figure 1. Geometry of the problem.

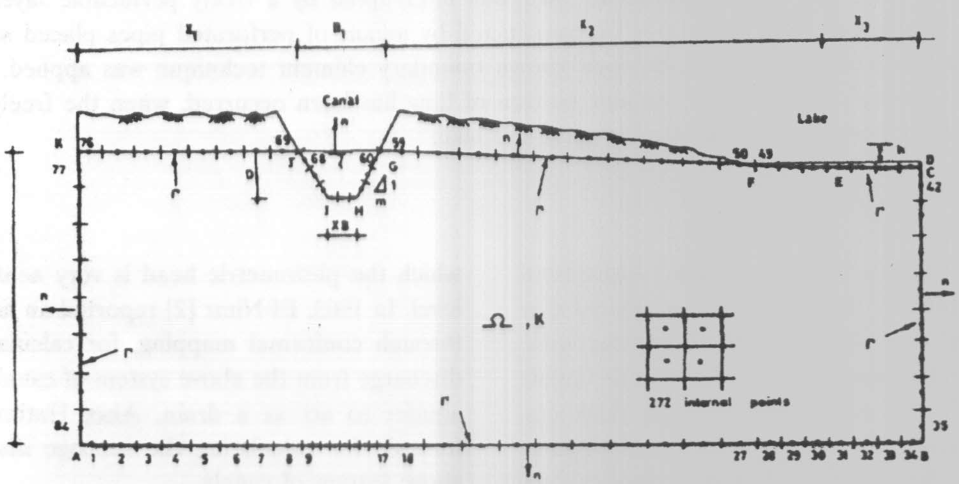

Figure 2. Idealization of the problem.

Governing Equation and Boundary Conditions

Figure (1) shows the geometry of the problem. In Figure (1-a), the canal is excavated in a semi-pervious layer of finite thickness which overlies an impermeable bed of rock, while in Figure (1-b), the horizontal drains were introduced (aquifer of a limited thickness). The top layer was considered to be homogeneous and isotropic with respect to permeability. The piezometric head at the top surface of the aquifer was considered to be zero. The idealization of the problem is shown in Figure (2), in which the boundary surface of the domain (Ω) is discretized into 84 linear elements, each is represented by a node at each centre. Also the domain (Ω) is discretized into 272 rectangular elements, these elements were represented by the nodal points at their centres. The right hand side (R.H.S.) vertical end zone boundary BD is passing through the toe point of the right hand side slope of the lake, while the left-hand side vertical end zone boundary (L.H.S) is brought from infinity. These vertical end zone boundaries are assumed to be impermeable, that is to say the velocity across these boundaries were considered to be zero.

Assuming AB a datum, the boundary conditions are as follows:

- Along the canal boundary GHIJ, the potential u is the rise y_1 of the surface water in the canal above the chosen datum.
- Along the lake boundary CEF the potential u is the rise of surface water in lake y_3 above the datum.
- Along the R.H.S. and L.H.S. vertical end zone boundaries AK and BC, the fluxes q normal to these boundaries vanish.
- Along the bottom face AB of the top layer the flux q normal to this face vanishes, in case of impermeable face; while the potential u vanishes in case of permeable face, (aquifer).
- The flux q normal to boundaries FG and JK also vanishes.

The boundary element formulation of two dimensional flow problem was given by numerous research-workers. For instant, Brebbia [6], as

$$\alpha u^i + \int_\Gamma u\, q^* d\Gamma = \int_\Gamma q\, u^* d\Gamma \qquad (1)$$

To make use of equation (1), the boundary of the domain Ω is discretized into n elements and the values of u and q are assumed to be constant on each element, and equal to the value of the mid-node of the element.

Thus equation (1) was placed in a discretized form as;

$$\alpha u^i + \sum_{j=1}^{n} u_j \int_{\Gamma_j} q^* d\Gamma = \sum_{j=1}^{n} q_j \int_{\Gamma_j} u^* d\Gamma \qquad (2)$$

Equation (2) was written for each node (i), to obtain n equations, and solved for the unknown boundary values of u and q. Once the unknown boundary values are obtained, the values of u_i and q_i (i=1,2) at any interior point within the domain are calculated, Brebbia [6],as;

$$\alpha u^i = \sum_{j=1}^{n} q_j G_{ij} - \sum_{j=1}^{n} u_j H_{ij} \qquad (3)$$

$$(q_1)^i = \int_\Gamma q \frac{\partial u^*}{\partial x} d\Gamma - \int_\Gamma u \frac{\partial q^*}{\partial x} d\Gamma \qquad (4)$$

$$(q_2)^i = \int_\Gamma q \frac{\partial u^*}{\partial y} d\Gamma - \int_\Gamma u \frac{\partial q^*}{\partial y} d\Gamma \qquad (5)$$

where,

$$G_{ij} = \int_\Gamma u^* d\Gamma,\; H_{ij} = \int_\Gamma q^* d\Gamma$$

A computer program (potential-2) was written to solve the problem, the output from this program are the flux q along the surface AB in case of permeable face, or the potential u along that surface, if the impermeable face is introduced, the flux q along the submerged boundaries of lake and canal, and the potential along the boundaries AK, BC, FG and JK.

