Journal of the Faculty of Environmental Science and Technology, Okayama University
Vol.4, No.1, pp.81-92, February 1999

In situ determination of field-saturated hydraulic conductivity of subsurface soil of vadose zone by technique of Pressure Infiltrometer

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(Received November 20 , 1998)

Abstract: For reducing or bridging gap between small scale laboratory investigations and large scale field investigations, a simple and portable model which is based on real situation and has a compatibility to laboratory core sampling, the pressure infiltrometer technique is introduced for determination of field-saturated hydraulic conductivity. The field -saturated hydraulic conductivity, K_{FS}, is obtained from measurements of the steady flow rates applying constant head as well as falling head principle. The device is also used for field core sampling on which laboratory constant head as well as falling head tests is carried out. The field device is validated through comparison to laboratory core sample experiment and other existing methods. This paper describes first time a versatile field device representing good performance for in situ determination of hydraulic parameters in a short time.

Key Words: In-situ test, Field-saturated Hydraulic conductivity, Matric flux potential, Wetting front, 3D-flow.

1. Introduction

In situ determination of variably saturated sub-soil hydraulic parameter in real situation is till now a challenge for geo-technical engineers. Avoiding of laboratory sampling disturbance and small scale laboratory specimens, field experimental procedure for finding hydraulic parameters in the soil of vadose zone is one of the prerequisites for controlling and monitoring of applications like design of irrigation water for a particular area, pumping wells in water plants, drainage systems in building pits etc. Also the gradual increasing global demands to protect vadose zone water resource free from present environmental problems due to pesticides & waste disposal, the most important hydraulic parameter of soil water movement is field-saturated hydraulic conductivity (K_{FS}). Any logical basis for characterizing in the vadose zone must be based upon fundamental concepts of field hydraulic conductivity. Downward variability saturated flow through the porous medium driven primarily by gravity, hydrostatic head and capillary force. Such flow sometimes diverted in vadose 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 vadose zone are directly related to wetting front movement of unsaturated flow of water. For actual measurement of water flow behavior in unsaturated soil, the measurement of hydraulic conductivity in the field is an essential task.

Three of the most important factors governing liquid transmission in unsaturated soils are field-saturated hydraulic conductivity, K_{FS}, matric flux potential, ϕ_m, and sorptivity, S. K_{FS} or field-saturated hydraulic conductivity refers to the saturated hydraulic conductivity of soil containing entrapped air. K_{FS} is more appropriate than the truly saturated hydraulic conductivity for vadose zone investigations. The K (ψ) relationship, known mathematically as the Kirchoff transform, has been shown Gardner[1] (1958) and others to be particularly useful for describing soil water flow. Matric flux potential. ϕ_m is a measure of the relative importance of gravity and capillary for soil-water movement in the particular soil. Fine-textured soils, where capillary tends to predominate, have small Alpha values; and coarse-textured soils, where gravity effects manifest themselves most readily, have large Alpha values (Fig. 1). Theoretically Alpha (α^*) parameters can be explained by Gardner [1] (1958) exponential function,

$$K(\psi)=K_{FS}\exp(\alpha\psi),\ \text{with } 0<\alpha<\infty \text{ and } \psi\leq 0 \qquad (1)$$

Where α (m^{-1}) is an unsaturated soil parameter simply called the Alpha parameter. The flux potential ϕ ($m^2.s^{-1}$) is defined as:

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$$\phi(\psi) \equiv \int_{\psi_i}^{\psi} K(\psi) d\psi \text{, where } \psi_i \leq \psi \tag{2}$$

Integrating between ψ_i and $\psi = 0$ gives:

$$\phi_m = \frac{K_{FS}}{\alpha} \left[e^{\alpha\psi} \right]_{\psi_i}^{0} \tag{3}$$

$$\alpha = \frac{K_{FS} - K_i}{\phi_m} = \lambda_c^{-1} \tag{4}$$

λ_c is the macroscopic capillary length (Philip [2], 1985). Here K_I is very small in comparison with K_{FS}, neglecting K_I for air dry soil in field situation we get the flowing relation.

$$\alpha \approx \frac{K_{FS}}{\phi_m} \equiv \alpha^* = \left| \psi_f \right|^{-1} \tag{5}$$

ψ_f is the effective wetting front potential for Green and Ampt [3] (1911) infiltration. α^*, α, λ_c, and ψ_f all of which are equivalent and represent single parameter estimates of the unsaturated hydraulic conductivity.

The values of Alpha depend on soil type and flow behavior is shown by an ideal line as in fig. 1.

