TILE DRAINS ASSISTED BY DOUBLE MOLE DRAINS

المصارف المغطاه التى تساعدها مصارف مشكلة مزدوجة

By

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الخلاصة ـ فى هذا البحث توصل الباحث الى تحليل نظام جديد للصرف وذلك باستخدام نظام يجمع بين المصارف المغطاة والمصارف المشكله . والهدف الرئيسى من هذا النظام الجديد هو الجدوى الاقتصادية من حيث تكلفة الانشاء ورفع كفاءة نظام المصارف المغطاة التقليدية والموجودة فعلا باستخدام المصارف المشكلة المزدوجه كمصارف مساعده . وقد تم التوصل الى استنتاج معادلات رياضية عامة جديدة تربط بين المصارف المغطاة والمصارف المشكله المزدوجة لايجاد دالة الجهد المركب (W) ودالة جهد السرعة (ϕ) ودالة السريان (ψ) كما تم استنتاج معادلتين جديدتين للتصرف لكل مصرف من المصارف المغطاه (q_T) والمصارف المشكلة المزدوجة (q_M). وقد شمل البحث أيضا استنتاج معادلة جديده تحكم التصميم (L) بين المصارف المغطاه . ويقدم البحث مثالا تحليليا يبين فائدة هذا النظام الجديد بالمقارنة باستخدام نظام المصارف المغطاة التقليدية .

ABSTRACT- The author presents in this paper an analysis of a tile drainage system which is assisted by double mole drains. This is in the case of the vertical downward seepage of rain or irrigation water to the above system in a heavy clayey soil underlain by a pervious sand aquifer of relatively low piezometric head.

The problem is treated mathematically using the theory of complex functions and the theory of images. The complex potential, the velocity potential and the stream function are established. New discharge formulas for tile drains and double mole drains are derived. Also, functions for velocity components at a general point in the flow field are derived. Finally a new design formula is concluded and an actual field problem is numerically solved.

INTRODUCTION

The need to keep productivity of agricultural soil led over a century ago to the use of subsurface drains properly spaced and dimensioned to give perfect control of the subsoil water level. Generally, subsurface drainage system is extensively used for draining agricultural land to increase land productivity and to save existing cultivated areas. The covered drainage system is regarded as the ideal system for drainage. It secures th maximum benefit with the minimum overall cost. The most important systems of cover drains are tile, plastic and mole drainage systems. Mole crain system is the cheapest a the simplest means for draining agricultural lands. (1,2 & 3)

In the present paper, the problem of a tile drainage system which is assistec a system of double mole drains is treated, for a clayey soil underlain by a sand ec of low piezometric head and high hydraulic conductivity. Figure (1) represents the geo of the problem.

