SEEPAGE UNDERNEATH DROP STRUCTURES CONSTRUCTED IN LINED CANALS

Mohammed A.Elganainy and Yousry Ghazaw
Hydraulics and Irrigation Engineering Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

The present paper is intended to investigate the characteristics of seepage flow beneath a drop structure constructed in a lined canal. The seepage occurs through limited cracked zones in the canal lining just upstream and downstream the solid floor. The structure has a single drop and provided with an end sheet pile. A pervious layer under the structure is assumed, such a layer is extended in the upstream and downstream direction, and downward to infinity. The finite element model with proper boundary conditions is used to simulate the seepage flow. The obtained results are verified using experimental measurements performed on electrical analogue model and good agreement is found to exist. Design charts are presented to calculate; the uplift pressures, maximum exit gradient, and the seepage discharge.

Keywords: Drop structures, Canal falls, Seepage, Finite element, Lined canals.

INTRODUCTION

In Egypt, the per capita cultivated area which was 0.51 fed. in 1897, 0.19 fed in 1960, is now only about 0.12 fed. To keep the per capita share of the agricultural area from decreasing still further, it is necessary to add new areas at rate of at least 150 000 fed./year [1, 6].

Due to the shortage of water required for irrigation, the irrigation system has to be improved to include the lining of canals, especially in the new reclaimed land, where the losses of water by percolation through the bed and walls of channel are quite high.

The mean ground surface slope in newly reclaimed desert areas is about 200 cm/km. Canals constructed in such lands with steep slopes must be provided with drop structures (falls) at appropriate places to reduce their longitudinal slopes. Elhamam canal, Figure (1), in the western Nubaria zone is an example for such canals. Such drop structures usually suffer from high values of heading up. Cracks may occur close to the upstream and the downstream edges of the structure's floor. This possibility comes from the difference in rigidity of the structure's floor and the canal lining. The seepage forces due to such cracks must be considered.

The work reported in the present paper covers the study of the characteristics of the seepage flow underneath the floors of single drop heading-up structures built in lined canals, and provided with end sheet piles. Upstream and downstream cracks of equal widths are assumed. An example of such structures is the clear overall weir, shown in Figure (2). A similar study is carried out for the case of drop structures founded in earthen canals, [3]. The studied seepage characteristics include the following:

1) The uplift pressures acting along the subsurface contour of the floor.
2) The maximum exit gradients at the downstream edge of the floor, point (G).
3) The seepage discharge underneath the structure.

The finite element method [8] is used to solve the problem. A computational model is designed to calculate the required seepage characteristics. The model is tested and verified. The accuracy of the results is assessed using an electrical analogue method [9]. The results are presented in the form of design charts. The effect of the variables on the seepage characteristics are discussed.

