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THREE DIMENSIONAL FINITE ANALYSIS OF SEEPAGE AROUND HEADING UP STRUCTURES

تحليل ثلاثى الأبعاد بطريقة العناصر المحددة للتسرب حول منشآت الحجز

BY

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خلاصة

تقام المنشآت الهيدروليكية على المجارى المائية حيث ترتكز أساساتها على تربة تأسيس تكون فى معظم الأحوال تربة رسوبية منفذة، مما يستلزم أن يتم التصميم بدقة لتقاوم جميع القوى التى تؤثر على سلامتها وإتزانها خاصة تلك الناتجة من تأثير سريان المياه أسفل وحول المنشأ وما يصاحبها من آثار جانبية قد تتسبب فى إنهياره. وتتولد هذه القوى نتيجة فرق المنسوب بين الأمام والخلف وتشمل قوى الضغط أسفل الفرشة والقوى الناتجة عن الميل الهيدروليكى عند المخرج على قاع وجوانب المجرى. وتعتمد معظم الطرق الحالية فى تصميم المنشآت الهيدروليكية على أن التسرب الناتج ثنائى الأبعاد، أى أسفل المنشأ فقط، مع إهمال تأثير التسرب الجانبى حول المنشأ والذى يجعل التسرب عمليا ثلاثى الأبعاد، وقد تؤدى هذه الطرق الى تصميم غير آمن قد ينتج عنه إنهيارات خاصة أمام المنشآت التى تتميز بفرق توازن كبير مثل محطات الرفع. لذا فالهدف من دراسة هذا البحث هو التحكم فى تسرب المياه أسفل وحول المنشآت الهيدروليكية بإعتبار التسرب ثلاثى الأبعاد ويتم التحكم إما بإستخدام الحوائط الراسية الغير منفذة للمياه أو بإستخدام المرشحات الجانبية ذات النفاذية العالية نسبيا وتستخدم طريقة العناصر المحددة كطريقة عددية للحل.

ABSTRACT:

Hydraulic structures´are commonly constructed on pervious soils through which seepage flow occurs and finds its way to the foundation. Most damages occur in a hydraulic structure may be attributed to the destructive effect of seepage. Design of hydraulic structures must include the analysis of the seepage flow beneath and around the structure with particular attention to the induced uplift forces, hydraulic gradients at the exit faces, water pressure on side walls and expected total seepage discharge. Most of researches deal with the the problem of seepage regards hydraulic structures as a two dimensional problem. Recent studies cope with three dimensional analysis including seepage around the structure to that occurs beneath the structure. Practically the seepage occurs beneath and around the hydraulic structure, therefore, the lateral seepage is a significant item and should be taken into consideration. The present study aims at controlling the seepage around a water retaining structure which has a horizontal floor provided with a single under floor cut-off. Two suggested control systems have been investigated, a lateral cut-off wall and a lateral relief filter. The problem has been investigated numerically as a three dimensional problem using the Finite Element Technique.

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KEYWORDS

Hydraulic structure, seepage, ground water, uplift pressure, Finite Element Method, cut-off walls, lateral filter, exit gradient, seepage discharge.

1. INTRODUCTION

The stability of hydraulic structures has to be insured against the effect of seepage characteristics. The design of such structures must include the analysis of seepage flow beneath and around the structure with particular attention to the induced uplift forces, hydraulic gradients at exit faces, water pressure on side walls and expected total seepage discharge. Many researches were carried out for studying the effect of seepage under structures as a two-dimensional flow only ignoring the effect of lateral seepage around the structure. Examples of actual field problems which demonstrate the importance of considering the lateral seepage and hence the use of three-dimensional analysis in the hydraulic design of hydraulic structures are Edko Pumping Station, and El Nasr Canal Pumping Stations at the west of Egypt.

In 1984, seepage problems started around Edko pump station, which pumps the drainage water from Edko drain to Lake Edko, by forming a longitudinal hole of 1.0 m diameter in the right upstream embankment. As a solution, concrete sidewalls were constructed upstream the station to prevent the side seepage effect. More deterioration occurred with almost a total collapse of the left bank. In 1994, the problem showed up again at the left bank pitching. Separation between walls of the station and entrance and exit embankments occurred accompanied by piping with sand loaded water issuing from the left bank. Appreciable settlement of lining panels at left side embankment in the suction side has been observed.

In 1982, the severe exit gradients at suction side of El Nasr Canal Pumping Stations, five pump stations along the canal, have led to lining failure and contributed to the instability of side slopes. Tunneling behind the concrete lining was reported. Also, a high uplift pressure on the lining may have caused its displacement and failure. A grouting with bentonite-cement mixture was used to reduce the soil permeability around the pumping stations. Moreover, a new earth canal was constructed on the left side, parallel to the existing one.

The present study aims at giving a practical solution for the control of the destructive effect of side seepage around hydraulic structures using either cut-off walls or lateral relief filters.

2. THE STATE OF THE ART

Control of seepage involves reducing the seepage flow and water pressure, or increasing the gravitational load that resists the water pressure. Two successful systems to control seepage are generally employed; either cutoffs constructed of impervious material or steel sheet piling or filter which acts as a device to accelerate the passage of water through it. The solution of seepage problems are based mainly on the well known Laplace equation and Darcy's law, Harr, 1962, (7), Bear ,1987,(3). The methods of solution for confined seepage problems can be classified as; empirical methods, approximate methods, experimental methods, analytical methods, and numerical methods. Empirical methods depend mainly on the experience in formulating a relationship between the percolation length and the uplift pressure as given by Bligh,1910, and Lane,1932,(9). Approximate methods depend mainly on solving the problem graphically using a net of stream lines and equipotential lines as given by Forchheimer, 1924,(2) and Pavlovsky, 1935,(7) .The aferomentioned methods are restricted to simulate two-dimensional steady seepage problems with simple boundary conditions.

Among the various types of experimental models which are used for studying seepage problems 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. Two dimensional seepage beneath hydraulic structures are simulated experimentally by using; Hele–Shaw model by Nasr, 1987, (11), Abo- Rehim, 1991,(1); sand model by Gewily, 1992, (5). Three dimensional electric models to study the characteristics of seepage around and beneath hydraulic structures were used by Nasr, 1995,(12), 1996(13), and Haszpra et al, 2001,(15). Analytical methods mainly depend on the conformal mapping technique clearly presented by Harr,(7), in which the obtained solutions for seepage problems satisfy both Laplace equation and the particular boundary conditions. Solutions for seepage beneath hydraulic structures employing conformal mapping are given by Hathoot, 1986,(8), Nasr, 1997,(14), and Salem and Ghazwa, 1999,(16).

The feasibility of numerical techniques, mainly the well established finite element method, finite difference method, and the boundary 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. Application of numerical techniques for confined seepage problems beneath hydraulic structures are treated as two-dimensional problem by Zienkiewicz , 1971, (19), Hendrix et al, 1991,(18) and as three-dimensional steady seepage problem employing the finite element program SWICHA by Shuluma, 1995, (17), El Dakak, 2002, (4), and Ghoraba, 2002, (6).

3. STATEMENT OF THE PROBLEM

Seepage around hydraulic structures can be controlled by using impervious lateral cut-off walls or lateral relief filter. Figure (1) shows simplified physical models for the two studied solutions. The effect of both cut-off walls and lateral filters dimensions and positions have been studied as a 3-D seepage problem. The studied hydraulic structure is assumed to be symmetrical about the vertical plane through the centerline of the waterway. The structure is assumed to be a solid block of length L and width E, and it is provided with a single under floor cut-off of Depth D at distance L_1 from the upstream edge. The structure is founded on a homogenous isotropic soil with a limited depth M and its floor is penetrated the founded soil with depth t. The maximum effective water head acting on the structure is assumed H. The lateral cut-off wall, Fig.(1-a) has a total depth Ds and it penetrates the canal bed by a depth ds. The lateral cut-off wall has a total length L_s for one side and it is constructed at distance L_1 measured from the upstream edge of the structure. Regards the lateral vertical relief filter, Fig.(1-b), it has a total depth D_f measured from the upstream water level. The filter has a total horizontal length L_f and it is constructed at distance L_{1f} from the upstream edge of the structure. The filter has a local effective head H_o that is measured from the canal bed level. The following main assumptions are considered: i) The pervious foundation layer is homogeneous, symmetrically isotropic, and physically stable, i.e. the hydraulic conductivity, k, is constant everywhere, ii) The soil considered in the study domain is fully saturated, iii) The seepage flow is steady, Darcian, incompressible and isothermal, iv) The canal idealization is rectangular with the same bed level in both upstream and downstream, and v) the material of the cut-off wall is impervious, i.e. k=0.0, while the permeability for the filter material is taken as 100 times the permeability of the soil. Considering the previous assumptions and combining the equations of continuity and the velocity potential for three dimensional flow, one obtains the well known Laplace equation for ideal irrotational three dimensional steady flow through homogeneous isotropic media, Harr (7),

$$\nabla^2 h = \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = 0 \qquad (1)$$

In which:

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

where

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

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 which is solved throughout the flow domain subjected to the following boundary conditions:

1. ***Prescribed Head Boundary:***

At the inlet surface of the hydraulic structures where: h = H,
at the exit surface of the hydraulic structure where: h = 0.0, and (3)
at the lateral relief filter where: $h = H_o$

2. ***Prescribed flux Boundary:***

The velocity component normal to the boundary at any point are assumed to be vanished ,i.e., $\frac{\partial h}{\partial n} = 0.0$,where n is the normal direction to the boundary, across the following boundaries:

- The contact boundary of the structure, floor and wall.
- The vertical plane of symmetry, coinciding with the centerline of the canal.
- An impervious horizontal layer at a depth M from the bottom of the canal.
- Upstream and downstream vertical lateral planes which are assumed at distances equal 5.5 L from the solid edges of the structures.
- Assumed longitudinal vertical planes, parallel to the vertical plane of symmetry.
- An impervious cut-off walls under the structure with depth D and width E, and a lateral cut-off wall with depth D_s and width L_s.