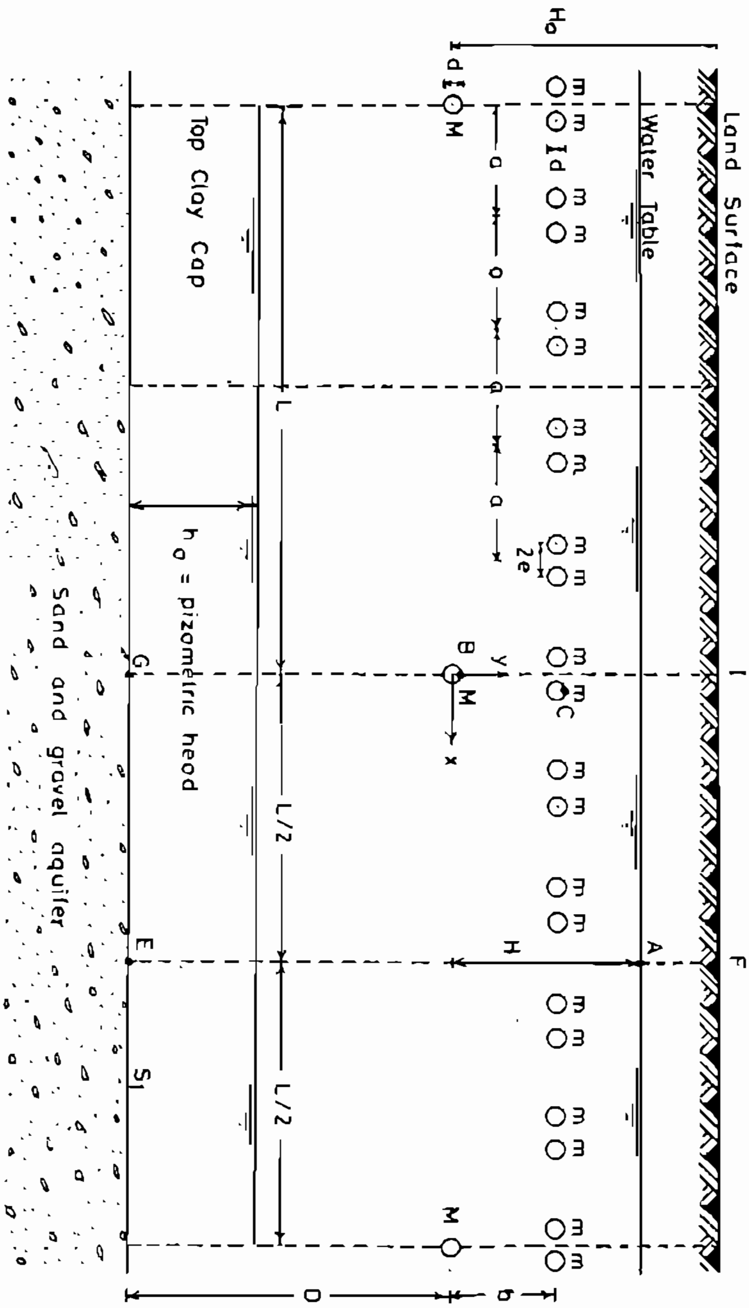

Fig.(1). Geometry of The Problem

MATHEMATICAL MODEL

The flow pattern may be simulated by assuming a vertical downward stream, U, representing rain or irrigation water past two rows of drains. The first row consists of an infinite number of equidistant double mole drains represented by equidistant pairs of sinks, each having a strength equal to m. The second row consists of an infinite number of equidistant tile drains represented by equidistant sinks, each having a strength equal to M. The system of tile and mole drains is installed as shown in figure (1). The spacing between tile drains equals L. A pair of mole drains is placed above each tile drain at a vertical distance equals b. An even number of mole drain pairs is located in the distance L, where the distance between two successive pairs equals a.

From figure (1) the complex potential for a downward vertical stream is

$$w_1 = -i\,U\,Z. \qquad \ldots (1)$$

The complex potential of an infinite number of tile drains is given as follows:

$$w2 = M.\ \ln \sin \frac{\pi Z}{L}. \qquad \ldots (2)$$

The complex potential of five double mole drains for one tile drain with the same specing is given by

$$\begin{aligned} W3 = {} & m\,.\,\ln \sin \frac{\pi}{L}(z - e - ib) + m\,.\,\ln \sin \frac{\pi}{L}(z + e - ib) \\ & + m\,.\,\ln \sin \frac{\pi}{L}(z - (a-e) - ib) + m\,.\,\ln \sin \frac{\pi}{L}(z - (a+e) - ib) \\ & + m\,.\,\ln \sin \frac{\pi}{L}(z + (a-e) - ib) + m\,.\,\ln \sin \frac{\pi}{L}(z + (a+e) - ib) \\ & + m\,.\,\ln \sin \frac{\pi}{L}(z - (2a-e) - ib) + m\,.\,\ln \sin \frac{\pi}{L}(z - (2a+e) - ib) \\ & + m\,.\,\ln \sin \frac{\pi}{L}(z + (2a-e) - ib) + m\,.\,\ln \sin \frac{\pi}{L}(z + (2a+e) - ib) \qquad \ldots (3) \end{aligned}$$

The complex potential of this system is

$$W = W1 + W2 + W3 \qquad \ldots (4)$$

Putting w_3 in a general form and substituting for $z = x + iy$, where $i = -1$, and simplifying:

