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Paper No. 23

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LABORATORY INVESTIGATIONS ON INTERCEPTOR DRAINS

by

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Prepared for presentation at Joint ARS-SCS
Irrigation-Drainage Conference
Colorado Springs, Colorado
January 14-17, 1957

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INTRODUCTION

There have been many studies made of drainage problems concerned with the relief or grid types of drains. However, there is little information available on the hydraulics of interceptor drainage. Interception of ground water flowing laterally from a source which may be outside the affected area is the common problem. The drain must be located for maximum benefit to the problem area. The variables to be considered are depth, length and size of drain, and the location relative to the problem area and source of seepage.

The purpose of this study (2) was to investigate a type of interceptor drain where there was a source of seepage at some finite distance from the projected location of the drain. In the experiment a permeable boundary with constant slope existed at some measurable distance below the ground surface. The source of seepage was such that the water depth at the source point would remain unchanged after drainage. The factors which were investigated were the flow into the drain after drain installation and the resulting drawdown curve.

The experiment was designed to establish the relationship between the pertinent variables and to obtain data for comparison with the results from other investigators. A check on the accuracy of theoretically derived relationships was one of the objectives. For this study, dimensional analysis was used to relate the variables for a more systematic study.

EQUIPMENT

The study was conducted in the Hydraulics Laboratory at Colorado A and M College utilizing a large tilting flume which is shown schematically in figure 1. The flume was 70 feet long, 2 feet wide and 4 feet high and could be adjusted for slope from horizontal to 3 per cent. The flume was filled with sand to a depth of 44 inches. A head and tail box with adjustable overflow devices were provided to control ground water levels. Tile drains were placed at three levels near the downstream end of the flume with an additional tile drain near the midpoint. Banks of manometers connected by plastic tubing to piezometers placed at intervals along the flume were used to determine the ground water profile. The outflow from the drains was weighed to determine the discharge.

