GROUND WATER RELIEF ON LINED CANALS USING TILE DRAINS

BY

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Abstract:

Occasionally canals lining are constructed in soil of high permeability, so the seepage losses from canals are to be minimum as much as possible. In areas where the ground water is likely to rise above level of the canal bed, canal lining suffers from a great value of uplift pressures, which lead to lining failure. In this study, the afrorementioned problem has been solved using a tile drain behind the canal lining to reduce the hydraulic static pressure. A viscous flow model (Hele-Shaw) is used to simulate the problem and an optimum position for the tile drain to give minimum uplift pressure under the canal lining was obtained for different cases of study. The problem is treated numerically by using the well known finite element method. A favorable agreement is obtained for the comparison between experimental and numerical results. A parametric study for a full practical range of parameters is achieved.

Keywords

Canal lining, seepage, groundwater uplift, tile drain, Hele-Shaw, Finite Element Method..

1. Introduction

The high losses of valuable irrigation water through unlined canals and waterlogging are the most serious problems in old fertile lands. Thus, it becomes necessary to line the canals more economically with the best possible type of lining. The main advantages derived from lining a canal are: minimizing seepage losses in canal, prevention of water-logging, increasing flow velocity, increasing bank stability, increase in commanded area, reduction in maintenance costs, elimination of flood dangers. Most of the lined canals may be failured due to uplift pressure forces under the lining, when the groundwater table rises above the canal bed during periods of low flow or no flow.

In the present study, tile drains have been used, behind a lined canal, to reduce the uplift pressure under the lining. The suggested tile drains are short lengthen cement pipes separated by joints of about 3 mm through which drainage water gets into drains. The joints usually surrounded by graded filters of sand and gravel. This type of drain is more suitable for light soils of relatively high hydraulic conductivity. The main objective of this study is to find the optimal position and diameter of the tile drains to reduce the uplift pressure force under the lined canals. Thus, reduce the thickness of the lining and save the big cost of lining. The physical models of this problem are shown in Fig. (1).

2. The State of the Art

Many types of lining are generally classified according to the material used for their construction as hard surface type lining, earth type lining, buried and protected membrane type lining. A review of the lined canals development, advantages, disadvantages, types, failures and methods of protection, experimental and numerical investigations related to the study is very vast.

Willson R. J. (1958), Ronald W. Wilkinson (1985), Rajendra Chalisgaonkar (1989) , Einert-Martin-P (1990), Khair, C. Nalluri and W. M. Kilkenny (1991), Hajela – Dr – RB (1994), and Chengchun – KE; Singh – VP (1996) have studied and discussed the feasibility and improvement of different canal lining including good seepage control, smooth lining surface, steeper side slopes, reliability, durability, and lower construction cost. *Asawa G. L. (1980), Ronald W. Wilkinson, M.1985, A. Khair (1991), and Mohamed A. M. Rezk (1995),* have studied the protection of canal lining against exccessive uplift pressures using mainly relief valves and drains satisfying filter criterion.

Among the various types of experimental models which are used for studying ground water movement are the sand model, the electric analogy, the heat analogy, the membrane analogy, and the viscous flow analogy, which is also known as the Hele-Shaw model. The Hele-Shaw model was first used by *H.S.Hele-Shaw* in England in 1897-1899, to study streamline flow patterns around variously shaped bodies placed between two parallel plates. The first to suggest the application of this model to ground water flow studies was *Dachler* in 1936. The main advantages of the Hele-Shaw model are: the exact shape of both the phreatic surface and flow lines which can be easily visualized and photographed and there is no problem of entrapped air. Few experimental studies have been conducted to analyze seepage problems related to lined channels. *Mohamed Abd EL-Razek M. Rezk 1995*, used a hydraulic sand model to study the optimum position of the relief valves in lined canals.

The feasibility of numerical techniques, mainly the well established finite element method, in solving groundwater and seepage problems has been attained in the last few decades. The solution based mainly on transforming the basic differential equations to a system of algebaric equations which to be solved simulteneously under the imposed boundary conditions, *Zienkiewicz(1965), France (1976), Reddy J. N. (1986) and Zeydan B. A.(1993).*

3. Statement of the Problem

The present study aims to determine the optimal position and diameter of proposed tile drains which give the minimum groundwater uplift pressure on the lined canal. The

lined canal of trapezoidal cross section is established through a homogeneous isotropic media which rests on an impermeable bed. Combining the equations of continuity and velocity potential for two – dimensional flow, one obtains the well known Laplace equation for ideal two – dimensional steady flow through homogeneous isotropic media, Harr (1962),

$$\nabla^2\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} = 0 \tag{1}$$

In which:

Φ is the velocity potential at any point (x, y) in the flow region.

Where

$$\phi = k\left(\frac{p}{\rho g} + y\right) \tag{2}$$

in which:

p is the pressure intensity at any point.

ρ is the fluid density.

g is the acceleration due to gravity.

k is the hydraulic conductivity of the soil.

y is the elevation head

equation (1) which is a second order partial differential equation is the governing equation in the present study and the assumptions presented are; the soil media is homogenuous, isotropic and physically stable, the pressure is atmospheric everywhere on the water table., the seepage flow is steady, the hydraulic conductivity, k, is constant everywhere, the dimensions and side slope of studied lined canal are kept constant and the flow through the tile drain is running free. Eq. (1) is solved throghout the flow domain in the present study subjected to the following boundary conditions, as shown by fig.(2):

1. Along the impervious boundary, the velocity component normal to the boundary at any point must be vanish, . $\frac{\partial \phi}{\partial n} = 0$ (3)

where n is the normal direction to the boundary.

2. Along the centerline of the lined canal, the flow is symmetrical, i.e. it acts as a streamline where the flow across it is vanished, Eq.(3)
3. Along the phreatic surface, the pressure at any point is atmospheric, i.e. the pressure, p=0, this reduces Eq.(2) to:

$$\phi(x, y) = y \tag{4}$$

4. Hele- Shaw Experimental Model:

The present problem has been studied experimentally by using a viscous flow model , (Hele – Shaw model). The principle of the Hele-Shaw model is based on relationship between the Navier-Stoke equation of motion, which is considered the most general governing equation of fluid flow, and general of Darcy' s law. The Hele-Shaw model consists of two parallel plates mounted vertically together with a uniform capillary interspace (0.5-3.5mm) between them. The analogy is based on the similarity between partial differential equations which describe the field of saturated flow of water through porous media and those for laminar flow of a highly viscous liquid through the capillary interspace between two vertical parallel plates. Therefore, the model is known also as the viscous flow model. It can be used for almost any study of two-dimensional flow in porous media. The mean velocity in the x and y directions in two-dimensional flow are given by:

$$V_x = -\frac{b^2 g}{12 v}\frac{\partial H}{\partial X}$$
$$V_y = -\frac{b^2 g}{12 v}\frac{\partial H}{\partial Y} \tag{5}$$

In which: b is the spacing between the two Perspex plates,
γ is the specific weight of the liquid, $\gamma = \rho g$
μ is the dynamic viscosity of the liquid,
ρ is the density of the liquid, $\mu = v\rho$
g is acceleration due to gravity, and
v is the kinematics viscosity of the liquid.

The similarity between equation (5) and Darcy' s law for flow of water through porous medium is obvious. Thus, the hydraulic conductivity of the model can be expressed as:

$$K_m = \frac{b^2 g}{12 v} \tag{6}$$

The physical models of the studied problems are shown in Fig. (3-a). If the distance (b) between the plates is small, the flow becomes two-dimensional In rectangular coordinates the x-axis will be chosen as horizontal and midway between the plates, the y-axis vertical, and the z-axis perpendicular to the plates.

Equation (5) also shows that the model is isotropic. The width between the two parallel plates and the kinematic viscosity of the liquid determine the hydraulic conductivity (permeability) of the model, which can be easily adjusted by the proper choice of these variables.The link between model and prototype consists of similar dimensionless expressions that have the same numerical value to describe either the model or the prototype, the analysis were made by Bear, 1979, on the basis of similar differential equations. An equal horizontal and vertical length scales was adopted in the present research, where the subscript (m) and (p) refer to model and prototype respectively. The subscript (r) refer to the ratio of corresponding parameters and prototypes, which is constant and the subscript x, y refers to the horizontal and vertical directions respectively. The discharge scale is obtained from Darcy' s law for isotropic soil,

conditions, as follows:

$$Q_r = K_r \cdot b_r \cdot L_r$$

Where:

$$L_r = \frac{X_m}{X_p} = \frac{Y_m}{Y_p} = \frac{L_m}{L_p} \qquad b_r = \frac{b_m}{b_p} \tag{8}$$

b_m	is the width of the interspace of the model and equal ($1,5.10^{-3}$ m).
b_p	is the width of the prototype and equal (1m).
L_m, L_p	is model and prototype corresponding dimensions,
K_p	is the hydraulic conductivity of the prototype (soil), it is
K_m	is the equivalent hydraulic conductivity of the model (oil),

A motor oil 20 w/50 was used as a flow medium between the two parallel plates. Its kinematic viscosity varies with the temperature e.g. v_m =5.18 cm^2 /sec. at 22^0C. The spacing between the two plates, b=1.5mm, was used in the current experimental work. It follow that, K_m = 0.355 cm/sec at 22^0C. It has a specific weight of 0.89 gm/cm^3 at 26.4 ^{0}C. The relationship between the kinematic viscosity, v, in stokes and the corresponding degree of temperature in centigrade is gven, Mazen,1. Experiments were made at a room temperature ranging between 17 ^{0}C and 23.5 ˚C. . The change in temperature was measured during operating the experimental runs by means of a mercury thermometer of accuracy 0.1^0C. Figure (3-b) shows a schematic diagram of the flow closed circuit.

