PREDICTING THE COEFFICIENT OF PERMEABILITY OF SOILS BASED ON GRAIN SIZE ANALYSIS

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PROJECT REPORT
Submitted in partial fulfillment of the requirement for the degree

Bachelor of Technology
in
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

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TAVANUR-679 573, MALAPPURAM
KERALA, INDIA
2009

DECLARATION

We hereby declare that this project report entitled, ***“PREDICTING THE COEFFICIENT OF PERMEABILITY OF SOILS BASED ON GRAIN SIZE ANALYSIS”*** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

Place: Tavanur

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CERTIFICATE

Certified that this project report entitled, ***"PREDICTING THE COEFFICIENT OF PERMEABILITY OF SOILS BASED ON GRAIN SIZE ANALYSIS"*** is a record of project work done jointly by Ashil,V.S., Drisya, J., Haritha, V.P. and Rose Antony under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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ACKNOWLEDGEMENT

We are exhilarated to express our utmost indebtedness and high sense of loyalty to our guide **Er. Renuka Kumari, J.,** Dept. of LWRCE, KCAET, Tavanur for her keen and abiding interest, effectual advices and didactic criticism during the course of this work and in the preparation of our B.Tech project work. Her uninterrupted suggestions and encouragements made us to work hard to complete this work in time.

It is our pleasure to offer sincere, whole hearted thanks to **Dr. E. K. Mathew,** Head, Dept. of LWRCE, KCAET, Tavanur, for his valuable suggestions, helpful advice, moral support provided especially during the project work.

It is our privilege to express profound and sincere sense of gratitude to **Dr. Anil Kumar, V., Er. Sasikala, D.,** and **Er. Vishnu, B.** for their constant encouragement, valuable advices and sustain interest at every stages of the investigations and the preparation of the project.

With deep sense of gratitude and due respect, we express our heart felt thanks to **Dr. Ganesan, V.,** Dean and Head, Dept. of PHT & AP, KCAET, Tavanur for his professional guidance and constructive suggestions offered during this study.

We are particularly thankful to **Er. Muhammad Raneef, S.**, IIT Roorkee for his help and co-operation at all stages of our work.

We remain indebted to our teachers of Dept. of LWRCE and IDE of KCAET, Tavanur for their unfailing support and encouragement throughout our study.

Our words of thanks, to our beloved friends, are beyond the limit of words and all are remembered at this context for their kindly help and friendliness.

The affection and prayers of our parents can never be forgotten at this moment. Above all we bow our head before God Almighty for his blessings bestowed on us.

The grace and blessings of the supreme power that encouraged us to fulfill this well nourished dream proves the utmost of all that we humbly acknowledge.

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Haritha, V. P.

Rose Antony

Dedicated to our Loving Parents

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SYMBOLS AND ABBREVIATIONS

%	percentage
/	per
^{0}C	degree Celsius
ϕ	porosity
σ	standard deviation
μ	dynamic viscosity of water
γ_w	specific weight of water
γ_d	dry unit weight
τ	tortuosity
μm	micro metre
ASTM	American Society for Testing Materials
BS	British Standards
cc	cubic centimetre
cm	centimetre
D	diameter

Dept.	department
e	voids ratio
erfinv	inverse error function
et al.	and other people
etc.	etcetera
G	specific gravity
g	acceleration due to gravity
h	hour
IDE	Irrigation and Drainage Engineering
IS	Indian Standards
J	journal
K	hydraulic conductivity
k	intrinsic permeability
KCAET	Kelappaji College of Agricultural Engineering and Technology
kg	kilogram
km	kilometre

kN	kilo newton
LWRCE	Land & Water Resources & Conservation Engineering
ln	natural logarithm
log	logarithm
mg	milligram
min.	minutes
ml	millilitre
mm	millimetre
N	cumulative percentage finer
No.	number
P	probability
R^2	coefficient of determination
s	second
S_o	sorting coefficient
V	volume
V_v	volume of voids

Introduction

CHAPTER I

INTRODUCTION

According to Indian mythology, whole universe is made up of five elements viz., Vayu, Jal, Bhoomi, Agni and Akash. These elements are to be respected and considered in planning the progress of any country to avoid disasters. Among these, the soil has been given a prime importance in the existence of life. The term soil has various meanings depending upon the general professional field in which it is being considered. To an agriculturist, soil is the substance existing on earth's surface which grows and develops plant's life. To an engineer, soil is the unaggregated or uncemented deposits of mineral or organic particles or fragments covering large portion of earth's crust.

In engineering aspects the soil is considered as a porous medium with a developed network of pores. Its natural ability to form aggregates implies that the soil pore network forms structures of a few different pore sizes. The greatest pores are on the external margins of soil aggregates while the smallest form a network of micropores inside the aggregates. Water is much more mobile in the macro than in the micropore network, which is a consequence of the character and intensity of forces acting on the water molecule in these two types of network.

Agricultural engineers deal with both the agronomic and engineering aspects of soil. They are concerned primarily with soil properties that influence the engineering phase of tillage, erosion, drainage, and irrigation. Irrigation, drainage and erosion control require knowledge of soil moisture and soil moisture movement, which depends on the soil property called as the "permeability" of the soil. Permeability is defined as the property of porous material which permits the passage or seepage of water through its interconnecting voids. Classification of soils with regard to permeability has been made basically on the level of the permeability coefficient "k". It is defined as the average velocity of flow that will occur through the total cross-sectional area of soil under unit hydraulic gradient. The hydraulic conductivity in unsaturated soils corresponds with the permeability coefficient corrected by a function describing the state of a soil.

Hydraulic conductivity plays a crucial role in issues connected with the flow of ground water and the migration of pollutants. In groundwater hydrology, the knowledge of saturated hydraulic conductivity of soil is necessary for modeling the water flow in the soil, both in the saturated and unsaturated zone, and transportation of water-soluble pollutants in the soil. It is also an important parameter for designing of the drainage of an area and in construction of earth dam and levee. Furthermore, it is of paramount importance in relation to some geotechnical problems, including the determination of seepage losses, settlement computations, and stability analyses. Above all, agricultural engineers always look for reliable techniques to determine the hydraulic conductivity of the aquifers with which they are concerned, for better groundwater development, management and conservation.

The occurrence of subsoil water in the site of a conservation structure often complicates realization of works and requires an additional intervention with the use of special equipment. The ability of water conduction in a soil is the essential factor in the consolidation process because it decides about the intensity of this phenomenon. The realization of structural constructions is, almost in every case, directly or indirectly connected with the flow of subsoil water. Thus the problem of water flow in soils has been the subject of scientific research for many years. Here comes the role of prediction of hydraulic conductivity of soils. Hydraulic conductivity prediction will be useful in the predrill evaluation of resources in potential reservoirs. It serves as soft input data for reservoir simulation. For the studies in hydrocarbon migration, distribution of hydrocarbon saturation it is unavoidable. For basin modeling predicted permeability data is more feasible. Finally it is more applicable for the interpretation of seismically derived attribution since hydraulic conductivity is connected to litho logical factors.

Methods of the determination of seepage parameters can be divided into two groups: computational (theoretical or semi-empirical) and research (experimental) methods. Analytical and empirical formulas, numerical modeling and mathematical inverse solutions are some of the computational methods. Experimental methods include laboratory testing of undisturbed or disturbed samples as well as in situ tests (field tests). All these methods can be divided into indirect and direct tests.

Direct measurements of the saturated hydraulic conductivity are time consuming, and a demand of their accuracy leads to a profound increase in their cost, therefore, much attention has been devoted to find out a reliable indirect method for estimation of this parameter. Experimental methods of the research are more accurate. The determination of permeability parameters of soils in an experimental way, however, constitutes a complicated problem because the permeability coefficient depends on many factors simultaneously existing during testing. Laboratory tests also, present formidable problems in the sense of obtaining representative samples and, very often, long testing times.

The water flow through a soil depends, to a large extent, on the structure of soil where this flow occurs and thus the permeability coefficient also gets affected. Mechanics of the water flow through a porous medium - like a soil - has already been well recognized and described. However, there is lack of well elaborated and standardized methodologies of the research. The most important thing in the methodology itself is the scale of a solved issue and the range of applied hydraulic gradients which are directly connected with the regime of moving water. Hence the quantitative research of soil microstructures becomes of greater importance. This research continuously requires stronger attention because in every case changes in a soil structure can be observed, which entails the necessity of developing models describing permeability parameters with large approximation and likeliness by the application of statistics.

In the last twenty years much progress has been made in indirect methods for estimation of different difficult to measure soil characteristics known as the pedotransfer function. In the solutions of these functions the hydraulic properties of the soil are determined on the basis of routinely, easily and cheaply measurable soil parameters. The pedotransfer function has been most often given on the basis of the soil texture, total porosity and bulk density, sometimes along with other soil parameters using the method of multiple regression analysis or the method of neural network analysis. The two approaches to obtain permeability function of unsaturated soil are empirical and statistical methods.

A statistical model can be used to predict permeability function when the saturated hydraulic conductivity and soil-water characteristic curves are available whereas for developing an empirical equation several measured permeability data are required.

In the last century, the engineer's effort was put into the estimation of permeability of three-phase soil media. Since the suction of a soil was related with the degree of its saturation, a relationship between the permeability coefficient and dampness had been sought. This relationship takes a less or more complicated form in different equations of various authors. Calculations based on analytical or empirical formulas using the grain size distribution curves as well as the estimation of the permeability coefficient according to inverse solutions or numeric analysis becomes another alternative. It has long been recognized that hydraulic conductivity is related to the grain-size distribution of granular porous media. This interrelationship is very useful for the estimation of conductivity values where direct permeability data are sparse such as in the early stages of aquifer exploration.

Grain- size methods are comparably less expensive and do not depend on the geometry and hydraulic boundaries of the aquifer. Most importantly, since information about the textural properties of soils or rock is more easily obtained, a potential alternative for estimating hydraulic conductivity of soils is from grain-size distribution. Although in hydromechanics, it would be more useful to characterize the diameters of pores rather than those of the grains, the pore size distribution is very difficult to determine, so that approximation of hydraulic properties are mostly based on the easy-to-measure grain size distribution as a substitute. Consequently, ground water professionals have tried for decades to relate hydraulic conductivity to grain size. The aim of our study was to select, a simple to use, accurate and readily available tool to predict hydraulic conductivity as an alternative to existing methods.

The objectives of our study include

1. Establishing a relationship between sorting and
    a. Calculated porosity
    b. Measured porosity
2. Prediction of coefficient of permeability from grain size
    a. Kozeny Carman model
    b. Alyamani and Sen model
3. Comparison of above result with laboratory methods
    a. Constant head permeability test
    b. Falling head permeability test

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

2.1 Definitions of commonly used terms

It is felt that it will be of great use if the definitions of some of the commonly used terms are given at the outset.

2.1.1 Hydraulic head

Hydraulic head is the elevation of a water body above a particular datum level. Specifically, the energy possessed by a unit weight of water at any particular point, at which water stands in a riser pipe or a manometer connected to it.

2.1.2 Hydraulic conductivity

Hydraulic conductivity, symbolically represented as *K*, is a property of soil that describes the ease with which water can move through pore spaces or fractures. It depends on the intrinsic permeability of the material and on the degree of saturation. Hydraulic conductivity is the proportionality constant in Darcy's law, which relates the amount of water which will flow through a unit cross-sectional area of aquifer under a unit gradient of hydraulic head.

$$K = k\left(\frac{\gamma}{\mu}\right)$$

Where

K is the hydraulic conductivity ($m\ s^{-1}$),

κ is the intrinsic permeability of the material (m^2),

γ is the specific weight of water ($N\ m^{-3}$),

μ is the dynamic viscosity of water (Nsm^{-2})

2.1.3 Void ratio

Void ratio is defined as the ratio of the volume of voids to the volume of soil solids in the given soil mass.

2.1.4 Porosity

The porosity of a soil sample is the ratio of the volume of the voids to the total volume of the given soil sample. It is an index of the relative volume of the pores.

2.1.5 Dry unit weight

The dry unit weight is the weight of solids per unit of its total volume (prior to drying) of the soil mass.

2.1.6 Specific weight of water

Specific weight of water is the ratio of the weight of water to its volume. The value of specific weight for water is 9.81 kN/m^3.

2.1.7 Specific gravity

Specific gravity is defined as the ratio of the weight of a given volume of soil solids at a given temperature to the weight of an equal volume of distilled water at that temperature, both weights being taken in air.

2.1.8 Grain size

The grain size can be quantified by measuring the grain diameter.

2.1.9 Sorting coefficient

Sorting coefficient is the qualitative measure of sorting. Sorting is usually expressed as qualitatively ranging from extremely well sorted to very poorly sorted. The sorting coefficient is expressed in terms of the logarithm of the grain diameter at the 25 and 75 percentile.

2.1.10 Tortuosity

The porous medium is modeled as a bundle of capillary tubes with a length L', that is greater than the system length, L, the ratio L'/L is called tortuosity. It has been empirically determined that this tortuosity factor can be approximated by the factor 25/12.

2.1.11 Particle size distribution curve

The results of the mechanical analysis are plotted to get a particle size distribution curve with the percentage finer (N) as the ordinate and the particle diameter as the abscissa, the diameter being plotted on a logarithmic scale.

The law of flow of water through soil was first studied by Darcy (1856) who demonstrated experimentally that, for laminar flow conditions in a saturated soil, the rate of flow or the discharge per unit time is proportional to hydraulic gradient. Thus the coefficient of permeability is defined as the average velocity of flow that will occur through the total cross-sectional area of soil under unit hydraulic gradient.

Allen Hazen (1892) concluded that the linear dependency of the velocity and hydraulic gradient existed if the effective size of soil did not exceed 3 mm. Hazen formula was originally developed for determination of hydraulic conductivity of uniformly graded sand but is also useful for fine sand to gravel range, provided the sediment has a uniformity coefficient less than 5.

$$v = K_S * i$$

Based on the experiments on filter sands of particle size between 0.1 mm and 3 mm having coefficient of uniformity less than 5, he proposed the relationship

$$K_S = CD^2_{10}$$

where K_S is expressed in cm/sec, C is a constant that varies from 1.0 to 1.5, and D_{10} is the soil particle diameter (mm) such that 10% of all soil particles are finer (smaller) by weight.

Francher *et al.* (1933) demonstrated experimentally that flow through sands remains laminar and Darcy's law is valid so long as the Reynold's number is equal to or less than unity.

Muskat (1937) pointed out that a more general coefficient of permeability, called the *physical permeability* k_p is related to Darcy's coefficient of permeability k as follows:

$$k_p = k\left(\frac{\eta}{\gamma_w}\right)$$

Krumbein and Monk (1943) proposed the equation:

$$k = bd_m^2\, e^{-a\,\sigma_\Phi}$$

where k is in darcies (1 darcy = 9.87E-09 cm^2), d_m is the geometric mean grain-size diameter (mm), σ_Φ is the geometric standard deviation (in Φ units, where Φ is –ln(d) and d is the grain-size diameter in mm), and a and b are empirical constants. This equation was based on experiments performed with sieved glacial outwash sands that were recombined to obtain various grain-size distributions.

Jaky (1944) found that a fair estimate of the magnitude of k can be obtained for all soils in terms of grain size D_m (in cm) that occurs with the greatest frequency.

$$K=100\, D^2_m$$

The method of Creager *et al.* (1945) provided a straightforward relation between the effective grain-diameter of 20% weight content (D_{20}) and conductivity.

Taylor (1948) developed an equation reflecting the influence of the permeant and the soil characteristics on permeability using Poiseuille's Law. This equation is based on considering flow through a porous media similar to flow through a bundle of capillary tubes.

Hvorslev (1949) notes a number of setups which can be used to measure the permeability of soil in field.

Kozeny Carman equation is one of the most widely accepted and used derivations of permeability as a function of the characteristics of the soil medium. This equation was originally proposed by Kozeny (1927) and was then modified by Carman (1937, 1956) to become the Kozeny Carman equation It indicates that the permeability increases with increasing the porosity, but decreases with getting smaller grain size. It is not appropriate for either soil with effective size above 3 mm or for clayey soils.

$$k = \frac{\phi^3 D_p{}^2}{150(1-\phi)^2}$$

Purcell (1949) developed an equation relating absolute permeability to the area under the capillary pressure curve generated from mercury injection. His equation assumes that fluid flow can be modeled using Poiseuille's Law where the rock pore system is represented by a bundle of parallel (but tortuous) capillary tubes of various radii. Further, the range of tube radii are characterized by the pore size distribution as computed from the area under the capillary pressure curve. Purcell's original permeability model is given by:

$$k = 10.66 \frac{\omega}{n} \frac{1}{2} (\sigma_{Hg-air} Cos\theta)^2 (1-S_{wi})^3 \phi^3 \int_0^1 \frac{1}{P_c^2} dS_w$$

where k = permeability(md), 10.66 = units conversion constant (md-(psia)^2/(dynes/ cm)^2), F_P = Purcell lithology factor (dimensionless), $\sigma_{Hg\text{-}air}$ = mercury-air interfacial tension (dynes/cm), θ = contact angle of incidence for wetting phase (radians), Φ = porosity (fraction of pore volume), S_w= wetting phase saturation (fraction of pore volume), p_c = capillary pressure (psia).

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Marshall (1958) went on to derive an equation for an isotropic material in which the mean radius of pores for each of 'm' equal fractions of the total pore space are represented by the corresponding mean radii ($r_1, r_2, \ldots, r_m$).

$$k = \frac{1}{8}\left\{n^2 m^{-2} \left[r_1^2 + 3r_2^2 + 5r_3^2 + \ldots \ (2n-1)\ r_m^2\right]\right\}$$

where k is in cm^2, r_i (cm) is the mean radius of the ith fraction, and r decreases in size from r_1 to r_m.

Terzaghi (1955) developed a formula for coefficient of permeability in fairly uniform sands which reflect the effect of grain size and voids ratio.

$$k = 200D_e^2e^2$$

where D_e=effective grain size , e = voids ratio.