There are a lot of methods for determination of hydraulic conductivity in laboratory and in the field. Nonhomogeneity and anisotropy of soils, fissures, tension cracks, and root holes commonly encountered in unsaturated soils can not be represented in small scale laboratory specimens. In reality, laboratory results of hydraulic conductivity are not representative data of actual field situation. It is very difficult to simulate natural field conditions in the laboratory. Considering this point, field test results are more reliable for analysis of flow in vadose zone. Among the direct and indirect field-methods for determination unsaturated hydraulic conductivity, ASTM [4] standard guide D 5126-90 reviews alternative field methods for available techniques for measuring K in the vadose zone. In these techniques there are a lot of limitations & assumptions for measuring hydraulic and transport properties at the unsaturated zone. Soil is assumed uniform, homogeneous and non-swelling in the most of experiments; but macropores, gradient in water content, soil bulk density, soil layering and changes in soil texture all occur near the soil surface, which can result in negative calculations of hydraulic conductivity. To minimize these limitations at some extent, Pressure Infiltrometer may be the most appropriate technique in actual field situation for determination of hydraulic conductivity. In the field and laboratory experiments, scale effect is an old problem for all researchers. As Pressure Infiltrometer is a simple apparatus, we can fix it's main ring dimension according to our needs. Consequently scale effects of in-situ experiments can be reduced to some extend of our goal. When any infiltration is occurred within a ring, there is an edge effect on actual flow behavior through any porous media of unsaturated soil. This edge effect can also be reduced by increasing the dimension of main ring of Pressure Infiltrometer while in-situ experiments are performed on any soil surface at field level.

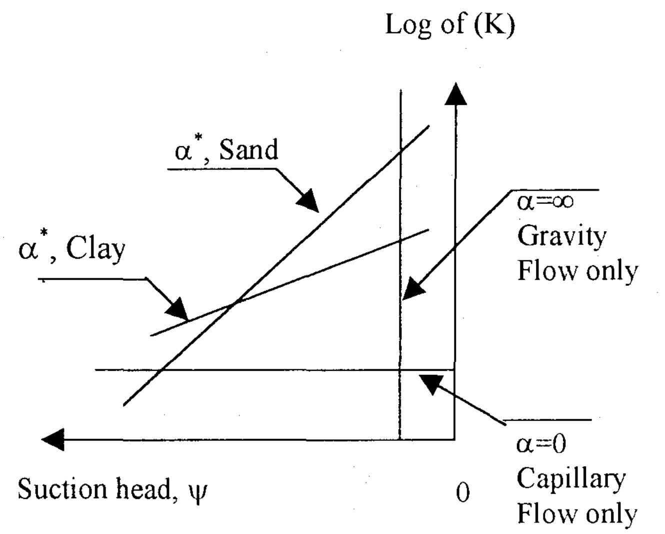

Fig. 1 An ideal relation of suction head ~ ln K. Slope indicates values of Alpha

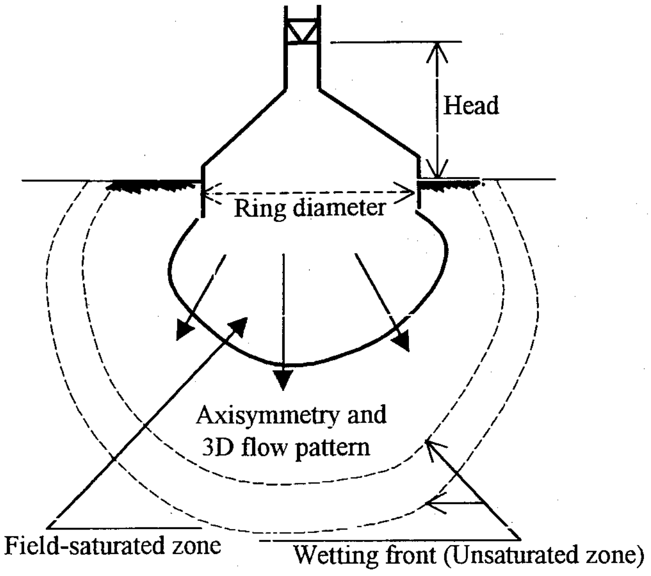

Fig. 2 Field-saturated and unsaturated flow behaviour of Pressure Infiltrometer

Water flow into unsaturated soil from Pressure Infiltrometer starts with an initial transient phase and then gradually approaches steady state. During the transient phase, both the field-saturated zone and unsaturated zone increase in size by migrating downward and outward from the infiltration surface. After steady flow is attained, the field-saturated zone (bulb) remains essentially constant in size and shape, while the unsaturated zone continues to increase in size by outward movement of wetting front. This outward movement is symmetrical about the vertical axis of Pressure Infiltrometer ring. The size of field-saturated bulb depends on the dimensions of infiltration surface, soil texture and structure, applied positive head on soil surface, and initial water potential (suction head of unsaturated soil).

2. Methodology

2.1 Experimental model

Our experimental model is a device designed to represent a simplified version of reality. This device can be used for the field experiment as well as in the laboratory experiment (see Fig.3 & Fig. 4). The previous device was in different form. The Mariotte reservoir was fixed at the top of ring. In our device, Mariotte reservoir is separated from ring. Consequently the device becomes more portable and stable at the in-situ experiment. There is a possibility of disturbance of soil while ring insertion into the soil surface is done; but separating the Mariotte reservior, degree of disturbance has been reduced at some extent. During field experiment, soil is assumed incompressible by any force applying from the surface. The possibilities of compression of surface layer of soil have been reduced in our modified arrangement. Due to compression of surface layer, soil hydraulic properties may be changed and it may be difficult to get our desired result. The field model having ring dimension, 95mm inside diam. & 65mm depth of insertion, is attached with Mariotte reservoir which control the positive constant head in situ test as well laboratory core sample test. The laboratory model is the modified assembling of field device. A bottom cap, a top cap and a spacer porous disk are assembled with the laboratory model. Here constant head as well as falling head principle is to be applied. Soil core sample having dimensioned 95mm by 65mm is be taken by inserting ring into the soil surface of vadose zone & laboratory test is to be carried out saturating soil sample and keeping same condition of the field. The clear standpipe is very useful for falling head recording of field and laboratory data. In vadose zone research works the falling head technique in the field is not established and available. This proposed modification is an evolution of in-situ falling head technique of measurement of field-saturated hydraulic conductivity in vadose zone. For relatively less permeable soil, constant head technique can not give accurate measurement of infiltration rate. Considering this point for in-situ test for fine soil applying falling head, a clear stand pipe having 20mm diameter is incorporated with Pressure Infiltrometer ring.

