Determination of Permeability of Stratified Soil - An Experimental Investigation

A dissertation submitted in partial fulfilment of the requirement for the award of degree of

Master of Technology
in
Geotechnical Engineering

By

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Candidate's Declaration

I do hereby certify that the work presented is the report entitled **"Effect of Stratified Soil System on the Permeability of Soils - An Experimental Investigation"** in partial fulfilment of the requirements for the award of the degree of "Master Of Technology in Geotechnical Engineering" submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work under the supervision of Dr. A. Trivedi, Professor, Department of Civil Engineering and Dean (IRD), DTU.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

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Certificate

This is to certify that the project entitled, **"Effect of Stratified Soil System on the Permeability of Soils - An Experimental Investigation"** was a bonafide record of works carried out by **Ashutosh Kumar** (Roll No. 2K15/GTE/05) under my guidance as a part of the partial fulfilment of the requirements for award of the degree of **Master of Technology in Geotechnical Engineering** to Delhi Technological University, Delhi.

This work reported here has not been submitted anywhere for the award of any other degree to the best of my knowledge.

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ABSTRACT

The coefficient of permeability of stratified soil deposits, when the flow is normal to the orientation of the bedding planes, has been observed to deviate from the value calculated theoretically. The coefficient of permeability is calculated by Darcy's law. The present technical study deals with the results from the study of permeability behaviour of two layer soil system and three-layer soil system. For two layer soil system the coefficient of permeability of exit layer is considering as controlling factor for three layer soil system the coefficient of permeability depends upon the relative positioning of soil. This study reinforces the point that the coefficient of permeability of a layered soil system, when the flow is normal to the orientation of the bedding planes, depends upon the relative positioning of the layers with different values of coefficient of permeability in the system.

CHAPTER 1

INTRODUCTION

1.1 General

The coefficient of permeability of stratified soil deposits, when the flow is normal to the orientation of the bedding planes, has been observed to deviate from the value calculated theoretically. The coefficient of permeability is calculated by Darcy's law. The present technical study deals with the results from the study of permeability behaviour of two-layer soil system and three-layer soil system. For two-layer soil system the coefficient of permeability of exit layer is considering as controlling factor for three-layer soil system the coefficient of permeability depends upon the relative positioning of soil. This study reinforces the point that the coefficient of permeability of a layered soil system, when the flow is normal to the orientation of the bedding planes, depends upon the relative positioning of the layers with different values of coefficient of permeability in the system.

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 in filtration-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 Darcy's law to be valid. If L1, L2, ..., Ln represent the thicknesses of individual layers and k1, k2, ..., kn are the corresponding coefficients of permeability, then the equivalent coefficients of permeability normal to the bedding plane, (keq)n and parallel to the bedding plane, (keq)p are obtained by(Keq)n

$$(K_{eq})_n = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} (L_i/K_i)}$$

$$(K_{eq})_p = \frac{\sum_{i=1}^{n} L_i K_i}{\sum_{i=1}^{n} L_i}$$

The permeability characteristics of homogeneous soil deposits are known to be functions of void ratio and the soil type. The permeability characteristics of stratified deposits (i.e., layered systems), predominantly when the flow is normal to the bedding plane, can further be complicated by the possible mutual interaction among the soils of different layers and their relative position in the deposit. Hence, in the present experimental investigation, it is proposed to study the permeability characteristics of stratified deposits when the flow is normalto the bedding planes, the factors affecting them, and the possible mechanisms controlling such flows. For the sake of simplicity, the simple cases of a two layered and three layered systems are considered.

1.2. Why permeability of soil is important to determine ?

Soil permeability is the property of soil to allow water and air to percolate in the soil and is one of the most important qualities. A pond built in impermeable soil will lose little water through seepage.

The more permeable soil has the greater seepage. Some soil is so permeable and seepage so great that it is not possible to build a pond without any special construction techniques.

Soil are generally made up of layers and soil quality often varies greatly from layer to another layer.

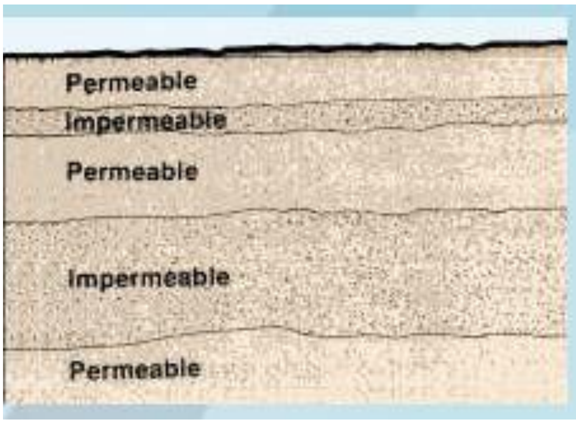

Fig. 1.1 Soil layered

1.2 Permeability variation according to soil texture

The size of the soil pores is of great importance with regards to the rate of infiltration (movement of water into the soil) and to the rate of percolation (movement of water through the soil). Pore size and number of pore closely relates to soil texture and structure and also influence soil permeability

Usually the finer soil texture, the slower the permeability as shown in Fig. 1.1.

