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Estimation of Unsaturated hydraulic parameters by In-situ technique

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In-situ determination of fundamental hydraulic parameters like variably saturated hydraulic conductivity (K_{fs}) and the matric flux potential (ϕ_m) provides a foundation from which several other unsaturated soil parameters can be estimated, namely the Alpha (α^*) parameter. This Alpha parameter is the one of the components of 3D unsaturated flow in vadose zone and its value is the measure of the capillary component of unsaturated flow pattern. Here an in-situ technique, Pressure Infiltrometer is introduced to record the steady flow rate applying a constant positive head on an unsaturated soil surface. The aim of this paper is to check the shape factor of 3D flow geometry and to find out its sensitivity on other unsaturated hydraulic parameters and to find out the influence of Alpha parameters on the results of the in-situ estimation of field-saturated hydraulic conductivity.

Key words: *Field-saturated hydraulic conductivity, Matric flux potential, Alpha parameter, Shape factor, In-situ test.*

1 INTRODUCTION

The characterization of unsaturated hydraulic parameters of three dimensional in-situ flow phenomenon is global demand in soil physics. Unsaturated hydraulic parameter estimation is a prerequisite approach for any modeling in ground water technology. In situ estimation of unsaturated hydraulic parameter is related to multi-dimensional phases of a porous soil mass in a vadose zone. But our research activities have affiliated to soil and water flow in unsaturated zone. Downward variability saturated flow through the porous medium driven primarily by gravity, hydrostatic head and capillary force. Such flow sometimes diverted in unsaturated zone by barriers causing lateral transport, or accentuated by preferred pathways promoting rapid downward transport. Accurate predicting the attenuation and eventual location of solutes or constituents in the unsaturated zone are directly related to wetting front movement of water. For actual prediction of water flow behavior in unsaturated soil, the in-situ measurement of unsaturated hydraulic parameters is an essential task for a researcher. We have introduced a simple technique, the Pressure Infiltromer, for determination of unsaturated hydraulic parameters in the field level that may provide basic information for future activities in the vadose zone. This easy approach of estimation in actual field situation is to be compared with other existing methods for justifying and getting more confidence on the technique. In our experimental study, we recorded steady flow of infiltration on soil surface to predict the unsaturated hydraulic parameter by Pressure Infiltrometer. The conceptual basis of field infiltration is shown as in fig.1. From the early state record of flow measurements, it is also possible to estimate the sorptivity which is unsaturated conductivity of at the beginning of flow through soil mass.

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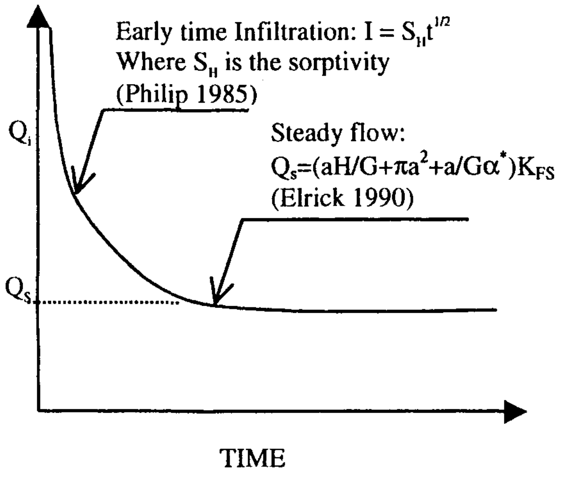

Fig. 1 Steady flow and Infiltration with time

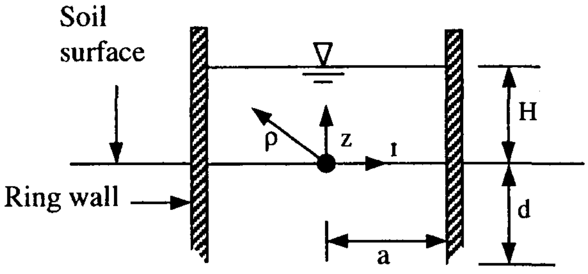

Fig. 2 Schematic of ponded flow from a ring (r, z = cylindrical coordinate direction, ρ= spherical coordinate direction, a = ring radius, d = depth of ring, H = steady depth of water).