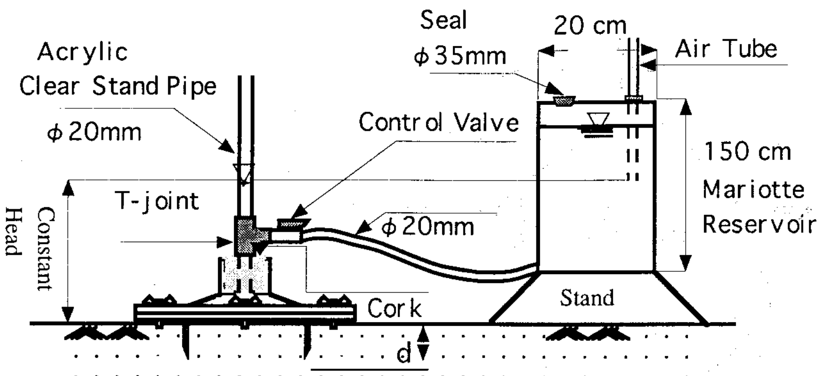

Fig. 3 Field Model of Modified Pressure Infiltrometer, Constant & Falling head.

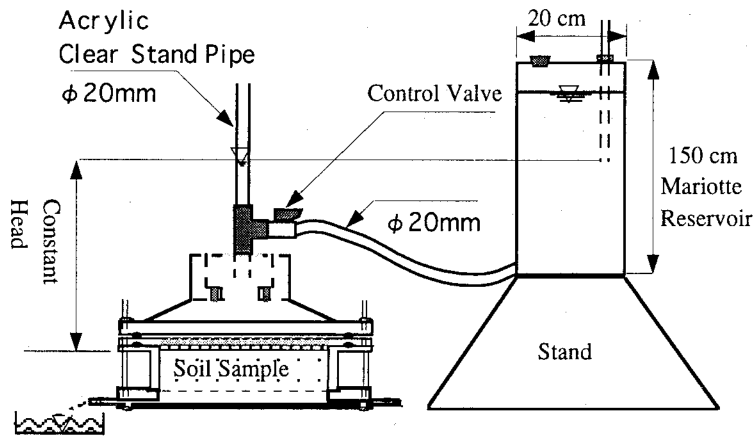

Fig. 4 Laboratory Model of Modified Pressure Infiltrometer, Contant & Falling head.

For both the cases, field and laboratory model, air tube is to be used to control constant head. The control valve is closed while falling head test in the field & laboratory is done. As a result the modified device is capable to measure in-situ hydraulic conductivity of a wide range of soil. In the falling head technique in the field, time requirements is an important factor. It is very usual that if we need long time for recording field data of fine soil using constant head principle, we have to take special precautions at site. But it is possible to record field data by this device using falling head technique also. Therefore we can propose to measure field-saturated hydraulic conductivity of different types of soil (10^{-2}cm/s $\geq K_{FS} \geq 10^{-6}$cm/s) using this simple device.

2. 2 Basic equation:

Considering a point source out side of a ring,, an analytical expression [7] for steady flow out of ring into rigid, homogeneous, isotropic, uniformly unsaturated soil is described as following:

$$Q_S=2\pi a\ (K_{FS}H+\phi_m)+\pi a^2K_{FS} \tag{6}$$

The above equation was developed considering a point source in a semi-infinite flow domain; but this was an approximation. Now if flow is considered within a ring, the flow geometry differs significantly from that of a point source. The steady flow equation within the a ring is written as following as

$$Q_S= a/G\ (K_{FS}\ H+\phi_m)+\pi a^2K_{FS} \tag{7}$$

An implicit requirement of above equation is that no surface ponding (flooding) occurs outside the ring. The presence of a wetting front on the surface is, however, permissible and expected.
Now field-saturated hydraulic conductivity (K_{FS}) can be calculated by two approaches-such as multiple head and single head. For multiple head approach, equation (7) can be written as

$$Q_{s1} = a/G\,(K_{FS}\,H_1+\phi_m) + \pi a^2 K_{FS} \qquad (8)$$

$$Q_{S2} = a/G\,(K_{FS}\,H_2+\phi_m) + \pi a^2 K_{FS} \qquad (9)$$

For single approach, equation (7) can be written as equation (10) using an important relationship of unsaturated soil water flow as $\phi_m = K_{FS}/\alpha^*$ (eq^n 5)

$$Q_s = [(aH/G + \pi a^2 + a/(\alpha G)]\,K_{FS} \quad \text{(Reynolds \& Elrick [5] 1990)}, \qquad (10)$$

where Q is the steady state flow rate, H is the constant head, a is the ring radius, G is a shape factor and α an unsaturated soil parameter representing the capillary component of 3D-flow of vadose zone. The equation (7) can be written as for estimating shape factor, G

$$G = a(H\,K_{FS}+\phi_m)/(Q_s-\pi a^2 K_{fs}) \quad \text{Where } H \geq 0 \qquad (11)$$