John *et al.* (1961) established a relationship between porosity, median size, and sorting coefficients. It has been investigated by studying synthetic sands with lognormal size distributions and various median sizes and sorting coefficients. Poorly sorted sands are considerably less porous than well sorted ones, and porosities show an inverse linear relationship to sorting coefficient except in very well sorted samples in which porosity increases more rapidly than sorting. Porosity is independent of median size in well sorted sands but appears to decrease slightly with increasing median size in poorly sorted sands. The relationship between median size and porosity probably results from the fact that larger grains have a higher sphericity and tend to pack more closely together than smaller, more irregularly shaped grain

Terzaghi *et al.* (1964) developed another formula for coefficient of permeability as

$$K = \frac{g}{\nu}.C_t\left(\frac{n-0.13}{\sqrt[3]{1-n}}\right)d_{10}{}^2$$

where the C_t = sorting coefficient and $6.1x10^{-3} < C_t < 107x10^{-3}$In this study, an average value of C_t is used. Terzaghi formula is most applicable for large-grain sand.

Scheidegger's (1957) collected data show that critical Reynold's number may vary from 0.1 to 75 for Darcy's law to be valid. Such a wide variation is partly due to the different interpretation given to the characteristics diameter used in the equation for Reynold's number. The degree of sorting of a soil can be estimated based on the range of its standard deviation. Following the formula of Folk and Ward (1957), the calculated standard deviation varied from 2 to 3.5 Φ, which correspond to very poorly to extremely poorly sorted sediments.

Bird *et al.* (1960) introduced the model for relating the flow resistance of porous media to the dimensions of the pores or particles called the Blake-Kozeny model.

This model represents the pore network of the porous medium as a bundle of capillary tubes with an average or equivalent radius, R, and an average length, L', that is somewhat longer than the system length. The effective radius is related to a particle diameter, D_p, by applying the hydraulic radius concept and assuming that the porous medium is a bed of uniform particles. The resulting expression is then compared with Darcy's law to determine an expression for the permeability of the medium in terms of the particle diameter and porosity.

Beard *et al.* (1973) gave quantitative measures of the grain size and sorting for different samples and illustrated different sorting for one value of median grain size. The distribution of permeability in porous media has been usually reported to approximate a log-normal distribution (Freeze, 1975; Sudicky, 1986).

The Sauerbrei formula is applicable when the grain-size diameter is no greater than 0.5 mm. It can be written as

$$K = \frac{g}{\nu}\beta_z\left(\frac{n^3}{(1-n)^2}\right)td^2\tau$$

while the Slichter formula can be applied for an effective grain diameter (d_e) ranging between 0.01 and 5 mm. It takes the form of:

$$K = \frac{g}{\nu}\beta_s\left(J(n)\right)d_D{}^2$$

In the above equations K, hydraulic conductivity; g, gravitational constant; ν, kinematic viscosity for a given temperature; n, porosity (unitless); βz and βs, constants; τ correction for temperature; J (n) porosity function; and d, effective grain diameter.

Puckett *et al.* (1985) sampled six soils at seven different locations in the Alabama lower coastal plain containing 34.6% to 88.5% sand-sized particles and 1.4% to 42.1% clay-sized particles, and used regression analysis to determine that percentage of clay-sized particles was the best predictor of K_s (R^2 = 0.77):

$$\mathrm{K_s} = 4.36 \text{ x } 10^{-3} e^{(-0.1975\mathrm{C})}$$

where K_s is expressed in cm/sec and C is the clay-sized particles (in percent) in the soil sample. Bulk density and porosity, often used in other pedotransfer functions, were not highly correlated with K_s for this data set of sandy soils.

Wendt *et al.* (1986) used multiple linear regressions to establish predictive equation for permeability in cored wells where both well log and lab measurements are available, then applied the same to the uncored wells. Problems encountered in their work were invariably related to the problem of measurement scale-sampling problems, well bore effect, resolution problems and the fact that the statistical predictors will almost always estimate the mean of values, underestimate the high value and overestimate the low value. He concluded that the regression modeling provides a good estimate of the averages and the use of multiple variables improved the match with the actual data.

Ahuja *et al.* (1989) estimated K_s using the generalized form of the Kozeny Carman equation:

$$K_s = B\Phi_e^{A}$$

where Φ_e is the total porosity minus the volumetric water content at 33 kPa of suction, and A and B are constants. A set of 297 data pairs from eight different southeastern U.S. soil series (Renfrow, Cecil, Lakeland, Norfolk, and Wagram plus three soil types from Hawaii) was used to develop an equation relating K_s and Φ_e ($R^2 = 0.71$):

$$K_s = 1058.4\Phi_e^{3.3545}$$

where K_s is expressed in cm/hr. Equations of the same form were also developed individually for the Cecil ($R^2 = 0.68$), Lakeland ($R^2 = 0.34$), and combined Norfolk and Wagram ($R^2 = 0.69$) soil series with varying degrees of success.

Rawls *et al.* (1989) used field data from 1323 soils across the U.S. to develop a regression equation that relates porosity n, and the percentages of sand (S) and clay-sized (C) particles in the sample to K_s.

Shepherd (1989) extended Hazen's work by performing power regression analysis on 19 sets of published data for unconsolidated sediments. The data sets ranged in size from 8 to 66 data pairs. He found that the exponent in Hazen's equation varies from 1.11 to 2.05 with an average value of 1.72 and that the value of the constant C is most often between 0.05 and 1.18 but can reach a value of 9.85. Values for both C and the exponent are typically higher for well-sorted samples with uniformly sized particles and highly spherical grains. Uma *et al.* (1989) suggested an equation to estimate the K_s and transmissivity of sandy aquifers of the same form as Hazen's equation, with C values that depend on the nature of the geologic environment. As summarized by Shepherd (1989), the correlation of permeability and grain size results in a power expression of the form

$$y = ax^b$$

where (y) is permeability when plotted against grain size (x), the coefficient a is the value of y at x = 1, and b is the slope of the line that is fitted to the data. In contrast to other formulas, this equation does not depend on the temperature of the medium

Franzmeier (1991) related K_s to Φ_e for Indiana soils. He measured K_s in the field on one set of samples, measured Φ_e in the laboratory on a different set of samples, and compared the results by soil lithomorphic class to yield $R^2 = 0.86$.

Dane *et al*. (1992) expanded the work of Puckett *et al*. (1985) with two more data sets from the lower coastal plain of Alabama. It consisted of grain-size data pairs from 60 locations in a 0.5-ha agricultural field in south central Alabama. Nonlinear regression analysis yielded the equation ($R^2 = 0.453$):

$$K_s = 7.77 \text{ x } 10^{-5} e^{(-0.116C)}$$

Jabro (1992) estimated K_s from grain-size and bulk density data. He used published data from 350 soil core samples of varying types to develop the following model ($R^2 = 0.68$):

$$\log(K_s) = 9.56 - 0.81 \log(S_i) - 1.09 \log(C) - 4.64 (B_d)$$

where S_i is the percentage of silt-sized particles, K_s is expressed in cm/hr and B_d is the soil bulk density (g/cm^3). Validation of the model with measured K_s, particle size distribution, and B_d values from nine sampling locations in Duffield silt loam yielded an $R^2 = 0.62$.

Vukovic *et al.* (1992) noted that the applications of different empirical formulae to the same porous medium material can yield different values of hydraulic conductivity, which may differ by a factor of 10 or even 20. Hydraulic conductivity (k) can be estimated by particle size analysis of the sediment of interest, using empirical equations relating either k to some size property of the sediment. They summarized several empirical methods from former studies and presented a general formula:

$$K = \frac{g}{\nu}.C.f(n).d_e^2$$

where k = hydraulic conductivity; g = acceleration due to gravity; v = kinematic viscosity ; C = sorting coefficient; f(n) = porosity function, and d_e = effective grain diameter. The kinematic viscosity (ν) is related to dynamic viscosity (μ) and the fluid (water) density (ρ) as follows:

$$\nu = \frac{\mu}{\rho}$$

The values of C, f (n) and d_e are dependent on the different methods used in the grain-size analysis. Porosity (n) was derived from the empirical relationship with the coefficient of grain uniformity (U) as follows:

$$n = 0.255(1 + 0.83^U)$$

where U is the coefficient of grain uniformity and is given by:

$$U = \left(\frac{d_{60}}{d_{10}}\right)$$

Here, d_{60} and d_{10} in the formula represent the grain diameter in (mm) for which 60% and 10% of the sample respectively are finer than. Former studies have presented the following formulae which take the general form presented in equation (1) above but with varying C, f (n) and de values and their domains of applicability.

Breyer gave the relationship for k without considering the porosity. Therefore, porosity function takes on value 1. Breyer formula is often considered most useful for materials with heterogeneous distributions and poorly sorted grains with uniformity coefficient between 1 and 20, and effective grain size between 0.06 mm and 0.6 mm.

$$K = \frac{g}{\nu}.6.10^{-4} \log \frac{500}{U} d^2{}_{10}$$

Alyamani and Sen (1993) sought to include more information about the entire grain-size distribution curve by relating K_s to the initial slope and intercept of the curve for 32 sandy soil samples obtained in Saudi Arabia and Australia with the equation:

$$K_s = 1.505\left[I_o + 0.025\left(D_{50} - D_{10}\right)\right]^2$$

where K_s is expressed in cm/sec, I_o is the X-intercept of the straight line formed by joining D_{50} and D_{10} of the grain-size distribution curve (mm). D_{50} is the mean grain-size for which 50% of the particles are finer by weight (mm). They found that a log-log plot of K_s vs. $[I_o + 0.025(D_{50} – D_{10})]$ for their data set yielded a straight line with $R^2 = 0.94$.

Nelson (1994) reviewed the historical development of empirical model that relate permeability to rock textured parameters. These include the experiments by Beard and Weyl in 1973 where they made artificial sand pack with different grain size and sorting class and measured permeability across them. He also reviewed the empirical formula with respect to the parameter used in the derivation. These include Kozeny Carman equation based on pore-throat geometry measurement.

Sperry *et al.* (1995) developed a linear model to estimate K_s based on grain size, shape, and porosity. They based their model on the results of 84 column experiments in which the hydraulic conductivity of granular materials (spherical glass beads, granular sand, and irregularly shaped, shredded glass particles) possessing tight grain-size distributions was measured using a constant head influent reservoir and a fixed wall permeameter. Regression analysis was used to obtain ($R^2 = 0.84$):

$$K_s = -1.28*10^{-1} + 9.5*10^{-4} D_{50} + 7.71*10^{-3} \gamma n$$

where K_s is expressed in cm/sec, D_{50} is expressed in μm, and γ is the angle of repose (degrees). A Kozeny Carman type equation based on the same experiments yielded a similar fit to the data ($R^2 = 0.85$):

$$K_s = 1.1 * 10^{-2} + 1.35 * 10^{-6} D^2_{50} + \left(1.14 * 10^{-6}\right) \left(\frac{n^3}{(1-n^2)}\right) D^2_{50}$$

The performance of the equations was compared to that of the Hazen (1892), Kozeny Carman (1953) and Alyamani and Sen (1993) models by applying each model to a test data set of 84 filter pack sands. The Hazen equation performed the best, with predicted values within 12% of measured values. The Kozeny Carman equation provided estimates that were 73% to 83% lower than the measured values, whereas the Alyamani and Sen Equation provided estimates that were 30% to 36% greater than the measured values. Estimates obtained were 49% to 74% lower than the measured values.

Moheghegh *et al.* (1997) demonstrated various review of prediction models in his paper. They used textural parameters from cored wells to predict the permeability in other cored wells, compared the predicted permeability to the actual measured data and repeated, and reported several orders of magnitude variations in the result.

Schaap *et al*. (1998) developed four neural network models to predict K_s from basic soil properties, each for a different level of input data. These models were based on the following data requirements: (1) sand, silt and clay percentages; (2) sand, silt and clay percentages and bulk density; (3) sand, silt and clay percentages, bulk density and water content at a suction of 33 kPa; and (4) sand, silt and clay percentages, bulk density and water contents at 33 and 1500 kPa.

Lebron *et al*. (1999) sought to improve upon K_s prediction methods by quantifying the characteristics of the pore spaces at a microscopic scale. Binary images were obtained via a backscattered electron detector from thin sections of soils. From these images, pore surface area, perimeter, roughness, circularity, and maximum and average diameter were quantified. They successfully predicted K_s using this microscopic pore information, supplemented by pH and B_d data, for Gilman silt loam soils from Coachella Valley, California (R^2 = 0.91).

Kasenow (2002) presented a detailed compilation of empirical formulas for hydraulic conductivity determination.

Huet (2005) presented the development and validation of a new semi-analytical, statistically-derived model for estimating absolute permeability from mercury-injection capillary pressure data. The final form of the proposed model allows to compute absolute permeability as a function of effective porosity, irreducible wetting phase saturation, displacement or threshold pressure, and basic pore size characteristics.

Morin (2006) concluded that grain size is the fundamental independent parameter that controls hydraulic conductivity in unconsolidated sediments but empirical formulas were elaborated introducing different relations and therefore, it is not unusual they yield divergent results. Since each formula bases its calculations on a different effective grain-diameter, more emphasis is made on a determined size fraction, which indefectibly leads to discrepancies in the conductivity distribution. Thus, defining the reliability of the determinations remains problematic.

Adrian *et al*. (2007) investigated hydraulic characteristics of sediments for the purpose of site characterization. A total of 340 samples extracted from nine exploratory wells were examined by standard laboratory tests and complemented with statistical analyses to quantitatively determine the main terrain attributes. Grain-size distribution derived from sieve analysis and the coefficient of uniformity showed that soils are poorly sorted. On the other hand, hydraulic conductivity was measured by a number of parameters such as a log-normal distribution. Conductivity was also predicted by empirical formulas, yielding values up to three orders of magnitude higher. Discrepancies were explained in terms of soil anisotropy and intrinsic differences in the calculation methods. Based on the Shepherd’s approach, a power relationship between permeability and grain size was found at two wells. Hydraulic conductivity was also correlated to porosity.

United States Bureau of Reclamation (USBR) formula calculates hydraulic conductivity from the effective grain size (d_{20}), and does not depend on porosity; hence porosity function is a unity. The formula is most suitable for medium-grain sand with uniformity coefficient less than 5 (Cheng *et al.* 2007).

$$K = \frac{g}{\nu} * 4.8 * 10^{-4} d^{0.3}{}_{20}$$

Justine Odong (2008) validated several empirical equations to calculate hydraulic conductivity using grain size distribution of unconsolidated aquifer materials. Grading analysis of soil samples extracted from test holes during groundwater investigation project was performed to determine their classification and particle size distribution characteristics; from which hydraulic conductivities were computed. Results showed that all the seven empirical formulae reliably estimated hydraulic conductivities of the various soil samples well within the known ranges. Kozeny Carman formula proved to be the best estimator of most samples analyzed, and may be, even for a wide range of other soil types. However, some of the formulae underestimated or overestimated hydraulic conductivity; even of the same soils.

Materials and Methods

CHAPTER-III

MATERIALS AND METHODS

Various methods and techniques used in the data generation and validation are described in this chapter.

3.1 Description of study area

3.1.1 Location of the study

Field experiments were conducted at KCAET campus, Tavanur. It comes under Malappuram District of Kerala State in India. It is situated at 10^0 52'30" North Latitude and 76^0 East Longitude.

3.1.2 Climate

Agro-climatically the area falls within the border line of northern zone, central zone and kole lands of Kerala. The average rainfall received in the area is about 2900 mm. and has a humid climate. Medium to high rainfall zones rainfall area are available within 10-15 km of the area. The area receives the rainfall mainly from south-west monsoon and north-east monsoon. The average maximum temperature of the study area was 32^oC and the average minimum temperature was 23^oC.

3.2 Experimental details

3.2.1 Preparation of soil sample

3.2.1.1 Sampling procedure

Ten samples were collected from two different locations of the study area. Five samples were collected randomly from each location for the data generation. Another set of five samples were collected using core cutter from the same locations for the purpose of validation of the results.

Plate 3.1 Sampling procedure

3.2.1.2 Topography and land use pattern

Location I

The first location selected had a mildly undulating topography. Most of the area was uncultivated and loamy sand was found in this area. Some part of the location was cultivated with coconut and occasional tillage practices were adopted in this area.

Location II

The second location was near to the banks of Bharathapuzha where the soil had a sandy texture. No tillage practices were followed in the field.

3.2.2 Data generation

3.2.2.1 Particle size distribution

The percentage of various sizes of particles in the dry soil sample was found by a particle size analysis or mechanical analysis. Mechanical analysis was meant for the separation of a soil into its different size fractions.

3.2.2.2 Sieve analysis

In the BS and ASTM standards, the sieve sizes are given in terms of the number of openings per inch. The number of openings per square inch is equal to the square of the number of sieve. The sieves used for fine sieve analysis are: 2.0 mm, 1.0 mm, 600 µm, 300 µm, 212 µm, 150 µm, & 75 µm IS sieves. For this purpose about 1kg of soil was collected from each site after removing a top layer of 5 cm depth. The soil was dried in the oven and about 500g soil was taken for analysis each time.

Sieving was performed by arranging the various sieves one over the other in the order of their mesh openings-the largest aperture sieve being kept at the top and the smallest aperture sieve being kept at the bottom. A receiver was kept at the bottom and a cover was kept at the top of the whole assembly. The weighed oven dried soil sample was put on the top sieve, and whole assembly was fitted on a sieve shaking machine. The amount of shaking depends upon the shape and the number of particles. At least ten minutes of shaking was done for soils with small particles. The portion of the soil sample retained on each sieve was weighed. The percentage of soil retained on each sieve was calculated on the basis of the total mass of the soil sample taken and from these results; percentage passing through each sieve was calculated.

Plate 3.2 Sieve analysis setup

3.2.2.3 Particle size distribution curve

The results of the mechanical analysis are plotted to get a particle size distribution curve with the percentage finer (N) as the ordinate and the particle diameter as the abscissa, the diameter being plotted on a logarithmic scale.

3.2.2.4 Porosity

The volumetric moisture content at saturation was determined by placing the soil cores vertically for about 24 hours in a water plate. This period was enough to saturate the soil pores by capillary rise. Then the soil core was left for about half an hour on a porous plate under zero pressure head to ensure that all the free water has been drained out before weighing it. The cores used for this purpose were of 12.5 cm in length and 10 cm in diameter. The core samplers were so selected that it will allow adequate capillary rise to make the sample saturated. The volumetric water content at saturation will give the porosity. It is given by the equation

$$\phi = \frac{Vv}{V}.100$$

ϕ = porosity in percentage,

V_v = volume of voids (cm^3),

V = total volume (cm^3).

