CONTROL OF SEEPAGE AROUND HYDRAULIC STRUCTURES-EXPERIMENTAL STUDY

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ABSTRACT

In this paper, the 3-D problem of seepage around a hydraulic structure with a single cutoff constructed near a branching point of a channel is experimentally studied . A lateral cutoff wall and a lateral relief filter, behind each side of the structure, are used to control the seepage around the structure under laboratory conditions. The study was carried out using the electrical analogue technique. Experimental results were obtained to investigate the effect of the two suggested control systems on the quantity of seepage around the structure, uplift pressure distributions under the structure, and ground water table behind the structure. The results are presented in the form of charts and analysed.

Keywords: Seepage, Hydraulic structures, Relief filter, Cutoff.

Notations

a	Cutoff distance from the U.S edge of the structure,
B	Water top width of channel-2 U.S the structure,
2-D	Two dimensional,
3-D	Three dimensional,
D	Penetration depth of the cutoff under the structure,
D_f	Depth of the relief filter measured from the U.S.W.L,
D_s	Depth of the lateral cutoff measured from the U.S.W.L,
D.S	Downstream,
E	Width of the structure,
G.W.T	Ground water Table,
H	Effective head of the structure,
H_f	Effective head of the filter,
k	Coefficient of permeability of the pervious soil under the structure,
L	Length of the structure,
L_c	Structure distance from the edge of branching channel(1),
L_f	Length of the relief filter for one side,
L_s	Length of the Lateral cutoff for one side,
M	Thickness of the pervious soil stratum measured from D.S bed,
Q	Quantity of seepage around the structure,
Q_d	Exit seepage discharge D.S the structure,
Q_f	Relief filter discharge,
Q_o	Quantity of seepage around the structure for L_f=L_s=0.0 and D/L =0.4,
Q_t	Total quantity of seepage around the structure,
Q_w	Quantity of seepage around the structure for L_f=L_s=0.0 and D = 0.0,
t	penetration depth of the structure through the soil,
t_f	Thickness of the relief filter,
U	Uplift pressure,
U.S	Upstream,
U.S.W.L	Upstream water level,and
D.S.W.L	Downstream water level.

INTRODUCTION

The stability of hydraulic structures has to be insured against the effect of seepage characteristics. Many researches were carried out for studying the effect of these characteristics under structures as 2-D problems [1,4 and 5]. For example, the problem of seepage under a single floor with a single cutoff had been studied, using a conformal mapping technique, by Khosla [5] and Kovacs [3]. Practically, the seepage flows under and around the hydraulic structures. Therefore, the lateral seepage, which flows around structure, is important item and should be taken into consideration in the design. Uifoludi [6] studied the problem of seepage around a single structure founded on two finite pervious layers as a 3-D problem. At the water branching structures such as: head regulators; tail escapage structures; head pump stations; Syhons; culverts;... etc, the lateral quantity of seepage has an appreciable values because it feeds from the two crossing channels. The best locations of these structures from the crossing points were studied, as 3-D problems, by Nasr [7].

In the present study, two systems are suggested to control the seepage around water branching hydraulic structures: (I) lateral cutoffs and (II) lateral relief filters. Figure (1) shows a schematic sketch of the problem and the two control systems. The structure is assumed to be a block form with single cutoff, fixed near the U.S side and founded on a finite homogenous and isotropic soil. The total quantity of seepage around the structure, uplift pressure distributions, and variation of the ground water table behind the structure are studied for the two control systems. A comparison between some of the results for the two systems is indicated. The present study is carried out using the electrical analogue technique. A special 3-D model was designed for the problem. The experimental results are plotted in the form of curves and analysed.

EXPERIMENTAL SET-UP

The experiments were carried out by using special 3-D electrical analogue model. The 3-D models were used before in other seepage problems such as Hdszpro [2], Uifaludi [6] and Nasr [7]. The main components of the experimental set-up which are: flow domain tank; structure model; inflow and outflow domain; and electric circle are indicated in details by Nasr [7]. The cutoff walls were simulated by thin prespex plates, 1 mm thick, while the relief filters were simulated by electrode materials, 1.5 thick. The dimensions of cutoff and filter models were adopted according to the study case. The filter head was simulated by a movable voltage which obtained from a generator and controlled by a voltameter. The water was used as a flow domain and its conductivity was measured in all experiments. The potential (Volt) and current (Ampere) which represent the water head and seepage discharge, respectively, were recorded for all runs.

