SEEPAGE UNDER THE FLOOR OF A PUMPING STATION DUE TO CRACKS IN THE CANAL LINING

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ABSTRACT

The problem of seepage under the floor of a pumping station, resulting from limited upstream and downstream cracks in the canal lining is investigated using the boundary-element method. The floor is provided at upstream and downstream ends with sheet piling walls and it has an intermediate vertical rise . The pumping station is resting on a permeable layer of finite depth. Effects of the different parameters on the velocity potential along the floor-soil interface and on the exit gradients along the upstream crack have been analyzed and graphically illustrated.

KEYWORDS

Seepage, pumping station, lined canal, cracks, sheet piling walls, boundary-element method, velocity potential, exit gradient.

NOTATIONS

The following symbols are used in this paper :

B	horizontal length of the floor;
B_1	location of the vertical rise;
b_1	B_1/B, relative location;
D	depth of the sheet piling walls;
d	D/B, relative depth;
D'	height of the vertical rise;
d'	D'/B, relative height;
G_E	exit gradient;
H	static pumping head;
h	H/B, relative static head;
k	coefficient of permeability;
L_1, L_2	distances between floor edges and the upstream and the downstream cracks, respectively;
l_1, l_2	L_1/B, L_2/B, relative distances;
p	pressure at any point in the flow domain;
Q	seepage discharge per unit width of the floor;
T	thickness of the pervious layer;
t	T/B, relative thickness;
$u = \phi/k = p/\gamma+z$	potential head;
W_1, W_2	widths of the upstream and the downstream cracks, respectively;
w_1, w_2	W_1/B, W_2/B, relative widths;
X_1	horizontal distance, downstream from the upstream edge of the floor;
X_1'	distance along the contact and interface surfaces, downstream from the upstream edge of the floor;
X_2	horizontal distance, upstream from the downstream end of the upstream crack;
x_1, x_1', x_2	X_1/B, X'_1/B, X_2/B, relative distances;
z	position head, measured upward from the upstream water level;
$\phi = k\,u$	velocity potential;
γ	unit weight of water.

INTRODUCTION

For some of the newly reclaimed desert areas e.g. as in the Nobaria area at the western desert of Egypt, pumping of water for irrigation through lined canals may be considered as the most economic alternative compared to pipelines or unlined canals. Limited cracks may, however, develop in the lining at the upstream (U/S) and/or the downstream (D/S) of the pumping station. The resulting changes in the uplift pressures on the floor and the exit velocity gradients may endanger the stability of the structure. A thorough analysis of such changes is, therefore, necessary.

In general, the problems of two-dimensional, confined seepage beneath hydraulic structures have been investigated analytically, numerically, and/or experimentally, for different boundary conditions and floor configurations, [1-4], but mostly for unlined canals. The problem of seepage under a simple flat floor due to lining cracks has been investigated by the authors [5] and the results were compared with the conformal mapping solution by Chawla [6] and with the line source - line sink approach by Hathoot [7]. In the present study, the two-dimensional seepage beneath the floor of a pumping station, constructed in a lined canal, is investigated, using the boundary-element method.

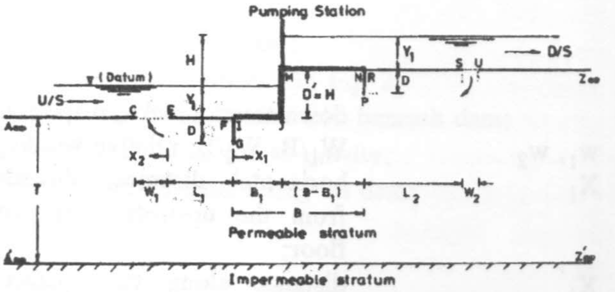

Figure 1. Physical model of the problem.

