Studies for Planning of Tile Drainage : in the Case of Rotational Farm from Flooded Rice Field to Dray Crop Field

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Studies for Planning of Tile Drainage
— in the Case of Rotational Farm from Flooded Rice Field to Dray Crop Field —

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Abstract

Recently, many paddy fields — (flooded rice fields) — have been rotated from paddy to dry crop farms. In order to control the over-production of rice, about 20 percent of all paddy fields in Japan, are changed temporarily to dry farming without major changes of the geophysical nature of the land. For these multi-use farm lands, many additional miles of drains are needed. Although many miles of drains are installed each year, they are still based on the trial and error system of the past. This report investigates the planning and use of tile drains for these rotational farms.

The results of this study are as follows;–
(1) the designed requirement of drainage is theoretically determined, (2) the criteria of whether or not drains are needed, (3) the calculation of spacing of drains, and (4) the integrated drainage systems installed are pointed out.

Introduction

Currently, many paddy fields (flooded rice fields) are rotated temporaly from paddy to dry farms [without any major change of geophysical aspects]. Farms using this method will be called "Rotational Farm" in this paper. As rotational farms depend on drainage to be used for dry farming, many additional miles of drains are needed. Each year, many such extensive drain systems are installed, based on the trial and error system used in the past. Since the first standard design book of irrigation and drainage engineering (Division of Tile Drainage in 1955) was published1), research on materials of drain pipes, machinery, methods and practices has continued. In 1979, this standard design book was rewritten2). The new standard design book corrects many details, presents more precisely theoretical problems, and thus has become more convenient for practical use.

Thereover, there is additional work for the future as indicated by the unanswered questions that continually confront us in the field of drainage research.

For convenience, this paper is divided into two sections, the first deals with the determination of the water requirement of drains, and the second, with the engineering design of tile drains.

The following notations are used:
Q = total discharge from farm per unit area in millimeters (mm)
R = amounts of inflow per unit area in millimeter (mm)
S = volume of storage, the allowable storage depth per unit area in millimeters (mm)
r = coefficient of percolation rate of precipiration in percent
T = a specific time interval
q = designed discharge depeth per unit time interval in millimeter per unit time
D = designed drainage requirement in millimeters per 24 hr period (mm/24 hr)

H = depth of percolation per 24 hr period (mm/24 hr)
L_o = distance between ditches measured from inside wall to inside wall in meter (m)
L = spacing of drains measured from center to center in meter (m)
K = hydraulic conductivity of the permeable surface layer
h = height of the ground water table midway between tile lines in meter (m)

I. The Determination of the Designed Drainage Requirement

A. Drainage Factors

In this section, a numbers of factors related to the drainage are considered for the practical design of drains. According to the water balance equation, the discharge from a farm (Q) is a function of both the amounts of inflow (R), [where R is either precipitation or the application of irrigation water], and the volume of storage (S). This may be written as

$$Q = Q\,(R, S) \quad \cdots\cdots \quad (1)$$

On the rotational farm, the main cause of drainage problem is the removal of the excess surface water due to the preciptation and the consequent interception of foreign water. Generally, the excessive application of irrigation water is not such a problem. The standard precipitation of the basic year, calculated stochastically, may be used as the inflow R. The colume of storage S is the allowable storage capacity or depth related to the situation, the shape of the ground water table and the flow pattern. We may therefore write that discharge Q:

$$Q = R \times r - S \quad \cdots\cdots \quad (2)$$

Where r is the coefficient percolation rate of the precipitation. By the use of a specific time interval T, equation (2) will show that

$$q = \frac{Q}{T} \quad \cdots\cdots \quad (3)$$

Where q is the designed discharge depth per unit time interval.

B. Designed Drainage Requirement D

The designed drainage requirement is described as the amount of water in millimeter (mm) to be removed from a given area within a specific time interval by drainage. After the discharge depth q is determined, the Designed Drainage Requirement D is calculated by substracting the depth of percolation per unit time interval H from q:

$$D = q - H \quad \cdots\cdots \quad (4)$$

The equation (4) is the criterion showing whether or not drains are required. If q is smaller than or equal to H then D is equal to zero or is negative, thus determining that no drains would be needed. If given that only vertical flow under a unit gradient is possible then the percolation depth (H) is equal to the hydraulic conductivity K.

C. Allowable Storage Capacity S

It is well known that the ground water table between two drain pipes forms a curved surface reaching its maximum height approximately midway between two neighboring drains. Since drainage problems in practice are extremely complicated, the situation and shape of ground water table cannot be known exactly, therefore a simple idealized picture of the flow system will be used. This system may be described as follows. Let us consider a system of parallel and equidistant tile drains situated at the same level in a homogeneous and isotropic soil resting on a horizontal impervious layer, where precipitation does occur and foreign water does not occur. Immediately after, the idealized precipitation has stopped, the ground water table will have achieved its maximum height. This maximum height is equivalent to the allowable storage capacity. However, the relationship between the shape of water table and the allowable storage capacity is more complicated, and cannot be determined theoretically. Therefore it is reasoanble to use the maximum amount of irrigation water supplied at one time, as the allowable storage capacity. According to "The Water Supply Planning for Field Irrigation",$^{3)}$ the maximum amount of irrigation water has been determined as *T R A M*, the total ready available moisture. Therefore we can substitute TRAM for the allowable storage capacity S.

