Infiltration, Permeability, Liquid Limit and Plastic Limit of Soil

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Abstract

Precipitation falling on the soil wets down and it starts penetrating into the soil. Water stores to the formal level the soil moisture deficiency excess moving down by the gravity force through percolation or seepage to build up the water table. The water is driven into the porous soil by force of gravity. First the water wets soil grain sand then the extra water moves down due to gravitational force. The rate at which a soil absorbing the water in a given time is called infiltration rate and it depends on soil characteristics such as hydraulic conductivity, soil structure, vegetation cover. The infiltration plays an important role in generation of runoff volume, if infiltration rate of given soil is less than intensity of rainfall then it results in either accumulation of water on soil surface or in runoff. The different soil conditions affect the soil infiltration rate. Compacted soils due to movement of agricultural machines have a low infiltration rate which is prone to runoff generation. Infiltration will be maximum at the beginning and it decays exponentially and gets a constant value. There will be a decrease in infiltration rate day by day due to the saturation of the soil where as on the first day the infiltration rate will be more because soil will be dry in condition. Infiltration of water into the soil has important impact in the overall functioning of the variable land based activities. Two factors can greatly undermine availability of water for crops which is impervious layer and ground water table. The former might be due to excess infiltration which mostly a function of soil characteristic get through the later may be largely due to the deposit of clay that can create crust below the surface. The study of infiltration comes in many hydrological problems like runoff estimation, soil moisture budgeting and for planning of irrigation. Infiltration has an important place in the hydrological cycle.
Keywords: Properties of Soil, Permeability flow of soils

I. INTRODUCTION

A. *General*

Permeability is one of the important physical properties of soil as some of the major problems of soil mechanics are directly connected with it. Design of highways, airports, earth dams, construction of foundation below water – table, yield from a well, settlement of foundation etc. depend upon the permeability of soil. Hence to become a good soil engineer the knowledge of permeability is very essential. A material is said to be permeable if it contains continuous voids. Since such voids are contained in all soils including the stiffest clay, all these are permeable. Gravels are highly permeable and stiff clay is the least permeable soil. The ability of various soils and rocks to allow water to move through them depends on several factors. That property is called permeability. Depending upon how porous a particular soil or rock is, it may act as a water-transporting layer called an aquifer. In this investigation, you will investigate the permeability of earth materials.

In the early 1990s, a Swedish scientist named Atterberg developed a method to describe the consistency of fine-grained soils with varying moisture contents. Atterberg limits are defined as the water corresponding to different behaviour conditions of fine-grained soil (silts and clays). The four states of consistency in Atterberg limits are liquid, plastic, semisolid and solid. The dividing line between liquid and plastic states is the liquid limit; the dividing line between plastic and semisolid states is the shrinkage limit. If a soil in the liquid state is gradually dried out, it wills past through the liquid limit, plastic state, plastic limit, semisolid state and shrinkage limit and reach the solid stage. The liquid, plastic and shrinkage limits are therefore quantified in terms of the water content at which a soil changes from the liquid to the plastic state. The difference between the liquid limit and plastic limit is the plasticity index. Because the liquid limit and plastic limit are the two most commonly used Atterberg limits, the following discussion is limited to the test procedures and calculation for these two laboratory tests.The liquid limit is that moisture content at which a soil changes from the liquid state to the plastic state. It along with the plastic limit provides a means of soil classification as well as being useful in determining other soil properties. As explained, plastic limit is the dividing line between the plastic and semisolid states. From a physical standpoint, it is the water content at which the soil will begin to crumble when rolled in small threads.

B. *Factors affecting Infiltration*

Factors affecting infiltration depends on both meteorological and many soil properties. These are

1) Texture
The liquid moves very quickly in large pores of sandy soil than it does through small pore in clayey soil. Texture plays main role in susceptible of soil only when the organic matter is low.
2) Clay Mineralogy
Some types of clay may develop cracks as they are dry. These kinds of cracks may rapidly conduct water to the sub-surface once and the seal shuts down once the soil becomes wet.
3) Vegetation
Soil covered with vegetation has grater infiltration than the barren land .Because of the bacterial activities, dense forest may have good infiltration rate than sparsely planted crops.
4) Physical Crusts
Physical crusts from when purely aggregated soil are subject to the impact of raindrops and/or to ponding. Particles broken from weak aggregates can clog pores and seal the surface, thus limiting water infiltration.
5) Soil Density
A compacted zone close to surface restricts the entry of water into the soil and often results in Surface ponding. Increased bulk density reduces pore space and thus the amount of water available for plant growth.
6) Biological crusts
Biological crusts can either increase or reduce the infiltration rate. This affects the infiltration rate on many other factors, including soil texture.
7) Antecedent Moisture content
Infiltration mainly depends on the presence moisture content in the soil. When compare to first day, the second day will have lesser infiltration rate because soil becomes saturated on the first day.
8) Human activities
When vegetation was done or a grass covering barren land has the high infiltration rate. Whereas the other side the construction work, over gazing of pastures and playgrounds reduce infiltration capacity of the area considerably.