THE PHYSICAL MODEL

Figure (1) shows the outlines of the physical model of the problem. The total horizontal length, B, of the floor is divided into two parts of lengths B_1 and $(B-B_1)$, by a vertical rise of a height D'. Assuming equal U/S and D/S water depths,then $D'=H$, the static pumping head. The floor has two sheet piling walls (SPWs) of equal depths D, at the U/S and the D/S ends. The permeable stratum is homogenous, isotropic, having constant coefficient of permeability, k, and finite depth, T. It is assumed that seepage occurs due to two limited cracks in the lining, of widths W_1 and W_2, at distances L_1 and L_2 from the floor edges. The U/S crack, CE, represents the exit surface and the D/S crack, SU, represents the inlet one. The physical parameters of the problem can be written in dimensionless forms as; $b_1 = B_1/B$, $h = H/B = D'/B = d'$, $d = D/B$, $t = T/B$, $w_1 = W_1/B$, $w_2 = W_2/B$, $l_1 = L_1/B$ and $l_2 = L_2/B$.

APPLICATION OF THE BOUNDARY-ELEMENT METHOD

For the application of the boundary- element method, the idealized form of the current problem is as shown in Figure (2). It is a mixed boundary-value problem, with the potential head, $u = \phi/k = (p/\gamma) + z$, or the flux q, specified on each portion of the boundary surfaces, S, where ϕ is the velocity potential, (p/γ) is the pressure head and z is the position head, measured upward from the U/S water level. At any point $(x_i, i=1,2)$ in the flow domain, Ω, Laplace's equation is given by :

$$u(x)_{,ii} = 0 \tag{1}$$

The corresponding components of the flow vector v_i are given by Darcy's law as :

$$v_i = -k\,u_{,i} \tag{2}$$

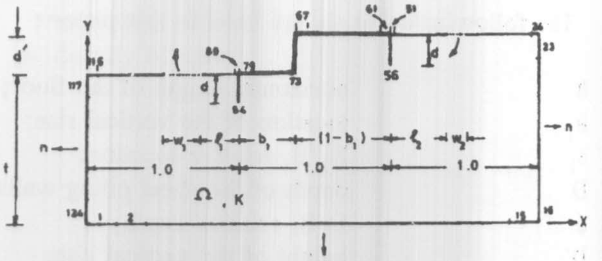

Figure 2. Idealization of the problem.

The boundary conditions for the idealized form are :

- The potential, u, along the U/S and the D/S cracks has the values : u = 0 and u = h, respectively.
- The rest of the boundary surfaces, including the SPWs, are impervious,with zero flux normal to them.

The solution of equation (1) together with these boundary conditions yields the unknown values of the potential along the impervious boundaries and the flux along the two cracks. The application of the boundary-element method to such a problem has been briefly outlined in reference [5]. Detailed presentation can be found in [7,8].

RESULTS AND DISCUSSION

a - Velocity Potentials and Pressures

Effects of the different parameters on the velocity potentials along the floor and the SPWs have been calculated and plotted, Figures (3) through (7). For convenience and representation of the results, the surfaces FGIJ...PR of the floor and SPWs, Figure (1), are spread horizontally. The total relative length of the resulting horizontal surface is equal to (1.0 + 4d + d'). The horizontal axis, x'_1, represents the relative distance, (X'_1/B), along this surface, measured from point F. Without loss of generality, it can be assumed that $Y_1 = Y_2 = 0$. The relative pressure head, $(p/\gamma H)$, at any point can be directly obtained from the relative velocity potential as follows :

$$p/(\gamma H) = \phi/(kH) - z/H \tag{3}$$

Thus, for the horizontal parts of the floor, as well as the lining itself, U/S and D/S of the vertical rise, the relative pressure head at any point is, respectively, given by :

$$p/(\gamma H) = \phi/(kH) \tag{4-a}$$

and

$$p/(\gamma H) = \phi/(kH) - 1.0 \tag{4-b}$$

As for the two SPWs and the vertical rise, the value of (z/H) varies linearly but the relative variation of $(p/\gamma H)$ will be similar to that of (ϕ/kH).