The values of G were determined numerically substituting the proper values of K_{FS}, ϕ_m, H, d, and Q_S values from numerical simulation [7]. It was found that G is independent of H greater than 0.05m. (Positive head on soil surface). W.D. Reynolds and D.E. Elrick[7] developed an empirical relationship among the shape factor, G, ring radius, a, and depth of ring insertion, d, into the soil surface as following.

$$G = 0.316\,d/a + 0.184 \qquad (12)$$

This relation is also used for our calculation of hydraulic conductivity in the field.

3. Description of site for in-situ test.

The site was selected at Okayama University campus. A hole having 160cm diameter and 150cm depth was dug. By bringing granite soil from other place, it was deposited near the hole side and to remove all gravel and stones having diam greater than 2mm , total soil was sieved by 2mm sieve. By using this granite soil the dug was filled. During filling of soil layer by layer, manual compaction was done. In this way an artificial land having

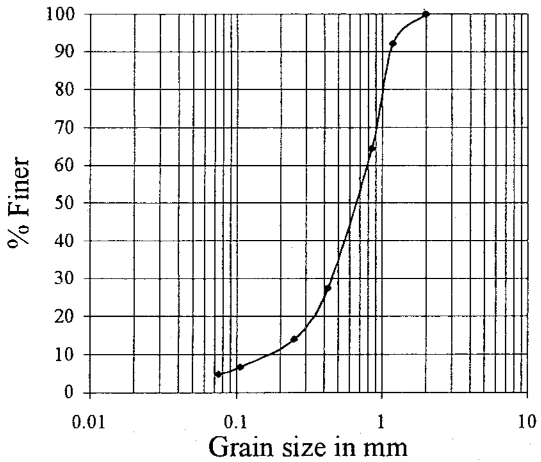

Fig. 6 Grain size of Granite soil of in-situ experiment.

Table 1 Index properties of site soil.

Description	Estimated value
Uniformity coefficient, C_u	4.8
Coefficient of Gradation, C_c	1.52
Bulk density (wet) ρ_b	1.83
Dry density, γ_d	1.66
Degree of saturation, S_r	84%
Specific Gravity, G_s	2.67
Void Ratio, e	0.608
Porosity, n	0.375

cylindrical shape of 160cm diameter & 150cm depth and free drainage boundary was made. The site for field experiment was kept open under normal weather conditions about six months. By natural rain fall and compaction this artificial land become a stable situation for field experiment. Five stations-A, B, C, D and E, having distance 40cm from each other were chosen for conducting in-situ experiments. Soil index properties (i.e., soil grain properties & soil aggregate properties) had been checked and found as in table-1. After checking soil grain size the modified Pressure Infiltrometer device was set at the soil surface and field measurements of steady flow rate and falling head were performed and temperature correction at field was done to adjust the field result.

From index properties of soil, it may be concluded that our experimental site is medium loose sandy soil. Grain size analysis was done by taking air-dry sample from the experimental site. There are a lot of methods for checking hydraulic conductivity from grain size curve. The prediction of hydraulic conductivity from grain size curves have to face a lot of limitations; but to get preliminary idea this grain size curve was developed.

4. Calculation approach

Considering the simultaneous equations (Multiple Head), the values of K_{FS} and matric flux potential, ϕ_m are calculated by solving equations (8) & (9). Multiple head technique is that independent measurements of hydraulic conductivity and flux potential are obtained; but limitation due to soil heterogeneity in the form of layering can give us unexpected values of field-saturated hydraulic conductivity (K_{FS}). But in our case soil was uniform and homogeneous.

Considering single head approach and applying one positive head and site estimating Alpha parameter, field-saturated hydraulic conductivity is calculated by using equation (10). In single head technique, only one water potential need to be applied to the infiltration surface of unsaturated soil and this tactic avoids the occurrence of negative value of hydraulic conductivity and flux potential. It also requires the independent measurement or estimation of Alpha (α^*) parameters. The previous study suggests that the single head method yield field-saturated hydraulic conductivity (K_{FS}) which is usually accurate to within a factor of 2 when Alpha (α^*) is site-estimated and selected from the categories in Table 3[5] (Elrick et. al., 1989). Our calculated values obtained by multiple head and single head are compared graphically in figure 10. These values are obtained from in-situ test on granite soil.