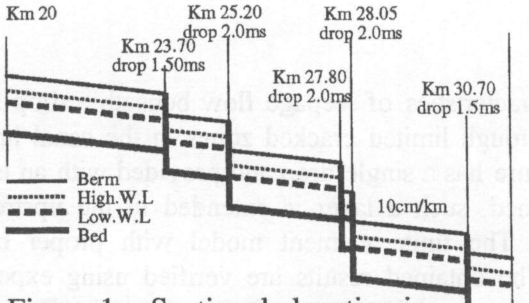


Figure.1.- Sectional elevation in El-Hammam canal, 3rd stage

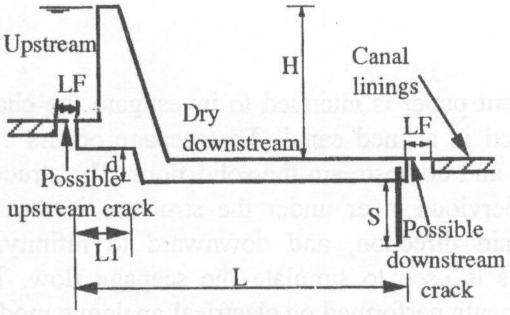
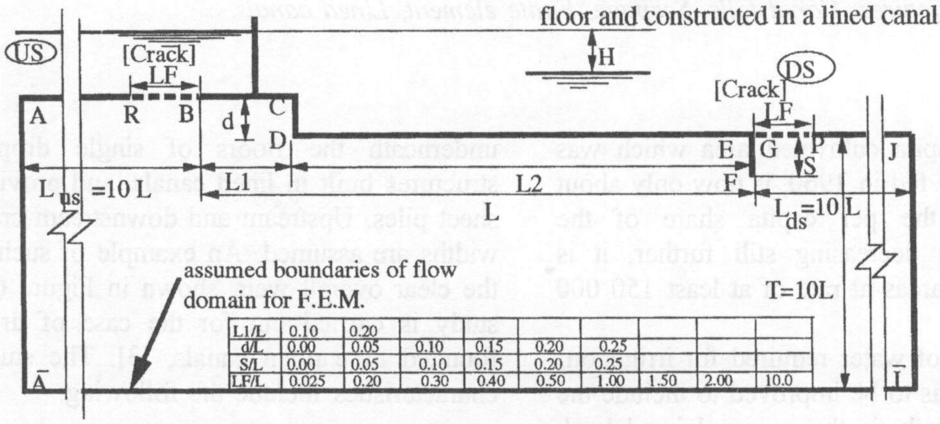


Figure. 2.-Definition sketch for a clear overfall weir provided with a single drop and a sheet pile at the downstream edge of the floor and constructed in a lined canal.



L1/L	0.10	0.20							
d/L	0.00	0.05	0.10	0.15	0.20	0.25			
S/L	0.00	0.05	0.10	0.15	0.20	0.25			
LF/L	0.025	0.20	0.30	0.40	0.50	1.00	1.50	2.00	10.0

Figure .3.- A schematic sketch for the proplem.

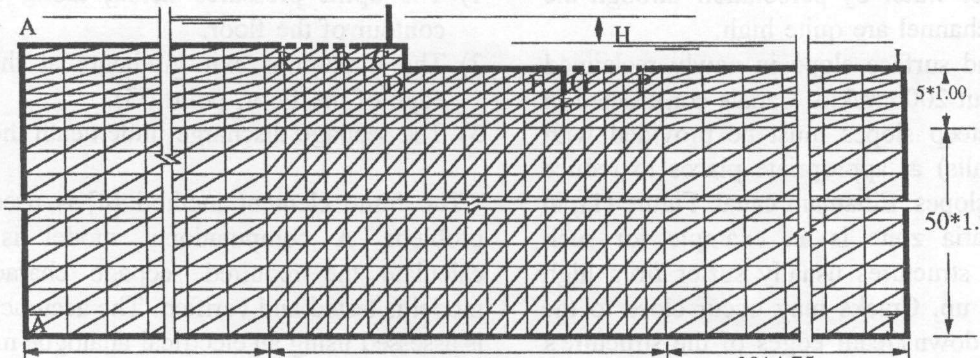


Figure. 4.- Finite element Mesh for a general case of a single drop structure built in a lined canal and provided with an end sheet pile at the downstream floor edge.

STATEMENT OF THE PROBLEM

The problem is shown schematically in Figure (3). The structure is founded in a homogeneous isotropic soil and is built in a lined canal. The effective head on the structure is (H). The floor of the structure has a drop depth d, located at distance L1 from its upstream edge. It has also a sheet pile located at the downstream edge and having a depth S. The projection of the floor on the horizontal has a length equal to L. The upstream and downstream cracked zones are equal, each having an overall length LF.

Preliminary studies show that increasing the values of T/L, Lus/L and Lds/L, more than 10 has negligible effects on the seepage characteristics. Therefore values for the length of both upstream and downstream reaches equal Lus=Lds=10L, and a value for the depth of the pervious layer equal T=10L were considered. The selected dimensions agree with those values recommended by Muthukumaran and Kulandaiswamy, [7], and appropriately represent infinite dimensions of porous media.

The objective of the present study is to determine the effect of the main parameters on the seepage characteristics, Such parameters can be written in dimensionless forms as follows: [LF/L, L1/L, d/L, S/L, and H/L]

THE BOUNDARY CONDITIONS

The velocity potential, ϕ, and the stream function, ψ, of the seepage flow satisfy the two-dimensional Laplaces's equation, [4] ;

$$\nabla^2\phi = \nabla^2\psi = 0.0 \qquad (1)$$

In the present study ϕ=-kh, in which h is the head (p/ρg+z), and k denotes the coefficient of permeability. where p is pressure intensity, ρ is water density, and z is elevation.