The porosity value can also be calculated from the relation

$$n = \frac{e}{1+e}$$

where e is the voids ratio and is calculated as follows

$$e = \frac{G\gamma_w}{\gamma_d} - 1$$

G= specific gravity,

γ_w = unit weight of water ($9.81 kN/m^3$),

γ_d =dry unit weight of soil sample (N/m^3).

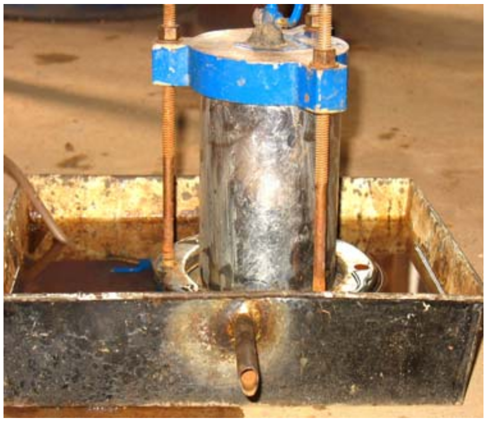

Plate 3.3 Soil sample kept for saturation in water plate

3.2.2.5 Specific gravity

Specific gravity of soil was found using a pycnometer. In this case the mass of empty, dry pycnometer M_1 was taken. About 250 g of oven dried sample was put in it and weighed to find mass M_2. Then it was filled with distilled water gradually, removing all entrapped air. Then the mass M_3 of the bottle, soil and water was taken. Finally, the pycnometer was emptied completely and thoroughly washed and clean water was filled to the top and the mass M_4 was taken. Then specific gravity G is given by

$$G = \frac{(M_2 - M_1)}{(M_2 - M_1) - (M_3 - M_4)}$$

Plate 3.4 Pycnometer for specific gravity determination

3.2.2.6 Constant head permeability test

A core cutter consisting of a steel cutter, 10 cm in diameter and 12.5 cm high, and a 2.5 cm high dolly was driven in the cleaned surface with the help of a rammer, till about 1 cm of the dolly protruded above the surface. The cutter, containing the soil, was dug out of the ground. The dolly was then removed and the excess soil was trimmed off. The sample was kept for saturation. After saturation it was placed in the mould assembly in the bottom tank and the bottom tank was filled with water up to its outlet. The outlet tube of the constant head tank was connected to the inlet nozzle of the permeameter, after removing the air in the flexible rubber tubing connecting the two. The hydraulic head was kept constant by adjusting the flow to the tank. The stop watch was started and at the same time a beaker was put under the outlet of the bottom tank. The test was run for a particular time interval and the quantity of water collected in the beaker during that time was measured. Then the coefficient of permeability (k) is given by

$$k = \frac{Q}{t} . \frac{L}{h} . \frac{1}{A}$$

where

Q = quantity of flow (m^3/s),

L = length of sample (m),

t = time interval (s),

h = hydraulic head (m),

A = cross sectional area of the sample (m^2).

Plate 3.5 Constant head permeability test

3.2.2.7 Falling head permeability test

The permeameter mould assembly was kept in the bottom tank and the bottom tank was filled with water up to its outlet. The water inlet nozzle of the mould was connected to the stand pipe filled with water. Water was permitted to flow till a steady state of flow was reached. The time interval required for water level in the standpipe to fall from a particular initial value to a particular final value was measured with the help of a stopwatch. Then the coefficient of permeability k is given by

$$k = \frac{aL}{At} . \ln \frac{h_1}{h_2}$$

where

a = area of stand pipe (m^2),

A = cross sectional area of the sample (m^2),

L = length of sample (m),

h_1 = initial head (m),

h_2 = final head (m),

t = time interval (s).

Plate 3.6 Falling head permeability test

3.3 Data analysis

3.3.1 Correlation of porosity with sorting

Sorting coefficient is the quantitative measure of sorting. Sorting is usually expressed as qualitatively ranging from extremely well sorted to very poorly sorted. Sorting coefficient is obtained from the particle size distribution curve. The sorting coefficient is defined as follows (Folk *et al*. (1957) and Jorden *et al*. (1984))

$$So = \left[\frac{d_{25}}{d_{75}}\right]^{\frac{1}{2}}$$

The grain size distribution was approximated by a log normal distribution. The grain size was then expressed as follows

$$y = \ln d$$

$$y = \mu + \sqrt{2}\sigma erfinv\left[2P\{y\} - 1\right]$$

Or

$$y = \mu + \sqrt{2}\sigma erfinv\left[1 - 2P\{y\}\right]$$

where

μ is the median of the distribution

σ is the standard deviation of the log normal distribution

The choice of above two expressions were made depending on whether the cumulative probability corresponds to less than grain size d or greater than grain size d. the sorting coefficient is then expressed in terms of logarithm of the grain diameter at the 25 and 75 percentile.

$$S_o = e^{\left(\frac{y_{25} - y_{75}}{2}\right)}$$

$$y_{25} - y_{75} = \sqrt{2}\sigma\left[erfinv(0.5) - erfinv(-0.5)\right]$$

$$S_o = e\left(0.6744\sigma\right)$$

$$\sigma = \frac{\ln S_o}{0.6744}$$

The standard deviation of the logarithm grain size distribution was plotted against measured and calculated porosity values and a relationship was established between them.

3.3.2 Hydraulic conductivity from grain size distribution

3.3.2.1 Kozeny Carman model

The soil sample was considered to be a homogenous porous medium which was assumed to be a packed bed of uniform spheres. Hence the particle diameter, D_p, can be related to the permeability and porosity. Kozeny Carman relation yields an equation for the permeability as a function of the particle diameter and porosity (Beard *et al.* (1973))

$$k = \frac{\phi^3 D_p{}^2}{150(1-\phi)^2}$$

where

k = permeability (cm^2),

ϕ = porosity,

D_p = particle diameter (m).

3.3.2.1.1 Average diameter of a group of particles

A given mass of granular soil constitutes particles of different sizes. One of the common methods to interpret the average diameter of particle is the harmonic mean method. It was done by plotting two sets of particle size distribution curves: (i) curve between percentage finer N and log D, and (ii) curve between percentage finer N and (1/D). The usual particle size distribution curve was plotted between N and D on the semi-logarithm graph. On the same sheet a curve was plotted between (1/D) and N (curve II). The area below the curve II was converted into a rectangle of height N=100 % by a vertical line such that the area above and below the curve within the rectangle was equal. This was done by trial and error. The vertical line cut the curve II at a point which was corresponding to the harmonic mean diameter. Then a horizontal line was drawn to intersect curve I at a point. This point was projected downwards on the log scale to get the required harmonic mean diameter.

3.3.2.2 Alyamani and Sen model

A normal plot of the grain size distribution was plotted in order to get an initial slope and intercept of the entire grain-size distribution curve. I_0 was related to hydraulic conductivity to yield an equation

$$K = 1300\left[I_o + 0.025\left(D_{50} - D_{10}\right)\right]^2$$

where

K = expressed in m/day,

I_o = the X-intercept of the straight line formed by joining D_{50} and D_{10} of the grain size distribution curve (mm),

D_{50}= the mean grain-size for which 50% of the particles are finer by weight (mm).

3.3.3 Comparison of predicted and measured permeability

The permeability values obtained from grain size distribution were compared with those obtained from (i) constant head permeability test and (ii) falling head permeability test. A graph was plotted between predicted permeability and measured permeability.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

Grain size methods are comparably less expensive method for determination of hydraulic conductivity and do not depend on the geometry and hydraulic boundaries of the aquifer. Most importantly, since information about the textural properties of soils are more easily obtained, potential alternative for estimating hydraulic conductivity of soils is predicting it from grain size distribution. The salient features of observation and results obtained from the study conducted for developing a relationship between standard deviation of log normal distribution of grain size and porosity, prediction of hydraulic conductivity from grain size using the two models and its comparison with laboratory methods are discussed in this chapter.

4.1 Sieve Analysis

Sieve analysis of soil samples collected from locations I and II were performed as per the procedure given in the section 3.2.2.2. And the results were plotted to get a particle size distribution curve. The d_{25} and d_{75} values were obtained from the curve and sorting coefficient S_o was calculated for each sample. Consequently the standard deviation of logarithm of grain size distribution was found as explained in section 3.3.1.

Table 4.1 Sieve analysis data for sample No. 1.1

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	147.5	29.5	29.5	70.5
2	1mm	1	87.5	17.5	47	53
3	600μm	0.6	78.5	15.7	62.7	37.3
4	300μm	0.3	77	15.4	78.1	21.9
5	212μm	0.212	55.05	11.01	89.11	10.89
6	150μm	0.15	10.62	2.124	91.234	8.766
7	75μm	0.075	24.6	4.92	96.154	3.846
8	pan	< 0.075	19.72	3.944	100.098	-0.098
			500.49			

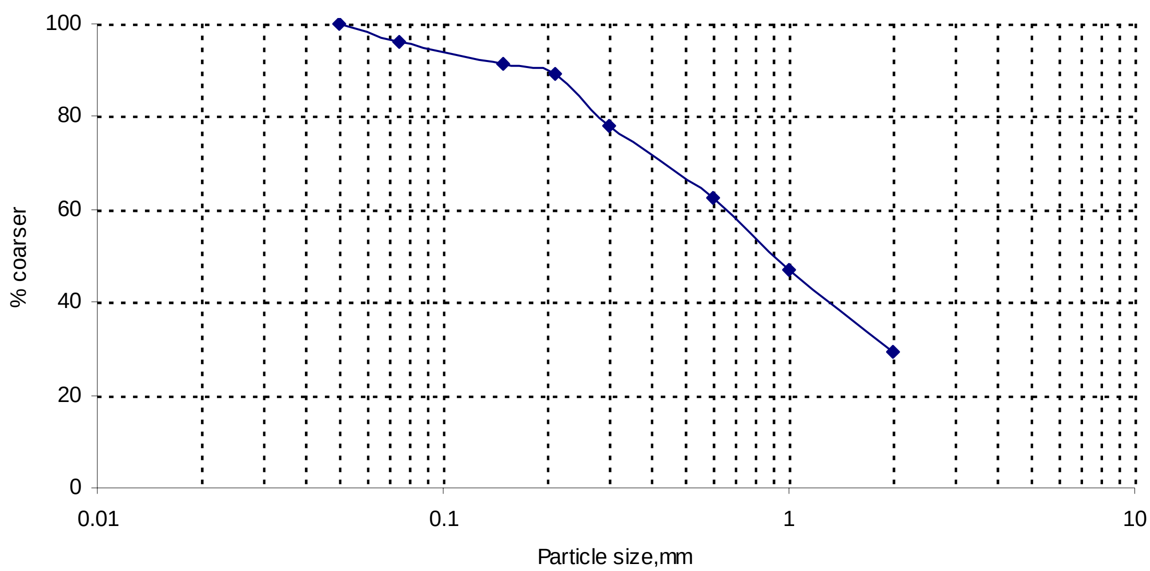

Fig. 4.1 Particle size distribution curve for sample No. 1.1

Table 4.2 Sieve analysis data for sample No. 1.2

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	137.65	27.53	27.53	72.47
2	1mm	1	74.72	14.944	42.474	57.526
3	600µm	0.6	65.03	13.006	55.48	44.52
4	300µm	0.3	71.18	14.236	69.716	30.284
5	212µm	0.212	68.92	13.784	83.5	16.5
6	150µm	0.15	14.96	2.992	86.492	13.508
7	75µm	0.075	36.9	7.38	93.872	6.128
8	pan	< 0.075	31.07	6.214	100.086	-0.086
			500.43			

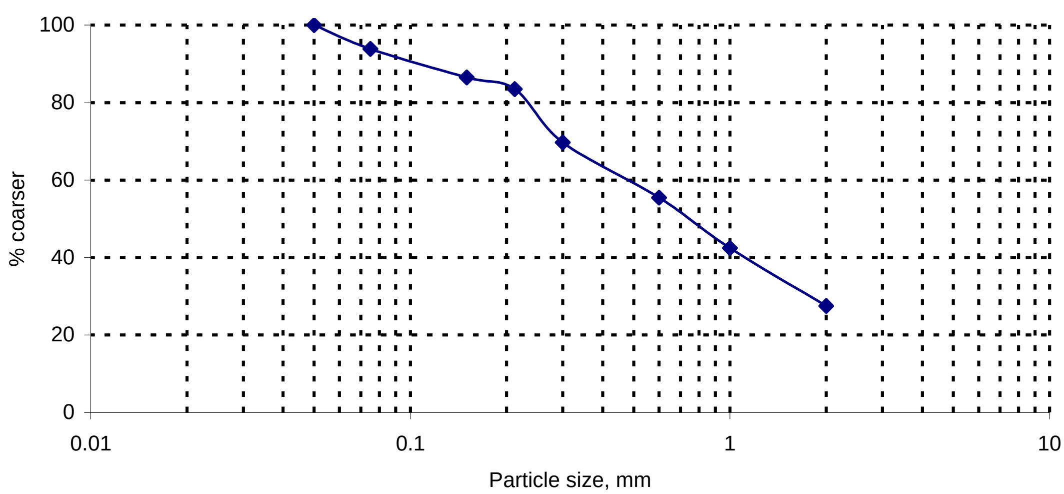

Fig. 4.2 Particle size distribution curve for sample No. 1.2

Table 4.3 Sieve analysis data for sample No. 1.3

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	140.52	28.104	28.104	71.896
2	1mm	1	84.55	16.91	45.014	54.986
3	600µm	0.6	78.77	15.754	60.768	39.232
4	300µm	0.3	80.23	16.046	76.814	23.186
5	212µm	0.212	62.52	12.504	89.318	10.682
6	150µm	0.15	12	2.4	91.718	8.282
7	75µm	0.075	24.87	4.974	96.692	3.308
8	pan	< 0.075	18.85	3.77	100.462	-0.462
			502.31			

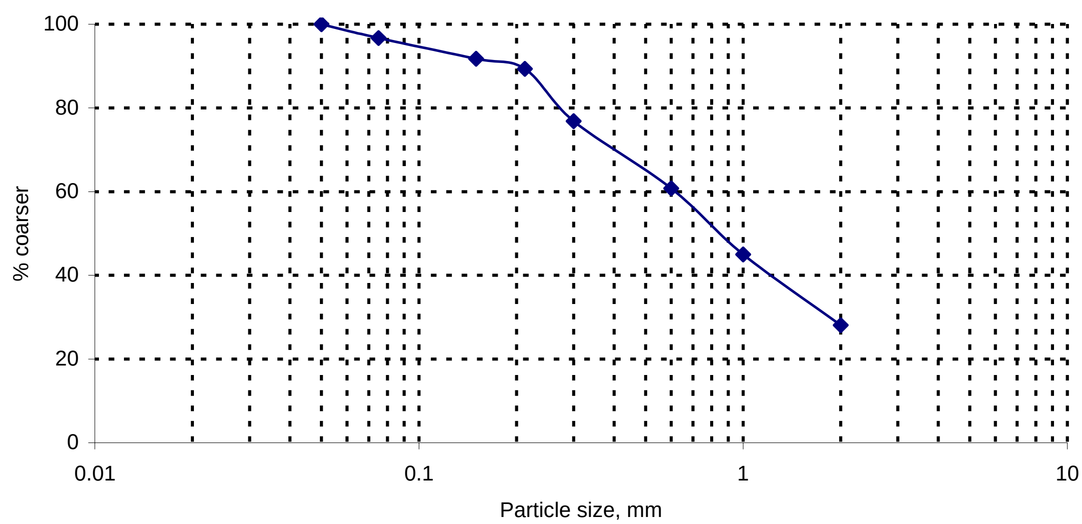

Fig. 4.3 Particle size distribution curve for sample No. 1.3

Table 4.4 Sieve analysis data for sample No. 1.4

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	136.29	27.258	27.258	72.742
2	1mm	1	83.08	16.616	43.874	56.126
3	600µm	0.6	77.7	15.54	59.414	40.586
4	300µm	0.3	86.75	17.35	76.764	23.236
5	212µm	0.212	76.36	15.272	92.036	7.964
6	150µm	0.15	15.39	3.078	95.114	4.886
7	75µm	0.075	20.84	4.168	99.282	0.718
8	pan	< 0.075	7.37	1.474	100.756	-0.756
			503.78			

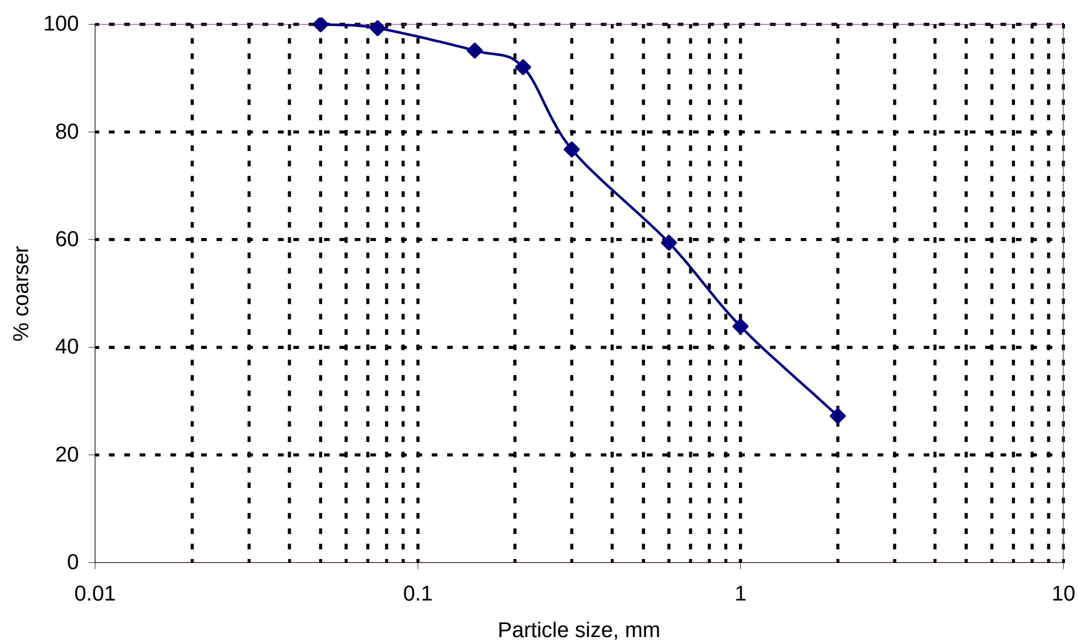

Fig. 4.4 Particle size distribution curve for sample No. 1.4

Table 4.5 Sieve analysis data for sample No. 1.5

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	133.64	26.728	26.728	73.272
2	1mm	1	82.03	16.406	43.134	56.866
3	600µm	0.6	72.19	14.438	57.572	42.428
4	300µm	0.3	76.04	15.208	72.78	27.22
5	212µm	0.212	75.72	15.144	87.924	12.076
6	150µm	0.15	13.71	2.742	90.666	9.334
7	75µm	0.075	30.82	6.164	96.83	3.17
8	pan	< 0.075	19.14	3.828	100.658	-0.658
			503.29			