$$\begin{aligned} W = {} & M\,.\,\ln\ [\sin\ \pi x/L\,.\,\cosh\ \pi Y/L + i \cos\ \pi x/L\,.\,\sinh\ \pi Y/L] \\ & + m \sum_{0}^{n} \ln[\sin\ \pi\ (x + (na + e))/L\ .\ \cosh\ \pi(y-b)/L + i\cos\ \pi(x + na + e)/L\ .\ \sinh\ \pi(y-b)/L] \\ & + m \sum_{0}^{n} \ln[\sin\ \pi\ (x - (na + e))/L\ .\ \cosh\ \pi(y-b)/L - i\cos\ \pi(x - (na+e))/L\ .\ \sinh\ \pi(y-b)/L] \\ & + m \sum_{1}^{n} \ln[\sin\ \pi\ (x + (na - e))/L\ .\ \cosh\ \pi(y-b)/L + i\cos\ \pi(x - (na-e))/L\ .\ \sinh\ \pi(y-b)/L \\ & + m \sum_{1}^{n} \ln[\sin\ \pi\ (x - (na + e))/L\ .\ \cosh\ \pi(y-b)/L + i\cos\ \pi(x - (na+e))/L\ .\ \sinh\ \pi(y-b)/L \\ & - i\,U\,X + U\,Y \qquad \ldots (5) \end{aligned}$$

where $n = (L/a - 1)/2$
$L/a = N$ = an odd number

Considering $w = \phi + i\,\psi$, where ϕ is the velocity potential and ψ is the stream function, and separating real and imaginary parts in the above equation we have:

$$\phi = + \frac{M}{2} \cdot \ln [\sin^2 \pi X/L + \sinh^2 \pi Y/L]$$
$$+ \frac{m}{2} \sum_{0}^{n} \ln [(\sin^2 \pi ((x+e) - na)/L + \sinh^2 \pi (y-b)/L) \cdot (\sin^2 \pi ((x-e)-na)/L + \sinh^2 \pi (y-b)/L)]$$
$$+ \frac{m}{2} \sum_{1}^{n} \ln [\sin^2 \pi ((x+e) + na)/L + \sinh^2 \pi (y-b)/L) \cdot (\sin^2 \pi ((x-e)+na)/L + \sinh^2 \pi (y-b)/L)]$$
$$+ U y \qquad \ldots (6)$$

$$\psi = + M \tan^{-1} (\cot \pi X/L \cdot \tanh \pi (y-b)/L)$$
$$+ m \sum_{0}^{n} [\tan^{-1} (\cot \pi ((x+e) - na)/L \cdot \tanh \pi (y-b)/L)$$
$$+ \tan^{-1} (\cot \pi ((x-e) - na)/L \cdot \tanh \pi (y-b)/L)]$$
$$+ m \sum_{1}^{n} [\tan^{-1} (\cot \pi ((x+e) + na)/L \cdot \tanh \pi (y-b)/L)$$
$$+ \tan^{-1} (\cot \pi ((x-e) + na)/L \cdot \tanh \pi (y-b)/L)]$$
$$- U X \qquad \ldots (7)$$

VELOCITY CONSIDERATIONS

The velocity components u and v at any point in the flow field[2] are given by:

$$u = - \partial\phi / \partial x \qquad \ldots (8)$$
$$v = - \partial\phi / \partial y \qquad \ldots (9)$$

where u and v are the velocity components in the x and y, respectively.

Differentiating Eq. (6), partially with respect to x and y, and simplifying, we get:

$$u = - M\pi /2L ((\sin 2 \pi x/L) / (\sin^2 \pi x/L + \sinh^2 \pi y/L)$$
$$- m\pi /2L \sum_{0}^{n} ((\sin 2 \pi ((x+e) - na)/L) / (\sin^2 \pi ((x+e) - na)/L + \sinh^2 \pi (y-b)/L)$$
$$- m\pi /2L \sum_{0}^{n} ((\sin 2 \pi ((x-e) - na)/L) / (\sin^2 \pi ((x-e) - na)/L + \sinh^2 \pi (y-b)/L))$$
$$- m\pi /2L \sum_{1}^{n} ((\sin 2 \pi ((x+e) + na)/L / (\sin^2 \pi ((x+e) + na)/L + \sinh^2 \pi (y-b)/L$$
$$- m\pi /2L \sum_{1}^{n} ((\sin 2 \pi ((x-e) + na)/L) / (\sin^2 \pi ((x-e) + na)/L + \sinh^2 \pi (y-b)/L \qquad \ldots (10)$$

and

$$v = -M\pi/2L\,(\sinh 2\pi y/L)/(\sin^2 \pi x/L + \sinh^2 \pi y/L))$$
$$-m\pi/2L\sum_{0}^{n}((\sinh 2\pi(y-b)/(\sin^2\pi((x+e)-na)/L + \sinh^2\pi(y-b)/L))$$
$$-m\pi/2L\sum_{0}^{n}((\sinh 2\pi(y-b)/L)/(\sin^2\pi((x-e)-na)/L + \sinh^2\pi(y-b)/L))$$
$$-m\pi/2L\sum_{1}^{n}((\sinh 2\pi(y-b)/L)/(\sin^2\pi((x+e)+na)/L + \sinh^2\pi(y-b)/L$$
$$-m\pi/2L\sum_{1}^{n}((\sinh 2\pi(y-b)/L)/(\sin^2\pi((x-e)+na)/L + \sinh^2\pi(y-b)/L)$$
$$-U \qquad \ldots(11)$$

