THE EFFECT OF AUGER HOLE DIAMETER CHANGES ON HYDRAULIC CONDUCTIVITY MEASUREMENTS

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Diameters of auger holes before and after hydraulic conductivity tests were measured by a straightforward technique. The effect of diameter increase was shown to bias systematically the field evaluations of hydraulic conductivity. The piezometer technique, in which volumes were measured in a pipe of constant diameter, was much less influenced by soil sloughing than was the auger-hole technique. Undetected auger hole diameter increases would result in greater intensity of subsurface drain pipes. Diameter changes should be taken into account by measuring hole diameters at representative sites.

INTRODUCTION

Hydraulic conductivity data from the auger-hole technique are useful for drainage design (Bouwer and Jackson 1974; Shady et al. 1977). Shady et al. (1977) have indicated that a perforated liner or screened casing is required in unstable soils to prevent cave-ins of the auger hole. The danger of cave-in has usually been associated with sandy soils whereas clay-rich soils have been assumed to remain stable. Van Beers (1976) has indicated in a general way that "sloughing" from the sides of the auger hole would cause one to read hydraulic conductivity values which are in error by percentages two times the percentage change in hole diameter. Neither the amount of sloughing which may occur nor an easy method for its measurement has been reported. In this paper we show that ignoring the sloughing of soil peds from the hole wall in well-structured clay-rich soils resulted in considerable error in the calculation of hydraulic conductivity when measuring with the auger-hole technique but not when using a piezometer.

MATERIALS AND METHODS

Hydraulic conductivity measurements were made in two clay soils near Ottawa, classified as Humic Gleysols (Dalhousie and Rideau soil associations (Marshall et al. 1979)). Ten different locations separated by 2 m, along a line, were chosen at each of the two sites. Holes, 10 cm in diameter, were augered at each location with an open-blade type auger similar to that shown by van Beers (1976) and Shady et al. (1977). The bottom of each hole was squared off using a bucket-type auger having flat cutting blades on both the bottom and the sides. This was necessary to assure the boundary conditions of the hole were those which were applied in the solutions of the flow equation. In each augered hole, measurements of saturated hydraulic conductivity (Ksat) were made at two depths by the auger-hole and horizontal piezometer methods as described by Topp and Sattlecker (1983). The depths were 1.1 m and 1.3 m.

Earlier experience to which reference was made by Topp and Sattlecker (1983) showed that hole diameters had increased at some point during the course of measuring Ksat. In the present experiment hole diameters were measured as shown schematically in Fig. 1. An inverted 'T' bar whose vertical bar had a length L2 was suspended from a pivot point at height L1 above the center of each auger-hole. The cross bar on the 'T' was 10 cm. The calculation of d2 after measurement of d1 at the surface gave the increase in diameter of the hole. Diameter measurements were made across the holes in two perpendicular directions at depths 10 cm and 30 cm above the bottom of the hole both before and after the determinations of hydraulic conductivity. When large values for d1 were measured or when the two values varied considerably two additional measurements were made at each depth.

The calculation of hydraulic conductivities, Ksat, made use of the equations presented in Topp and Sattlecker (1983). The effect of hole diameter changes was ascertained by making calculations of Ksat first, assuming hole diameters of 10 cm and second, using hole diameters as measured above.

RESULTS AND DISCUSSION

For both sites there was a considerable increase in diameter of the holes at depths of 0.9 and 1.2 m. At the Dalhousie soil site the increase in diameter during the first set of measurements was 10%, on average, with a range from 2 to 20%. After a second set of measurements the hole diameters had increased an additional 8.5% for a total of 18.5% (range 7–28). There was less diameter increase at the Rideau site, e.g. 6% (0–13%) after one set of measurements and 10% (4.5–16%) after both sets of measurement.

The influence of these hole diameter increases on Ksat was greatest for the auger-hole method (Table I). Figure 2 shows a hole by hole comparison of Ksat for Dalhousie soil if we had assumed a 10-cm diameter hole as compared to that given by measuring the diameter of each hole. The ratio of the mean Ksat from the holes as measured to those assuming 10 cm was 1.36 for the Dalhousie soil and 1.19 for the Rideau soil. For the case of the piezometer measurement to determine the horizontal component of Ksat the corresponding ratios were 0.93 for the Dalhousie soil and 0.97 for the Rideau soil. These changes are shown as percent changes in Table I for measurements made in the holes 1.3 m deep at each site.

