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Fabrication of Permeameter for Determination of Hydraulic Conductivity of Earth Materials

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Abstract: ***Laboratory investigation is one of the major ways of assessing soil hydraulic conductivity. Determination of hydraulic conductivity aids in engineering design of well pumping, prediction concerning spread of polluting fluids, embankment of canal bank affected by seepage, flooding solutions and stability of earth dams. However, different studies have shown that there are alternative models to Darcy's law which governs the widely use of laboratory measurement of hydraulic conductivity. The deficiencies accustomed to the conventional permeameter such as the time wastage and cost-intensivehas led to different research modification. A low-cost permeameter was fabricated using a plastic column, hose pipe, to serve as water inlet and outlet connected to two manometer tubes to measure the pressure head difference. The hydraulic conductivities measured using the low-cost were 4.31$\times 10^{-1}$ cm/s, 8.14$\times 10^{-2}$ cm/s, 6.12$\times 10^{-5}$ cm/s, 5.86$\times 10^{-7}$ cm/s for 0.3 mm coarse sand, 0.85-1 mm fine sand, sandy clay and silty clay respectively. In comparison of the fabricated permeameter with conventional permeameter and other fabricated laboratory permeameters, it was observed that the hydraulic conductivity obtained is consistent with the typical permeability range for each soil type.***

Keywords: hydraulic conductivity; conventional permeameter; laboratory test; fabricated permeameter.

I. INTRODUCTION

Coefficient of permeability (hydraulic conductivity) is a variable that significantly depend on water content (or degree of saturation) for unsaturated soil [1]. Hydraulic conductivity is one crucial soil property that gives the information required for evaluating aquifer performance, determining the transport of contaminant plumes in subsurface environments and characterizing contaminated sites for remediation [2]. The application of this soil property include construction of landfill liner, measurement of water for underground construction while pumping, quantification of seepage water with various hydraulic head [3]. Several studies have been conducted to determine the hydraulic conductivity on the field or in the laboratory [4]. Numerous methods have been used in the laboratory to estimate both saturated and unsaturated coefficient of permeability of earth materials. The sampling techniques commonly used for saturated soil in the laboratory include the constant method, the falling head permeameter method and particle-size distribution measurement [2].

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Laboratory techniques for unsaturated coefficient of permeability of soils are transient method: the ultracentrifuge method, the instantaneous profile method (IPM); the pressure-plate method; the BrukeKlute method; and the one-step outflow method and the steady-state method [2]. The conventional permeameter operates on the basis of creating a head difference on both ends of the soil samples and estimating the flow of water. Therefore, permeability can be determined using Darcy's principle [5]. Falling head permeameter are used for fine grain (cohesive) soils. Constant head permeameter is used for coarse grain (non-cohesive) soil [3]. Researchers [6, 7, 8] reported that the conventional permeameters have several deficiencies. Some of the deficiencies include time wastage, inaccurate result and non-automation of result. Therefore, different researchers have developed alternative permeameters.These fabricated (modified) permeameters include the automation of falling head permeameter [4], centrifuge permeameter of unsaturated soils [9] and modified permeameter to characterize dual porosity media [10]. In addition, most of these modified permeameter have been used to investigate hydraulic conductivity successfully.A low cost self-constructed permeameter was constructed to determine the hydraulic conductivity of soil samples using both the constant head and falling head method. The fabricated permeameter has some features that overcome some of the deficiencies of the conventional permeameter. It is alwsys good to use affordable and economical materials for fabrication of devices so that common populace will be able to purchase the items [11, 12, 13]. The materials used in fabricating this permeameter are home-made improvised materials which eliminate the issue of cost-intensiveness and complexity of the conventional permeameter. The objective of this paper is to determine the hydraulic conductivity of soils using a fabricated permeameter. The uniqueness of this permeameter is the time taken by the water to pass through the soil sample which gives better accuracy to the measured value. Also, the permeameter setup is of low cost with zero complexity. The study also compares the fabricated permeameter with other permeameters fabricated by different authors and the conventional permeameter.
Relevant literatures were consulted in order to obtain articles related to other fabricated permeameter and conventional permeameter. General article information, perceive deficiencies worked on, discoveries and knowledge gap were also recorded in Table 1. Test result from trial samples from conventional permeameter and other fabricated permeameter were also compared. Some of the fabricated permeameter by other authors are presented in Table 1. Cogent discoveries as well as knowledge gap are itemized.