Free surface elevation was recorded by means of transparent rule graduated into millimeters, and its zero level (datum) was coinciding with the horizontal of the lined canal bed. Drain discharge was measured by collecting oil from drain outflow tube in a significant time, the drain discharge, Q_m, can be calculated as follows: Q_m=Volume/time. After several test runs carried on the model, it was prepared to carry out the required experimental runs.

The parameters which have been taken into consideration during experiments are:

1-The relative ground water head (H/B),
2-The relative drain position (X/B, Y/B),
3-The relative drain diameter (d/B), and

5. NUMERICAL ANALYSIS USING FININTE ELEMENT METHOD

The problem of reducing the uplift pressure under lined canals, by using the tile drains behind the canal lining is studied numerically in the present study by using the finite element method, and the flow is characterized as unconfined flow. The main purpose of the mathematical problem is to determine the seepage characteristics which are: the phreatic surface profile, the uplift pressure distributions under the canal lining and the quantity of seepage through the drain. The finite element method is used in the present study as a two dimensional problem, considering all boundary condition of the problem. The (FEM 2D) program is employed in the present study, the features and advantages of the pakage is given by *Reddy, 1986*. The numerical results are plotted in dimensionless form in comparison with the experimental results.

The governing equation (1) of seepage flow is solved using Finite Element Method The flow domain is discretisized into triangular finite elements fig.(4), connected at a finite number of nodes. An equation is formulated for each element and an assemblage of equations for the global domain is presented such that the continuity of head is ensured at each node where the elements are connected.. The system of algebraic equations is solved simultenously subjected to the imposed boundary conditions at predefined nodes for the nodal heads as the independent variables. In the present study three noded triangular elements are used to discrete the domain. The well known shape functions and variational methods of the finite element technique are presented. over each element domain which forms the basis of the finite element model of the basic differential equation(1). If Φ is approximated by the expression:

$$\phi = \sum_{j=1}^{n} \phi_j \psi_j \qquad (9)$$

Where: Φ_j: are the values of Φ at any point (x_j, y_j).
Ψ_j: are linear interpolation functions
n: number of the nodes in the finite element grid.
Then, the following element equation can be obtained:

$$[k^e]\{\phi^e\} = \{f^e \qquad (10)$$

where

$[k^e]$: the element conductance matrix
$\{f^e$: the element flux vector
$\{\phi^e$: the element nodal potential head vecto

The assemblage of eq.(10) over the entire domain leads to the global system of equations

$$[K]\{\phi\} = \{F\} \tag{11}$$

As the location and the shape of the phreatic surface are apriori unknown in the present problem, as in all phreatic seepage problem, and their determination constitutes part of the required solution, this complication can be overcome by an iterative procedure with an initial estimate for the location of the phreatic surface. Equation (11) is solved for the prescribed nodal boundary conditions to give the solution in terms of nodal head values and mean element flow velocity.

In the present study, the following data are required as input data for the computer program; the element type, the number of nodes per element, the problem type, the mesh generation, the number of elements in the mesh, the number of nodes in the mesh, the conductivity matrix, coordinates of nodes, soil conductivity, the specified boundary conditions. The tile drain is presented by four noded square element lie around the drain have a constant value of the head measured from the datum according to vertical position of the drain The following output data are obtained; final phreatic surface profile by using the interative procedure until the difference between the new height of any point at the phreatic surface and its previous value is less than a certain value, final hydraulic head at every node of the domain (mesh) (Φ), the uplift pressure distributions under the lining (U), element velocity component (v_x , v_y) and the drain discharge (q).

6. Comparative Study Analysis:

The numerical results of the FEM model in the present study is compared with the measured experimentally by using the Hele – Shaw model. Experimental readings and measurments in comparison with those of corresponding numerical results are shown in Figs. (5) through (8). A favorable agreement is obtained between experimantal and numerical results. From the figures, it can be noticed that greatest difference between numerical results and experimental readings is above the tile drain. This difference may be due to the drain entrance losses in experimental which is neglected in the numerical model. Maximum difference between numerical results and experimental readings is within the range of 10-15%. The comparison between numerical results and experimental readings can be classified according to the parameter variations as follows:

(i) ***Effect of relative horizontal position of the drain (X/B):*** in this part of comparison the value of relative drain diameter (d/B) is kept constant and equals 0.02, relative horizontal position of the drain (X/B) at Y/B=0.0, H/B=0.75 and d/B=0.02. are 0.625, 0.875, 1.125 and 1.625. The maximum difference, for different values of relative horizontal position of the drain (X/B, between numerical and experimental readings of phreatic surface profile, uplift pressure values under the lining and relative total uplift pressure (U/U_0) for different values of (X/B) reaches about 6.5%.and ranges from 10.40% to 2.60%, Figs(5-6).

(ii)***Eeffect of Relative Head (H/B)*** :in this case of comparison the relative horizontal position of the drain X/B is kept constant (X/B=0.875) and the value of relative drain diameter (d/B) equals 0.02. The value of relative head (H/B) is changed as H/B=0.75, 0.625, 0.5 and 0.375. The results show the comparison between numerical results and experimental readings of phreatic surface profile and uplift pressure distributions under the lining. The maximum difference between the numerical results and corresponding experimental readings of phreatic surface profile, uplift pressure values under the lining and relative total uplift pressure (U/U_0) ranges between 12% and 8.0%, Fig.(7-8).

7. Analysis of Results

The experiments conducted in the present study are mainly to determine the phreatic surface location behind the lining, uplift pressure distributions under the lining, total uplift pressure (U) under the lining, drain discharge (Q), vertical component of the effective length of the side lining (a_v) . The experimental results are plotted in the form of dimensionless curves and analyzed.

The experimental runs for different cases are plotted for four different values of relative head (H/B=0.75, 0.625, 0.5 and 0.375), four different values of relative drain diameter (d/B=0.0125, 0.015, 0.02 and 0.025) and sixteen different values of relative positions of the drain (X/B, Y/B). In the present study the lined canal has constant side slope 1.5: 1 and the relative vertical depth of the impervious layer under the canal bed (D/B=1.45), where B is the canal bed width.

7.1. Effect of Relative Head (H/B)

The effect of the relative head (H/B) on the seepage characteristics for different values of (H/B) while the other parameters are kept constant. Figs. (9) to (11) show the effect of relative head (H/B) on the phreatic surface location for different values of drain diameter (d/B) and relative position of the drain (X/B=0.875, Y/B=0.0) for two values of relative horizontal position of the drain (X/B=0.875 and 1.625) at Y/B=0.0, d/B=0.02 and D/B=1.625, 5-3) for two values of relative vertical position of the drain (Y/B=0.0 and -0.25) at X/B=0.875 and d/B=0.02. These figures indicate that the phreatic surface location is lowered by decreasing the relative head value (H/B) for all cases. It is clear that the maximum change in the phreatic surface location occurs near the drain. The rate of reduction in the head is increased around the drain.

Figs. (12) shows the effect of relative head (H/B) on the relative total uplift pressure (U/U_0) distributions under the lining. The obtained results indicate that the uplift pressure values under the lining decrease by decreasing the relative head (H/B) and the maximum uplift pressure value under the lining lies at the center of the canal bed.

7.2. Effect of Relative Horizontal Position of the Drain (X/B)

Fig. (13) shows the effect of relative horizontal position of the drain (X/B) on the phreatic surface location for two values of relative vertical position of the drain (Y/B=0.0 and 0.25) at H/B=0.75, d/B=0.02 and D/B=1.45. It can be concluded, from these results, that the best position of the drain should be lied as nearest as possible the canal.

Fig. (14) shows the effect of relative horizontal position of the drain (X/B) on the uplift pressure distributions under the lining for two values of its relative vertical position, from the figure, it can be noticed that the maximum uplift pressure under the lining lies at the center of the canal bed. Fig. (15) shows the effect of the relative horizontal position of the drain (X/B) on the relative total uplift pressure (U/U_0). It can be concluded that the relative total uplift pressure (U/U_0) is increased as the drain far from the canal. The drain should be as close as possible to the canal.

Figs. (16) shows the effect of relative horizontal position of the drain (X/B) on the relative drain discharge (q/KH). It can be concluded that the best location of the drain should be lied as nearest as possible of the canal bed.