From Eqs. (10) and (11) the flow velocity at a general point (x,y) can be obtained. At x=0 and x=L/2 the horizontal velocity component, u, is zero which is the condition for the vertical lines IG and FE to be lines of symmetry.

DISCHARGE FORMULAS

The equipotential function, ϕ, may be written in the following form[2 & 7]

$$\phi = k\left(\frac{p}{\rho g} + y\right) \qquad \ldots(12)$$

where k is the hydraulic conductivity of clay, p is the gauge pressure, ρ is the density of drained water and g is the acceleration due to gravity.

Applying Eqs. (6) and (12) to point A (L/2,H), figure (1), we obtain

$$K.H = +\frac{M}{2}.\ln\cosh^2\pi H/L + m.\ln(\cos^2\pi e/L + \sinh^2\pi(H-b)/L)$$
$$+m\sum_{1}^{n}\ln[\cos^2\pi(e+na)/L + \sinh^2\pi(H-b)/L]$$
$$+m\sum_{1}^{n}\ln[\cos^2\pi(e-na)/L + \sinh^2\pi(H-b)/L] + UH \qquad \ldots(13)$$

Applying Eqs. (6) and (12) to point B (0.0, $\frac{d}{2}$), we get

$$k.\frac{d}{2} = +\frac{M}{2}.\ln(\sinh^2\frac{\pi d}{2L}) + m.\ln(\sin^2\pi e/L + \sinh^2\pi(d/2-b)/L$$
$$+m\sum_{1}^{n}\ln(\sin^2\pi(e+na)/L + \sinh^2\pi(d/2-b)/L)$$
$$+m\sum_{1}^{n}\ln(\sin^2\pi(e-na)/L + \sinh^2\pi(c/2-b)/L + U\frac{d}{2} \qquad \ldots(14)$$

Applying Eqs. (6) and (12) to point E (L/2 , - D), we have

$$k\,(ho - D) = -\frac{M}{2} \,.\, \ln \cosh^2 \frac{\pi D}{L} + m.\ \ln\,(\cos^2 \pi\ e/L + \sinh^2 \pi\,(D+b)/L)$$
$$+ m \sum_1^n \ln\,(\cos^2 \pi\,(e-na)/L + \sinh^2 \pi\,(D+b)/L\,)$$
$$+ m \sum_1^n \ln\,(\cos^2 \pi\,(e+na)/L + \sinh^2 \pi\,(D+b)/L) - UD \qquad \ldots (15)$$

Applying Eqs. (6) and (12) to point C (e , (b+d/2)) , we get

$$k\,(b+\frac{d}{2}) = +\frac{M}{2} \,.\, \ln\,(\sin^2 \pi\,e/L + \sinh^2 \pi\,(b+d/2)/L) + \frac{m}{2} \,.\, \ln\,(\sin^2 2\pi\ e/L$$
$$+ \sinh^2 \pi d/2L) \,.\, (\sinh^2 \pi\ d/2L)$$
$$+ \frac{m}{2} \sum_1^n \ln\,(\sin^2 \pi\,(2e-na)/L + \sinh^2 \pi d/2L) .. (\sin^2 (-n\ \pi\ a/L) + \sinh^2 \pi d/2L)$$
$$+ \frac{m}{2} \sum_1^n \ln\,(\sin^2 \pi\,(2e+na)/L + \sinh^2 \pi\ d/2L) \,.\, (\sin^2 \pi\ na/L + \sinh^2 \pi d/2L)$$
$$+ U\,(b+d/2) \qquad \ldots (16)$$