3. ***Phreatic surface Boundary:***

The pressure at any point along the phreatic surface around the hydraulic structure is atmospheric as capillary fringe is neglected, i.e. the pressure, p=0, this reduces Eq.(2) to:

$$h(x,y) = y \qquad (4)$$

4. NUMERICAL MODELING USING FINITE ELEMENT METHOD

The problem of control of seepage beneath and around hydraulic structure by using lateral cut-off or relief filter is studied numerically in the present study by using the finite element method, and the flow is characterized as unconfined flow around the structure and confined flow beneath the structure floor. The main purpose of the mathematical problem is to determine the seepage characteristics. The finite element method is used in the present study as a three dimensional problem, considering all boundary conditions of the problem. The governing equation (1') of seepage flow is solved employing the Finite Element model SWICHA in the present study, the features and advantages of the pakage is given by Lester, 1991, (10). The SWICHA code incorporates both the saturated fluid flow and the single species solute transport models.

The flow domain is discretisized into eight noded isoparametric finite elements, connected at a finite number of nodes, with total number of nodes ranges from 4185 to 6045 and total number of elements ranges from 3780 to 5040 according to cases of study. 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. 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 h is approximated by the expression:

$$h = \sum_{j=1}^{n} h_j \psi_j \tag{9}$$

Where: h_j: are the values of h 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:

$$\left[k^e\right]\left\{h^e\right\} = \left\{f^e\right\} \tag{10}$$

where

$\left[k^e\right]$: the element conductance matrix

$\left\{f^e\right.$: the element flux vector

$\left\{h^e\right.$: the element nodal potential head vector

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

$$[\mathrm{K}]\{h\} = \{\mathrm{F}\} \tag{11}$$

As the location and the shape of the phreatic surface are apriori unknown in the present problem, as in all phreatic seepage problems, 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;

i) System geometry includes 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, coordinates of nodes.

ii) Porous medium properties include the conductivity matrix, soil conductivity,

iii) Boundary conditions include the specified nodal head and flux boundary conditions

The output for the computer program includes nodal head values as dependent variables and element centroidal values of Darcy's velocity components as independent variables can be obtained if required.

The following computational procedures are followed in the solution:

- The dimensions, boundary conditions and medium properties for each element in the domain are prepared for each case of study.
- The finite element mesh is arranged.
- The phreatic surface profile is assumed as a horizontal plane at the first run, and the nodal head values are obtained for each node according to the program formatting.
- To get the actual phreatic surface successive iteration procedure is adopted.
- For each run, the elements having values of head less than elevation are eliminated. This process was repeated until the difference between head and elevation along the phreatic surface lies within a specified tolerance limit.

4.1. Verification of the Numerical Model:

The numerical results of the SWICHA model were verified using the experimental results of two 3-D problems. Nasr, (12), studied experimentally the 3-D seepage around a tail hydraulic structure founded on a finite pervious stratum, using a three dimensional electric analogue model with the following relative dimensions, $L_c/L=3.0$, $T/L=1.6$, $M/L=1.5$, $t/L=0.085$ and $E/L=2.0$. Nasr, (13), studied also the effect of lateral relief filter as a control system os seepage around a hydraulic structure with a single cut-off, constructed near a branching point of channel, Fig.(2), using the 3-D electrical analogue model with the relative dimensions, $L_f/L=2$, $D_f/L=0.4$, $H_f/L=0.25$, $D/L= 0.4$, $E/L=2.0$, $t/L=2.0$, $t/L=0.085$, $L_{1f}/L=0.1$, $M/L=1.5$ and $L_c/L=2.0$. Ground water contours around the structure and piezometric heads underneath its subsurface in comparison with those of the experimental results are plotted in dimensionless forms in Fig.(3). From the comparison between the numerical and experimental results, it can be concluded that the 3-D finite element model is fairly accurate and suitable for the study of the current 3-D problem.

5. PARAMETRIC STUDY

The present study covers a practical range of parameters of the two studied cases and the results are presented in dimensionless form in terms of relative cut-off depth under the structure D/L, relative total depth of lateral cut-off wall, D_s/L, relative penetration depth of the lateral cut-off wall under the canal bed level d_s/L, relative distance of the wall from the upstream edge of the structure L1/Land the relative lateral cut-off wall length L_s/L for the case of lateral cut-off wall, and in terms of relative vertical filter depth D_f/H, relative filter head H_o/H, relative filter length L_f/L and relative distance of the wall from the upstream edge of the structure L_{1f}/L, Fig.(1). The considered seepage characteristics are:

- Relative piezometric head values underneath the subsurface contour of the structure's floor, h/H.
- Ground water levels and their variations around the structure.
- Relative exit velocity gradients along downstream bed and sides.
- Relative quantity of seepage discharges underneath the structure, and around the structure, side discharge.

For the case of lateral cut-off wall the dependant relative variables were chosen for a practical range as follows, Fig.(1-a): $D/L=0.0$, 0.25, 0.5, 0.75 and 1.0; $D_s/L= 0.0$, 0.04,0.12, 0.2, 0.2+d_s and 0.45; $d_s/L=$ 0.0, 0.25,0.5, 0.75 and 1.0; L_l/L=0.0, 0.25,0.5, 0.75 and 1.0; L_s/L=0.0, 0.5,1.0, 1.5 and 3.0, and the values of H/L=0.2, E/L=0.2, T/L=1.6, M/L=1.5 and t/L=0.085 are kept constant for all runs.

For the case of lateral relief filter wall the dependant relative variables were chosen for a practical range as follows, Fig.(1-b): D_f/H=1.0, 0.8, 0.6 and 0.4; H_o/H= 0.0, 0.2, 0.4, 0.6 and 0.8; L_f/L= 0.5, 1.0, 2.0 and 3.0; L_{1f}/L=0.0, 0.25,0.5 and 1.5 and the values of H/L=0.2, E/L=0.2, T/L=1.6, M/L=1.5, D/L=0.25, L1/L=0.25 and t/L=0.085 are kept constant for all runs.

6. ANALYSIS OF RESULTS FOR CASE OF LATERAL CUT-OFF WALL

For this case the effect of the relative dimensions of the lateral cut-off wall, the relative depth of cut-off wall under the structure, the cut-off relative position, relative exit gradients and relative discharges are considered in the following sections.

6.1. Effect of under floor cut-off relative depth (D/L)

The relative piezometric heads under the structure's floor are plotted in form of equipotential lines on the subsurface plane of the floor as shown in Fig.(4). Relative piezometric heads diagrams are plotted along both the centerlines and the side edge of the floor as shown in Fig.(5). It can be noticed that the increase of relative under floor cut-off depth (D/L) causes an increase in the relative piezometric heads under the floor (h/H) upstream the cut-off position, while the pressure values are decreased downstream the cut-off. Along the centerline of the structure, the increase in the value of D/L from 0.0 to 1.0 causes a reduction in the value of h/H, just downstream the vertical cut-off by 52.2%, while the same range causes along the side edge of the structure a decrease in h/H at the downstream of the cut-off by 23.7%. The results indicate that the relative piezometric head (h/H) for 2-D and 3-D are very close. Fig.(6) shows the ground water contours around the studied structure, which are plotted as fractions of H and considering the canal bed level as a datum. The results indicate that for the increase of the under floor cut-off depth, the ground water table has a small drawdown through the region downstream the cut-off. A slight effect of under floor cut-off relative depth on the relative exit velocity gradient and the relative seepage discharge.

6.2. Effect of lateral cut-off relative total depth (D_s/L)

The effect of the relative total depth of lateral cut-off wall (D_s/L) on relative piezometric head is given through the plan view of the floor in Fig.(7). The results indicate that the maximum difference of contours positions lie at the side edge of the floor with a relatively small effect on the relative peizometric head (h/H). The maximum difference between 2-D and 3-D lies behind the cutoff position and it is and it is about 20% and the results are very closed at point of 0.6L measured from the upstream side of the floor as shown in Fig.(8). The variation of the relative total depth of lateral cut-off gives a slight effect on the ground water table as shown in Fig.(9).The obtained results, (6), show that the variation of Ds/L from 0.0 to 0.2 has almost no effect on the relative exit gradients at both bed and side surfaces. The values of exit gradients computed by 3-D model are always higher than the obtained from 2-D model, for all values of D_s/L. The results revealed that both inlet and exit relative seepage discharge are constant.

6.3. Effect of lateral cut-off relative penetration depth (d_s/L) under the bottom of the canal

The effect of the relative penetration depth of lateral cut-off (d_s/L) on the piezometric head contours under the floor are given in Fig.(10). The results indicate that appreciable effect on the values of relative piezometric heads (h/H) along the side edge of the structure and a small effect on the relative peizometric heads along the centerlines. The increase of the value of d_s/L from 0.0 to 1.0 causes an increase in the value of h/H by 22.9% immediately at the upstream of the cut-off. The results also indicate that here is no appreciable difference between the 2-D and 3-D results along the centerline section while the difference is increased up to 21.5% along the side edge section. Fig.(11) shows a small zoomed area around structure where the variation of contours due to the change of d_s/L values are clearly illustrated. The figure indicates that the ground water table has an appreciable effect according to the variation of lateral cut-off penetration depth under the canal level (d_s/L). On the other hand, at a distance $Y/L=2.0$, the phreatic surface has not any change due to variation of d_s/L. The values of of relative exit velocity gradient computed by 3-D model are always higher than those obtained by 2-D model for all cases studied. Fig.(12) shows the variation of relative bed and side seepage discharges at inlet and exit surfaces with the relative penetration depth of lateral cut-off under the canal d_s/L. As the value of d_s/L increases from 0.0 to 1.0, the relative bed discharge (Q_b/Q_t), increases then it becomes constant. Meanwhile, the relative side discharge (Q_s/Q_t), slightly decreases and becomes nearly constant for $d_s/L > 0.75$.