C. Factors affecting permeability

1) Particle size
It was studied by Allen Hazen that the coefficient of permeability (k) of a soil is directly proportional to the square of the particle size (D). Thus permeability of coarse grained soil is very large as compared to that of fine grained soil. The permeability of coarse sand may be more than one million times as much that of clay.
2) Impurities in water
Any foreign matter in water has a tendency to plug the flow passage and reduce the effective voids and hence the permeability of soil.
3) Void ratio
The coefficient of permeability varies with the void ratio as $e^3/(1+e)$. For a given soil, the greater the void ratio, the higher the value of the coefficient of permeability. Here 'e' is the void ratio.Based on other concepts it has been established that the permeability of a soil varies as e^2 or $e^2/(1+e)$. Whatever may be the exact relationship, all soils have e versus log k plot as a straight line.
4) Degree of Saturation
If the soil is not fully saturated, it contains air pockets. The permeability is reduced due to the presence of air which causes a blockage to the passage of water. Consequently, the permeability of a partially saturated soil is considerably smaller than that of fully saturated soil. In fact, Darcy's Law is not strictly applicable to such soils.
5) Adsorbed Water
Fine grained soils have a layer of adsorbed water strongly attached to their surface. This adsorbed layer is not free to move under gravity. It causes an obstruction to the flow of water in the pores and hence reduces the permeability of soils.
6) Air and Organic matter
Air entrapped in the soil and organic matter block the passage of water through soil, hence permeability considerably decreases. In permeability tests, the sample of soil used should be fully saturated to avoid errors.

II. LITERATURE REVIEW

Hsin –Yu Shan; (1991)
Explained that 4 types of setup can be used in ring infiltrometer i.e. open single or double ringinfiltrometer and sealed single or double ring infiltrometer.
Srinivasan & S.Poongothai; (2007)
Experimented to determine the infiltration rate of soil samples for the particle size distribution in laboratory
Sebastien Fortin, Elrick & Reynolds ;(1992)
Measured the field saturated hydraulic conductivities i.e. often done by bore hole permeameters.
I.A.Johnson; (1963)
Studied that the infiltration rate have applications, such as liquid waste disposal, evaluation of potential septic tank disposal fields,

leaching &drainage efficiencies, irrigation requirement.
Scott Andres, Edward Walther, Muserref Turkmen ;(2010)
Done an experiment of mechanical valve system in a small building in the middle of the array of 8 infiltration basin.

A. *Types of Permeability flow of soils*

1) Saturated flow e.g. the flow of water below the permanent ground-water level, with voids full of water (100$ saturated)
2) Unsaturated flow or flow of water below a temporary elevated ground water level - i.e., a free water surface with different degrees of saturation and air clogging of soil voids.

Important examples of this are:

a) Flow of water through river banks or levees caused by rising g flood stages of a river
b) Flow of water through earth dams caused by risin g water level in a reservoir
c) The infiltration of rain water downward into the soil. In these cases permeability flow applies some distance back from the advancing front of capillary flow, where the soil is completely saturated with water.

1) *Liquid limit*

Atterberg (1911) proposed a method for measuring the liquid limit of soils based on the number of blows required to cause a groove in a clay bed to collapse when the soil container was struck on the hand. As slope stability is a strength-based phenomenon, it would seem rational to assume that soil at the liquid limit exhibits a fixed soil strength that could in principle be measured by more repeatable methods. The fall cone test now used in BS 1377
(BSI, 1990) is a measurement of soil strength, as shown via plasticity analysis by Houls by (1982).

2) *Plastic limit test*

The plastic limit, given by the rolling test, has a long history in geotechnics. In this paper it will be shown that while the test appears unscientific, the test is actually well designed to test the onset of brittleness in a way that is not the case with the alternatives proposed to date.The plastic limit or the lower limit of plasticity is found in the following way: take some of the previous clay paste (it is often advantageous to mix this with some clay powder), and roll into wires with the fingers on a pad of paper. The wires are put together and are rolled out again until they break into chunks. If the wires break into shorter pieces, this has no meaning, if the pieces, when combined, can be rolled out again.

Wintermeyer (1926) and Terzaghi (1926a) standardised tests for Atterberg's limits which evolved into the procedures now used in practice.