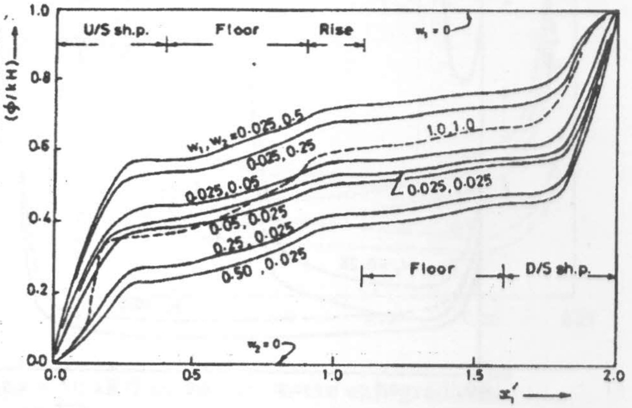

Figure 3. Effect of w_1 and w_2 on the velocity potential "ϕ" ($t = 1.0$ $\ell_1 = \ell_2 = 0$, $b_1 = 0.5$, $d = d' = 0.2$).

Figure (3) shows the effects of the relative widths, w_1 and w_2 of the U/S and the D/S cracks on the relative velocity potential, for $t = 1.0$, $l_1 = l_2 = 0$, $b1 = 0.5$ and $d = d' = 0.2$. As the width w_1 of the U/S crack decreases and/or the width w_2 of the D/S crack increases, the velocity potentials, hence, the uplift pressures on the floor build up gradually. In all cases, more than 75% of the total potential head, H, on the structure is dissipated along the two SPWs, of which about 65% is lost along their outer faces. For small values of (w_1/w_2), the U/S-SPW causes most of these losses and vice versa. The dashed curve, $w_1 = w_2 = 1.0$, approximates the conditions for unlined canals.

The effects of the relative thickness, t, of the pervious layer on the velocity potential are illustrated in Figure (4). Reducing this thickness from 1.0 to 0.25 results in a significant increase in the potential along the floor and the SPWs. For the horizontal parts of the floor, the average increase ranges between 9%, for $w_1 = 0.025$ and $w_2 = 0.250$, to about 50%, for $w_1 = 0.250$ and $w_2 = 0.025$. A smaller thickness of the pervious layer forces the flow lines to be concentrated in a narrow zone beneath the U/S SPW which causes a pressure build up on the floor. The greater the ratio w_1/w_2, the higher is the resulting percentage increase.

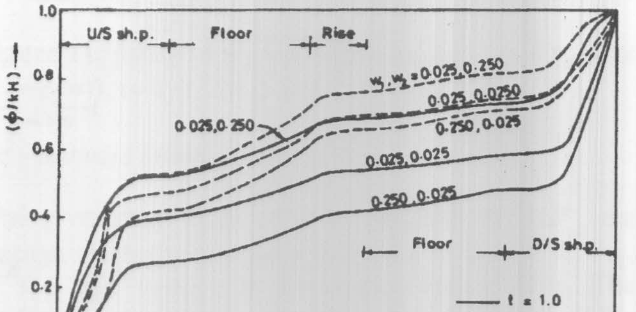

Figure 4. Effect of "t" on the velocity potential "ϕ" ($b_1 = 0.5$, $\ell_1 = \ell_2 = 0$, $d = d' = 0.2$).

The variation of the relative locations, l_1 and l_2, of the U/S and the D/S cracks introduces rather small changes in the velocity potential along the floor, Figure (5), except for the outer faces of the SPWs. Contrary to the case of a simple flat floor [5], the complex interrelationship between the different parameters here makes it very difficult to predict either the direction or the quantity of such changes.

The relative location, b_1, of the vertical rise has an insignificant influence on the potential values along the floor, as illustrated by Figure (6). However, equation (3) indicates that the uplift pressures are dependent on that location.

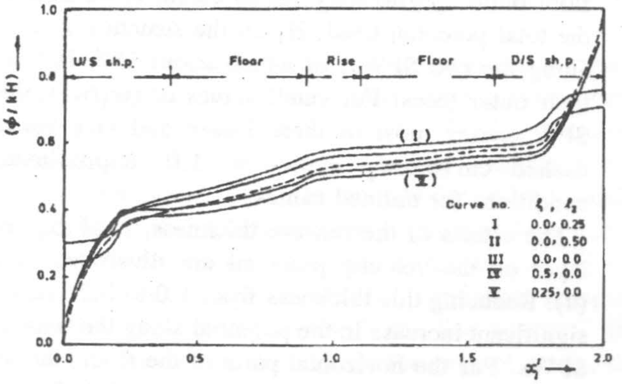

Figure 5. Effect of ℓ_1 and ℓ_2 on the velocity potential ($t=1.0$, $w_1 = w_2 = 0.025$, $d'=0.2$, $b_1=0.5$, $d = 0.2$).