Table 1.1. Permeability variation according to texture

Soil	Texture	Permeability
Clayey soil	Fine	
Loamy soil	Moderately fine and coarse	From very slow to very rapid
Sandy soil	Coarse	

1.4 Classes soil permeability

Permeability is measured in terms of the rate of water flow through the soil in a given period of time. it is usually expressed either as a permeability rate in centimetres per hour or as a coefficient of permeability k in metres per second.

Generally, soil permeability classes are based on permeability rates and for civil engineering, soil permeability are based on coefficient of permeability as shown in fig.

Table 1.2 Soil permeability classes

Soil permeability classes	Coefficient of permeability (K in m/s)	
	Lower limit	Upper limit
Permeable	2×10^{-7}	2×10^{-1}
Semi-permeable	1×10^{-11}	1×10^{-5}
Impermeable	1×10^{-11}	5×10^{-7}

1.5. Objectives

- To determine equivalent coefficient of permeability of two-layered soil system
- To determine equivalent coefficient of permeability of three layerd soil system
- Comparison of experimental values of permeability to theoretical values of permeability calculated from Darcy's law.

CHAPTER 2

LITERATURE REVIEW

The subject of flow of water through porous soil media is important in soil mechanics,

1. Involving the amount of water flows through soil (i.e. determination of leakage through an earth dam)
2. Involving rate of settlement of a foundation
3. Involving strength (i.e. the evaluation of factor of safety of an embankment)

The water does not flow from one point to another point in a straight line at constant velocity but rather in a winding path from pore to pore As per Bernoulli's equation the total head at a point in water under motion can be given by the sum of pressure head, velocity head, and elevation head

$$H = \frac{P_W}{\gamma} + \frac{v^2}{2g} + Z$$

Pw/γ represents the pressure head of the fluid and has unit of length, v2/2g represents the kinetic or velocity head of fluid and also have unit of length since water is flowing in typically has very small velocities the kinetic head or velocity head is typically negligible compared to that of the pressure and elevation heads for this reason the velocity head is neglected in soil mechanics. Z represents the elevation head with respect to an arbitrary datum the value is the distance of the point at which head is being measured above the datum this can be either positive if the point is above the datum or negative if the point is below the datum therefore

$$H = \frac{P}{\gamma w} + Z$$

$i = (h_1 - h_2) / L$

Where i is the hydraulic gradient, L is the length of flow beyond which the loss of head take place.

Darcy's law:

Equation for the discharge velocity of flow through saturated soils which may be expressed as

$$V = Ki$$

Where,

K= Coefficient of permeability (cm/s)

V= Discharge velocity or superficial velocity (cm/s)

Assumptions:

1. Soil is fully saturated.

2. Frictionless boundaries.

3. Flow in laminar (i.e. Reynolds number <1).

$$Re = \frac{\rho \, v \, D10}{\mu s}$$

v = discharge velocity

D_{10} = effective particle size

μs = dynamic velocity of water

When water flows through the soil media it exerts drag forces called seepage forces on individual grains of the soil the presence of seepage forces which causes changes in the direction of flow, will cause changes in the pore water pressure and effective stresses in the soil.

The value of coefficient of permeability K depends on:

1. Average size of pores and is related to the particle sizes and their packing

2. Particle shape

3. Soil structure

Factors affecting permeability:

Kozeny Carman equation:

$$v = \frac{1}{CsT^2}\left(\frac{\gamma w}{\mu}\right)\left(\frac{e^3}{1+e}\right)i$$

Equations reflecting the influence of permeant and the soil characteristics on k by Taylor (1948) using polssenlles law:

$$v = c(de^2)\left(\frac{\gamma w}{\mu}\right)\left(\frac{e^2}{1+e}\right)t$$

Both the equations assume interconnected voids are visualized as a number of capillary tubes through which water can flow.

V= discharge velocity

Cs= shape factor for granular soils = 2.5

Ss = surface area

T = Tortuosity factor = 1.414 (for granular soil)

K = intrinsic permeability or absolute permeability

$$k = \frac{1}{CsSsT^2}\left(\frac{e^3}{1+e}\right)$$

Units of k: Darcy's or cm2

1 Darcy = 0.987×10-5 cm2

List of factors affecting permeability:

- Void Ratio
- Degree of saturation
- Composition of soil particles
- Soil Structure
- Viscosity of the permeant
- Density and concentration of the permeant
- Shape and size of soil particles
- Effect of Grain size:

$$k = C(d_{10})^2$$

C is a constant which includes effect of shape of the pore channels in direction of flow.
The permeability of granular soil depends mainly on the cross-sectional area of the pore channels, since the average diameter of the pores in a soil at a given porosity increases in proportion to the average grain size, the permeability of the granular soil might be expected to increase as the square of some characteristics grain size.
Effect of degree of saturation:

$$k \propto S\gamma$$

At low saturation, there will be reduction in flow channels available for flow.

Effect of soil structure:

The permeability of soil deposits is significantly affected by its place structure

A loose granular soil with flocculent structure will have higher permeability than soil with dispersed structure.
Even at similar void ratios a clay with an undisturbed flocculated structure will possess larger void openings than the same clay having a dispersed structure.
Compactive effort: With increase in compactive effort permeability decreases.

Effect of soil type:

The volume of water that can flow through a soil mass is related more to the size of the void openings than to the number or total number of voids. Even though void ratios are frequently greater than for fine grained soil.