III. SOILS AND TYPES OF SOILS FOUND IN STUDY AREA

1) Black Cotton Soils
2) Red Soils
3) Laterite and Lateritic Soils
4) Alluvial soil
5) Forest and Mountain Soils
6) Arid and Desert Soils
7) Saline and Alkaline soils
8) Peaty and Marshy Soils

A. *Black Cotton Soil*

Black cotton soils are inorganic clays of medium to high compressibility and form a major soil group in India. They are characterized by high shrinkage and swelling properties. This Black cotton soils occurs mostly in the central and western parts and covers approximately 20% of the total area of India. Because of its high swelling and shrinkage characteristics, the Black cotton soils (BC soils) has been a challenge to the highway engineers. The Black cotton soils is very hard when dry, but loses its strength completely when in wet condition.
Materials for Soil Stabilization The materials for Black cotton soil (BC soil) stabilization shall comprise lime or Ordinary Portland Cement (OPC)43 grade, moorum of approved quality, sand and Cohesive Non swelling Soil (CNS) having properties given below:

1) The Black cotton soil (BC soil) having characteristics as given in Table 1.
2) OPC 43 grade as per IS: 8112- 1989.
3) Well graded granular moorum having minimum 4 day soaked CBR of 10% and maximum laboratory dry unit weight when tested as per IS:2720 (Part-8) shall not be less than 17.50 kN/m3.
4) The sand shall be as per IS: 383-1970.
5) The material for CNS soil should be good quality soil having laboratory dry unit weight when tested as per IS: 2720 (Part-8) not less than 16kN/m^3.

B. *Red Soil*

Red soil is a type of soil that develops in a warm, temperate, moist climate under deciduous or mixed forests and that have thin organic and organic-mineral layers overlying a yellowish-brown leached layer resting on an illuvial (see illuviation) red layer. Red soils generally derived from crystalline rock. They are usually poor growing soils, low in nutrients and humus and difficult to cultivate because of its low water holding capacity. Red soils denote the third largest soil group of India covering an area of about 3.5 lakhs sq. km (10.6% of India's area) over the Peninsula from Tamil Nadu in the south to Bundelkhand in the north and Rajmahal hills in the east to Kachchh in the west. They surround the black soils on their south, east and north. Red soils are highly leached soils of the humid tropics having a high content of sesquioxides. In the current system of U. S. Soil Taxonomy, red soils are usually designated under the orders of Oxisols, Ultisols, and occasionally Alfisols, Mollisols and even Inceptisols. Red soils are predominantly found in South America, Central Africa, South and Southeast Asia, China, India, Japan and Australia. In general, these soils have good physical conditions for plant growth although they often have very low water-holding capacity. Low natural fertility is the main limiting factor for good crop production on these soils and they are frequently acidic and deficient in all essential nutrients, especially N, P, K, Ca, Mg, S, Zn, B, and Cu. Adequate applications of lime and fertilizers are important strategies for replenishing soil fertility and improving crop yields on these soils.

The texture of red soils varies from sand to clay, the majority being loam. Their other characteristics include porous and friable structure, absence of lime, kankar and free carbonates, and small quantity of soluble salts. Their chemical composition include non-soluble material 90.47%, iron 3.61%, aluminium 2.92%, organic matter 1.01%, magnesium 0.70%, lime 0.56%, carbon-Di-oxide 0.30%, potash 0.24%, soda 0.12%, phosphorus 0.09% and nitrogen 0.08%. However significant regional differences are observed in the chemical composition.

C. Laterite Soil

Laterite is a soil and rock type rich in iron and aluminium, and is commonly considered to have formed in hot and wet tropical areas. Nearly all laterites are of rusty-red coloration, because of high iron oxide content. They develop by intensive and long-lasting weathering of the underlying parent rock. Tropical weathering (laterization) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils. The majority of the land area containing laterites is between the tropics of Cancer and Capricorn.