RESULTS AND ANALYSIS

As shown in Figure (1), the investigated hydraulic structure has a length L, width E, effective head H, and penetration depth through the soil t. The structure has a cutoff wall with depth D fixed under the structure at distance a from the U.S edge. The structure is founded on the channel (2) which has a water top width B and on a finite homogenous and isotropic permeable soil of depth M and far by a distance L_c from the edge of the branching channel (1). These parameters are presented in a dimensionless form and kept constant for all runs as follows: E/L= 2.0; t/L =0.085; D/L = 0.40; a/L=0.10; M/L=1.5; and L_c/L is taken 3.0 for the lateral cutoff system and 2.0 for the relief filter system.

The effect of the two control systems are studied on the following seepage characteristics:

1- Total quantity of seepage discharge around the structure,
2- Uplift pressure distribution under the structure, and
3- Ground water table behind the structure.

A- Control of Seepage by Lateral Cutoff Walls

The lateral cutoff length L_s is measured from the structure side, whereas,the depth D_s is measured from the upstream water level. These values are presented in a dimensionless form as: L_s/L and D_s/L.

1- *Seepage discharge*

The relative quantity of seepage under a floor with a single cutoff wall, q/kH, is calculated as a 2-D problem using Kovacs [3] analytical solution for D/L= 0.4. The calculated value of q/kH equals 7.268×10^{-3}, while, the corresponding measured value Q/kHB, for D/L =0.4 and L_s/L =0.0, is found 0.022188. The 3-D seepage value is found as nearly as three times of the 2-D value. This indicates that, for the investigated problem, a 2/3 of the total seepage discharge comes from the lateral seepage.

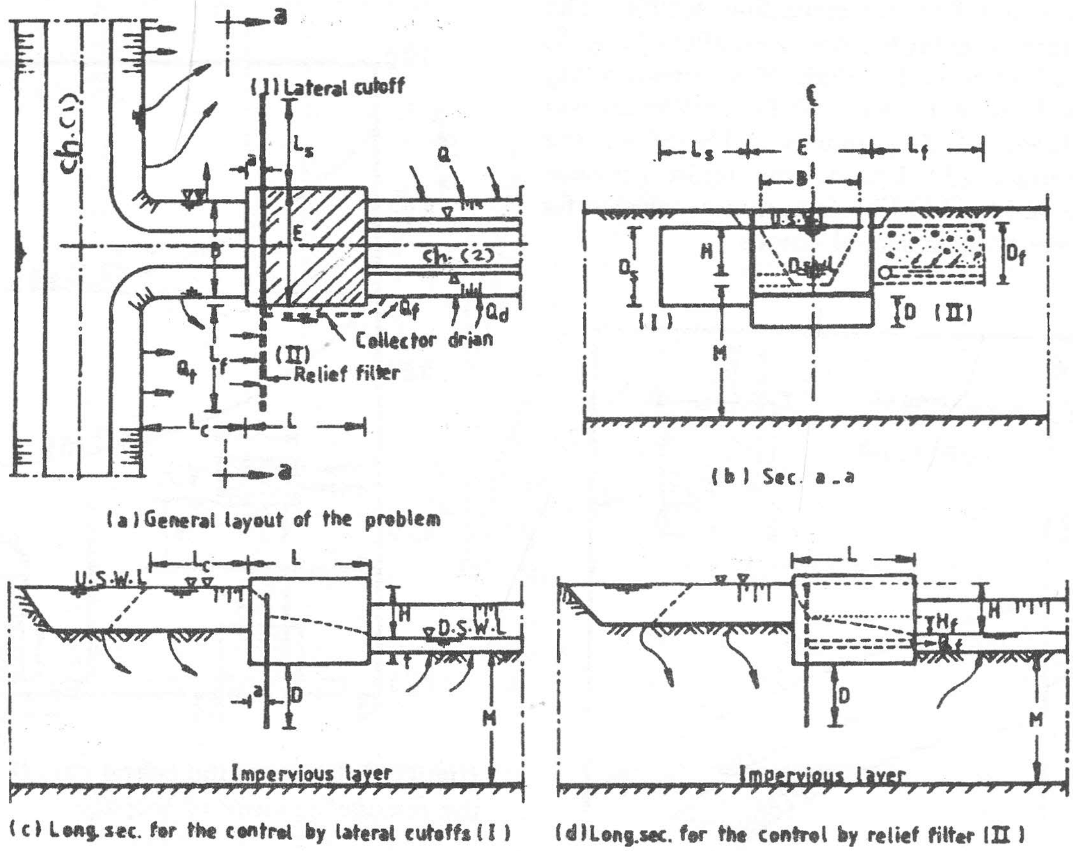

Figure 1. Schematic sketch of the problem.

