*Journal of Agricultural Engineering Vol. **46(2)**: April-June, 2009*

Research Note

Effect of Pumping Depth on Hydraulic Conductivity Measurement by Auger Hole Method

Raj Kumar Jhorar[1] and B. Anjaneyulu[2]

ABSTRACT

The flow dynamics of auger hole method, used for hydraulic conductivity measurements, was examined with the help of streamlines. Values of stream function around an auger hole penetrating to an impervious layer were calculated for different depths of pumped water level in the hole. Streamlines were drawn around an auger hole for four cases of pumped water level- auger hole empty, one-fourth full, half full and three-fourth full. Examination of streamlines highlighted the consequence of change in pumped water level on flow toward the auger hole. Contrary to the earlier belief that auger hole measurements give average horizontal saturated hydraulic conductivity of the soil zone from static water table level to the bottom of the auger hole, it is shown that this is true only in case of uniform isotropic soils. It is suggested that the auger hole tests for subsurface drainage design must be conducted with very small amount of pumping (say 25 %) so that the soil region and flow direction used for measurement of saturated hydraulic conductivity adequately represent the soil and flow direction in the actual system. It was also observed that the measured value of saturated hydraulic conductivity, particularly for a soil with variable conductivity with depth, would be more representative of the average if measurements are taken with small depth of water pumped from the hole.

Knowledge of reliable value of saturated hydraulic conductivity (K_{sat}) is important for the design and selection of optimum drainage facilities. A number of tests for determining in place K_{sat} below a water table have been developed. These include auger hole (Hooghaudt, 1940), tube (Kirkham, 1946), piezometer (Luthin and Kirkham, 1949), two well (Childs *et al.,* 1953), four well (Snell and van Schilfgaarde, 1964) and pit bailing method (Bouwer and Rice, 1983). The method for measuring K_{sat} for drainage design should in principle be selected so that the soil region and flow direction used for measurement of K_{sat} adequately represent the soil and flow direction in the actual system. The auger hole method is probably the most widely used and accepted method for measuring K_{sat}, for use in subsurface drainage design. It is believed that the method measures the average horizontal K_{sat} of the soil from the static water table to the bottom of the hole (USDI, 1978), but the question of how good this average remains to be confirmed (Rogers, 1986).

The auger hole theory and procedure has been discussed in detail by Kirkham and van Bavel (1948), Johnson *et al.,* (1952), Ernst (1950), van Beer (1963), Boast and Kirkham (1971) and Kessler and Oosterbaan (1974). Field procedure for measurement of K_{sat} with the auger hole method has been standardised with the tacit assumption of isotropic soils and belief that the method gives an "averaged" value of K_{sat} for a soil profile. Little attention is paid on the change in behaviour of flow to an auger hole under different test conditions. Rogers (1986) and Rogers and Carter (1987) did show that, for a layered soil, the value of measured K_{sat} vary with depth of water removed from the auger hole during tests.

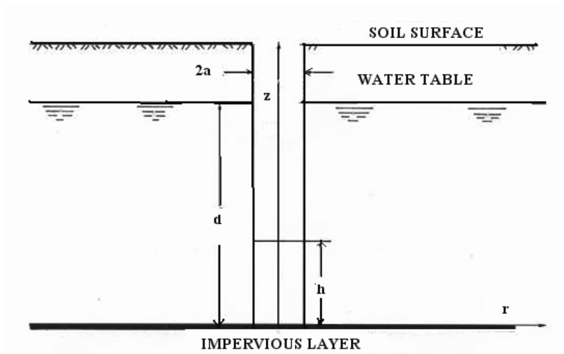
The purpose of this study was to draw streamlines around an auger hole, penetrating to an impervious layer, and then to use these streamlines to examine the flow to an auger hole. An attempt has been made in this paper to predict and show the effects of pumping depth on the flow to an auger hole. Manipulation of pumped water level in an auger hole, in a way to achieve the earlier mentioned desired requirement of measurements where the soil and flow direction adequately represent the actual drainage system, is also discussed.