The above equations may be rewritten as follows:

$$KH = M\delta 1 + m\delta 2 + UH \qquad \ldots (17)$$
$$K\,d/2 = M\delta 3 + m\delta 4 + U\,d/2 \qquad \ldots (18)$$
$$k\,(ho - D) = M\delta 5 + m\,\delta 6 - UD \qquad \ldots (19)$$
$$k\,(b + d/2) = M\delta 7 + m\,\delta 8 + U\,(b+d/2) \qquad \ldots (20)$$

where

$$\delta 1 = 1/2 \,.\, \ln\ \cosh^2 \pi H/L$$
$$\delta 2 = \ln\,[\,\cos^2 \pi e/L + \sinh^2 \pi\,(H-b)/L\,]$$
$$+ \sum_1^n \ln\,[\,\cos^2 \pi\,(e+na)/L + \sinh^2 \pi\,(H-b)/L\,] \,.\, [\,\cos^2 \pi\,(e-na)/L + \sinh^2 \pi\,(H-b)/L]$$
$$\delta 3 = 1/2 \,.\, \ln\ \sinh^2 \pi d/2L$$
$$\delta 4 = \ln\,[\,\sin^2 \pi e/L + \sinh^2 \pi\,(d/2 - b)/L\,]$$
$$+ \sum_1^n \ln\,[\,\sin^2 \pi\ e+na)/L - \sinh^2 \pi\,(d/2-b)/L] \,.\, [\,\sin^2 \pi\,(e-na)/L + \sinh^2 \pi\,(d/2 - b)/L\,]$$
$$\delta 5 = 1/2 \,.\, \ln\ \cosh^2 \pi\ D/L$$
$$\delta 6 = \ln\,[\,\cos^2 \pi\ e/L - \sinh^2 \pi(D+b)/L\,]$$
$$+ \sum_1^n \ln\,[\,\cos^2 \pi(e-na)/L + \sinh^2 \pi\,(D+b)/L\,] \,.\, [\,\cos^2 \pi(e+na)/L + \sinh^2 (D+b)/L]$$
$$\delta 7 = 1/2 \,.\, \ln\,[\,\sin^2 \pi e/L + \sinh^2 \pi(b+d/2)/L\,]$$
$$\delta 8 = 1/2\ \ln\,[\,\sin^2 2\pi e/L + \sinh^2 \pi d/2L\,] \,.\, [\,\sinh^2 \pi d/2L\,]$$

$$+ 1/2 \sum_{1}^{n} \ln [\sin^2 \pi(2e - na)/L + \sinh^2 \pi d/2L] . [\sin^2 \pi na/L + \sinh^2 \pi d/2L$$

$$+ 1/2 \sum_{1}^{n} \ln [\sin^2 \pi(2e+na)/L + \sinh^2 \pi d/2L] . [\sin^2 \pi na/L + \sinh^2 \pi d/2L]$$

Subtracting Eqs. (18) , (19) and (20) from Eq. (17)

$$k (H-d/2) = M (\delta 1-\delta 3) + m (\delta 2-\delta 4) + U(H-d/2) \quad \ldots (21)$$
$$k (H+D-ho) = M (\delta 1-\delta 5) + m (\delta 2-\delta 6) + U(H+D) \quad \ldots (22)$$
$$k (H-b-d/2) = M (\delta 1-\delta 7) + m (\delta 2-\delta 8) + U(H-b-d/2) \quad \ldots (23)$$

The above equations may be rewritten as follows :

$$k\vartheta 1 = M\vartheta 2 + m.\vartheta 3 + U.\vartheta 1 \quad \ldots (24)$$
$$k.\vartheta 4 = M\vartheta 5 + m\vartheta 6 + U\vartheta 7 \quad \ldots (25)$$
$$k\vartheta 8 = M\vartheta 9 + m.\vartheta 10 + U\vartheta 8 \quad \ldots (26)$$

where

$\vartheta 1 = H - d/2$ $\quad \vartheta 2 = \delta 1 - \delta 3$ $\quad \vartheta 3 = \delta 2 - \delta 4$

$\vartheta 4 = H + D - ho$ $\quad \vartheta 5 = \delta 1 - \delta 5$ $\quad \vartheta 6 = \delta 2 - \delta 6$

$\vartheta 7 = H+D$ $\quad \vartheta 8 = H-b-d/2$ $\quad \vartheta 9 = \delta 1 - \delta 7$

$\vartheta 10 = \delta 2 - \delta 8$

Eliminating U between Eqs. (24) and (25), and solving for M and m, we get

$$M = (k \vartheta 1(\vartheta 7-\vartheta 4)/\vartheta 2\vartheta 7 - \vartheta 1\vartheta 2) - m ((\vartheta 3\vartheta 7 - \vartheta 1\vartheta 6)/(\vartheta 2\vartheta 7 - \vartheta 1\vartheta 5)) \quad \ldots (27)$$