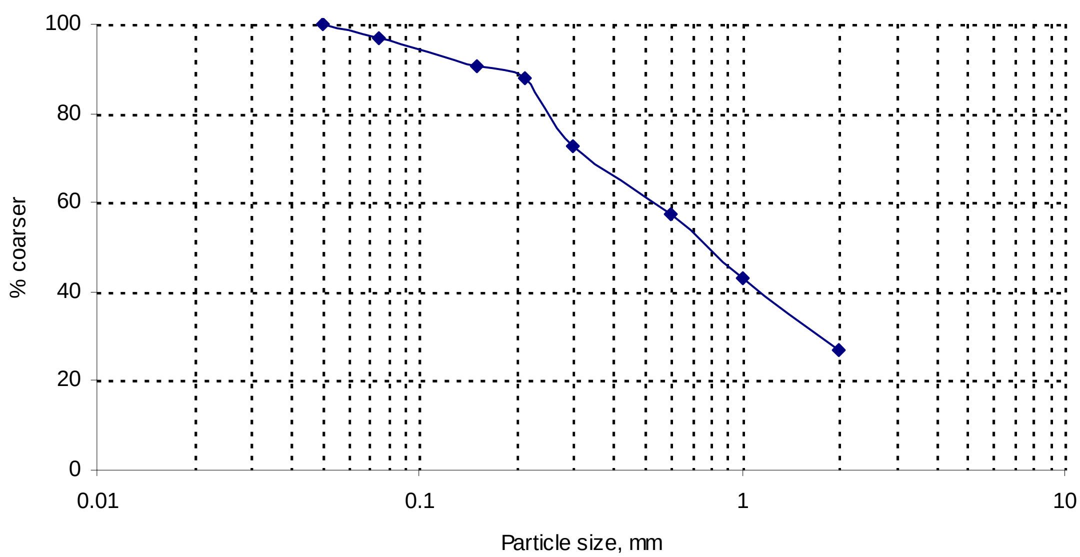

Fig. 4.5 Particle size distribution curve for sample No. 1.5

Table 4.6 Sieve analysis data for sample No. 2.1

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	14.7	2.94	2.94	97.06
2	1mm	1	15.59	3.118	6.058	93.942
3	600µm	0.6	13.83	2.766	8.824	91.176
4	300µm	0.3	25.41	5.082	13.906	86.094
5	212µm	0.212	194.38	38.876	52.782	47.218
6	150µm	0.15	27	5.4	58.182	41.818
7	75µm	0.075	159.6	31.92	90.102	9.898
8	pan	< 0.075	48.85	9.77	99.872	0.128
			499.36			

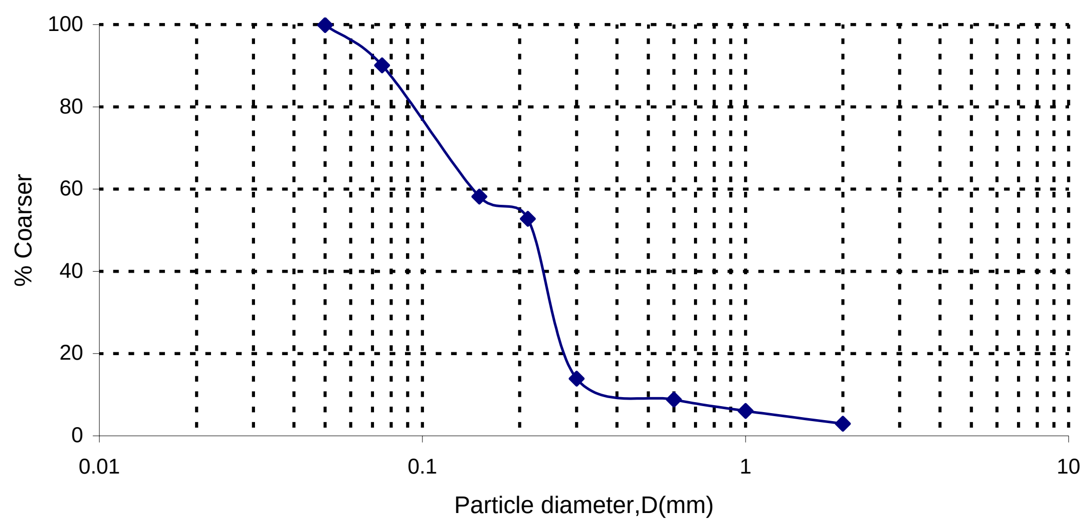

Fig. 4.6 Particle size distribution curve for sample No. 2.1

Table 4.7 Sieve analysis data for sample No. 2.2

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	11.47	2.294	2.294	97.706
2	1mm	1	13.4	2.68	4.974	95.026
3	600µm	0.6	16.15	3.23	8.204	91.796
4	300µm	0.3	26.71	5.342	13.546	86.454
5	212µm	0.212	183.33	36.666	50.212	49.788
6	150µm	0.15	38.43	7.686	57.898	42.102
7	75µm	0.075	166.85	33.37	91.268	8.732
8	pan	< 0.075	43.72	8.744	100.012	-0.012
			500.06			

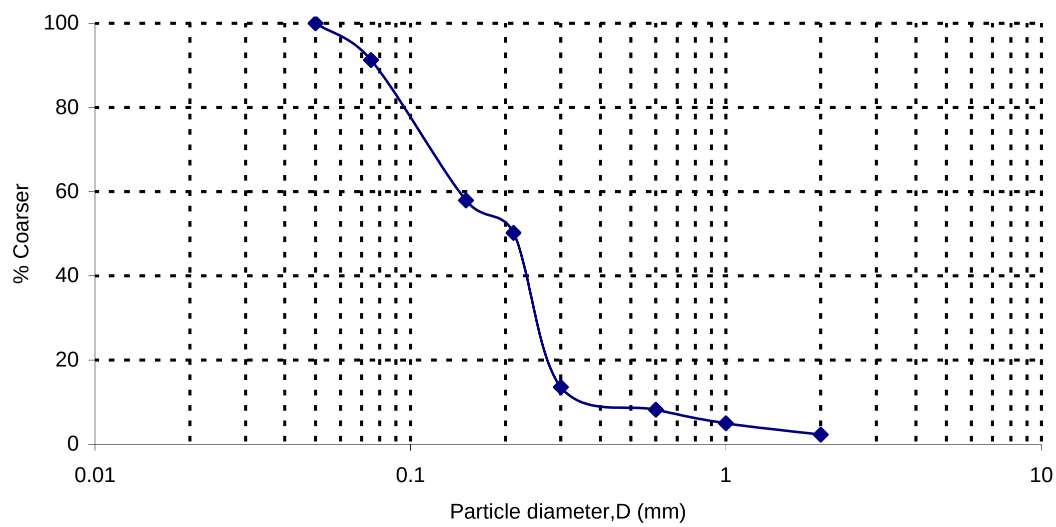

Fig. 4.7 Particle size distribution curve for sample No. 2.2

Table 4.8 Sieve analysis data for sample No. 2.3

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	13.0583	2.61166	2.61166	97.38834
2	1mm	1	14.49	2.898	5.50966	94.49034
3	600µm	0.6	14.99	2.998	8.50766	91.49234
4	300µm	0.3	26.06	5.212	13.71966	86.28034
5	212µm	0.212	188.86	37.772	51.49166	48.50834
6	150µm	0.15	32.72	6.544	58.03566	41.96434
7	75µm	0.075	163.3	32.66	90.69566	9.30434
8	pan	< 0.075	46.29	9.258	99.95366	0.04634
			499.7683			

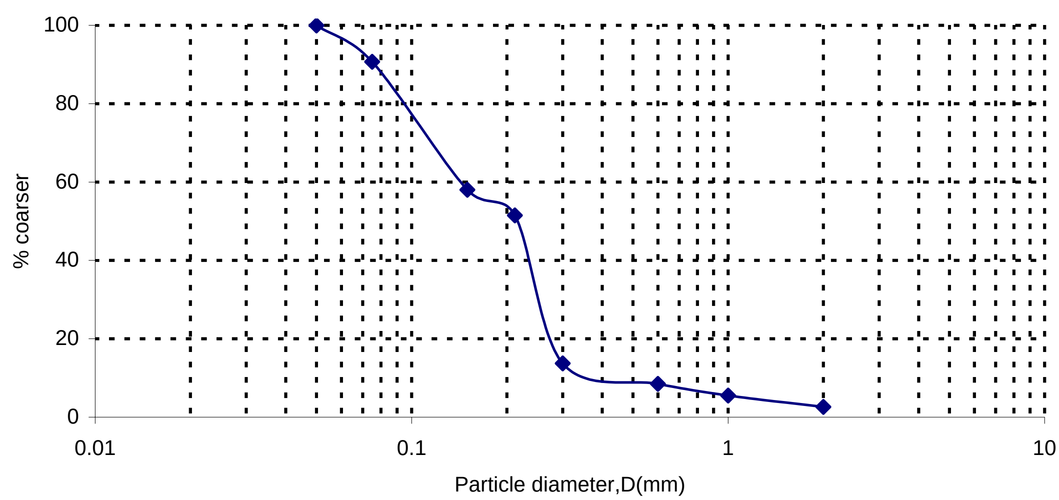

Fig. 4.8 Particle size distribution curve for sample No. 2.3

Table 4.9 Sieve analysis data for sample No. 2.4

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	12.46	2.492	2.492	97.508
2	1mm	1	15.32	3.064	5.556	94.444
3	600µm	0.6	13.8	2.76	8.316	91.684
4	300µm	0.3	27.61	5.522	13.838	86.162
5	212µm	0.212	185.96	37.192	51.03	48.97
6	150µm	0.15	33.21	6.642	57.672	42.328
7	75µm	0.075	168.59	33.718	91.39	8.61
8	pan	< 0.075	42.76	8.552	99.942	0.058
			499.71			

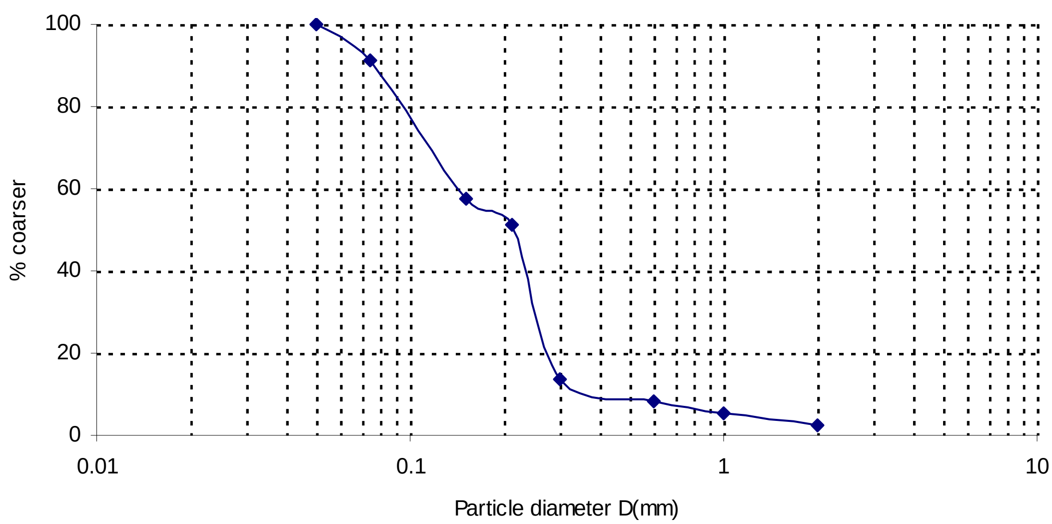

Fig. 4.9 Particle size distribution curve for sample No.2.4

Table 4.10 Sieve analysis data for sample No. 2.5

Sl No:	IS Sieve	Particle size D (mm)	Mass retained (g)	Percentage retained	Cumulative % retained	Cumulative % finer (N)
1	2mm	2	11.1	2.22	2.22	97.78
2	1mm	1	18.13	3.626	5.846	94.154
3	600µm	0.6	12.46	2.492	8.338	91.662
4	300µm	0.3	28.31	5.662	14.000	86
5	212µm	0.212	184.87	36.974	50.974	49.026
6	150µm	0.15	32.78	6.556	57.53	42.47
7	75µm	0.075	169.05	33.81	91.34	8.66
8	pan	< 0.075	43.36	8.672	100.012	-0.012
			500.06			

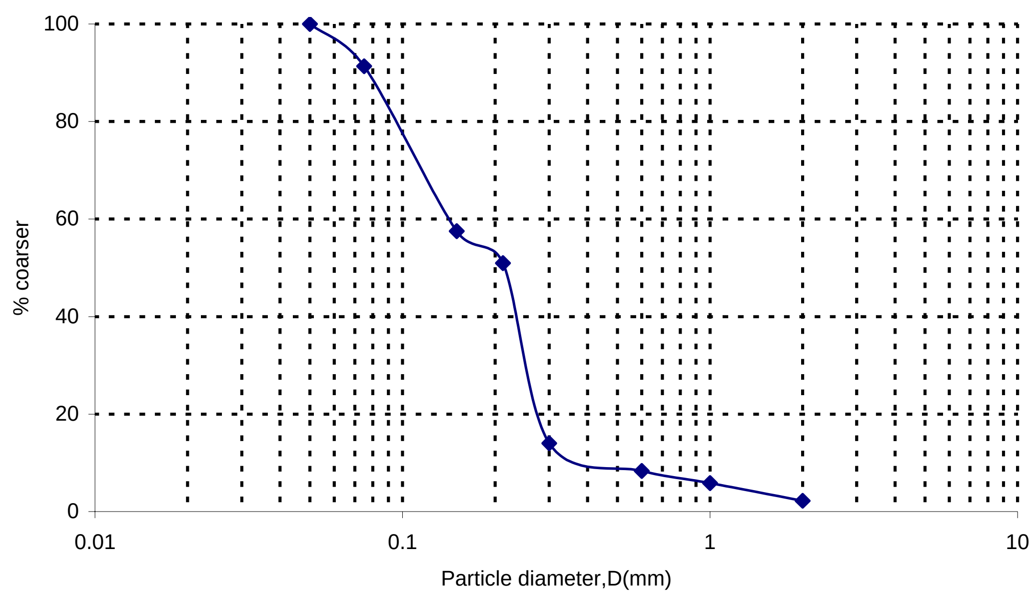

Fig. 4.10 Particle size distribution curve for sample No. 2.5

Table 4.11 Standard deviation of the logarithm of grain size distribution

Sample No.	d_{25}	d_{75}	S_0	σ
1.1	2.2	0.35	2.507	1.362
1.2	2.1	0.25	2.898	1.577
1.3	2.1	0.32	2.561	1.394
1.4	2.1	0.3	2.645	1.442
1.5	2.0	0.29	2.626	1.431
2.1	0.28	0.10	1.673	0.763
2.2	0.26	0.11	1.537	0.637
2.3	0.26	0.10	1.612	0.708
2.4	0.27	0.11	1.566	0.665
2.5	0.27	0.11	1.566	0.6654

The transformation from the sorting coefficient S_o to qualitative sorting is given in Appendix I. From this it was interpreted that the samples collected from location I were poorly sorted while that from location II were moderately sorted.

4.2 Porosity of soil samples

Porosity of the samples was determined as per the procedure given in the section 3.2.2.4. Data for the calculations are given in Appendix II and the results are as tabulated below.

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Table 4.12 Measured porosity of the soil samples

Sample No.	Total volume(cm^3)	Volume of voids(cm^3)	Porosity (%)
1.1	981.7	378	38.50
1.2	981.7	380	38.71
1.3	981.7	360	36.67
1.4	981.7	359	36.57
1.5	981.7	374	38.10
2.1	981.7	366	37.28
2.2	981.7	373	38.00
2.3	981.7	376	38.30
2.4	981.7	350	35.65
2.5	981.7	345	35.14

Table 4.13 Calculated porosity of the soil samples

Sample No.	Specific gravity, G	Unit weight of water g/cc	Dry unit weight of soil γ_d , g/cc	Voids ratio, e	Porosity, n
1.1	2.67	1	1.73	0.543	35.20
1.2	2.68	1	1.75	0.531	34.70
1.3	2.77	1	1.98	0.399	28.50
1.4	2.63	1	1.97	0.335	25.10
1.5	2.68	1	1.96	0.367	26.90
2.1	2.68	1	1.59	0.686	40.70
2.2	2.68	1	1.75	0.531	34.70
2.3	2.58	1	1.63	0.583	36.80
2.4	2.55	1	1.65	0.545	35.30
2.5	2.63	1	1.69	0.556	35.70

4.3 Correlation of porosity with sorting

The standard deviation of the logarithm grain size distribution was plotted against measured and calculated porosity values and a relationship was established between them.