7.3. Effect of Relative Vertical Position of the Drain (Y/B)

The effect of relative drain vertical position (Y/B) is studied with all other parameters are kept constant. Fig. (17) shows the effect of relative vertical position of the drain (Y/B) on the phreatic surface location. It can be concluded that the drain must be lied as low as possible below the canal bed to reduce the phreatic surface levels. Figure (18) shows the effect of relative vertical position of the drain (Y/B) on uplift pressure distributions under the lining. It can be concluded that the drain must be lied as low as possible to reduce the relative total uplift pressure value (U/U_0). Fig. (19) shows the effect of relative vertical position of the drain (Y/B) on the relative drain discharge (q/KH). The figure indicates that the variation of Y/B gives a significant change in relative drain discharge for the two studied cases.

7.4. Effect of Relative Drain Diameter (d/B)

The effect of relative drain diameter on seepage characteristics is studied for different values of (d/B) while all other parameters are kept constant. Fig. (20) shows the effect of relative drain diameter (d/B) on the phreatic surface location The figure indicates that the phreatic surface location is lowered by increasing the relative drain diameter (d/B). The maximum reduction in the phreatic surface occurred over the drain. The rate of reduction is decreased with increasing the diameter of the drain. Fig. (21) shows the effect of relative drain diameter (d/B) on the relative total uplift pressure (U/U_0). The figure indicates that the relative total uplift pressure (U/U_0) is decreased by increasing the relative drain diameter (d/B). It can be concluded that the increase of the drain diameter gives an economical design of the canal lining. Fig. (22) shows the effect of relative drain diameter (d/B) on the relative drain discharge (q/KH). The figure indicates that the relative drain discharge value (q/KH) is increased by increasing the relative drain diameter value (d/B).

8. Conclusions

A solution of the problem of groundwater relief under lined canals by using tile drains has been studied. The problem was investigated by conducting experiments on a special Hele – Shaw model using motor oil as a viscous liquid. A numerical method, using a finite element method, was used to solve the problem numerically. A computer program FEM – 2D was used to compute the seepage characteristics. A favorable agreement between experimental and numerical results was obtained for seepage characteristics. From the obtained results and their discussions, the following conclusions can be listed:

- The experimental measurements showed a good agreement with the numerical results for all tested cases. Measurements of the phreatic surface profile behind the canal lined and uplift pressure distributions under the lining indicated that the most of difference between experimental readings and numerical results are less than 10%. This means that the computer program can be used to find the solution of the present problem for any boundary conditions.
- The drain should be designed for the case of maximum predicted head (H).
- It is observed that the maximum uplift pressure value under the canal lining lies at the center of the canal bed for all studied cases.
- For the same location of the drain and drain diameter, it is found that a reduction of the relative total uplift pressure (U/U_0) can be done by decreasing the relative head (H/B). The reduction equals about 80% when the drain is lied at the same level of the canal bed, while it equals about 95% when the drain is lied under the canal bed.
- For constant relative head and drain diameter, it is found that the relative total uplift pressure is decreased as the drain is closed to the canal. Therefor, the best location of the drain should be lied as near as possible to the canal.
- When the drain lies under the canal bed, the best location of the drain should be lied under the outside quarter part of the canal bed. In this case and for big drain diameters, the canal bed does not affected by any uplift pressure forces.

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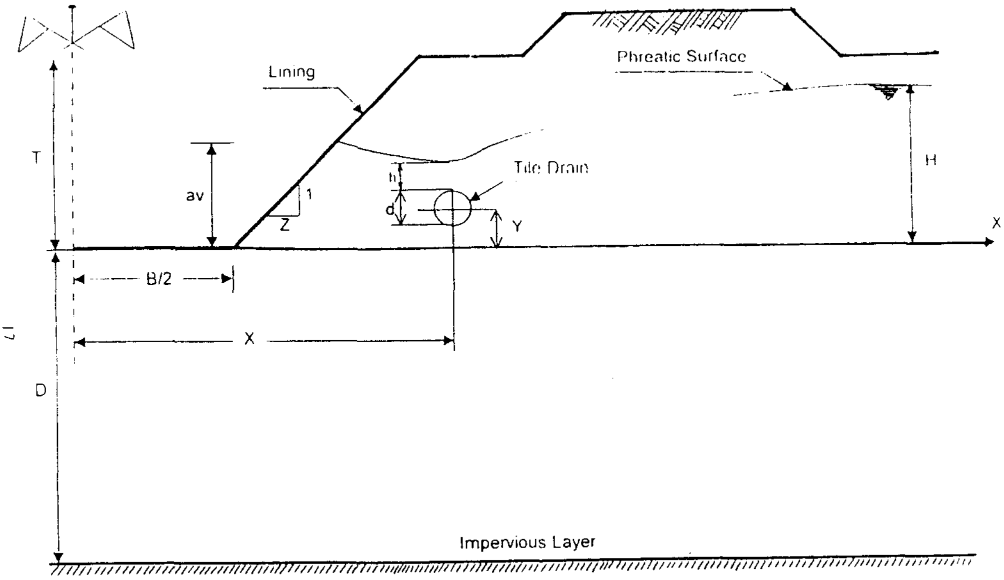


