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**A TERM PAPER ON SOIL PERMEABILITY AND SOIL CAPILLARITY**

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**MATRIC NO: 17/ENG03/003**

**A TERM PAPER SUBMITTED TO: ENGR. EMEKA NNOCHIRI OF THE CIVIL ENGINEERING DEPARTMENT, COLLEGE OF ENGINEERING, ABUAD, IN RELATION TO CVE 306, SOIL MECHANICS.**

**DATE: 14TH APRIL, 2020**

**ABSTRACT**

 In soil mechanics and the civil engineering field of learning, one must be familiar with how water enters, moves and how much water is flowing through a soil in unit time. This knowledge is essential to design earth dams, determine the quantity of seepage under hydraulic structures such as aqueducts and drainage trenches etc. and dewater before and during the construction of foundations.

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**INTRODUCTION**

 The amount, distribution, and the movement of water in soil have an important bearing on the properties and behavior of soil. The civil engineer involved in any structural project should know the principles of fluid flow, as groundwater conditions are regularly encountered on construction projects. Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles, which are produced by the mechanical and chemical disintegration of rocks, regardless of whether or not they contain an admixture of organic constituents and clay minerals.

 Soil consists of different phases of solid, liquid, and gas and its characteristics depend on the interacting behavior of these phases, and on the stress applied. The solid phase includes clay, non-clay minerals, and organic matter. These elements are categorized by their size as clay, sand, and gravel. The liquid phase is composed of water that contains organic compounds available from chemical spills, wastes, and ground water, while the gas phase is normally air.

The size, form, chemical properties, compressibility, and load carrying capability of the soil particles are determined by soil mineralogy, which is a science related with the chemistry, structure, and physical properties of minerals. The structure of a soil depends upon the arrangement of particles, particle groups, pore spaces, and the composition.

 These basic characteristics determine the type of structure to be built and what external support measures, if any, has to be taken to make the structure last long and bear the effects of earthquake, water seepage, and other external factors. Water pressure is always measured relative to atmospheric pressure, and water table is the level at which the pressure is atmospheric. Soil mass is divided into two zones with respect to the water table:

1. below the water table (a saturated zone with 100% degree of saturation) and
2. (Ii) Just above the water table (called the capillary zone with degree of saturation ≤100%).

Below the water table, the pore water may be static or seeping through the soil under hydraulic potential. This chapter and the next have been devoted to give an accurate and complete knowledge of the water condition in the soil.

Soil is a particulate material and has pores that provide a passage for water. Such passages vary in size and are tortuous and interconnected. A sufficiently large number of such paths of flow are grouped to act together, and the average rate of flow is considered to represent a property of the soil. This property is termed permeability of the soil and may be defined as the capacity of a soil to permit water to pass through its interconnected void spaces.

**WHAT IS SOIL PEMEABILITY?**

Permeability is the property of rocks that is an indication of the ability for fluids (gas or liquid) to flow through rocks. High permeability will allow fluids to move rapidly through rocks. Permeability is affected by the pressure in a rock. The unit of measure is called the [Darcy](https://en.wikipedia.org/wiki/Darcy_%28unit%29), named after [Henry Darcy](https://en.wikipedia.org/wiki/Henry_Darcy) (1803–1858). Sandstones may vary in permeability from less than one to over 50,000 millidarcys (md). Permeability’s are more commonly in the range of tens to hundreds of militaries. A rock with 25% porosity and a permeability of 1 md will not yield a significant flow of water. Such “tight” rocks are usually artificially stimulated (fractured or acidized) to create permeability and yield a flow.

Permeability of Soil: Definition, Darcy’s Law and Tests. Definition of Permeability: It is defined as the property of a porous material which permits the passage or seepage of water (or other fluids) through its interconnecting voids

The ability of soil to allow flow of water through it is called as permeability of soil. It is very important factor for the structures which are in contact with water. Flow of water in soil takes place through void spaces, which are interconnected. Water does not flow in a straight line, but in a winding path. However in soil mechanics flow is considered to be in a straight line at an effective velocity. The velocity of flow depends on size of pores.

**IMPORTANCE AND APPLICATION OF SOIL PEMEABILITY**

* Permeability influences the rate of settlement of a saturated soil under load.
* The stability of slopes and retaining structures can be greatly affected by the *permeability* involved.
* The design of earth dams is very much based upon the*permeability of soil* used.
* Filters made of soils are designed based upon their permeability.