Referring to Figure (3), the inlet face along the upstream bed (RB) and the exit face along the downstream bed (GP) are both equipotential lines. Without losing the generality, the following relations can be written:

$$\left.\begin{aligned} \text{Along RB}\,\phi_{RB} &= -kH \\ \text{Along GP}\,\phi_{GP} &= 0.0 \end{aligned}\right\} \qquad (2)$$

This effectively assumes a datum at the downstream water surface.

The first streamline, ψ=0, coincides with the subsurface contour of the floor (BCDEFG) and the last streamline, ψ=q coincides with the outer boundary (RA $\overline{\text{AJ}}$ JP), The flow is coming from the inlet face (RB) and draining out through the exit face (GP). Thus

$$\left.\begin{aligned} \text{Along BCDEFG}\,\frac{\partial\phi}{\partial n} &= 0.0 \\ \text{Along RA}\overline{\text{AJ}}\text{JP}\,\frac{\partial\phi}{\partial n} &= 0.0 \end{aligned}\right\} \qquad (3)$$

where n is the normal direction to the flow.

METHOD OF ANALYSIS AND MODEL DIMENSIONS

The governing equation (1) has been solved numerically using the finite element method, for the given boundary conditions using the Galerkin formulation [2]. Adopting the shape function [N] as the weights, the weighted- residual of an element is given by

$$R^e = -\int_A [N]^T\left(k_x\frac{\partial^2\phi}{\partial x^2} + k_y\frac{\partial^2\phi}{\partial y^2}\right)dA \qquad (4)$$

Applying the Green's theorem and the principle of finite element, the equilibrium equation for the seepage problem can be reduced to

$$\sum k^e\phi = \{f\} \qquad (5)$$

where {f} = flow rate of point sources or sinks

$$k^e = -\int_A [B]^T[D][B]\,dA \qquad (6)$$

The [B] and [D] matrices are given by

$$[B]^T = \left[\frac{\partial [N]^T}{\partial x} \;\; \frac{\partial [N]^T}{\partial y} \right] \text{and} \, [D] = \begin{bmatrix} k_x & 0 \\ o & k_y \end{bmatrix} \qquad (7)$$

The confined flow problem under consideration can be solved by the direct application of equation (5).

The Finite Element Program FEM2DV2 [8] is used to calculate the required seepage characteristics. Four hundred and fifty runs of the computer program were carried out. Each run is characterised by certain dimensions for the floor and the length of the cracked zone. The dimensions of the flow domain beneath the floor are discretized automatically using a specially designed subroutine. The relative dimensions of the structure are shown in Figure (3). Figures (4) shows the finite element mesh for the flow domain for case of L1/L=0.20, d/L=0.20, S/L=0.25 and F/L=0.30.

EXPERIMENTAL VERIFICATION

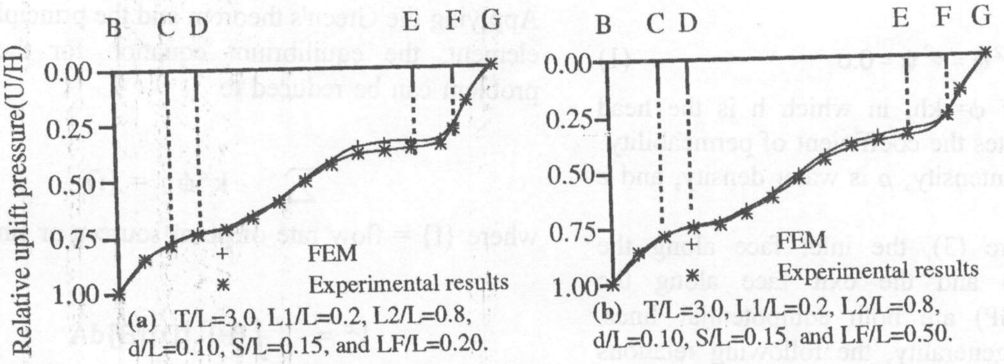
In order to verify the calculated results from the numerical model, a twelve tests using electrical analogue method have been carried out. A set of typical results is presented in Figure (5), where uplift pressure along the subsurface structure contour is plotted from both experimental and numerical results for the same dimensionless parameters. Upon observing the curves in these Figures one can immediately see that a good agreement between experimental and theoretical results prevails. The maximum value of the percentage error between the experimental results and numerical results is less than 5%. This effectively substantiates the use of the FEM. by virtue of its accuracy and versatility.

