Development Of Cost Effective Soil Permeability Testing Apparatus

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Masters of Technology

by

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This is to certify that the thesis entitled **Development Of Cost Effective Soil Permeability Testing Apparatus**, submitted by **Shashanka Sekhar Palai**, to Siksha 'O' Anusandhan University Bhubaneswar, is a record of bonafide research work under our supervision and we consider it worthy of consideration for the award of the degree of Master of Technology of the University.

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Date:

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I am always thankful to our all faculty members provides us the motivation to work. I also like to thank whole ITER community as wherever I go, I will remember you all.

Shashanka Sekhar Palai

DECLARATION

I certify that:

a. The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor(s).

b. The work has not been submitted to any other Institute for any degree or diploma.

c. I have followed the guidelines provided by the Institute in writing the thesis.

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ABSTRACT

In this thesis, The methods of measuring the permeability of sands in the laboratory are investigated. Constant head tests in the triaxial enclosed cell are best suited for testing large specimen under field stress conditions provided the cell is modified to eliminate leakage. Using this type of test, the validity of Darcy's law is confirmed. Falling head tests in the oedometer are very simple to perform and subject to minimal sources of errors. However, small size specimens may not be totally representative. Indirect evaluations of the permeability from consolidation tests are shown to be unreliable. In this piece of research, Development of cost effective permeability apparatus is attempted. The test set up is used to determine the laboratory hydraulic conductivity of sand in horizontal and vertical flow direction. The results are validated with that of generally found permeability results. Throughout the work, necessary steps are taken to eliminate leakage, non-laminar nature of flow and violation of Darcy's law. In the end, It can be inferred that a low cost model for measurement of field and laboratory permeability can be employed at any facility without much economical barriers.

Keywords: Permeability, Sands, Laboratory Tests, Test Equipment, Low Cost, Cost Effective.

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Chapter 1

Introduction

Hydraulic properties of soil are most important in all cases of construction. Be it dams, bridges and building foundations. In this thesis, we are dealing with cost effective ways to analyze movement of water through soil. This collective term ”movement of water” can be established in basically three divisions permeability, porosity and capillarity. All three will be discussed on by one in this chapter.

1.1 Permeability

Permeability, also known as hydraulic conductivity, is the property that represents the ease with which water flows through porous media[6]. It is one of the most important physical properties of soil used in geotechnical engineering. The rate of settlement of saturated soils under load, the stability of slopes and retaining structures, the design of filters made of soil, and the design of earth dams are some of the examples of applications of permeability in geotechnical engineering. The capacity of a soil to permit the passage of fluids through its interconnecting voids, is one of the most important soil engineering properties. The study of the permeability of soils is important in soil mechanics. It is essential for calculating the quantity of underground seepage under various hydraulic conditions, In common practice, the permeability coefficient is usually obtained by constant head permeability test, and is utilized infiltration drainage, settlement, and stability calculations. These problems are extremely important for environmental aspects such as waste water management, slope stability control, erosion, and structural failure related with the ground settlement issues. The drainage and water movement in fine-grained soils are of primary importance

to geotechnical engineering, soil science, and hydrology. In the field of geotechnical engineering, permeability has a significant influence on the consolidation characteristics of soil and as a consequence of drainage, on the mobilization of shear strength of soils.
In addition, the study of the seepage through the body of earth dams, slope stability problems, ground water flow, and many related topics requires reliable information on permeability characteristics of fine-grained soils. For layered soil system the bedding planes of the layers may be horizontal or vertical or inclined. Each layer will have its own value of coefficient of permeability, k. The average or equivalent coefficient of permeability of the stratified deposit, keq, depends upon the direction of flow in relation to the orientation of the bedding planes.
Two simple cases are as follows:

1. Flow is normal to the soil layer.

2. Flow is parallel to the soil layer.

The equivalent coefficient of permeability in both the cases is calculated assuming the Darcys law to be valid. The permeability characteristics of homogeneous soil deposits are known to be functions of void ratio and the soil type.