But it should be realized that, the potential u at any point along the free water surface GF and JK is equal to the height of that point above the chosen datum. Thus, the location of the free water surface was first, assumed, and its location was altered by iteration process.

DISCUSSION OF THE RESULTS

Free Water Surface

It is anticipated that in case of existing aquifer, both the lake and the canal are the sources of seepage water to the aquifer (drains); yet, a difference in potential between the canal and the lake exists.

Figure (3) illustrates the locations of phreatic surfaces for a typical cross-section of canal-lake system, at different x_2/h ratios. It is obvious from the figure that, a unique phreatic surface, of a parabolic shape, for each geometrical pattern has been achieved, regardless of the assumed initial location of that surface, with maximum potential values at the canal and the lake and a minimum value at the mid-way between the two sources. The inclination of the tangent to the phreatic surface with the horizontal, decreases as the distance from either of the two sources increases, up to the mid-way between the two sources where a unique inclination value of zero is obvious, that is to say the horizontal components of the seepage velocities along this plane are equal to zero. Thus the vertical plane, passing through the mid-way between the two sources, represents the plane of zero horizontal seepage velocity and the zone of the domain to the right hand side (R.H.S.) of this plane is responsible for the seepage flow from the lake, whereas the water from the canal seeps through the zone to the left hand side (L.H.S.), without any seepage from the canal to the lake.

Figure (3) shows that as the distance between the canal and the lake increases, the vertex of the parabola increases, and consequently the influence of the interaction of the two sources on the seepage flow decreases, and consequently, the seepage velocity from both the lake and the canal decreases. At $x_2/h=100$, the phreatic surface touches the interface surface of the aquifer. This implies that, there is no interaction between the canal and the lake and the seepage water from the two sources is equal to the sum of the seepage water from the canal and the lake individually. Figure (3) indicates that permeable aquifer (drains) pulls the phreatic surface of seepage flow downwards, leaving a big unsaturated zone between the lake and the canal. Whereas, in case of existence of an impermeable layer, the phreatic surface can be approximated by a plane surface connecting the surface water in canal and that in the lake.

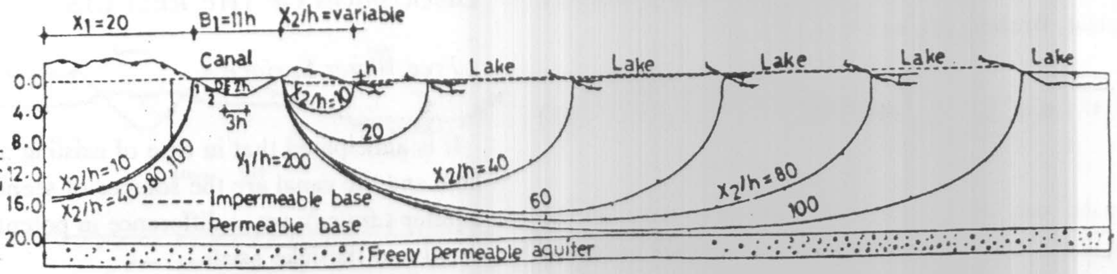

Figure 3. Phreatic surface.

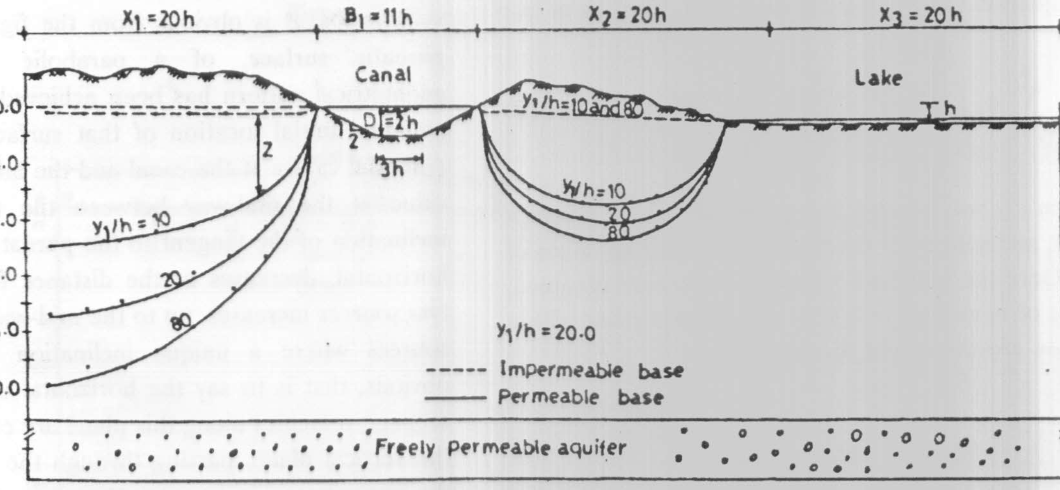

Figure 4. Phreatic surface.