ANALYSIS OF RESULTS

The obtained results are used to:

1- Show the individual effect of each of the considered parameters on the studied seepage characteristics, Figures (6.a, b, and c).
2- Prepare design charts, which can be used directly by the designer to calculate the required seepage characteristics in practice, Figures (7) and (8).

The results show that for all the tested values the relative uplift pressures at point (C) increases with increasing of drop depth (d/L). The increase of drop depth (d/L) causes a decrease in the relative uplift pressures at point D, (UD/H). The increase in the drop depth practically has no effect on the relative uplift pressures (UE/H) and (UF/H) at points (E) and (F), respectively, Figure (6.a). These effects are consistent with the relative position of points C, D, E, and F in relation to the position of the drop depth. Increasing the drop depth d, causes an increase in the total length of the subsurface contour. Therefore it produces a significant decrease in the values of the relative exit gradient at point (G) [Imax/(H/L)]. Figure (6.a) shows also an insignificant reduction in the seepage discharge (q/KH) as drop depth increases.



(a) T/L=3.0, L1/L=0.2, L2/L=0.8, d/L=0.10, S/L=0.15, and LF/L=0.20.

(b) T/L=3.0, L1/L=0.2, L2/L=0.8, d/L=0.10, S/L=0.15, and LF/L=0.50.

Figure.5.- Relative uplift pressure distribution along the subsurface contour.

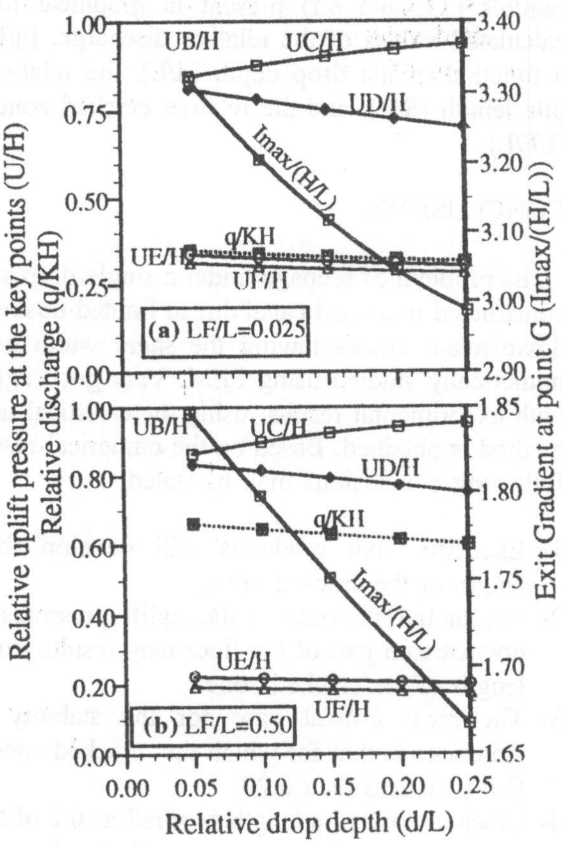


FIG. 6.a- Effect of the relative drop depth (d/L), on the relative uplift pressure along the subsurface contour of the floor, exit gradient at point G, and relative discharge (q/KH). (L1/L=0.10, S/L=0.10)