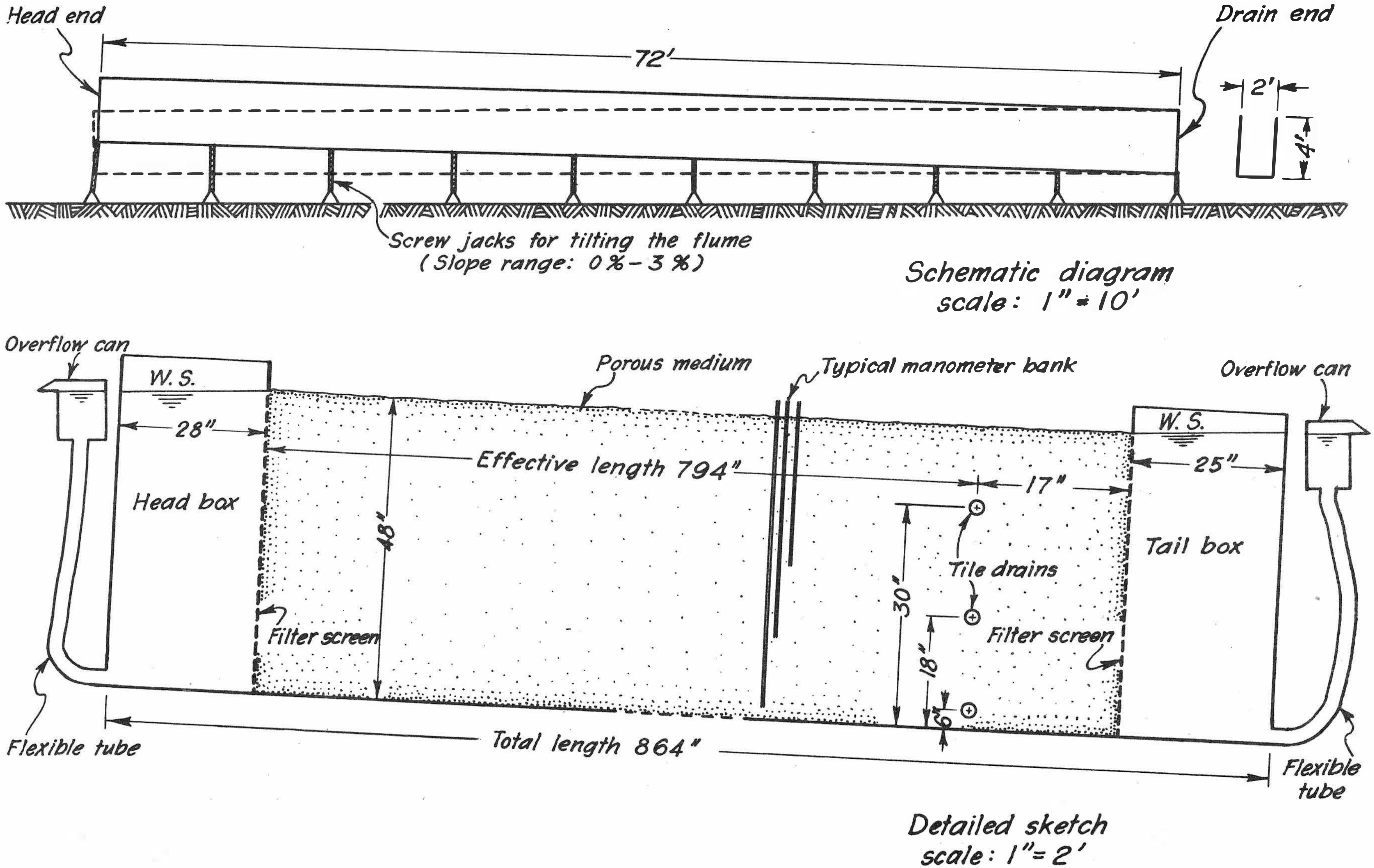

Fig. 1 Lay-out of tilting flume.

The material used in the study was a decomposed granitic sand having a mean size of 0.107 inches (2.72 mm) and a uniformity coefficient of 2.0. Hydraulic conductivity was determined to be 0.038 feet per hour and a capillary rise of 1.5 inches was indicated. The material was compacted to uniform density as indicated by conductivity measurements made with variable depths of ground water in the flume. The porosity of the in-place material was determined to be 36.8 per cent and the specific yield was 25.7 per cent.

PROCEDURE

The procedure used was such that the drawdown curve being investigated was preceded by a higher drawdown curve. A minimum of three hours was allowed after a given set of boundary conditions was imposed in order that equilibrium be established. With the head water depth held constant, one of a series of drainage conditions was imposed. This was accomplished either by opening the valve for any one of the tile drains or by adjusting the level of the tail water. The tail box actually simulated an open, interceptor drain.

Head water depths were varied over a range from 8 to 40 inches. Various tile drains were operated with each constant head water depth. The slope was varied in one-half per cent increments from 0 to 3 per cent.

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THEORETICAL ANALYSES

Flow into Drain

At this point it is necessary to show by dimensional analysis, the relationships that exist for the flow. For a simple system with no drain the variables for a two dimensional system may be expressed by

$$q_o = \phi_1 (s\ ,\ K\ ,\ H) \tag{1}$$

q_o is the flow per unit width, K is the hydraulic conductivity and H is the depth of ground water above an impermeable boundary of slope s. The function is represented by ϕ. Choosing K and H as repeating variables yields

$$q_o/KH = \phi_2 (s) \quad . \tag{2}$$

In general, one must determine ϕ_2 by experimentation. However, from Darcy's law

$$q_o = KHs \quad , \tag{3}$$

which leads to the conclusion that $\phi_2(s) = s$.

When a drain is installed as in figure 2, the relationship that exists is

$$q_d = \emptyset_3 \, (s \, , \, K \, , \, r \, , \, L \, , \, H \, , \, h) \quad , \tag{4}$$

where q_d is the resulting flow in the drain, r is the radius of the tile, L is the distance from the tile line to the source of seepage, and h is the distance above the barrier layer to the drain. The remaining variables have the same meaning as in equation 1. Equation 4 may be rewritten in more usable terms;

$$q_d = \emptyset_4 \left[s \, , \, K \, , \, r \, , (H + sL) \, , \, H \, , \, h \right] \, . \tag{5}$$

Choosing K and H as repeating variables and combining, yields

$$q_d/HKs = \emptyset_5 \left[r/H \, , \, (H + sL)/H \, , \, h/H \right] = q_d/q_o \, . \tag{6}$$

The parameter r/H is not important provided the tile is large enough to carry the required flow. The converse of the reciprocal of $(H + sL)/H$ is a more useful form so that equation 6 is changed to

$$q_d/q_o = \emptyset_6 \left[sL/(H + sL) \, , \, h/H \right] \quad . \tag{7}$$

Equation 7 is the flow analysis of the type of interceptor drain studied.