It is clear from Figure (3) that, the phreatic surface of seepage water (L.H.S.) of the canal is inappreciably affected by the distance between the lake and the canal x_2/h. However, Figure (4) indicates that, to lower the phreatic water surface at the L.H.S. of the canal, it is necessary to construct embedded drains, and as the depth of these drains increases (depth of aquifer), the unsaturated zone of the soil above the phreatic surface increases. Nevertheless when the depth of the aquifer increases, a slight downward movement of the phreatic surface at the zone between the lake and the canal takes place. This really implies practical difficulties to allocate artificial drains below the two sources to satisfy all the necessary requirements. It can be seen that as the depth of embedment of the drains increases, that is to say the cost of construction increases, an appreciable unsaturated zone of soil to the L.H.S. of the canal can be achieved, but without practical noticeable achievement to the unsaturated zone of soil between the lake and the drain. However to attain a practical downward movement of the phreatic surface of water in the zone between the lake an the canal, it is necessary to increase the distance betwe the two sources, Figure (3).

Dynamic Pattern of Flow

Figures (5) and (6) show the dynamic pattern of flo within the domain at $x_2/h=20$ and 100 respectively, in cas of semi-pervious layer underlain by freely permeab aquifer (artificial drains). These figures confirm that, bo canal and lake are the sources of seepage water to t aquifer (drains), and as the distance between the can and the lake increases, the interaction between the tv sources decreases, and at $x_2/h=100$ both of the tv sources seep to the aquifer individually without a interaction between them. The figures, also indicate th the direction of seepage velocity of water from lake ne by R.H.S. vertical end zone boundary of the domain mainly vertical and consequently the horizontal compon of the velocity is vanished.

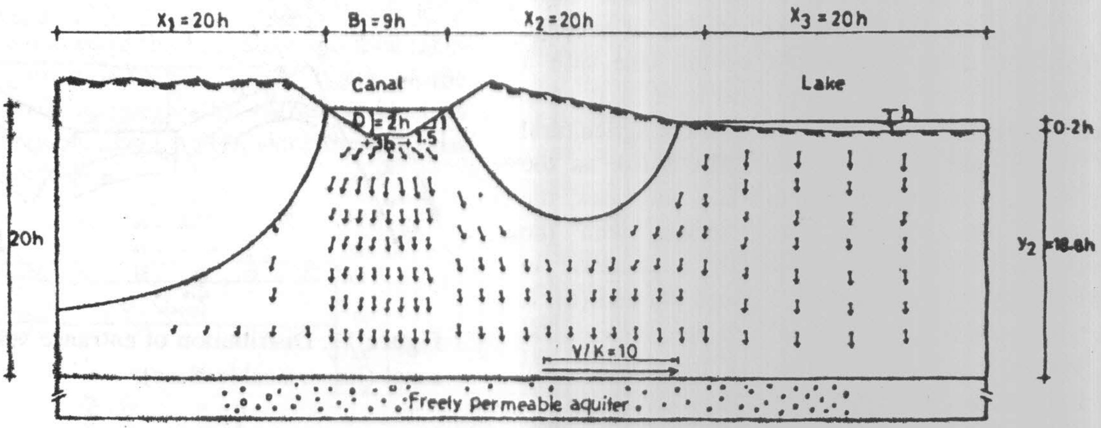

Figure 5. Velocity fields (freely permeable aquifer).

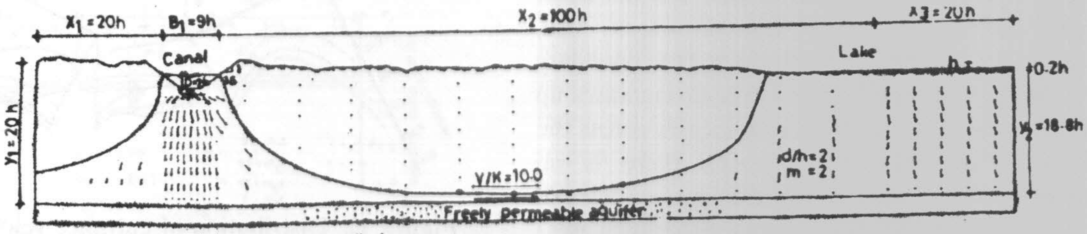

Figure 6. Velocity field (freely permeable aquifer).