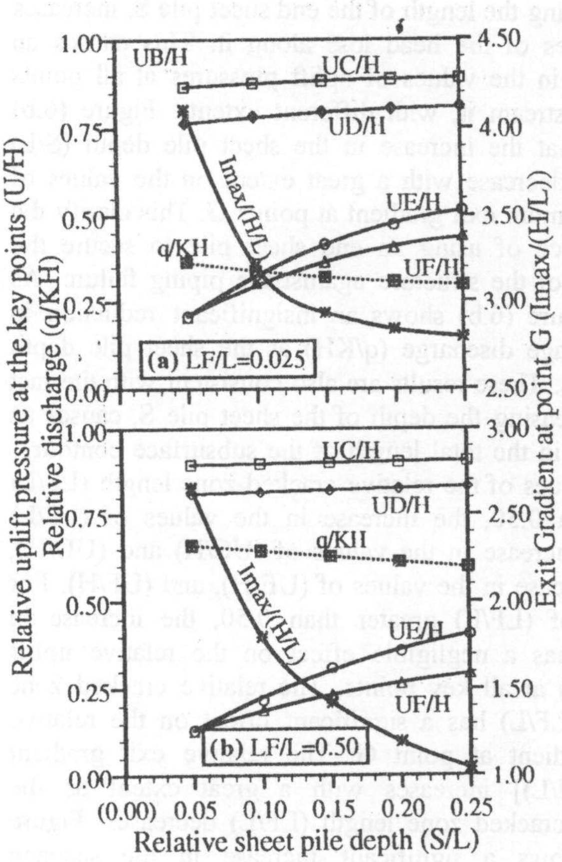


FIG. 6.b- Effect of the relative sheet pile depth (S/L), on the relative uplift pressure along the subsurface contour of the floor, exit gradient at point G, and relative discharge (q/KH). (L1/L=0.10, d/L=0.10)

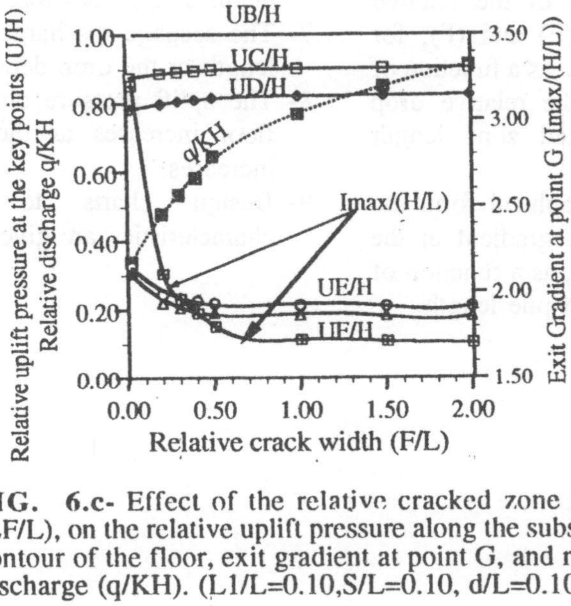


FIG. 6.c- Effect of the relative cracked zone length (LF/L), on the relative uplift pressure along the subsurface contour of the floor, exit gradient at point G, and relative discharge (q/KH). (L1/L=0.10,S/L=0.10, d/L=0.10)

Increasing the length of the end sheet pile S, increases the values of the head loss along it. This causes an increase in the values of uplift pressures at all points lying upstream it, with different extents. Figure (6.b) shows that the increase in the sheet pile depth (S/L) cause a decrease with a great extent on the values of the maximum exit gradient at points G. This clarify the importance of using an end sheet pile to secure the stability of the structure against the piping failure. As well Figure (6.b) shows an insignificant reduction in the seepage discharge (q/KH) as the sheet pile depth increases. These results are also consistent with the fact that increasing the depth of the sheet pile S, causes an increase in the total length of the subsurface contour.

For values of the relative cracked zone length (LF/L) less than 0.50, the increase in the values of (LF/L) causes increase in the values of (UC/H) and (UD/H), and decrease in the values of (UE/H), and (UF/H). For values of (LF/L) greater than 0.50, the increase in (LF/L) has a negligible effect on the relative uplift pressures at all key points. The relative cracked zone length (LF/L) has a significant effect on the relative exit gradient at point G. The relative exit gradient [Imax/(H/L)] increases with a great extent as the relative cracked zone length (LF/L) decreases. Figure (6.c) shows a significant increase in the seepage discharge (q/KH) occurs as relative cracked zone length (LF/L), increases.

The graphical correlation method [5] and the computer statistical facilities are used to construct the design charts shown in Figures (7) and (8).

Figures (7.a, b, c, d, and 8.a, b, c, d) present in graphical form the calculated values of the relative uplift pressures at points (C), (D), (E) and (F); for L1/L=0.10 and L1/L=0.20; respectively as a function of the relative sheet pile depth (S/L), the relative drop depth (d/L), and the relative cracked zone length (LF/L).