MATERIALS AND METHODS

The auger hole method of hydraulic conductivity determination under shallow water table condition consists of auguring a cylindrical hole into a saturated soil; allowing water to seep into and fill the auger hole to the level of static water table level; quickly removing some or all of the water from the auger hole; and finally, recording the

[1]*Associate Professor, Department of Soil and Water Engineering, COAE&T, CCS HAU, Hisar (jhorar@yahoo.com); , [2]Professor (Retd), IIT Kharagpur*

instantaneous rate of flow to the auger hole, immediately following the removal of water from the hole, which is related to the K_{sat}. The geometry of flow and symbols for an auger hole penetrating to impervious layer are shown in Fig 1.



d: Effective depth of auger hole from static water level to impervious layer
a: Radius of auger hole
h : Depth of water in auger hole after pumping
r, z: Two axes of radial coordinates.

Fig. 1: Geometry of flow for auger hole method

Saturated seepage flow problems are best studied by streamlines. Streamlines are paths of the seepage flow. The stream differential equation, in two dimensional radial coordinates for the flow geometry, may be written as

$$\partial^2\psi/\partial^2\rho - (1/\rho)\partial\psi/\partial\rho + \partial^2\psi/\partial^2 z = 0 \qquad ...(1)$$

Where,

ψ = Stream function, and

r and z = Two axes of radial coordinates.

The stream function represents a series of numbers distributed in two dimensional spaces which can be contoured to give streamlines (Fogg and Senger, 1985). In other words, lines along which ø has a constant value are streamlines. On using the separation of variable technique, Zaslavsky and Kirkham (1964) found a solution to equation 1 as

$$\psi = K_{sat} \frac{8d}{\pi^2} \Sigma \frac{1}{n^2} \cos\frac{n\pi h}{2d}\, r \frac{K_1(n\pi r/2d)}{K_0(n\pi a/2d)} \operatorname{Sin}\frac{n\pi z}{2d} + M \qquad ...(2)$$

Where, K_0 and K_1 = Zeroth and first order modified Bessel function of the second kind, respectively, and M = A constant.

To draw the streamlines, another function ψ' is defined as

$$\psi' = \frac{\psi(a,d,h) - \psi(r,z,h)}{\psi(a,d,h) - \psi(a,0,h)} \times 100 \qquad ...(3)$$

The constant M in equation (2) need not be evaluated as it cancels out in both the numerator and denominator of Equation 3. Another important feature of the equation (3) is that K_{sat} also cancels out implying that the shape of streamlines for a given set of conditions are same for all the values of K_{sat}.

Bessel functions K_0 and K_1 were estimated using the polynomial approximation given by Olver (1965) and a set of values of ψ' were calculated for the actual pumped water level, h, and for a number of values of r and z. The value of ψ' varies from 0 to 100. Streamlines are the contours of ψ'. The difference in values of ψ' between a pair of streamlines gives the percentage of the total flow passing between the streamlines. For the present study, an auger hole having effective depth (d) of 2.0 m and radius (a) of 0.1 m was considered. The values of ø' were computed for different amounts of pumped water from the auger hole.

RESULTS AND DISCUSSION

Four cases of pumped water level for an auger hole were considered viz. (I) complete pumping with auger hole empty (h = 0.0 m); (II) auger hole one-fourth full (h = 0.5 m); (III) auger hole half full (h = 1.0 m); and (IV) auger hole three-fourth full (h = 1.5 m). The streamlines about an auger hole, for the four cases, obtained by drawing contours of ψ' are presented in Fig. 2. Fig. 2a shows streamlines about an auger hole, assuming that all the water has been pumped out of the hole (Case I). Figures 2b, 2c and 2d shows streamlines in the soil about the same auger hole when 75 (Case II), 50 (Case III) and 25 (Case IV) per cent of the water has been pumped out, respectively.

