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Study of relation of Permeability and compaction characteristics of clayey soil with specific surface area

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Abstract – *The arrangement of primary soil particles and its aggregation forms the soil structure. The surfaces of soil solid particles play an important role in many soil processes like adsorption, swelling, shrinking, water penetration and soil aggregation. Clay-size particles, and particularly some layer silicate minerals, contribute most of the inorganic surface area to soils. The surface area of a soil is a function of the size, shape and mineralogy of the constituent particles. The type of minerals present in soil largely determines the soil specific surface and related properties. Permeability and compaction characteristics of soil are greatly influenced by specific surface area of solid particles, since it determines the water influx and adsorption of water with increase in water content. The aim of this study is to investigate the effect of specific surface area on permeability and Standard Proctor characteristics of clayey soil. It involves determination of permeability, maximum dry density and optimum moisture content of soil samples collected from Kuttanad region and determination of specific surface area by adopting BET and BJH methods of analysis. The relationship between the parameters is investigated and an attempt is done to obtain the equation involving the parameters by linear regression. The results from the study show that relation exists between the parameters. The predictions from BET method were found to be more accurate.*

***Key Words*: Specific surface area, permeability, Compaction, Optimum moisture content, Dry density, Regression analysis**

1. INTRODUCTION

Physical and chemical properties of fine-grained soils, especially clays, may be greatly influenced by the amount of its surface area. Fine-grained soils differ in surface area predominantly as a result of differences in texture (grain-size distribution) and types and amounts of different clay minerals. The term “Specific Surface Area” (SSA) refers to the area per unit weight of soil and is usually expressed as m^2/g. Clay minerals differ substantially in Specific Surface Area. Non-swelling minerals, such as kaolinite, have only external surface, whereas swelling minerals like montmorillonite have a great deal of internal as well as external surface. Natural clay deposits can have a wide range of total surface area since the combination of external and internal surface areas may vary simply because of the mixed layer minerals that may exist and the variations in clay mineralogy. Additionally, the clay mineral fraction that is part of the overall grain-size distribution can vary greatly.

The behavior of fine-grained soils may be explained by the relationship between surface area and other geotechnical properties. This study is more relevant in problematic soil like Kuttanad clay. Kuttanad is located in Alappuzha district of Kerala, India. It is an agricultural area and is known for underwater. The clay in this region is dark grey colour and the dominant clay minerals are kaolinite and illite. Kuttanad clay is characterized by its high compressibility and low shear strength .The low bearing capacity of the soil has lead to foundation failures and embankment failures [7].

Several studies have been done which includes determination of specific surface area employing different methods. Most of them are restricted to investigating modification of soil textural properties after soil treatment or by addition of materials or replacement of soil by other materials for the purpose of stabilization or strengthening of soil. Very few have been done to study the correlation of geotechnical properties with Specific surface area of soil, especially in clayey soil which could be problematic for stability of foundation. Based on several assumptions, **Dolinar (2012)** proposed a simplified method for determining the external specific surface area of non-swelling fine-grained soils[1] by an equation which relates the external specific surface area (BET-nitrogen) with percentage of clay fraction, determined by hydrometer method, and plasticity index (Atterberg).

Garzon and Soto (2015) developed an improved method for determining the external specific surface area of fine-grained clay samples. Instead of percentage of clay fraction, it was proposed to use the clay mineral content estimated by XRD methods [2].

This study focuses on investigating the relationship between textural surface area and two important geotechnical properties, permeability and Standard Proctor characteristics, for clayey soil of Kuttanad region.

1.1 Clay mineralogy and Surface area

The surface area of a soil is a function of the size, shape and mineralogy of the constituent particles. The specific surface of a soil is defined as the area (in square meters) per gram of soil particles. The shape of soil grains is of importance, as the surface area per unit volume changes with the shape of the particles. A specific grain having a shape of a sphere has the smallest surface area, but will exhibit the greatest surface area when deformed into an extremely thin disc or sheet [4]. Surface area increases with decreasing size of particles and this is particularly true for clay fractions containing smectite and vermiculite, which have considerable internal surface area [5].