6.4. Effect of lateral cut-off relative position (L_1/L)

The effect of the relative cut-off wall position(L_1/L) on the relative acting piezometric heads under the structure floor are given in Fig.(13). The figure show that, the change in the cut-off walls position (L_1/L) gives an appreciable effect on the peizometric head distribution under the structure(h/H). If the cut-off wall are moved from the upstream side edge to the downstream edge of the structure, piezometric head along the two studied sections are increased by about 20% of the total head. Fig.(14) shows the ground water contours around the studied structure. These contours are plotted as a relative values of H and a small zoomed area around the structure is given by Fig.(14). The figure indicates that the ground water table is appreciably affected by the variation of cut-off walls position. When the cut-off walls are moved towards the downstream direction an appreciable rising of the ground water table through the region upstream the lateral cut-off and appreciable drawdown on the ground water table through the downstream region are achieved. The change in the value of cut-off walls relative position L_1/L from 0.0 to 0.75, gives a small effect on the values of the exit gradients along the three studied sections, (6). A large decrease in the relative exit gradient values occurs when the cut-off walls are located at the end of the structure where $L_1/L=1.0$. Results indicate that most of the seepage discharge around the structure, more than 96%, are passing through the downstream bed at the exit face.

6.5. Effect of lateral cut-off relative length (L_s/L)

The effect of lateral cut-off wall relative length (L_s/L) on the relative uplift pressure heads under the structure floor heads is studied and all results are compared with the corresponding 2-D case. Fig.(15) shows the peizometric head contours under the floor, the results indicate that the variation of lateral cut-off relative length (L_s/L) from 0.0 to 3.0 causes small effect on the values of relative piezometric heads (h/H) along both the centerline and the side edge. The figure also indicates that there is no appreciable difference between 2-D and 3-D results along the centerline section while the difference increases up to 18% along the side edge section. Effect of the relative length of lateral cut-off (L_s/L) on the ground water contours around the structure is given by Fig.(16). The canal bed level is taken as a datum, and the figure indicates that the ground water table has an appreciable effect according to the variation of (L_s/L). The results revealed that no significant effect for the variation of (L_s/L) on both relative exit velocity gradient and relative bed and side seepage discharges.

7. ANALYSIS OF RESULTS FOR CASE OF LATERAL RELIEF FILTER

For this case the effect of the relative dimensions of the lateral filter, the filter relative head, the filter relative position, relative exit gradients and relative discharges are considered in the following sections.

7.1 Effect of lateral filter relative depth (D_f/H)

The effect of the lateral filter relative depth (D_f/H) on the relative acting piezometric heads under the structure floor is presented by Fig.(17). The change of lateral filter depth (D_f/H) gives an appreciable effect on the values of relative piezometric heads (h/H) along the side edge of the structure and a very small effect on the relative piezometric heads along the centerline of the structure,(6). The increase in the value of (D_f/H) from 0.4 to 1.0 causes a decrease in the value of h/H by about 13.8% just upstream the structure floor. For all values of (D_f/H), the relative piezometric head values h/H become nearly equal at $X/L=1.0$. Fig. (6) shows the ground water contours around the studied structure, the results indicate that the ground water table has a very slight effect according to the variation of the lateral filter relative depth (D_f/H). The increase of (D_f/H) from 0.4 to 1.0 gives a very small decrease on the phreatic surface. The obtained results depict that for specific values for (D_f/H) relative exit gradients at the side edge of the downstream bed are always greater than other sections, Fig.(18). The results illustrate that the worst section of the exit velocity gradients is the side edge of the bed downstream the structure which should be checked due to the allowable value of the founded soil. As the value of (D_f/H) increases from 0.4 to 1.0, the relative bed discharge Q_b/Q_t is decreased with decreasing rate, meanwhile the relative side discharge Q_s/Q_t is increased. The side seepage has a minimum value when the lateral filter depth is $D_f/H=1.0$.

7.2 Effect of lateral filter relative head (H_o/H)

The effect of the lateral filter relative head (H_o/H) on the relative acting piezometric heads under the floor of the structure are given in Figs.(19) and (20) which indicate an appreciable effect due to the variation of (H_o/H). Along the centerline of the structure, the increase of lateral filter relative head (H_o/H) from 0.0 to 0.8 causes an increase in the value of h/H, just upstream the vertical under floor cut-off, by about 9.7 % meanwhile along the side edge of the structure, the increase of (H_o/H) for the same range causes an increase in h/H at the end of floor by about 59.3%. Effect of relative head of lateral filter (H_o/H) on the ground water contours around the structure as a relative values of H taken the canal bed as a reference for a zoomed area is given by Fig.(21) and Fig.(22). The figures indicate that the ground water contours move to the upstream side for decreasing the value of (H_o/H) which means that the decrease of the lateral filter relative head causes a decrease on the lateral water pressures on the structure side walls. For a point lies at the lower section of the canal side and at a relative distance X/L=0.5, from the structure floor, the decrease of (H_o/H) from 0.8 to 0.0 causes a reduction in the relative exit gradients by about 43.3%, (6). The same decrease of (H_o/H) gives about 45.2% of the relative exit gradient at a point of X/L=0.1. This means that the relative exit gradients at any point along the lower section of the side of canal is increased as its location is closer to the downstream floor edge. At the downstream exit relative bed discharge Q_b/Q_t is decreased while the side seepage is increased, (6).

7.3 Effect of lateral filter relative length (L_f/L)

The effect of the lateral filter relative length (L_f/H) on the relative piezometric heads under the floor of the structure are given in Fig.(23) which indicate a slight effect due to the variation of (L_f/L). The contours are moved to the downstream side of the floor for increasing the value of (L_f/L). Along the centerline of the structure, the relative piezometric head, h/H, has a drop by about 37.13% at X/L=0.25, where the under floor cut-off is located at D/L=0.25. Along the same section, the relative piezometric head has a drop by about 10.7% just upstream the floor, where the filter is located. Meanwhile along the side edge of the structure, the piezometric head has a drop by about 6.7% at X/L=0.0 due to existence of the lateral filter position. Fig.(24) shows the ground water contours around the structure as a relative values of H taken the canal bed as a reference for a zoomed area. The figure indicates that the ground water table has an appreciable effect according to the variation of lateral filter relative length (L_f/L). For the case of $L_f/L=2.0$ the phreatic surface has a drop at the position where the filter is located and extended to reach the studied section. The obtained results, (6), show that the variation of (L_f/L) from 0.5 to 3.0 gives a slight effect on exit gradients at both bed and side surfaces. For specific values of (L_f/L) exit velocity gradients at the side edge of the downstream bed are always greater than all other sections. As the value of (L_f/L) increases from 0.5 to 3.0 the relative bed discharge (Q_b/Q_t) has a gradual decrease, meanwhile the relative side discharge (Q_s/Q_t) increases, for both upstream and downstream discharge surfaces, (6).

7.4 Effect of lateral filter relative position (L_{lf}/L)

The effect of the lateral filter relative position (L_{lf}/L) on the relative piezometric heads h/H under the floor of the structure are given in Fig.(25) which indicate an appreciable effect due to the variation of (L_{lf}/L) along the side edge of the structure and a small effect on the relative piezometric heads h/H along the centerline. Along the centerline of the structure, the increase in the value of (L_{lf}/L) from 0.0 to 1.0 causes a small increase in the value of h/H by about 0.05H along the whole section. The sudden drop in the values of piezometric head at a distance X/L=0.25 is due to the under floor cut off wall at the same point. Meanwhile along the side edge of the structure, the increase in value of (L_{lf}/L) from 0.0 to 1.0 causes an increase in the value of h/H by about 0.18H just upstream the floor at X/L=0.0. The analysis of the results shows that the piezometric head values increase under the floor as the lateral filter is moving to the downstream side. Fig.(26) shows the ground water contours around the structure as a relative values of H taken the canal bed as a reference for a zoomed area. The figure indicates that the ground water table has an appreciable effect according to the variation of lateral filter relative position (L_{lf}/L). Moving the lateral filter position to the downstream side causes a variation of the ground water contours to the downstream side. The obtained results, (6), show that the variation of (L_{lf}/L) from 0.0 to 1.0 causes an increase in the relative exit gradient by about 13.47%. This means that the effect of the variation of (L_{lf}/L) on the relative exit gradients at any point along centerline is increased as its location is closer to the floor end. As the value of (L_{lf}/L) increases from 0.0 to 1.0 the relative upstream bed discharge (Q_b/Q_t) increases while the relative downstream bed discharge (Q_b/Q_t) decreases, (6). The analysis of the results revealed that the effect of the filter position on the relative quantity of seepage decreases as the filter moves towards the downstream side.