Fig. (1) Physical Model of the Problem

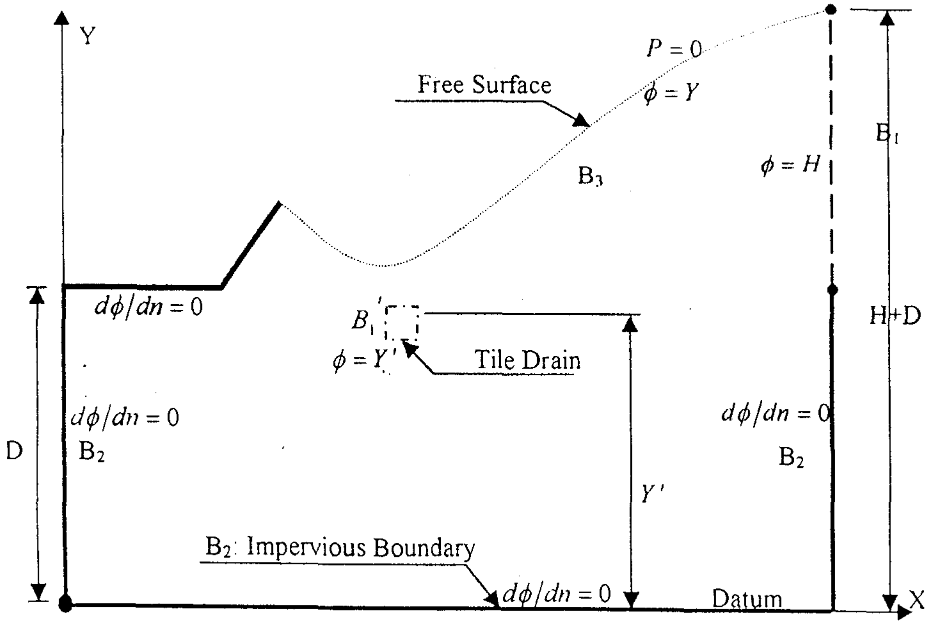


Fig. (2) Boundary Conditions of the Problem

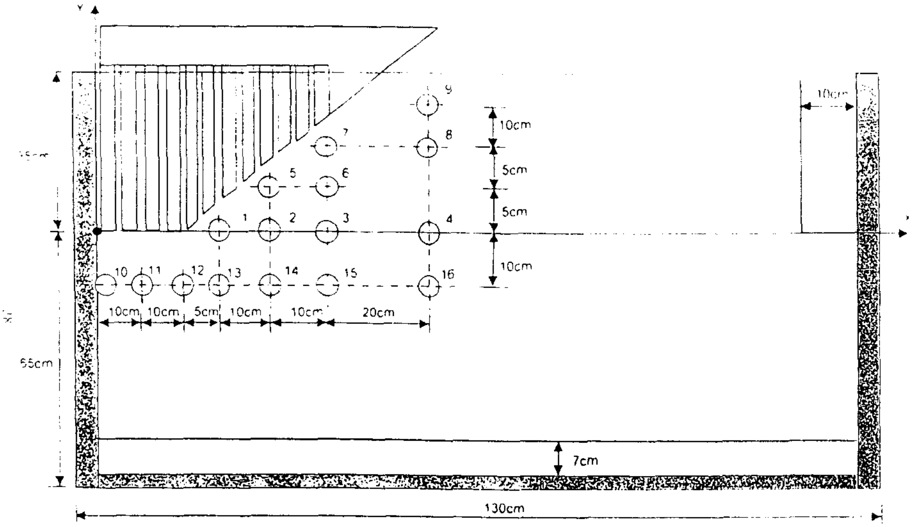


Fig (3,a) Drains Positions Distribution on the Hele - Shaw Model

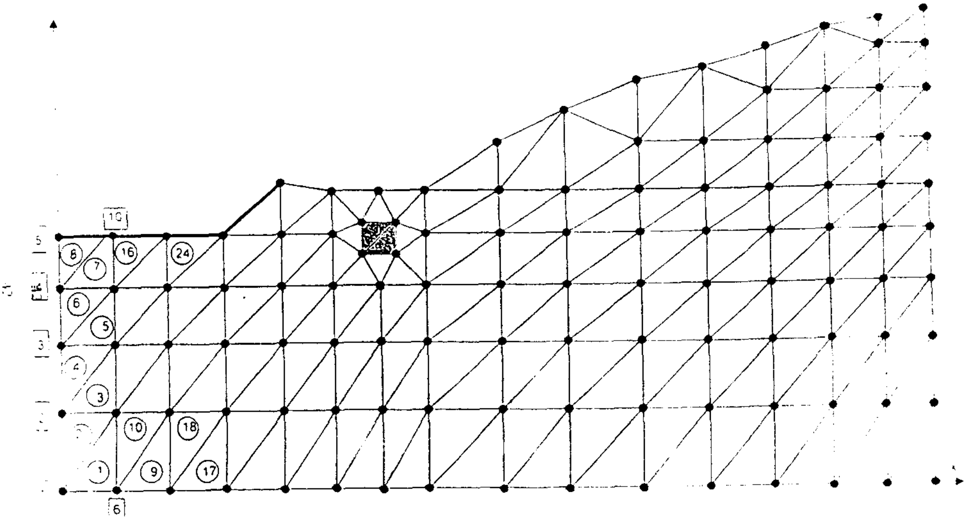


Fig (4) Finite Element Mesh of the Problem

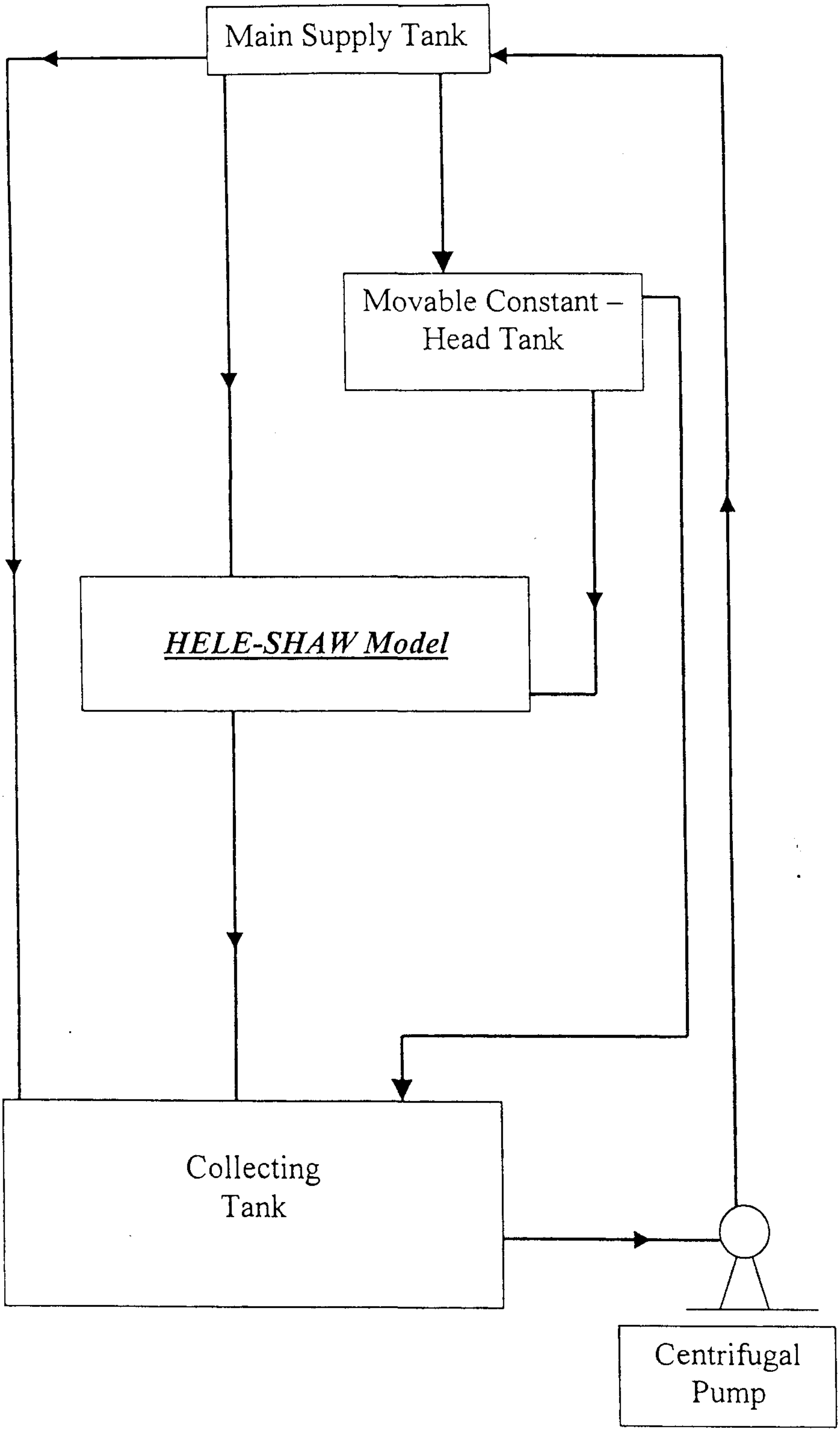


Figure (3-b): The Flow Closed Circuit

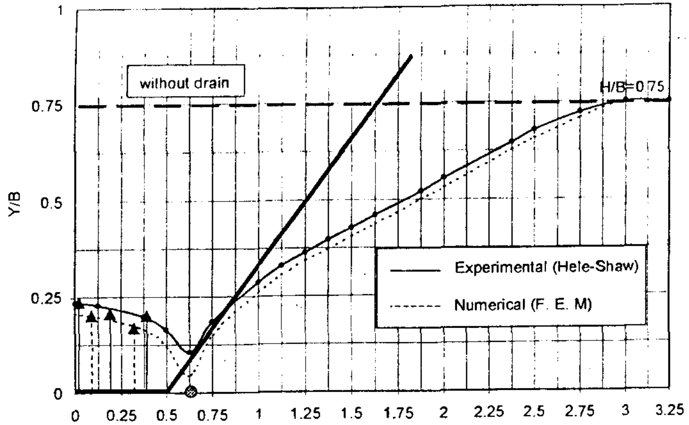


Fig. (5 -a) - X/B=0.625

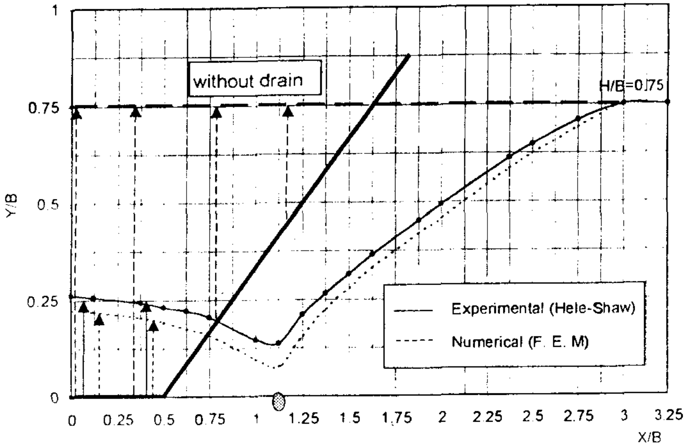


Fig. (5 -b) - X/B=1.125

Fig. (5) Comparison between Experimental (Hele-Shaw) and Numerical (F E M) Results for Different Values of Drain Horizontal Position (X/B) (Y/B=0.0 , H/B=0.75 , d/B=0.02)

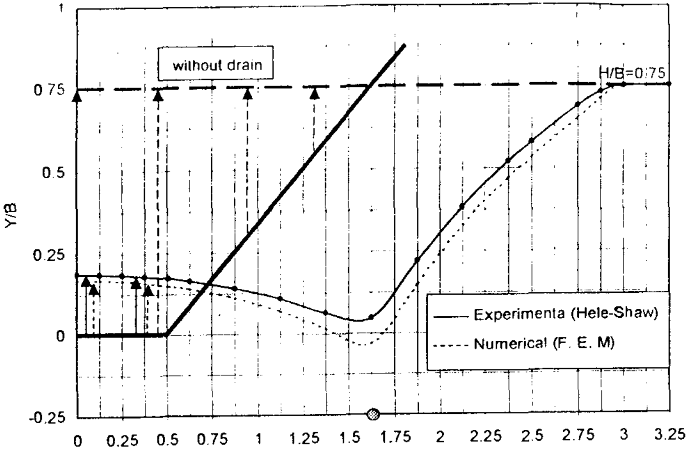


Fig. (6 -a) - X/B=1.625

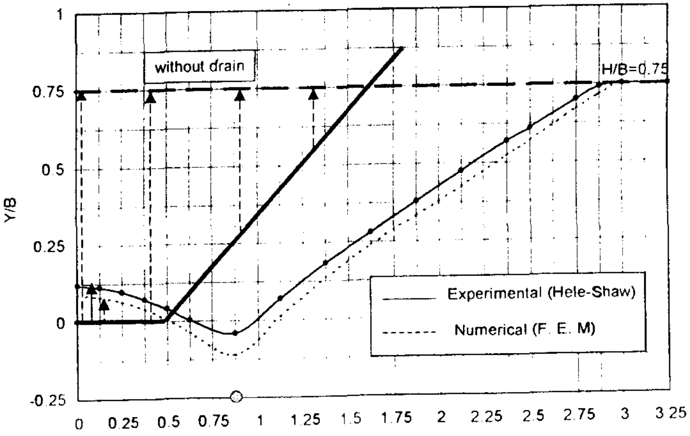


Fig. (6 -b) - X/B=0.875

Fig. (6) Comparison between Experimental (Hele-Shaw) and Numerical (F E M) Results for Different Values of Drain Horizontal Position (X/B) (Y/B=-0.25 H/B=0.75 d/B=0.02)