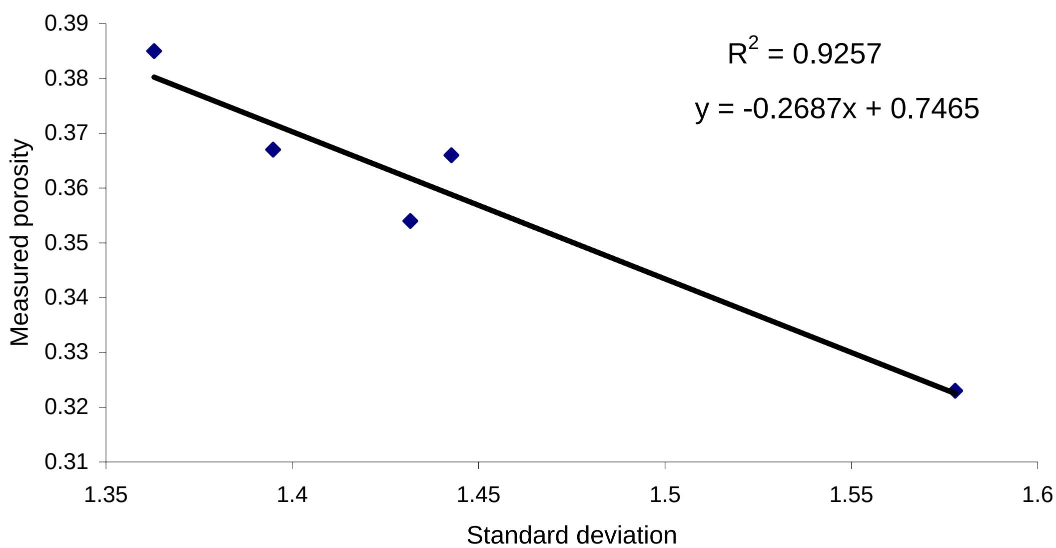

Fig. 4.11 Correlation of measured porosity with sorting for location I

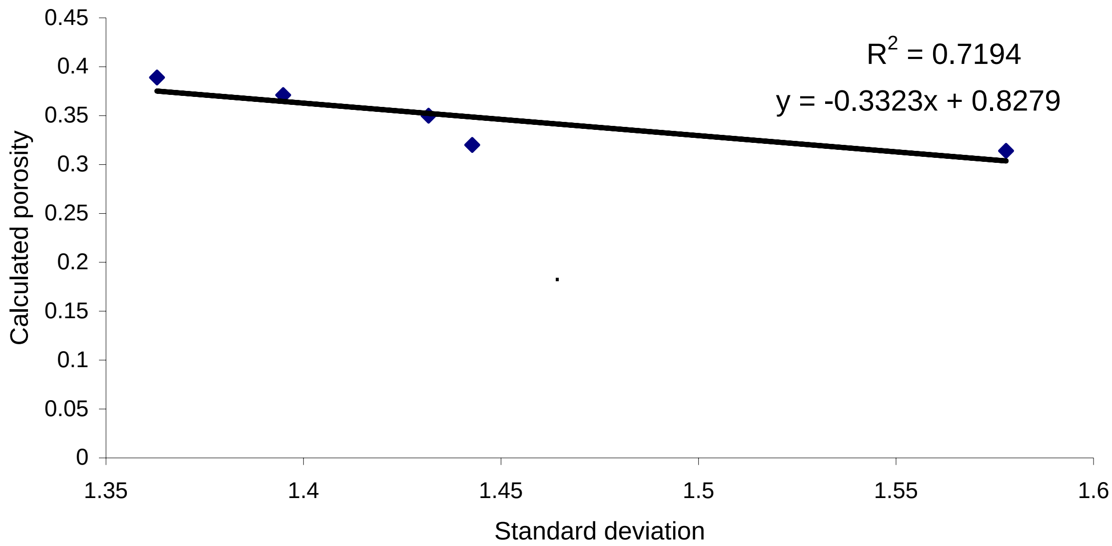

Fig. 4.12 Correlation of calculated porosity with sorting for location I

The regression of porosity with standard deviation for the observed data yielded the following linear relationships. For the measured porosity the relationship was found to be

$$\phi = 0.746 - 0.2687\sigma \ , (R^2=0.9257)$$

For the calculated porosity the relationship obtained was

$$\phi = 0.8279 - 0.3323\sigma \, , (R^2=0.7194)$$

The slight variations in the above equations are because of the variations in porosity. There are various factors which influence porosity resulting in wide variations from the actual one. The porosity of unconsolidated materials depends on the packing of the grains, their shape, arrangement, and the size distribution. It may be also due to tillage and compaction effects which needs further study.

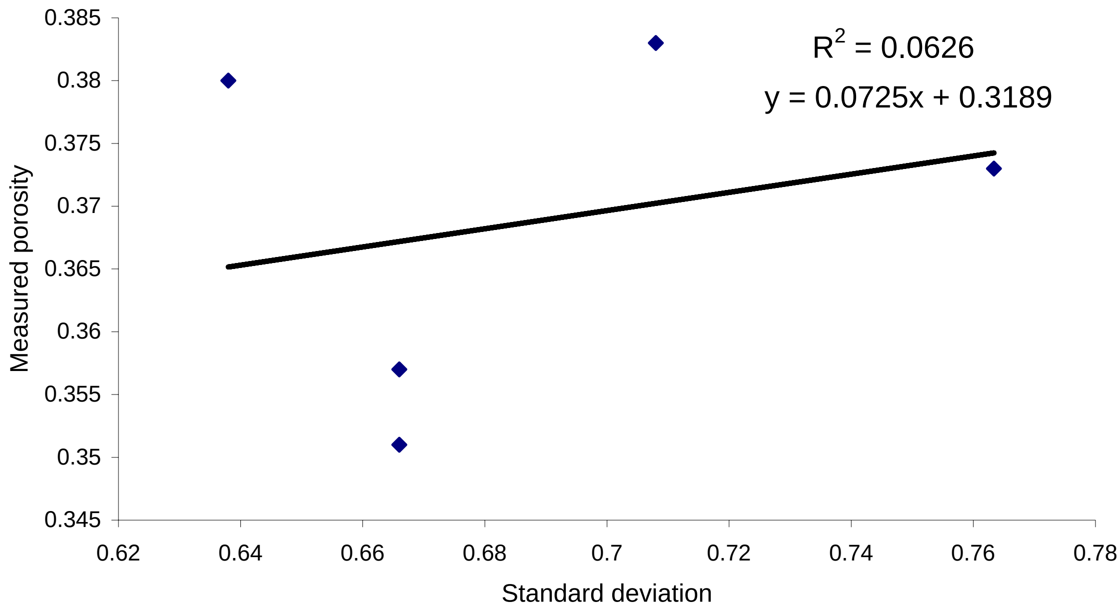

Fig. 4.13 Correlation of measured porosity with sorting for location II

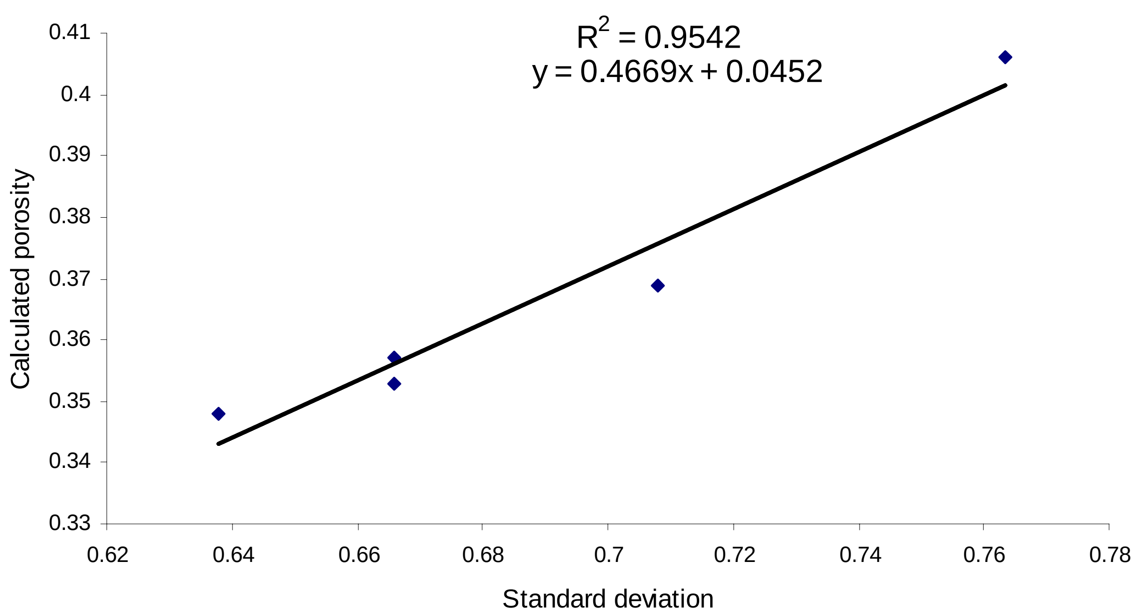

Fig. 4.14 Correlation of measured porosity with sorting for location II

The regression of porosity with standard deviation for the observed dataset of location II yielded the following linear relationships. For the measured porosity the relationship was found to be

$\phi = 0.073\sigma + 0.3189$, ($R^2$=0.0626)

For the calculated porosity the relationship obtained was

$\phi = 0.467\sigma + 0.0452$, ($R^2$=0.9542)

Thus the calculated porosity was found to be more linear for moderately sorted soil. The variations in the results of measured porosity could be due to a phenomenon called bulking of sand. Bulking is a phenomenon which shows an increase in volume by 40 %.

Among the interconnected pores there are some classes of pores which contribute very little to the flow, called the dead-end pores or stagnant pockets. It is important to take into consideration these pores in certain mechanisms of flow. In fine textured porous media there are indications of an immobile or highly viscous water layer on the particle surface that makes calculated porosity much smaller than the measured one (Coats *et al.*(1964).

The particle size distribution may appreciably affect the resulting porosity as small particles may occupy pores formed between the large particles, thus reducing the porosity. Hence other parameters being equal, poorly sorted sediments will have a considerably lower porosity than well sorted ones.

4.4 Prediction of hydraulic conductivity from grain size distribution

4.4.1 Kozeny Carman model

Hydraulic conductivity was predicted using the grain size distribution parameters. For this the knowledge of average particle size was required which was found using the procedure as per section 3.3.2.1.

