Comparative Study on Steady and Non-Steady state Formulae of Subsurface Drain Spacing : Design on Subsurface Drainage in Paddies (I)

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Comparative Study on Steady and Non-Steady state Formulae of Subsurface Drain Spacing
— Design on Subsurface Drainage in Paddies (I) —

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Abstract

The performance of a steady state method, proposed by the authors, for determining subsurface drain spacing in paddies was examined and evaluated as compared to a non-steady state method. The steady formula, in which a certain drainage rate (design drainage rate) was used, became equivalent to non-steady formula under the condition that excess water in topsoil is to be removed within a day, a twenty four hour period.

It was, however, revealed experimentally that to represent porosity of shallow topsoil used in the non-steady formula, with a single value was difficult, and consequently, the non-steady formula gave unstable spacing. The steady method, on the other hand, performed and determined spacing without any soil parameters even if drainage testing was carried out.

Introduction

In the drainage design of paddies a major role of the subsurface drainage is defined as removing the excess water which is stored in the shallow topsoil and remains on the ground surface after the surface drainage, not to lower the water table constantly[1)]. It seems, therefore, to be reasonable to apply non-steady state formulae to predict a spacing of the subsurface drains having such a role, but they are not used in practice, because drainage design criteria are not yet established quantitatively based on non-steady state conditions such as the effect of fluctuating water table on soils and crops, and drainage flow mechanism.

In a design which the authors proposed, a steady state method is to be used, too[2~6)]. However, a following newly devised drainage rate is employed as a design drainage rate in the formula; the drainage rate is an initial drainage rate (D in mm/day) able to remove the excess water (V in mm) within a certain period of time (design drainage time; T in day). The value of D is given from the relation with V and T proposed[5)].

There seems to be no design concept that the non-steady drainage process is built upon in a steady state method, though there are simulartion models of drainflow rate and water table levels during or immediately after reinfall in shallow topsoil[7)].

In this paper it is evaluated that a steady state formula using the design drainage rate (D) predicts a drain spacing close to the one predicted by a non-steady state formula and is performable in practical drainage design.

Drain Spacing formulae

1. Drainage Design Criteria

In most cases design can be based on steady state conditions which are considered to occur when the water table does not change position and the drainage rate remains constant over a sufficiently long period of time. But these conditions will not easily met in paddies.

A paddy is in following stage after the surface drainage; the topsoil is saturated with water and there is no ponding water on the ground surface. This is the steady stage for applying a steady state formula, and also the initial stage for a non-steady state formula. It is, therefore, necessary for a steady state formula to employ the drainage rate (D) as mentioned above. In a non-steady state formula, a drain spacing is determined as to lower the water table at a midpoint between drains from the ground surface to a certain given depth within the design drainage time (T).

2. Steady State Formula

Figure 1 shows a flow pattern in the shallow permeable topsoil overlying a impermeable plowsole layer in a paddy. In a trench, pipe envelopes such as rice husks and/or gravel are backfilled up to the topsoil to reduce the head loss by facilitating the downward

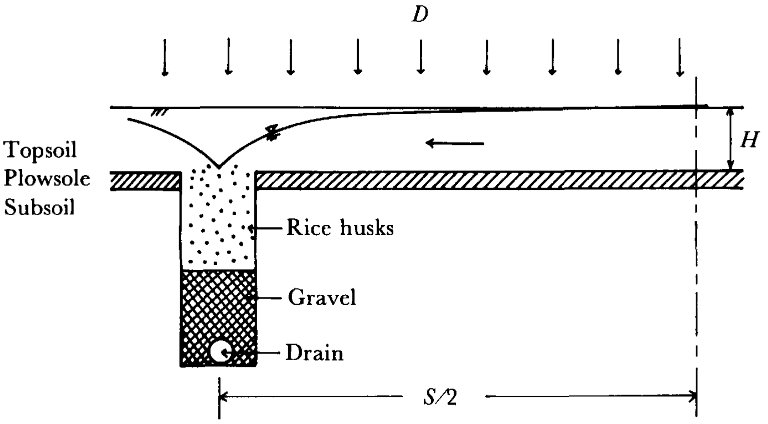

Fig. 1 Flow pattern in shallow topsoil

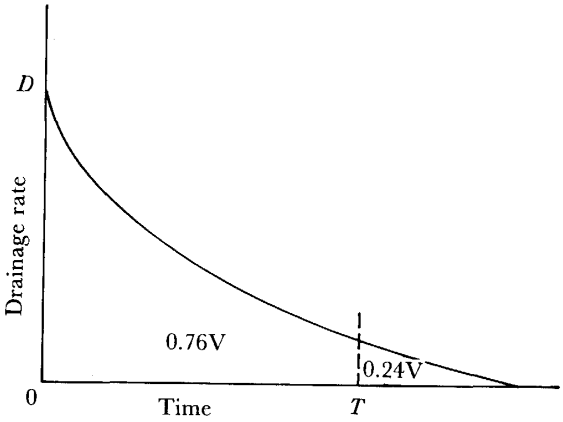

Fig. 2 Designe drainage rate (D) and its relationship with V and T in a recession curve