From Elrick's quasi-empirical equation, it is found that the value of Alpha (α^*) and the value of shape factor, G are the most important governing factors for the in-situ determination of hydraulic conductivity. The Alpha can be explained by Gardner (1958) exponential function. The shape factor is explained as below according to the flow geometry.The flow geometry imposed by the ring (Fig. 2) differs significantly from that of a point source in a semi-infinite flow domain. From the geometry of ring, Reynolds and Elrick developed the following equation:

$$Q_s = a/G\ (K_{FS} H + \phi_m) + \pi a^2 K_{FS} \qquad (1)$$

Where "G" is a dimensionless shape factor. The G values were determined numerically based flow geometry and Richards' equation for three–dimensional, saturated-unsaturated flow. They derived the following relation for shape factor

$$G = 0.316\ (d/a) + 00.184 \qquad (2)$$

Here the value of shape factor is a function of ring radius, 'a' and depth of ring insertion, 'd' of Pressure Infiltrometer. From the flow geometry it seems that the value of G has a relation with applied positive head on the soil surface. Another important unsaturated hydraulic parameter is the matric flux potential (ϕ_m). This is also an important factor in Elrick's equation. The matric flux potential is defined as below:

$$\phi_m = \int_{\psi_i}^{0} K(\psi)d\psi \qquad (3)$$

From Gardner exponential function, a relationship among the three unsaturated parameters, namely matric flux potential, Alpha and field-saturated hydraulic conductivity is found as shown below:

$$\phi_m = K_{FS}/\ \alpha^* \qquad (4)$$

For estimation of K_{FS} and ϕ_m from the ponded flow measurements within the ring, Elrick assumed various models of flow condition. In our research works we tried to measure K_{FS} and ϕ_m assuming 3D flow model of field-saturated condition. In this case air entrapment in porous soil may give lower value than saturated value of conductivity. This air may be removed in laboratory core sample test.

This flux potential measurement in unsaturated zone is somewhat complex task but in saturated zone it can be measured very easily. In our approach of determination the value of matric flux potential , it was tried to estimate by multiple head technique of Pressure Infiltrometer. Solving equation (5) and (6), estimation of K_{FS} and ϕ_m is to be done. Now from the equation (4), the value of Alpha parameter can be estimated. This simple way of our approach may provides us new idea of unsaturated parameters in the field.

$$Q_1 = (aH_1/G + \pi a^2)\, K_{FS} + (a/G)\, \phi_m \qquad (5)$$

$$Q_2 = (aH_2/G + \pi a^2)\, K_{FS} + (a/G)\, \phi_m \qquad (6)$$

2 METHOD OF EXPERIMENTS

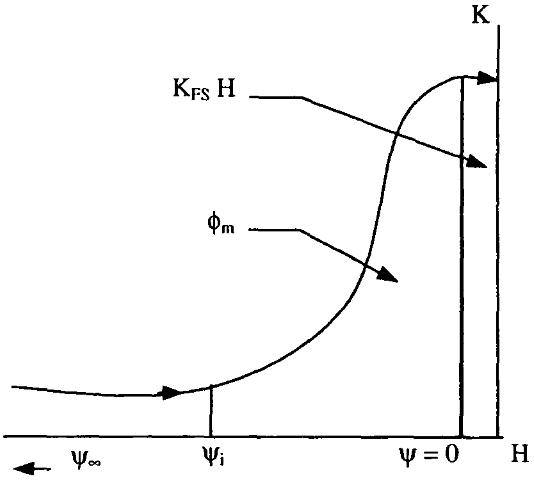

Fig.3 Schematic of matric flux potential vs hydraulic conductivity function . From $\psi = 0$ to pressure head, H indicates the value of K_{FS} ,from pressure head, ψ_i to $\psi = 0$, indicates the value of matric flux potential and from ψ_i to ψ_∞ indicates the value of residual matric flux potential for dry soil.

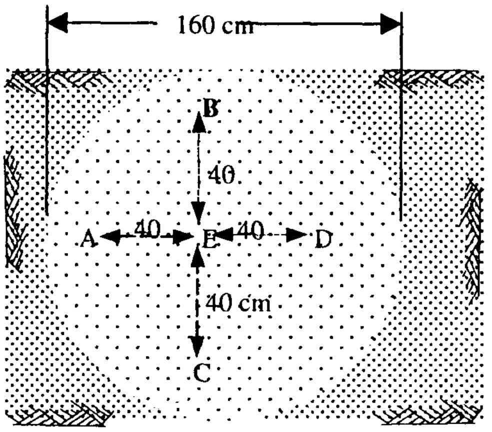

Fig. 4 Plan view of the location A, B, C, D and E.