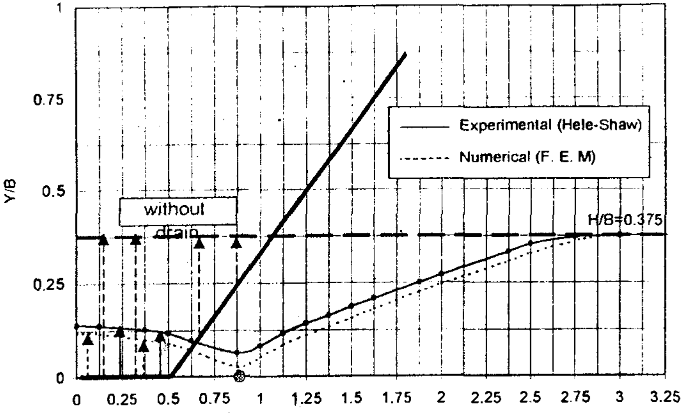


Fig. (7 -a) - H/B=0.375

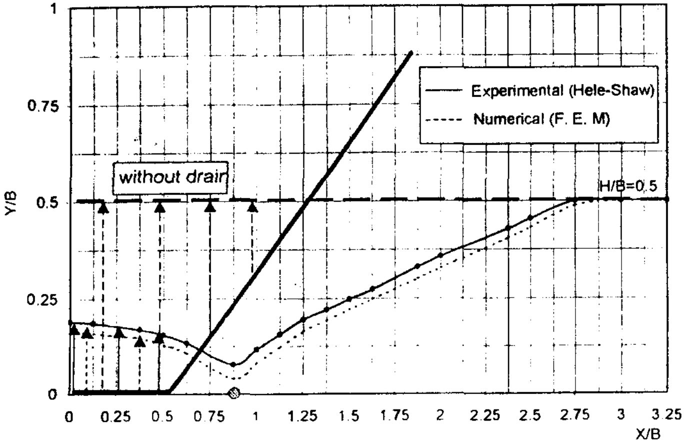


Fig. (7-b) - H/B=0.5

Fig. (7) Comparison between Experimental (Hele-Shaw) and Numerical (F E M) Results for Different Values of Relative Head (H/B) (X/B=0.875 , Y/B=0.0 , H/B=0.75 . d/B=0.02)

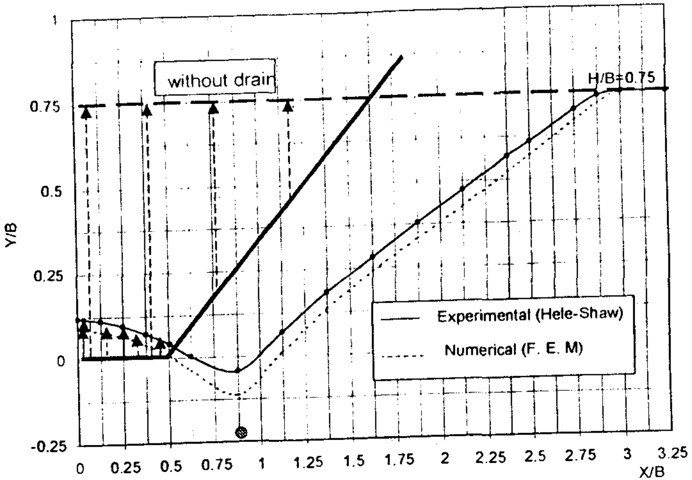


Fig. (8 -a) - H/B=0.75

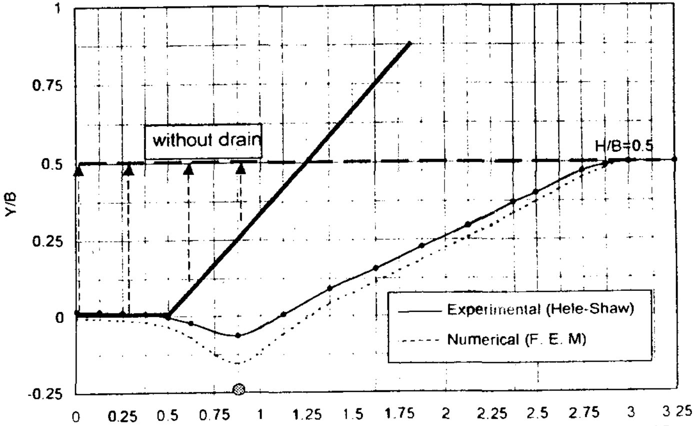


Fig. (8 -b) - H/B=0.5

Fig. (8) Comparison between Experimental (Hele-Shaw) and Numerical (F E M) Results for Different Values of Relative Head (H/B) (X/B=0.875 Y/B=-0.25 H/B=0.75 . d/B=0.02)

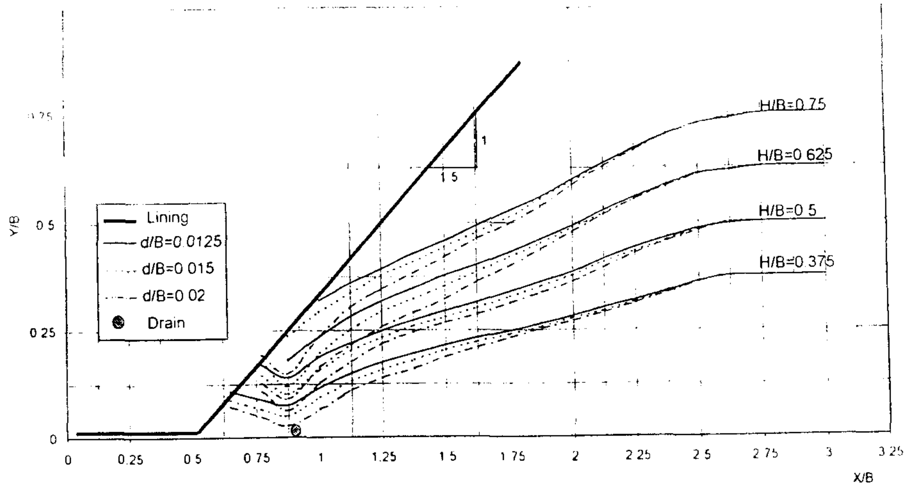


Fig. (9) Effect of Relative Head (H/B) on the Phreatic Surface Profile for Different Values of the Relative Drain Diameter (d/B) (X/B=0.875 , Y/B=0.0)

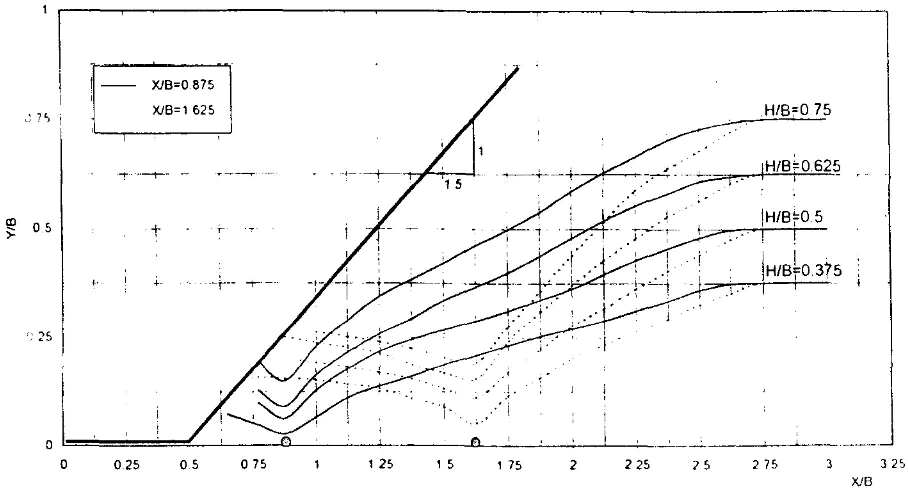


Fig. (10) Effect of Relative Head (H/B) on the Phreatic Surface Profile for Different Values of Relative Drain Horizontal Position (X/B) (Y/B=0.0 d/B=0.02)