Different fabricated permeameters have been developed to counter different deficiencies of conventional permeameter. Such deficiencies includes long time period required to attain equilibrium conditions, and improper assessment of flow behaviour. [4] reported some limitations such as only one sample can be measured at a given time and that measurement are not automated. [8] observed the inability to independently control and measure the total stress, the pore-air pressure and pore water pressure. Examples of fabricated permeameters include the bridge permeameter [14], centrifuge permeameter [9], sonic permeameter [15], and the modified flexible wall [16].

Table 1: Observation from modified permeameter from different authors

Author(s)	Workdone	Samples	Discovered	Knowledge gap
[10]	Evaluation and improvement of a modified permeameter to characterize dual porosity media	Sand	New electrical conductivity probes were made to improve the performance of the permeameter and a second set was re-platinized, which allowed more precise and accurate readings of the solution concentrations. The results indicated that the porous stones, which are used to distribute solution evenly over a specimen's cross-section, have a significant effect on solution dispersion affecting the measured soil dispersion coefficients.	Implementation of a computer program is needed due to the complexity of the modified apparatus. In other for the probes properties to last for a longer period of time, electrical conductivity probes that are less sensitive with time and more resistant is required.
[7]	A flexible wall permeameter for measurements of water and air coefficients of permeability of residual soils.	Residual soils	Its measures water and air coefficient of permeability at high matric suction values while the conventional permeameter measures water and air coefficient of permeability at low matric suction (less than 100kPa). With this device, stress-state variable of soil specimen can be controlled during experiment making it possible to relate the permeability of the soils to their stress state compared to the conventional permeameter. Confining pressure can be applied, hence sidewall leakage which commonly occurs in the conventional rigid wall permeameters can be avoided.	Flexible wall permeameter are generally preferred for grained soil especially for intact samples in other words not suitable for coarse samples. It is not cost effective. Since the determination of water coefficient of permeability takes much time compared to the measurement of air coefficient, the determination of water coefficient is more susceptible to errors especially at high matric suction where water coefficient is low and the flow involved is very small.

[4]	Automation of a falling head permeameter for rapid determination of hydraulic conductivity of multiple samples.	30 sandy soil, 23 silt loam soil and 11 silty clay loam (64 core samples)	The automated unit allows for six samples to be processed with minimal human oversight compared with only one sample being read manually (conventional permeameter).	Larger number of samples can be measured using this technique, however it should be noted that samples within a given texture classification can be analysed together.Forcing the sample over a large cylinder may cause disturbance to the soil or leakage in the permeameter. Data logger sampling rates cannot be set at small time steps because of the slow rate of conductivity of clay samples for sufficient changes in the hydraulic head to permit calculation of ks values > 0.
[16]	A modified permeameter for determination of unsaturated coefficient of permeability	Coarse grain soil	The features incorporated in the new device in comparison to a conventional permeameter include the use of a large specimen and monitoring specimen consolidation while collecting the flow characteristics data using non-destructive testing techniques.	The modified permeameter provides value of unsaturated permeability with remarkable little scatter over low suction range (meaning results cannot be extended to higher range suction values. Ease of manufacture was not evaluated based on the complexity of the design itself and also required a trained personnel to operate.
[9]	Centrifuge permeameter of unsaturated soil II. Measurement of the hydraulic characteristics of an unsaturated clay	Clay	An important advantage of the new equipment over the normal conventional permeameter (such as the steady state centrifuge SSC apparatus and the unsaturated apparatus) is that it included a fully functional data acquisition system for in-flight monitoring. A steady state condition can be reached in shorter period of time.	The centrifuge method is not a feasible for routine geotechnical testing as it requires a commercial centrifuge and elaborate testing facilities.This method also applies stress to the specimen through centrifugal force during testing and is suitable only for soils whose flow behaviour is not sensitive to applied stress state.