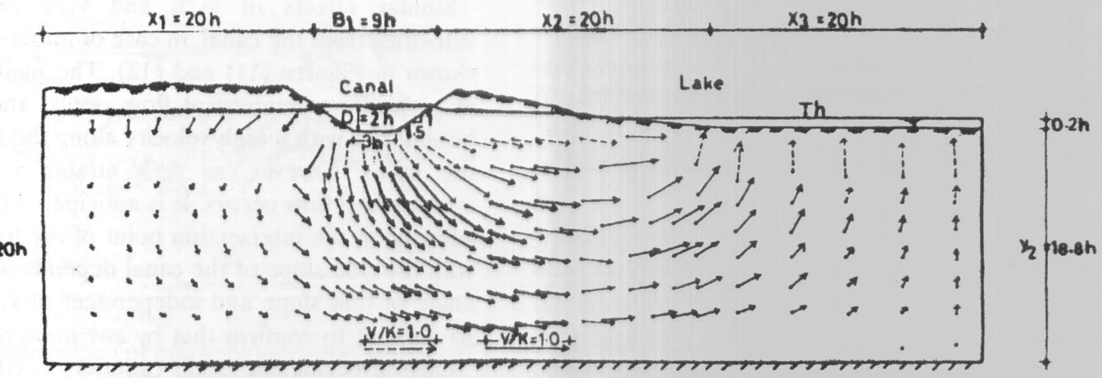

Figure 7. Velocity field (impermeable base).

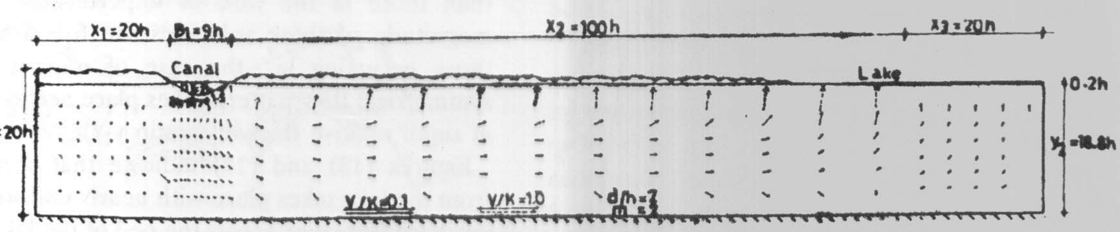

Figure 8. Velocity fields (impermeable base).

The velocity fields, in case of impermeable base, Figures (7) and (8) show that the amount of seepage water from the canal is collected by the lake with a phreatic water surface near the ground level. It is clear that such situation of canal and lake spoil the agricultural land at L.H.S. and R.H.S. of the canal. Also, as the distance between the canal and the lake increases, the inclination of the phreatic water surface with the horizontal decreases and consequently a decrease in seepage velocities are anticipated, Figures (7) and (8). It is clear also, in this case, that the seepage velocities at R.H.S., vertical end zone boundary of the domain, are vertical which satisfy the applied boundary conditions.

Figure (9) illustrates the effect of the distance between the canal and the lake, in case of impermeable base, on the exit seepage velocity of water across the lake, it can be seen that as the distance between the lake and the canal increases the exit velocity to the lake decreases. Also, these exit velocities decrease towards the R.H.S. boundary of the lake. As the thickness of the top layer increases up to $y_1/h=20$, the magnitude of the exit velocities across the lake decrease. For values of $y_1/h>20$, there is no appreciable effect of the thickness of the layer on the exit velocities, Figure (10).

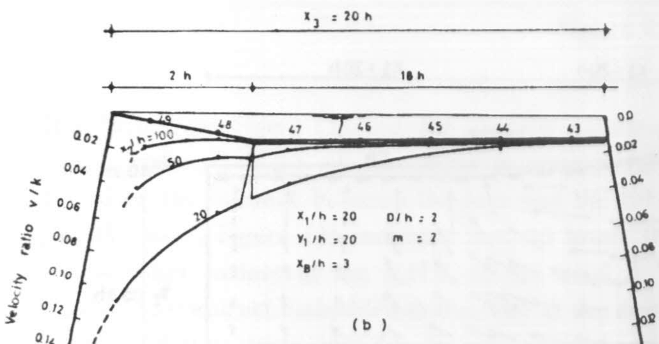

Figure 9. Distribution of exit velocity across the lake (impermeable Base).

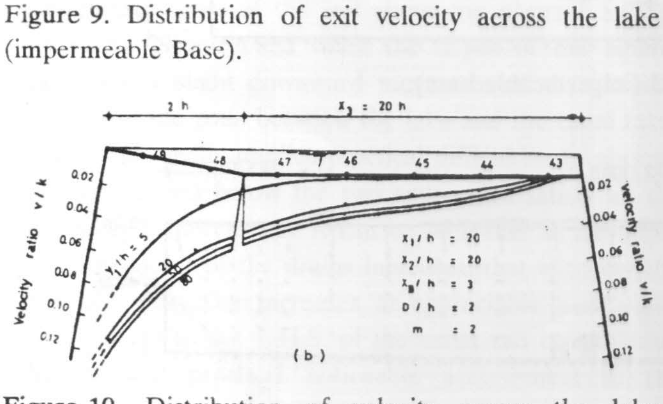

Figure 10. Distribution of velocity across the lake (impermeable base).