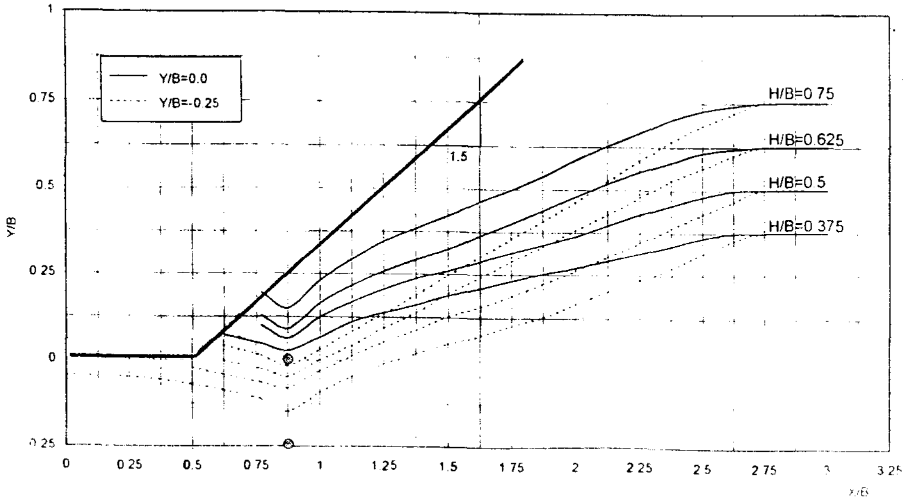
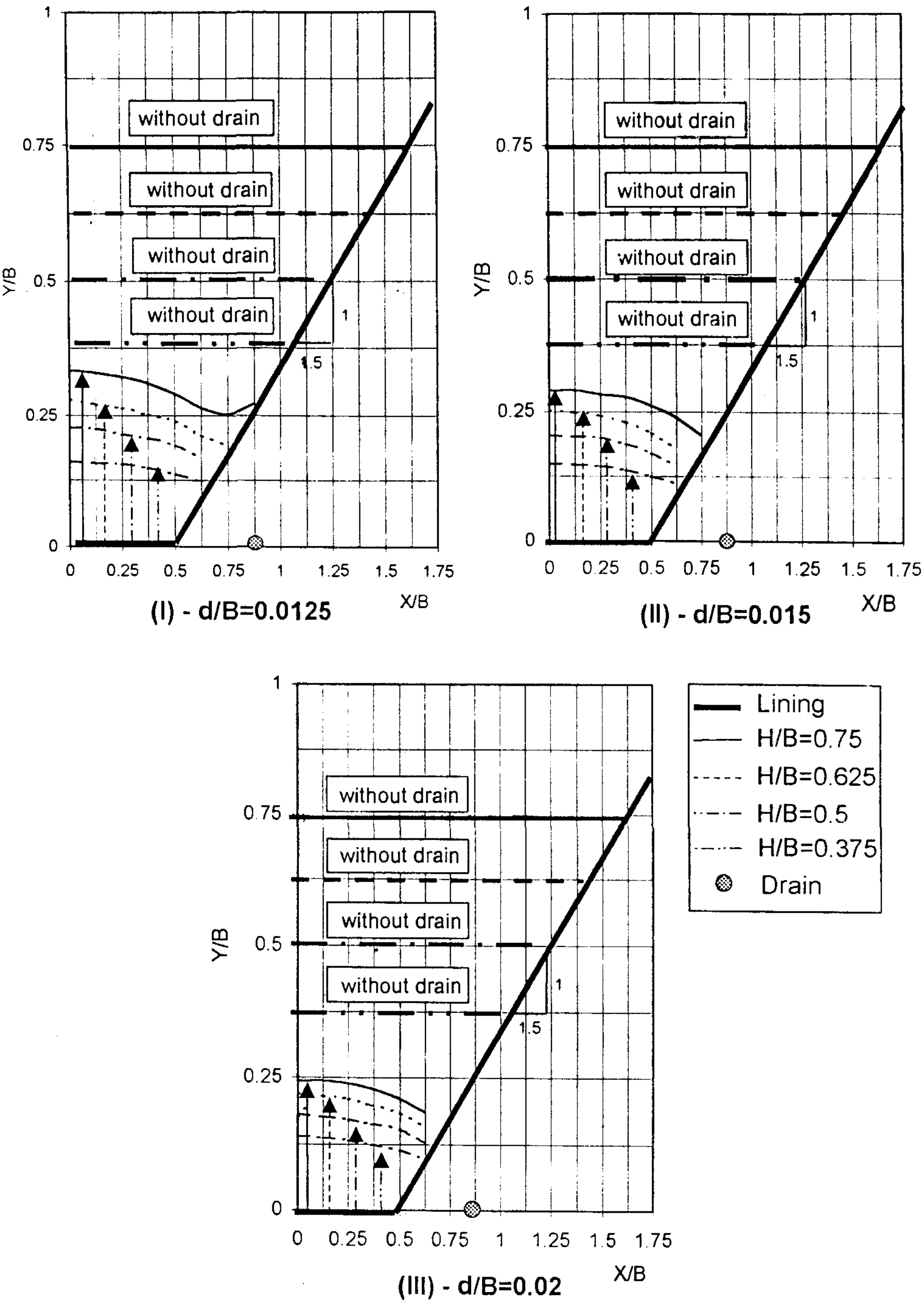


Fig. (11) Effect of Relative Head (H/B) on the Phreatic Surface Profile for Different Values of Relative [illegible]

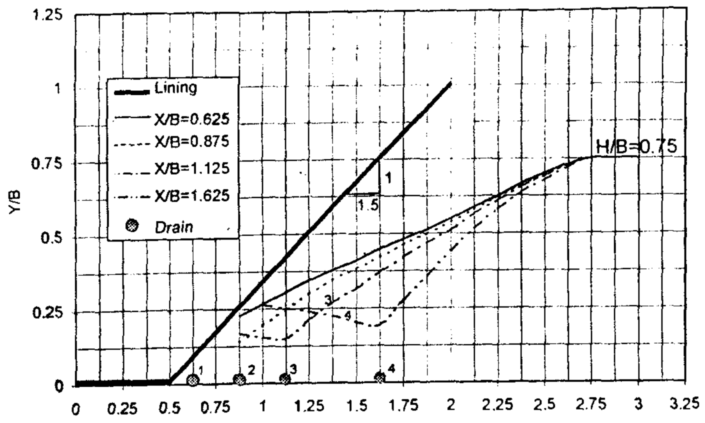


(I) - d/B=0.0125

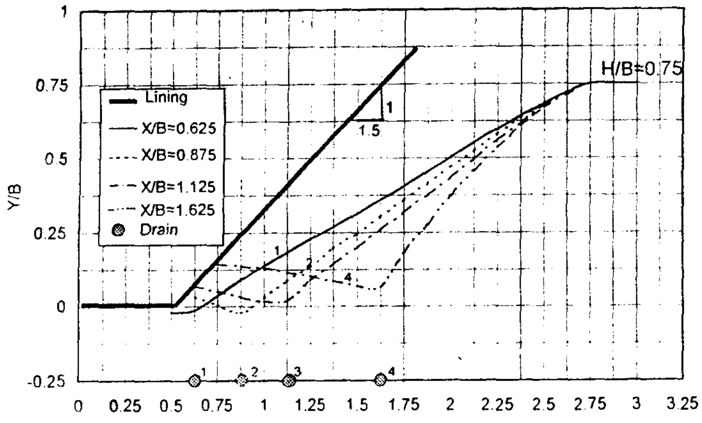
(II) - d/B=0.015

(III) - d/B=0.02

Fig. (12) Effect of Relative Head (H/B) on Uplift Pressure Distributions under the Lining for Different Values of Relative Drain Diameter (d/B) (Y/B=0.0 , X/B=0.875)