1.1.1 Factors affecting permeability

Permeability is depend as the property of a porous material which permits the passage or seepage of water through its interconnecting voids. For a fact, Gravels are highly permeable and stratified is clay least permeable. In soils, the interconnected pores provide passage for water. A large number of such flow paths act together, and the average rate of flow is termed the coefficient of permeability, or just permeability.
It is a measure of the ease that the soil provides to the flow of water through its pores. Permeability (k) is an engineering property of soils and is a function of the soil type. Its value depends on the average size of the pores and is related to the distribution of particle sizes, particle shape and soil structure. The ratio of permeabilities of typical sands/gravels to those of typical clays is of the order of 106. A small proportion of fine material in a coarse-grained soil can lead to a significant reduction in permeability. The coefficient of permeability of a granular soil is influenced by its particle size distribution. Consequently, well-graded soils can be expected to be less permeable than 22 more uniform soils.

The particle size of soil is the main factor affecting the coefficient of permeability, especially finer particles. The smaller the particles, the smaller the voids between them; therefore, the coefficient of permeability decreases with decreasing particle size. The effects of finer particles has been studied widely. Barber and Sawyer [1] shows that the finer the particles, the lower the coefficient of permeability. List of such factors that affects permeability are given below.

- Grain size
- Properties of pore water pressure
- Temperature
- Void ratio
- Stratification of soil
- Entrapped air and organic impurities
- Adsorbed water
- Degree of saturation
- Shape of particles
- Structure of soil mass

Table 1.1: General values of Permeabilities of different soil

Soil	k (cm/sec)
Coarse sand	100 to 10^{-1}
Medium sand	10^{-1} to 10^{-2}
Fine sand	10^{-2} to 10^{-3}
Silty sand	10^{-3} to 10^{-4}
Silt	10^{-5} to 10^{-7}
Clay	10^{-7} to 10^{-9}

1.2 Porosity

Porosity is the quality of being porous, or full of tiny holes. Liquids go right through things that have porosity. Go back far enough and you will find that porosity stems from the Greek word porosity for "pore", which means passage. Porosity, usually given as a percent, is the amount of empty space inside of a rock.

The space between particles is called pore space. Pore space determines the amount of water that a given volume of soil can hold. Porosity refers to how many pores, or holes, a soil has. The porosity of a soil is expressed as a percentage of the total volume of the soil material.

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Table 1.2: Porosity Values of Particles

Particle	**Porosity**
Gravel	0.25 - 0.40
Sand	0.25 - 0.5
Silt	0.35 to 0.50

Total porosity is depend as the ratio of the entire pore space in a rock to its bulk volume. Effective porosity is the total porosity less the fraction of the pore space occupied by shale or clay.

1.3 Capillarity

Capillarity is the primary force that enables the soil to retain water, as well as to regulate its movement. Capillary action is the same effect that causes porous materials, such as sponges, to soak up liquids. Capillarity, rise or depression of a liquid in a small passage such as a tube of small cross-sectional area, like the spaces between the fibers of a towel or the openings in a porous material. Capillarity is the result of surface, or interfacial, forces. Capillary action (sometimes capillarity, capillary motion, or wicking) is the ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to, external forces like gravity, capillary water. Water that remains in the soil after gravitational water is drained out, that is subject to the laws of capillary movement, and that is in the form of a film around the soil grains.

1.4 Objectives Of Thesis

Objective of this thesis is to develop and suggest a method based on Darcy's law to find out permeability and hydraulic properties of soil from a cost effective arrangement which will require least mount of skill to work with.

1.5 Organization Of Thesis

This thesis is divided in five parts:

1. Introduction: Definition of problem and Importance of solution.
2. Literature Review and Approach: Study of literature for previous works on the same problem and to find the innovation in our work.
3. Experimental Setup: Development of cost effective mechanism to find hydraulic properties and its testing.
4. Results: Validation of experimental analysis and observations of Laboratory work.
5. Conclusion and Scope for future works: Conclusion of thesis and suggestions on what more can be done on this topic.

Chapter 2

Literature Review and Approach

Literature survey for this thesis basically comes from the working of constant head and falling head permeability apparatus, which itself is based on Darcy's law. Whereas many other literature have been studied to reach a conclusion on approach towards our problem statement.