8. CONCLUSIONS

A solution of the 3-D problem of steady seepage flow beneath and around water retaining structure provided with a single under floor cut-off has been studied. A lateral cut-off or a lateral relief filter is suggested to control the seepage around the structure. A parametric study for a practical range of variables for each system is achieved and presented in dimensionless form. The problem was investigated numerically employing the three dimensional finite element program SWICHA to evaluate seepage characteristics. From the results obtained and their discussions, the following main conclusions may be listed:

- The under floor cut-off wall has no effect on the piezometric head diagrams along the side edge of the structure.
- The best location of the cut-off walls for the exit gradient is at the toe of the floor where the value of exit gradients at both bed and side become infinite at a minimum value.
- The relative bed seepage discharge presents about 80% at the upstream inlet while it reaches more than 99% at the downstream exit which means that the relative side seepage has a little contribution to the total seepage.
- The values of of relative exit velocity gradient computed by 3-D model are always higher than those obtained by 2-D model for all cases studied.
- The analysis of the results shows that the piezometric head values increase under the floor as the lateral filter is moving to the downstream side.
- The effect of variation of lateral filter relative position, L_{lf}/L, at any point along the bed and side edge of the structure is increased as its location becomes closer to the floor end.
- The effect of the filter position on the relative quantity of seepage decreases as the filter moves towards the downstream side.

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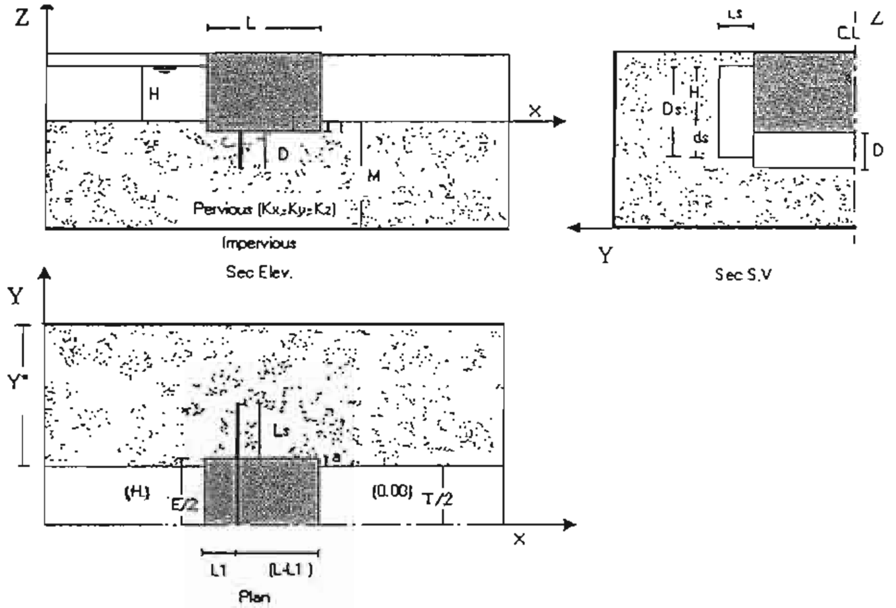
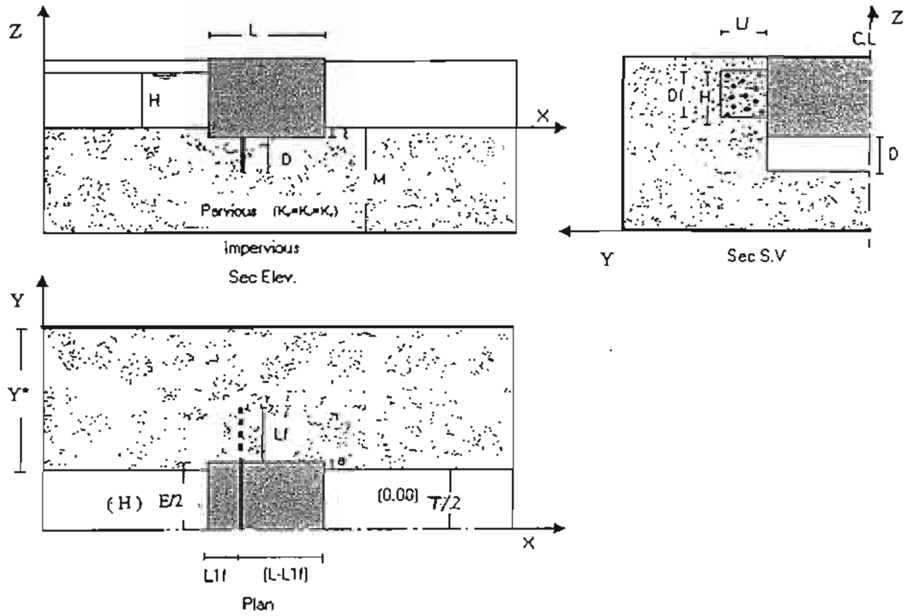
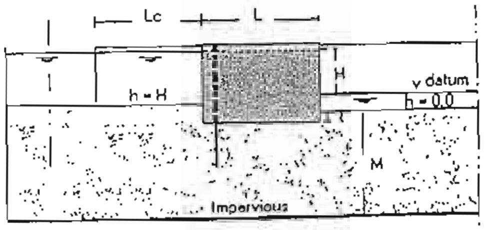


a) Layout of the problem for the case of lateral cut-off wall

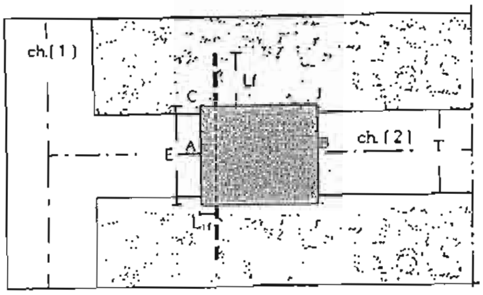


b) Layout of the problem for the case of lateral vertical relief filter.

Fig. (1) Problems Definition



ELEV.



PLAN

Fig(2) Schematic sketch of the second verified 3-D problem
(case of lateral relief filter)

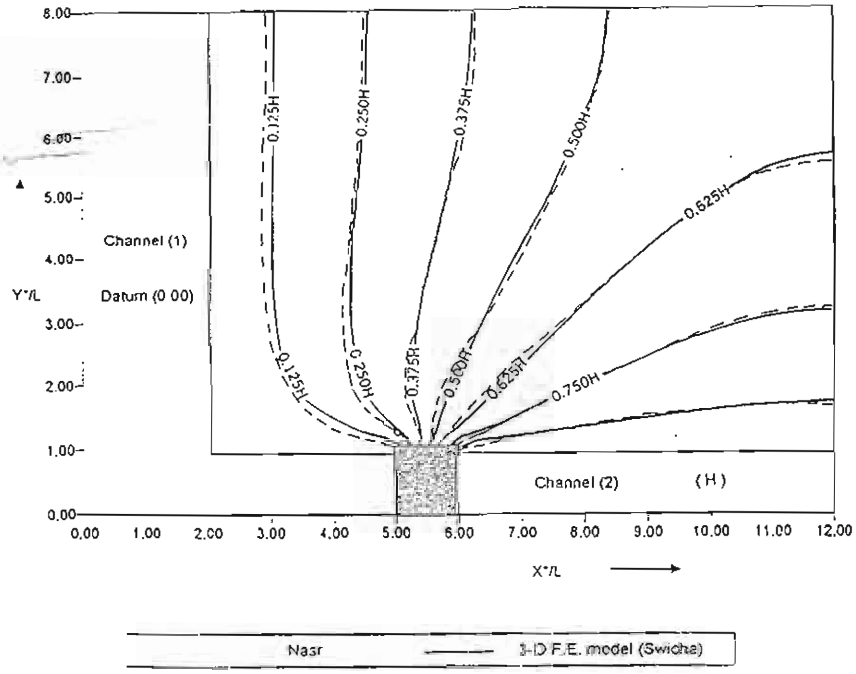


Fig.(3.3) Ground water levels around the structure
(case of simple block structure)

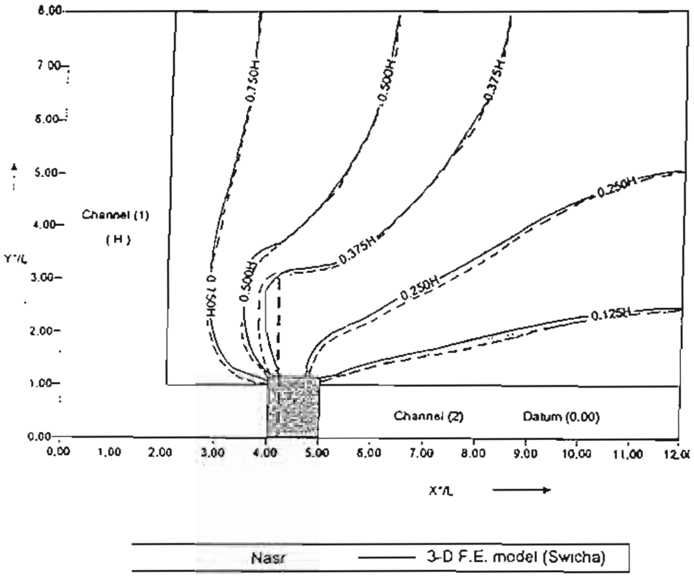


Fig (3-b) Ground water levels around the structure.