Both the soils studied are of clay texture and are well structured. The medium to strong subangular blocky structure was slightly more adhesive in the Rideau soil than was the same structure in the Dalhousie soil. The peds in the Rideau soil, about 2 cm across, were about twice the size of those in the Dalhousie soil. Both the size of peds and the greater adhesion of peds probably resulted in the auger holes in the Rideau soil being more stable than in the Dalhousie soil. In the usual practice of measuring Ksat by the auger-hole method, hole diameter increases would go undetected for two reasons. Firstly, at most times the hole is filled or filling with muddy water which obstructs the view of the hole and secondly, from a standing position, looking into a hole > 1 m deep and 10 cm diam., one cannot accurately perceive by eye a 20% increase in diameter.

The greater influence of hole diameter on the auger-hole than on the piezometer

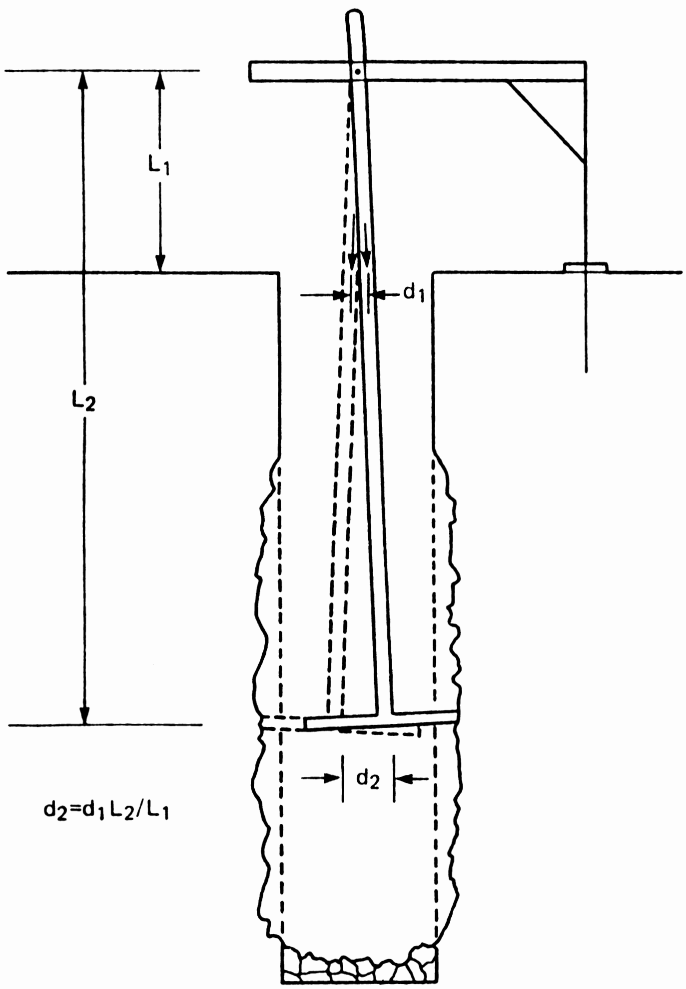

Figure 1. Procedure used to measure auger hole diameters below the water table.

TABLE I. THE EFFECT OF HOLE DIAMETERS ON Ksat ($m \cdot d^{-1}$) BY THE AUGER-HOLE (K_{ah}) AND PIEZOMETER (K_h) METHODS

	Diameter				Diameter			
	10 cm		as-measured		10 cm		as-measured	
Location	K_{ah}	K_h	K_{ah}	K_h	K_{ah}	K_h	K_{ah}	K_h
	Dalhousie soil				Rideau soil			
1	55.1	33.9	74.9	31.2	7.43	22.9	9.54	22.9
2	14.6	30.8	24.1	29.8	7.99	20.8	10.8	20.4
3	15.0	25.2	17.3	23.9	12.9	23.2	14.2	22.6
4	20.4	38.5	27.1	35.4	12.2	16.5	14.0	16.0
5	23.8	28.0	31.3	25.5	6.2	13.9	8.57	13.1
6	17.1	17.1	19.0	17.0	14.9	34.2	18.3	33.5
7	22.3		31.9		11.0	20.9	12.4	20.1
8	76.0	79.3	102.0	61.2	8.75	22.0	9.16	20.9
9	17.2	19.5	25.6	19.5	11.3	15.9	12.6	15.9
10	26.5	45.7	40.5	43.6	6.72	29.1	8.05	28.1
Geometric mean	24.5	31.9	33.3	29.7	9.54	21.1	11.4	20.6
SD factor	1.74	1.59	1.77	1.49	1.35	1.31	1.3	1.32
% change			+36%	−7%			+19%	−3%

