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In the name of Allah

بنام خدا

MINELAND SEEPAGE AND ITS CONTROL[1]

نشت آب اسیدی از معادن و کنترل آن

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بترتیب استادیار بخش منابع آب دانشگاه صنعتی اصفهان و استاد بازنشسته افتخاری فیزیک خاک دانشگاه ایالتی آیوا

ABSTRACT

A previously used potential function is altered to solve the problem of seepage of acid water in mineland spoil, in which tile drains are installed. The spoil overlies an impervious barrier. The boundary conditions of the problem are mixed; that is, some boundaries are pervious and some impervious. Two tile locations are studied; one when the tile drain is half-embedded in the impervious layer, and the other when the tile drain is above the impervious layer. Flownets are drawn for these two situations.

خلاصه

جهت حل مسئله نشت آب اسیدی در خاکهای پس مانده از معادن زغال سنگ، در یک تابع پتانسیلی که قبلا" مورد استفاده واقع شده بود تغییراتی داده شد. در این خاکها میتوان از زهکش زیرزمینی برای خارج کردن آب اسیدی استفاده کرد. در این مقاله فرض میشود که در زیر خاک یک لایه غیرقابل نفوذ قرار دارد. وضعیت مرزی این لایه نا مشخص است بدینمعنی که در بعضی جاها قابل نفوذ و در بعضی جاها غیرقابل نفوذ است. دو محل زهکش مورد مطالعه قرار گرفت. یکی در حالتیکه نصف زهکش در لایه غیرقابل نفوذ فرورفته و دیگری زمانیکه زهکش در بالای لایه غیرقابل نفوذ قرار دارد که برای این دو حالت شبکه جریان آب رسم گردید.

INTRODUCTION

Strip mining for coal often exposes pyrite material to atmospheric oxygen. Pyrite is oxidized to soluble acids which are readily leached by rain or seeping water. This process creates acid drainage, seeps, and affects the reclamation of these areas.

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Coal-mined areas must be converted to productive lands. One way is to establish adaptable vegetation on them in order to produce commercial crops. In a field experiment, Geyer and Rogers (1) planted different commercial trees on coal-mined spoils in Kansas. They stated that toxicity of spoils, as well as drought and high temperatures, caused high mortality during the first growing season. Rogowski (7) studied physical and chemical processes that affect the quality and quantity of water on reclaimed areas in Appalachia.

In southern Iowa, crops like corn (*Zea mays* L.), soybeans [*Glycine max* (L.) Merr.], and some other vegetative covers have been grown successfully (2). However, there are some places where on the slopes, water with high acidity comes to the surface of the soil and prevents vegetative growth. Two sources of seepage water are postulated for such cases: (i) seepage of rainfall from the soil above the seep area and (ii) a pond which is about the back side of the seep area.

MATERIALS AND METHODS

Tile drains provide a practical solution with two alternative installations shown in Fig. 1. We will analyze two conditions: (i) the effect of recharge by pond, and (ii) the effect of the pond is negligible, with the vertical recharge from rain supplying all the seepage water.

Tile Drain Half-Embedded, Pond Situation

Flow model and potential function. Following Kirkham and Van der Ploeg (3) and Najmaii (5), we shall first consider a tile drain half-embedded in the impervious layer (Fig. 2). A system of polar coordinates r and Θ, with origin o at the tile center is used to solve the problem. The tile drain is assumed to run full with zero back pressure. The dashed line in the lower section of Fig. 2 is the image of