Eliminating U between Eqs. (24) and (26) and solving for M and m, we get

$$M = m (\vartheta 1.\vartheta 10 - \vartheta 3\vartheta 8) / (\vartheta 2\vartheta 8 - \vartheta 1\vartheta 9)) \quad \ldots (28)$$

subtracting Eq. (28) from Eq. (27), we have

$$m = k\vartheta 1 (\vartheta 7 - \vartheta 4) / (\vartheta 2\vartheta 7 - \vartheta 1.\vartheta 5) . (\theta 1 - \theta 2) \quad \ldots (29)$$
$$M = k.\vartheta 1(\vartheta 7 - \vartheta 4) \theta 1 / (\vartheta 2\vartheta 7 - \vartheta 1.\vartheta 5) . (\theta 1 + \theta 2) \quad \ldots (30)$$

where

$$\theta 1 = (\vartheta 1.\vartheta 10 - \vartheta 3.\vartheta 8) / (\vartheta 2.\vartheta 8 - \vartheta 1\vartheta 9)$$
$$\theta 2 = (\vartheta 3.\vartheta 7 - \vartheta 1.\vartheta 6) / (\vartheta 2.\vartheta 7 - \vartheta 1.\vartheta 5)$$

Therefore, from Eq.(29), the discharge reaching each unit length of mole drain is given by

$$Q_{mole} = 2 \pi k\vartheta 1 (\vartheta 7 - \vartheta 4) / (\vartheta 2\vartheta 7 - \vartheta 1.\vartheta 5) . (\theta 1 + \theta 2) \quad \ldots (31)$$

Also, from Eq. (30), the discharge reaching each unit length of tile drain is given by

$$Q_{Tile} = 2 \pi k\vartheta 1 (\vartheta 7 - \vartheta 4).\theta 1 / (\vartheta 2\vartheta 7 - \vartheta 1\vartheta 5)(\theta 1 + \theta 2) \quad \ldots (32)$$

NATURAL DRAINAG DISCHARGE

The discharge crossing the interface (S1) to the sand aquifer may be obtained as follow

$$V_{sI} = \frac{M\pi}{2L}\left(\left(\sinh\frac{2\pi D}{L}\right) / \left(\sin^2\frac{\pi X}{L} + \sinh^2\frac{\pi D}{L}\right)\right)$$

$$+ \frac{m\pi}{2L}\sum_{o}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((x+e)-na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$+ \frac{m\pi}{2L}\sum_{o}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((x-e)-na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$+ \frac{m\pi}{L}\sum_{1}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((x-e)+na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$+ \frac{m\pi}{L}\sum_{1}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((x-e)+na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$- U \qquad (33)$$

The maximum vertical velocity is at point (E)

$$V_E = \frac{M\pi}{2L}\cdot\frac{\sinh(2\pi D/L)}{\cosh^2(\pi D/L)} + \frac{m\pi}{2L}\sum_{o}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((L/2+e)-na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$+ \frac{m\pi}{2L}\sum_{o}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((L/2-e)-na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$+ \frac{m\pi}{2L}\sum_{1}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((L/2+e)+na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right.\right.$$

$$+ \frac{m\pi}{2L}\sum_{1}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \left(\sin^2\frac{\pi((L/2-e)+na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\right)$$

$$- U \qquad (34)$$

The minimum vertical velocity is at point (G)

$$V_G = \frac{M\pi}{2L}\left(\sinh\frac{2\pi D}{L}\right) / \sinh^2\frac{\pi D}{L}\,)\,]$$

$$+ \frac{m\pi}{2L}\sum_{o}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \sin^2\frac{\pi(e-na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\Big)$$

$$+ \frac{m\pi}{2L}\sum_{o}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \sin^2\frac{\pi(-e-na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\Big)$$

$$+ \frac{m\pi}{2L}\sum_{1}^{n}\left(\left(\sinh\frac{2\pi(D+b)}{L}\right) / \sin^2\frac{\pi(e+na)}{L} + \sinh^2\frac{\pi(D+b)}{L}\right)\Big)$$

$$+ \frac{m\pi}{2L} \sum_{1}^{n} ((\sinh \frac{2\pi(D+b)}{L}) / \sin^2 \frac{\pi(-e+na)}{L} + \sinh^2 \frac{\pi(D+b)}{L}))$$

$$-U \qquad (35)$$

U may be calculated from equation (19).