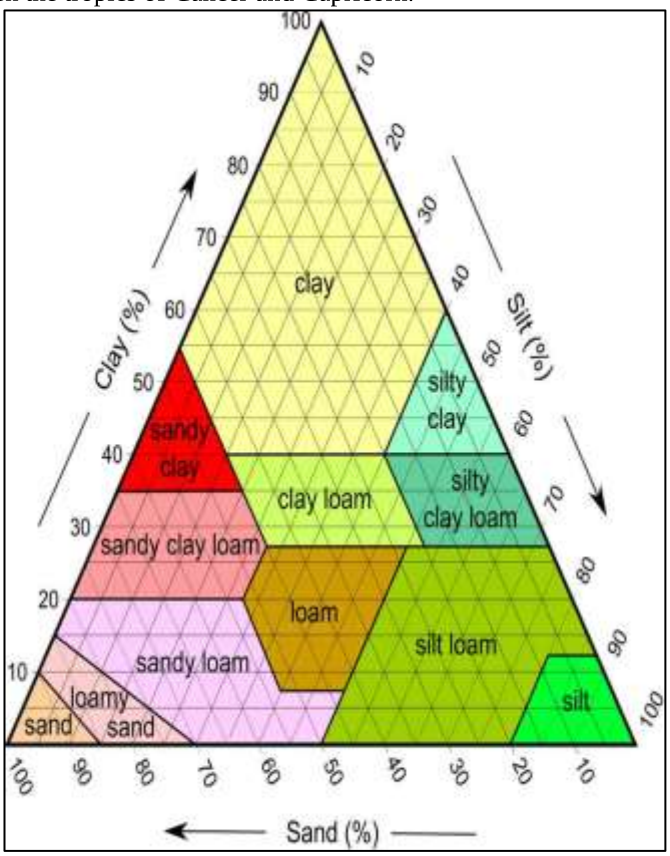

Fig. 1: Laterite Soil

D. Alluvial Soils

Alluvial soils are by far the largest and the most important soil group of India. Covering about 15 lakh sq km or about 45.6 per cent of the total land area of the country, these soils contribute the largest share of our agricultural wealth and support the bulk of India's population.

Most of the alluvial soils are derived from the sediments deposited by rivers as in the Indo-Gangetic plain although some alluvial soils in the coastal areas have been formed by the sea waves. Thus the parent material of these soils is all of transported origin.

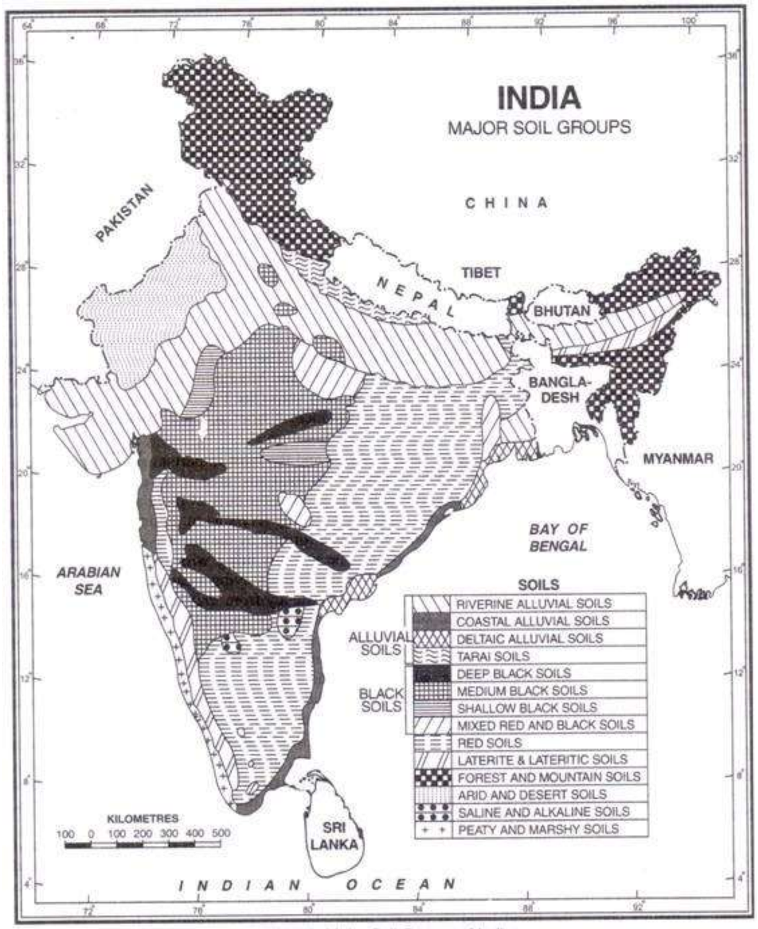

Fig. 2: Major Soil groups of India

E. Forest and Mountain Soils:

Such soils are mainly found on the hill slopes covered by forests. These soils occupy about 2.85 lakh sq km which is about 8.67 per cent of the total land area of India. The formation of these soils is mainly governed by the characteristic deposition of organic matter derived from forest growth.

F. Arid and Desert Soils

A large part of the arid and semi-arid region in Rajasthan and adjoining areas of Punjab and Haryana lying between the Indus and the Aravalis, covering an area of 1.42 lakh sq km (or 4.32% of total area) and receiving less than 50 cm of annual rainfall, is affected by desert conditions.

G. Saline and Alkaline Soils

These soils are found in Andhra Pradesh and Karnataka. In the drier parts of Bihar, Uttar Pradesh, Haryana, Punjab, Rajasthan and Maharashtra, there are salt-impregnated or alkaline soils occupying 68,000 sq km of area. These soils are liable to saline and alkaline efflorescences and are known by different names such as reh, kallar, usar, thur, rakar, karl and chopan.