[1]	Laboratory measurement of hydraulic conductivity functions of two unsaturated sandy soils during drying and wetting processes	Two identical sandy soil specimens.	The improvised permeameter uses cellulose filters instead of ceramic disks to reduce testing time.	Soil whose volume contrasts during drying, cannot be used as this contraction creates void between the upper filter and the top soil surface. This gap creates discontinuity in the path of the water flow through the sample. The steel filters have an air-entry value of 12kPa, therefore, the peremameter cannot be used to measure the hydraulic conductivity at suction levels greater than 12kPa.
[6]	A modification of the constant head permeameter to measure saturated hydraulic conductivity of highly permeable media	Coarse sand	Using the constant head method, testing of the low-resistance permeameter demonstrated no systematic bias in the value k_s compared to the conventional permeameter that has tube that collect water under the sample which introduce a hydraulic head-dependent resistance for highly permeable media and result in an underestimation of Ks.	The developed instrument cannot be truly justified since the low-resistance permeameter was tested with only one highly permeable sample.
[14]	Bridge permeameter	Not mentioned	Its provides an alternative process for the single- phase steady-state measurement in terms of high differential pressures and low flow rates are required when testing lower permeability rocks which the conventional permeameter find it difficult to analyse. The bridge paths include low resistors having a predetermined resistance to fluid flow. The permeability of the sample is determined from measured pressure drops, predetermined resistances, and fluid viscosity at the resistances. Another objective of this invention is to provide lower cost apparatus for single phase, steady state permeability measurement.	The presence of turbulent flow can lead to a slight change in the results. Different set of resistors will probably be required to cover full range of permeameter.

II. MATERIALS AND METHODS

A simple linear low-cost permeameter was constructed using a plastic sand column, a hose pipe connected to the column bottom which serves as the water inlet as shown in Figure 1. Two other hose pipes connected to manometer tubes were attached tothe sides of the plastic column each. The manometer tubes are both mounted on a wooden wall in such a way that they can both be moved at a particular elevation at the same time. Another hose pipe was attached to the side which serves as the water outlet. The hose pipes were connected to the glued metallic pipe, inserted along the plastic column by drilling holes on the plastic and fastened using hose clamps. Metallic pipes are just to make the connection firm and to avoid any leakage. The constant head technique was used for silica sand samples while the falling head method was used for the laterite and kaolinite samples. The samples were air dried and weighed using a weighing balance. The measuredair dried sand was collected in a container. The diameter of the specimen tube was determined using a Vernier calliper. The required length of the sample height in the column was marked to correspond to twice the inner diameter in accordance to American Society for Testing and Materials (ASTM) standard D2434 (standard test method for permeability of granular soils). The bottom porous stone was slipped into the plastic column. A scoop was used to pour the sand into the plastic column in small layers and a tamping device was used to compact the sample to the desired density at regular interval. The top porous stone was slipped into the tube torest firmly on the sample. The mass of the assembly was determined. The specimen was saturated by running water through the bottom of the permeameter to the sample through the bottom hose pipe (inlet). After a steady flow was established, the water flowing out of the constant head chamber was collected into a graduated cylinder (volume measure) and head difference was measured using a simple meter rule. Collection time (t) was recorded using a stop watch. Collection of water flowing out of the constant head chamber was repeated on different trials. For falling head the metre rule was placed directly behind the manometer, so the height of water in the manometer above the chamber out flow port was read. The sample was saturated again and the above steps were followed. After a stable flow has been established, the heights of the two levels from the outflow level were measured.

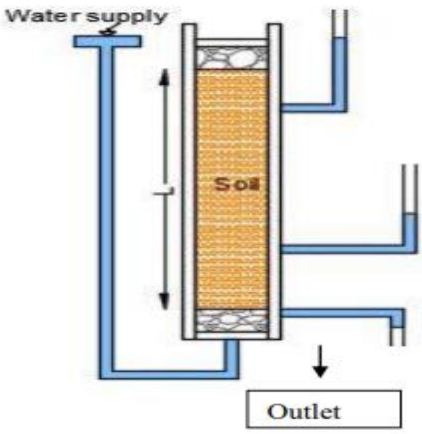

Figure 1: Schematic diagram of the fabricated permeameter

For constant head method, a constant head difference (h) is applied across the sample producing a volumetric flow rate Q. Using Darcy'sprinciple; the hydraulic conductivity was computed using equation 1