flow of the water. Therefore, a drain depth below the plowsole can be neglected in the consideration on drain spacing.

By using *Dupit-Forchheimer* assumptions, drain spacing is written as follows[2];

$$S = 2H\sqrt{\frac{k}{D}86.4} \tag{1}$$

where S: drain spacing in m, D: design drainage rate in mm/day, H: topsoil thickness in cm, k: hydraulic conductivity of the topsoil in cm/s and 86.4: constant for conversion of time unit.

The design drainage rate (D) is an initial drainage rate in a recession curve of drains in spacing S as shown in Fig. 2. The recession curve shows drainage rate from the initially saturated topsoil and water volume V in mm is finally drained at the design drainage time T. If a spacing is wider than the value of S, the same water volume of V never drain out within the time T.

The relation of D with T and V can be written as follows[5];

$$D = 3\frac{V}{T} \tag{2}$$

The value of D in Eq. (2) is practically defined as the initial drainage rate to remove 76% of V within T=1 day long, because it seems to be reasonable to cut off long-lasting tail recession after T=1 day (Fig. 2).

From Eqs. (1) and (2), drain spacing S is rewritten as follows;

$$S = H\sqrt{115\frac{k}{V}} \tag{3}$$

3. Non-Steady state formula

In the case of the non-steady conditions the head, the depth of water above the bottom of topsoil, varies with time. If h represents the head at some horizontal distance x measured from one line of the drains toward the other, as shown in Fig. 3, then the condition of continuity is as follows[8),9)];

$$\frac{\partial}{\partial x}\left(kh\frac{\partial h}{\partial x}\right) = f\frac{\partial h}{\partial t} \tag{4}$$

where f: drainable porosity, and t: time.
With assuptions as;

$$\begin{array}{lll} h=H & \text{at } x=S/2 & \text{for } t=0 \\ h=0 & \text{at } x=0 \text{ and } x=S & \text{for } t>0 \\ dh/dx=0 & \text{at } x=S/2 & \text{for } t>0 \end{array} \tag{5}$$

the head ($h_{s/2}$) at $x=S/2$ is given by;

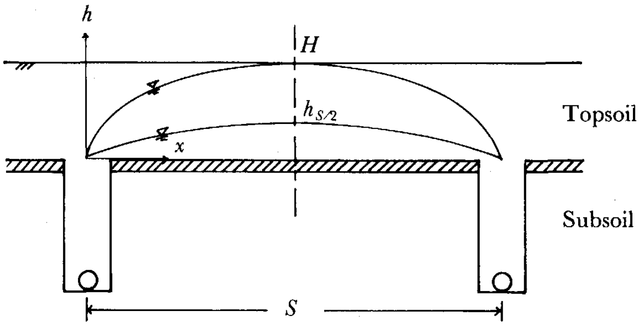

Fig. 3 Geometry and symbols used in deriration of non-steady state formula

$$\frac{h_{s/2}}{H}=\frac{2S^2f}{9\mathrm{kH}t+2S^2f} \tag{6}$$

Solving for S, the drain spacing is

$$S=\sqrt{\frac{9\mathrm{kH}t}{2f(\frac{H}{h_{s/2}}-1)}} \tag{7}$$

Under the same condition, as the steady state method, that the criterion is to lower the head $h_{s/2}$ from h=H for t=0 to h=0.24H for t=1 day, a fall of 76% of the head H, drain spacing is given by

$$S=\sqrt{12.3H\frac{k}{f}} \tag{8}$$

and, furthermore, assuming f=V/H, and average value throughout the topsoil,

$$S=H\sqrt{123\frac{k}{V}} \tag{9}$$

Comparing Eqs. (3) and (9), the difference in spacings is 3 percent. The steady state formula using the design drainage rate (D) can predict a drain spacing with equivalent accuracy to the one is calculated by the non-steady state formula.