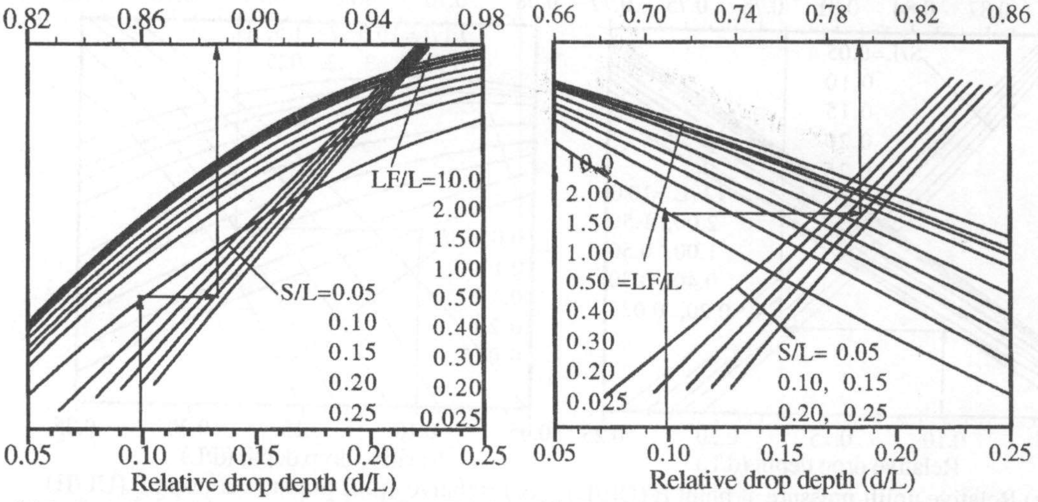
Figures (7.e, and 8.e) present in graphical form the calculated values of the relative exit gradient at the downstream edge of the floor, point G, as a function of the drop depth (d/L), the relative sheet pile length (S/L), and the relative cracked zone length (LF/L). Figures (7.f, and 8.f) present in graphical form the calculated values of the relative discharge, [q/KH], as a function of the drop depth (d/L), the relative sheet pile length (S/L), and the relative cracked zone length (LF/L).

CONCLUSIONS

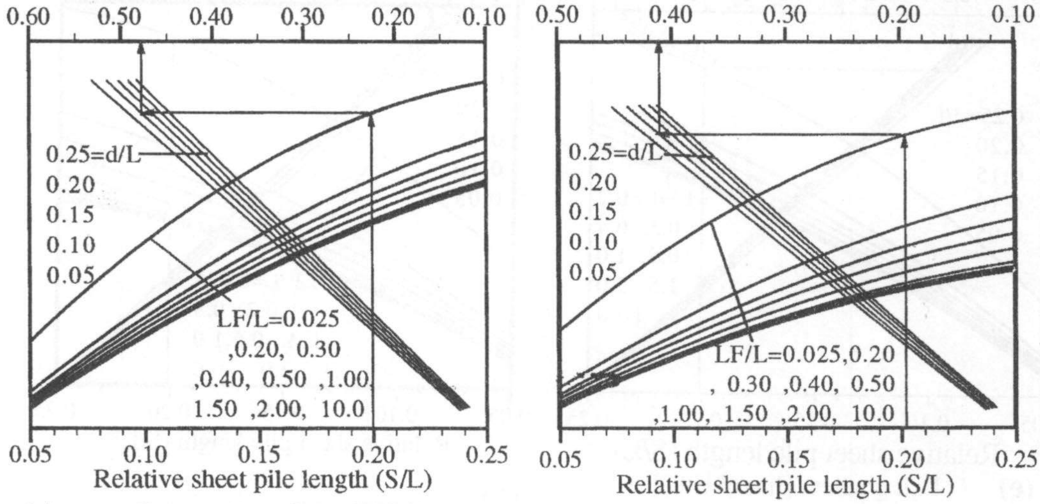
The problem of seepage under a single drop structure constructed in a lined canal due to limited upstream and downstream cracks having the same width has been numerically studied using FEM. Very good agreement with experimental results, using the electrical analogue method is obtained. Based on the numerical results, the following conclusions may be stated;