Figure (2) shows that the relative quantity of seepage (Q/Q_w) is decreased for increasing the length (L_s)and /or the depth of the lateral cutoff (D_s), where Q_w is the total quantity of seepage around the structure without any cutoff. The values of Q/Q_w is decreased by 5% and 15% when the cutoff is fixed under the structure only (L_s=0.0) for depths D_s/L = 0.40 and 0.80, respectively. A reduction in Q/Q_w by about 10% is obtained by increasing the relative lateral cutoff length (L_s/L) to 6.0 for relative depth D_s/L = 0.4. A half of this reduction can be obtained for L_s/L = 1.50 only. Therefore, the depth (D_s) contributes more towards seepage reduction compared to the length of lateral cutoff (L_s). As shown in Figure (2), only about 25% reduction in Q/Q_w can be obtained when the cutoff is fixed under the structure (D/L = 0.8) and extending to 6.0 L behind the structure(D_s/L = 0.8). Therefore, the lateral cutoff is not recommended for decreasing the quantity of seepage around the water branching hydraulic structures. Since the most of seepage discharge comes from the branching channel (1), as shown in Figure (1-a).

2- *Uplift Pressures*

The uplift pressure distribution is essential for the design of hydraulic structures. In the present 3-D problem, the uplift pressures are measured under the floor plane of the structure. The structure has a cutoff wall with constant relative depth D/L = 0.40. Figure (3) shows the relative uplift pressure diagram (U/H) along each of the centerline AB and the side edge CD of the floor for various values of L_s/L. The uplift pressure diagram, for the 2-D solution, which was obtained by Khosla [5] is also plotted in the figure for D/L = 0.4. The figure indicates that the uplift pressure values are decreased when the lateral cutoff length is increased. For constant D_s/L =0.40and for extending L_s/L to 1.0 ,the average reduction in uplift pressures is about 30% for side edge section and 25% for centerline section. The uplift pressure diagram has not been affect for $L_s/L \geq 1.0$. The 2-D curve lies under the corresponding 3-D curves (L_s=0.0), because the floor thickness was not considered in 2-D solution. Therefore, the designer should add 18% to the uplift pressure values obtained by 2-D Khosla analytical solution for the structures without lateral cutoffs.

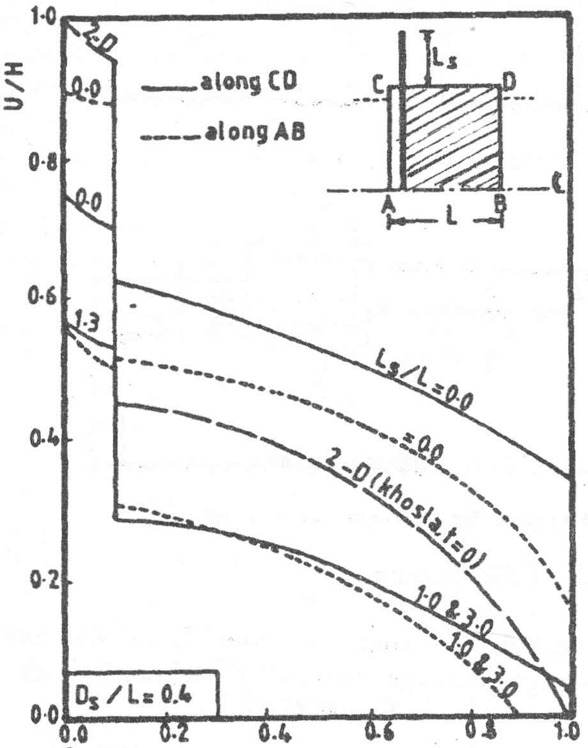

Figure 2. Effect of the lateral cutoff length on the uplift pressure diagrams under the structure.

3- *Ground Water Table (G.W.T)*

The change of ground water table according to the variation of hydraulic structures geometries is an important environmental item to be studied. The exit velocity gradient distributions along downstream bed and sides, the lateral pressures on the structure sides, and the definition of the streamlines can be obtained by the aid of G.W.T contours. Figure (4) shows the G.W.T contours around the investigated structure for constant D_s/L = 0.40 and for different values of L_s/L. The figure indicates that the G.W.T has a slight effect according to the change in L_s/L. This is because most of the streamlines come from the branching channel (1).