2.1 Laboratory Apparatus for Hydraulic Conductivity

Working of constant and falling head permeability testing setup is almost same with a slight difference. Generally, the oversize particles were removed by sieving the soil specimen and the dimensions of the permeameter was noted and its volume is calculated. The amount of water and dry soil was calculated to achieve a particular density and moisture content the height of mold marked in three equal parts. And the soil was compacted into the mold in three layers after fixing the mold to its base plate containing porous stone and placing the collar on the top. Put the porous stone on the top of the soil and fix the top plate which is provided with an inlet valve and air cock. Filter paper was added on the top and bottom of the soil. Secure both the base plate and top plate to mould with suitable clamps and rubber gasket to make the entire assembly water tight. Attach the constant head water tank with the sliding bracket to a vertical stand. This tank has three openings one of them connected to water supply source, the second to overflow tube and the third to inlet valve provided on the cap of the permeameter. Allow the soil sample to saturate. When the steady state flow is attained, the sufficient quantity of water (about 250 cc) and time interval is noted .and the procedure is repeat three to four times.

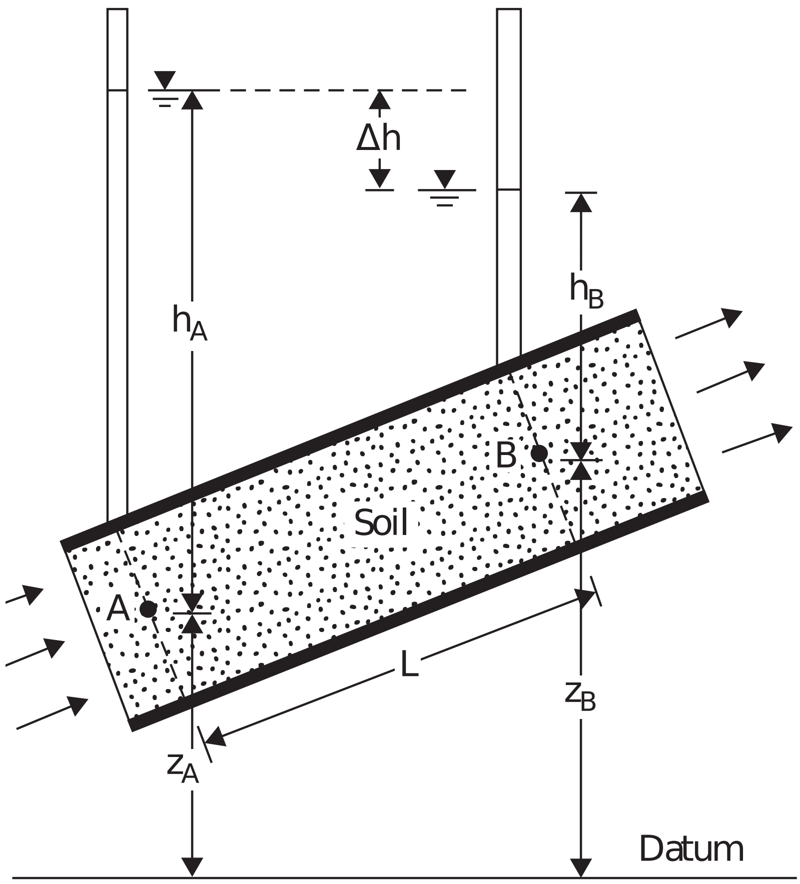

Figure 2.1: Flow according to Darcy's Law

For falling head, the water is supplied through a stand pipe. Water was poured into the stand pipe and allowed to run through the sample. The cross sectional area of stand pipe was determined. Inlet valve was opened and water was allowed flow through the soil sample. Initial height of the water level in the stand pipe was noted and at the same time stop watch had started. Time is taken such that water level falls by 30 to 50 cm. in the stand pipe. Height of the water level and time was noted.

Both follow Darcy's law, i.e. Velocity of fluid in soil mass is directly proportional to Hydraulic gradient. In constant head as well as falling head it follows that. As shown in Figure 2.1.

Mathematically,

$\Delta h = (\ z_A + h_A)(z_B + h_B)$

$i = \frac{\Delta h}{L}$

$V \propto i$

, Which gives,

$V = Ki$

And can be employed for Laboratory tests as:

K= $Q \times A \times i \times t$

Where V = Discharge Velocity

K= coefficient of permeability

Q = total discharge

A= cross section area of specimen in cm2

i= hydraulic gradient

t = times in seconds

2.2 Review of Literatures on Hydraulic Properties of Soil

In this section literature related to permeability and some of work done on permeability are discussed.