Shape of the Drawdown Curve

An analysis similar to that for the flow analysis was made for the shape of the drawdown curve but was found to be difficult to handle because of the number of parameters involved. It was found that a previous theoretically derived relationship was applicable. One purpose of this study was to check this equation using model techniques. This equation which was presented by Donnan (1) is

$$x = \frac{H \log_e (H - h)/(H - y) - (y - h)}{s} \quad , \tag{8}$$

where x and y are the coordinates of any point on the drawdown curve as shown by figure 2 and the remaining variables have the same meaning as in equations 1 and 4. This equation yields infinite values of x when $s = 0$ or $y = H$. The assumption was made that the flow remains constant before and after drainage.

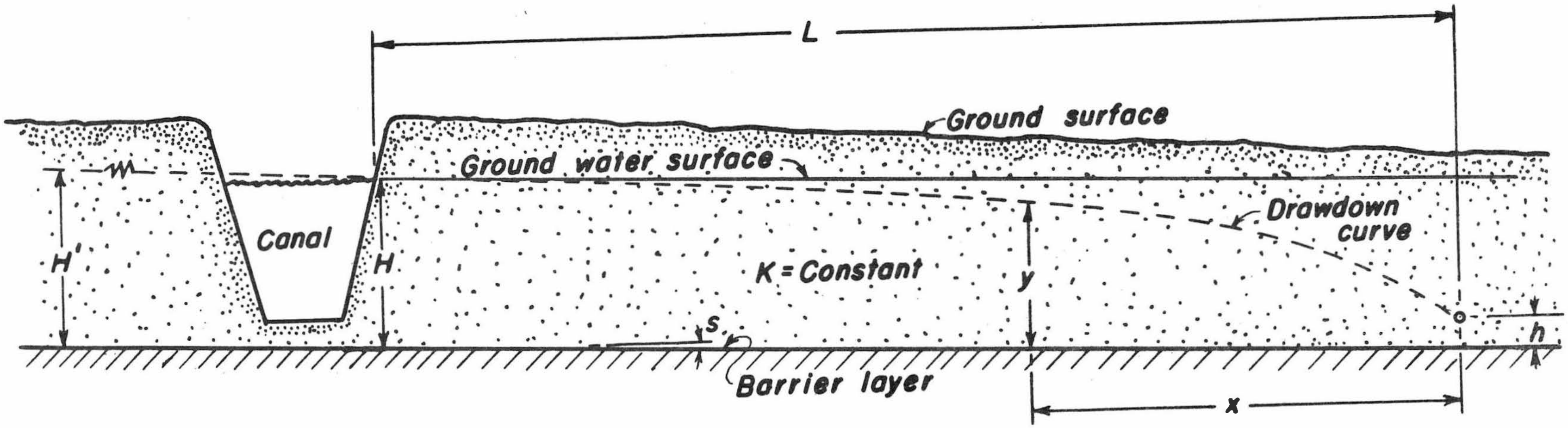

Fig. 2 Layout of a tile interceptor drain.

ANALYSES OF DATA

If all variables had been given proper consideration in the dimensional analyses, the resulting parameters would be functionally related. The relationship would be demonstrated by the alignment of experimental data when plotted. The value of dimensional analysis is reflected by the degree to which the data are summarized, condensed or generalized by plotting in the dimensionless form.

Flow into Drain

In the analysis of the flow data, three assumptions were made. The first was that the capillary flow was negligible. The second assumption was that the tile drains were completely effective, i.e. there was no bypass flow over the drains. The third was that an open ditch interceptor was simulated by using the tail box to intercept all the flow.