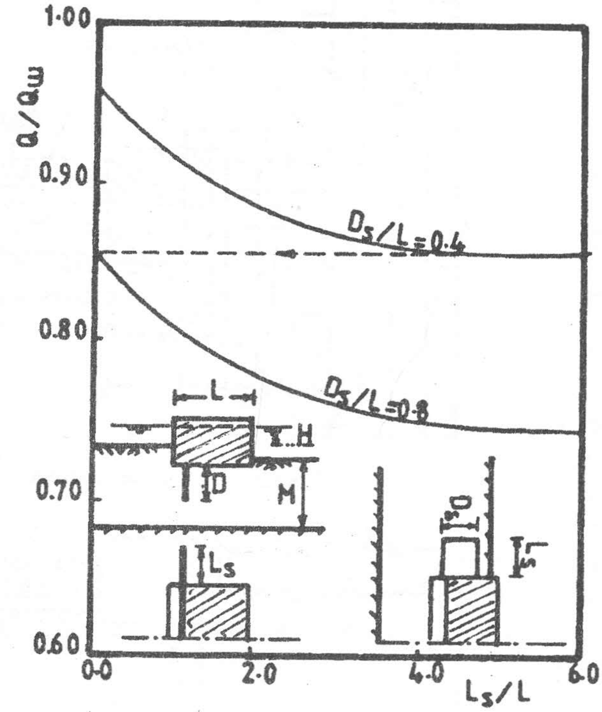

Figure 3. Effect of the lateral cut off dimensions on the relative quantity of seepage.

B- Control of Seepage by Relief Filter

This system aims to relief the pressures and control the seeped water around hydraulic structures. The system consists of a vertical relief filter to collect the seeped water and a collector drain to carry the filter discharge (Q_f) into the downstream side. The filter discharge can be controlled by the filter dimension (D_f, L_f and t_f), filter permeability, filter effective head (H_f) and structure effective head (H). The filter discharge should be considered upon conducting the hydraulic design of the structure. Figures (1-a,b&d) show Schematic sketches of the system. In the present study, the investigated structure dimensions are kept constant as listed before and the structure has a cutoff wall under the structure of fixed depth, D/L = 0.40. The filter is located at the same line of the structure cutoff. The filter thickness (t_f) and permeability are held constants for all experiments. The main variables of the study are: the relative filter depth (D_f/L), the relative filter length (L_f/L) and relative filter head (H_f/H).

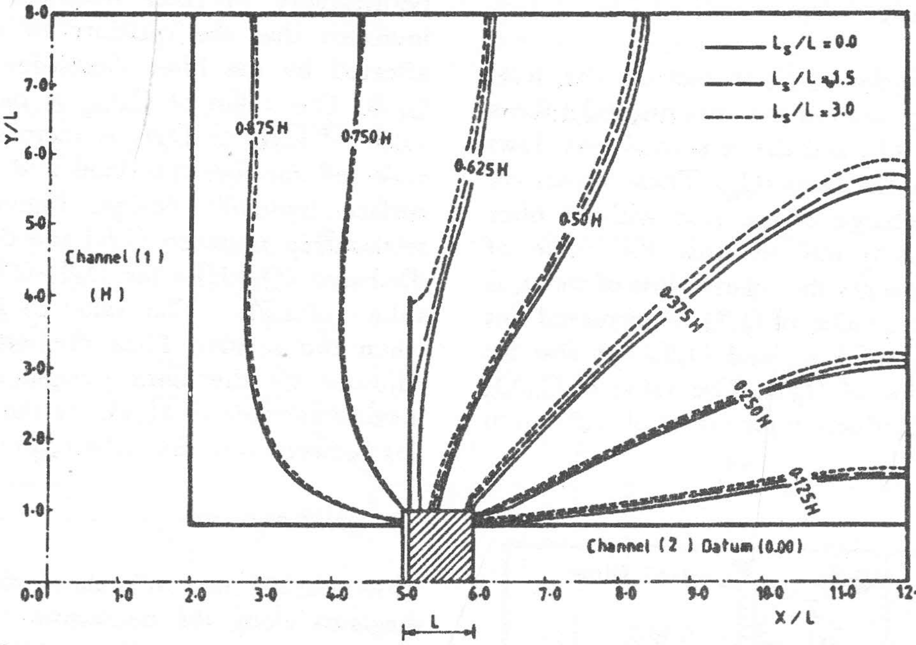

Figure 4. Effect of the relative cutoff length (L_s/L) on the ground water levels around the structure (D_s/L = 0.40, D/L=0.40).