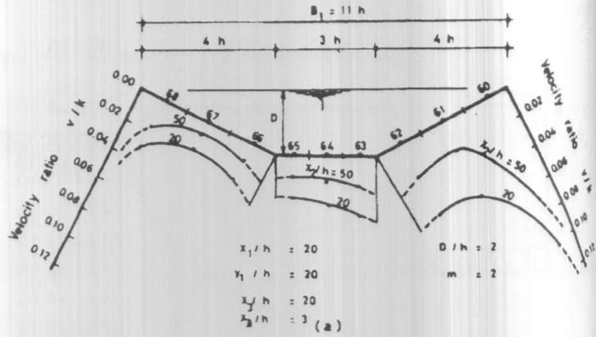

Figure 11. Distribution of entrance velocity across the canal (impermeable Base).

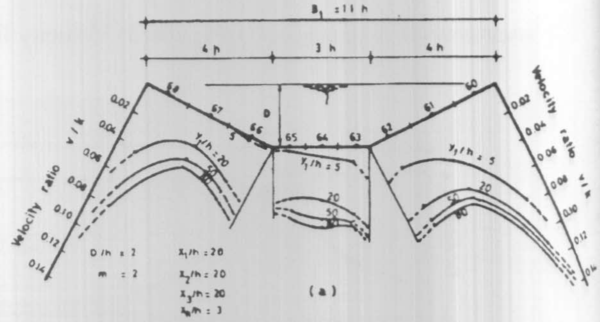

Figure 12. Distribution of entrance velocity across the canal (impermeable base).

Similar effects of x_2/h and y_1/h on the entrance velocities from the canal, in case of impermeable base, are shown in Figures (11) and (12). The figures indicate that at $y_1/h \leq 5$ unsymmetrical flow occurs through the canal boundaries with a high velocity along the canal side facing the lake. However, as y_1/h attains a value of 20, a symmetrical flow occurs. It is anticipated that the entrance velocity, at the intersection point of the free water surface with the side slope of the canal depends on the inclination angle of that slope and independent of y_1/h or x_2/h. It is so difficult to confirm that by any numerical solution.

Once a permeable drain (aquifer) is constructed under the canal and the lake, the entrance velocities across the lake and the canal, Figures (13) to (16), become higher than those in the case of impermeable interface. The magnitude of these velocities are found to be 50 times those occurring in the case of impermeable base. A symmetrical flow pattern takes place across the canal even at small relative thickness ratio y_1/h.

Figures (13) and (14) indicate that seepage of water from the lake takes place with nearly uniformly distributed entrance velocities across the bed of the lake, except along its side slope. As the distance between the lake and the drain increases, x_2/h increases, the entrance velocity from the lake, along its side slope, decreases, and it is inappreciably affected along the bed, since the flow takes place in vertical direction. While as the depth of the (aquifer) drains y_1/h increases, the entrance velocities across the lake increases, Figure (14), since the potential causing the flow increases.

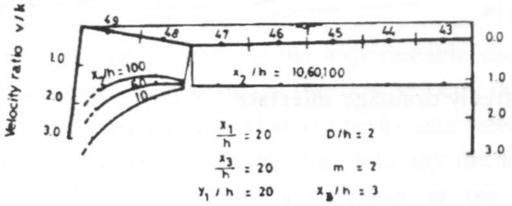

Figure 13. Distribution of entrance velocity across the lake (freely permeable aquifer).

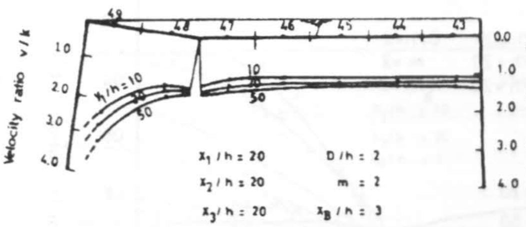

Figure 14. Distribution of entrance velocity across the lake (freely permeable aquifer).

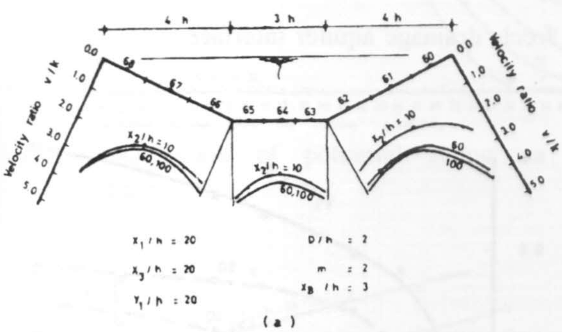

Figure 15. Distribution of entrance velocities across the canal (freely permeable aquifer).