Figure 3 is a plot of the dimensionless parameters given in equation 7. The parameter h/H is a ratio of height of drain above the impermeable boundary to the depth of water-bearing stratum. A value of h/H equal to zero indicated the drain was placed on the barrier layer. The parameter $sL/(H + sL)$ shows the relationship of energy in a system because of slope to that due to slope and depth. This approaches a value of one for a great length or small values of H and decreases as the distance from the source to the drain decreases or H increases. The alignment of points in figure 3 indicates that all the factors influencing the problem had been considered.

The use of this plot can be explained by using an example. Given a length (L) of 200 feet, a water-bearing aquifer 10 feet thick (H) overlying an impermeable boundary of slope 0.01 (s) with a tile drain installed 4 feet (h) above the barrier layer. Solving for the known variables yields

$$sL/(H + sL) = 0.17 \quad \text{and} \quad h/H = 0.4 \quad .$$

From figure 3

$$q_d/q_o = 2.3 \quad \text{or} \quad q_d = 2.3\, q_o \quad .$$

The discharge in the drain would be 2.3 times the flow per linear foot of width which was occurring before drainage. If the hydraulic conductivity of the water-bearing stratum is known, the actual discharge in the drain can be computed. Assuming a conductivity of 0.0001 foot per second (4.3 inches per hour)