$$K = \frac{VL}{Ath} \qquad (1)$$

K is the saturated hydraulic conductivity (cm/s), L is the length of sample, A is the cross-sectional area of the permeameter, V is the volume of water collected in time t and h is the constant hydraulic head (cm). While for falling head method, the water level in the falling-head tube is allowed to drop, and then head measurements are recorded frequently until no flow occurs in the permeameter. Flow rate in the tube must be equal to that in the column. Hydraulic conductivity of the saturated soil sample can be obtained from the relationship in equation 2.

$$K = 2.3\frac{aL}{At}\log\frac{h_o}{h_1} \qquad (2)$$

L is the sample length, h_0 is the initial hydraulic head in the falling-head tube, h is final hydraulic head in the falling-head tube at time t, t is the time that it takes for head to change from h_0 to h_1.

III. RESULTS AND DISCUSSION

The volumetric flow rates of different samples were measured. It was observed that the 0.3 mm silica sand has the flow rate range from $2.78 - 3.1\, cm^3/s$ with the mean value of $2.902\, cm^3/s$. The flow rate range of silica sand (0.85 - 1 mm) is $10-14.3\, cm^3/s$ with the mean value of $11.972\, cm^3/s$. While that of laterite ranges from $0.22 - 0.27\, cm^3/s$ with the mean value of $0.242\, cm^3/s$. Lastly, kaolinite flow rate ranges from $0.082 - 0.092\, cm^3/s$ with the mean value of $0.0872\, cm^3/s$. Figure 2 is the graphical representation of volume measured with time. The volume of water of the soil samples, from five different trials, for four soil types used, were plotted as a function of time showing a linear increase in time as volume increases.The classification of these samples into different soil types are shown in Table 2 according to their average K_s values and Table 4 according to their degree of permeability. It was detected that silica sand (0.3mm) with the average K_s value of $4.31 \times 10^{-1}\, cm/s$ can be classified under the coarse sand soil type because of its very high degree of permeability. Silica sand (0.85 – 1 mm) can be said to have a medium degree of permeability because it is fine sand with average K_s value of $8.14 \times 10^{-2}\, cm/s$. Meanwhile, laterite clay can be classified as sandy clay because of its low degree of permeability with an average K_s value of $6.12 \times 10^{-5}\, cm/s$. Lastly, kaolinite can be classified as silty clay because of its very low degree of permeability with an average K_s value of $5.86 \times 10^{-7}\, cm/s$. In addition, the results of this study is in agreement with report from [6] and

[9] where coarse soil has high degree of permeability and silt clay soil with low degree of permeability. Consequently, the experiment shows the influence of factors such as porosity of the soil, particle-size distribution, shape and orientation of soil particles, degree of saturation or presence of air and the thickness of adsorbed layers associated with clay mineral. The pore sizes within the soil cavity influences the degree of permeability. Coarse sand is the most porous, followed by the fine sand, sand clay and the silt clay. The order of porosity influences the degree of permeability. Therefore, the highest degree of permeability was observed to be the course soil and the lowest with the silt clay. A look at the soil grain distribution shows that soil with a single particle size as in the case of coarse sand, encourages the movement of water through it. When the particle sizes are reduced, the flow of water is reduced and hence reduction in the permeability. The presence of fines i.e. sand and clay in the soil matric reduces space within the soil as the small sized particles reduced voids, clogging up spaces. This was observed in the two clay samples. The clay sample with sand allowed more infiltration of water through it. However, the presence of silt, i.e. particles size less than 0.004 mm-0.062 mm, makes the soil so dense and results in reduced seepage paths for water, hence reduced permeability. It shows that silica sand is more porous than laterite and kaolinite. From the results, kaolinite retains water than laterite and sand does not retain water at all. Irrespective of the modifications, the coefficients of permeability obtai ned are still within the typical values as shown in Table 3. Therefore, the incorporation of different principles, model or mechanism has not resulted in ambiguous values. Table 4 is the result obtained from the laboratory test using the fabricated permeameter with different soil samples. Consistency of the result with theory shows that the fabricated permeameter can be reliably estimate soil hydraulic properties in the absence of sophisticated instruments.