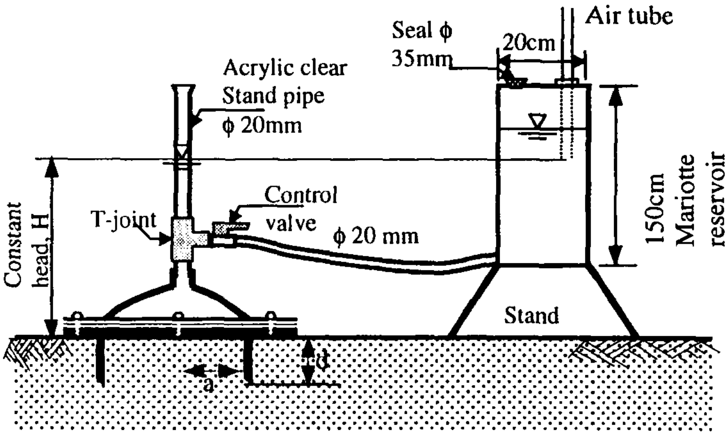

Fig. 5 Schematic of Pressure Infiltrometer at in-situ test.

A hole having 160cm diameter and 150cm depth was dug. By bringing granite soil from other place, it was deposited near the hole and an artificial land was made. The installation of our field device was done at the site of Granite soil at location A, B, C, D and E. In this time the ring insertion into the soil was done considering three shape factors at each site. The gap between two locations was 40 cm and positive pressure head was applied at each case of experiments. At each location the head H1, H2, H3, H4, H5, H6, H7 and H8 was recorded and corresponding steady flow was calculated from the Mariotte reservoir. After site cleaning for in-situ test at each location, the ring insertion into the soli mass was done by applying pushing force vertically downward. This is very important to get a suitable depth of ring in which no disturbance of site soil occurs to avoid the over flow along the ring wall. After insertion of ring, it was connected with Mariotte resrvoir by flexible pipe having control valve. When control valve in opened, the water flow is started from the reservoir. The constant head is controlled by air tube of the Mariotte principle. This air tube attached with an airtight mechanism and o-ring arrangement. The acrylic clear stand pipe is attached with ring by a T-joint. This acrylic pipe is used to read the reading of constant head applied on soil surface. In our experiment, in all most cases, the steady state flow was found within 15 minutes from the starting time of experiment. At each case we recorded the flow rate at two minutes interval.

Table 1 In situ test data

The name of site location of in-situ test		Case-1 G = 0.38		Case - 2 G=0.5		Case - 3 G=0.62	
		d = 3cm	a = 4.75 cm	d = 4.8 cm	a =4.75cm	d=6.5cm	a=4.75cm
		Constant Head (cm)	Flow rate Q_s (cm^3/s)	Constant Head (cm)	Flow rate Qs(cm^3/s)	Constant Head (cm)	Flow rate Qs (cm^3/s)
A	H1	4.9	0.121	5.1	0.122	5.0	0.121
	H2	9.1	0.152	9.1	0.150	10.5	0.154
	H3	14.2	0.190	14.1	0.186	15.4	0.187
	H4	17.4	0.218	17.4	0.216	20.6	0.216
	H5	19.9	0.240	19.9	0.231	25.5	0.242
	H6	22.5	0.260	22.5	0.251	30.4	0.274
	H7	27.8	0.300	27.8	0.291	35.6	0.300
	H8	35.0	over flow	32.5	0.321	40.5	0.330
B	H1	5.5	0.122	5	0.121	5.0	0.121
	H2	9.6	0.153	11.1	0.152	11.5	0.153
	H3	14.5	0.191	17.2	0.186	17.5	0.187
	H4	17.8	0.219	23.3	0.215	22.5	0.216
	H5	20.5	0.241	29.1	0.242	27.5	0.242
	H6	22.8	0.261	35.4	0.275	32.4	0.274
	H7	25.5	0.280	41.1	0.311	37.5	0.300
	H8	34.0	over flow	37.2	0.330	42.7	0.330
C	H1	5.3	0.122	5	0.121	5.5	0.122
	H2	9.4	0.152	12.1	0.153	12.5	0.152
	H3	14.3	0.191	18.2	0.186	18.4	0.186
	H4	17.6	0.218	24.3	0.216	23.4	0.215
	H5	20.3	0.241	30.1	0.242	28.3	0.241
	H6	22.7	0.260	36.2	0.275	33.5	0.274
	H7	26.8	0.290	42.3	0.311	38.8	0.290
	H8	33.0	over flow	48.2	0.330	43.7	0.320
D	H1	5.2	0.122	6	0.122	6.1	0.122
	H2	11.3	0.152	13	0.154	12.5	0.152
	H3	17.2	0.191	19.1	0.187	18.5	0.186
	H4	23.1	0.218	25.2	0.216	23.5	0.216
	H5	29.2	0.241	31	0.242	28.4	0.241
	H6	35.2	0.291	37.2	0.275	33.4	0.271
	H7	36.5	over flow	43	0.300	38.5	0.300
E	H1	5.0	0.122	6.5	0.123	6.4	0.122
	H2	9.1	0.152	13.5	0.154	12.7	0.153
	H3	15.2	0.191	19.5	0.187	18.6	0.187
	H4	21.1	0.218	25.4	0.216	23.6	0.215
	H5	27.3	0.251	31.6	0.242	28.9	0.242
	H6	33.3	0.281	37.4	0.274	34.0	0.271
	H7	34.5	over flow	43.4	0.310	39.0	0.300
	H8	34.5	over flow	48.5	0.320	42.5	0.320