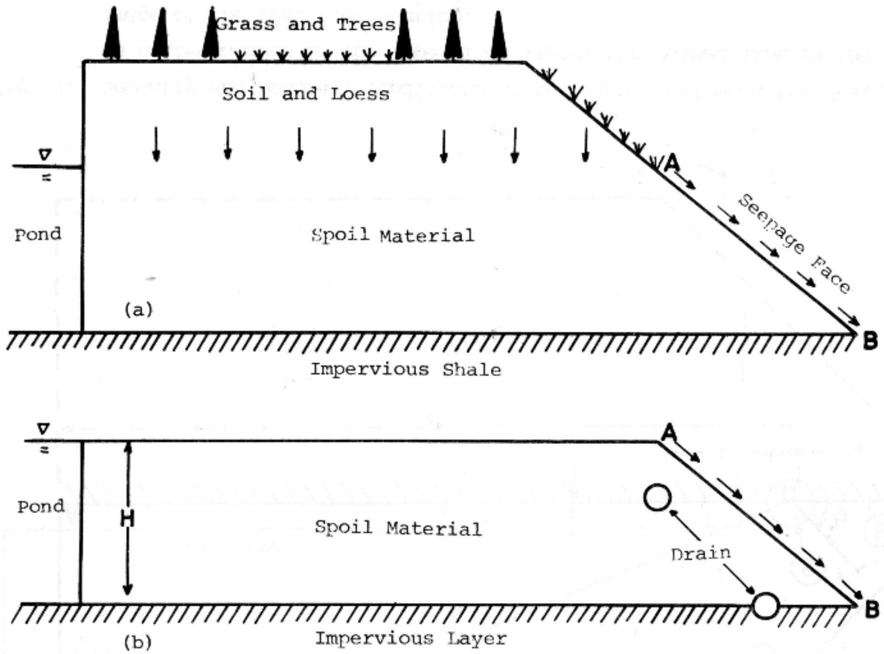

Fig. 1. Schematic sketches of the seepy area of the Hull Site, (a) flow section, (b) the bottom part of (a) showing location of two possible tile drains.

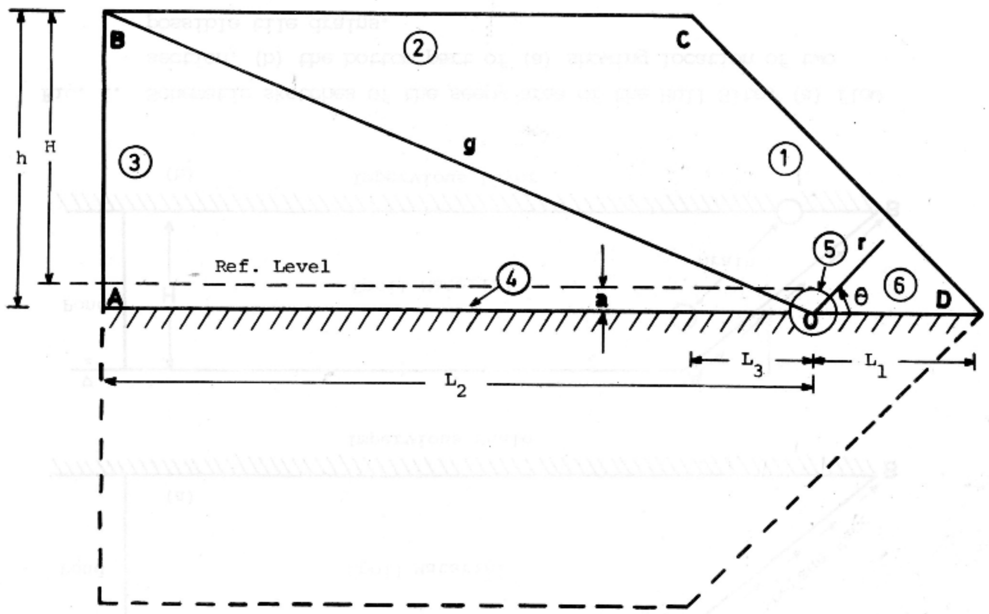

Fig. 2. Geometry and boundary conditions of the flow model when the drain is half-embedded in the impervious layer; the dashed line is the image of the real flow section.

the real soil with respect to the impervious layer. Use of the image region simplifies the solution.