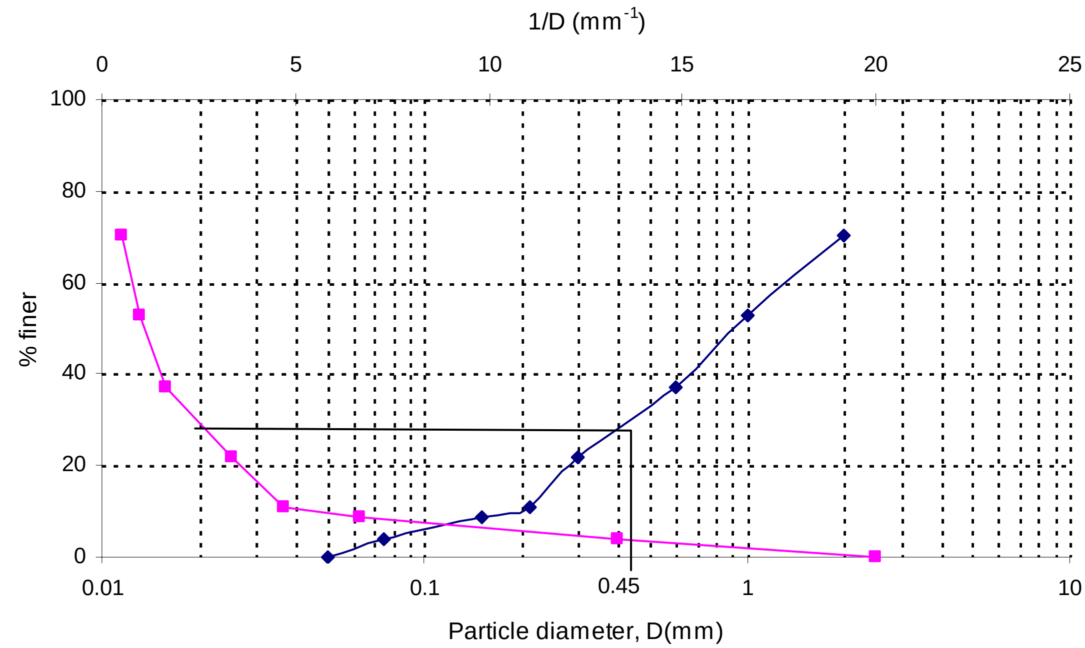

Fig. 4.15 Average particle diameter of sample No. 1.1

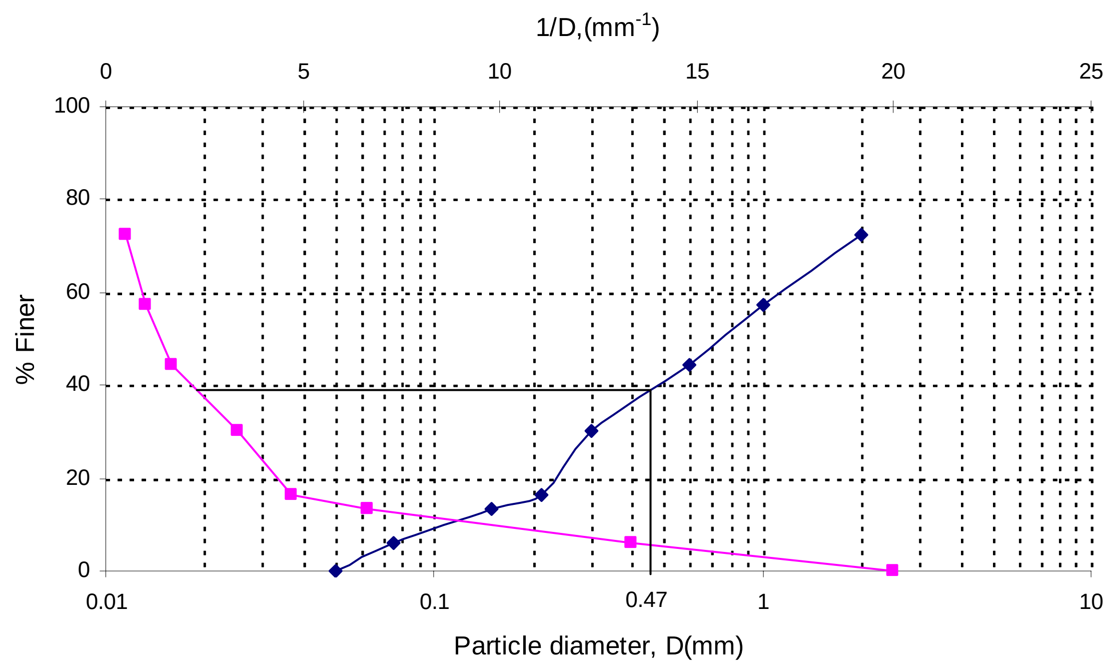

Fig. 4.16 Average particle diameter of sample No.1.2

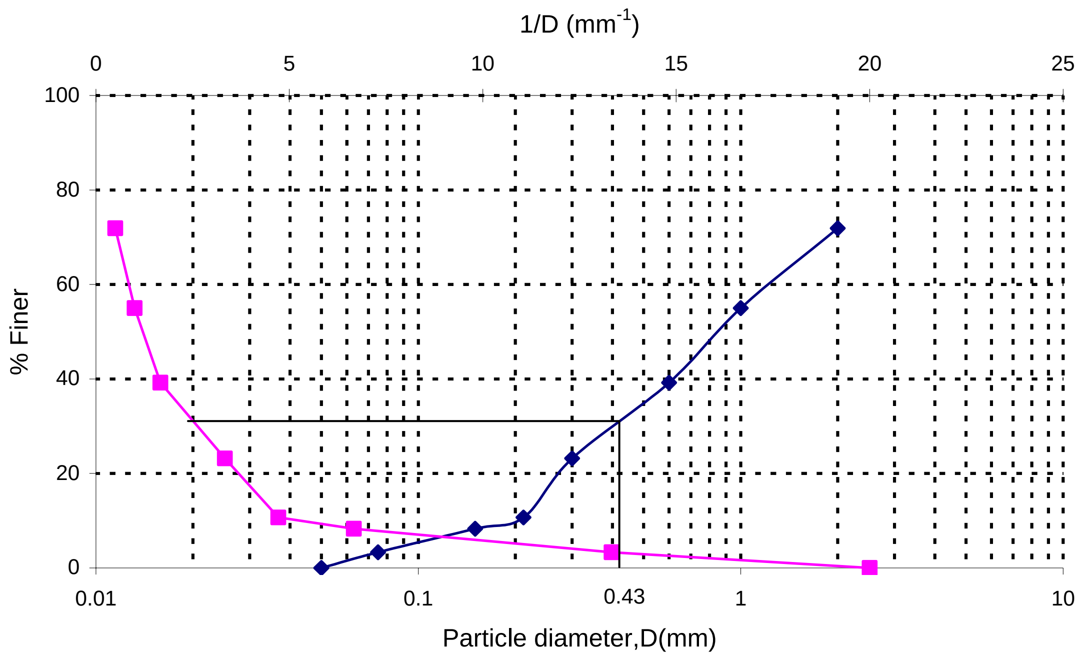

Fig. 4.17 Average particle diameter of sample No. 1.3

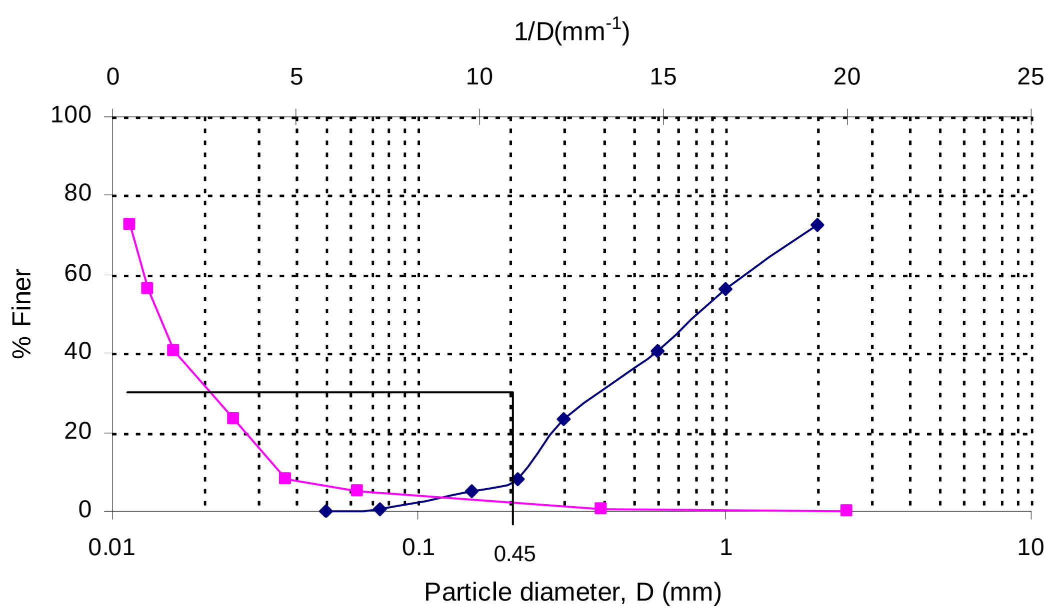

Fig.4.18 Average particle diameter of sample No. 1.4

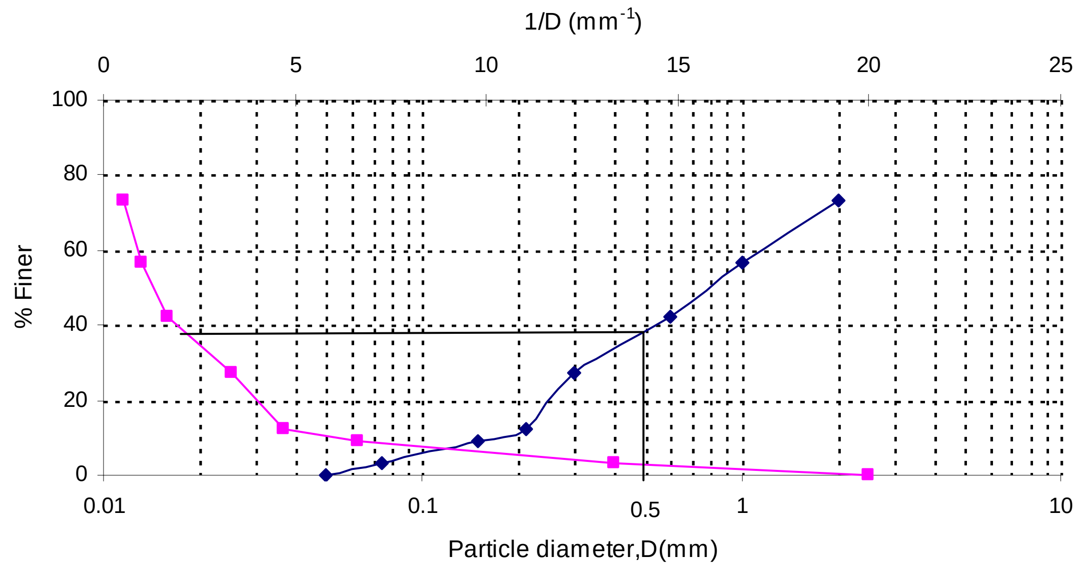

Fig. 4.19 Average particle diameter of sample No. 1.5

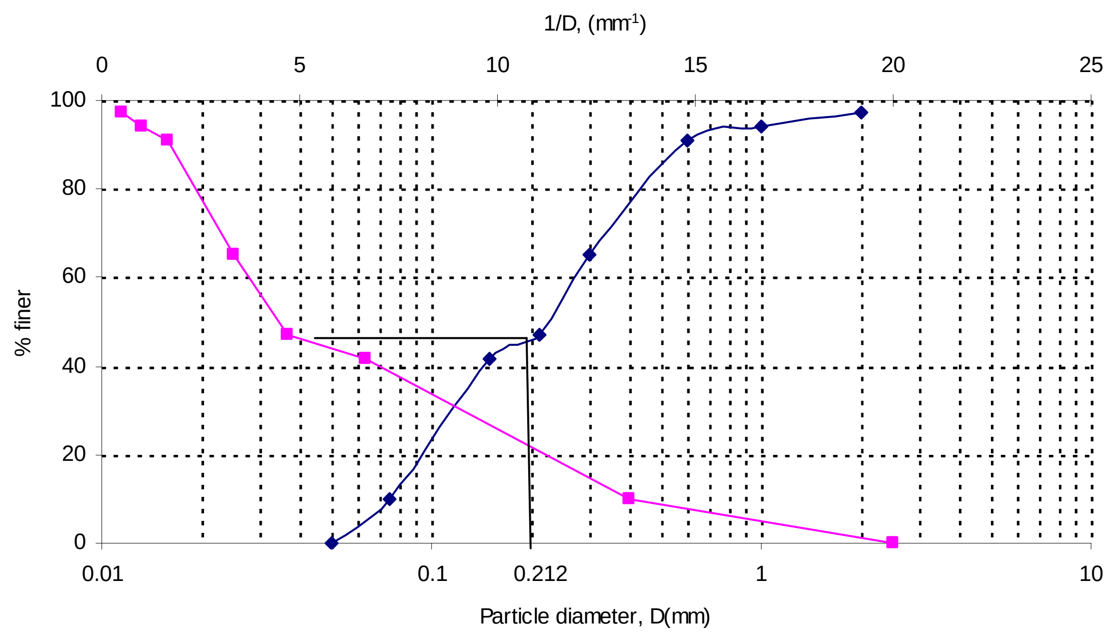

Fig. 4.20 Average particle diameter of sample No. 2.1

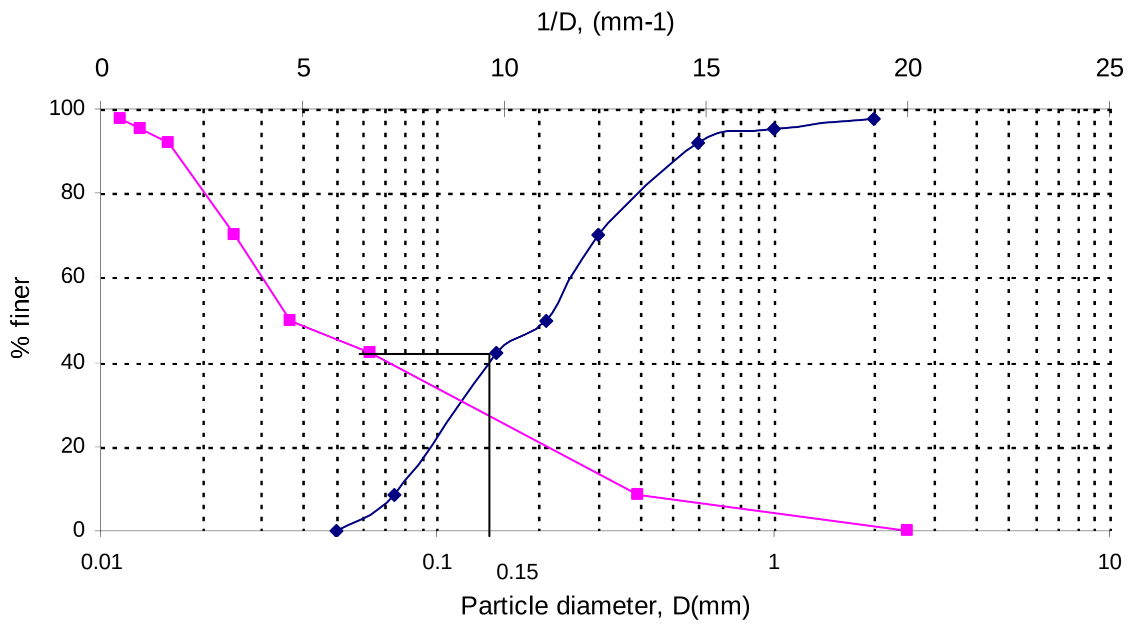

Fig. 4.21 Average particle diameter of sample No. 2.2

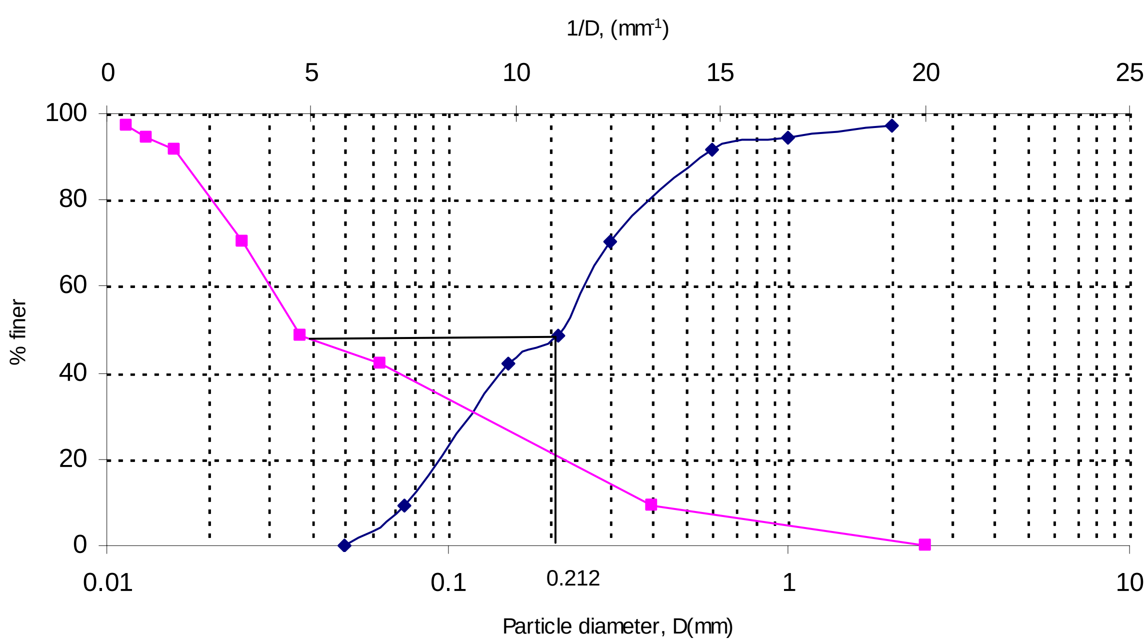

Fig. 4.22 Average particle diameter of sample No. 2.3

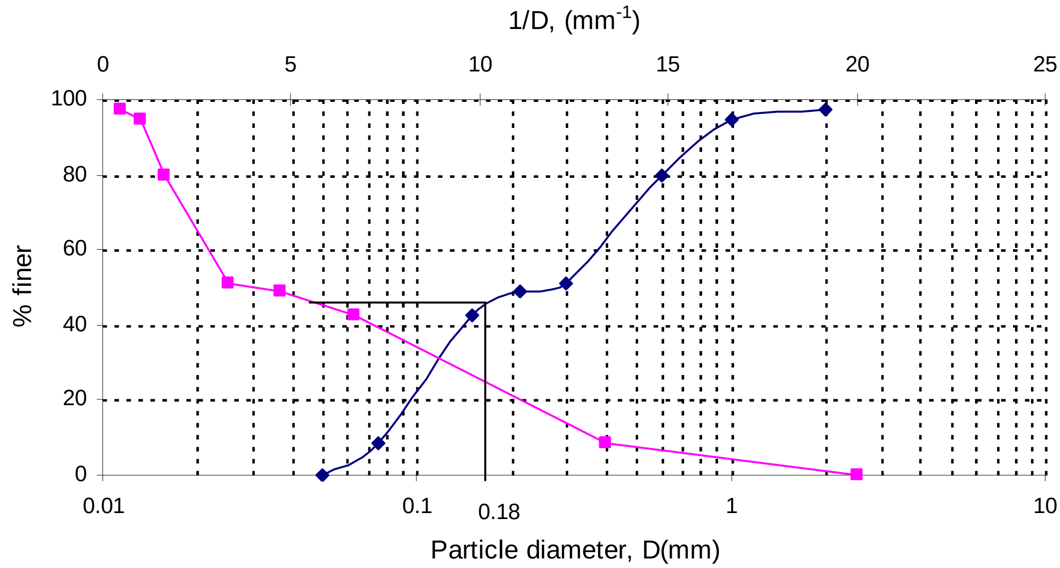

Fig. 4.23 Average particle diameter of sample No. 2.4

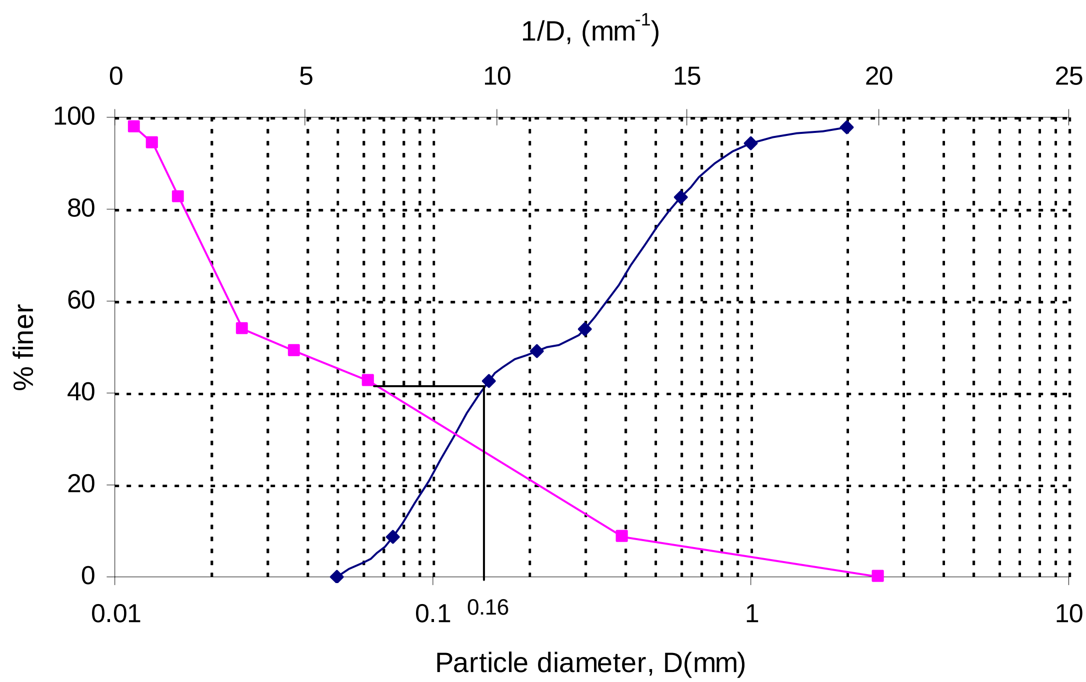

Fig. 4.24 Average particle diameter of sample No. 2.5

Table 4.14 Hydraulic conductivity based on Kozeny Carman model

Sample No	Measured porosity	Calculated porosity	D_p (cm)	K based on measured porosity (cm/s)	K based on calculated porosity (cm/s)
1.1	0.385	0.389	0.045	0.0023	0.0025
1.2	0.387	0.314	0.047	0.0026	0.0011
1.3	0.367	0.371	0.043	0.0018	0.0018
1.4	0.366	0.32	0.045	0.0019	0.0011
1.5	0.381	0.35	0.05	0.0028	0.0019
2.1	0.373	0.406	0.02	0.0004	0.0006
2.2	0.38	0.348	0.015	0.0002	0.0002
2.3	0.383	0.369	0.0212	0.0005	0.0004
2.4	0.357	0.353	0.018	0.0003	0.0003
2.5	0.351	0.357	0.016	0.0002	0.0002

This table depicts the coefficient of permeability based on measured porosity and calculated porosity of samples of both the locations was equal. Only very little variations were found and these may be due to negligence of the dead end pores. Also the Kozeny Carman model needs the determination of effective porosity which is very difficult to measure accurately.

4.4.2 Alyamani and Sen model

In this method the hydraulic conductivity was determined by using a normal plot of grain size distribution. For this, the percentage finer was plotted against the grain size using the 50th percentile and 10th percentile and it was extended towards the X axis to get the X-intercept. The coefficient of permeability was then obtained as per section 3.3.2.2.