1- Excessive exit gradients will develop for short length of the cracked zone.
2- Substantial increase in the uplift pressures on the downstream part of the floor may results from short length of the cracked zone.
3- The most critical case for the stability of the structures is that for which the cracked zone length (LF/L) is less than 0.20.
4- Cracked zone of a length as small as 0.2 of the floor length may produce a seepage discharge amounting to 40% of that for unlined canal.
5- Excessive exit gradients will develop for short sheet pile.
6- The uplift pressure at the upstream part of the structure will increase with the increase of the drop depth of the floor (d/L).
7- The seepage discharge decreases as the sheet pile length or the drop depth of the floor increases.
8- The uplift pressure on the downstream part of the floor increases as the relative sheet pile length increases.
9- Design charts to determine the seepage characteristics are given in Figures (7, 8).

(a) Relative uplift pressure at point C (UC/H) **(b)** Relative uplift pressure at point D (UD/H)



(c) Relative uplift pressure at point E (UE/H) **(d)** Relative uplift pressure at point F (UF/H)



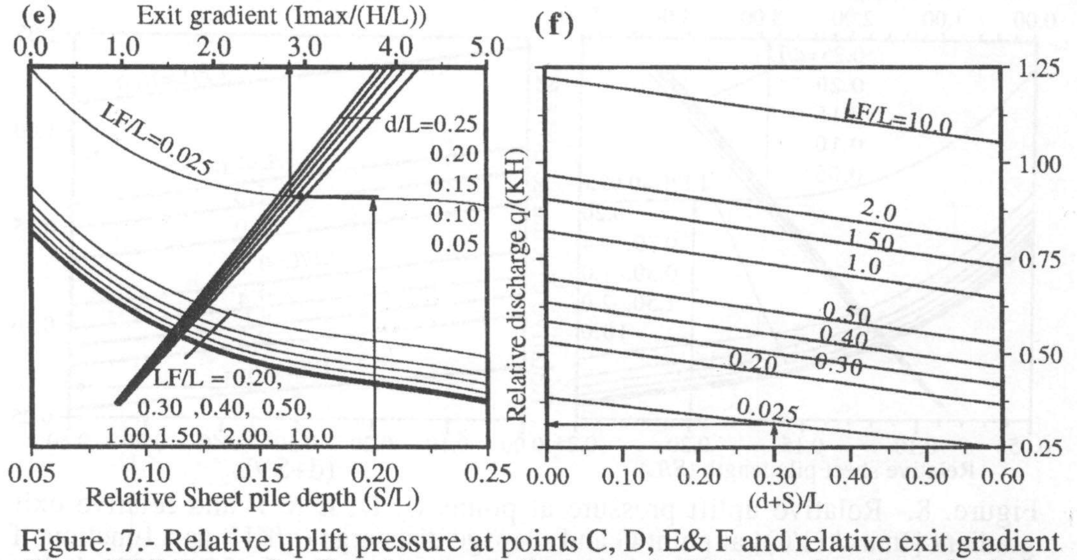


Figure. 7.- Relative uplift pressure at points C, D, E& F and relative exit gradient [Imax/(H/L)] at point G and seepage discharge (q/KH) as a function of relative cracked zone length (LF/L), relative sheet pile depth (S/L), and relative drop depth (d/L). for (L1/L=0.10)