The assumed boundary conditions (circled numbers in Fig. 2) are:

B.C.1 along DC; $\partial\phi/\partial n = 0$, $0 \leq \theta \leq \theta_1$
where θ_1 = angle DOC

B.C.2 along CB; $\partial\phi/\partial n = 0$, $\theta_1 \leq \theta \leq \theta_2$
where θ_2 = angle DOB

B.C.3 along BA; $\phi/H = 1$, $\theta_2 \leq \theta \leq \pi$

B.C.4 along AO; $\partial\phi/\partial y = 0$, $\theta = \pi$

B.C.5 along tile wall; $\phi = 0$, $0 \leq \theta \leq \pi$

B.C.6 along OD; $\partial\phi/\partial y = 0$, $\theta = 0$

where n denotes distance as measured normally outward from a boundary surface and x and y are standard Cartesian coordinates superimposed on the polar coordinates (r, θ).

Boundary condition 1 says that, with the tile drain in place, there is no flow out of or into the spoil medium. Boundary condition 2 states that there is no contribution of seepage from above, and water seeps only from the pond (B.C.3).

An expression for hydraulic head has been found in polar coordinates by Kirkham and Van der Ploeg (3). Their equation 3, after a change of notations, becomes:

$$\frac{\phi}{H} = A_{NO}\frac{\ln(r/a)}{\ln(g/a)} + \sum_{m=1,2,\dots}^{N} A_{Nm}\frac{(r/g)^m - (a^2/gr)^m}{1 - (a^2/g^2)^m}\cos m\theta \qquad [1]$$

where ϕ = potential head,

H = height of the pond water level above the reference level,

a = radius of the tile drain, and

r = radial distance from center of the tile to any point on the boundaries.

The A_{Nm} (m=0,1,2,..., N) are arbitrary constants to be determined. The double subscript Nm on the A illustrates that the value of each A_{Nm} will depend on the number N of terms in the series. Equation [1] satisfies B.C. 4,5, and 6 for every set of A_{Nm}. We must determine the A_{Nm} in such a way that the rest of boundary conditions are satisfied. For $N \to \infty$, the right side of Eq. [1] should exactly yield the left side. For N=0,1,2, and so on, the right side of Eq. [1] is an approximation.

By checking boundary conditions 1 and 2, we come up with the following equations (4):

$$O = A_{NO} \frac{\sin\theta + s\cos\theta}{r\ln(g/a)} + \sum_{m=1,2,\ldots}^{N} A_{Nm} \left[\frac{m(\sin\theta + s\cos\theta)}{r} \left(\frac{(r/g)^m + (a^2/gr)^m}{1 - (a^2/g^2)^m}\right) \cos m\theta - \frac{m(\cos\theta - s\sin\theta)}{r} \left(\frac{(r/g)^m - (a^2/gr^2)^m}{1 - (a^2/g^2)^m}\right) \sin m\theta \right] \quad [2]$$

and

$$O = A_{NO} \frac{\sin\theta}{r\ln(g/a)} \sum_{m=1,2,\ldots}^{N} A_{Nm} \left[\frac{m\sin\theta}{r} \left(\frac{(r/g)^m + (a^2/gr)^m}{1 - (a^2/g^2)^m}\right) \cos m\theta - \frac{m\cos\theta}{r} \left(\frac{(r/g)^m - (a^2/gr)^m}{1 - (a^2/g^2)^m}\right) \sin m\theta \right] \quad [3]$$

where s is the tangent of angle CDO.

Now, we shall find a set of A_{Nm} that satisfies Eqs. [2] and [3] and B.C.3 simultaneously. To do this, we use the procedure of PKS (6). We write a function $f(\theta)$ as:

$$f(\theta) = \sum_{m=0,1,2,...}^{N} A_{Nm}\ \mu_m(\theta) \qquad [4]$$

A FORTRAN computer program is written to get A_{Nm} and to approximate the function $f(\theta)$ of Eq. [4].