5. Experimental results and discussion

At first in our in-situ experiments dimensions of the device were fixed on the basis of previous researchers [5] as radius of ring, a=4.75 cm, depth of ring insertion into soil, d=6.5 cm then the device was installed at the site and field data was recorded. A good relationship between steady flow rate (Q_S) and applied head (H) was found (fig.7). The consistency in steady flow rate to applied head results better performance of our in-situ device than any conventional field techniques. While field experiment was conducting there was no instability problem due to high head as Mariotte reservoir is separated from top portion of ring which need careful insertion into the unsaturated soil surface. In previous technique of Pressure Infiltrometer th Mariotte reservoir was fixed on the ring. As result it was very difficult to keep stable condition in the field during the ring insertion into the unsaturated soil surface of vadose zone Three forces are acting on unsaturated soil surface while experiment is running in the field-such as gravity force, hydraulic force and capillary force. When high head is applied the hydraulic push has a great contribution on hydraulic conductivity. Constant head as well as falling head principles were applied in the field soil at the stations A, B, C, D, and E. Core samples were taken from each site and constant head as well as falling head principle were applied at the laboratory model. The results are shown in table 2. Our results for Granite represents good performance of Pressure Infiltrometer; but to reduce scale effect and edge effect for in-situ test, the ring dimension should be as large as practical. From the present field observations during in-situ experiments on Granite soil, the depth of ring insertion (d) should be greater than 5 cm from soil surface to avoid surface ponding out side the ring. It is also our observations that insertion of Infiltrometer ring may affect the accurate results of field infiltration. So during insertion of ring, soil surface should be leveled carefully and Pressure Infiltrometer ring should be kept in vertical position and gradually downward push is to be applied. It is better to use a wooden small hammer to insert the ring into the soil up to the full height of ring which can avoid any water flooding out side the ring.

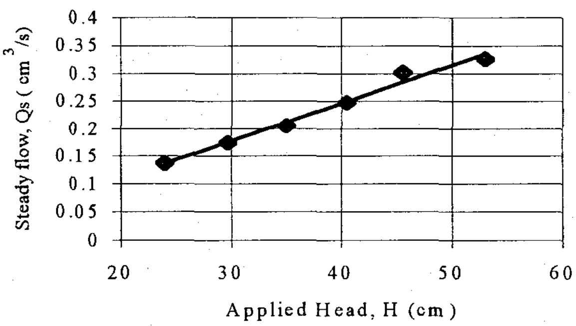

Fig. 7 A stable relationship between steady flow & applied head at in-situ experiment on Granite soil.

Table 2 Field-saturated (K_{FS}) and Saturated (K_{LS}) hydraulic conductivity of Granite soil.

Site	Field-saturated, K_{FS}, cm/sec		Lab saturated, K_{LS}, cm/sec	
	Constant head	Falling head	Constant head	Falling head
A	4.50×10^{-4}	4.52×10^{-4}	7.84×10^{-4}	7.13×10^{-4}
B	4.90×10^{-4}	4.28×10^{-4}	6.64×10^{-4}	7.38×10^{-4}
C	5.68×10^{-4}	4.40×10^{-4}	6.48×10^{-4}	7.80×10^{-4}
D	5.58×10^{-4}	4.60×10^{-4}	7.25×10^{-4}	7.50×10^{-4}
E	6.12×10^{-4}	3.98×10^{-4}	6.32×10^{-4}	8.63×10^{-4}
Average	5.36×10^{-4}	4.36×10^{-4}	6.71×10^{-4}	7.70×10^{-4}
Mean	4.90×10^{-4}		7.30×10^{-4}	
SDF	0.0007		0.0001	

To estimate the magnitude of variation of field and laboratory results at different stations, mean value of K_{FS} & SDF (Standard Deviation Factor) was calculated. For field experiment, mean of K_{FS}=4.90×10^{-4}cm/s, SDF=0.0007, For Laboratory experiment, mean of K_{LS}= 7.30×10^{-4} , SDF= 0.0001. Laboratory results are 1.5 times greater than field results; because during field experiment entrapped air make disturbance to the flow of water within pore space. The standard deviation is negligible; because our experimental site was an artificial land of same type of Granite soil. The standard deviation calculation of K_{FS} is the representative of variability of the site; but we need sufficient field data of K_{FS} to check the variability of any site.

Validity of field results was checked by laboratory core sample test; but the core sample test was done by a new laboratory model of Pressure Infiltrometer technique. The mean value of field-saturated hydraulic conductivity (K_{FS}) of each station are compared to mean value of core sample results