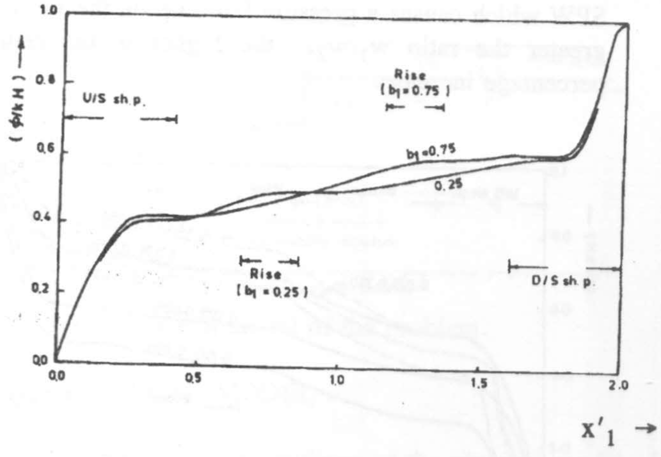

Figure 6. Effect of b on the velocity potential ($t=1.0$ $w_1=w_2=0.025$, $\ell_1 = \ell_2 = 0$, $d' = 0.2$).

As expected, the percentage of the total head, H, dissipated along the two SPWs increases, but with a decreasing rate, for greater relative depths, d, of the SPWs, Figure (7). Table (1) clearly shows that most of the head is dissipated along the outer faces of the two SPWs. Figure (7) also indicates that velocity potential and uplift pressures along the U/S part of the horizontal floor significantly increases when relatively shallow SPWs are used.

Table 1. Percentage Head Dissipated Along The different Elements (for $t=1.0$, $w_1=w_2=0.25$, $l_1=l_2=0.0$, $d'=0.2$, $b_1=0.5$).

SPW depth, d	0.00	0.10	0.20	0.30
Horizontal floor & rise	100	22.5	19.0	18.5
Inner SPWs surfaces	0.0	10.5	7.0	6.5
Outer SPWs surfaces	0.0	67.0	74.0	75.0

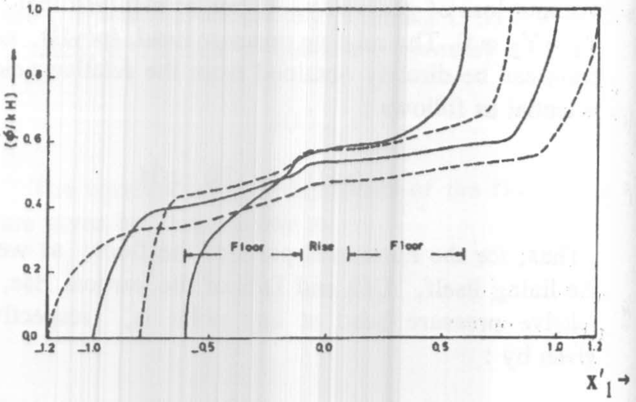

Figure 7. Effect of "d" on the velocity potential ($t=1.0$, $w_1=w_2=0.025$, $\ell_1=\ell_2=0$, $d'=0.5$).