Stream function and flownet. Equation 191 of Van der Ploeg (8) is used as a stream function for our model:

$$\frac{\psi}{H} = K\ A_{NO}\ \frac{\theta}{\ln(g/a)} + \sum_{m=1,2,...}^{N} A_{Nm}\ \frac{(r/g)^m + (a^2/gr)^m}{1 - (a^2/g^2)^m} \sin m\theta \qquad [5]$$

A flownet is drawn by using Eqs. [1] and [5].

Tile Drain Half-Embedded, Steady Rainfall Situation

Boundary conditions. In Fig. 2, if we assume that there is no pond on the left side and the seepage water comes only from steady recharge above line BC, then B.C. 2 and 3 change to :

B.C.2	$\partial\phi/\partial n = R/K$	$\theta_1 \leq \theta \leq \theta_2$
B.C.3	$\partial\phi/\partial n = 0$	$\theta_2 \leq \theta \leq \pi$

and the rest of the B.C.'s are the same. We solve for $\partial\phi/\partial n$ of boundary conditions 1,2, and 3 as before.

Tile Drain Above the Impervious Layer, Pond Situation

Flow model and potential function. Figure 3 shows geometry of a flow model for controlling the acid seepage, when tile drain is installed above the impervious layer. Boundary conditions for Fig. 3 are:

B.C.1 (along DC) $\partial\phi/\partial n = 0$, $0 \leq \theta \leq \theta_1$, θ_1 = angle DOC

B.C.2 (along CB) $\partial\phi/\partial n = 0$, $\theta_1 \leq \theta \leq \theta_2$, θ_2 = angle DOB

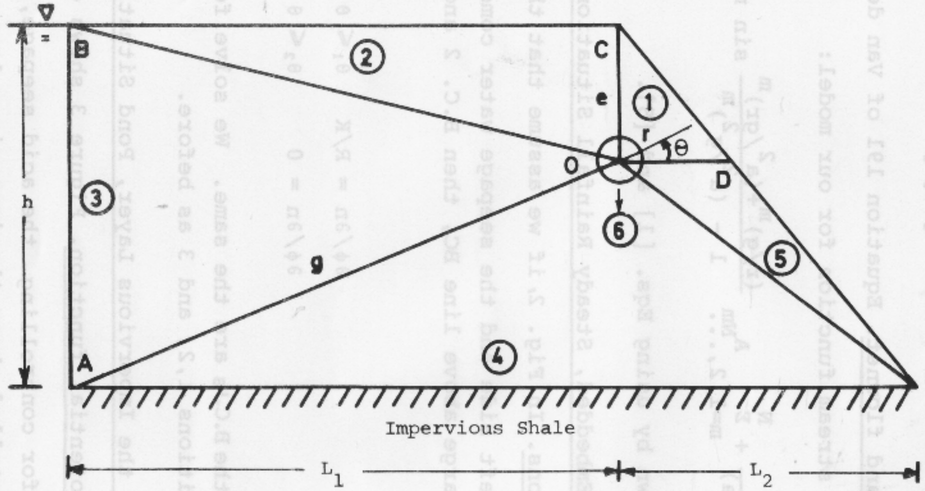

Fig. 3. Flow model when the drain is above the impervious layer and a pond is at the left.

B.C.3 (along BA) $\phi/h = 1$, $\theta_2 \leqslant \theta \leqslant \theta_3$, θ_3 = angle DOA

B.C.4 (along AE) $\partial\phi/\partial n = 0$, $\theta_3 \leqslant \theta \leqslant \theta_4$, θ_4 = angle DOE

B.C.5 (along ED) $\partial\phi/\partial n = 0$, $\theta_4 \leqslant \theta \leqslant 2\pi$