The concept of permeability is of importance in determining the flow characteristics of [hydrocarbons](https://en.wikipedia.org/wiki/Hydrocarbons) in [oil](https://en.wikipedia.org/wiki/Petroleum) and [gas](https://en.wikipedia.org/wiki/Gas) reservoirs[[1]](https://en.wikipedia.org/wiki/Permeability_%28Earth_sciences%29#cite_note-1), and of [groundwater](https://en.wikipedia.org/wiki/Groundwater) in [aquifers](https://en.wikipedia.org/wiki/Aquifer) [[2]](https://en.wikipedia.org/wiki/Permeability_%28Earth_sciences%29#cite_note-2).For a rock to be considered as an exploitable hydrocarbon reservoir without stimulation, its permeability must be greater than approximately 100 md (depending on the nature of the hydrocarbon – gas reservoirs with lower permeability’s are still exploitable because of the lower [viscosity](https://en.wikipedia.org/wiki/Viscosity) of gas with respect to oil). Rocks with permeability’s significantly lower than 100 md can form efficient *seals* (see [petroleum geology](https://en.wikipedia.org/wiki/Petroleum_geology)). Unconsolidated sands may have permeability’s of over 5000 md.The concept also has many practical applications outside of geology, for example in [chemical engineering](https://en.wikipedia.org/wiki/Chemical_engineering) (e.g., [filtration](https://en.wikipedia.org/wiki/Filtration)), as well as in Civil Engineering when determining whether the ground conditions of a site are suitable for construction.

**FACTORS AND PROPERTIES AFFECTING SOIL PEMEABILITY**

* Grain size or Particle size

The above equation is given by Alan Hazen. Permeability depends on shape and soil of soil particles. Permeability varies with square of particle size diameter.

* Void Ratio

If the presence of voids is more than the permeability is also more.



* Composition

For gravels, sand and silts presence of mica can decrease the *permeability of soil.*For clay, water attracted between clay particles reduces the permeability.

* Structural Arrangement

Remolding of natural soil reduces permeability. If soil contains more rounded particles, the permeability is more.

* Stratification

When flow of water is parallel to strata, permeability will be more when compared with flow perpendicular to strata.

* Presence of foreign particles and entrapped air

This affects the*permeability*as it reduces void space and it blocks the inter-connectivity between the pores.

* Degree of saturation

If the soil is dry or partly saturated the permeability of soil is always less.

**Properties of Permeability of Soil**

* Solving problems involving pumping seepage water from construction excavation.
* Estimating the quantity of underground seepage.
* Stability analysis of earth structures and earth retaining walls subjected to seepage forces.

**TEST FOR SOIL PERMEABILITY**

Soil permeability measurements determine how well water flows through soil. Large pores in sand or granular soil allow water to move rapidly, while small pores in silt or clay cause water to seep through slowly. The main tests to measure soil permeability are the constant head, the falling head and the percolation test. Homeowners may need a permeability test for building, landscape or major gardening projects. You can easily do a percolation test yourself, but first check whether local laws require you to hire a professional.

**Soil Permeability Test Applications**

Soil permeability measurements help determine the rate of soil settling, which you need to know before constructing buildings or determining how much water will flow toward an excavation. Good drainage from high soil permeability is needed for installation of a septic system. Low permeability, found in clay soils, works well for placement of ponds, such as a fish pond. Soil permeability measurements also help determine the stability of slopes and earth dams. Growing vegetables requires good drainage; a permeability test can indicate whether your soil is suitable or needs to be amended before planting.

**Constant Head Permeability Test**

The constant head test is a laboratory test done on sandy or granular soil samples. Under constant pressure, a piston forces water through a column of water-saturated soil to determine the flow rate of water. The water in the test is de-aired and kept at constant temperature. The test apparatus has a water reservoir on top and an outlet reservoir on the bottom. The permeability of the soil sample is calculated from the height of the soil sample, the sample's cross section, pressure measurements, the volume of passed water and the time interval.

**Falling Head Permeability Test**

The falling head permeability test is for low permeability soils, such as silts and clays. A relatively small soil sample is used, because water flow will be slow. After tamping down the sample and saturating it with water, a standpipe is connected to the container holding the soil. The standpipe is filled with water, and the initial water level is measured. The decline in water level in the standpipe is measured again after the water flows through the sample in a specified time. The permeability of the soil sample is calculated from the size of the soil sample, the cross section of the standpipe, the drop in water level and the time taken.

**Percolation Test**

For the percolation test, a field test done in the area of interest, a tester digs a series of holes in the ground and fills them with water for a few hours or overnight to saturate the soil. Sandy or gravelly soils take shorter than salty or clay soils to become saturated. After water has saturated the soil surrounding the test holes, the tester adds new water and records the time it takes for the water level in the holes to drop. The permeability, or more accurately the percolation rate, is calculated from the drop in water level in inches or centimeters per specified time.