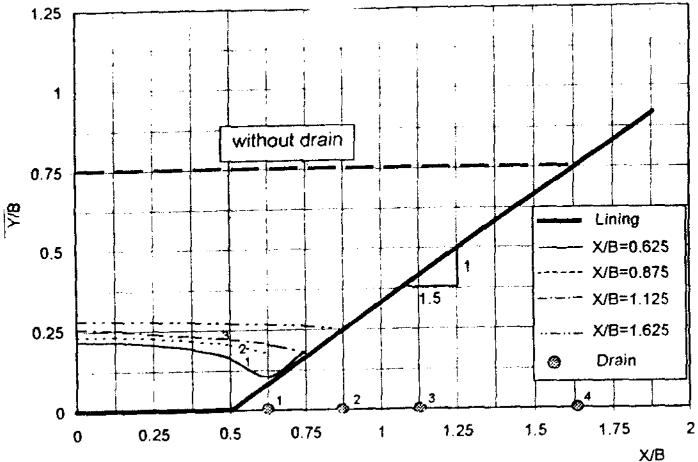


(I) - Y/B=0.0

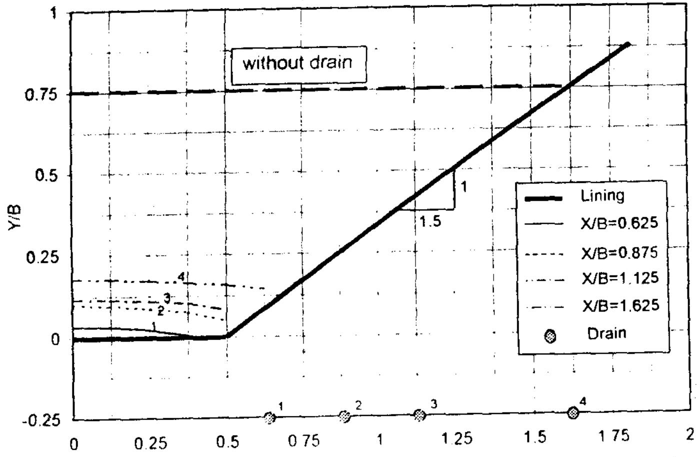


(II) - Y/B=-0.25

Fig. (13) Effect of Relative Drain Horizontal Position (X/B) on the Phreatic Surface Profile for Different Values of Relative Drain Vertical Position (Y/B) (H/B=0.75 , d/B=0.02)

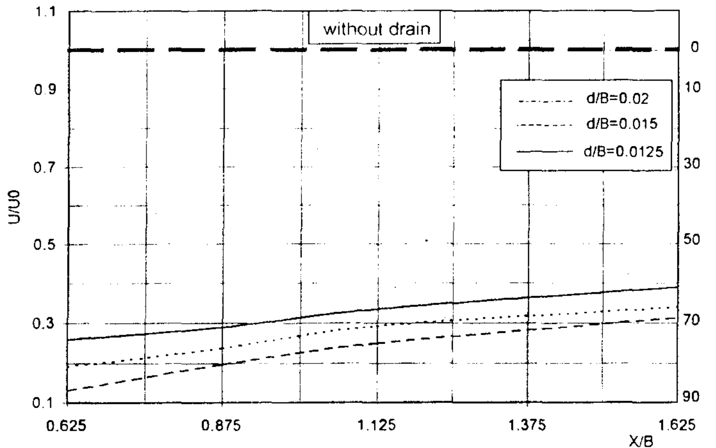


(I) - Y/B=0.0

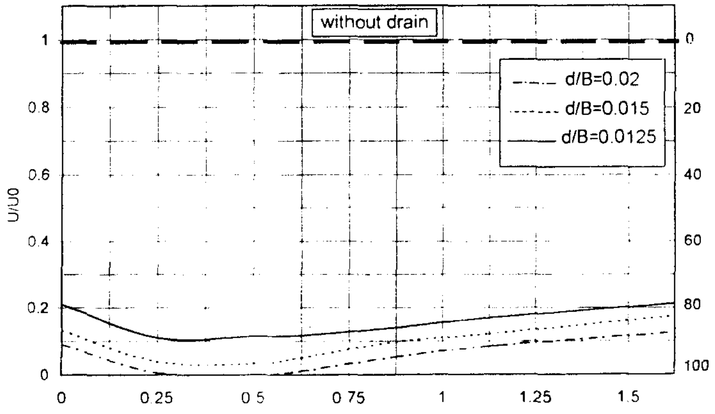


Y/B=-0.25

Fig. (14) Effect of Relative Drain Horizontal Position (X/B) on the Uplift Pressure Distributions under the Lining for Different Values of Relative Drain Vertical Position (Y/B)at (H/B=0.75 , d/B=0.02, Y/B=-0.25)

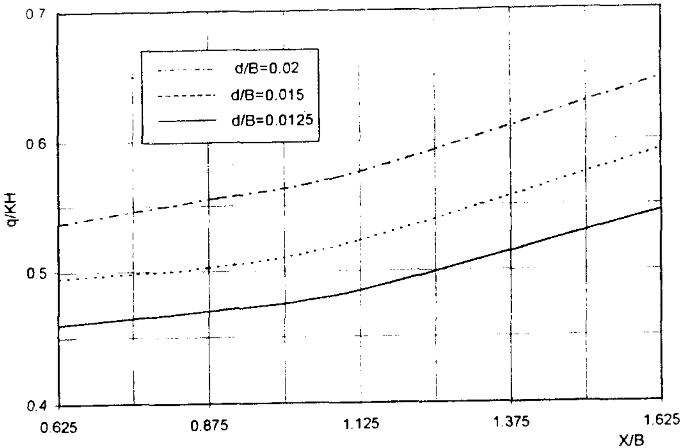


(I) - Y/B=0

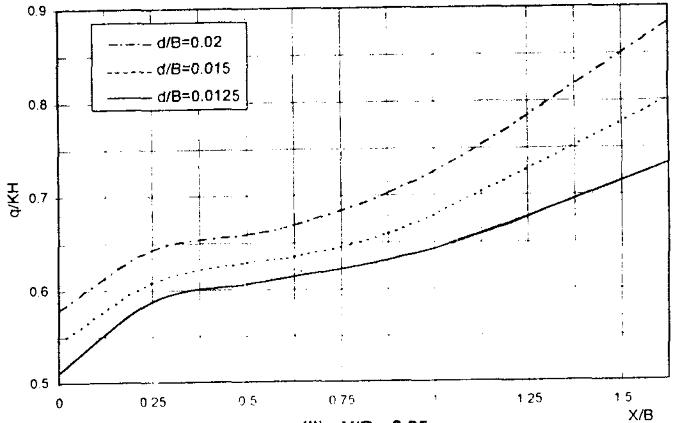


(II) - Y/B=-0.25

Fig. (15) Effect of Relative Drain Horizontal Position (X/B) on the Relative Total Uplift Pressure (U/U0) for Different Values of Relative Drain Diameter (d/B) and Relative Drain Vertical Position (Y/B) (H/B=0.75)

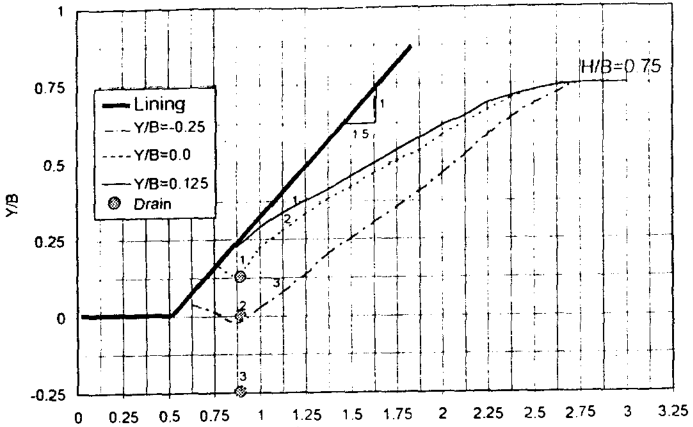


(I) - Y/B=0

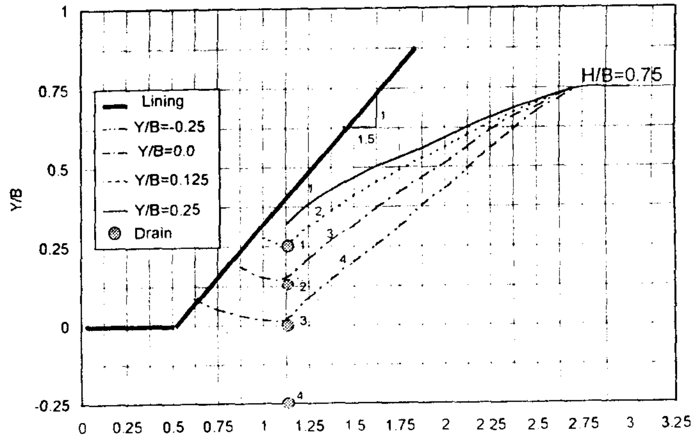


(II) - Y/B=-0.25

Fig. (16) Effect of Relative Drain Horizontal Position (X/B) on the Relative Drain Discharge (q/KH) for Different Values of Relative Drain Diameter (d/B) and Relative Drain Vertical Position (Y/B) (H/B=0.75)