D. Determining Numerical Values

To establish the drainage design on a farm, these values must be determined. First, the amounts of inflow on farm which are calculated stochastically from precipitation records. One can use relatively short return periods; for example, 3 yrs, 5 yrs or 10 yrs and so on. Rainfall data based on the 24 hr max. record or the day time record should be used.

Given that the coefficient of runoff for paddy fields is estimated to be 20–30 percent, the coefficient of percolation rate (r) is then estimated to be about 0.7–0.8. The time interval (T) may be determined by crop type; for example 1, 2, or 3 days intervals. As the percolation depth (H) for that same time interval is difficult to determine theoretically, but it can be substituted by the water depth requirement of the paddy field (measured or calculated).

For example, in the case of the Sourthern part of Osaka Prefecture, the calculation of D is as followed: R(1/10), R(1/5) and R(1/2) are 166 mm, 145 mm, and 97 mm, respectively.$^{4)}$ If $r = 0.7$ and $T = 1$ day, then $S = 50$ mm, $H = 20$ mm,

R (1/10) . . . . $D = 46$ mm
R (1/5) . . . . $D = 31$ mm
R (1/2) . . . . $D = -2$ mm

In the case of R(1/2) no drains would be needed.

II. Engineering Design for Tile Drains

A. Determination of the spacing of tile drains

A number of theories for tile and ditch drainage have been proposed in recent years which would anable the rational design of drainage systems. This section is limited to the determination of thd spacing of drains to control the ground water table.

For convenient, it is assumed that (1) there is uniformed downward infiltration toward the ground water table in the case of flat drains imbedded in a horizontal impermeable layer, (2) the tile drains are equidistant, (3) the soil is homogeneous, (4) the surface cultivated soil is permeable, and (5) the subsurface soil is impermeable. (see Fig. 1) ENGELUND[5)] provides the equation for a steady state flow through a homogeneous isotropic soil situated over an impermeable layer in which drains are imbedded. By the use of the ENGELUND's formula, one is able to determine the spacing of drains pipes. The equation for the ground water table of this flow problem is:

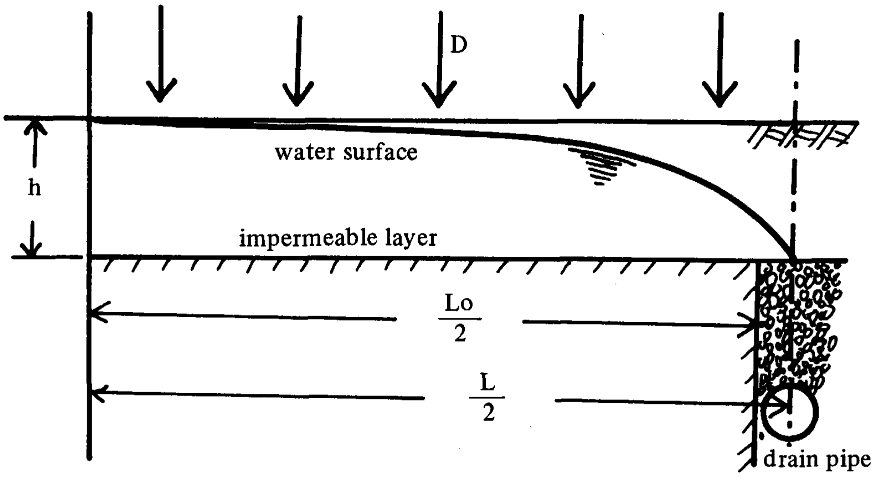

Fig. 1 Drains imbedded in an impermeable layer From Engelund (1951)

$$\frac{X^2}{\left(\frac{1}{2}L_0\sqrt{\frac{K}{K-D}}\right)^2} - \frac{Y^2}{\left(\frac{1}{2}L_0\sqrt{\frac{D}{K-D}}\right)^2} = 1 \quad \cdots\cdots (5)$$

Therefore the spacing of drains measured between center is

$$L = L_0\left(\frac{K}{K-D}\right)^{1/2} = \sqrt{\frac{4K}{D}}\,h \quad \cdots\cdots (6)$$

The height of water table midway between the tile lines is:

$$h = \frac{1}{2}L_0\left(\frac{D}{K-D}\right)^{1/2} \quad \cdots\cdots (7)$$

By this equation, from each of the various values of hydraulic conductivity K, the spacing of drains L can be calculated, as shown in Fig. 2.