(case of lateral relief filter)

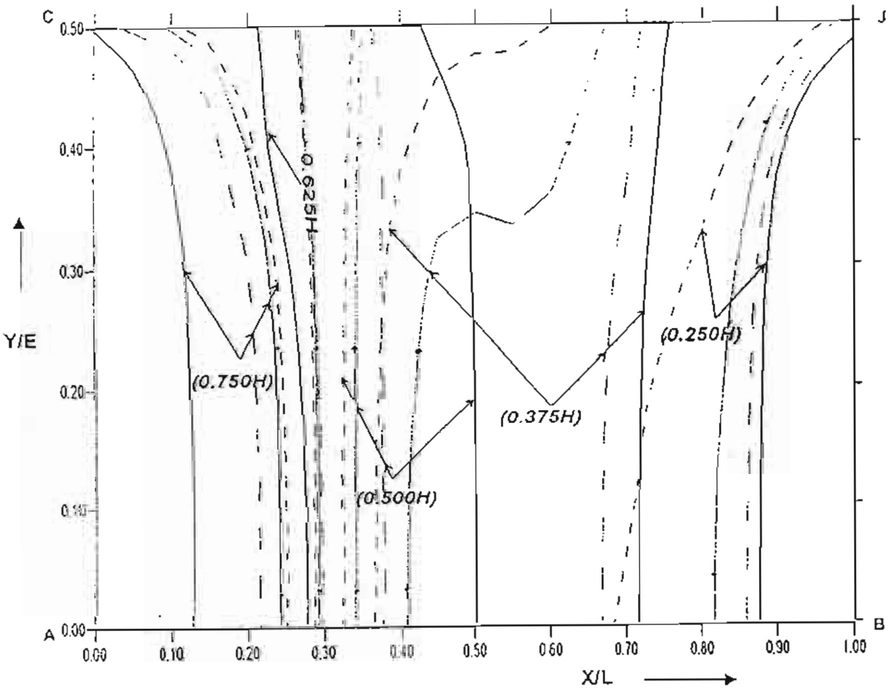
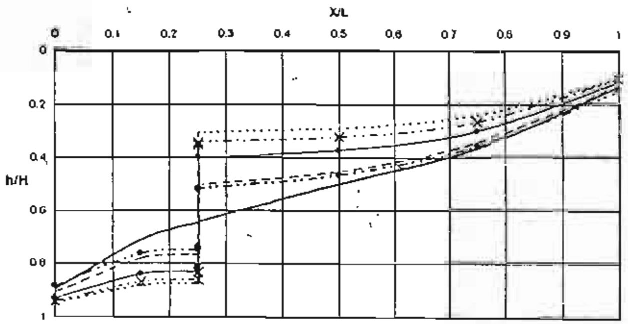


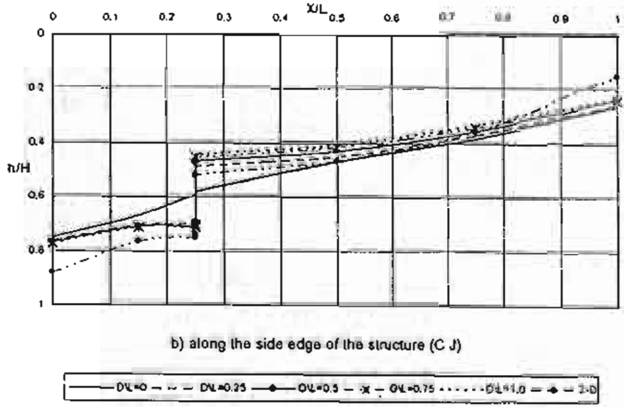
Fig.(4) Effect of cut-off relative depth (D/L) on piezometric head contours under the structure's floor

(L[illegible]/L=0.25, cs/L=0.25, Ls/L=1.0, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085)

——— D/L=0.0 — — D/L=0.25 —·— D/L=0.5 — — — D/L=1.0



a) along the C.L of the structure (A B)



b) along the side edge of the structure (C J)

Fig(5)Effect of cutoff relative depth (D/L) on the piezometric head diagrams along the floor

[ds/L=0.25, Ls/L=1.0, Ds/L=0.45, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085]

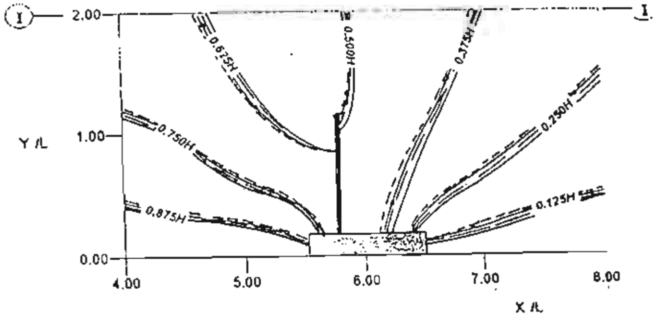


Fig.(6) Effect of cut-off relative depth (D/L) on ground water levels around the structure.

[D/L= 0.25, L1/L=0.25, Ls/L=1 0, H/L=0.2, E/L=2 0, T/L=1.6, M/L=1.5, t/L=0 085]

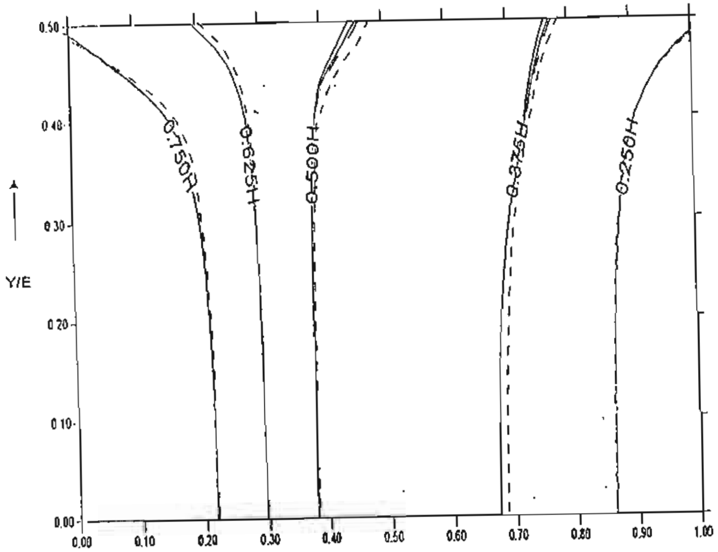
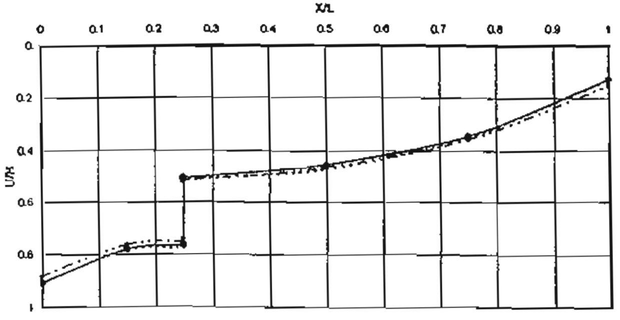
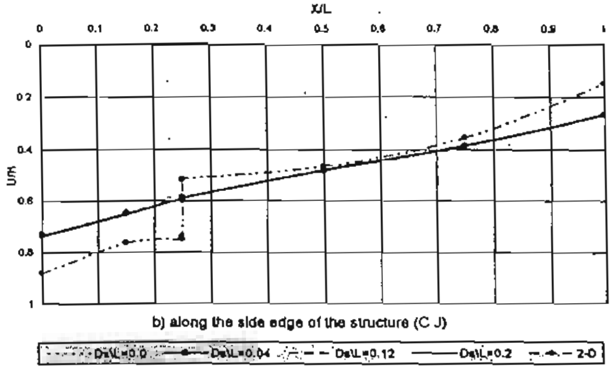


Fig.(7) Effect of lateral cut-off relative depth (Ds/L) on the Uplift pressure contours under the structure floor.

(L1/L=0.25, D/L=0.25 , Ls/L=1.0, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.6, I/L=0.085)



a) along the C.L of the structure (A B)



b) along the side edge of the structure (C J)

Fig(8) Effect of the lateral cutoff relative depth (Ds/L) on the uplift pressure diagrams along the floor.

[Ls/L=1.0 ,D/L=0.25 ,L1/L=0.25 ,H/L=0.2 , E/L=2.0 ,T/L=1.6 ,M/L=1.5 ,I/L=0.085]

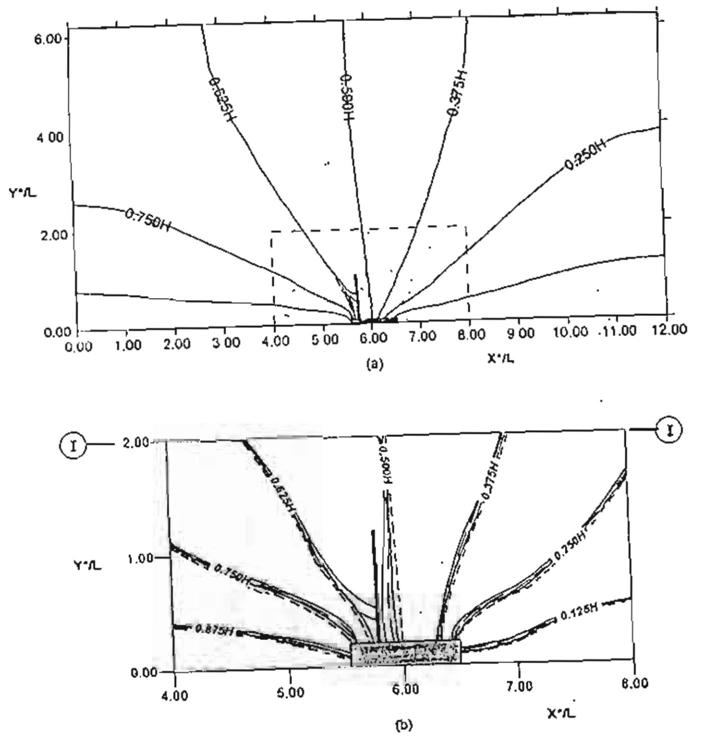


Fig.(9) Effect of lateral cut-off relative depth (Ds/L) on ground water levels around the structure.