B.C.6 (on drain) $\phi = 0$, $0 \leqslant \theta \leqslant 2\pi$, $r=a$

Equation 1 of Kirkham and Van der Ploeg (3) with change of notations to ours, fits our flow model and becomes:

$$\frac{\phi}{h} = A_{NO}\frac{\ln(r/a)}{\ln(g/a)} + \sum_{m=2,4,\ldots}^{N} A_{Nm}\frac{(r/g)^{m/2} - (a^2/gr)^{m/2}}{1-(a^2/g^2)^{m/2}}\cos\frac{m}{2}\theta$$

$$+\sum_{m=1,3,\ldots}^{N} A_{Nm}\frac{(r/g)^{(m+1)/2} - (a^2/gr)^{(m+1)/2}}{1-(a^2/g^2)^{(m+1)/2}}\sin\frac{m+1}{2}\theta \qquad [6]$$

This equation satisfies B.G.6 for every set of A_{Nm}. We proceed, as before, to find a set of A_{Nm} that satisfies other B.C.'s simultaneously. Since the resultant analytical equations are lengthy, we do not copy them here.

Stream function. Based on Eq. [6], a stream function has been found by Kirkham and Van der Ploeg (3) which with our notations will be:

$$\frac{\psi}{h} = K\frac{A_{NO}\,\theta}{\ln(g/a)} + \sum_{m=2,4,\ldots}^{N} A_{Nm}\frac{(r/g)^{m/2}+(a^2/gr)^{m/2}}{1-(a^2/g^2)^{m/2}}\sin\frac{m}{2}\theta$$

$$-\sum_{m=1,3,\ldots}^{N} A_{Nm}\frac{(r/g)^{(m+1)/2} + (A^2/gr)^{(m+1)/2}}{1-(a^2/g^2)^{(m+1)/2}}\cos\frac{m+1}{2}\theta \qquad [7]$$

A flownet is now drawn by the use of Eqs. [6] and [7] after the set of A_{Nm} has been found.

RESULTS AND DISCUSSION

Results for Tile Drain Half-Embedded, Pond Situation

The result of one flow model when L_1=1.22m, L_2 = 7.92m, H=2.28m, a=0.15m, and s=1.25 is shown in Fig. 4. The approximation of $f(\theta)$ is drawn for N=0,8, and 16. The circled points which are the approximation $f_N(\theta)$ of $f(\theta)$ show a good fit when N=16. The A_{Nm} associated with N=16 are used in the potential and stream functions when a flownet is programmed. Figure 5 is a flownet for this geometry. This flownet shows that no water is leaving the medium from the sloped section as was set up in the boundary condition 1. In Fig. 5, three piezometers are shown. The two piezometers at points "a" and "b" show that the water is under tension. This means that seepage water is not going to leak out of the soil medium even if there is no barrier and the soil will support a water saturated fringe. The piezometer at point "c" shows a positive pressure, so there would be very small outflow of seepage at this corner of the soil if the "barrier" of boundary condition 1 in Fig. 5 were removed. We think that if the radius of the tile is larger than 0.15m, this small outflow will not occur.

We drew these piezometric heights as follows:
Knowing the total head at point "a" in Fig. 5, the pressure head is obtained by substracting the elevation of the point "a" with respect to the reference level from the potential head. The value of the total head is the level at which water stands in the piezometer (level "a'"). The pressure head is negative for point "a", and the absolute value will be the difference between "a" and "a'" levels.