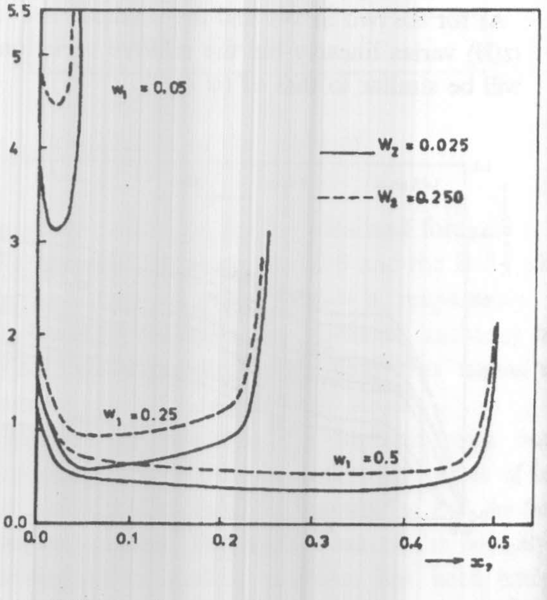

Figure 8. Effect of w_1 and w_2 on the exit gradients ($t=1.0$, $\ell_1=\ell_2=0$, $d=d'=0.2$, $b_1 = 0.5$).

b- Exit gradients

In the current problem, the U/S crack, CE, Figure (1), represents the exit surface whereas the D/S crack, SU, represents the inlet one. Figure (8) shows that the relative exit gradients, G_E/h, where $G_E = V_E/k$, V_E is the exit velocity, decrease rapidly as the width, w_1, of the U/S crack increases. They also decrease, but with a much smaller rate as the width, w_2, of the D/S crack decreases. For wide U/S crack, $w_1 > 0.5$, the effect of w_2 on the exit gradients becomes negligible.

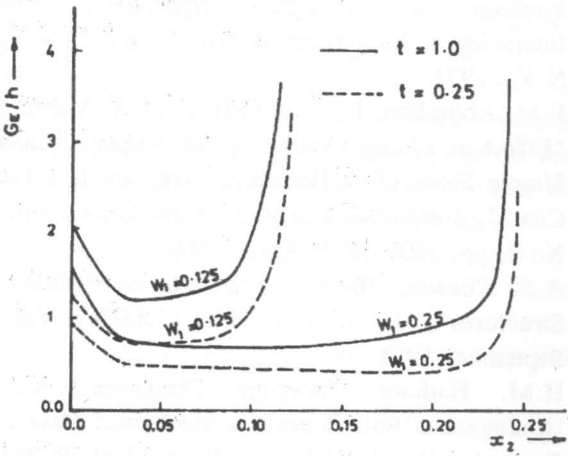

Figure 9. Effect of "t" on the exit gradients (w_2=0.025, $\ell_1=\ell_2$=0, d=d´=0.2, b_1 = 0.5).

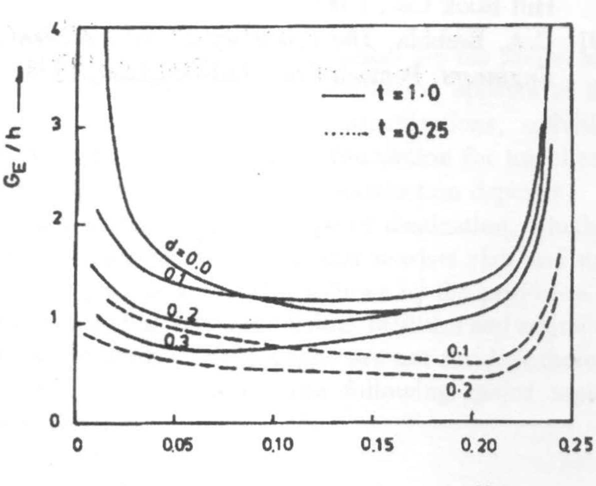

Figure 10. Effect of "d" on the exit gradients ($w_1=w_2$=0.025, $\ell_1=\ell_2$=0, d´=0.2, b_1 = 0.5).

The effects of the relative thickness,t, of the permeable layer on the exit gradients are illustrated in Figure (9). Though exit gradients become smaller for thinner permeable layer, they are not very sensitive to small variations of that thickness. If no U/S SPW is provided and/or the U/S crack is not adjacent to the floor, i.e. $l_1 > 0.0$, exit gradient values at both ends of the crack become theoretically infinity, as indicated by the curve : d = 0, Figure (10). The provision of an U/S SPW significantly reduces the exit gradients at the vicinity of the crack's end, E, close to the floor. Limited increase will occur at the U/S part of the crack for relative SPW depth $d < 0.2$. Similar variations are experienced for smaller thicknesses of the pervious layer.