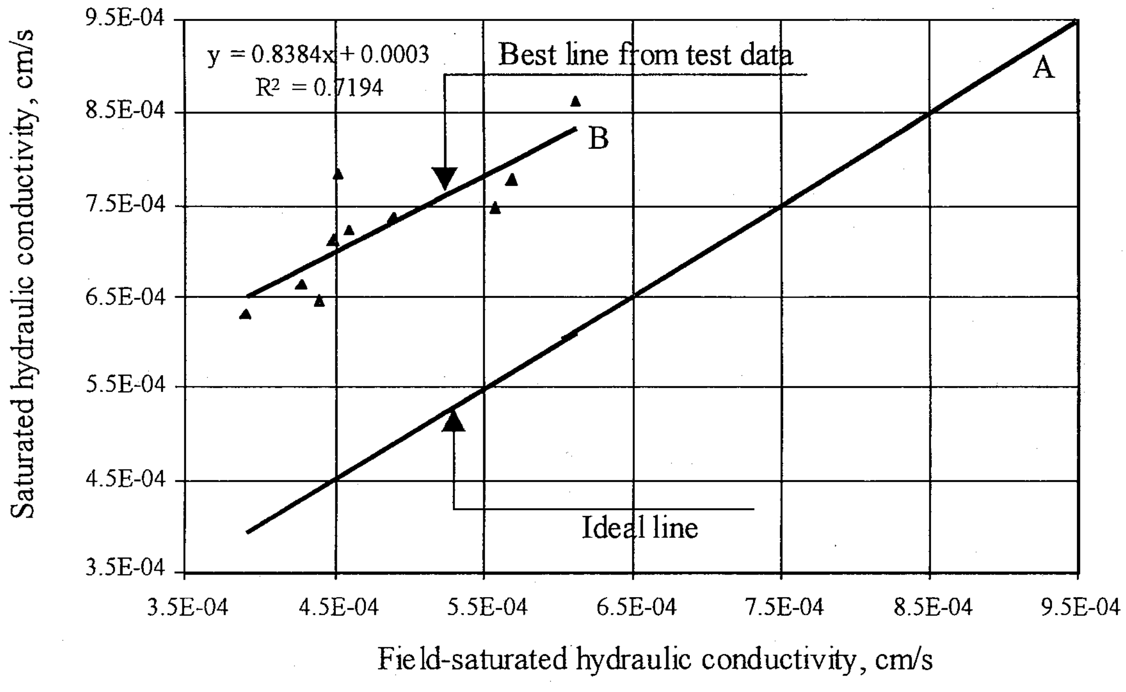

Fig. 8 Relationship between saturated and field-saturated hydraulic conductivity for Granite soil.

The regression line 'B' is obtained from experimental data and it represents a good relationship between saturated and field-saturated hydraulic conductivity; because the line 'B' is near about parallel to the line of agreement (i.e., ideal line 'A'). The variation of mean value from the estimated value of regression line was compared to the variation of mean value from individual value at different points (R^2=SS_r/SS_T).

The equation of best fitted line is used to predict field-saturated values using laboratory core sample experimental results of Granite soil. It is observed that experimental results agree with predicted values.

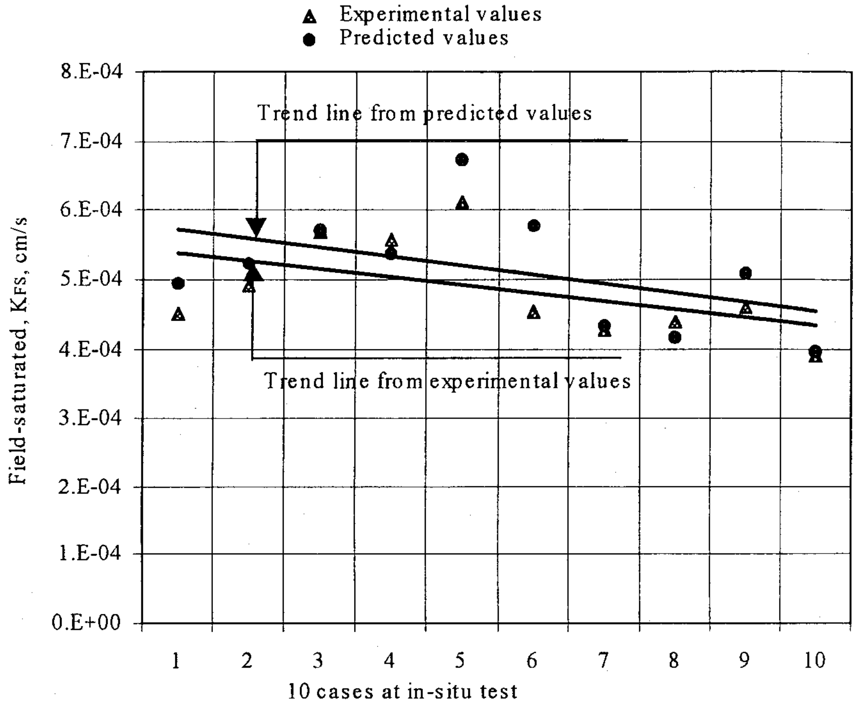

Fig. 9 Comparison of predicted values of K_{FS} with in-situ experimental results.