$$q_o = HKs = (10)(.0001)(.01) = 0.00001 \text{ cfs/linear foot}$$

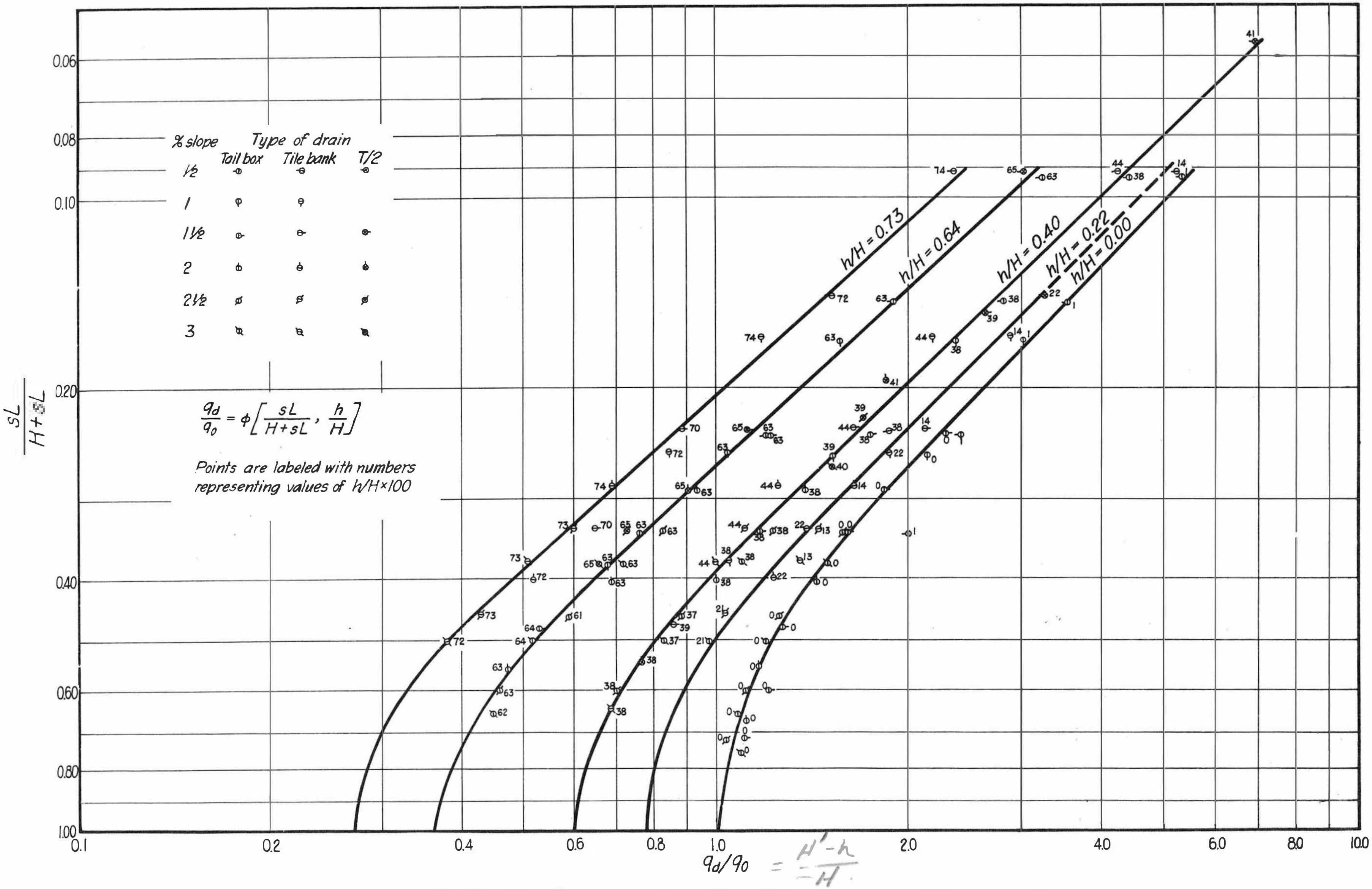

Fig. 3 Discharge of interceptor drains for slopes greater than zero.

or

$$q_o = 4.5 \text{ gal./min./1000 linear feet}$$

since

$$q_d = 2.3\ q_o\ ,$$

$$q_d = 10.4 \text{ gal./min./1000 linear feet of drain}\ .$$

Shape of Drawdown Curve

The comparison of equation 8 and experimental data is shown in figure 4. The results of two tests are shown, one of which could be considered a relatively short system ($H = 40$, $L = 811$, $h = 0.0$) and the other relatively long ($H = 13.3$, $L = 794$, $h = 5.0$) . For the short system there was a considerable difference between the observed drawdown curve and the computed curve. Some adjustment was therefore necessary in equation 8. This was accomplished by computing a new value for H in the equation which will hereafter be called H' and was done by substituting $x = L$ and $y = H$ back into the equation and solving for H' . Using this new value for H' , equation 8 checked with observed data as can be seen in figure 4. Equation 8 then becomes

$$x = \frac{H' \operatorname{Log}_e (H' - h)/(H' - y) - (y - h)}{s}\ . \qquad (9)$$

At this point it was noted that the shape analysis was related to the flow analysis. The following relationship will illustrate this statement.

$$q_d/q_o = \frac{H'Ks - hKs}{HKs} = \frac{H' - h}{H}\ . \qquad (10)$$

The substitution is again made of $y = H$ and $x = L$ so that the parameters from the flow analyses become

$$h/H = h/y\ ,$$

$$sL/(H + sL) = sx/(y + sx)\ ,$$

$$(H' - h)/H = (H' - h)/y\ .$$

Figure 5 is a plot using these parameters which was computed using equation 9. It should be noted that this is exactly the same plot as figure 3 which was obtained from observed flow data. Essentially, one plot would give both the flow and shape analyses for this type of interceptor drain.