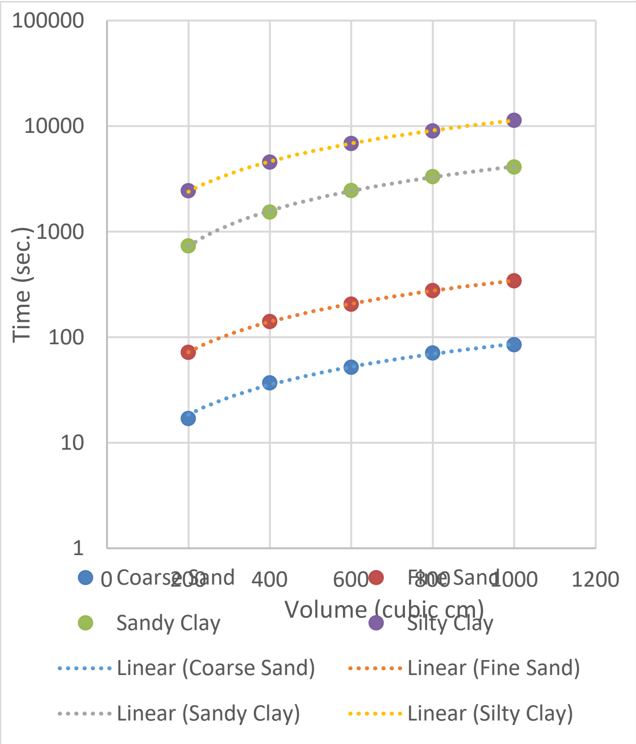

Figure 2: Volumetric flow of the materials

Table 2: Average K value for classification to the soil type

Soil sample	Average value of K (cm/s)	Soil type
Silica sand (0.3mm)	4.31×10^{-1}	Coarse sand
Silica sand (0.85-1mm)	8.14×10^{-2}	Fine sand
Laterite	6.12×10^{-5}	Sandy clay
Kaolinite	5.86×10^{-7}	Silt clay

Table 3:Degree and permeability for various soil type

Type of soil	Typical permeability	Degree of permeability
Gravels	$> 10^{-1}$	Very high
Coarse sand	10^{0} to 10^{-1}	Very high
Sandy gravel, clean sand, fine sands	10^{-1} to 10^{-3}	Medium
Silty sand	10^{-3} to 10^{-5}	Low
Silts, silty clay, sandy clay	10^{-5} to 10^{-7}	Very low
Clay	$< 10^{-7}$	Virtually impermeable

Table 4: Comparison of coefficient of permeability measured with other authors

Range of Ks (cm/s)	Soil tested	Degree of permeability	References
8.4×10^{-1}	Coarse sand	Very high	[6]
2×10^{-5} – 8×10^{-9}	Clay	Low to Virtually impermeable	[9]
5.0×10^{-3}	Sand	Low	[1]
2.14×10^{-2} 1.48×10^{-3} 6.70×10^{-5}	Sand Silt loam Silt clay loam	Medium Low Very low	[4]
5×10^{-9}	Clay	Virtually impermeable	[8]
4.45×10^{-8}	Clay	Virtually impermeable	[7]
4.31×10^{-1} 8.14×10^{-2} 6.12×10^{-5} 5.86×10^{-7}	Coarse Sand Fine Sand Sandy clay Silt clay	Very high Medium Very low Very low	Present study

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IV. CONCLUSION

This study established that the fabricated and permeameters fabricated by other authors can be used as an alternate over the conventional permeameter and still yield results within the typical permeability range of type of soil tested. The conventional permeameter can be upgraded by integrating some of the functions of the fabricated permeameter.The study hereby recommends that other principles such as sound wave attenuation and dispersion in a dry porous material as against the conventional Darcy's law can be employed. The automation of falling head permeameter with the use of pressure transducers for rapid determination of hydraulic conductivity using multiple samples is also viable.

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