[D/L= 0.25, L1/L=0.25, Ls/L=1.0, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085]

— — — Ds/L=0.0 ——— Ds/L=0.04 —— Ds/L=0.12 ——— Ds/L=0.2

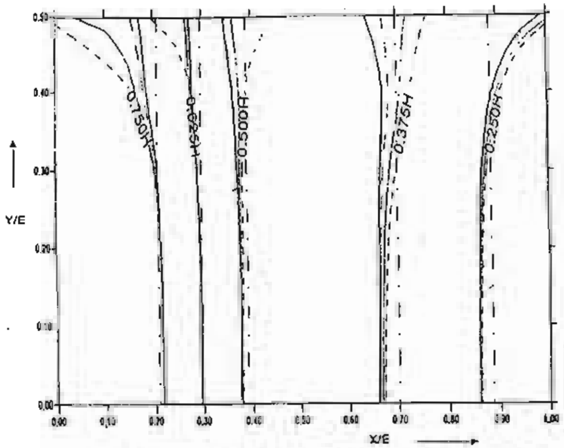


Fig.(10) Effect of lateral cut-off relative depth (ds/L) on Uplift pressure contours under the structure floor.

(L1/L=0.25, D/L=0.25, Ls/L=1.0, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085)

— — — ds/L=0.0 ——— ds/L=0.25 — — ds/L=0.5 ——— ds/L=1.0 — · + (2 D)

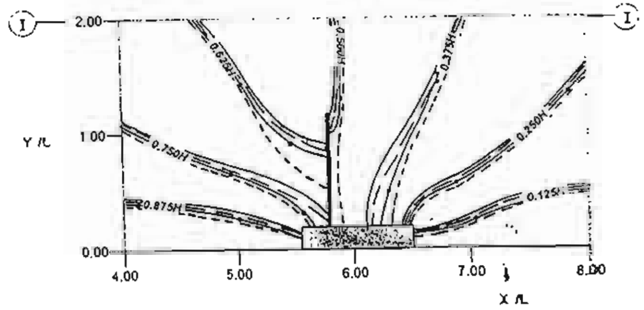


Fig.(11) Effect of lateral cut-off relative depth (ds/L) on ground water levels around the structure.

[D/L= 0.25, L1/L=0.25, Ls/L=1.0, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085].

— — — ds/L=0.0 ——·—— ds/L=0.25 — — ds/L=0.5 ——— ds/L=1.0

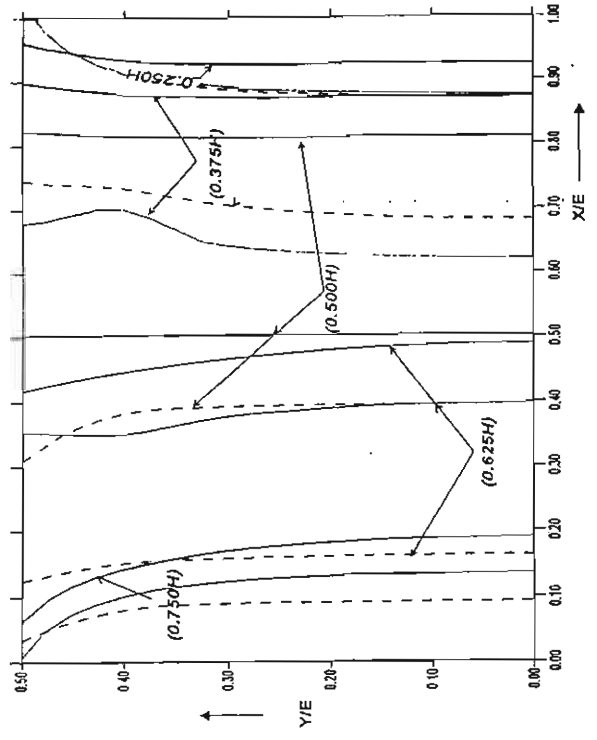
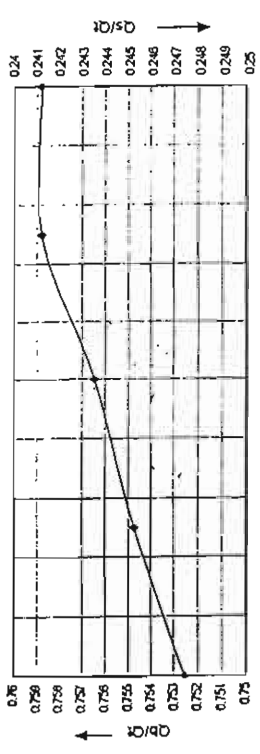
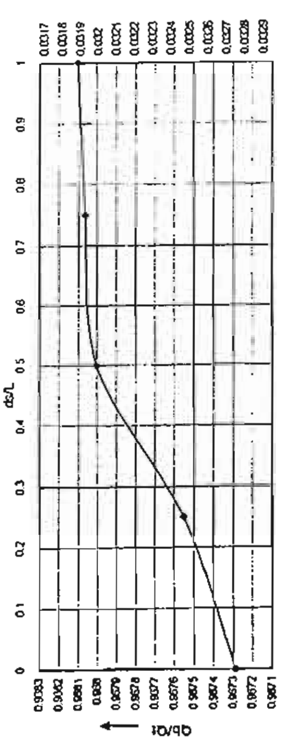


Fig.(13) Effect of cut-offs relative position (L1/L) on Uplift pressure contours under the structure floor

(D/L= ds/L=0.25, Ds/L=0.45, Ls/L=1.5, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085)



a) at the U.S. inlet



e) at the D.S. exit

Fig.(12) Effect of the lateral cutoff relative depth (ds/L) on the bed and side relative seepage discharges (Qb/Qt & Qs/Qt).

(Ls/L=1.0, D/L=0.25, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085)

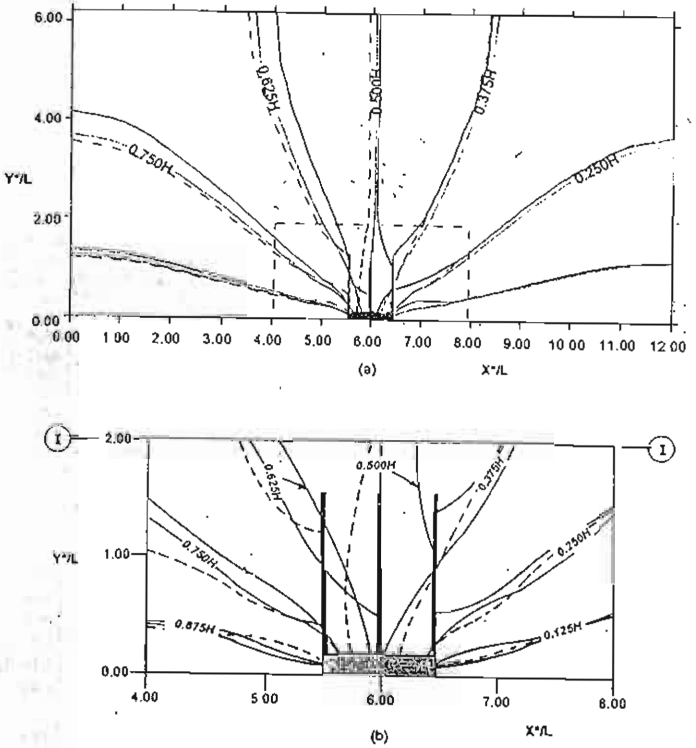


Fig.(14) Effect of cut-offs relative position (L1/L) on ground water levels around the structure.

[D/L= ds/L=0.2, Ds/L=0.45, Ls/L=1.5, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085]

- - - - L1/L=0.0 ——— L1/L=0.5 ——— L1/L=1.0

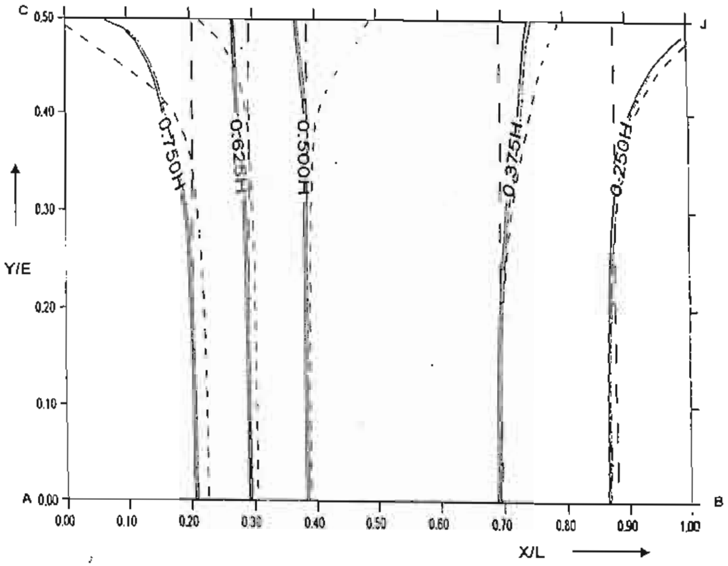


Fig.(15) Effect of lateral cut-off relative length (Ls/L) on piezometric head contours under the structure floor.