The name of our site location is mentioned in the above table 1. Here, d = depth of ring insertion into soil mass. The three depth of ring was selected at the each location of experimental site, a = ring radius which was same in all cases of experiments. This is a very important factor for selecting the ring dimension at the site soil. In our experiments, we selected ring diameter equal to 95 cm and it worked good. For less permeable soil, the ring dimension can be enlarged as need as practical situation to get more flow rate at a short interval of time. The detail dimension, applied constant head and corresponding flow rate at the location is listed in the table 1. The shape factor, G is to be calculated from equation (2) using the value of ring radius and depth of ring insertion.

From the field record of applied head and steady flow rate, the three hydraulic parameters, K_{FS}, ϕ_m and α^* were estimated by multiple head. The estimated values are listed in tabular form as mentioned below:

3. RESULTS & DISCUSSION

Table 2 Estimated value by multiple head (Case -1, Shape factor, G=0.38)

Location -A

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	5.3x10^{-4}	7.0x10^{-4}	5.7x10^{-4}	7.2x 10^{-4}	6.3x10^{-4}	6.0x10^{-4}	6.2x10^{-4}
ϕ_m cm^2/s	4.1x10^{-3}	4.6x10^{-3}	4.2x10^{-3}	9.0x10^{-3}	3.5x10^{-3}	3.9x10^{-3}	4.8x10^{-3}
α^* cm^{-1}	0.12	0.15	0.13	0.07	0.17	0.15	0.13

Location -B

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	6.2x10^{-4}	6.0x10^{-4}	6.7x10^{-4}	6.5x 10^{-4}	6.6x10^{-4}	5.9x10^{-4}	6.3x10^{-4}
ϕ_m cm^2/s	2.8x10^{-3}	3.1x10^{-3}	1.8x10^{-3}	2.2x10^{-3}	2.0x10^{-3}	4.0x10^{-3}	2.7x10^{-3}
α^* cm^{-1}	0.21	0.19	0.3	0.28	0.33	0.14	0.24

Location -C

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	5.8x10^{-4}	6.3x10^{-4}	6.7x10^{-4}	6.7x 10^{-4}	6.6x10^{-4}	5.8x10^{-4}	6.3x10^{-4}
ϕ_m cm^2/s	3.4x10^{-3}	2.6x10^{-3}	1.8x10^{-3}	1.8x10^{-3}	2.0x10^{-3}	4.3x10^{-3}	2.6x10^{-3}
α^* cm^{-1}	0.17	0.24	0.36	0.37	0.33	0.14	0.26

Location -D

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	3.9x10^{-4}	5.1x10^{-4}	3.7x10^{-4}	3.0x 10^{-4}	6.5x10^{-4}	error	4.4x10^{-4}
ϕ_m cm^2/s	5.5x10^{-3}	3.5x10^{-3}	6.7x10^{-3}	8.7x10^{-3}	3.3x10^{-3}	error	2.6x10^{-3}
α^* cm^{-1}	0.07	0.14	0.05	0.03	0.19	error	0.1