There are many undecomposed rock and mineral fragments which on weathering liberate sodium, magnesium and calcium salts and sulphurous acid. Some of the salts are transported in solution by the rivers, which percolate in the sub-soils of the plains.

IV. STUDY AREA AND DATA ANALYSIS

Fig. 3: Study Area and Data Analysis

A. Variation of Infiltration Rate

The infiltration rate is determined from the observed data and the infiltration capacity decreases with time and ultimately, it should reach a constant rate, caused by filling of soil pores with water, which reduces the capillary suction. From the data it was found that all the data points are not converging to a steady state conditions. Hence, all the plots are not considered for further study. The variation of infiltration rate with time is plotted for all the locations. The variation of cumulative infiltration and infiltration rate with time for different location is plotted.

Fig. 4: Variation of Infiltration Rate

B. Details of the Field Study Area& Analysis

The study area selected is of Saveetha University of Tamilnadu state. Infiltration tests were conducted in different sites in the Saveetha University at different locations. To deal with the infiltration characteristics, permeability characteristics, the experiments have been carried out at 20 different locations of the study site. For understanding the infiltration properties and permeability properties of the soil in 20 locations in saveetha university

Table - 4.3.1
Soil classification according to range of hydraulic conductivity

Soil (according the relative permeable)	*Approximate rang of saturated hydraulic conductivity(m)*
Highly impermeable	*< 10-10*
Impermeable	*from 10-8 to 10-10*
Lowly (poorly) permeable	*from 10-6 to 10-8*
Permeable	*from 10-4 to 10-6*
Highly permeable	*> 10-4*

1) *Infiltration rate with time*

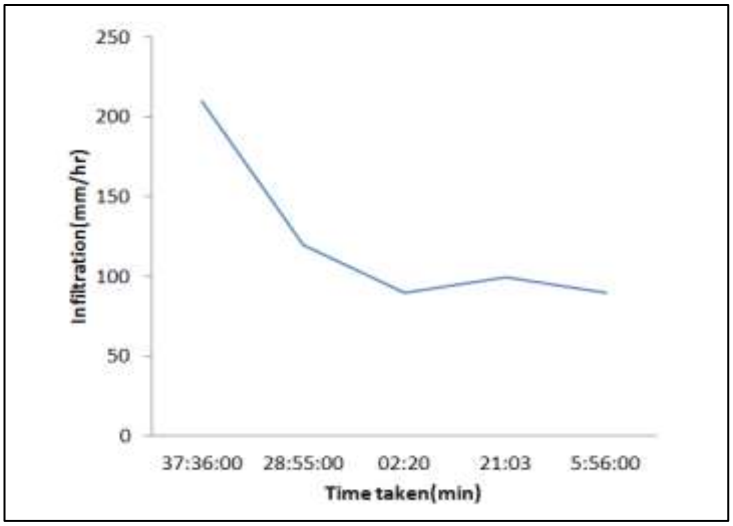

Fig. 4.3.1:

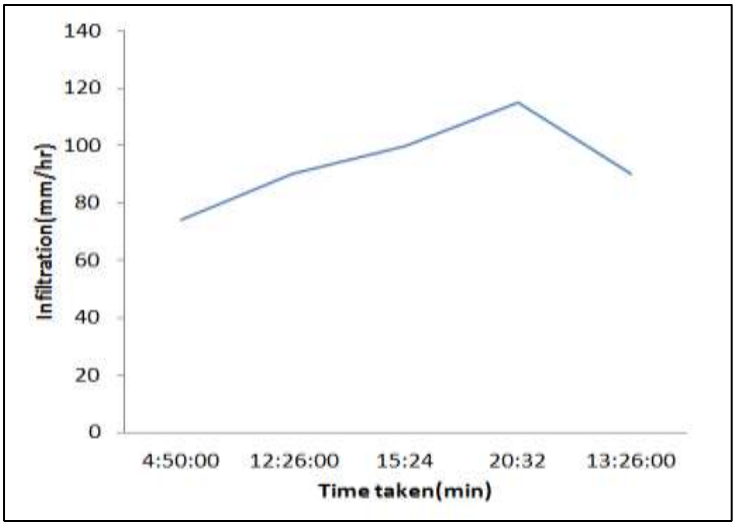

Fig. 4.3.2:

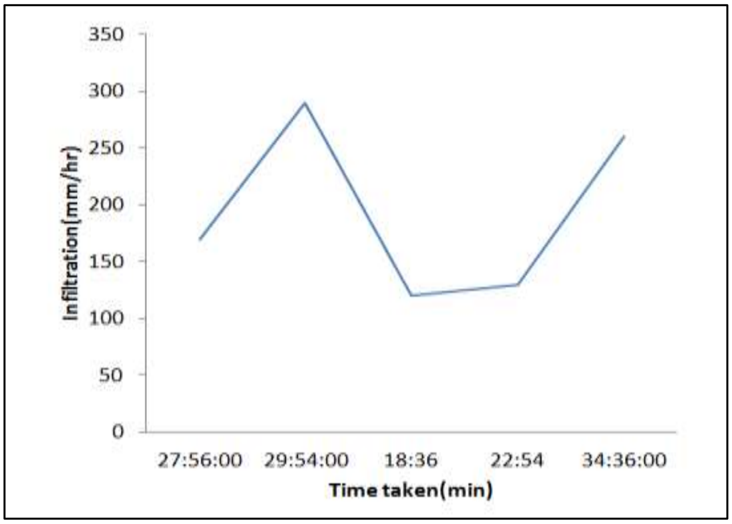

Fig. 4.3.3:

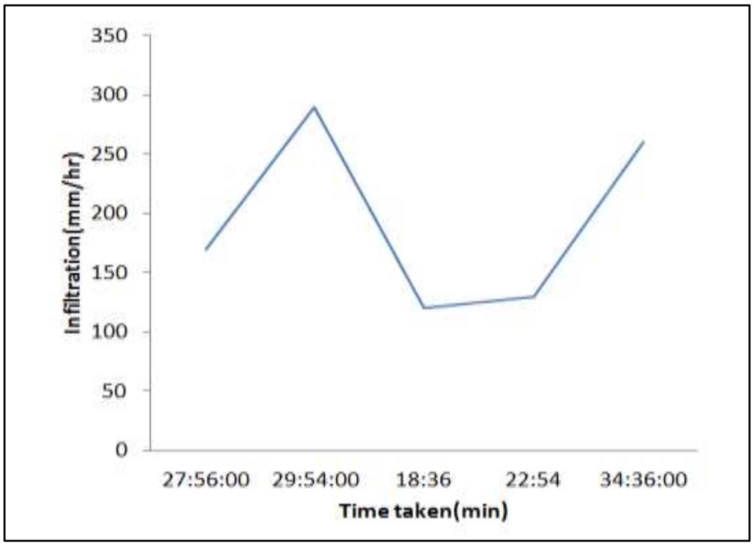

Fig. 4.3.4:

V. METHODOLOGY

Infiltration rate usually is determined from field data. Many different methods and types of equipment have been used for measuring infiltration rate, but the principal methods are flooding of basins or furrows, sprinkling (to simulate rain), and measuring water entry from cylinders (infiltrometer rings). The rate of subsidence of the water surface, or the rate of flow required maintaining a constant level in a large basin, or a very large ring infiltrometer is taken as a measure of the infiltration rate. If smaller infiltrometer rings are used, the rate of flow or subsidence for the period during which the wetting front is moving downward through the enclosed part of the soil column is taken as the infiltration rate. Infiltration is a component of the general mass balance hydrologic budget. There are several ways to estimate the volume and/or the rate of infiltration of water into a soil. The rigorous standard that fully couples groundwater to surface water through a non-homogeneous soil is the numerical solution of Richards' equation. A newer method that allows full groundwater and surface water coupling in homogeneous soil layers, and that is related to the Richards equation is the Finite water-content vadose zone flow method. In the case of uniform initial soil water content and a deep well-drained soil, there are some excellent approximate methods to solve for the infiltration flux for a single rainfall event. Among these are the Green and Ampt (1911) method, Parange et al. (1982). Beyond these methods there are a host of empirical methods such as, SCS method, Horton's method, etc., that are little more than curve fitting exercises

A. Single-Ring Infiltrometer

Single-ring Infiltrometer test was conducted using 15cm and 30 rings as shown in the figure. The ring is driven into the soil approximately 12-14 inches into the soil. Then water is poured into the ring that above the soil surface. In some cases the above surface of the ring is covered to avoid evaporation. For measuring the depth of water in ring we need hook gage, steel tape or scale. We should take care of a ring while it is driving into the ground there may be chance of having hapless connections between the thin wall of a ring and soil. That hapless connection may cause leak of water and that leads to over estimation of an Infiltration rate.