Uppot and Stephenson [12]: Two clays are subjected to organic and inorganic permeants to study the changes in permeability caused by the reaction between clays and permeants.

Haug and Wong [5]: The laboratory permeability tests were conducted on a prototype liner formed of Ottawa sand and sodium bentonite. This material was mixed, moisture-conditioned, and compacted into reinforced wooden frames. The in situ permeability test results were verified with low gradient, back-pressure saturated triaxial permeameter tests conducted on undisturbed cored and remolded samples.

Stormont [11]: A finite difference solution was used to develop estimates of permeability and porosity which match the measured data. The gas permeability of the undisturbed rock salt (1 to 5 m from an excavation) is very low, corresponding to a gas permeability of less than 1021 m2. Between the undisturbed region and the excavation, the interpreted permeabilities range from 1016 to 1020m2. Generally, immediately above and below excavations, relatively great permeabilities are measured in the interbed layers. These measurements substantiate the existence and nature of a limited disturbed rock zone surrounding excavations in a bedded rock salt formation.

Sepulveda et al. [9]: this work presents a comparative study of structural and aerodynamic properties of cellular ceramics prepared by two different techniques: the ceramic replication of an organic substrate and the gelcasting of foams. Permeability constants calculated from Ergun's equation were related to their apparent porosity and pore size. The technique of gelcasting of foams yielded structures as porous as the replication technique does, but with smaller pores and a fully densified strut. This type of structure ensures a higher mechanical strength without a significant decrease in the permeability.

Sridharan and Prakash [10]: A detailed study of two-layer soil systems indicates that the mutual interaction among different layers of different soil types forming a stratified deposit affects the equivalent permeability of the stratified deposit, which cannot be simply calculated by the use of the equation for the equivalent coefficient of permeability of a stratified deposit when the flow is normal to the orientation of the bedding planes based on the Darcys law. The permeability of the exit layer controls whether the measured permeability is greater or lesser than the theoretical values for a stratified deposit. The coefficient of permeability of a soil appears to be also a function of the interaction between the soil and the surrounding soil(s) with which it is in contact, in addition to the void ratio, thickness, and the soil type in the case of layered system. In this context, the coefficient of permeability of a soil in a layered system has to be considered as dependent upon how the layers of different k are relatively placed, their thicknesses, and the flow direction. While the present investigation is purely experimental, it opens up the scope for further work in that the validity of the results and proposed hypothesis have to be ascertained mathematically.

de Brito Galvão et al. [3]: Coefficient of permeability of saprolitic soil increased about five times when two percent lime was added and then decreased on further addition of lime. This is assign to the creation of chemical bonds and aggregation. As for lateritic soil, the coefficient of permeability decreased as lime was added. This is also assign to the same mechanism except that the bonds are weaker than those developed in Soil. Similar work was done by Leong and Rahardjo [7].

Chegenizadeh and Nikraz [2]: A series of laboratory permeability tests carried out to evaluate fiber effect on hydraulic conductivity behavior of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement.

Prakash and Sridharan [8]: A comparative study of the measured equivalent coefficient of permeability of three-layer soil sediments with the theoretically calculated values has been made. The results demonstrate that, by and large, the coefficient of permeability of the bottom layer controls whether the measured value of equivalent coefficient of permeability is greater or lesser than the theoretically calculated value. The consequence of this observation is the realization that the equivalent coefficient of permeability of any layered soil deposit is not just dependent upon the values of k of the individual layers constituting the deposit, and that it also depends upon the relative positioning of the layers in the system.
From Above literature, The basic knowledge about principles of working out a way to find hydraulic conductivity of soil as well as the behavior of different soils in different situations are studied. This study is the basis of our work which is done to make the testing procedure cost effective with making it efficient and leak-proof.

Chapter 3

Experimental Setup

This chapter deals with the applications of principles which are followed by cost effective vertical and horizontal permeability setup. Low cost permeability apparatus is built in Geotechnical laboratory with the help of some ordinary accessories which are low cost and recycled waste. Major problem encountered while building this kind of apparatus is management of water leaks. Thats why several different versions of apparatus are tried for the purpose and final apparatus is shown here, for which the hydraulic conductivities are validated from the general values found from literatures. Although this thesis is mainly based on the works of Fwa et al. [4] and Vinegar and Waxman [13].