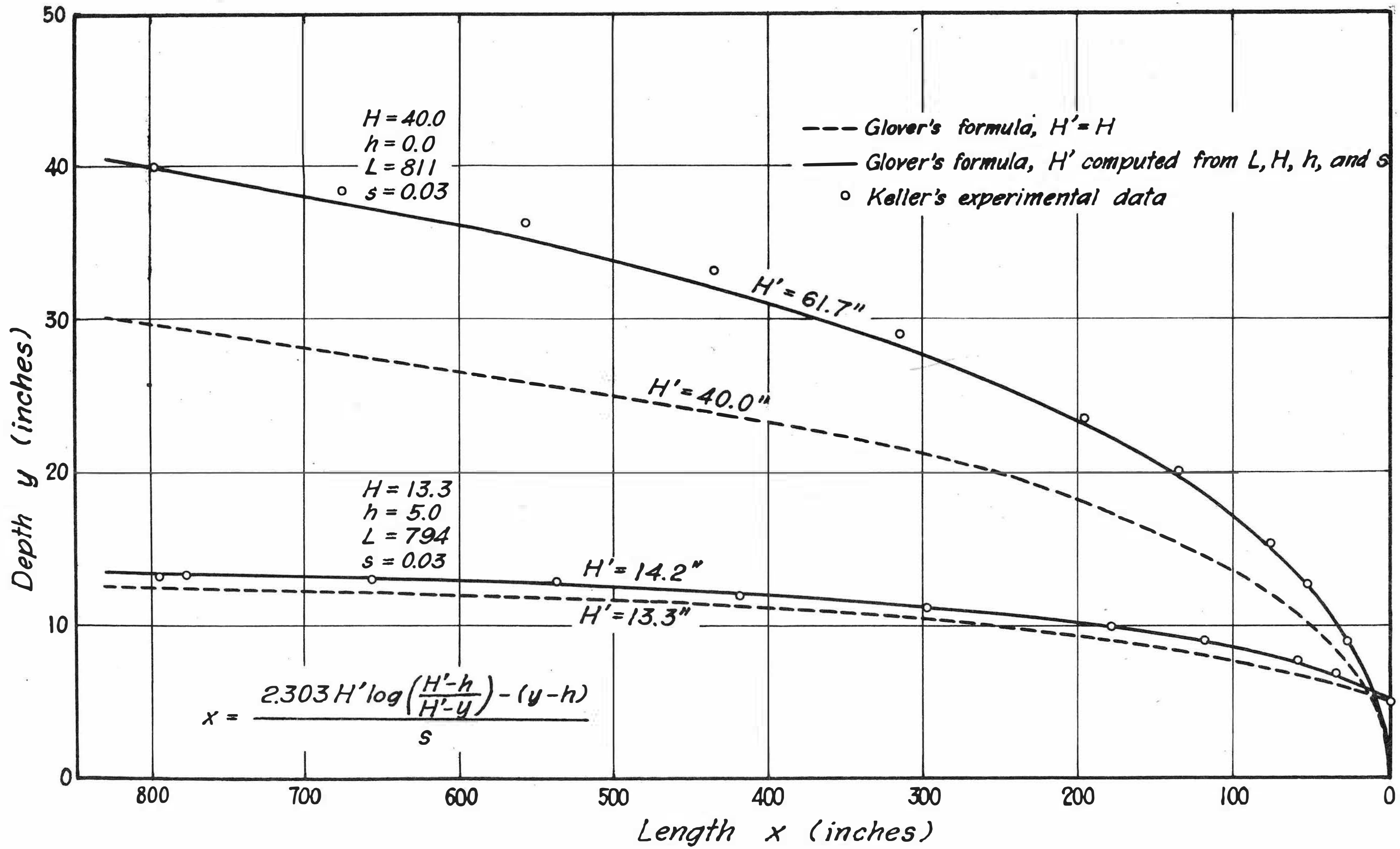

Fig. 4 Comparison of observed drawdown curves with Glover's formula for slopes greater than zero.