For water filled surface of the auger hole, streamlines entered perpendicular to the wall of the hole (Figs. 2b, 2c and 2d), as they should, since the water filled surface of the hole was an equipotential. Above the water filled part of the hole, the streamlines entered at an angle depending on the angle at which the equipotential (not shown) enter the hole. Streamlines entering perpendicular to the wall of the hole indicated horizontal flow direction. As pumped water level reached nearer to the static water

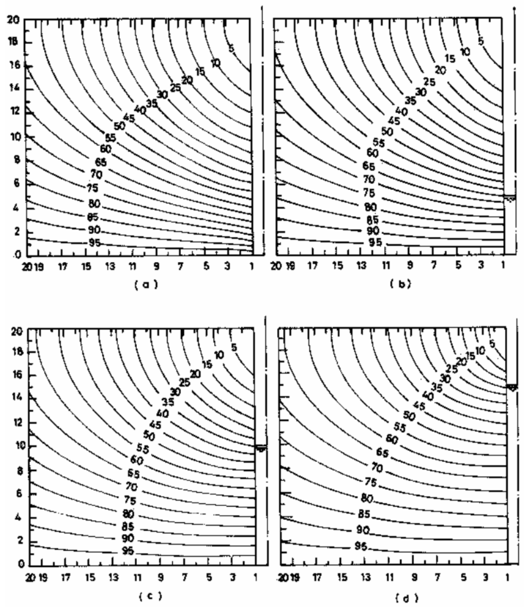


Fig. 2: Streamlines around an auger hole for a) an empty auger hole, b) one-fourth full auger hole, c) half full auger hole and d) three-fourth full auger hole

table level, more streamlines tended to become horizontal near the hole, while for empty auger hole (Fig. 2a) streamlines were mostly inclined. So long as the soil is isotropic, it made no difference whether the streamlines entering an auger hole were horizontal or inclined. With the anisotropic postulate in mind, one may consider the manner in which flow entering the hole is affected. As can be seen from the Fig. 2d, the estimated value of K_{sat} with case IV would be more representative of horizontal K_{sat} as 75% of the total hole depth received mostly horizontal flow near the hole, while case I would be more representative of vertical K_{sat}. For subsurface drainage design, K_{sat} would be more representative of horizontal direction, hence, must plan auger hole tests according to case IV.

It may also be observed from Figs 2a to 2d that for water filled portion, streamlines entered at equal spacing, but above the water filled portion streamlines were spaced at varied spacing (increasing towards top). As can be seen from Fig 2b, about 40% of the total flow entering the hole was through equally spaced streamlines in case of three-fourth pumping. In case of one-fourth pumping, about 80% of the total flow entering the hole was through equally spaced streamlines (Fig. 2d). In case of complete pumping, all streamlines were spaced at varied spacing (Fig. 2a). Auger hole tests are expected to give average value of the soil zone tested, this is true in case of uniform soils but in case of layered soils, test conducted with small pumping (e.g. Fig 2d) will give more representative value of K_{sat}, as about 80% of the flow was through equal size soil strips (in the vicinity of the auger hole) giving more equal weightage to each portion of the soil zone.

Streamlines show the flow direction as also the relative magnitude of the velocity along the channel between the two streamlines. The velocity at any point in the stream channel varies in inverse proportion to the spacing of the streamlines near that point. Fig 2a (empty auger hole) shows that streamlines at bottom were narrowly spaced indicating higher velocity of flow near the bottom and therefore, indicated that the soil near the bottom of the auger hole would be of primary importance in determining the flow rate. Auger hole measurements are also expected to represent K_{sat} for whole depth from bottom of the hole to the top of the static water table. As seen from Fig. 2a, in case of empty auger hole, 80% of the total flow was entering from the bottom 55% portion of the hole, and in case of three-fourth full auger hole (one-fourth pumped out), 80% of the total flow was entering from the bottom 75% of the hole. This means that case IV was more representative of what was expected.