Drainage Testing

1. *Methods*

An evaluation of the performance of the steady and non-steady state methods was carried out through drainage tests in an experimental plot where drains were installed with spacing S' for drainage testing. Based on observed recession curves of the drainage rate and the head, procedures to determine drain spacing (S) are as follows;

In the steady state method, if q_0 in mm/h represents and initial drainage rate of spacing S' drain system, the relation between q_0 and S' can be writien by using Eq. (1) as follows[6]

$$S' = 2H\sqrt{\frac{k}{q_0}3.6} \qquad (10)$$

where 3.6: constant for conversion of time unit. From Eqs. (1) and (10), eliminating hydraulic conductivity of the topsoil (k) and the topsoil thickness (H), and solving for drain spacing (S), S can be rewritten and calculated without k and H as follows;

$$S = S'\sqrt{\frac{q_0}{D}24} \qquad (11)$$

where S': drain spacing installed for drainage testing, and 24: constant for conversion of time unit. D is predicted from Eq. (2).

In the non-steady state method, if a parameter of k/f is obtained so as to give a fitted curve of Eq. (6) to a observed head recession curve, a drain spacing S is calculated from Eq. (8) in which the observed parameter of k/f is substituted.

2. *Results and Discussion*

Observations of subsurface drainage discharge (drainage rate; q) and falling water table (the head; h) were carried out in an experimental plot where artificial rainfall by sprinklers and subsurface drainage system were installed. The plot is 8 m long and 3 m wide where a drain is installed in 8 m length and 3 m spacing (S').

(1) Steady state method

Figure 4 shows an observed drainage rate-time hydrograph under a constant intensity of artificial rainfall. After a steady state condition of drainage rate, $q_0 = 50$ mm/h, is obtained, artificial rainfall is stopped at 12:10 (t=0). An excess water volume drained after

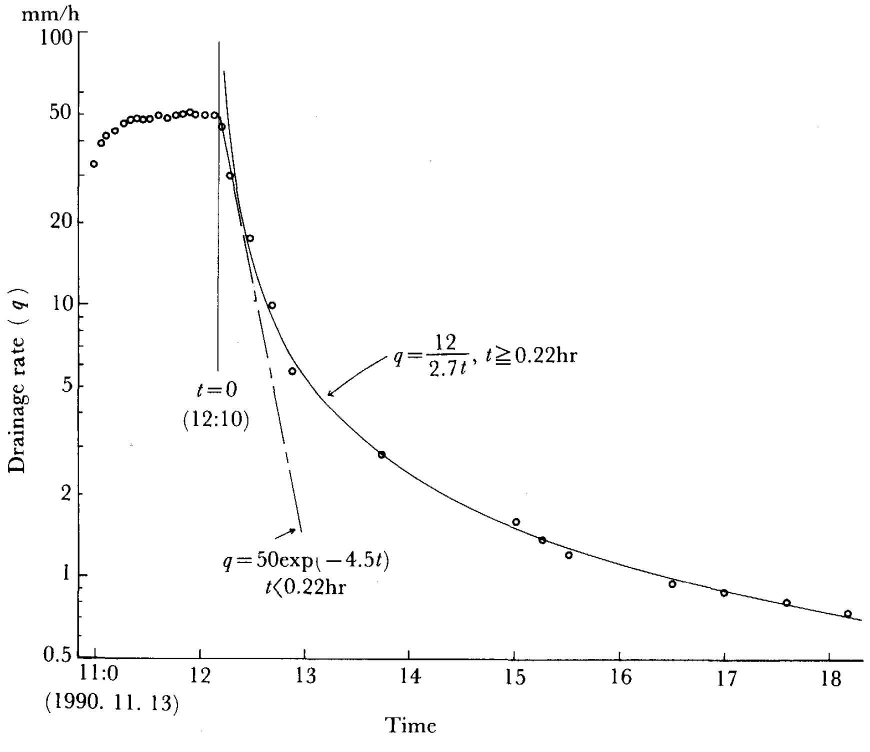

Fig. 4 Observed hydrograph of drainage discharge and fitting curves to the recession characteristics