For fine grained soils when void spaces are very small all lines of flow are physically close to the wall of conduit and therefore only low velocity flow occurs

In clays flow in already small channels is further hampered because some of water in the voids is held or adsorbed to the clay particles reducing the flow area and further restricting flow

Hence $K_{clay} <<< K_{sand}$

Effect of specific surface area:

$$K \propto \frac{1}{S}$$

Table 2.1: Classification of soils according to their coefficient of permeability

Degree of permeability	K (m/s)
High	$>10^{-3}$
Medium	10^{-3} to 10^{-5}
Low	10^{-5} to 10^{-7}
Very low	10^{-7} to 10^{-9}

Nikraz et al. (2011)

A series of laboratory permeability tests carried out to evaluate fiber effect on hydraulic conductivity behaviour of composite sand. Clayey sand was selected as soil part of the composite and natural fiber was used as reinforcement.

Galvaeo et al. (2004)

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.

Sridharan and Prakash (2013)

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

Haug et al. (1990)

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.

Uppot et al. (1989)

Two clays are subjected to organic and inorganic permeants to study the changes in permeability caused by the reaction between clays and permeants.

CHAPTER 3

METHODOLOGY

3.1 Experimental Set Up

1. Acrylic sheet

Acrylic is made up of lightweight, rigid thermoplastic material that has many times the breakage resistance of standard window pane glass. It is highly resistant to weather conditions. It is suitable for most utilitarian applications and is ultraviolet light absorbing up to approximately 360 nanometres Acrylic is more impact-resistant than glass. If subjected to impact beyond the limit of its resistance, it does not shatter into small slivers but breaks into comparatively large pieces.

Acrylic offers better weather resistance than other types of transparent plastics. Acrylic will withstand exposure to blazing sun, extreme cold, sudden temperature changes, salt water spray and other harsh conditions. It will not deteriorate after many years of service because of the inherent stability of acrylic.

Acrylic Sheets used to make Acrylic are less than half the weight of glass, and 43% the weight of aluminum. One square foot of 1/8" (3.0 mm) thick Acrylic sheet weighs less than ¾ pound (1/3 kilogram). Acrylic Sheets used are not as rigid as glass or metals. However, it is more rigid than many other plastics such as acetates, polycarbonates or vinyl's.

Although the tensile strength of Acrylic sheets used is (69 MPa) at room temperature (ASTM D638), stress crazing can be caused by continuous loads below this value. For most applications, continuously imposed design loads should not exceed (10.4 MPa). Localized, concentrated stresses must be avoided. All thermoplastic materials-including acrylic will gradually lose tensile strength as the temperature approaches the maximum recommended for continuous service. For acrylic, the maximum is 180°F (82°C).

Acrylic has excellent resistance to many chemicals including:

- Solutions of inorganic alkalis such as ammonia
- dilute acids such as sulphuric acid up to a concentration of 30%
- Aliphatic hydrocarbons such as hexane
- Acrylic is not attacked by most foods, and foods are not affected by it.

It is attacked, in varying degrees, by:

- Aromatic solvents such as benzene and toluene
- Chlorinated hydrocarbons such as methylene chloride and carbon tetrachloride
- Ethyl and methyl alcohols
- Some organic acids such as acetic acid

Fig.3.1 An Acrylic sheet

2. **Acrylic pipe**

   A pipe of dimension 130mm and 120mm of length 45cm each are used thickness of pipe are 3mm each. A perforated circular disc of thickness 8mm are used to support the soil.