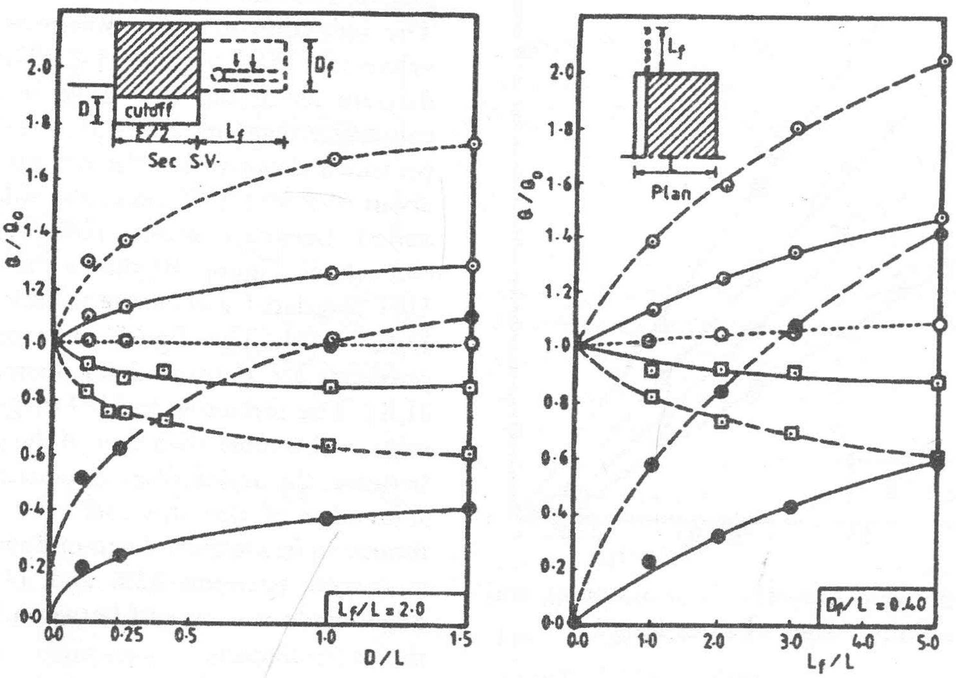

Figure 5. Effect of the filter dimensions and head on the relative quantity of seegae

1- *Seepage Discharge*

As shown in Figure (1-a), a part of the total quantity of seepage around the structure (Q_t) flows to the relief filter (Q_f) and the remained part flows to the downstream exit faces (Q_d). These values are related to the discharge of the case without filter (Q_o). Figure (5-a&b) indicate that the value of Q_d/Q_o, which represents the relative loss of water, is decreased ,while the value of Q_t/Q_o is increased not only for increasing of L_f/L and D_f/L but also for decreasing the value of H_f/H. The value of Q_d/Q_o has an appreciable reduction for values of D_f/L up to 0.5.

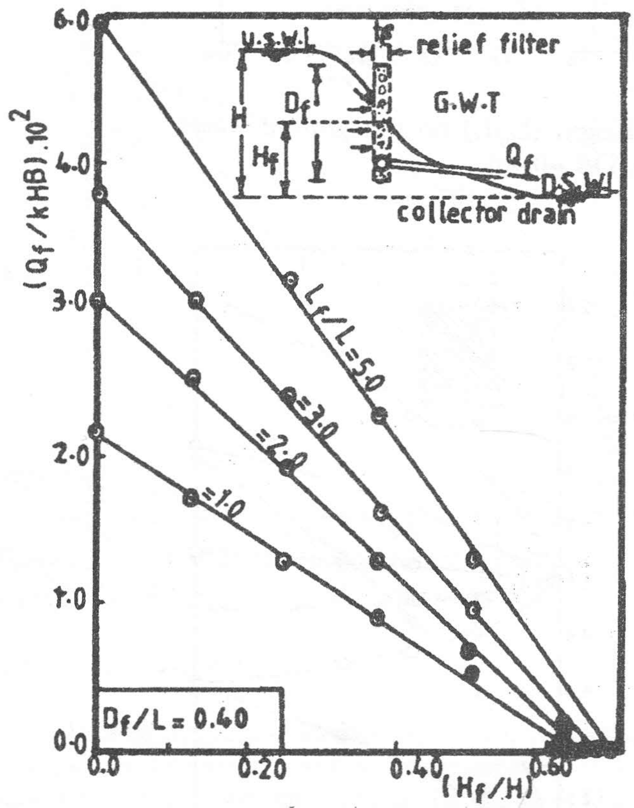

Figure 6. Relationship between filter discharge and filter head for various values of filter length.