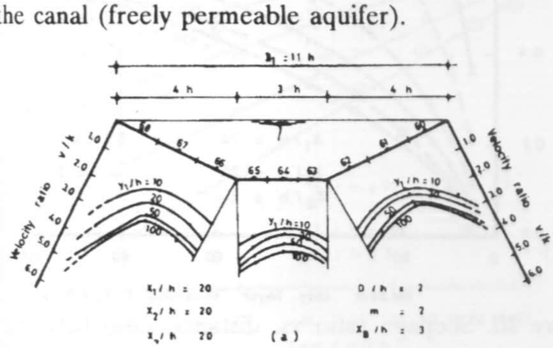

Figure 16. Distribution of entrance velocities across the canal (freely permeable aquifer).

Figures (15) and (16) illustrate the effect of the depth of aquifer (drains) y_1/h and the distance between the lake and the canal on the entrance velocities across the canal. It is obvious that as the distance between the lake and the canal x_2/h increases, that is to say the interaction effect between the two sources decreases the exit velocities from the canal increases, Figure (15).

Figure (17), illustrates the distribution of water entrance velocity to the aquifer (drains). It is clear that the seepage water enters the aquifer with relatively high velocities, in the regions under the canal and the lake, and with a relatively slower velocities in the regions between the two sources. The magnitude of these velocities are practically important for the design of filter material around the drain. These entrance velocities in the region to the L.H.S. of the canal seems to be independent of the ratio x_2/h, whereas in the region between canal and lake the magnitude of the entrance velocity decreases as x_2/h increases. It is worth note that as the depth of aquifer increases the entrance velocity along the aquifer in the region under the canal, increases. However, an adverse behaviour is noticed in the region under the lake, Figure (18). The increase of the top layer thickness, that is to say the increase of the depth of aquifer (drains), is associated with two challenging effects, first, is the potential increase across the layer which in turn increases the seepage velocity through the layer. Second is the increase in the entrance length of the flow to the drain, Figures (5) and (6), which leads to a decrease in the entrance velocity.

Rate of Discharge

Figure (19) illustrates the variation of seepage discharge ratio Q_1/kh of canal, in case of impermeable base, with the variation of the distance of L.H.S. vertical end zone boundary of domain from the canal. It is clear from the figure that, there is no appreciable effect of the relative distance x_1/h on the seepage discharge from the canal. Thus the adopted location of L.H.S. vertical end zone boundary is justified.

Figures (20) illustrates the variation of seepage discharge ratio Q_1/kh from the canal to the lake, in case of impermeable base, with the change of both the thickness ratio of the top semi-pervious layer y_1/h and the distance ratio x_2/h between the canal and the lake. It is obvious, from Figure (20) that the seepage ratio Q_1/kh increases as y_1/h increases. Nevertheless the discharge ratio Q_1/kh has limited values which depend on the distance between the canal and the lake.

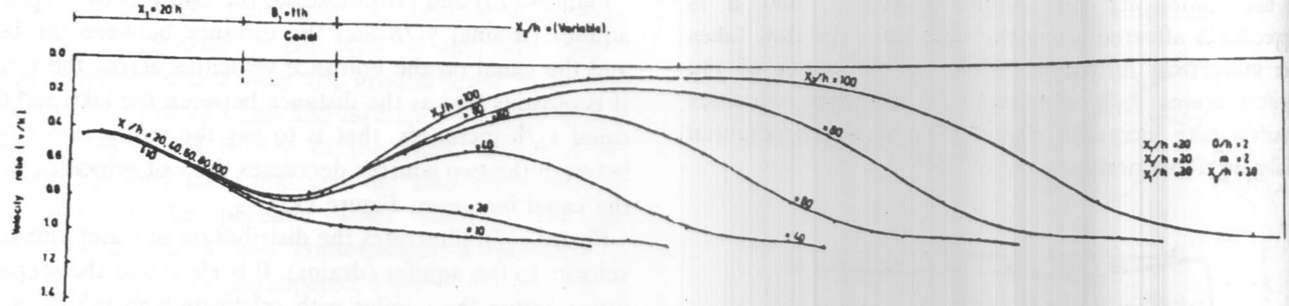

Figure 17. Distribution of velocity across the freely drainage interface.