(D/L=ds/L=0.25, Ds/L=0.45, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.85)

- - - - Ls/L=0.0 ——— Ls/L=1.5 ——— Ls/L=3.0 — — - (2-D)

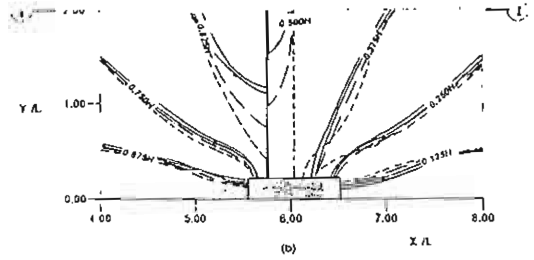


Fig.(16) Effect of lateral cut-off relative length (Ls/L) on ground water levels around the structure

(D/L= ds/L=0.25, Ds/L=0.45, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085)

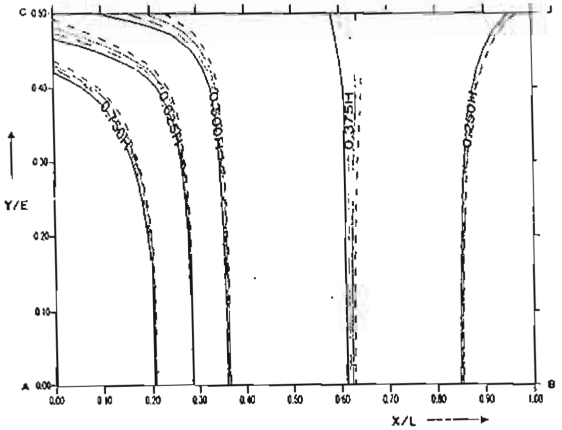


Fig.(17) Effect of lateral filter relative depth (Df/H) on piezometric head contours under the structure floor.

(Lf/L=1.0, Ho/H=0.4, L1f/L=0.0, L1/L=0.25, D/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6 ,M/L=1.5 ,t/L=0.085)

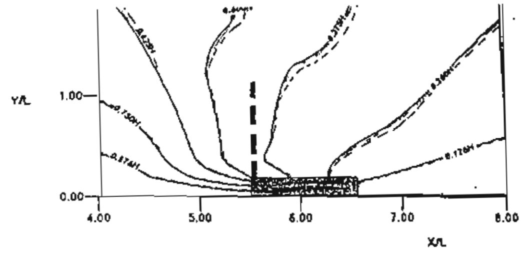


Fig.(18) Effect of lateral filter relative depth (Df/H) on ground water levels around the structure.

L1f/L=0.0 ,Lf/L=1.0 ,Ho/H=0.4 ,D/L= 0.25 ,L1/L=0.25 , E/L=2.0 ,B/L=1.6 ,M/L=1.5 ,t/L=0.085

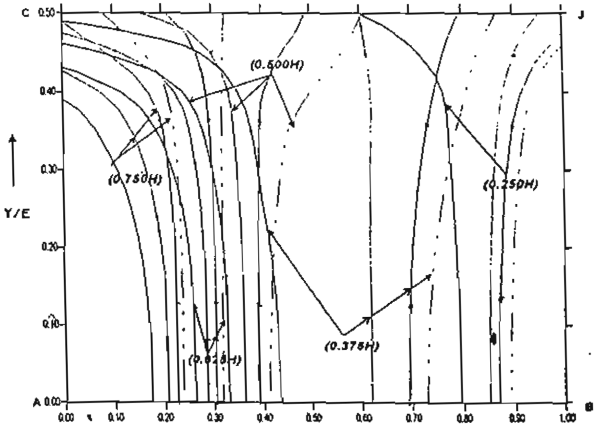
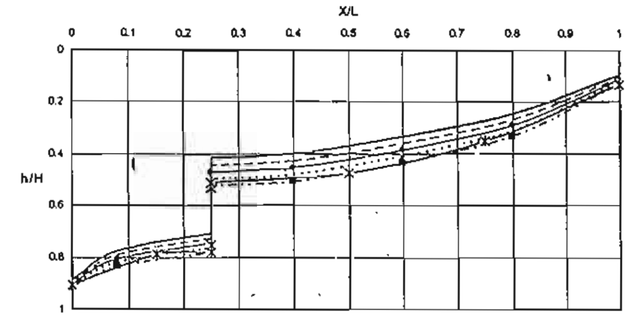
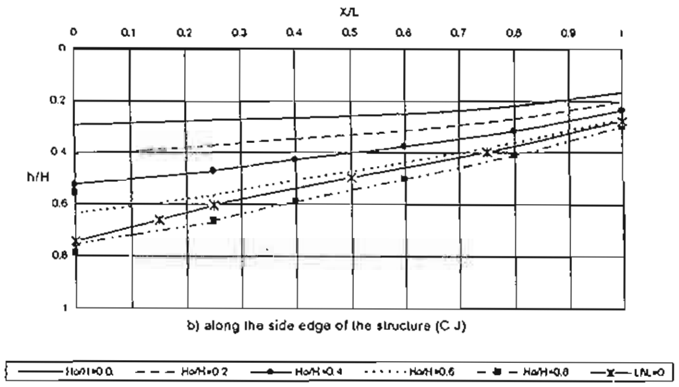


Fig.(19) Effect of lateral filter relative head (Ho/H) on piezometric head contours under the structure floor.

(Lf/L=1.0, Df/H=0.8, L1f/L=0.0, L1/L=0.25, D/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085)



a) along the C L of the structure (A B)



b) along the side edge of the structure (C J)

ig(20) Effect of lateral filter relative head (Ho/H) on the piezometric head diagrams along the floor.

[Df/H=0.8, Lf/L=1.0, L1f/L=0.0, D/L=0.25, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1 5, l/L=0.085]

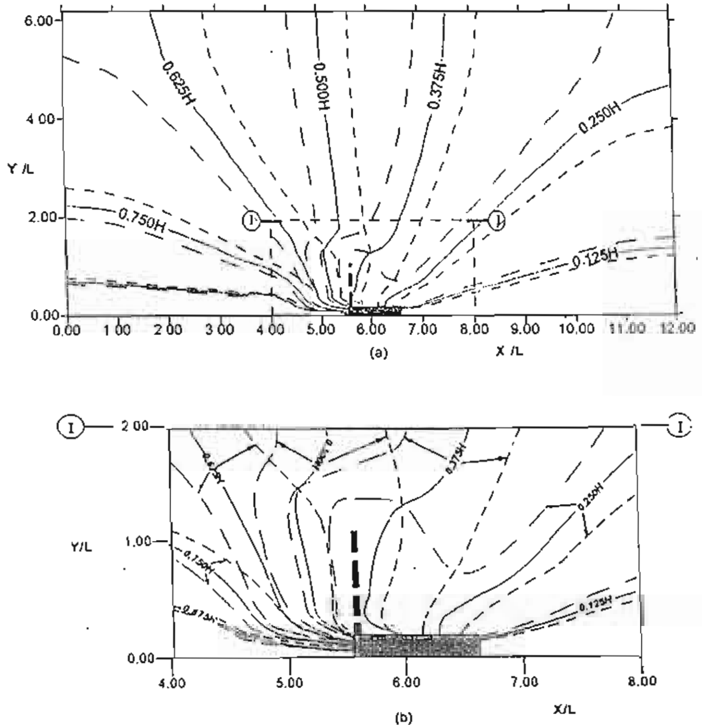
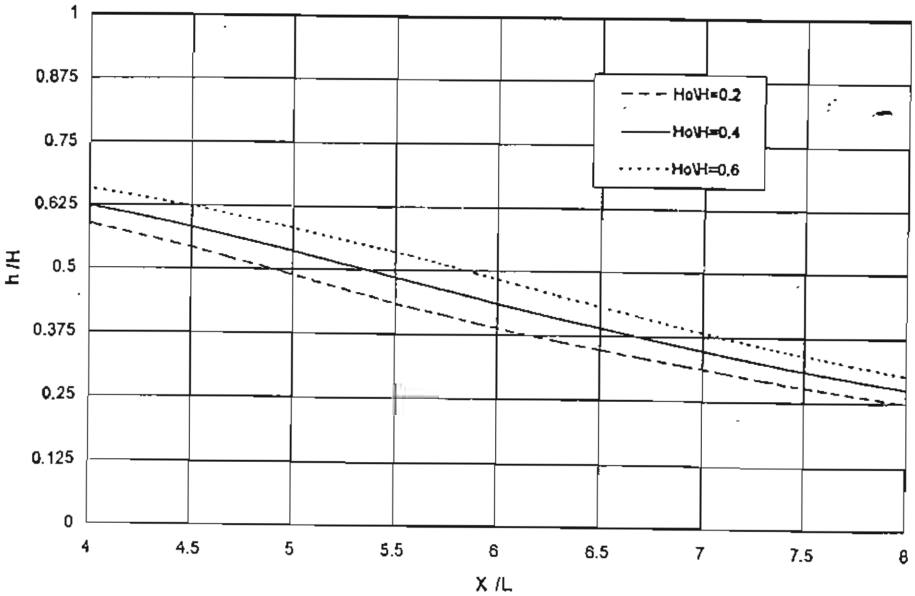


Fig.(21) Effect of lateral filter relative head (Ho/H) on ground water levels around the structure.