For the investigated case, the value of Q_d/Q_o can be reduced by about 30% and 10% by using a filter dimension $L_f/L = 2.0$ and $D_f/L = 0.4$ for $H_f/H = 0.25$ and 0.5, respectively. Therefore, the filter head (H_f/H) is the active parameter in this system and it can be adjusted by the filter thickness (t_f) and the permeability of filter material. The figure also indicates that the quantity of seepage does not affected by the filter dimensions for the case of $Q_f=0$. The value of Q_f/Q_o is increased when the value of L_f/L or D_f/L is increased but it can be collected through the drain and considered in the surface hydraulic design. Figure (6) shows the relationship between H_f/H and dimensionless filter discharge (Q_f/kHB) for $D_f/L=0.40$ and for various values of L_f/L . The value of H_f/H is decreased when the relative filter discharge, which can be adjusted by the filter design, is increased. The maximum value of H_f/H, for the investigated case, lies between 0.63 and 0.66 ($Q_f=0.0$).

2- *Uplift pressure*

Figures (7) and (8) show the uplift pressure diagrams along the centerline and along the side edge of the structure. Figure (7) shows the effect of L_f/L on relative uplift pressures (U/H) for constant values of $D_f/L = 0.4$ and $H_f/H = 0.25$. The uplift pressure values are decreased for increasing L_f/L. The reduction in uplift pressures have appreciable values for L_f/L up to 1.0. The uplift pressure diagram along the side edge is affected than the centerline diagram. For $L_f/L = 1.0$, the reduction in pressures downstream the cut off is varied between about 35% and 10% along the side edge, while it is varied between about 10% and 5% along the centerline. Figure (8) shows the effect of H_f/H on U/H diagram for constant values of $L_f/L = 2.0$ and $D_f/L = 0.40$.The figure indicates that the uplift pressures are decreased for decreasing the value of H_f/H. The reduction in U/H diagram along the side edge is also more than that of the centerline diagram because the relief filter is constructed behind the side edge of the structure. For $H_f/H = 0.25$, the reduction in pressure diagram downstream the cutoff is ranged between 35% and 14% along the side edge, while it is ranged between 13% and 5% along the centerline.

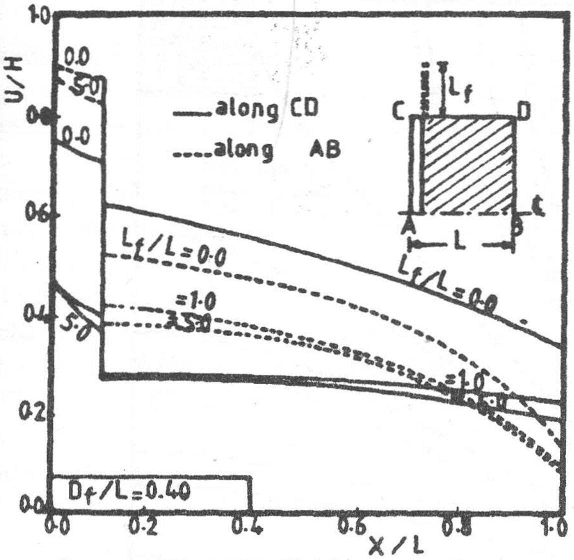

Figure 7. Effect of the relative filter length on the uplift pressure diagrams under the structure (H_f/H=0.25).

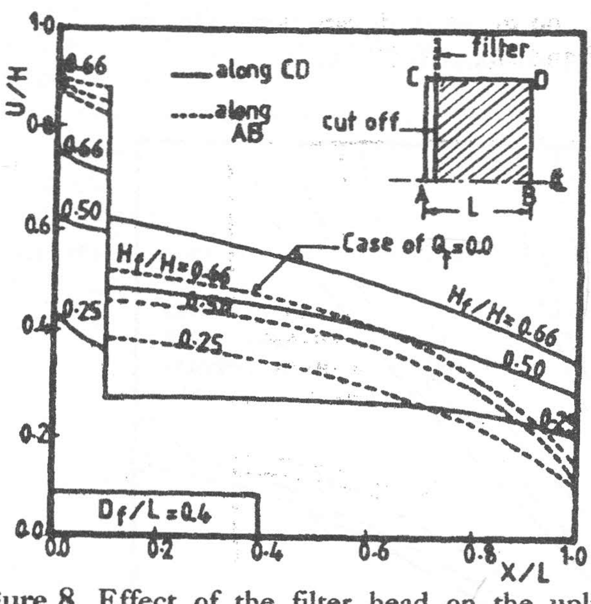

Figure 8. Effect of the filter head on the uplift pressure diagrams under the structure (L_f/L=2.0).