3.1 Vertical permeability apparatus

Vertical permeability apparatus is made from a plastic container of 5 Kg capacity. Below given steps are performed to transform it into a cost effective apparatus for permeability testing.

- A hole of 3 cm diameter was drilled at the bottom of the container which was covered by a plastic filter of hole sizes about 0.5 cm. This allow only water to pass through.
- Over hole and plastic filter, gravels are placed in a 5 to 7 cm thick layer. and after that a plastic disk is placed with holes of size 0.5 cm and covered with one plastic filter of same hole size. This double layer of filters will hinder the soil particle movement with water.
- After that a soil column of about 15-20 cm thickness is placed over gravels covered by

filter layers. Over the soil column another layer of filter is placed in similar fashion as above mentioned. to make the motion of water from turbulent to laminar in case.

- Finally water collection hole is sealed and fixed with a pipe to collect infiltrated/percolated water.

Schemtic diagram of Vertical permeability testing apparatus is given below:

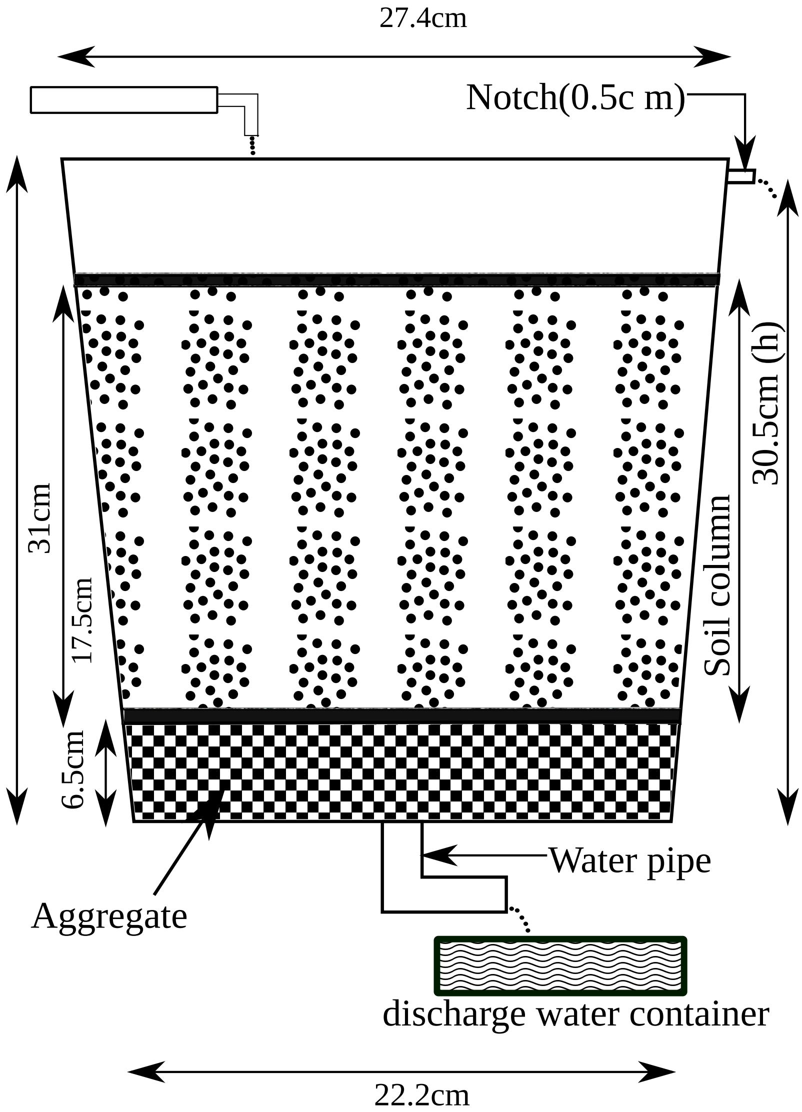

Figure 3.1: Vertical permeability testing apparatus

As given in Figure 3.1, total height of container is 31 cm so the remaining height after gravel and soil columns is used for the maintenance of constant head. A notch of 0.5 cm is cut at the top of the bucket that exits the constant head water to remove any error if the bucket is tilted slightly. The water supply can directly be connected to the container and when the saturation is achieved the water can be collected with the measurement of time. From the data, constant head permeability can be found for a soil. A falling head test can also be performed on clay by reducing the height of soil column and increasing the height of water column and letting the the test for 24 hours.