Fig. 3.2. Acrylics pipe

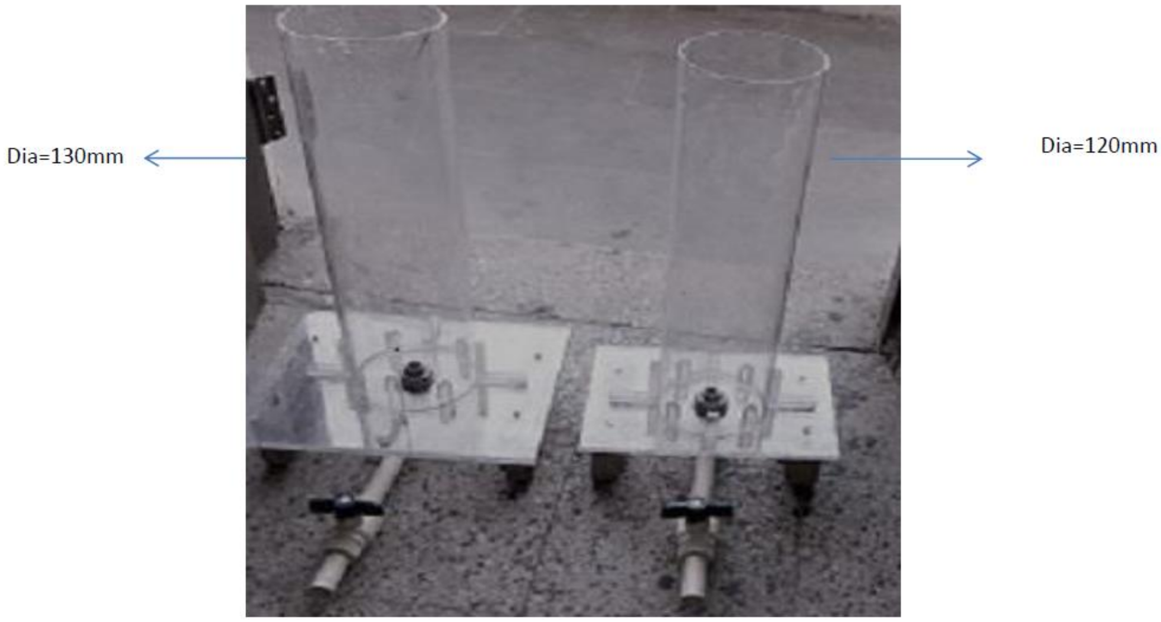

Fig . 3.3 Permeabilitymeter of Diameter, D =130 mm and D= 120 mm

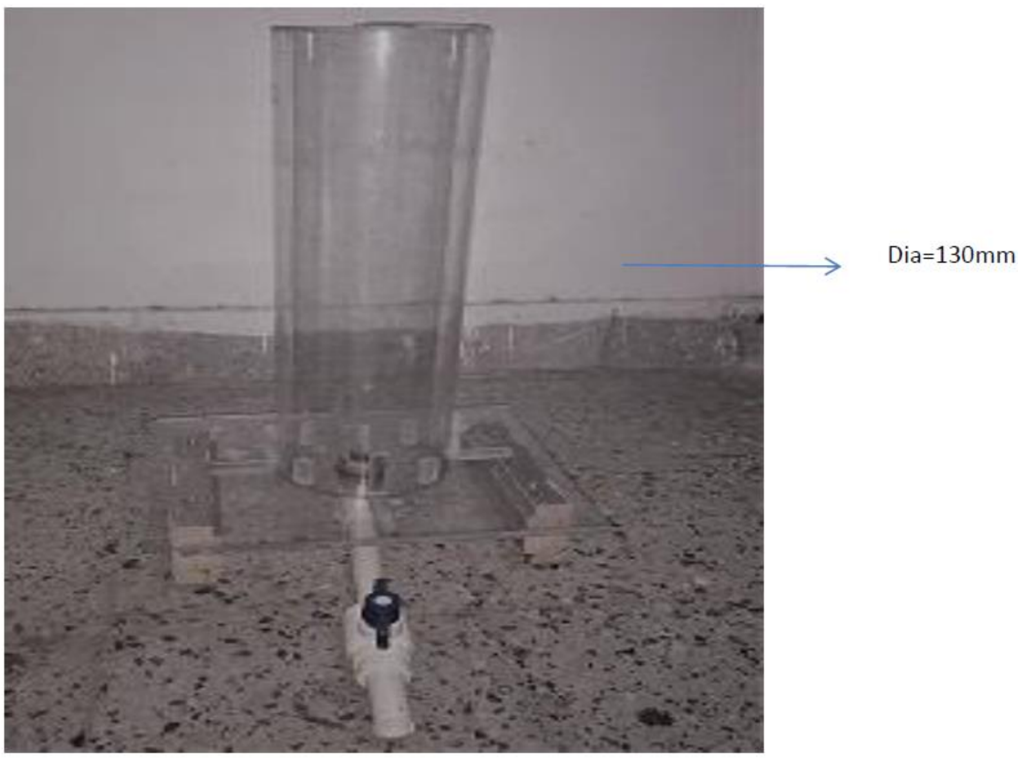

Fig. 3.4 Permeabilitymeter of Diameter, D =130 mm

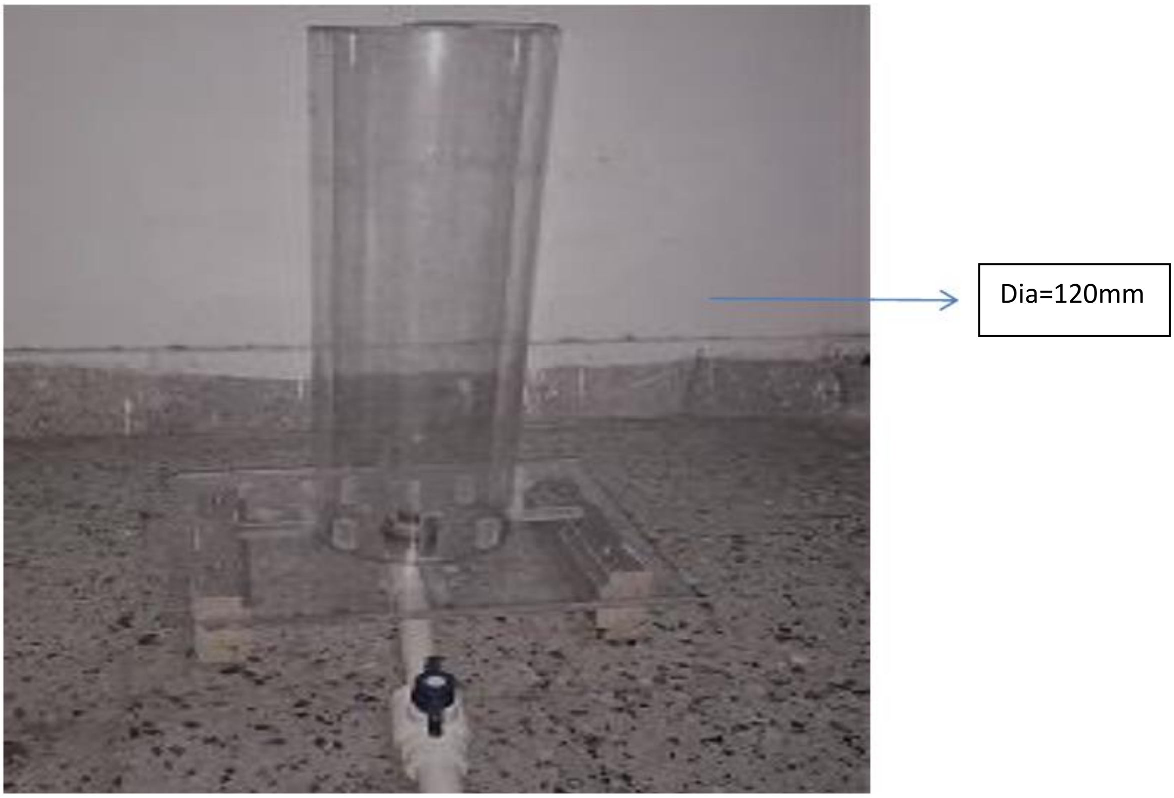

Fig. 3.5 Permeabilitymeter D = 120mm

3.2 Sieve analysis

Sieving is conducted by arranging the various sieves over one another in order of their mesh openings biggest aperture at the top and smallest at the bottom. A holder is kept at the bottom and a cover is put at the top of the whole setup. The soil is put through the top sieve and adequate amount of shaking is done to let the soil particles pass through the various sieves. 4.25mm, 2mm, 1mm, 425 micron, 150 micron and 75 micron IS sieves were used to perform the sieving. The results of sieve analysis are plotted on a graph of percentage passing versus the sieve size. On the graph the sieve size scale is logarithmic. To find the percentage of cumulative passing through each sieve, the percentage retained on each sieve is found.After this the cumulative percentage of aggregate retained in a sieve is found. To do so, the total amount of aggregate that is retained on each sieve and the amount in the previous sieve are added up. The cumulative percentage passing of the aggregate is found by subtracting the percentage retained from 100%.The values are then plotted on a graph with cumulative percentage passing on the y axis and logarithmic sieve size on the x axis.

3.3 Dry density

The bulk density of soil is also known as dry bulk density of soil, is the weight of dry soil divided by the total volume of soil. The volume of soil is the combined volume of solid and pores which may contain air or water or both. The average value of air, water and solid in soil are easily measured and are a useful indication of a soil physical condition.

Bulk density of soil and porosity reflects the size shape and arrangement of particles and voids.

3.4 Standard proctor test