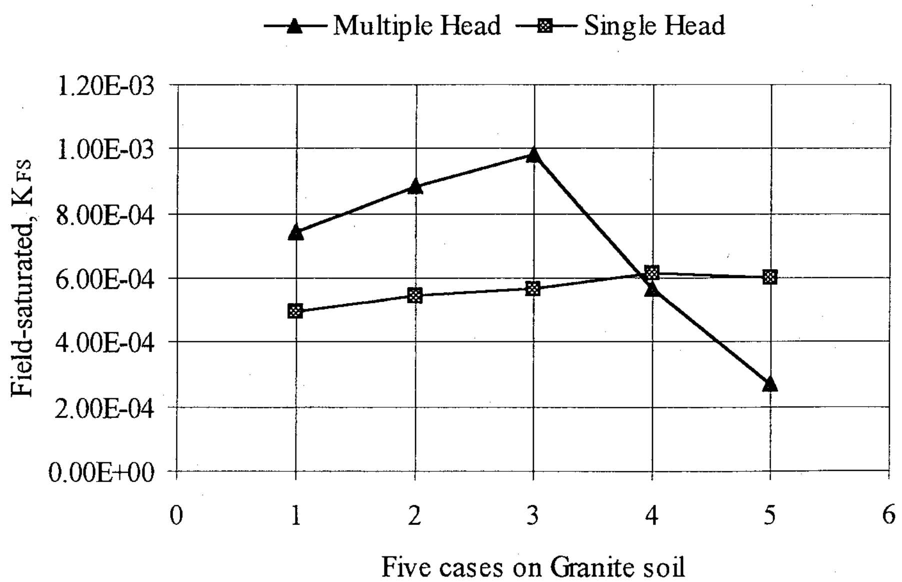

Fig. 10 Comparison of single head and multiple head calculation approach

It is observed from the results of 5 cases of our site that single head approach of estimation of hydraulic conductivity is more consistence & less sensitive to soil variability (Fig. 10). For Granite soil of our site was homogeneous. Therefore in both the cases results were acceptable; but single head results are more stable indicating good performance. In single head approach it is possible to measure field-saturated hydraulic conductivity in the field applying only one positive head on soil surface and considering the value of Alpha parameter in site estimation from Elrick suggested values (table-3) and this approach of measurement is needed short time

Single head approach of calculation of hydraulic conductivity needs independent measurement of Alpha parameter or site estimation from Elrick Table 3. Our estimation of Alpha parameter was done(Fig 10) by fitting field data of lnK and suction head (ψ) of Instantaneous profile technique at the field of Tottri dune sand. Estimated value of Alpha parameter was found 0.39 cm^{-1}. According to Elrick (1990) suggestion (Table 3), the site estimation of Alpha value was 0.36 cm^{-1}. It is found that the field-saturated hydraulic conductivity (K_{FS}) calculated by considering 0.36 cm^{-1} from Elrick table and by estimating from field data is shown in the table 4. The variation of the results of K_{FS} is 12%, which represents acceptable values of Alpha in table 3. Therefore our estimation agrees with the suggested table 3 of Elrick et. al.,(1990).

Table. 3[5] (Elrick et.al., 1990)

Soil texture/structure category	$\alpha^* cm^{-1}$
Compacted structureless clayey soil	0.01
Fine texture clayey and unstructured	0.04
Most structure soils from clays through loam including fine sand	0.12
Coarse and gravelly sands	0.36

Table. 4 Values of K_{FS} on Alpha consideration

Alpha selection for In-situ test.	Calculated value of K_{FS}
Elrick suggested value, α^*=0.36cm^{-1}	2.4x10^{-2}cm/sec
Estimated value, α^*=0.39cm^{-1}	2.7x10^{-2}cm/sec

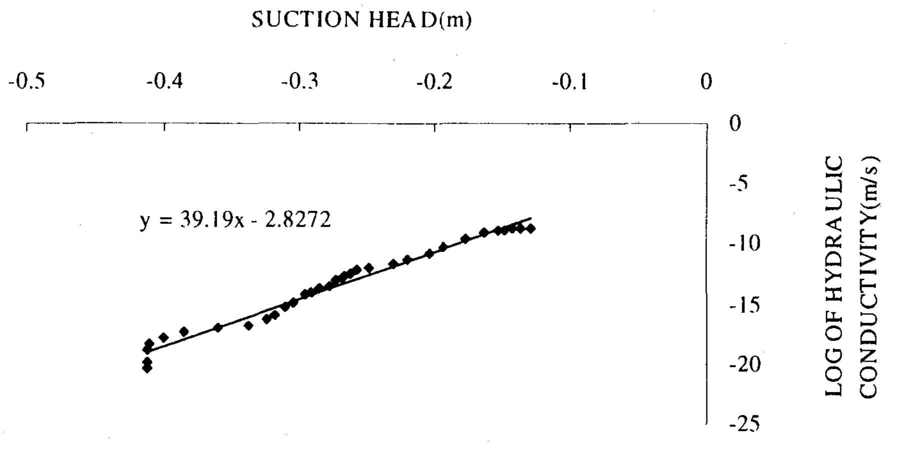

Fig. 11 Estimation of Alpha (α^*) by using in-situ experimental data.

Influence of Alpha parameter on K_{FS} was checked by using field data of steady flow rate on Granite soil at our site of artificial land. Our field parameters were as following:

Steady flow rate (Q_s) = 0.22 cm^3/sec, Radious ring = 4.75 cm, Positive head on soil surface = 50.6 cm, Shape factor (G) = 0.631 and the range of values of Alpha were from 0.1 to 1 assuming rate of increment 0.05. A relationship between field-saturated hydraulic conductivity and Alpha parameter is found (Fig. 12). From this relationship it is observed that the value of site estimation of Alpha parameter can be assumed within a range

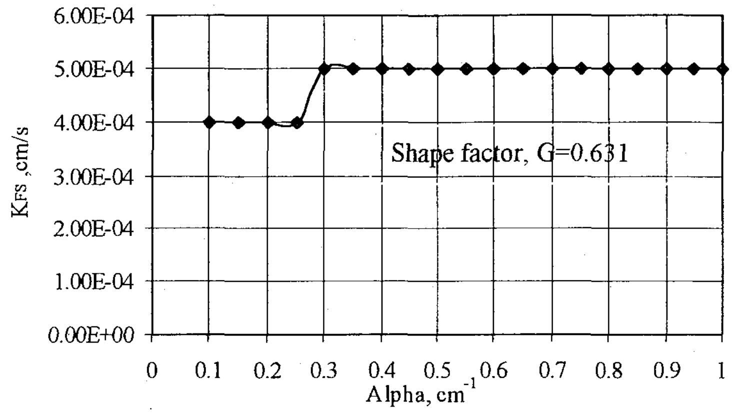

Fig. 12 Influence of Alpha values on field-saturated hydraulic conductivity (K_{FS}) when shape factor, G=0.631.

from 0.25 to 0.30 cm^{-1}; because the calculated value of field-saturated hydraulic conductivity (K_{FS}) becomes same beyond the value of 0.3 of Alpha.