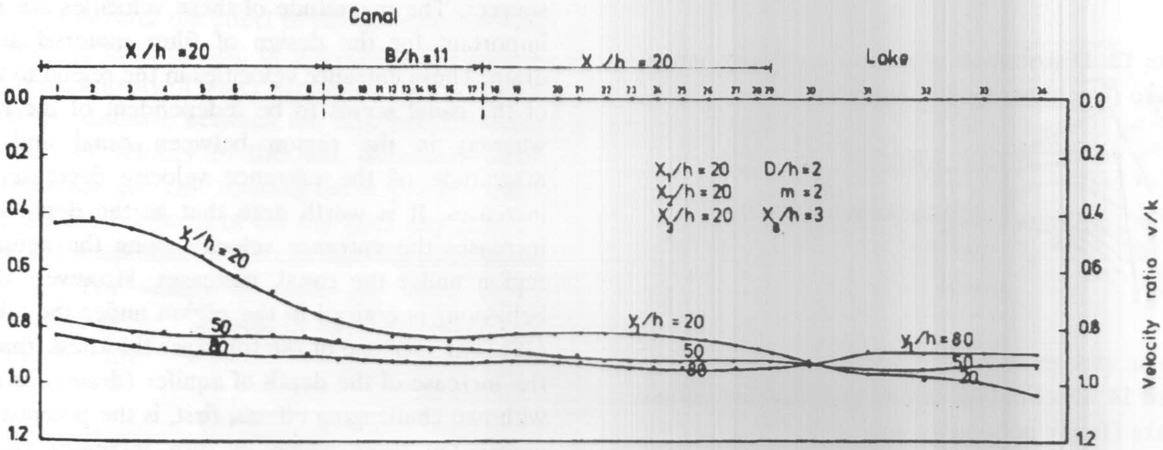

Figure 18. Distribution of velocity across the freely drainage aquifer interface.

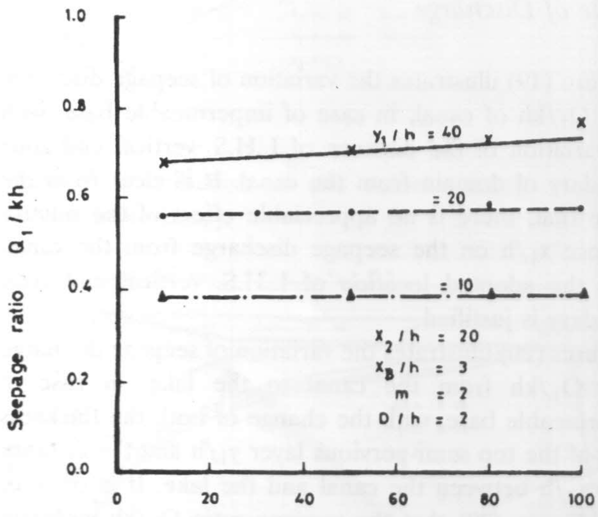

Figure 19. Seepage ratio vs. X_1/h (impermeable base).

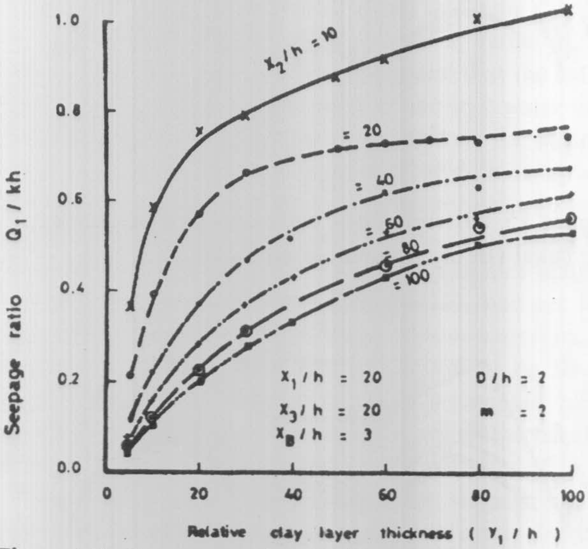

Figure 20. Seepage ratio vs. distance ratio between the canal and the lake.

These values are accomplished at $y_1/h = 100$. That is to say the quantity of seepage ratio Q_1/kh from the canal requires a specified zone that is to say specified depth, of soil to pass through to the lake, and any excess depth of clay layer more than that depth will not eventually be associated with an increase in quantity of seepage water. This is clear from Figure (21) which confirms that, as the thickness of the top layer increases, the values of $\partial h/\partial x$, the hydraulic gradient along the impermeable base of the layer decreases, that is to say the flow velocity decreases. Also Figure (20) indicates that as the distance between the canal and the lake increases, that is to say the hydraulic gradient $\partial h/\partial x$ decreases, a decrease in the rate of discharge ratio Q_1/kh is anticipated. But limited small values of Q_1/kh have been attained at $x_2/h = 100$.

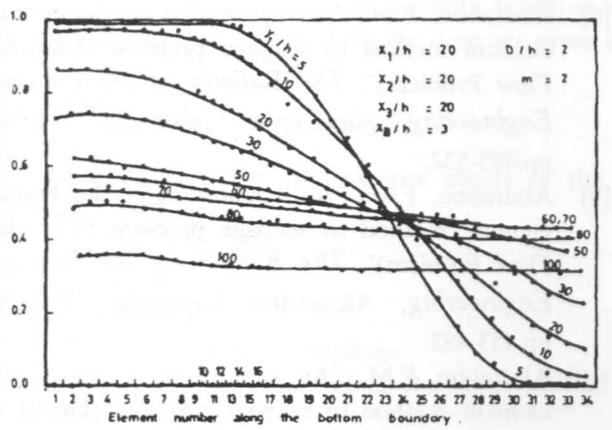

Figure 21. Distribution of potential acting on the impermeable base.