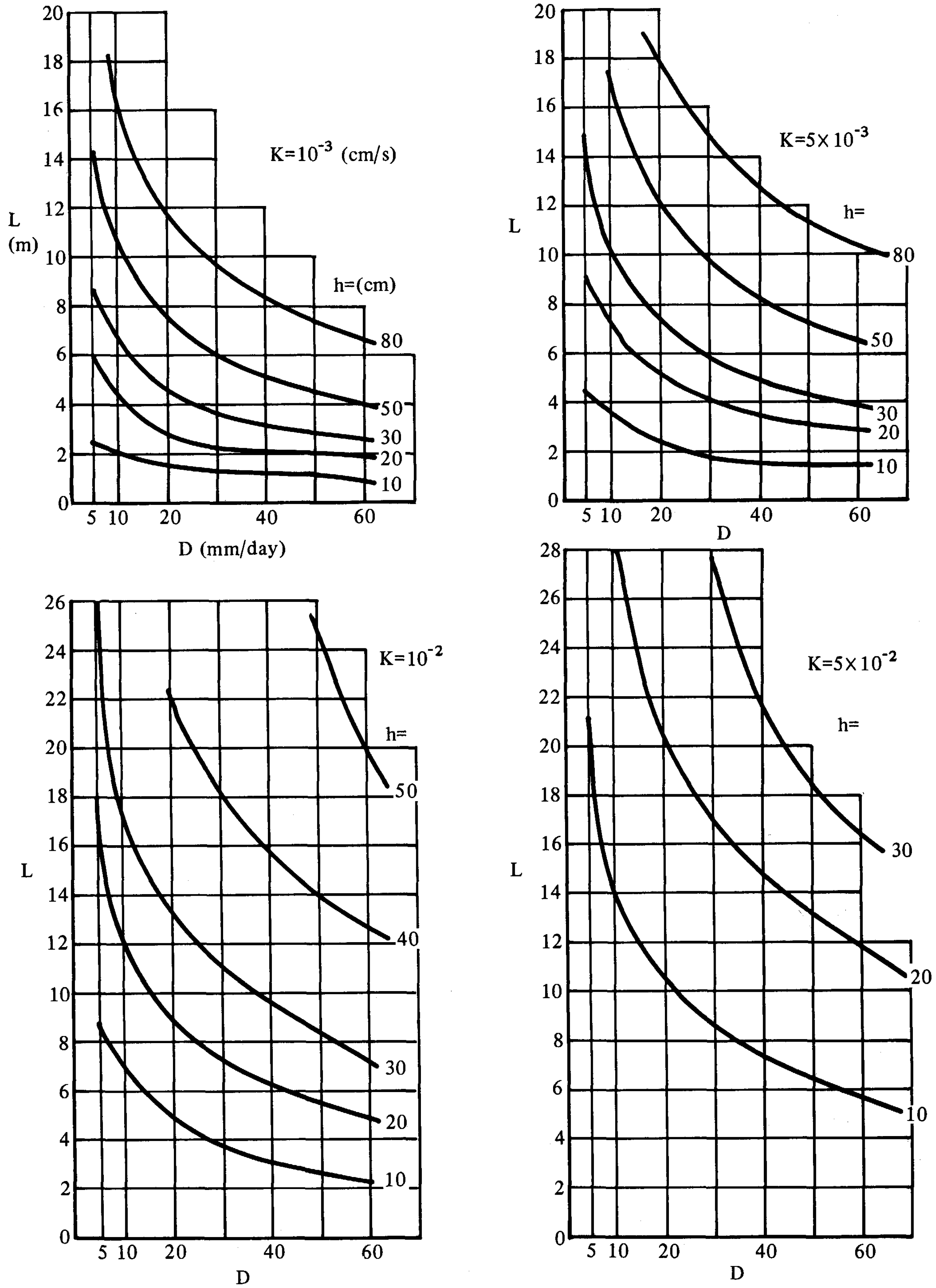

Fig. 2. Calculated diagram for various Value of K, Spacing of drains L v.s. designed requirement depth D

B. Considerations of the subsoil improvement

Generally speaking, it may be said that the theoretical results give a fundamentally correct picture of the entire flow system. From Fig. 2, one might assure that subsoil improvement is necessary to increase the efficiency of drainage.

As the depth of permeable layer increases due to suboil improvement, so does the allowable storage capacity S and the percolation depth H. Correspondingly the drainage requirement D become smaller in value. Particularly for paddy fields, which are characterized by a shallow hardpan layer, techniques such as ripper tillage, mole drains and the addition of organic material might be used. An integrated drainage system should involve both suboil improvement and tile drains.$^{6)}$ In addition, practices such as high ridge cropping could be employed.

Summary

There are two questions to be asked in the planning of tile drainage. First, how to determine the spacing of drains under the given physical soil conditions and secondary, how to improve the soil given the spacing of drains existings, as determined by a cost-benefit ratio. In principle, the planning of tile drains should solve both questions. In this paper, the author and his co-worker have attemped to answer these two questions. However, there is additional future work to be done.

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