The vertical velocity across the line SI may be obtained as $V_{av} = (V_E + V_G)/2$ (36)

The natural seepage disharge QS crossing a distance L of the interface Si between sand and clay may be calculated as follows $QS = L \times | V_{av} |$

SPACING DESIGN FORMULA

The free water surface may be assumed nearly a horizontal surface. The rate of drop of the water surface may be taken equal to the drop at point A. Therefore, the rate of drop of the water surface may be written as follow

$$\frac{dH}{dt} = \frac{Q_{Tile} + 2N\,Q_{mole} + Q_s}{\mu \cdot L} \qquad (37)$$

Also, the spacing Design formula may be expressed as follow

$$L = \frac{Q_{Tile} + 2NQ_{mole} + Q_s}{\mu \cdot (dH/dt)} \qquad (38)$$

Numerical Example

The following particular are taken from a typical area in Egypt:
$D = 15.0$ m ; $hs = 14.0$ m ; $Ho = 2$ m ; $d = 0.1$ m ; $k = 0.1$ m/ day ; and $\mu = 0.03$
we proceed to show how the above design formulas may be applied to design an ordinary tile drainage system according to Hammad and Hothoot's equation (4) and a tile drainage assisted by mole drainage and natural drainage according to equation (38)

For the ordinary tile drainage system.
for a first trial assume $L = 65$ m

$Q_{Tile} = 0.1886532$

$Q_s = 0.3127494$

$T = 2$ days $\quad h = 0.5$ m $\quad \frac{dH}{dt} = \frac{h}{T} = \frac{0.5}{2} = 0.25$

$$L = \frac{Q_{Tile} + Q_s}{\mu\,(dH/dt)} = \frac{0.1886532 + 0.3127494}{0.03 \times 0.25} = 66.85 \text{ m}$$

Therefore, the design spacing is taken $L = 65$
For the present system
for a first trial assume $L = 110$ m , $N = 13$, $b = 0.8$ m and $e = 0.2$ m

$Q'_{Tile} = 0.15040 82$

$Q_{mole} = 0.00572526$

$Q_s = 0.5242479$

$T = 2$ days $\quad h = 0.5$ m $\quad \frac{dH}{dt} = \frac{h}{T} = \frac{0.5}{2} = 0.25$

$$L = \frac{Q_{Tile} + 2.N.Q_{mole} + Q_s}{\mu \cdot (dH/dt)} = \frac{0.1204082 + 2 \times 13 \times 0.00572526 + 0.5242479}{0.03 \times 0.25} =$$

$= 109.80$ m

Therefore, the design spacing is taken L = 110.0

CONCLUSIONS

New formulas for a tile drainage system assisted by a double mole drainage system and natural drainage is studied in this paper. The complex potential, the velocity potential and stream functions are derived. Mathematical solution when checked by applying the velocity formulas, is found to satisfy boundary conditions. The discharge formulas for tile drains, mole drains and natural drainage are established. Using double mole drains and introducing the natural drainage effect as well as tile drains increase tile drain spacing which means more economical designs. Finally a new spacing design formula is concluded and an actual field problem is numerically solved.

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NOTATION

The following symbols have been adopted for use in this paper:

- a = spacing between two successive mole drains;
- b = vertical spacing between lines of tile drains and mole drains;
- d = drain diameter for both tile and mole drains;
- D = depth of clay layer below tile drains;
- 2e = distance between two mole drains in one pair;
- g = acceleration due to gravity;

ho = piezometric head of sand and gravel aquifer;
H = height of water table above tile drains at the mid point between two successive tile drains;
i = $\sqrt{-1}$;
k = Hydraulic conductivity of clay;
L = spacing between two successive tile drains;
m = strength of a point sink for mole drains;
M = strength of a point sink for tile drains;
N = L/a = an odd number
n = ((L/a) - 1) / 2 ;
P = pressure at any general point (x,y) ;
Q_m = discharge reaching each unit length of mole drains ;
Q_T = discharge reaching each unit length of tile drains ;
u = velocity component in the x - direction ;
V = velocity component in the y - direction ;
w = complex potential = $\Phi + i\psi$
x,y = coordinates of any point in the field of motion ;
z = complex number = x + iy ;
Φ = the velocity potential ;
Ψ = the stream function ; and
ρ = water density