3.2 Cylindrical horizontal permeability apparatus

Horizontal permeability testing apparatus was made firstly by two waste water bottles of about 2 liter capacity joined in same fashion as a cheap water rocket. Below given steps are performed to transform it into a cost effective apparatus for permeability testing.

- Both water bottles are cut from about middle and joined together in a temporary joint which can be made leak-proof after placing a soil sample in between them.
- A circular holed perforated plastic foam of thickness 2 cm is placed at curved part of one bottle and soil is placed over it, which then covered by a similar circular holed perforated plastic foam to stop motion of soil with water from both ends.
- A standing pipe is connected to the mouth of bottle by an arrangement as water supply line and another water collecting pipe is connected to the other bottle.
- Finally all ends are sealed and the joint of both bottles is also sealed.

Schemtic diagram of Cylindrical horizontal permeability testing apparatus is given below:

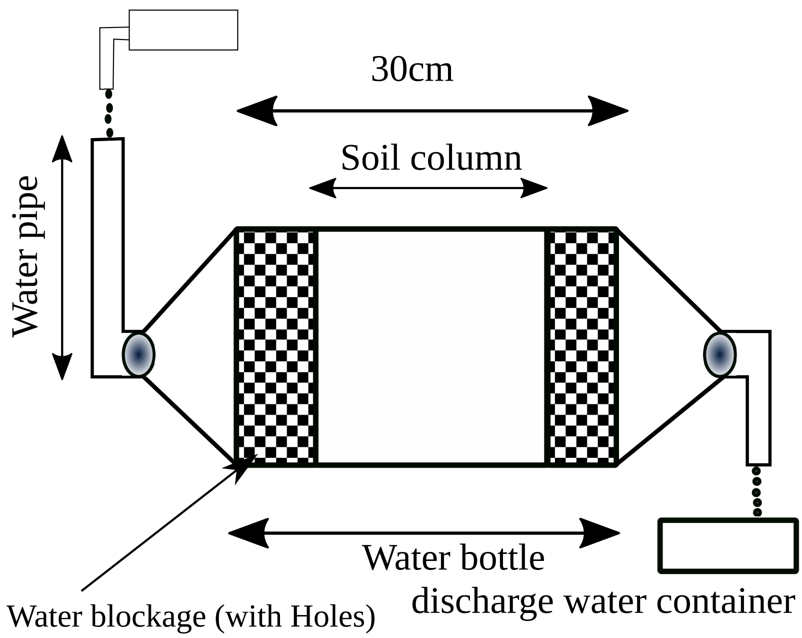

Figure 3.2: Cylindrical horizontal permeability apparatus

Major problem with testing above apparatus was that the leakage at the middle joint and cavitation of sand. There is no pressure applied from both the horizontal sides while applying water for testing. Hence when the sand saturates it starts flowing with the water and gravity further deteriorates the situation and an air pocket is formed. To solve this problem, an odeometeric type of solution is thought out for horizontal permeability testing.

3.3 Rectangular horizontal permeability apparatus

This time horizontal permeability testing is done with the help of a 2 kg rectangular plastic container. Below given steps are performed to transform it into a cost effective apparatus for permeability testing. Schematic diagram of Rectangular horizontal permeability testing apparatus is given below:

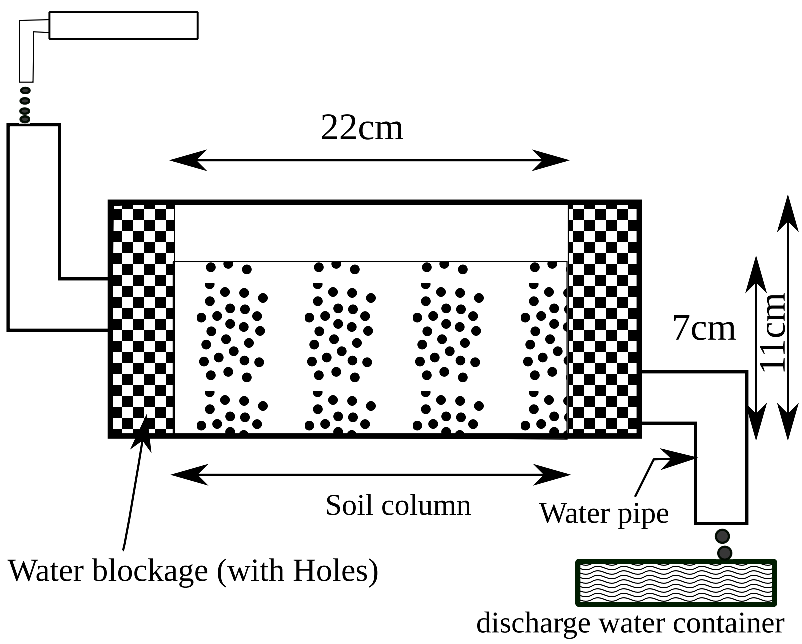

Figure 3.3: Rectangular horizontal permeability apparatus

- Holes of 3 cm diameter were made on both shorter sides at the center of the faces for water supply and collection.
- Both holes were covered with 2 cm thick perforated plastic foam to obstruct flow of soil with water.
- Head for the supply line was limited to the height of sand in the container box to avoid quick sand condition.

- To further safety, top part of sand is covered odeometrically (vertically waterproof) by a 2 cm thick plastic foam to stop any leak.

Problems with leakage and sand flow were almost eliminated from this set up. Further application of stress on top surface of sand covers for any other leak due to head irregularity. Before this permeability testing, particle size distribution of sand is performed. The sand was found to be almost uniformly graded fine sand. The validation of hydraulic conductivity of this sand is performed with the data given in Table 1.1.
Results of tests performed are given in next chapter.

Chapter 4

Results

4.1 Observation : Vertical permeability

For vertical permeability test, At the bottom of cylindrical container, 6.5 cm of gravel layer is placed below 17.5 cm soil column both separated by plastic filters on both side to avoid direct water contact.

Figure 4.1: Laboratory Set up for Vertical permeability

Tests are performed on soil after its saturation by water. Three observations of 10 minutes are made. Collected water weighted and permeability measured. For calculation one approximation is done on the area of cross section as the cylinder was actually a frustum and soil strata has a variation of diameter from 26 cm to 23 cm from top to bottom, an average of 24.5 cm cylinder cross section is assumed. Below formula is employed. $k_v = \frac{Q \times L}{h \times A \times t}$

where, L = length of soil column, 17.5 cm

h = head loss, 30.5 cm

A = Area of cross section, $\pi \times r^2$ where r = 24.5 cm

t = Time of experiment, 10 minutes Results are shown in Table 4.1. It is clearly visible that the permeability matches general results for fine sand.

In Figure 4.1, It shows how the laboratory apparatus in real time works. Centimeter graduations and collection pipes can be seen. Water collection bucket was placed below the pipe. To avoid sand filtering from circumference, a 2 cm thick plastic foam was placed at periphery as seen. Gravels are covered by foam hence can't be seen in the image.

Table 4.1: Table of Vertical permeability

Quantity	Test-1	Test-2	Test-3
Weight of empty bucket(kg)	0.370	0.370	0.370
Total weight of bucket + Weight of water(kg)	3.530	3.455	3.470
Weight of discharge water(kg)	3.16	3.085	3.1
Volume of discharge water, Q ($10^{-3} \times m^3$)	3.16	3.085	3.1
k_v (cm/sec)	3.260×10^{-2}	1.043×10^{-3}	1.048×10^{-3}

4.2 Observation : Horizontal permeability

Major problem with cylindrical horizontal permeability testing set up as shown in Figure 4.2, leakage and loosening of sand due to cavitation due to gravity and bulking. It was solved in rectangular horizontal permeability set up as shown in Figure 4.3.

Figure 4.2: Cylindrical apparatus for horizontal permeability in laboratory

Figure 4.3: Rectangular apparatus for horizontal permeability in laboratory

In the testing apparatus, the sand was filled to a height of 7 cm and the length of sand column (in this case beam) is 22 cm i.e. shortest path for water to zero head. Standing pipes was made shorter than or equal to the box height to avoid initial head getting more than the height of sand column to avoid quick condition.