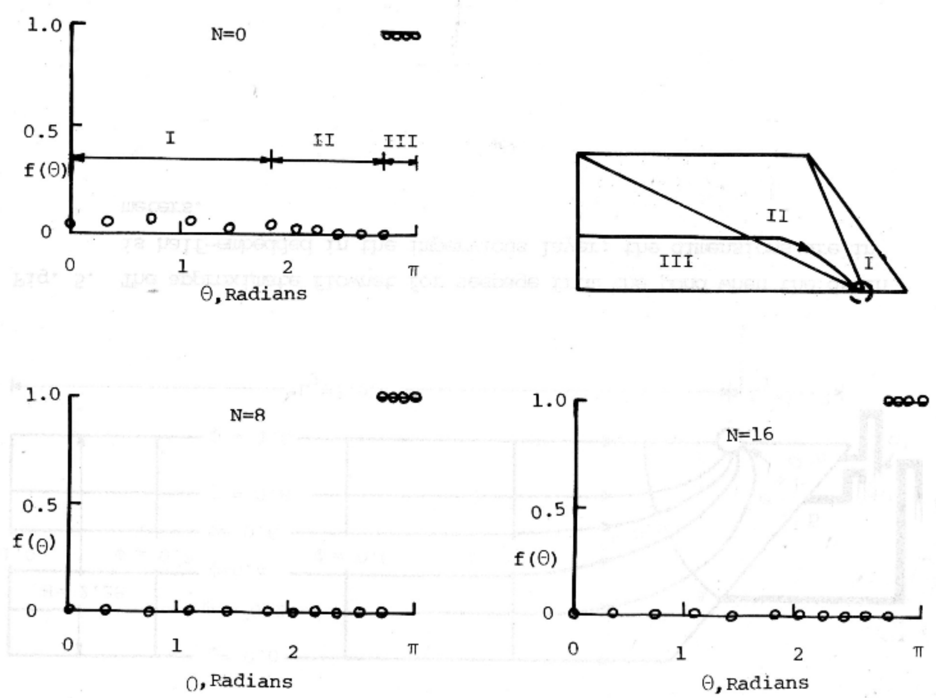

Fig. 4. Graphs of $f(\theta)$ and $f_N(\theta)$ versus angle θ for N=0, 8, and 16: the Roman numerals I, II, and III indicate the angle ranges associated with boundary conditions 1, 2, and 3, respectively.

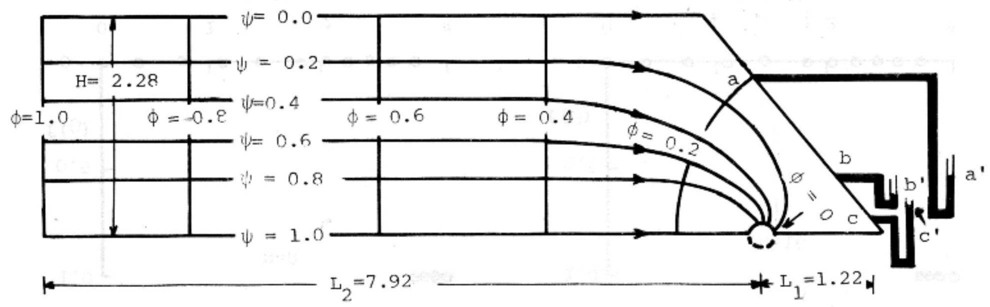

Fig. 5. The approximate flownet for seepage from the pond when the drain is half-embedded in the impervious layer; the dimensions are in meters.

Results for Tile Drain Half-Embedded, Steady Rainfall Situation

Figure 6 shows a flownet when L_1= 1.22m, L_2= 7.92m, H=2.28m, a=0.15m, s=1.25, and R/K = 0.2. The two piezometers at "a" and "b" show that water stands at "a'" and "b'" levels. The dashed line shows the position of the water table. Points above the dashed line in the porous medium are under tension. Thus the model assumes that there is a water saturated capillary fringe region above the dashed line. In other words, the soil must be sufficiently fine to support the fringe. In reality, the soil will be partially unsaturated and the capillary conductivity will be less than the hydraulic conductivity. Below the dashed line, the water is under positive pressure and there would be an outflow along the right face of the model if the impervious "barrier" ($\partial\phi/\partial n = 0$ of B.C.1) is removed. The piezometer at "a" shows tension.

Results for Tile Drain Above the Impervious Layer, Pond Situation

Figure 7 is a flownet for the situation where L_1= 1.83m, L_2= 7.31m, a = 0.15m, H=3.05m, and s=1.25. Piezometers show that at points "a" and "b", the soil is under tension and pressure, respectively. Thus, approximately at point D, the piezometric pressure is zero and point D is an stagnation point. Piezometer "b" shows that if the impervious "barrier" ($\partial\phi/\partial n$=0 of B.C.5) is removed, there would be an outflow from ED section.