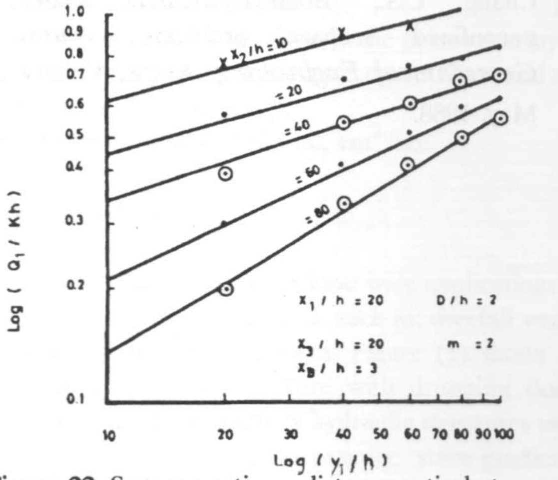

Figure 22. Seepage ratio vs distance ratio between the canal and the lake (impermeable base).

Figure (20) was recompiled again, Figure (22), from this figure it is interesting to note clear that the value of (Q_1/kh) varies linearly with (y_1/h), in a logarithmic plot.

Once horizontal drains are installed under the canal and the lake at a depth y_1/h, which simulate the case of an existing aquifer, the rate of seepage discharge from the canal increases attaining a value equal to 40 times that in case of impermeable base, Figures (23) and (24).

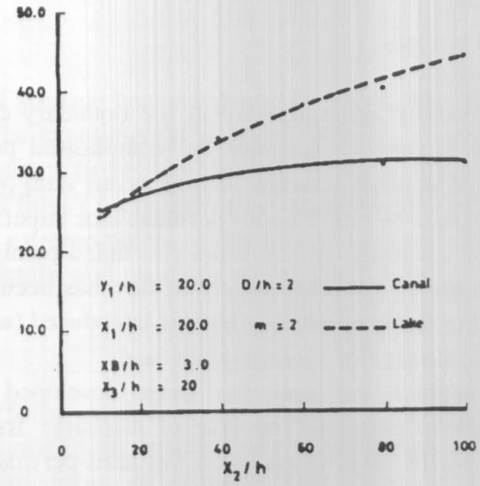

Figure 23. Discharge ratio vs X_2/h (freely permeable aquifer).

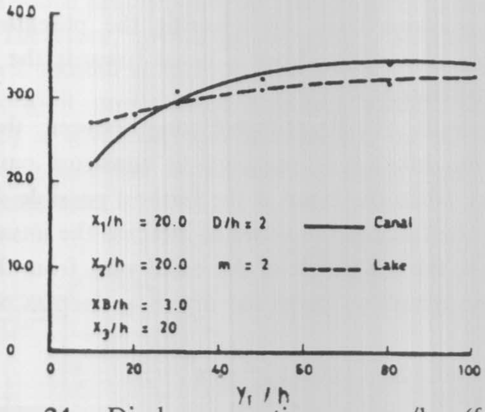

Figure 24. Discharge ratio vs y_1/h (freely permeable aquifer).

These figures demonstrate that the rate of discharge from both the lake and the canal increases as the distance between the two sources increases, and as the depth of aquifer increases. But it seems that the rate of discharge from both the lake and the canal are attaining their maximum values at y_1/h equal to 100, Figure (24). Thus such results can be used for obtaining the most economical depth of artificial drains. Also as x_2/h increases the interaction between the lake and the drain decreases and consequently the rate of discharge from both the lake and the drain increases; but the effect of x_2/h on the rate of discharge from lake is more pronounced than that accomplished from the canal.

Practically, such results are useful for the design of artificial drains, and the capacity of the necessary water pumps and their attachments.

CONCLUSIONS

The versatility and simplicity of the boundary element technique enables to consider the complicated practical problem of seepage through homogeneous semi-pervious layer underlain by either highly permeable or impermeable layer. The following are the main concluded points:

1. A completely dynamic pattern of flow has been found, once the freely permeable layer is introduced (artificial drains) under the semi-pervious layer.
2. A computer program has been developed which enables to calculate the rate of discharge from the canal to the lake, in case of a top semi-pervious layer underlain by an impervious bed of soil, and from both the canal and the lake through the top layer towards an underlaying aquifer (artificial drains).
3. The versatility of embedded artificial drains in a semi-pervious layer on lowering the phreatic water surface of seepage from a canal towards the lake is demonstrated.
4. To increase the unsaturated zone between the canal and the lake, it is required to construct embedded drains, while the canal at the farthest possible distance from the lake, and in order to increase the unsaturated zone to the other side of the canal away from the lake, it is necessary to install the drains as deep as possible.

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