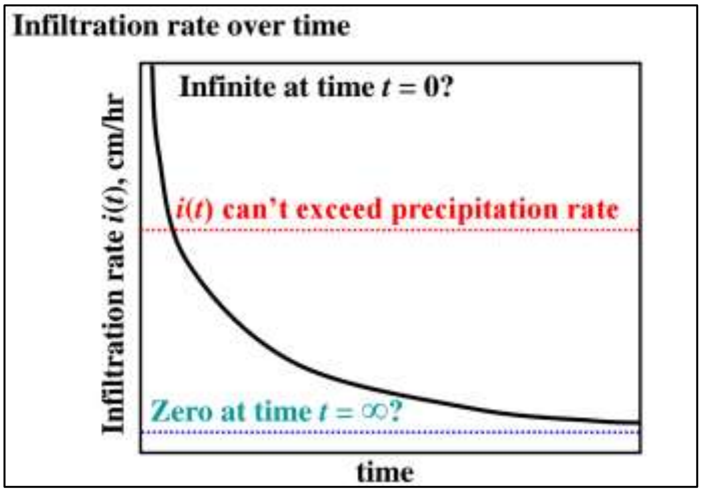

Fig. 5: Infiltration rate over Time

B. Permeability of soil constant head permeability

Permeability is a measure of the ease in which water can flow through a soil volume. It is one of the most important geotechnical parameters. However, it is probably the most difficult parameter to determine. In large part, it controls the strength and deformation behavior of soils. It directly affects the following:

1) Quantity of water that will flow toward an excavation
2) Design of cut-offs beneath dams on permeable foundations
3) Design of the clay layer for a landfill liner.

For fine grained soil Falling head permeability test is done, whereas constant head permeability test is done for the coarse grained soil.

C. Materials and Methods

This laboratory study was aimed to assess effects of soil texture on soil consistency limits and soil compactability parameters. Atterberg limit tests were conducted following the Australian standard test methods for Atterberg limits (AS, 1995). To define the liquid limits of the sediments, the results of the percussion-cup test and the fall cone test are compared for raw sediments and treated sediments. For the determination of the plastic limit, the results of the rolling test method are compared to the prediction of the fall cone test. Finally, the relationship between the water contents and the penetration depths between the liquid limit and the plastic limit is explored.

The plastic limits measured by the rolling test method. The relationships between the water content and the penetration depth of the cone, between the liquid limits and the plastic limits, are investigated.

On the basis of the liquid limit and the plastic limit, the plasticity index (PI) can be defined as the numerical difference between them:

$$PI = LL - PL$$

The plasticity index is expressed in percent of the dry weight of the soil sample. It shows the size of the range of the moisture contents at which the soil remains plastic.

VI. RESULTS

A. Results and Discussions

Infiltration Test Results by Single Ring Infiltrometer

Table - 6.1

Soil sample	*Wt. of soil (kg)*	*Amount of water added(ml)*	*Amount of water infiltrated(ml)*	*Time Taken*
1	1.543	500	210	37:36
2	2.315	400	120	28:55
3	0.798	150	90	2:20
4	1.102	300	100	21:03
5	0.845	200	90	5:56
6	0.131	150	74	4:50
7	0.989	300	90	12:26
8	0.864	250	100	15:24
9	1.1	300	115	20:32
10	0.789	250	90	13:26

Table - 6.1.1

Soil sample	*Wt. of soil (kg)*	*Amount of water added(ml)*	*Amount of water infiltrated(ml)*	*Time Taken*
11	1.1	400	160	24:12
12	0.768	250	80	14:34
13	0.792	300	120	9:15
14	1.067	300	140	11:36
15	1.03	400	120	23:45
16	1.317	400	170	27:56
17	1.334	500	290	29:54
18	0.81	300	120	18:36
19	1.118	400	130	22:54
20	1.4	500	260	34:36

B. Permeability Test Results

Table - 6.1.2

Soil Sample	*Wt. of soil(kg)*	*Amount of water added(ml)*	*Amount of water collected(ml)*	*Time taken*
1	1.543	500	290	37:36
2	1.315	400	180	28:55
3	0.798	150	60	2:10

4	1.102	300	200	21:03
5	0.845	200	110	5:56
6	0.731	150	76	4:50
7	0.989	300	210	12:26
8	0.864		150	15:24
9	1.1	300	185	20:32
10	0.789	250	160	13:26