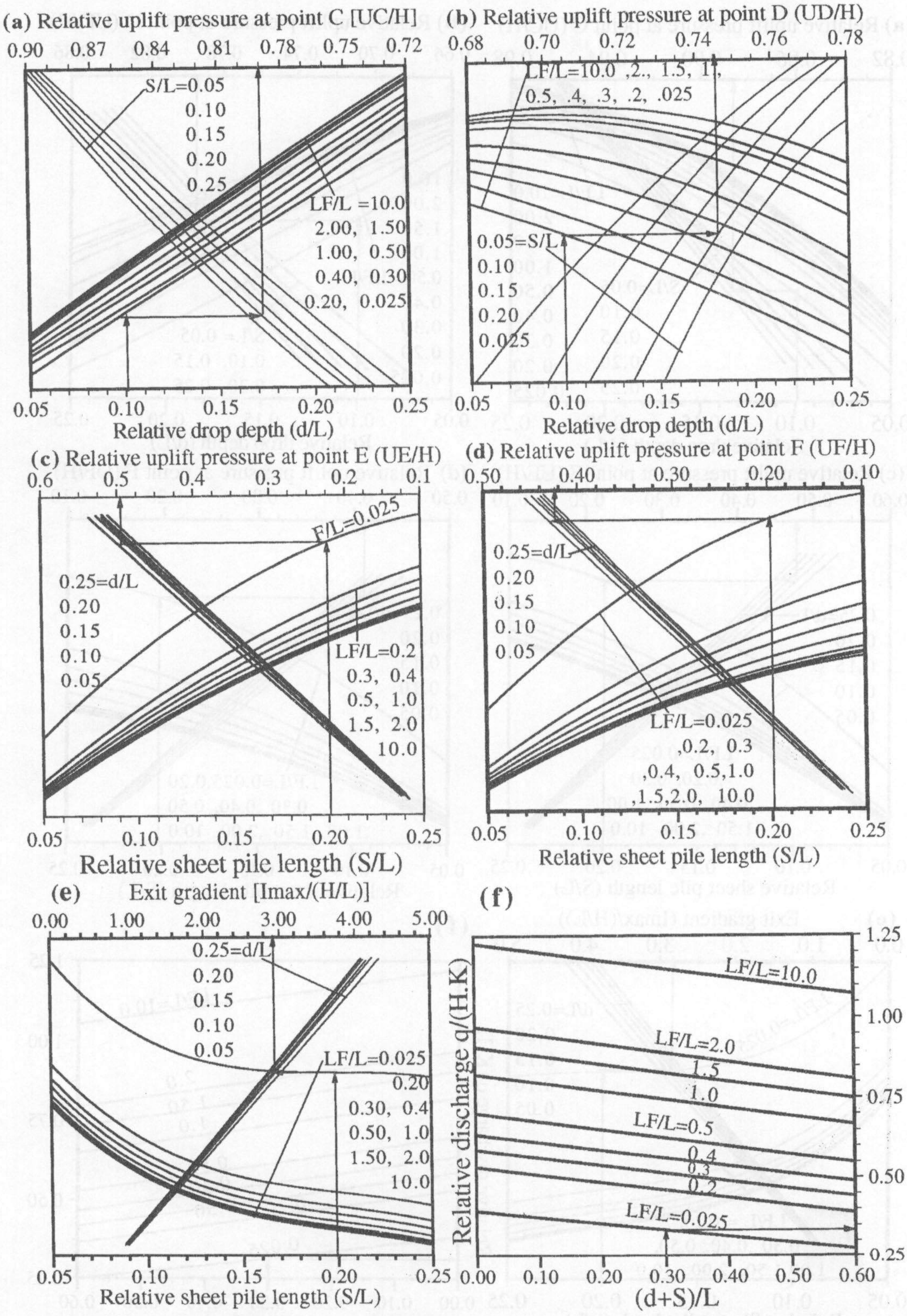


Figure. 8.- Relative uplift pressure at points C, D, E & F and relative exit gradient [Imax/(H/L)] at point G and seepage discharge (q/KH) as a function of relative cracked zone length (LF/L), relative sheet pile depth (S/L), and relative drop depth (d/L), for (L1/L=0.20).

Appendix I.

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Appendix II.

Notation:

The following symbols are used in this paper:

BCDEFG = subsurface contour of the floor;
d = drop depth;
LF = length of cracked zone;
Fed. = 4200.81 ms2
FEM = finite element method;
FEM2DV2 = two dimensional finite element program;
g = gravitational acceleration;
GP = exit face;
H = head difference between upstream and downstream water levels;
Imax = exit gradient at point G;
k = hydraulic conductivity;
L = projection of the impervious floor on the horizontal;
L1 = length of the upstream floor apron;
L2 = length of the downstream floor apron;
Lds = Length of the downstream reach;
Lus = Length of the upstream reach;
$p/\gamma H$ = relative pressure head
q = quantity of seepage per unit length of the structure;
RB = inlet face;
S = depth of the end sheet pile;
T = pervious stratum depth;
UC,UD,UE and UF = uplift pressure at points C, D, E, and F, respectively;
z = position head, measured upward from the downstream water level;
[N] = shape function;
ρ = water density;
ψ = stream function; and
ϕ = velocity potential.