The empty mould was weighted the mould was fixed to the base plate at attach collar to the mould a thin layer of grease applied to the inside surface of mould and collar around 2.4 kg soil passing through 4.75mm size sieve was taken and water added to bring its moisture content about 14% in case of clayey soil for uniformity this quantity of water is sprinkled on the soil and the soil is mixed thoroughly. The weight of soil divided into three equal parts one part of mould was filled with soil and compacted to 25 evenly distributed blows with the standard rammer this process was repeated for second and third part of soil taking precaution to scratch the top of the previously compacted layer with a spatula in order to avoid stratification the collar was removed by rotating it and trim the top of the soil to flash with the top of the mould detach the mould from the base plate the weight of compacted soil taken with the mould extract the soil from the mould and take some wet soil from the core of compacted soil and determine the moisture content. This procedure is repeated by taking fresh soil sample and adding water to make the water content 2 to 4 % more than the previous water content**.**

3.5 Specific gravity test

Specific gravity is defined as the ratio of the weight in air of a given volume of the material at a specified temperature to the weight in air of an equal volume of distilled water at a specified temperature. The purpose of the test is to define the specific gravity of soil passing the 4.75 mm sieve by density bottle method. 50g of sample of soil is taken in each 3 bottles and added to distilled water; the weight of the water + bottle is taken. Then all the 3 bottle are subjected to sand bath, heating is done up to air bubbles are seen in the bottle. This is done to remove the entrapped air in the mixture; the bottle is kept for around 1 hour so that the temperature comes to 27oC.

Fig.3.6 DTU soil specimen

Fig 3.7 Badarpur sand specimen

Fig 3.8 Yamuna sand specimen

Fig 3.9 Grinding of soil specimen

Fig 3.10. 50 ml measuring jar

CHAPTER-4

TEST RESULTS

a) Sieve Analysis

Table 4.1 Sieve analysis (as per IS:2720 (Part.4) 1985 Grain size analysis)

Sl.no.	Sieve size(mm)	Wt. Retained(g)	% Retained	% Finer
1	4.75	68.84	6.88	93.11
2	2.36	128.81	12.88	80.23
3	1.18	205.66	20.56	59.66
4	0.600	142.72	14.27	45.39
5	0.425	138.7	13.87	31.52
6	0.150	281.27	28.12	3.4
7	0.075	28.62	2.86	.53
8	PAN	5.38	0.53	0