Location -E

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	6.9x10^{-4}	4.4x10^{-4}	3.6x10^{-4}	4.2x 10^{-4}	4.0x10^{-4}	error	4.6x10^{-4}
ϕ_m cm^2/s	2.4x10^{-3}	6.1x10^{-3}	7.7x10^{-3}	6.1x10^{-3}	6.8x10^{-3}	error	5.8x10^{-3}
α^* cm^{-1}	0.28	0.07	0.04	0.06	0.05	error	0.1

The mean value of K_{FS} = 5.6 x 10^{-4} cm/s , ϕ_m = 3.7 x 10^{-3} cm^2/s and α^* = 0.16 cm^{-1}. The values of the hydraulic conductivity at location A, B, C, D and E differ little from each case to other. The minimum value of K_{FS} is found 3x10^{4} cm/s at location D and the maximum value of K_{FS} is found 7.2x10^{-4} cm/s at location A (Table 2). This variation is reasonable for in-situ test results of a particular soil type.

Some primary factors can affect the accuracy of in-situ test results including over flow along the ring, air entrapment within connecting pipe at the beginning of test, pushing technique of ring into the soil mass and ambient temperature. In our experiments, the over flow was observed at high head and low depth of ring. An implicit requirement of equation (1) is that no surface ponding occur out side the ring. When over flow phenomenon was found, the corresponding calculation gave us an error of results. All most situation, our calculated values of above mention cases were found acceptable and desirable.

Table 3 Estimated value by multiple head (Case -2, Shape factor, G = 0.5)

Location -A

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	$7.2x10^{-4}$	$7.6x10^{-4}$	$9.3x10^{-4}$	$6.8x\ 10^{-4}$	$8.0x10^{-4}$	$7.9x10^{-4}$	$7.8x10^{-4}$
ϕ_m cm^2/s	$3.7x10^{-3}$	$3.1x10^{-3}$	$5.5x10^{-3}$	$5.7x10^{-3}$	$2.4x10^{-3}$	$2.7x10^{-3}$	$4.6x10^{-3}$
α^* cm^{-1}	0.19	0.24	0.16	0.11	0.33	0.29	0.22

Location -B

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	$5.4x10^{-4}$	$5.7x10^{-4}$	$5.0x10^{-4}$	$4.8x\ 10^{-4}$	$5.6x10^{-4}$	$6.6x10^{-4}$	$5.5x10^{-4}$
ϕ_m cm^2/s	$5.9x10^{-3}$	$5.4x10^{-3}$	$7.1x10^{-3}$	$7.8x10^{-3}$	$4.9x10^{-3}$	$6.1x10^{-3}$	$6.2x10^{-3}$
α^* cm^{-1}	0.09	0.1	0.07	0.06	0.11	0.1	0.08

Location -C

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	$4.7x10^{-4}$	$5.5x10^{-4}$	$5.0x10^{-4}$	$4.8x\ 10^{-4}$	$5.7x10^{-4}$	$6.2x10^{-4}$	$5.3x10^{-4}$
ϕ_m cm^2/s	$6.8x10^{-3}$	$5.3x10^{-3}$	$6.6x10^{-3}$	$7.3x10^{-3}$	$3.9x10^{-3}$	$1.8x10^{-3}$	$5.2x10^{-3}$
α^* cm^{-1}	0.07	0.1	0.07	0.06	0.14	0.34	0.13

Location -D

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	$4.8x10^{-4}$	$5.5x10^{-4}$	$5.0x10^{-4}$	$4.6x\ 10^{-4}$	$5.6x10^{-4}$	$4.4x10^{-4}$	$4.9x10^{-4}$
ϕ_m cm^2/s	$6.3x10^{-3}$	$4.9x10^{-3}$	$6.3x10^{-3}$	$7.6x10^{-3}$	$3.8x10^{-3}$	$9.2x10^{-3}$	$6.3x10^{-3}$
α^* cm^{-1}	0.07	0.11	0.08	0.06	0.14	0.04	0.08

Location -E

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	$4.7x10^{-4}$	$5.6x10^{-4}$	$5.2x10^{-4}$	$4.3x\ 10^{-4}$	$5.8x10^{-4}$	$4.5x10^{-4}$	$5.0x10^{-4}$
ϕ_m cm^2/s	$6.3x10^{-3}$	$4.4x10^{-3}$	$5.5x10^{-3}$	$8.5x10^{-3}$	$2.7x10^{-3}$	$8.6x10^{-3}$	$6.0x10^{-3}$
α^* cm^{-1}	0.07	0.12	0.1	0.05	0.21	0.05	0.1