[L1f/L=0.0, Lf/L=1.0, Df/H=0.8, D/L= 0.25, L1/L=0.25, H/L=0.2, E/L=2.0,T/L=1.6, M/L=1 5, l/L=0.085]



Fig(22) Effect of lateral filter relative head (Ho\H) on the phreatic surface profile along section I - I

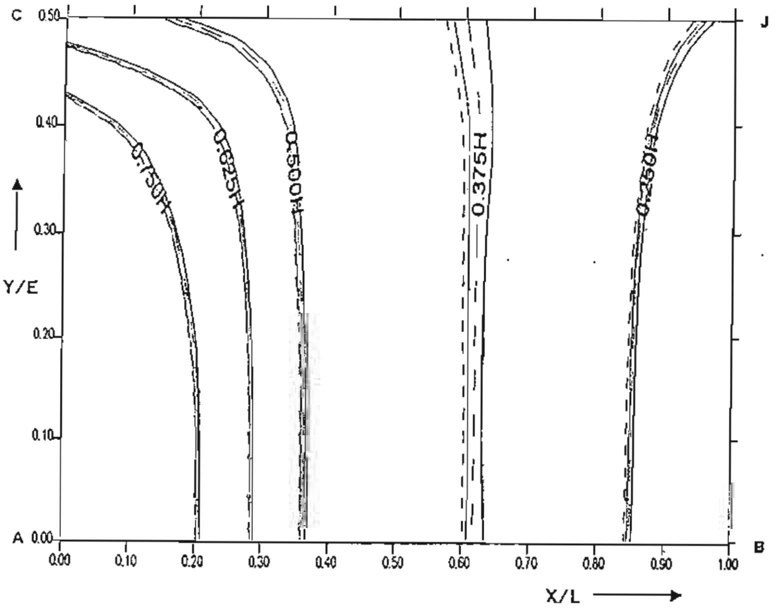


Fig.(23) Effect of lateral filter relative length (Lf/L) on piezometric headcontours under the structure floor.

(L1f/L=0.0, Df/H=0.8, Ho/H=0.4, L1/L=0.25, D/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6 ,M/L=1.5 ,t/L=0.085

——— Lf/L=0.5	— — — Lf/L=1.0	——— Lf/L=2.0	– – – – – Lf/L=3.0

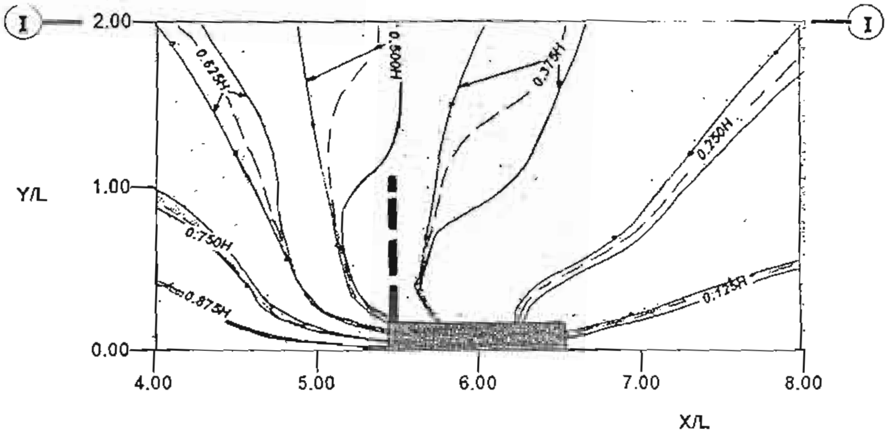


Fig.(24) Effect of lateral filter relative length (Lf/L) on ground water levels around the structure.

[L1f/L=0.0, Ho/H=0.4, Df/H=0.8, D/L=0.25, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, l/L=0.085

Lf/L=0.5 Lf/L=1.0 Lf/L=2.0

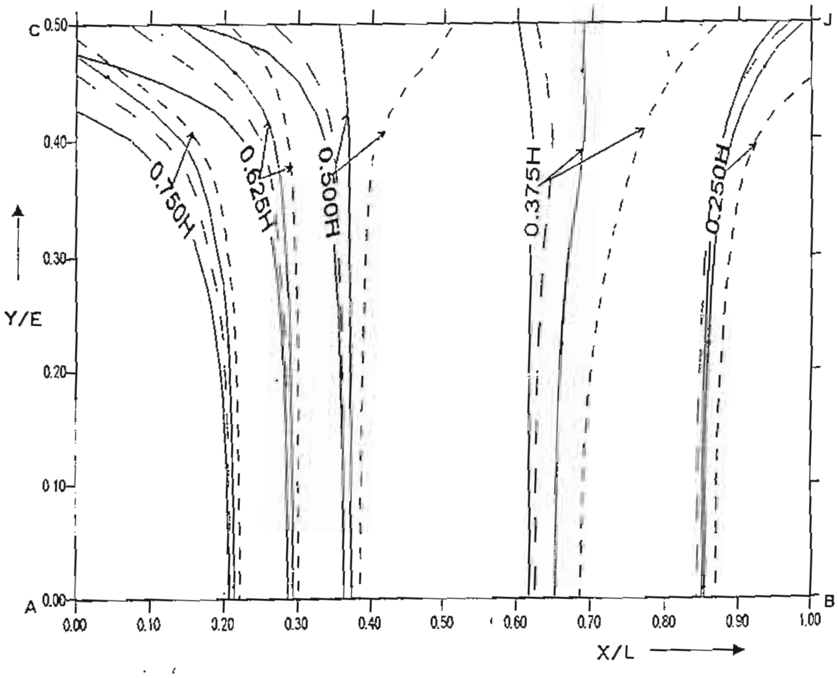


Fig.(25) Effect of lateral filter relative position (L1f/L) on piezometric head contours under the structure floor.

(Lf/L=1.0, Df/H=0.8, Ho/H=0.4, L1/L=0.25, D/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6 ,M/L=1.5 ,l/L=0.085)

L1f/L=0.0 L1f/L=0.25 L1f/L=0.5 L1f/L=1.0

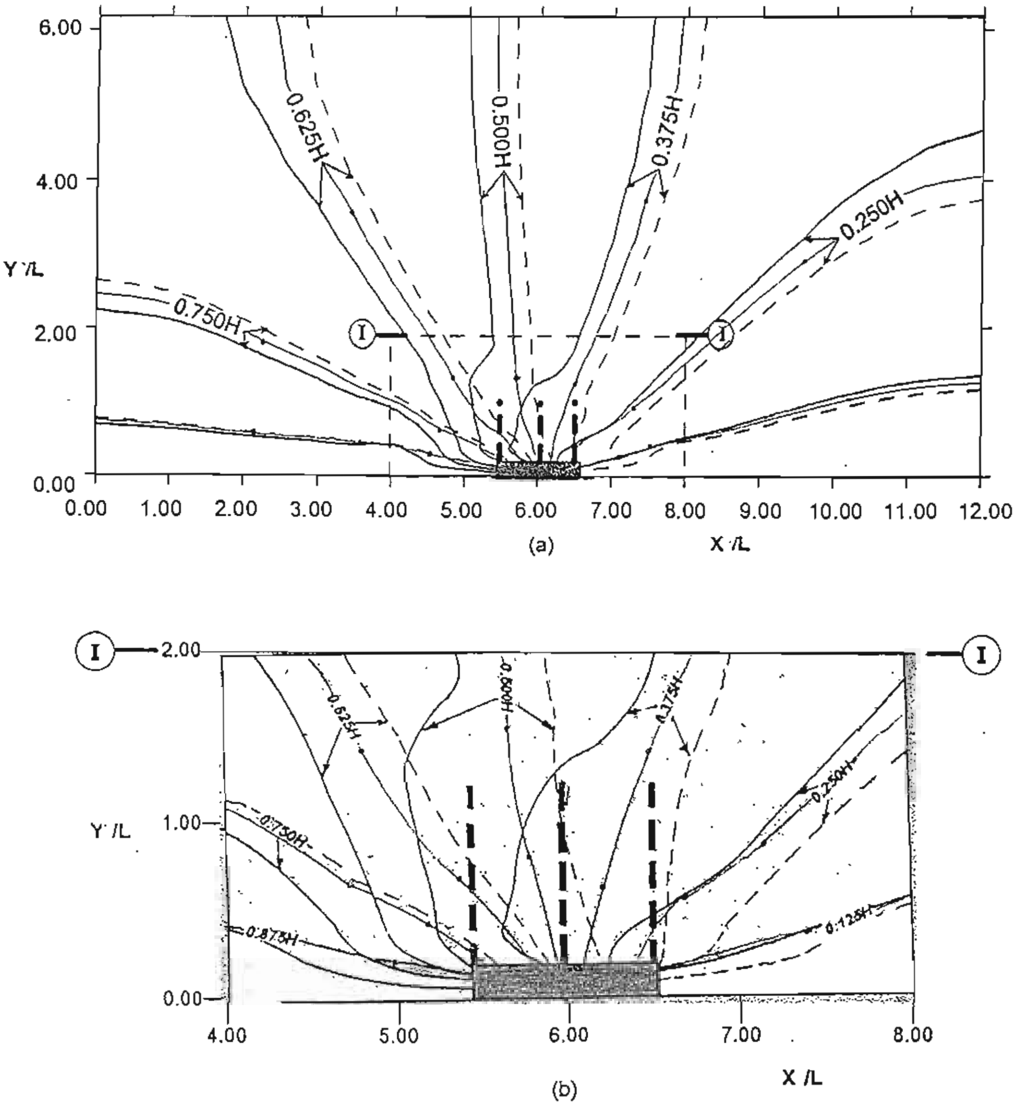


Fig.(26) Effect of lateral filter relative position (L1f/L) on ground water levels around the structure

[Lf/L=1.0, Ho/H=0.4, Df/H=0.8, D/L=0.25, L1/L=0.25, H/L=0.2, E/L=2.0, T/L=1.6, M/L=1.5, t/L=0.085]

——— L1f/L=0.0	———•——— L1f/L=0.5	— — — — L1f/L=1.0