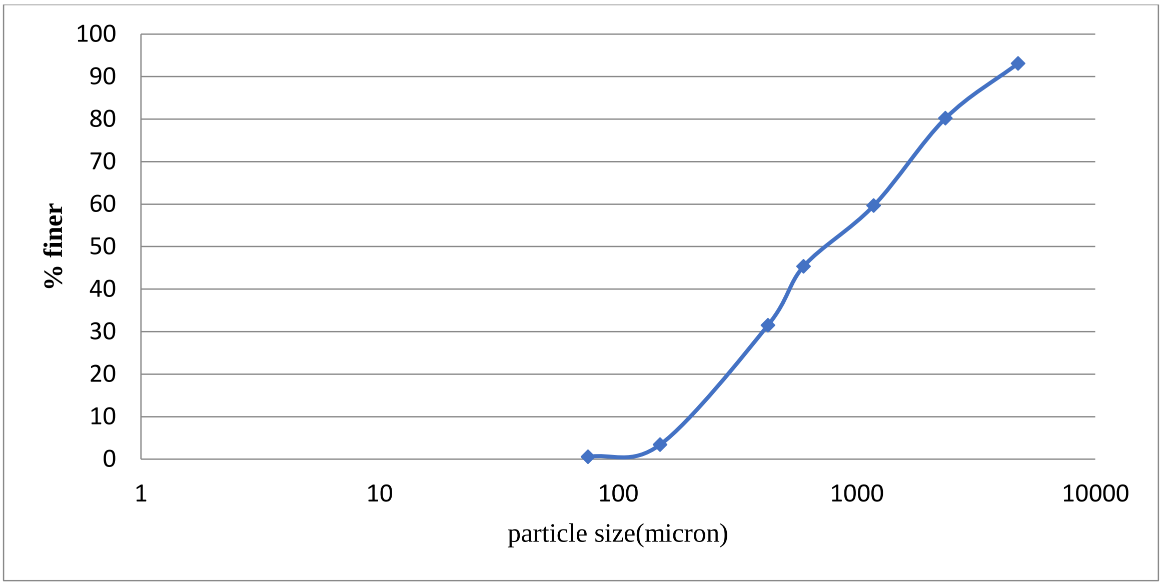

Fig 4.1 Particle size distribution curve

D_{10}= 0.12 mm, D_{30}= 0.33 mm, D_{60}=1.3mm, C_C =0.698, C_u= 1.83.

Hence the soil used is classified as poorly graded sand (SP).

b) Dry Density

In order to obtain optimum moisture content Standard proctor test is performed as per IS: 2720 (Part. VII) 1980. Determination of water content - dry density relation using light compaction.

Table 4.2 Observation table for standard proctor test (as per IS: 2720 (Part. VII) 1980

S.No	Mass of soil + mould(Kg)	Mass of soil (kg)	Bulk density (kN/m^3)	Water content(%)	Dry density(kN/ m^3)
1	5.70	1.50	15.87	7.3	14.79
2	5.75	1.55	16.40	9.0	15.04
3	5.80	1.60	16.93	11.0	15.25
4	5.85	1.65	17.51	15.0	15.23
5	5.79	1.59	16.82	17.0	14.38

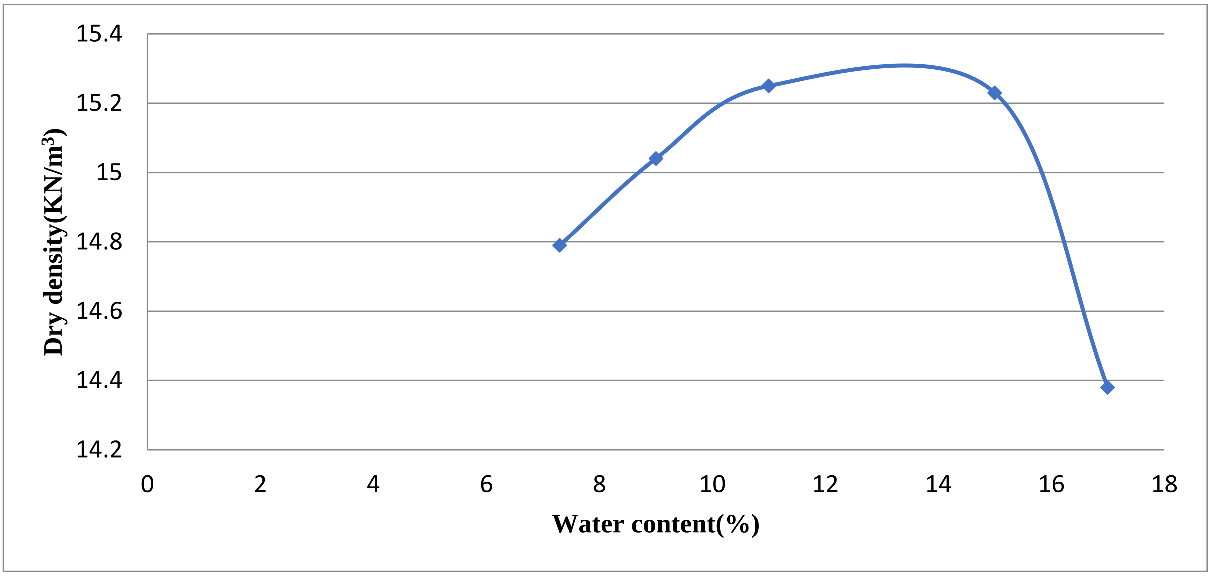

Fig4.2 Dry density vs water content curve

Weight of empty mould = 4.2kg
Vol. of standard proctor mould = 945 x $10^{-3}m^3$
Max. dry density(from fig 3.7) =15.058KN/m^3
Optimum moisture content (from fig3.7) =13.5%