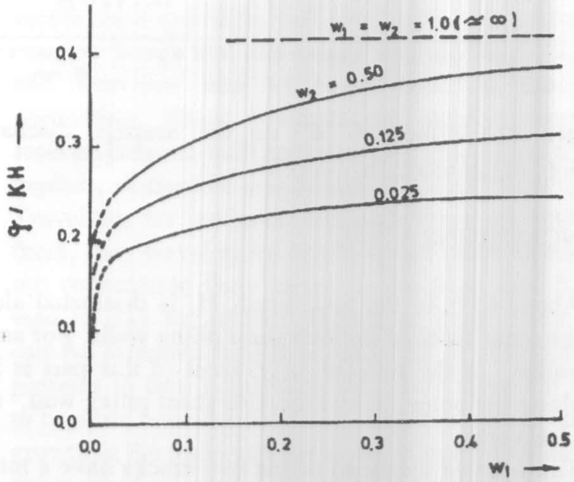

Figure 11. Effect of w_1 and w_2 on the seepage discharge ($\ell_1=\ell_2$=0, t=1.0, d=d´=0.2, b_1 = 0.5).

c - Seepage Discharge

For a constant width ,w_2, of the inlet surface , the seepage discharge gradually increases as the width, w_1, of the exit surface is increased, Figure (11). The discharge approaches a constant value for $w_1 > 0.5$. The variation of the inlet width ,w_2, while w_1 is kept constant , produces almost the same effects on the discharge. About 92% of the discharge corresponding to $w_1 = w_2 = \infty$, i.e. the no-lining discharge, is attained when both w_1 and w_2 are greater than 0.5. A crack width as small as 0.025 of the floor length will produce more than 42% of the no-lining discharge. Figure (12) shows that seepage discharge gradually decreases with the increase of the relative SPW depth, d. For narrow cracks, the discharge reaches a constant value as the depth ,d, exceeds 0.1. For wide cracks, however, it decreases continuously at a nearly constant rate. This indicates that the definition of narrow and wide cracks should be also related to the thickness, T, of the pervious layer.

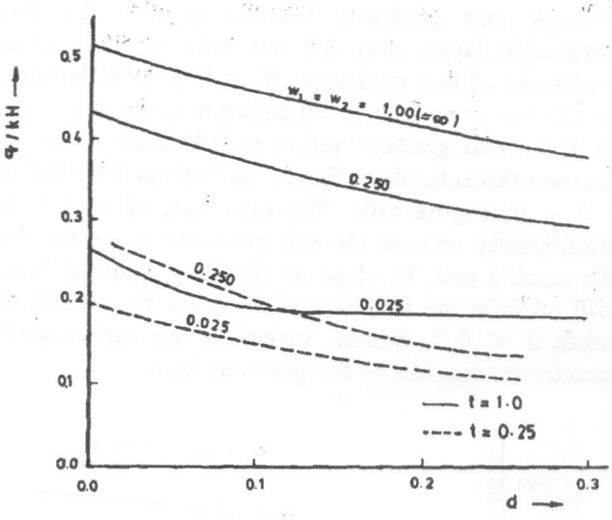

Figure 12. Effect of "d" on the seepage discharge ($\ell_1=\ell_2=0, d'=0.2, b_1 = 0.5$).

CONCLUSIONS

1. About 65% of the total head, H, is dissipated along the outer faces of the two sheet piling walls. For small values of the ratio(w_1/w_2), most of this part is lost along the outer face of the U/S sheet piling wall, and vice versa.
2. The relative locations of the two cracks have a minor influence on the potential along the horizontal floor.
3. Significant increase in the uplift pressures on the U/S part of the floor may result if relatively shallow sheet piling walls are used.
4. Exit gradients decrease rapidly if the U/S crack is widened and slowly if the D/S one is narrowed.
5. More than 42% of the no-lining discharge will result from crack widths as small as 0.025 of the floor length. About 92% of the no-lining discharge will result if both w_1 and w_2 are greater than 0.50

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