General Discussion

We have presented an approximate flow model (Fig. 2) for seepage from a pond or from steady recharge through mineland soil for two locations of tile drains. One drain is half-embedded in the impervious layer (Fig. 3) and the other above the impervious layer (Fig. 4). In practice,

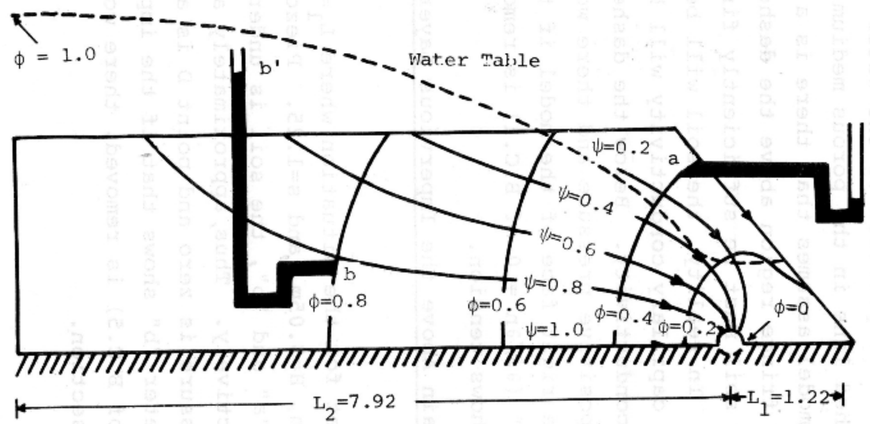

Fig. 6. The approximate flownet for seepage to a tile drain when the recharge is steady; the recharge R to conductivity K ratio is 0.2.

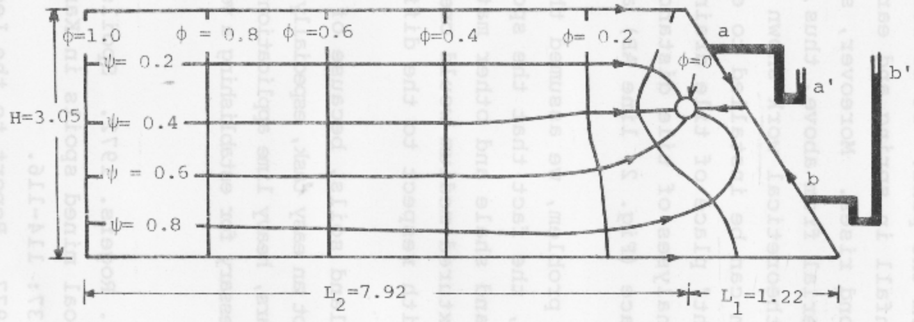

Fig. 7. The approximate flownet of seepage to a tile drain when it is above the impervious layer; the dimensions are L_1= 1.22m, L_2= 7.92m, and a = 0.15m.

the drain of Fig. 3 is installed just above the impervious layer. The drains are assumed to collect acid seepage from the mineland soil before the seepage can reach the sloped surface (Fig. 2, line AB).

The source of seepage water is either from the soil above the spoil material or from the pond. It is reasonable to say that, after heavy rainfall in spring and early fall, the water level in the pond rises. Moreover, some water seeps into the spoil material from above, thus emerging on the slope. With the theoretical work shown above, it appears that a tile drain can be installed to control this seepage water. The "right" place of tile drain should be selected after several analyses of tile distance with respect to the seepage face (Fig. 2, line AB) and impervious layer.

In solving the seepage problem, we assumed that the soil is homogeneous. However, the fact that the spoil materials with chunks of soil and shale and other materials do not make a uniform textured medium would create a need for integrated studies with respect to the different soil properties.

Rehabilitation of mineland soils, because of the erosion and seepage hazards, is not an easy task, especially on the slopes. In the first few years, heavy lime application along with tile drains appear to be necessary for establishing a vegetative cover.

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