determinations results mainly from the influence of hole diameter on the measurement of rate of flow into the hole. The equations used to calculate Ksat were:

$$K_{ah} = C_{bk}\,(\Delta y/\Delta t) \qquad \text{for the auger-hole} \qquad (1)$$

$$K_h = (\pi r^2/S)\ln(y_o/y_t)/\Delta t \qquad \text{for the piezometer measurement} \qquad (2)$$

where K_{ah} and K_h represent the Ksat by the two methods, C_{bk} is a parameter determined from tables in Boast and Kirkham (1971), y is the measured height of water in the hole or pipe at various times (t), S is a shape factor for the piezometer geometry and boundary conditions (Youngs 1968); and r is the radius of the pipe used for the piezometer.

From the geometry of the augered hole

$$Q = \pi r_c^2\,(\Delta y/\Delta t) \qquad (3)$$

where r_c is the radius of the auger-hole, Q is the rate of flow of water into the hole (i.e. the rate at which water arrives at the wall of the hole).

Boast and Kirkham (1971) rearranged Eq. 1 as:

$$C_{bk} = (K_{ah}\pi r_c^2)/Q \qquad (4)$$

Based on the procedure given by Stout (1950), an error analysis for one factor takes the form

$$dK = \text{Probable error of } K \text{ due error in } r_c = \frac{\partial K}{\partial r_c}\,dr_c \qquad (5)$$

When this is applied to Eq. 4 for the auger-hole method

$$dC_{bk} = [(2K\pi r_c)/Q]dr_c \qquad (6)$$

If dr_c is expressed as a fraction of r_c, say $0.1\,r_c$, then

$$dC_{bk} = 0.2\,C_{bk}$$

or

$$\frac{dK_{ah}}{K_{ah}} = 2\,\frac{dr_c}{r_c}$$

A similar analysis of Eq. 2 for the effect of error in r_c on the shape factor showed that

$$\frac{dK_h}{K_h} \geqslant -0.5\,\frac{dr_c}{r_c}$$

for the range of values for S appropriate for the data reported here.

This shows how hole diameter increases of 18.5% gave mean increases in K_{ah} of 36% for the Dalhousie soil by the auger-hole measurement as opposed to assuming the original hole diameter. For the piezometer method a 10% increase in hole diameter for the Rideau soil resulted in a mean decrease in K_h of 3%. For the piezometer the measurement of the rate of flow into the hole was not influenced by the hole diameter because measurement took place in the pipe of constant diameter, $2r$.

The above discussion on the effect of changes in hole diameter on the calculated Ksat assumed the hole diameter changes had occurred prior to the measurement of the rise of water level in the hole. Dylla and Michener (1971) pointed out that if soil is sloughing off the wall from above the

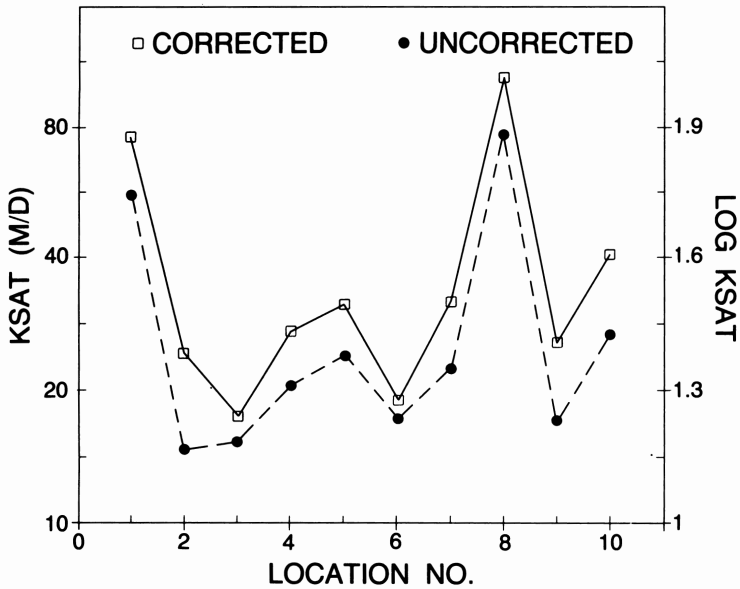

Figure 2. A comparison of Ksat values for the Dalhousie soil showing the effect of hole diameter changes.