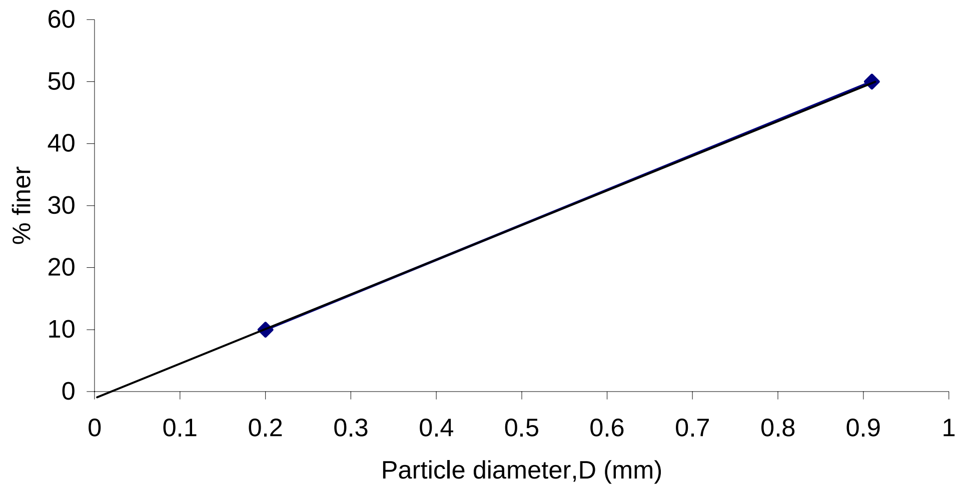

Fig. 4.25 Normal plot of grain size distribution for sample No. 1.1

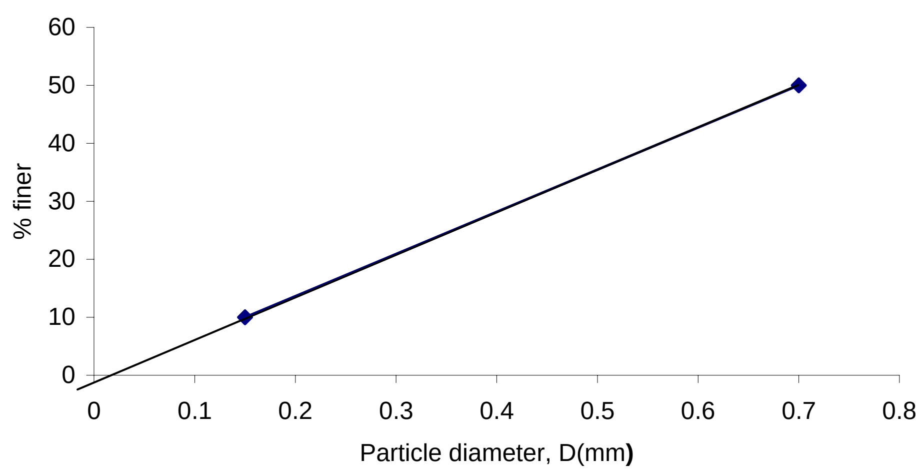

Fig. 4.26 Normal plot of grain size distribution for sample No. 1.2

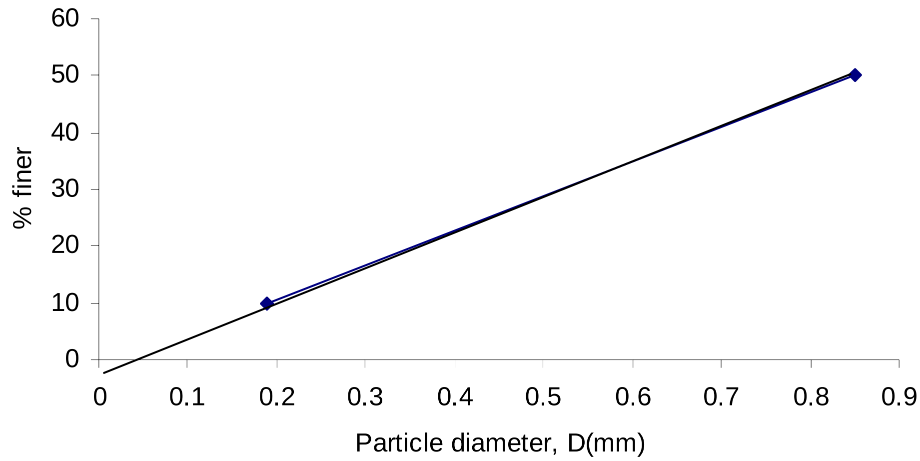

Fig. 4.27 Normal plot of grain size distribution for sample No. 1.3

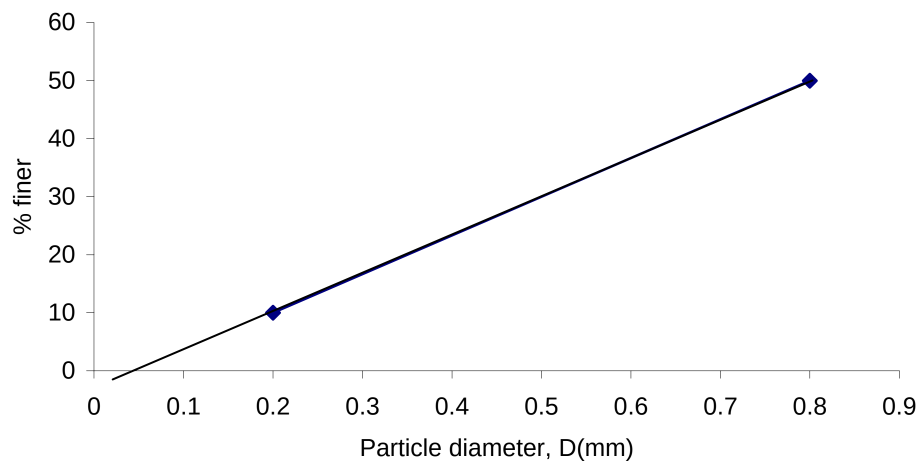

Fig. 4.28 Normal plot of grain size distribution for sample No. 1.4

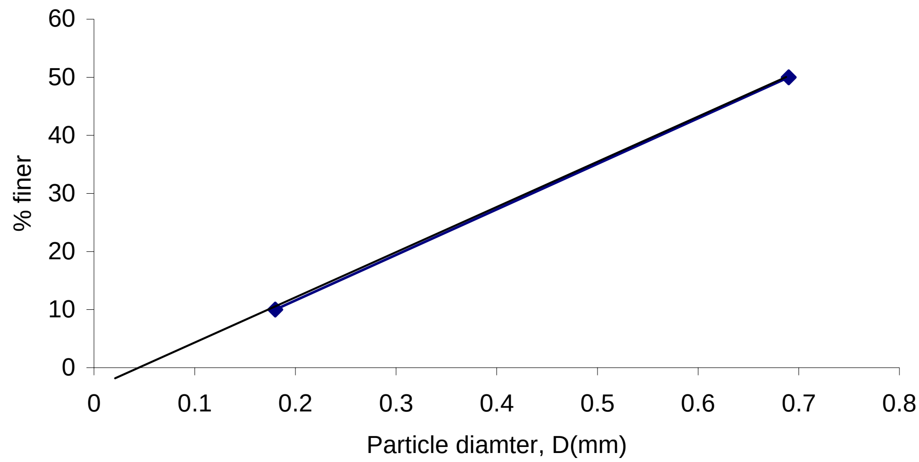

Fig. 4.29 Normal plot of grain size distribution for sample No. 1.5

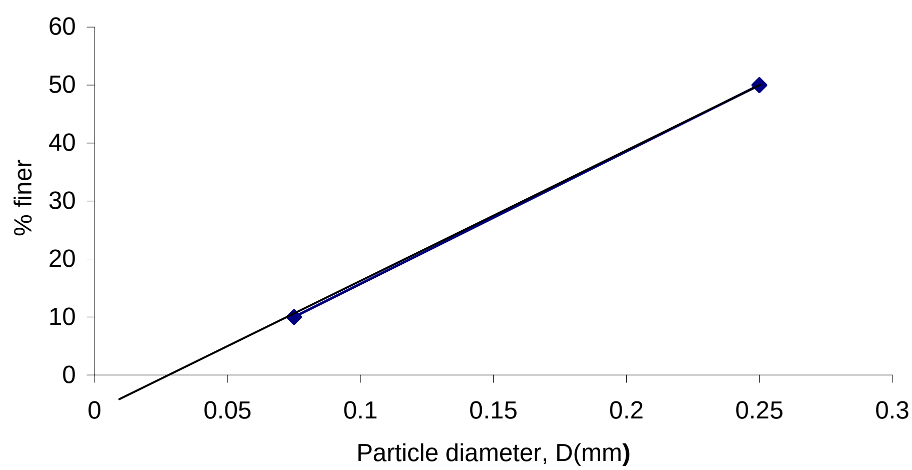

Fig. 4.30 Normal plot of grain size distribution for sample No. 2.1

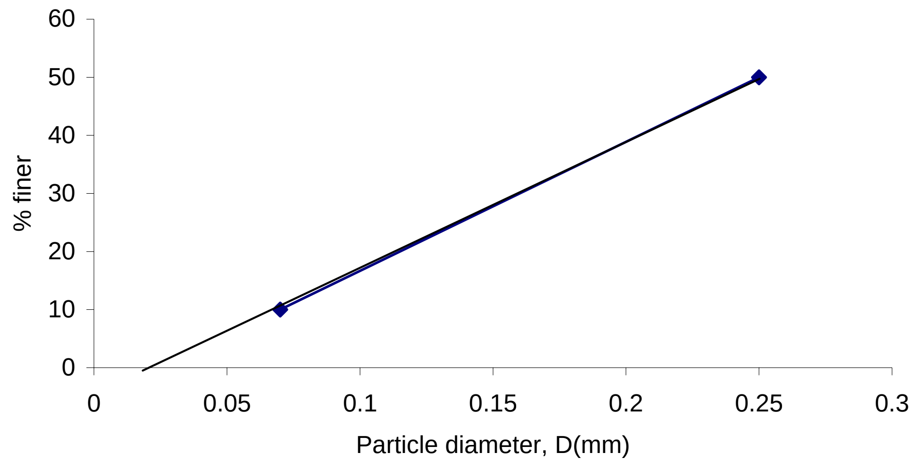

Fig. 4.31 Normal plot of grain size distribution for sample No. 2.2

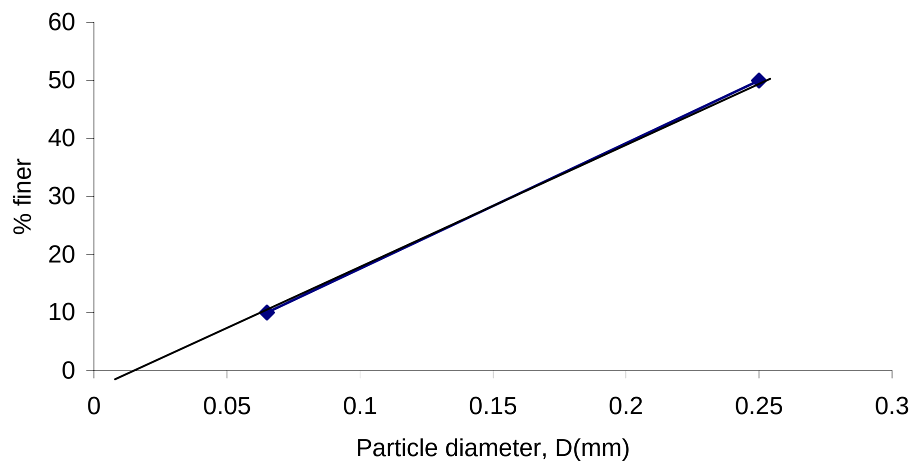

Fig. 4.32 Normal plot of grain size distribution for sample No 2.3

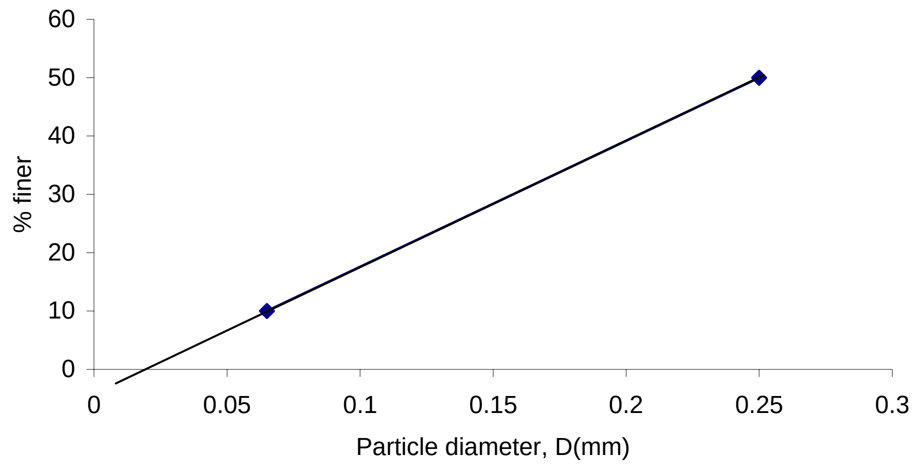

Fig. 4.33 Normal plot of grain size distribution for sample No 2.4

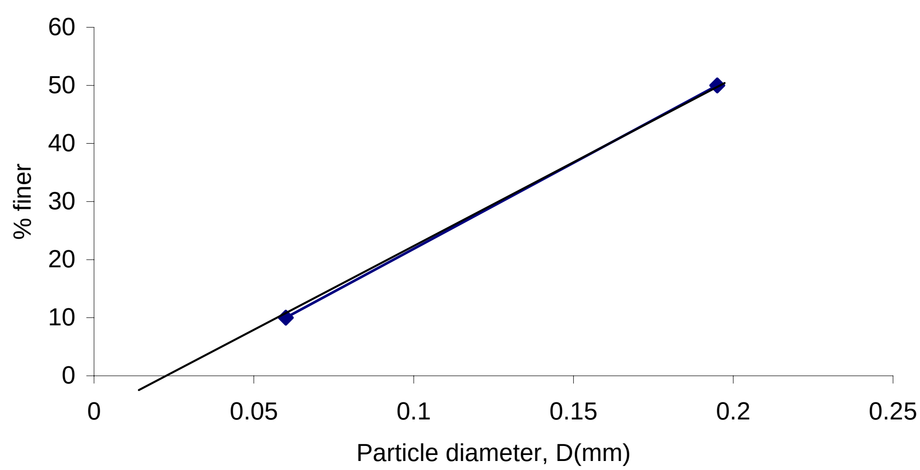

Fig. 4.34 Normal plot of grain size distribution for sample No 2.5

Table 4.15 Hydraulic conductivity based on Alyamani and Sen model

Sample No.	d_{10}	d_{50}	I_o	K (cm/s)
1.1	0.2	0.91	0.03	0.0034
1.2	0.15	0.7	0.02	0.0017
1.3	0.19	0.85	0.02	0.0021
1.4	0.2	0.8	0.05	0.0063
1.5	0.18	0.69	0.05	0.0060
2.1	0.075	0.25	0.02	0.0008
2.2	0.07	0.25	0.02	0.0009
2.3	0.065	0.25	0.01	0.00033
2.4	0.065	0.25	0.02	0.0009
2.5	0.06	0.195	0.02	0.0008

4.5 Comparison of predicted hydraulic conductivity based on Kozeny Carman model with laboratory methods

Hydraulic conductivity obtained from laboratory methods; constant head permeability test and falling head permeability test as per section 3.2.2.6 and 3.2.2.7 respectively, were compared with the results shown in Table 14. Table 16 depicts the results for the average hydraulic conductivity for constant head permeability test and falling head permeability test for the entire soil samples. Data and observation sheet for laboratory methods is given in Appendix IV and Appendix V.

Table 4.16 Hydraulic conductivity based on laboratory experiments

Sample No	k constant head(cm/s)	k falling head(cm/s)	k average
1.1	0.0040	0.0035	0.0038
1.2	0.0036	0.0035	0.0036
1.3	0.0018	0.0024	0.0021
1.4	0.0025	0.0056	0.0041
1.5	0.0062	0.0060	0.0061
2.1	0.0007	0.0007	0.0007
2.2	0.0006	0.0006	0.0006
2.3	0.0005	0.0006	0.0006
2.4	0.0007	0.0007	0.0007
2.5	0.0006	0.0006	0.0006

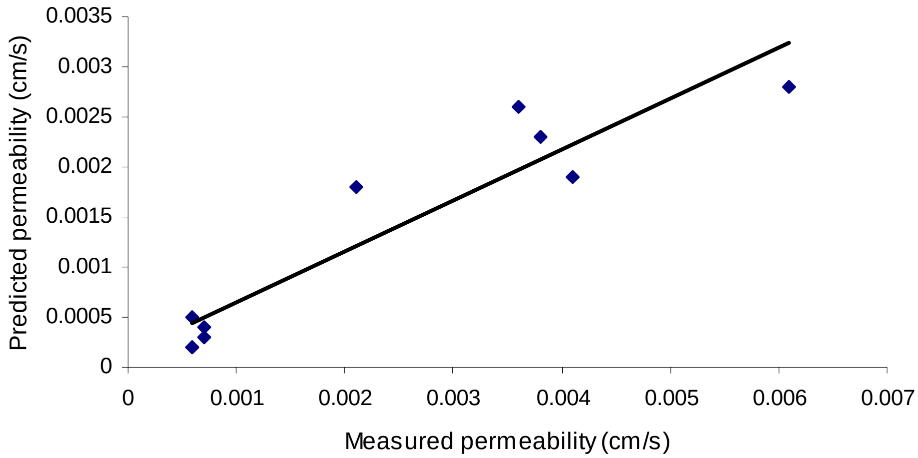

Fig. 4.34 Comparison of permeability predicted from Kozeny Carman model based on measured porosity with laboratory method

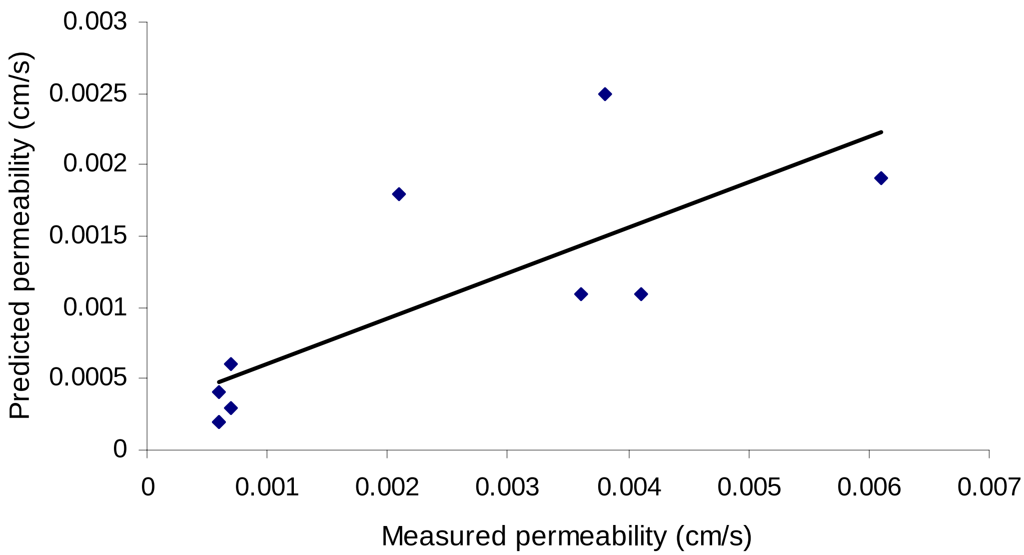

Fig. 4.35 Comparison of permeability predicted from Kozeny Carman model based on calculated porosity with laboratory method

4.6 Comparison of predicted hydraulic conductivity based on Alyamani and Sen model with laboratory methods

Hydraulic conductivity obtained as per Alyamani and Sen model shown in table 15, was also compared with that of laboratory results which was already tabulated in table 16.

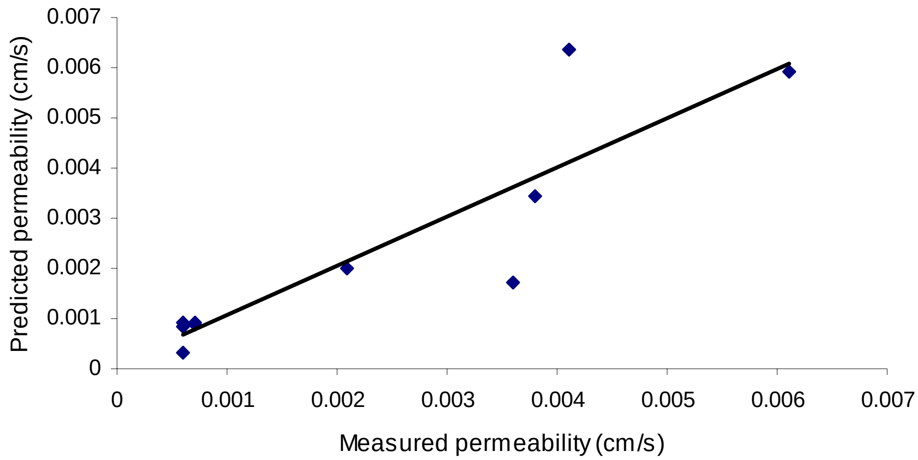

Fig. 4.36 Comparison of permeability predicted from Alyamani and Sen model with laboratory method

From the results shown above we concluded that the hydraulic conductivity predicted from grain size parameters was in very close agreement with that of the laboratory method for both models. Therefore the above illustrated method is simple to use, reliable, and accurate tool that can be adopted as an alternative to the existing methods and serve as a check for the existing methods.