Figure (9) shows a comparison between the effect of both lateral cutoff and relief filter, for the same dimensions (L_s/L = L_f/L=2.0 and D_s/L=D_f/L=0.4), on the uplift pressure contours under the structure. The figure also shows the case without lateral cutoff (L_s=0) and without filter (L_f=0). The figure indicates that the uplift pressures are decreased due to each of the two suggested systems. The lateral cutoff system gives more reductions in uplift pressures than the filter system.

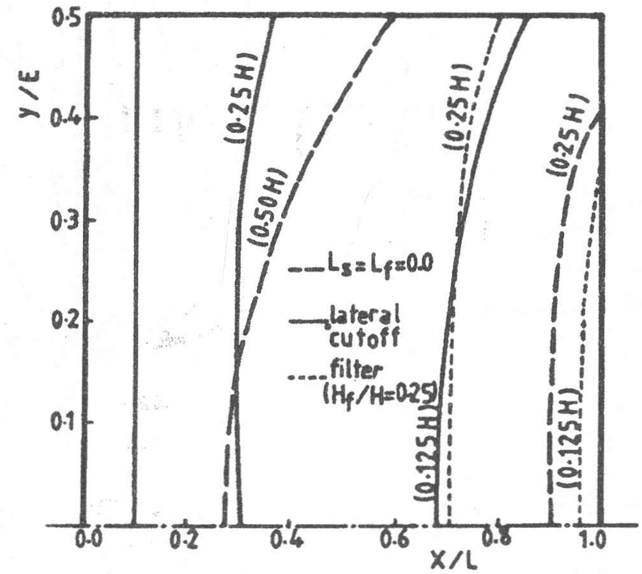

Figure 9. Comparison between cutoff and filter effect on uplift pressure contours under the structure (L_s/L=L_f/L=2.0&D_s/L=D_f/L=0.40).

3- *Ground water Table (G.W.T)*

Figure (10) shows the effect of L_f/L on the ground water contours around the investigated hydraulic structure for constant values of D_f/L and H_f/H. As shown in the figure, the G.W.T contours have appreciable variations due to the change of L_f/L. For increasing the value of L_f/L, the contours move to the upstream side, therefore, the exit velocity gradients from the downstream channel bed and sides; and lateral pressures along the structure side are decreased. Figure (11) shows the effect of H_f/H on the G.W.T for constant values of L_f/L and D_f/L. The contours of G.W.T are also moved to the U.S channel by decreasing the value of H_f/H. Therefore, the D.S channel bed and sides and structure sides can be insured against gradient pressures by decreasing the filter relative head (H_f/H).