The mean value of $K_{FS} = 5.7 \times 10^{-4}$ cm/s , $\phi_m = 5.6 \times 10^{-3}$ cm^2/s , and $\alpha^* = 0.12$ cm^{-1}. The above results, table 3 is the estimated values of case-2. In this case the maximum value of K_{FS} is found $9.3x10^{-4}$ cm/s at location A and the minimum value of K_{FS} is found $4.3x10^{-4}$ cm/s at location E. Our site soil at location A, B, C, D and E is almost homogeneous, and ambient temperature and other environmental condition was moderate; but this variation is neither more or less than seems right. The values of other two parameters namely Alpha (α^*) and matric flux potential (ϕ_m) has a relation with the value of K_{FS} (Equation. 4). Therefore it is possible to guess the performance of the in-situ method by the observation of the estimated value of field-saturated hydraulic conductivity in a real condition of unsaturated soil of vadose zone. Some other factors which may affect the accuracy of steady flow measurements – such as soil macrostructure collapse and soil matrix compression in case of wet soil. But in our experimental results show the expecting and desirable values of parameters. This results give us a basic information about soil variability in a soil water flow region for unsaturated soil and encourage us to proceed our research study in a various situation for various kinds of soil using this simple in-situ technique at the field level experimental activities for finding more information about hydraulic parameters comparing the accuracy of the result that can be achieved by using the existing and traditional methodology available in the quantitative approach of geo-technical research field.

Table 4 Estimated value by multiple head (Case -3, Shape factor, G=0.62)

Location -A

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	8.0x10^{-4}	8.7x10^{-4}	7.1x10^{-4}	6.9x 10^{-4}	8.5x10^{-4}	6.7x10^{-4}	7.6x10^{-4}
ϕ_m cm^2/s	4.3x10^{-3}	2.9x10^{-3}	6.8x10^{-3}	7.7x10^{-3}	1.9x10^{-3}	9.9x10^{-3}	5.5x10^{-3}
α^* cm^{-1}	0.18	0.3	0.1	0.09	0.4	0.06	0.18

Location -B

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	6.4x10^{-4}	7.4x10^{-4}	7.4x10^{-4}	6.8x 10^{-4}	8.5x10^{-4}	6.6x10^{-4}	7.1x10^{-4}
ϕ_m cm^2/s	6.5x10^{-3}	4.5x10^{-3}	4.6x10^{-3}	6.5x10^{-3}	2.1x10^{-3}	8.2x10^{-3}	5.4x10^{-3}
α^* cm^{-1}	0.09	0.16	0.16	0.1	0.4	0.08	0.16

Location -C

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	5.5x10^{-4}	7.4x10^{-4}	7.5x10^{-4}	6.9x 10^{-4}	8.2x10^{-4}	4.0x10^{-4}	6.5x10^{-4}
ϕ_m cm^2/s	7.4x10^{-3}	3.5x10^{-3}	3.4x10^{-3}	5.4x10^{-3}	1.4x10^{-3}	1.8x10^{-3}	3.8x10^{-3}
α^* cm^{-1}	0.07	0.21	0.22	0.12	0.5	0.22	0.22

Location -D

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	6.0x10^{-4}	7.3x10^{-4}	7.6x10^{-4}	6.9x 10^{-4}	7.8x10^{-4}	7.4x10^{-4}	7.1x10^{-4}
ϕ_m cm^2/s	6.6x10^{-3}	3.9x10^{-3}	3.1x10^{-3}	5.4x10^{-3}	2.5x10^{-3}	3.7x10^{-3}	4.2x10^{-3}
α^* cm^{-1}	0.09	0.18	0.24	0.12	0.3	0.2	0.18

Location -E

Head	H1 &H2	H2 &H3	H3&H4	H4&H5	H5&H6	H6&H7	Average
K_{FS} cm/s	6.3x10^{-4}	7.6x10^{-4}	7.2x10^{-4}	6.6x 10^{-4}	7.4x10^{-4}	7.6x10^{-4}	7.2x10^{-4}
ϕ_m cm^2/s	6.0x10^{-3}	3.2x10^{-3}	4.5x10^{-3}	6.3x10^{-3}	3.2x10^{-3}	2.4x10^{-3}	4.2x10^{-3}
α^* cm^{-1}	0.1	0.23	0.16	0.1	0.23	0.31	0.18