**Units**

The SI unit for permeability is m2. A practical unit for permeability is the *Darcy* (d), or more commonly the *military* (md) (1 Darcy {\displaystyle \approx }10−12m2). The name honors the French Engineer Henry Darcy who first described the flow of water through sand filters for potable water supply. Permeability values for sandstones range typically from a fraction of a *Darcy* to several *Darcy’s*. The unit of cm2 is also sometimes used (1 cm2 = 10−4 m2 {\displaystyle \approx } 108 d).

**FORMULAR AND DETERMINATION OF HYDRAULIC CONDUCTIVITY (K)**

The proportionality constant specifically for the flow of water through a porous media is called the hydraulic conductivity permeability is a portion of this, and is a property of the porous media only, not the fluid. Given the value of hydraulic conductivity for a subsurface system, the permeability can be calculated as follows:

{\displaystyle k=K{\frac {\mu }{\rho g}}}Where

* {\displaystyle k} is the permeability, m2
* {\displaystyle K} is the hydraulic conductivity, m/s
* {\displaystyle \mu } is the dynamic viscosity of the fluid, Pays
* {\displaystyle \rho } is the density of the fluid, kg/m3
* {\displaystyle g} Is the acceleration due to gravity, m/s2.

**Determination**

Permeability is typically determined in the lab by application of Darcy's law under steady state conditions or, more generally, by application of various solutions to the diffusion equation for unsteady flow conditions.

Permeability needs to be measured, either directly (using Darcy's law), or through estimation using empirically derived formulas. However, for some simple models of porous media, permeability can be calculated (e.g., random close packing of identical spheres).

**Permeability model based on conduit flow**

Based on the Hagen–Poiseuille equation for viscous flow in a pipe, permeability can be expressed as:

{\displaystyle k\_{I}=C\cdot d^{2}}Where:

{\displaystyle k\_{I}} (k1) is the intrinsic permeability [length2]

{\displaystyle C} (C) Is a dimensionless constant that is related to the configuration of the flow-paths?

{\displaystyle d} (d) Is the average, or effective pore diameter [length].

Ranges of common intrinsic permeability’s

These values do not depend on the fluid properties; see the table derived from the same source for values of hydraulic conductivity, which are specific to the material through which the fluid is flowing.

|  |  |  |  |
| --- | --- | --- | --- |
| **Permeability** | **Pervious** | **Semi-pervious** | **Impervious** |
| **Unconsolidated sand and gravel** | Well sorted [gravel](https://en.wikipedia.org/wiki/Gravel) | Well sorted [sand](https://en.wikipedia.org/wiki/Sand) or sand and gravel | Very fine sand, silt, [loess](https://en.wikipedia.org/wiki/Loess), [loam](https://en.wikipedia.org/wiki/Loam) |  |
| **Unconsolidated clay and organic** |  | [Peat](https://en.wikipedia.org/wiki/Peat) | Layered [clay](https://en.wikipedia.org/wiki/Clay) | Untethered clay |
| **Consolidated rocks** | Highly fractured rocks | [Oil reservoir](https://en.wikipedia.org/wiki/Petroleum_geology) rocks | Fresh [sandstone](https://en.wikipedia.org/wiki/Sandstone) | Fresh [limestone](https://en.wikipedia.org/wiki/Limestone), [dolomite](https://en.wikipedia.org/wiki/Dolomite_%28rock%29) | Fresh [granite](https://en.wikipedia.org/wiki/Granite) |
| ***k* (cm2)** | 0.001 | 0.0001 | 10−5 | 10−6 | 10−7 | 10−8 | 10−9 | 10−10 | 10−11 | 10−12 | 10−13 | 10−14 | 10−15 |
| ***k* (military)** | 10+8 | 10+7 | 10+6 | 10+5 | 10,000 | 1,000 | 100 | 10 | 1 | 0.1 | 0.01 | 0.001 | 0.0001 |

**WHAT IS SOIL CAPILLARITY?**

 Capillarity is the phenomenon by which water rises in a cylindrical column. The narrower the column the higher the capillarity; similarly, the denser the substratum present in the column, the higher the capillary effect. Capillarity is the phenomenon by which water rises in a cylindrical column. The narrower the column the higher the capillarity; similarly, the denser the substratum present in the column, the higher the capillary effect.