water level and falling into the water this soil volume becomes a part of the volume of water that is measured. This would give higher Ksat than the true value. We observed little evidence of soil falling into the water as the hole was filling. We believe that the majority of the hole diameter increase occurred during the bailing out of the water. The bailer was an aluminum irrigation tube, 7.6 cm diameter by 1.5 m long, with a ball valve at the bottom. The bailer was filled each time by several quick and short up and down thrusts. The up and down motion of the bailer caused some splash of water against the hole wall and was probably the cause of soil peds being dislodged from the wall of the hole.

Although the effect of undetected hole diameter changes is less than the variability of Ksat usually encountered in a field it is always in one direction resulting in a systematic error. In addition, it is relatively easy to make the hole diameter measurements and incorporate the necessary corrections. For practical purposes it is probably sufficient to measure the diameter changes in a number of holes representative of the soil being measured. Then all measurements of Ksat can be corrected by the same relative amount that the diameter increase has on C_{bk} in Eq. 4. If the correction for this systematic error were not made the hole diameter increases would bias the drain spacing specifications. Luthin (1973) presented a widely used form of Hooghoudt's drain spacing formula in which drain spacing varies inversely as $(\mathrm{Ksat})^{1/2}$. Above we have shown that Ksat varies as r_c^2. Therefore, drain spacing varies approximately as the assumed radius or diameter of the hole. Thus an undetected 20% increase in hole diameter would result in a value of Ksat that would be about 40% lower than the actual value. The resultant drain spacing specification would indicate 20% narrower spacing than should be required. For the farmer this represents an unnecessary increase in capital cost of 20%.

CONCLUSIONS

During measurement of Ksat by the auger-hole and piezometer techniques the diameter of the auger hole increased measurably in two clay-rich well-structured soils. The relative effect of the diameter increase had a doubling effect on the resulting Ksat by the auger-hole method. Undetected hole diameter increases would result in a proportional increase in the subsurface drain requirements. Measurements of Ksat by the auger-hole method should include an assessment of the magnitude of diameter change resulting from soil sloughing.

REFERENCES

BOAST, C. W. and D. KIRKHAM. 1971. Auger hole seepage theory. Soil. Sci. Soc. Am. Proc. **35**: 365–374.

BOUWER, H. and R. D. JACKSON. 1974. Determining soil properties. Pages 611–672 *in* J. van Schilfgaarde, ed. Drainage for Agriculture. Agronomy no. 17. Am. Soc. Agron., Madison, Wis.

DYLLA, A. S. and D. W. MICHENER. 1971. Auger-hole hydraulic conductivity: First versus second test. Trans. ASAE (Am. Soc. Agric. Eng.) **14**: 582–583.

LUTHIN, J. N. 1973. Depth and spacing of drains. Pages 149–173 *in* Drainage engineering. Robert E. Krieger Publ. Co., New York.

MARSHALL, I. B., J. DUMANSKI, E. C. HUFFMAN, and P. J. LAJOIE. 1979. Soils, capability and land use in the Ottawa urban fringe. Report no. 47 of the Ontario Soil Survey, Land Resource Research Inst., Agriculture Canada, Ottawa, Ont. 59 pp.

SHADY, A. M., R. S. BROUGHTON, Y. BERNIER, U. DELISLE, and G. SYLVESTRE. 1977. Experience with production scale field measurements of hydraulic conductivity. Third National Drainage Symposium. Am. Soc. Agric. Eng., St. Joseph, Mich. Publ. 1–77. 12–116.

STOUT, M. B. 1950. Basic electrical measurements. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 504 pp.

TOPP, G. C. and S. SATTLECKER. 1983. A rapid measurement of horizontal and vertical components of saturated hydraulic conductivity. Can. Agric. Eng. **25**: 193–197.

VAN BEERS, W. F. J. 1976. The auger hole method. 4th ed. Bulletin no. 1, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. 24 pp.

YOUNGS, E. G. 1968. Shape factors for Kirkham's piezometer method for determining the hydraulic conductivity of soil *in situ* for soils overlying an impermeable floor or infinitely permeable stratum. Soil Sci. **106**: 235–237.