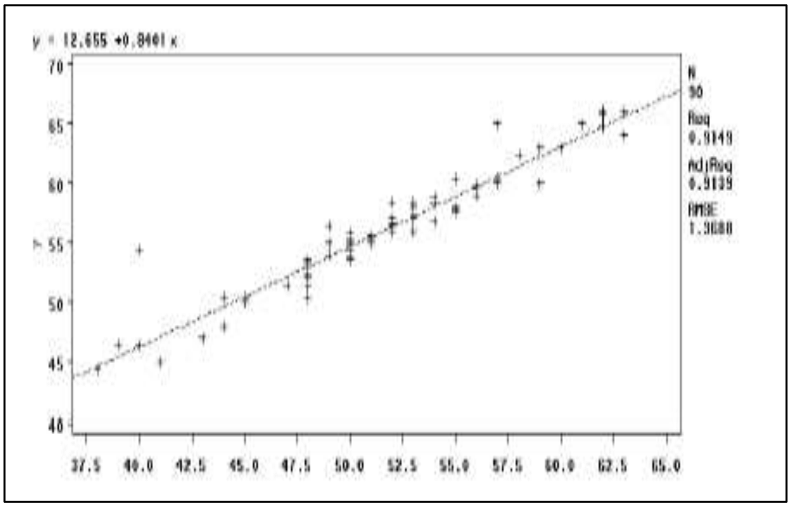

Fig. 6.1.1: Regression Analysis of liquid limit in clay soil texure class

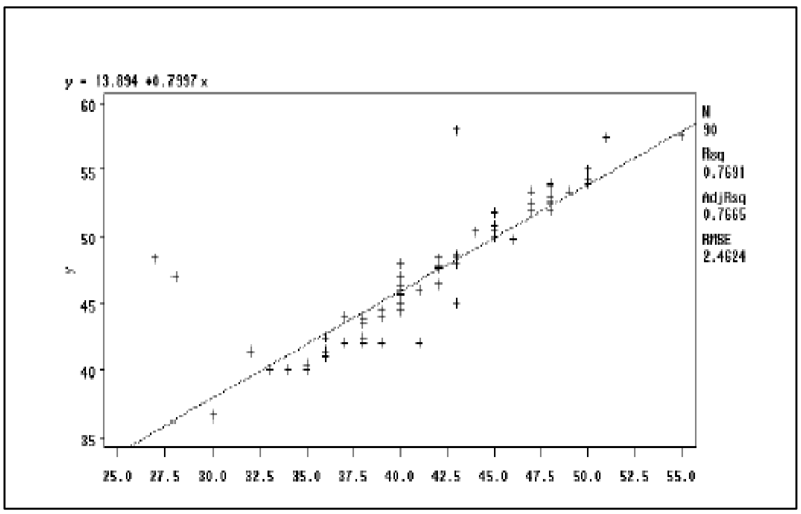

Fig. 6.1.2: Regression Analysis of liquid limit in silty soil texture class

Table - 6.1.2

Soil Sample	Wt. of soil(kg)	Amount of water added(ml)	Amount of water collected(ml)	Time taken
11	1.1	400	240	24:12
12	0.768	250	165	14:34
13	0.792	300	180	9:15
14	1.067	300	160	11:36
15	1.03	400	280	23:45
16	1.317	400	230	27:56
17	1.334	500	310	29:54
18	0.81	300	180	18:36
19	1.118	400	270	24:54
20	1.4	500	240	34:36

Fig. 7: Thread produced by rolling device

VII. CONCLUSION

As the measurements were taken in NIT field and water was spread for plants in regular interval. So, the infiltration to the soil got constant after a short time interval due to saturation of the soil. From the results it was concluded that the double ring infiltrometer gives better infiltration rate than single Infiltrometer of 15cm.

From the research work it was found that constant infiltration rate was occurring in a short time.

From the result after analysis it was found that an infiltration models varies. From correlation coefficient and Standard Error it was found that Horton's model is the best fitting model with high degree correlation coefficient and minimum standard error.
From research work it was also found that soil conditions effects infiltration rate. From the graphs of infiltration rates against time it is found that initial infiltration rates were high and decreased with time up to constant infiltration rate. There are many factors which affects the soil infiltration rates. The major factor which affect the infiltration rates are soil parameters. Many tests were conducted in past and the infiltration rates, bulk density and water content were determined for different sites. The results shown that their exists some relation between all parameters. On some places the infiltration rates were negatively affected by bulk density of soil. While at some sites it has been concluded that urban compacted soils have low infiltration rates as compared to the forests. The results have also shown that the cultivated and grazed land compared to the forest infiltration rate and water content were 70% and 45% and bulk density 13-20% larger. Therefore the research into the definite relation on influence of soil parameters on infiltration capacity is required to establish As a conclusion, we get the time is found to be constant at volume of water. The time weget is faster. This is because the permeability of the gravel soil absorbs the water is low. This gravel soil has a large molecular space. Therefore, the water diffusion rate is low. It appears to bea function of three factors for a constant paste amount and character: effective air void content, effective void size and drain down. From the coefficient of permeability for the given sample of soil value, we can say that the rate of flow the sample has get the value higher. The soil permeability plays an important role in selecting infiltration based storm water management strategies. Due to the lack of studies on soil properties, design of storm water management control structures in land development area is not in proper order.

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