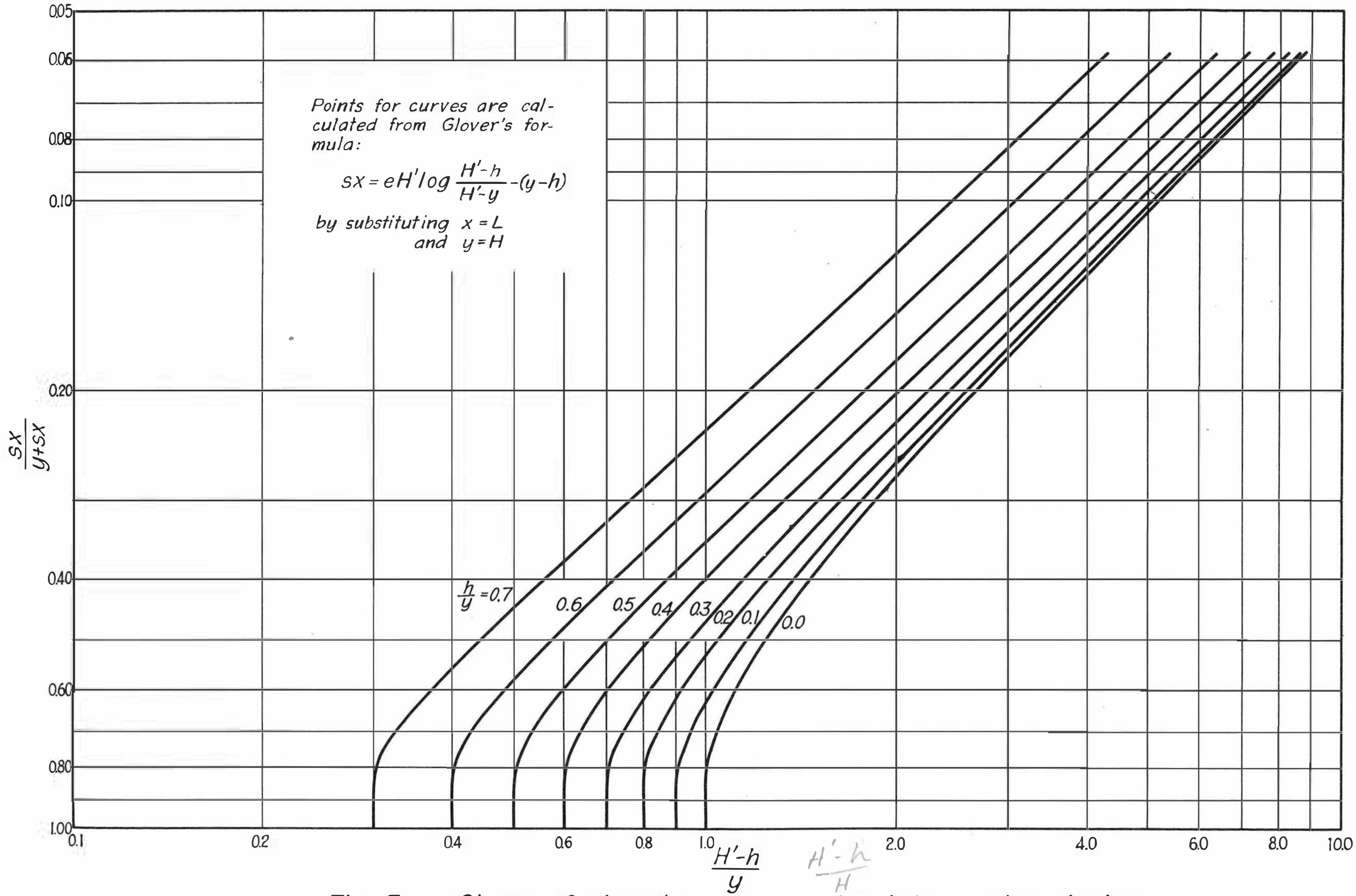

Fig. 5 Shape of drawdown curves for interceptor drains

As a practical problem suppose that the original depth of water-bearing strata was 10 feet, the drain was 5 feet above the barrier layer which had a slope of 0.02 and was installed at a distance of 500 feet from the known source of seepage. Then

$$h/H = 0.5 \qquad\qquad sL/(H + sL) = 0.5 \ ,$$

from figure 3

$$q_d/q_o = 0.69 = (H' - h)/H \ ,$$

$$H' = 11.9 \ .$$

The problem is to determine the distance (x) from the drain that the ground water would be lowered 2.5 feet from its original level. Then

$$y = 5.0 + 2.5 = 7.5 \text{ ft.} \ ,$$

$$h/y = 5/7.5 = 0.67 \ ,$$

$$(H' - h)/y = 0.92 \ .$$

From figure 5

$$sx/(y + sx) = 0.27 \ ,$$

$$x = 139 \text{ ft.} \ .$$

Therefore, the ground water surface would be 2.5 feet below its level before drainage at a distance of 139 feet from the drain. Figure 5 can be used for finding the coordinates of any point on the drawdown curve.

SUMMARY

A method has been proposed for determining both the resulting flow and shape of the drawdown curve of an interceptor drain using dimensionless plots. These plots were obtained from experimental data and previously determined theoretical relationships. This method is applicable for cases where the source is either known or from engineering judgment an equivalent source is determined and a barrier layer is confining the flow through a relatively shallow strata.

In many cases where a drain is constructed near the seepage source, such as a canal, the quantity of seepage may be increased to a large extent by the proximity of the drain.

REFERENCE CITED

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