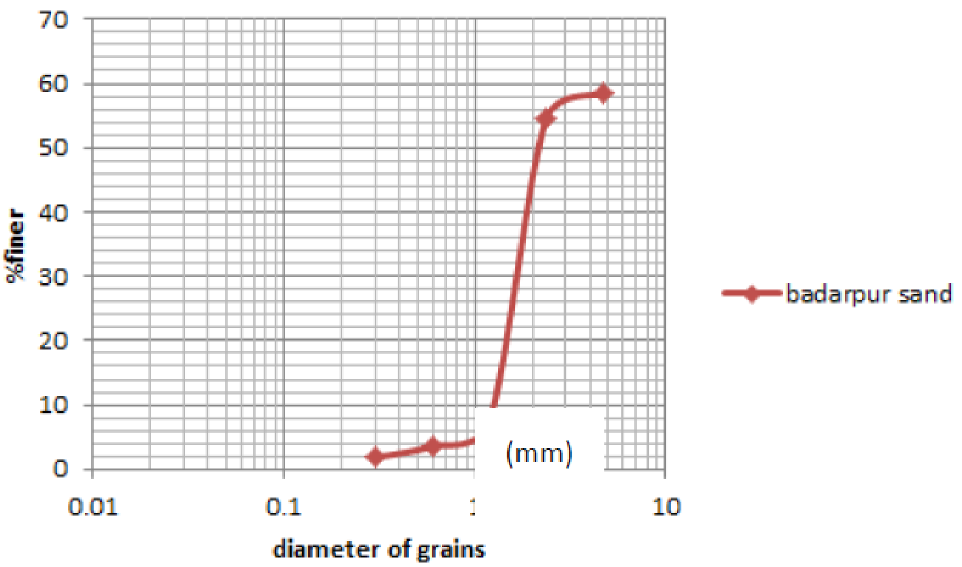

Fig 4.3 Grain size distribution curve of Badarpur sand

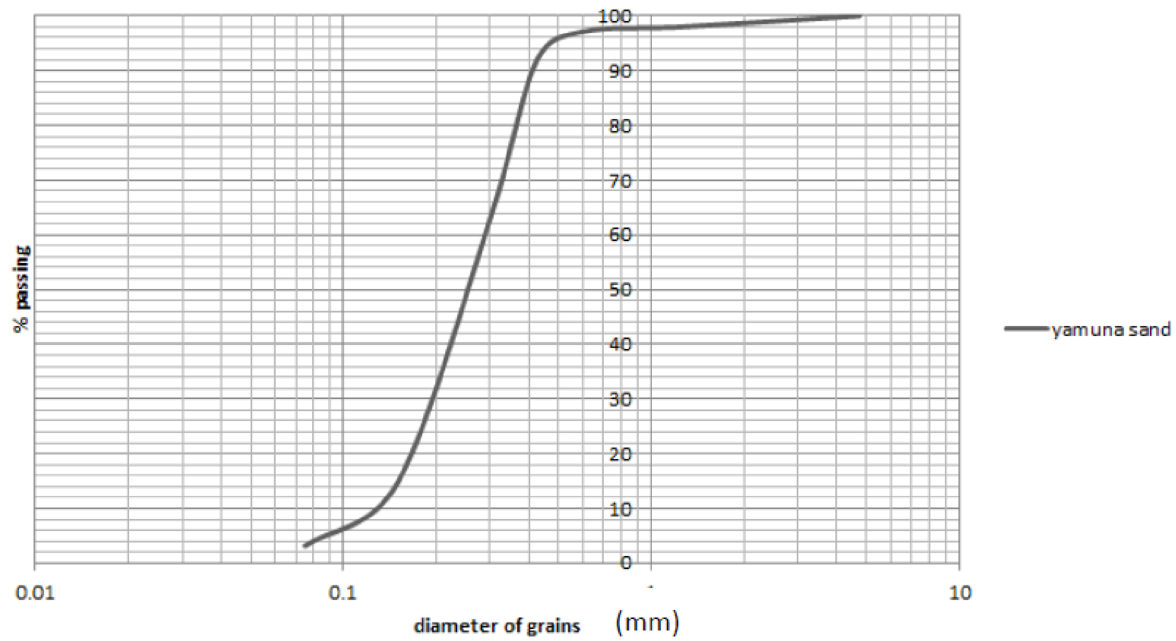

Fig 4.4 sieve analysis of Yamuna sand

a) **Determination of permeability of Badarpur sand.**

Fig.4.5 Experimental setup for determination of permeability of Badarpur sand

Length of soil sample (L) =10cm. Diameter of soil sample (D) =12cm
Head difference (H) =87cm. Area of soil sample (A) =113.04 cm2

Table 4.3 volume of water collected v/s time for Badarpur sand.

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	7
2	50	8
3	50	7
4	50	7
5	50	8
6	Average volume=50	Average time=7.40

Discharge (q) $= volume/time$ =507.4=6.756 cm3/sec.
Permeability of Badarpur sand=k=qL/AH=6.869×10-3 cm/sec.

b) Determination of permeability of Yamuna sand.

Fig 4.6 determination of permeability of Yamuna sand.

Length of soil sample (L) =10cm, Diameter of soil sample (D) =12cm
Head difference (H) =87cm, Area of soil sample (A) =113.04 cm2.