 *Soil Capillarity* is the primary force that enables the soil to retain water, as well as to regulate its movement throughout the layers of soil on the earth’s crust and through the roots and stems of plants from the soil which they reside on. In soil, there are millions of vertical channels/pipes called "capillary tubes". Whenever there is a downpour, excess water runs underground through these capillary tubes and when it is dry, these same tubes transport water to the surface.

Trees have their roots in these capillary tubes which also contain threads of fungi which are hygroscopic (attracting water) and with their lateral roots, they soak up capillary water when it is hot and dry. This is how a tree survives heat and drought. Even in rocks, minuscule and invisible fissures function as capillary tubes. Water molecules behave in two ways;

* Cohesion Force: Because of cohesion forces, water molecules are attracted to one another. Cohesion causes water molecules to stick to one another and form water droplets.
* Adhesion Force: This force is responsible for the attraction between water and solid surfaces. For example, a drop of water can stick to a glass surface as the result of adhesion.

**CAPILLARY ACTION:**

* + Capillary action, also referred to as capillary motion or capillarity, is a combination of cohesion/adhesion and surface tension forces.
	+ Capillary action is demonstrated by the upward movement of water through a narrow [tube](http://en.wikipedia.org/wiki/Tube) against the [force](http://en.wikipedia.org/wiki/Force) of [gravity](http://en.wikipedia.org/wiki/Gravity).
	+ Capillary action occurs when the [adhesive](http://en.wikipedia.org/wiki/Adhesion) [intermolecular forces](http://en.wikipedia.org/wiki/Intermolecular_force) between a [liquid](http://en.wikipedia.org/wiki/Liquid), such as water, and the [solid](http://en.wikipedia.org/wiki/Solid) surface of the tube are stronger than the [cohesive](http://en.wikipedia.org/wiki/Cohesion_%28chemistry%29) intermolecular forces between water molecules.
	+ As the result of capillarity, a [concave](http://en.wikipedia.org/wiki/Concave) [meniscus](http://en.wikipedia.org/wiki/Meniscus) (or curved, U-shaped surface) forms where the liquid is in contact with a vertical surface.
	+ Capillary rise is the height to which the water rises within the tube, and decreases as the width of the tube increases. Thus, the narrower the tube, the water will rise to a greater height.



**Capillarity in different sizes of tubes**

**SOIL SURFACE TENSION**

Interconnected pore space in soils hold water due to *surface tension* effects. The pores in a soil act like capillaries that absorb and retain water, the smaller the pore, the larger the energy with which water is retained in the soil (large pores are easy to drain, and small ones are difficult to drain).

 Water surfaces behave in an unusual way because of cohesion. Since water molecules are more attracted to other water molecules as opposed to air particles, water surfaces behave like expandable films. This phenomenon is what makes it possible for certain insects to walk along water surfaces.

**CAPILLARY RISE IN DIFFERENT SOILS**

The phenomenon of capillarity also occurs in the soil. In the same way that water moves upwards through a tube against the force of gravity; water moves upwards through soil pores, or the spaces between soil particles.

* The height to which the water rises is dependent upon pore size. As a result, the smaller the soil pores, the higher the capillary rise.
* Finely-textured soils typically have smaller pores than coarsely-textured soils. Therefore finely-textured soils have a greater ability to hold and retain water in the soil in the inter-particle spaces. We refer to the pores between small clay particles as microspores. In contrast, the larger pore spacing between lager particles, such as sand, are called macrospores.
* In addition to water retention, capillarity in soil also enables the upward and horizontal movement of water within the soil profile, as opposed to downward movement caused by gravity. This upward and horizontal movement occurs when lower soil layers have more moisture than the upper soil layers and is important because it may be absorbed by roots.



**RELATIONSHIP BETWEEN SOIL PERMEABILITY AND CAPILLARITY**

 The size of the soil pores is of great importance with regard 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 the number of pores closely relate to soil texture and structure, and also influence soil permeability and capillarity as shown above.

The permeability of individual soil horizons may be evaluated by the visual study of particular soil characteristics which have been shown by soil scientists to be closely related to permeability classes. The most significant factor in evaluating permeability is structure: its type, grade, and aggregation characteristics, such as the relationship between the length of horizontal and vertical axes of the aggregates and the direction and amount of overlap, since the soil capillarity deals with the vertical movement of water molecules through the soil capillary pores against gravity, we can say that the greater the permeability of a soil sample, the less the capillarity of the soil sample.

Higher permeability means wider pores within the soil sample, therefore the surface tension existing will be less rather than more in a soil sample with less permeability. Hence, we can say that soil permeability is inversely proportional to capillarity.