Influence of Alpha parameter was also checked using field data recorded during in-situ experiments. our site at dune sand has high hydraulic conductivity and rate of steady flow was also very high. Steady flow rate, Q_s=10.72 cm^3/sec, Radious of ring = 4.75 cm, Positive head on soil surface = 23.50 cm, Shape factor (G) = 0.384 and the range of values of Alpha were from 0.01 to 1 assuming rate of increment, 0.01.

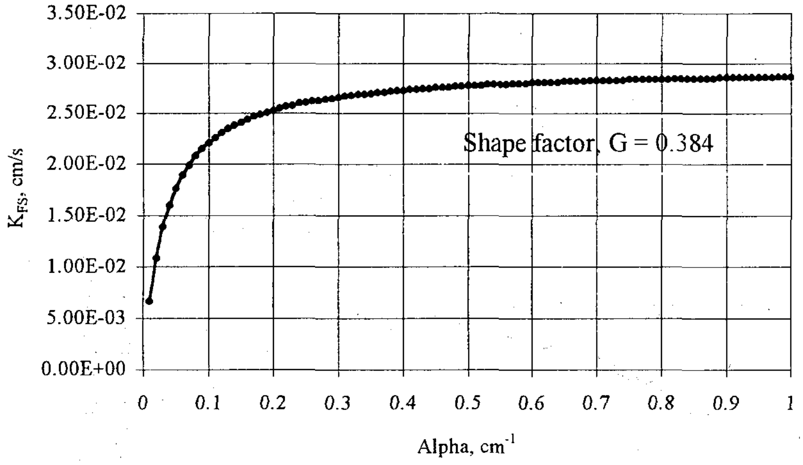

Fig. 13 Influence Alpha values on field-saturated hydraulic conductivity (K_{FS}) when shape factor, G = 0.385

It is evident from fig. (12) and fig. (13) that the Alpha parameter has a little influence of field-saturated hydraulic conductivity in case of sandy soil while water flow through unsaturated soil is dominated by gravity force. Also due to different values of shape factor, the influence pattern gives us a little different phenomenon.

6. Comparison of in-situ experimental results

Results of in-situ experiment with the results of other existing and conventional methods are shown below:

Table. 5 Results of different methods.

Site	Methods	Hydraulic conductivity
Tottori dune sand	In-situ test by Pressure Infiltrometer	K_{FS}=2.80x10^{-2} cm/s
Tottori dune sand	Instantaneous profile technique	K_{FS}=2.00x10^{-2} cm/s
Okayama, Granite soil	In-situ test by Pressure Infiltrometer	K_{FS}=4.90x10^{-4} cm/s
Okayama, Granite soil	Laboratory P.I core-sample	K_{LS}=7.30x10^{-4} cm/s
Okayama, Granite soil	Laboratory Conventional method	K_{LS}=3.60x10^{-3} cm/s

Laboratory core sample result is 1.5 times greater than field result as core sample was fully saturated. Laboratory conventional method gives us 10 times higher value than the field value as in conventional method, soil was disturbed and conditions were different than core sample.

7. Advantages

1) Falling head as well as constant head technique can be applied at in-situ investigation of hydraulic conductivity using this device very smoothly. 2) By making the device compatible to laboratory core sample test, Pressure Infiltrometer device can be used in the field as well as in the laboratory. 3) The method is handy, less expensive, easy to installation. 4) By using only one positive head (H), we can estimate field-saturated hydraulic conductivity (K_{FS}) within 1 hour. 5) The device is less susceptible to soil heterogeneity than other conventional and existing methods.

8. Limitations

1) This device can not be applied at gravelly and stony soil.
2) Additional water flow along the wall of ring inserted into unsaturated dry soil may affect the accuracy of measurement of actual amount of infiltration during in-situ investigation of hydraulic parameters of vadose zone.

9. Conclusion

If we look for last two decades, it has become clear that the in situ measurement of soil hydraulic properties is essential for dealing with the complexities of water and solute movement in the field. It is therefore essential that accurate field methods be developed for measuring these properties. If we summarized, the main results of this research works are as following:

1) The results of field-saturated hydraulic conductivity estimated by considering site estimation of Alpha parameter agree with the results of field-saturated hydraulic conductivity estimated by independent measurement of Alpha parameter.
2) The value of laboratory saturated hydraulic conductivity (K_{LS}) is found approximately 1.5 times greater than the value of field-saturated hydraulic conductivity (K_{FS}) which was determined by our in-situ device compatible to laboratory core sample test method.
3) Alpha parameter has a little influence on field-saturated hydraulic conductivity (K_{FS}) in case of Granite soil.
4) Single head approach of calculation is more stable and less sensitive to soil heterogeneity than multiple heads approach of calculation.
5) Our device is more stable to applied positive head and less vulnerable to the assumption of incompressible of surface soil during in-situ experiments.

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