Table 4.4 Volume of water collected v/s time for Yamuna sand

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	16
2	50	17
3	50	17
4	50	18
5	50	17
6	Average volume=50	Average time=17

Discharge (q) $=volume/time$ =5017=2.941 cm3/sec.

Permeability of Yamuna sand=k=qL/AH=2.991×10-3 cm/sec.

c) Determination of permeability of DTU soil.

Fig. 4.7 Determination of permeability of DTU soil.

Length of soil sample (L) = 10cm, Diameter of soil sample (D) =12cm
Head difference (H) = 60.cm, Area of soil sample (A) =113.04 cm^2

Table 4.5. Volume of water collected v/s time for DTU soil.

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	11
2	50	10
3	50	11
4	50	10
5	50	10
6	Average volume=50	Average time=10.40

Discharge (q) $=volume/time$ =5010.4=4.807 cm3/sec.

Permeability of DTU soil=k=qL/AH=7.087×10-3 cm/sec.

d) Determination of permeability of stratified soil.

Fig 4.8. Experimental setup for determination of permeability of stratified soil

Length of soil sample (L) =30cm.

Diameter of soil sample (D) =12cm

Head difference (H) =170cm.

Area of soil sample (A) =113.04 cm^2

Table 4.6 Volume of water collected v/s time for stratified soil.

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	145
2	50	144
3	50	144
4	50	145
5	50	145
6	Average volume=50	Average time=144.6

Discharge (q) $=volume/time$ = 50144.6 = 0.345 cm3/sec.

Permeability of stratified soil=k=qL/AH = 5.385×10-4 cm/sec.

Table 4.7. Overall result for diameter of permeameter, D=12cm

S.N	Type of soil	Permeability(k)(sec)
1	Yamuna sand	2.991×10^{-3}
2	Badarpur sand	6.869×10^{-3}
3	DTU soil	7.087×10^{-3}
4	Stratified soil	5.385×10^{-4}

Effects of diameter of Permeameter on permeability of different soil:

1) Determination of permeability of Yamuna sand (D=13cm)

Length of soil sample (L) =10cm. Diameter of soil sample (D) =13cm

Head difference (H) =87cm. Area of soil sample (A) =132.665 cm^2.

Table 4.8 Volume of water collected v/s time for Yamuna sand.

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	14
2	50	13
3	50	13
4	50	14
5	50	13
6	Average volume=50	Average time=13.4

Discharge (q) =$volume/time$ = 5013.4 = 3.731 cm3/sec.

Permeability of Yamuna sand =k = qL/AH = 3.232×10-3 cm/sec.

2) Determination of permeability of Badarpur sand. (D=13cm)

Length of soil sample (L) =10cm. Diameter of soil sample (D) =13cm

Head difference (H) =87cm. Area of soil sample (A) =132.7cm^2.

Table 4.9 Volume of water collected v/s time for Badarpur sand.

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	6
2	50	5
3	50	5
4	50	6
5	50	6
6	Average volume=50	Average time=5.6

Discharge (q) = $volume/time$ = 505.6 = 8.928 cm3/sec.

Permeability of Badarpur sand=k = qL/AH = 7.735×10-3 cm/sec

3) Determination of permeability of DTU soil. (D=13cm)

Length of soil sample (L) =10cm. Diameter of soil sample (D) =13cm

Head difference (H) =87cm. Area of soil sample (A) =132.7 cm^2.

Table 4.10 Volume of water collected v/s time for DTU soil

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	7
2	50	8
3	50	7
4	50	9
5	50	8
6	Average volume=50	Average time=7.8

Discharge (q) =$volume/time$ =507.8=6.410 cm3/sec.

Permeability of DTU soil=k=qL/AH=5.553×10-3 cm/sec.

4) Determination of permeability of stratified soil.(D=13cm)

Length of soil sample (L) = 30cm. Diameter of soil sample (D) =13cm

Head difference (H) =170cm. Area of soil sample (A) =132.665cm2

Table 4.11 Volume of water collected v/s time for stratified soil system

S.N	Volume of water collected.(cm^3)	Time (sec)
1	50	135
2	50	136
3	50	136
4	50	137
5	50	136
6	Average volume=50	Average time=136

Discharge (q) =$volume/time$ =50136=0.367cm3/sec.

Permeability of stratified soil=k=qL/AH=4.881×10-4 cm/sec.

Table 4.12. Overall result for diameter of permeameter D=13cm

S.N	Type of soil	Permeability(k)(sec)
1	Yamuna sand	3.232×10^{-3}
2	Badarpur sand	7.735×10^{-3}
3	DTU soil	5.553×10^{-3}
4	stratified soil	4.881×10^{-4}

CHAPTER-5

CONCLUSION

A experimental study was done for two layered and three layered soil system at laboratory scale having different types of soil and sand, type of layer, varying proportion and position for soil, Yamuna sand and Badarpur sand. It is found that the coefficient of permeability differs from the value calculated from Darcy's law. The permeability of the exit layer controls whether the measured permeability is greater or lesser than the theoretical values for stratified soil deposits. The coefficient of permeability of 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 soil systems. And hence, the coefficient of permeability of a soil in a layered system has to be considered as dependent upon flow direction, relative position and thickness of layered soils. The present study is an experimental investigation and it shows the need for a need for further studies to obtain mathematical equations for permeability of soil in stratified soil systems.

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