Although spatial variability (soil heterogeneity) is a greater uncertainty in defining large-area hydraulic conductivity, every effort must be made to conduct individual tests as precisely as possible. Inability to keep same pumping level in all the tests may lead to misleading interpretation/ conclusions about the actual spatial variability, particularly when soil profile layering and anisotropic conditions are important.

CONCLUSIONS

i) A procedure was developed to draw streamlines in the soil around an auger hole penetrating to an impervious layer, for different depths of water pumped from the hole.

ii) The flow geometry (flow direction and soil region tested) of the auger hole measurements were greatly influenced by the depth of water pumped from the hole.

iii) The measured value of saturated hydraulic conductivity, particularly for a soil with variable conductivity with depth, would be more representative of the average if measurements are taken with small depth of water pumped from the hole.

iv) It is recommended that the auger hole tests conducted for subsurface drainage design must be with small depth of water pumped from the hole to adequately represent the soil and flow direction in the actual system. Special care must be given to the depth of water pumped from the auger hole when determining representative hydraulic conductivity value for large-areas.

REFERENCES

Boast C W; Kirkham D. 1971. Auger hole seepage theory. Soil Sci. Soc. Amer. Proc., 35, 365-373.

Bouwer H; Rice R C. 1983. The pit bailing method for hydraulic conductivity measurements of isotropic or anisotropic soil. Trans. ASAE, 26, 1435-1439.

Childs E C; Cole A H; Edwards, D H. 1953. The measurement of the hydraulic permeability of saturated soils in situ. II. Roy. Soc. (London), Proc., A 216, 72-89.

Ernst L F. 1950. A new formula for the calculation of the permeability factor with the auger hole method. T.N.O. Groningen 1950. Translated from the Dutch by H. Bouwer, Cornell Univ. Ithaca, New York, 1955.

Fogg E F; Senger R K. 1985. Automatic generation of flow nets with conventional ground-water modeling algorithms. Ground Water, 23(3), 336-344.

Hooghoudt S B. 1940. Bepaling van den doorlaatfacyor van den ground met behulp van pompproeven, (z.g. boorgaten methode). Verslag Landbouwk. Onderzoek, 42, 449-541.

Johnson H P; Frevert R K; Evans D D. 1952. Simplified procedure for the measurement and computation of soil permeability below the water table. Agril. Engg., 33, 283-286.

Kessler J; Oosterbaan R J. 1974. Determining hydraulic conductivity of soils. In Drainage Principles and Applications. ILRI, Wageningen, The Netherlands, 3(16), 253-296.

Kirkham D. 1946. Proposed method for field measurement of permeability of soil below the water table. Soil Sci. Soc. Amer. Proc., 10, 58-68.

Kirkham D; van Bavel C H M. 1948. Theory of seepage into auger holes. Soil Sci. Soc. Amer. Proc., 13, 75-83.

Luthin J N; Kirkham D. 1949. A piezometer method for measuring permeability of soil in situ below a water table. Soil Sci., 68, 349-358.

Olver F W J. 1965. Bessel functions of integer order. In: Milton Abramowitz and Irene A.Stegun (Editors), Handbook of Mathematical Functions, Dover Publications, Inc., New York, 355-433.

Rogers J S. 1986. Finite element model of flow to an auger hole in layered soils. Trans ASAE, 29(4), 1005-1011.

Rogers J S; Carter C E. 1987. Auger hole hydraulic conductivity determination in layered soils. Trans ASAE, 30(2), 374-378.

Snell A W; van Schilfgaarde J. 1964. Four well method of measuring hydraulic conductivity in saturated soils. Trans ASAE, 7, 83-87, 91.

USDI. 1978. Drainage Manual. Oxford and IBH Publishing Company, New Delhi, pp. 286.

Zaslavsky D; Kirkham D. 1964. The streamline function for axially symmetric groundwater movement. Soil Sci. Soc. Amer. Proc., 28, 156-160.