Using same formula as above with different numbers. $k_h = \frac{Q \times L}{h \times A \times t}$

where, L = length of soil column, 22 cm

h = head loss, 11 cm - 4 cm = 7 cm

A = Area of cross section, $l \times b = 12 \times 7 = 84\ cm^2$

t = Time of experiment, 15 minutes

Results are tabulated in Table 4.2.

Table 4.2: Observations of horizontal permeability test

Quantity	Test-1	Test-2	Test-3
Weight of empty bucket (kg)	0.370	0.370	0.370
Total weight of bucket + Weight of water (kg)	6.375	5.895	5.530
Weight of discharge water (kg)	6.005	5.525	5.16
Volume of discharge water ($10^{-3} \times m^3$), Q	6.005	5.525	5.16
k_h (cm/sec)	0.516	0.475	0.468

4.3 Inferences

From above results, it is clear that cost effective permeability testing procedures can be accurate. As it can be seen from particle size distribution of soil sample in Figure 4.4 that it is fine sand and the values given in Table 1.1 and values found in Table 4.1 and 4.2 validate each other.

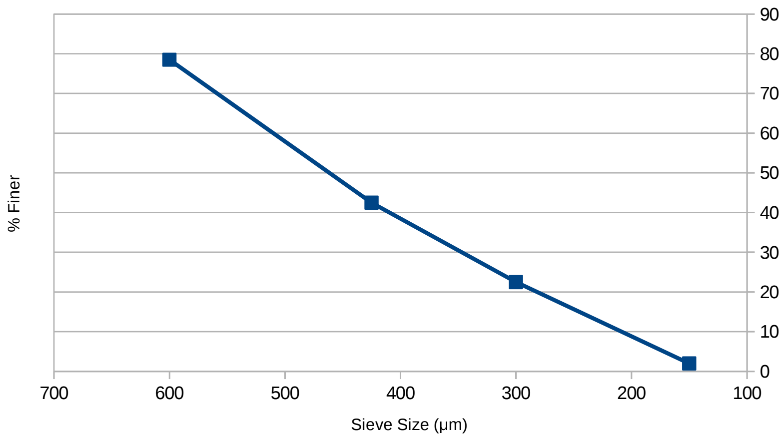

Figure 4.4: Particle size distribution of soil sample

Table 4.3: Observation of permeability test in laboratory

Quantity	Test-1	Test-2	Test-3
k_v (cm/sec)	4.113×10^{-2}	2.105×10^{-3}	1.201×10^{-3}
k_h (cm/sec)	0.325	0.455	0.547

Table 4.3 shows the laboratory permeability measured by constant head permeability for validation of apparatus presented in this report. Both horizontal and vertical permeability comes in the $\pm 15\%$ of values measured by our device. This uncertainty shows that a lot of work could be done on the apparatus in terms of leakage and soil compaction.

Chapter 5

Conclusion and Scope for Future works

5.1 Conclusions

- Both low cost permeability apparatus works fine with given arrangements and require very little skill to work on.
- A single apparatus costs around Rs 500/-. Whereas the standard permeability testing setup has a market price of about Rs 10,000/-.
- Constant head as well as Falling head testing can be performed with adding an extra standing pipe on both the apparatus.
- Although the apparatus was tested only on sand but it works fine on laterite soil (silty sand).
- Maintaining a head lower than the height of the container and height of the sand column in horizontal permeability testing works fine.
- Almost zero leakage is achieved in both apparatus testing by sealing and taping. All the tinkering is done with the help of waste materials and it worked fine in cost optimization.

5.2 Scope for Future works

- Apparatus can be automated with the help of weight sensors, which can be used with a collection bucket to weigh the water in real time and raspberry computers, which are programmable to take any required task. Computer program which can calculate permeability according to Darcy's law can be employed to record and plot permeability of soil from unsaturated to saturated state.
- Further validation of this testing method can be done from a model for calculating seepage under concrete dam. This can verify both k_h and k_v.
- Apparatus can be redesigned for permeability for testing over clay as a little leakage in case of clay is unacceptable.
- Spilling of water in constant head testing can be avoided by providing constant head through another plastic container by siphon action.

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