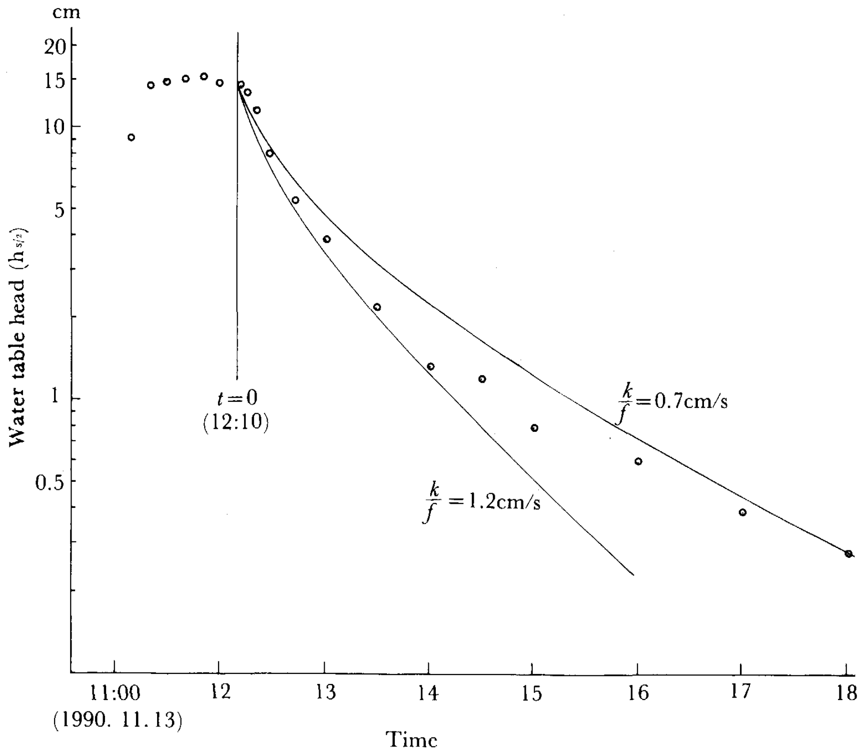

Fig. 5 Observed hydrograph of water table head and fitting curves to falling characteristics

$t=0$ is calculated as $V=30$ mm from the recession curve approximated by $q=50\exp(-4.5t)$ and $q=11.9/(2.7t)$.

From these values of q_0 and V, the design drainage rate (D) and the drain spacing (S) are obtained as $D=90$ mm/d and $S=11$ m by using Eq. (2) and Eq. (11) respectively.

(2) Non-steady state method

Figure 5 shows an observed head-time hydrograph. The recession after 12:10 ($t=0$) can not be represented by a single curve with a constant parameter (k/f) but seems to be in the range of $k/f=0.7$ to 1.2 cm/s.

A larger parameter, $k/f=1.2$ cm/s, which appears on early stage of the recession brings a wider spacing of 15 m, calculated by Eq. (8), which is undersirable outcome in the drainage design. The parameter of $k/f=0.7$ cm/s brings a drain spacing of 11 m which is equal to that predicted by the steady state method. It was described in section II. 3. that a non-steady state method with one average parameter of the porosity (f) brings the same spacing (S) as that predicted by a steady state method with the desgn drainage rate (D).

3. Practical Design Method/Conclusion

Though a topsoil is a permeable layer typically distinguished from impermeable subsoil by plowsole in paddy soil profile, it is difficult to represent the permeability or the porosity of the topsoil with a single value of it as shown Fig. 5. The soil parameters vary with depth even in the shallow topsoil. This is one of the reasons why theoretical non-steady state methods are not employed in a practical design but a design is normally based on steady state formulae and criteria, though it is recognized that the drainage process is in fact non-steady[10]. The accuracy with which a drain spacing can be determined is limited by the accuracy of the soil parameters (due especially to the high variability of the hydraulic conductivity) rather than by the formula adopted.

In most cases in some European countries *Hooghoudt* formula[11,12], a steady state formula, is used because of its wide applicability and a relatively simple structure. In paddies, however, this formula does not perform a design criterion in relation to the non-steady state conditions. Under such conditions the steady state method, Eq. (1), using the design drainage rate (D), Eq. (2), is evaluated as a performable design method in practice.

For a typical paddy, an excess water volume $V=7$ to 10 mm, then $D=20$ to 30 mm/day[5]. These values of D are twice and/or three times of those for grassland and arable land in some European countries[13]. In a design using Eq. (1), there is another problem how to determine hydraualic conductivity (k) of the topsoil. It is difficult to determine the value of k even by using such methods as the auger hole method. A method, however, is proposed to establish it by modifying a measure of hydraulic conductivity[2),4]. Furthermore, if a drainage test is carried out in a representative paddy plot, a drain spacing (S) for paddies having the same drainage conditions is determined without the hydraulic conductivity as mentioned in section III. 1., which is a practical and convenient design method.

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