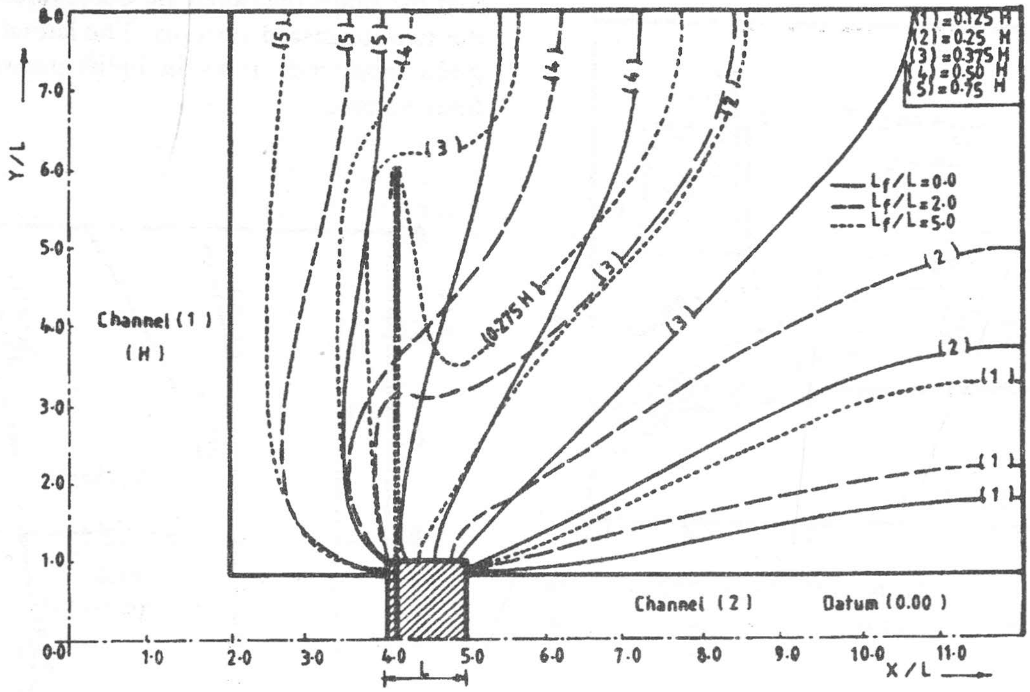

Figure 10. Effect of the relative filter length (L_f/L) on the ground water levels around the structure (D/L-0.4-D_f/L=0.4 and H_f/H=0.25).

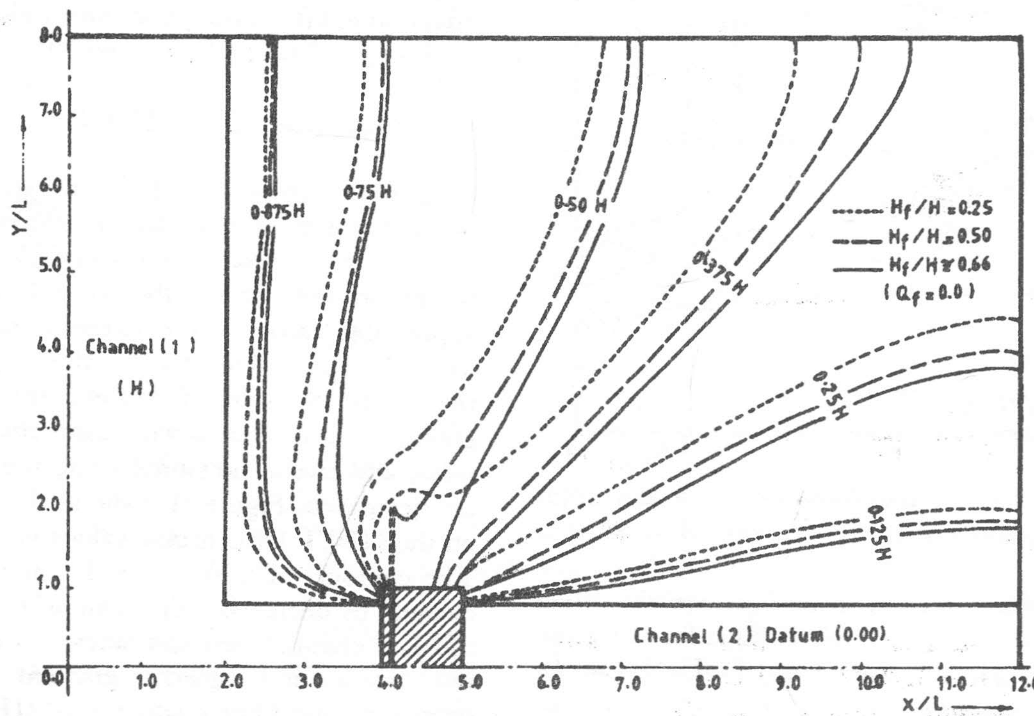

Figure 11. Effect of the relative filter length (H_f/H) on the ground water levels around the structure (D/L-0.4-D_f/L=0.4 and L_f/L=1.0).

CONCLUSIONS

Eiether, a Lateral cutoff, or a lateral relief filter is suggested to control the seepage around a water branching hydraulic structure with a single cutoff. The effect of the parameters of each system are studied on the seepage characteristics. The analysis of the experimental results gives the following conclusions:

1- The lateral cutoff system gives a considerable effect on uplift pressures and a slight effect on both quantity of seepage and variation of G.W.T.

2- The relief filter system gives an appreciable effect on all seepage characteristics which may be summarized as follows:

i) The D.S exit discharge and exit gradients, in both bed and sides, could be decreased by increasing filter dimensions or by decreasing filter head.

ii) The filter discharge, which is collected by drains, could be considered in the hydraulic design of the structure.

iii) The uplift pressures could be decreased by decreasing filter head or by increasing the relative filter length L_f/L upto 1.0.

iv) The G.W.T through the structure region can be controlled by filter head and/or filter dimensions.

3- The relief filter system is recommended for controlling the seepage around hydraulic structures.

Acknowlegment

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