Summary and Conclusions

CHAPTER V

SUMMARY AND CONCLUSIONS

Hydraulic conductivity plays a crucial role in issues connected with the flow of ground water, migration of pollutants and stability analysis. The determination of permeability analysis of soil in laboratory presents problems in the sense of obtaining representative samples and very often has very long testing times. It also constitutes a complicated problem because the hydraulic conductivity depends on many factors simultaneously existing during testing.

To overcome the aforesaid difficulties we selected a much easier method which relates hydraulic conductivity to grain size distribution. The work started with the purpose of investigating the inter-relation between hydraulic conductivity and grain size distribution curve parameters. Firstly the grain size distribution was approximated to a log normal distribution, which helped to develop a linear relationship between porosity and sorting. Consequently, in order to predict hydraulic conductivity we selected two commonly used models, namely the Kozeny Carman model and the Alyamani & Sen model. The hydraulic conductivity values predicted from these models were found to be in very close agreement with the laboratory values. In all these cases the hydraulic conductivity is related to the effective diameter, average diameter or grain size corresponding to a particular percentage.

We observed that grain size methods are comparably less expensive and do not depend on the geometry and hydraulic boundaries of the aquifer. Most importantly, since information about the textural properties of soils or rock is more easily obtained, a potential alternative for estimating hydraulic conductivity of soils is from grain-size distribution.

However slight variations were observed during the study. The difference between the predicted and measured permeability values may be due to inaccurate estimation of specific surface, erroneous permeability testing procedure such as incomplete saturation etc. The equations used were derived with the assumption that the flow is isotropic, but in most practical cases coefficient of permeability is an anisotropic parameter. This is one reason; the predictions are only approximately valid. These results cannot be extrapolated to another liquid. For such an extension other properties of liquid and of the solid–liquid interface should be considered. These formulae assume that there are no electro-chemical reactions between soil particles and water. It also assumes that the soil particles are relatively compact. The formula is not appropriate if the particle size distribution have a long, flat tail in the fine fraction.

Kozeny Carman model constitutes a term accounting for effective porosity which is difficult to measure accurately. There are various factors which influence porosity resulting in wide variations from the actual one .The porosity of unconsolidated materials depends on the packing of the grains, their shape, arrangement, and the size distribution. The particle size distribution may appreciably affect the resulting porosity as small particles may occupy pores formed between the large particles, thus reducing the porosity. Earlier studies revealed that among the interconnected pores there are some classes of pores which contribute very little to the flow, called the dead-end pores or stagnant pockets. It is important to take into consideration these pores in certain mechanisms of flow. In fine textured porous media there are indications of an immobile or highly viscous water layer on the particle surface that makes effective porosity much smaller than the measured one. A more accurate predicted permeability value can be derived by considering all the factors above.

Nevertheless, we infer that the hydraulic conductivity obtained from grain size parameters is a good predictive tool for any natural homogeneous soil. Specialists in the field of geotechnical engineering and hydrogeology should use it more systematically. It may be concluded that coefficient of permeability predicted from grain size analysis can be used accurately and conveniently to give the best value of the same.

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V

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Appendices

APPENDIX I

Qualitative measures of sorting (Beard and Weyl, 1973).

Sorting	So
Extremely well sorted	1.0-1.11
Very well sorted	1.1-1.2
Well sorted	1.2-1.4
Moderately sorted	1.4-2.0
Poorly sorted	2.0-2.7
Very poorly sorted	2.7-5.7

APPENDIX II

Observations and calculations for determination of porosity

Sample No: 1.1

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2078.5
2	Dry weight of the sample	g	1700.5
3	Moisture content	g	378
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.385046

Sample No: 1.2

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2035
2	Dry weight of the sample	g	1718
3	Moisture content	g	317
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.387084

Sample No: 1.3

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2308
2	Dry weight of the sample	g	1948
3	Moisture content	g	360
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.366711

Sample No: 1.4

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2295
2	Dry weight of the sample	g	1936
3	Moisture content	g	359
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.365692

Sample No: 1.5

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2305
2	Dry weight of the sample	g	1931
3	Moisture content	g	374
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.380972

Sample No: 2.1

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	1931
2	Dry weight of the sample	g	1565
3	Moisture content	g	366
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.372823

Sample No: 2.2

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2093
2	Dry weight of the sample	g	1720
3	Moisture content	g	373
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.379953

Sample No: 2.3

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	1980
2	Dry weight of the sample	g	1604
3	Moisture content	g	376
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.383009

Sample No: 2.4

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	1973
2	Dry weight of the sample	g	1623
3	Moisture content	g	350
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.356524

Sample No: 2.5

Sr. No.	Parameter	Unit	Magnitude
1	Weight of saturated sample	g	2005
2	Dry weight of the sample	g	1660
3	Moisture content	g	345
4	Volume of soil sample	cm^3	981.7
5	Porosity		0.351431

APPENDIX III

Observation and calculation for determination of specific gravity

Sample No: 1.1

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	424	422	424
2. Mass of Pycnometer + soil(M_2)g	680	680	682
3. Mass of Pycnometer + soil + water (M_3)g	1630	1632	1631
4. Mass of Pycnometer + water (M_4)g	1470	1470	1470
5. Specific gravity	2.6666667	2.6875	2.659794
Average specific gravity			2.6713202

Sample No: 1.2

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	427	422	428
2. Mass of Pycnometer+soil(M_2)g	677	722	728
3. Mass of Pycnometer + soil + water (M_3)g	1522	1672	1665
4. Mass of Pycnometer + water (M_4)g	1361	1492	1474
5. Specific gravity	2.8089888	2.5	2.752294
Average specific gravity			2.6870941

Sample No: 1.3

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	427	422	428
2. Mass of Pycnometer+soil(M_2)g	680	723	730
3. Mass of Pycnometer + soil + water (M_3)g	1522	1675	1665
4. Mass of Pycnometer + water (M_4)g	1361	1480	1474
5. Specific gravity	2.75	2.839623	2.720721
Average specific gravity			2.7701145

Sample No: 1.4

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	422	424	428
2. Mass of Pycnometer+soil(M_2)g	687	730	735
3. Mass of Pycnometer + soil + water (M_3)g	1530	1658	1670
4. Mass of Pycnometer + water (M_4)g	1371	1468	1474
5. Specific gravity	2.5	2.637931	2.765766
Average specific gravity			2.6345656

Sample No: 1.5

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	422	424	428
2. Mass of Pycnometer+soil(M_2)g	685	732	734
3. Mass of Pycnometer + soil + water (M_3)g	1543	1655	1676
4. Mass of Pycnometer + water (M_4)g	1375	1466	1484
5. Specific gravity	2.7684211	2.588235	2.684211
Average specific gravity			2.680289

Sample No: 2.1

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	424	422	424
2. Mass of Pycnometer+soil(M_2)g	667	665	682
3. Mass of Pycnometer + soil + water (M_3)g	1623	1642	1631
4. Mass of Pycnometer + water (M_4)g	1470	1492	1468
5. Specific gravity	2.7	2.612903	2.715789
Average specific gravity			2.676231

Sample No: 2.2

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	427	422	428
2. Mass of Pycnometer+soil(M_2)g	740	722	728
3. Mass of Pycnometer + soil + water (M_3)g	1680	1687	1665
4. Mass of Pycnometer + water (M_4)g	1488	1492	1480
5. Specific gravity	2.586777	2.857143	2.608696
Average specific gravity			2.684205

Sample No: 2.3

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	427	422	428
2. Mass of Pycnometer+soil(M_2)g	720	727	730
3. Mass of Pycnometer + soil + water (M_3)g	1683	1670	1674
4. Mass of Pycnometer + water (M_4)g	1498	1480	1499
5.Specific gravity	2.712963	2.652174	2.377953
Average specific gravity			2.58103

Sample No: 2.4

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	422	424	428
2. Mass of Pycnometer+soil(M_2)g	688	735	720
3. Mass of Pycnometer + soil + water (M_3)g	1530	1659	1670
4. Mass of Pycnometer + water (M_4)g	1371	1472	1488
5. Specific gravity	2.485981	2.508065	2.654545
Average specific gravity			2.54953

Sample No: 2.5

Determination No	1	2	3
1. Mass of Pycnometer (M_1)g	422	424	428
2. Mass of Pycnometer+soil(M_2)g	686	736	730
3. Mass of Pycnometer + soil + water (M_3)g	1534	1655	1672
4. Mass of Pycnometer + water (M_4)g	1370	1463	1484
5. Specific gravity	2.64	2.6	2.649123
Average specific gravity			2.629708

APPENDIX IV

Data and observation sheet for constant head permeability test

Sample No: 1.1

Sr No	Parameters	Unit	I test
1	Hydraulic head (h)	cm	131
2	Length of the sample	cm	12.5
3	Hydraulic gradient		10.48
4	Cross-sectional area of sample	cm^2	78.5
5	Time interval (t)	sec	180
6	Quantity of flow (Q)	ml	590
7	Coefficient of permeability	cm/s	0.003984

Sample No: 1.2

Sr No	Parameters	Unit	I test	II test
1	Hydraulic head (h)	cm	152	151
2	Length of the sample	cm	12.5	12.5
3	Hydraulic gradient		12.16	12.08
4	Cross-sectional area of sample	cm^2	78.5	78.5
5	Time interval (t)	sec	60	101
6	Quantity of flow (Q)	ml	204	340
7	Coefficient of permeability	cm/s	0.003562	0.00355
8	Average permeability	cm/s		0.00356

Sample No: 1.3

Sr No	Parameters	Unit	I test	II test
1	Hydraulic head (h)	cm	147	145.5
2	Length of the sample	cm	12.5	12.5
3	Hydraulic gradient		11.76	11.64
4	Cross-sectional area of sample	cm^2	78.5	78.5
5	Time interval (t)	sec	72	80
6	Quantity of flow (Q)	ml	168	92
7	Coefficient of permeability	cm/s	0.002528	0.001259
8	Average permeability	cm/s		0.00176

Sample No: 1.4

Sr No	Parameters	Unit	I test	II test
1	Hydraulic head (h)	cm	125	133
2	Length of the sample	cm	12.5	12.5
3	Hydraulic gradient		10	10.64
4	Cross-sectional area of sample	cm^2	78.5	78.5
5	Time interval (t)	sec	60	60
6	Quantity of flow (Q)	ml	126	112.5
7	Coefficient of permeability	cm/s	0.002675	0.002245
8	Average permeability	cm/s		0.00246

Sample No: 1.5

Sr No	Parameters	Unit	I test	II test
1	Hydraulic head (h)	cm	155.7	151.6
2	Length of the sample	cm	12.5	12.5
3	Hydraulic gradient		12.456	12.128
4	Cross-sectional area of sample	cm^2	78.5	78.5
5	Time interval (t)	sec	60	60
6	Quantity of flow (Q)	ml	346	368
7	Coefficient of permeability	cm/s	0.005898	0.006442
8	Average permeability	cm/s		0.0062

Sample No: 2.1

Sr No	Parameter	Unit	Magnitude
1	Hydraulic head (h)	cm	154
2	Length of the sample	cm	12.5
3	Hydraulic gradient		12.32
4	Cross-sectional area of sample	cm^2	78.5
5	Time interval (t)	sec	60
6	Quantity of flow (Q)	ml	40
7	Coefficient of permeability	cm/s	0.000689

Sample No: 2.2

Sr No	Parameters	Unit	Magnitude
1	Hydraulic head (h)	cm	148.3
2	Length of the sample	cm	12.5
3	Hydraulic gradient		11.864
4	Cross-sectional area of sample	cm^2	78.5
5	Time interval (t)	sec	60
6	Quantity of flow (Q)	ml	32
7	Coefficient of permeability	cm/s	0.000573

Sample No: 2.3

Sr No	Parameter	Unit	Magnitude
1	Hydraulic head (h)	cm	145
2	Length of the sample	cm	12.5
3	Hydraulic gradient		11.6
4	Cross-sectional area of sample	cm^2	78.5
5	Time interval (t)	sec	75
6	Quantity of flow (Q)	ml	34
7	Coefficient of permeability	cm/s	0.000498

Sample No: 2.4

Sr No	Parameter	Unit	Magnitude
1	Hydraulic head (h)	cm	132
2	Length of the sample	cm	12.5
3	Hydraulic gradient		10.56
4	Cross-sectional area of sample	cm^2	78.5
5	Time interval (t)	sec	65
6	Quantity of flow (Q)	ml	35
7	Coefficient of permeability	cm/s	0.00065

Sample No: 2.5

Sr No	Parameter	Unit	Magnitude
1	Hydraulic head (h)	cm	150
2	Length of the sample	cm	12.5
3	Hydraulic gradient		12
4	Cross-sectional area of sample	cm^2	78.5
5	Time interval (t)	sec	120
6	Quantity of flow (Q)	ml	65
7	Coefficient of permeability	cm/s	0.000575

APPENDIX V

Data and observation sheet for variable head permeability test

Sample No: 1.1

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	115	105	105	105	95
5	Final head(h_2)	cm	95	85	85	75	65
6	Time interval	sec	6	7	7	11	13
7	Coefficient of permeability	cm/sec	0.00371	0.00351	0.003514	0.0036	0.0034
8	Average permeability	cm/s	0.0035				

Sample No: 1.2

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	115	105	95	95	105
5	Final head(h_2)	cm	95	75	65	75	85
6	Time interval	sec	5	12	13	9	7
7	Coefficient of permeability	cm/s	0.0044	0.0033	0.0034	0.00305	0.0035
8	Average permeability	cm/s	0.00353				

Sample No: 1.3

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	90	105	105	65	85
5	Final head(h_2)	cm	70	75	85	45	65
6	Time interval	sec	12	16	10	18	14
7	Coefficient of permeability	cm/s	0.00243	0.00244	0.00245	0.00237	0.0022
8	Average permeability	cm/s					0.0024

Sample No: 1.4

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	95	105	95	105	95
5	Final head(h_2)	cm	65	75	55	85	62
6	Time interval	sec	8	7	12	4	9
7	Coefficient of permeability	cm/s	0.00552	0.00559	0.00530	0.00615	0.00552
8	Average permeability	cm/s					0.0056

Sample No: 1.5

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	105	95	105	105	95
5	Final head(h_2)	cm	75	65	65	85	55
6	Time interval	sec	6	7	9	5	11
7	Coefficient of permeability	cm/s	0.00653	0.00631	0.0062	0.0049	0.0058
8	Average permeability	cm/s					0.00595

Sample No: 2.1

Sr No	Parameters	Unit	I test	II test	III test	IV test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	102	115	105	71
5	Final head(h_2)	cm	92	95	85	41
6	Time interval	sec	16	40	34	93
7	Coefficient of permeability	cm/s	0.00075	0.00056	0.000723	0.0007
8	Average permeability	cm/s	0.00068			

Sample No: 2.2

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	105	104	106	109	111
5	Final head(h_2)	cm	95	97	100	99	102
6	Time interval	sec	15	18	13	14	16
7	Coefficient of permeability	cm/s	0.00078	0.00045	0.000522	0.0008	0.0006
8	Average permeability	cm/s	0.000633				

Sample No: 2.3

Sr No	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	106	110	120	130	125
5	Final head(h_2)	cm	101	100	110	120	115
6	Time interval	sec	12	16	17	18	14
7	Coefficient of permeability	cm/s	0.00047	0.00069	0.000596	0.0005	0.0007
8	Average permeability	cm/s	0.000594				

Sample No: 2.4

Sr no	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	115	130	120	125	135
5	Final head(h_2)	cm	95	115	110	115	125
6	Time interval	sec	30	15	13	15	18
7	Coefficient of permeability	cm/s	0.00074	0.00095	0.000779	0.0006	0.0005
8	Average permeability	cm/s					0.00723

Sample No: 2.5

Sr no	Parameters	Unit	I test	II test	III test	IV test	V test
1	Area of stand pipe(a)	cm^2	0.731	0.731	0.731	0.731	0.731
2	Cross-sectional area of soil sample(A)	cm^2	78.5	78.5	78.5	78.5	78.5
3	Length of sample(L)	cm	12.5	12.5	12.5	12.5	12.5
4	Initial head(h_1)	cm	105	95	115	125	130
5	Final head(h_2)	cm	85	75	110	115	120
6	Time interval	sec	45	35	12	13	11
7	Coefficient of permeability	cm/s	0.00055	0.00079	0.000431	0.0007	0.0008
8	Average permeability	cm/s					0.000672

PREDICTING THE COEFFICIENT OF PERMEABILITY OF SOILS BASED ON GRAIN SIZE ANALYSIS

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ABSTRACT OF THE PROJECT REPORT
Submitted in partial fulfillment of the
Requirement for the degree

Bachelor of Technology
in
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Land & Water Resources & Conservation Engineering
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2009

ABSTRACT

In the current status of soil studies, the accurate recognition of properties of soil becomes indispensable. The permeability of soil is very important in the field of agricultural engineering as it is connected with various issues of soil and water conservation. Hydraulic conductivity is also of paramount importance in relation to some geotechnical problems including the determination of seepage losses, settlement computations and stability analysis. The laboratory methods of determination of coefficient of permeability are complicated and consume time. In order to combat these shortcomings two models were selected for predicting the hydraulic conductivity using grain size namely, Kozeny Carman model and Alyamani and Sen model. Kozeny Carman model was based on average particle diameter and porosity of which particle diameter was determined by Kozeny graphical method. Alyamani and Sen model was based on normal plot of grain size distribution which uses intercept and grain size corresponding to particular percentages. The method is comparably less expensive and do not depend on geometry and hydraulic boundaries of aquifer. The results of the study showed that the permeability values predicted using the model was in very close agreement with the laboratory values. Hence this method proves to be a potential predictive tool for determination of hydraulic conductivity.