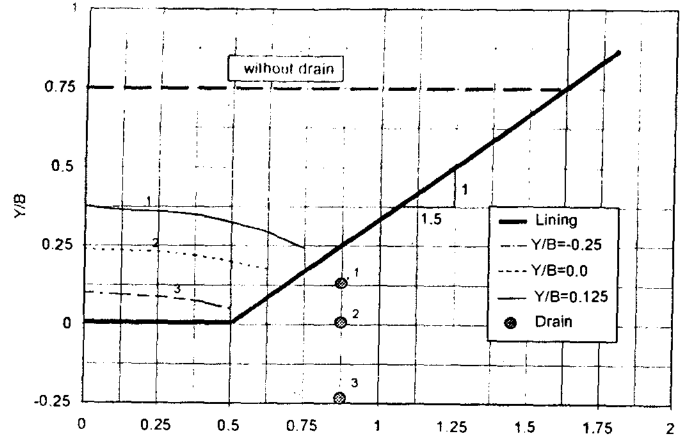


(I) - X/B=0.875

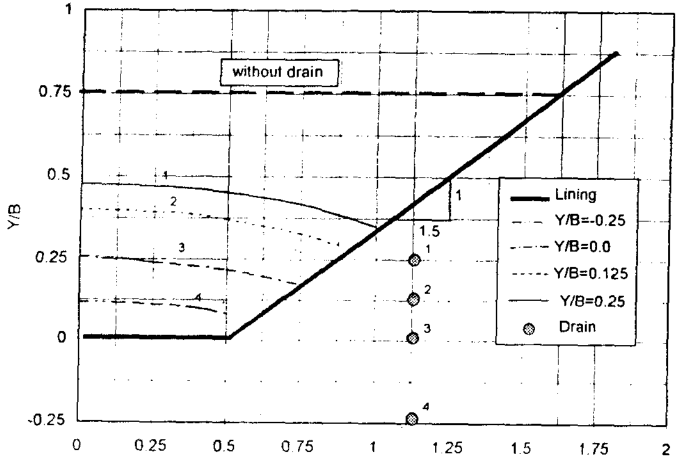


(II) - X/B=1.125

Fig. (17) Effect of Relative Drain Vertical Position (Y/B) on the Phreatic Surface Profile for Different Values of Relative Drain Horizontal Position (X/B) (H/B=0.75 d/B=0.02)



(I) - X/B=0.875



(II) - X/B=1.125

Fig. (18) Effect of Relative Drain Vertical Position (Y/B) on Uplift Pressure Distributions under the Lining for Different Values of Relative Drain Horizontal Position (X/B) (H/B=0.75 d/B=0.02)

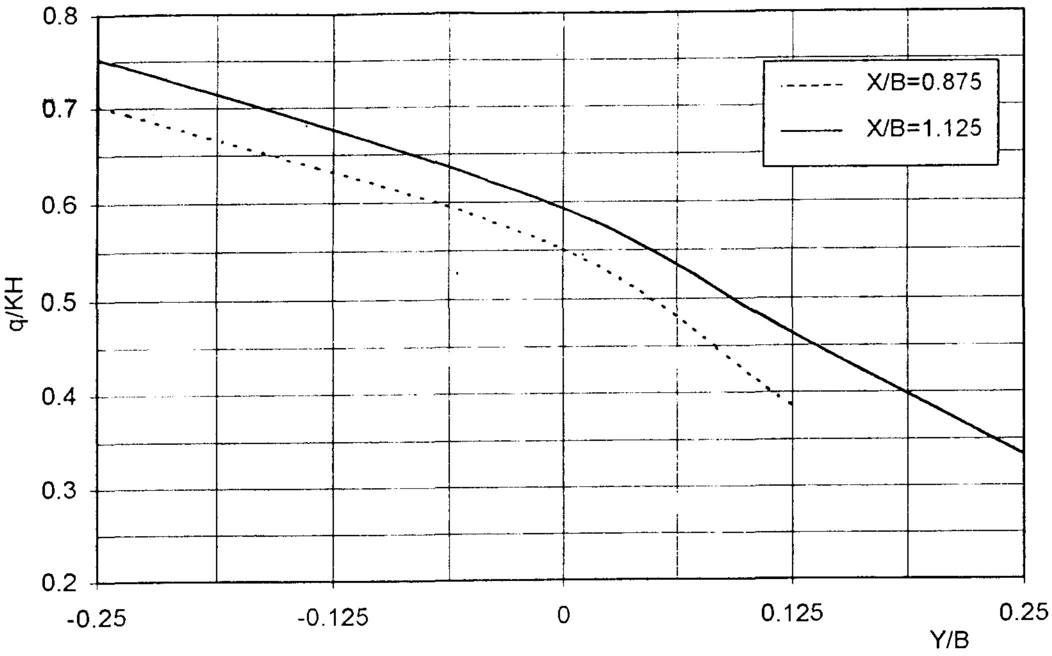
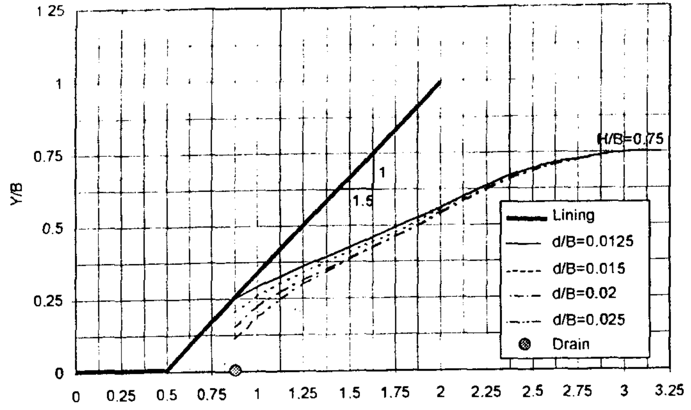
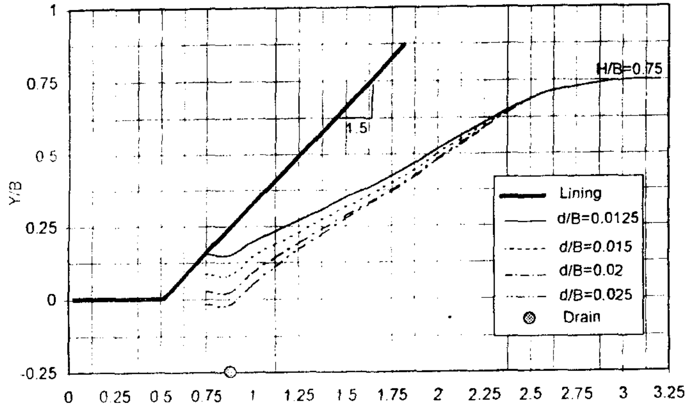


Fig. (19) Effect of Relative Drain Vertical Position (Y/B) on the Relative Drain Discharge (q/KH) for Different Values of Relative Drain Horizontal Position (X/B) (H/B=0.75 , d/B=0.02).



(I) - Y/B=0.0



(II) - Y/B=-0.25

Fig. (20) Effect of Relative Drain Diameter (d/B) on the Phreatic Surface Profile for Different Values of Relative Drain Vertical Position (Y/B) (H/B=0.75 X/B=0.875)

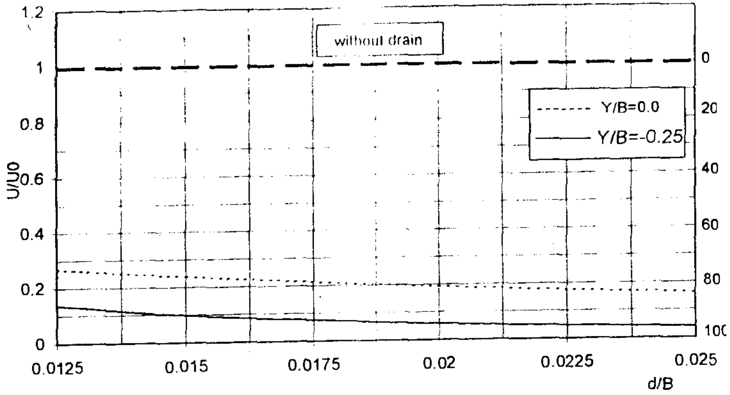


Fig. (21) Effect of Relative Drain Diameter (d/B) on Relative Total Uplift Pressure (U/U0) for Different Values of Relative Drain Vertical Position (Y/B) (H/B=0.75 , X/B=0.875)

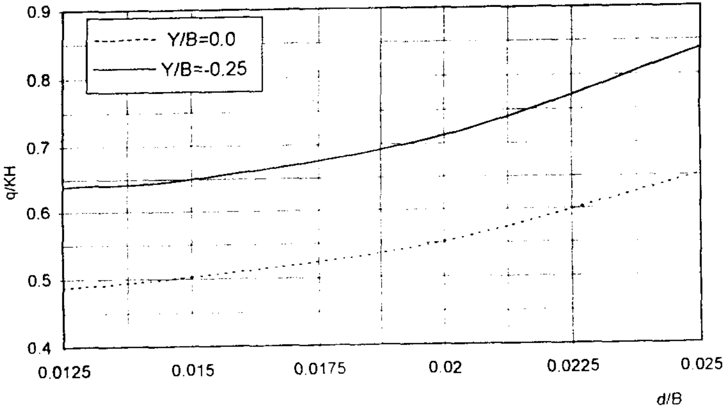


Fig. (22) Effect of Relative Drain Diameter (d/B) on Relative Drain Discharge (q/KH) for Different Values of Relative Drain Vertical Position (Y/B) (H/B=0.75 X/B=0.875)