The mean value of K_{FS} = 7.1 x 10^{-4} cm/s , ϕ_m = 4.6 x 10^{-3} cm^2/s and α^* = 0.18 cm^{-1}. From the observation of this results, it is evident that the deviation of the value of K_{FS} of each location from mean value is negligible. In our field experiments of case-3, it was done by full insertion of ring of Pressure Infiltrometer. Therefore it is clearly indicates that full insertion is the most stable situation for getting a realistic and acceptable results from natural unsaturated soil.

Table 5 Shape factor and values of K_{FS} relationship

Shape factor	Values of K_{FS} cm/s					Mean
	A	B	C	D	E	K_{FS} cm/s
0.38	6.2x10^{-4}	6.3x10^{-4}	6.3x10 -^{4}	4.4x10^{-4}	4.6x10^{-4}	5.6x10^{-4}
0.5	7.8x10^{-4}	5.5x10^{-4}	5.3x10^{-4}	4.9x10^{-4}	5.0x10^{-4}	5.7x10^{-4}
0.62	7.6x10^{-4}	7.1x10^{-4}	6.5x10^{-4}	7.1x10^{-4}	7.2x10^{-4}	7.1x10^{-4}
Lab test	7.8x10^{-4}	6.6x10^{-4}	6.5x10^{-4}	7.3x10^{-4}	6.3x10^{-4}	6.7x10^{-4}

We can make a comparison (table 5) of our results with three shape factors those were considered for in-situ experimental study in our site location. The deviation of result from mean value and core sample test value is moderate.

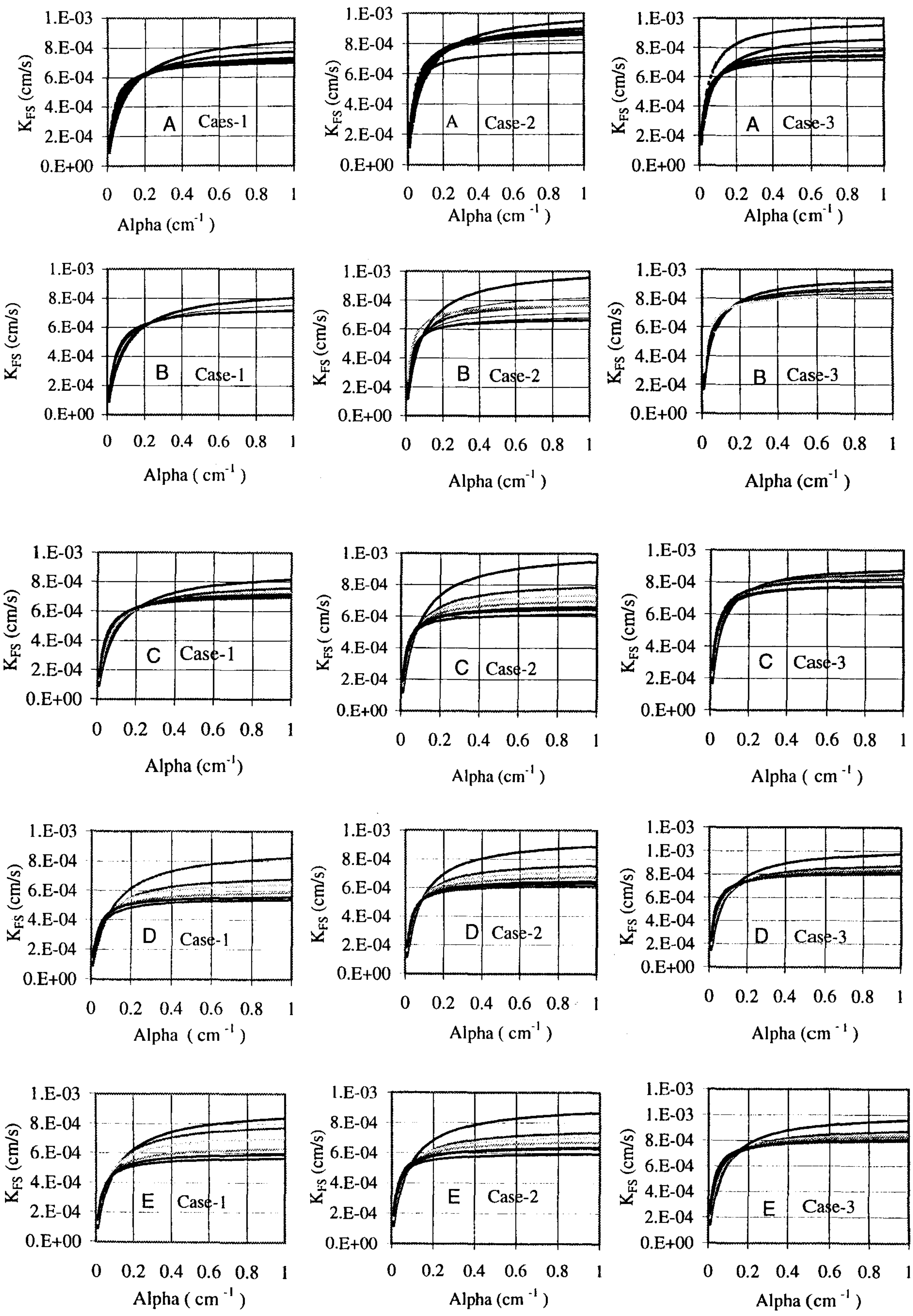

Fig. 6 Alpha and K_{FS} relationship at location A, B, C,D and E of in-situ experiments representing maximun and minimum range of its values of unsaturated soil.

The validity of field results was checked by laboratory core sample test. The previous works of the laboratory core sample test (I. KOHNO et. al,1999) result at each location is mentioned in table (5). By comparison field and laboratory results, this research study shows an excellent performance for in-situ determination of hydraulic conductivity.

There is a higher increasing tendency of the results of field–saturated hydraulic conductivity (K_{FS}) with the higher value of the shape factor (G). The soil in our flow domain was assumed to be homogeneous and having same index properties. At the same location and at the same situation, only the value of shape factor was changed. Consequently the complex flow geometry (fig. 2) was changed and little variation of results was found. This mild fluctuation of results may not be countable. But we can't say that the value of K_{FS} is fully independent of shape factor (G).

The important relationship between K_{FS} and Alpha parameter (α^*) was found from analytical solution of Elrick's empirical equation using field steady flow rate (Q_S) and applied positive head (H). This relation is graphically presented in fig.(6). It has been established that the values of Alpha parameter is the indicator of the relative magnitude of capillary and gravity component of water flow through unsaturated soil mass in a vadose zone. In our analysis, the sensitivity of Alpha value on other parameters mainly field-saturated hydraulic conductivity is obviously describing. At each site location for three cases, we have plotted the relationship using field data such as applied constant head and corresponding steady flow measurements. At each case we found the upper and lower limit of K_{FS} and the sensitivity of the values of Alpha from minimum to maximum. At each location the sensitivity of graph and its range showing more or less same nature due to homogeneous soil of field experiments. But this excellent relationship is the representative out put of this method at field level research in case of unsaturated soil. Now using this good relationship, we proceed for further research doing various experiments for different kinds of unsaturated soil in the vadose zone. We can say that this relationship provides us a basic idea for further work.

From experimental results, it is found that the value of Alpha is fluctuated from 0.08 cm^{-1} to 0.26 cm^{-1} while multiple approach of calculation is performed; but from the analytical calculation of Alpha is fluctuated from a minimum value of 0.01 cm^{-1} to a maximum value of 0.30 cm^{-1}. This research provides us a range of Alpha values instead of a fixed value.

Table 6 Values of Alpha range and K_{FS}

Shape factor,G	Alpha (cm^{-1})		K_{FS} (cm/s)	
	minimum	maximum	minimum	maximum
0.38	0.1	0.26	4.4×10^{-4}	6.3×10^{-4}
0.50	0.08	0.22	4.9×10^{-4}	7.8×10^{-4}
0.62	0.16	0.22	6.5×10^{-4}	7.6×10^{-4}

4. CONCLUSION

1) The field-saturated hydraulic conductivity (K_{FS}) has mild dependency on shape factor (G).

2) Full insertion of ring into the soil may provide us with more accurate results than partial insertion.

3) This research study provides us a range of Alpha values (minimum = 0.08 cm^{-1} to maximum = 0.30 cm^{-1}) instead of a fixed value.

4) This research result of K_{FS} may reflect primarily the soil structure at the field.

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