1.2 Determination of surface area

The adsorption of nitrogen and the application to the isotherms of the BET (Brunauer, Emmett and Teller) Method equation is widely recognized method for determining the "external" Surface Area of soil particles [3]. Weakly adsorbed nitrogen does not penetrate the interlayer surfaces so that the measurement obtained is only for external surfaces, whereas polar molecules such as ethylene glycol mono-ethyl ether are strongly adsorbed and penetrate into the interlayer surfaces producing total Surface Area measurements. Although "total area" of soils containing swelling clay minerals cannot be determined, the method remains a useful means of comparing two different soils.

Fig -1: Quantachrome Apparatus for performing BET Analysis

The BET method works by measuring the quantity of adsorbate gas adsorbed on a solid surface by sensing the change in thermal conductivity of a flowing mixture of adsorbate and an inert carrier gas. Usually the adsorbate is nitrogen and the inert carrier gas is helium. A small soil sample is placed in a sample tube and inserted into the cell holder. A Dewar flask is filled with liquid nitrogen and raised until the liquid nitrogen is close to the top of the cell. The flow of gas begins and nitrogen is adsorbed. The liquid nitrogen is removed and desorption of the gas from the soil begins. When desorption is completed, the integrator will display a number which is the sample Surface Area in square meters. Dividing by the sample weight gives the external Specific Surface Area of the sample.

The advantages to this method are that it is fast and reproducible. In less than ten minutes, the external Specific Surface Area can be determined. The BET method has been compared with the CPB and EGME methods and is accurate within 1 to 2 m^2/g [6]. One disadvantage for the BET method is that it utilizes elaborate and expensive equipment. The cost of the equipment prohibits many laboratories from performing Specific Surface Area determinations.

BJH (Barrett, Joyner, and Halenda) method of analysis can also be employed to determine pore area and specific pore volume using adsorption and desorption techniques. This technique characterizes pore size distribution independent of external area due to particle size of the sample. It applies only to the mesopore and small macropore size range.

In this study, Quantachrome analyzer was used for determination of surface area.

2. METHODOLOGY

2.1 Sample collection

For an appreciable conclusion to be establish, 20 clay soil samples is collected from different locations in Kuttanad region.

2.2 Soil Testing

The soil samples collected were subjected to the following tests:

1. Initial testing of soil
   a) Specific gravity test [IS 2720 (PART 3/SEC 1)-1980]
   b) Atterberg Limits [IS 2720 (PART 16) 1979]
   c) Wet sieve analysis [IS 2720 (PART-3) 1985]
   d) Hydrometer analysis [IS 2720 (PART 4) 1985]
2. One dimensional consolidation test [IS 2720 (PART 15)-1986]
3. Standard Proctor test [IS 2720 (PART VII)]
   To determine the optimum moisture content and maximum dry density of the samples
4. BET analysis
   To determine specific surface area
5. BJH analysis
   To determine specific surface area

Specific gravity tests were conducted on all 20 samples. For liquid limit of the soil, samples should be sieved through 425 micron sieve and take 120g sample and is thoroughly mixed with distilled water in an evaporating dish to form uniform paste. The paste shall have a consistency that will require 30 to 35 drops of the cup to cause the required closure of the standard groove. The soil should be re-mixed thoroughly before the test. A portion of the paste shall be placed in the cup. The soil is trimmed to a depth equal to one centimeter throughout the cup. Then a groove is cut with the grooving tool. The cup shall be fitted and dropped by turning the crank at the rate of two revolutions per second until the two halves of the soil cake come in contact bottom of the groove close for the length of 12mm shall be recorded. A flow curve is plotted in a semi logarithmic graph with number of drops in logarithmic scale on X-axis and corresponding moisture content on Y-axis in arithmetic scale. The moisture content corresponding to 25 numbers of blows is taken as liquid limit. To find plastic limit of soil sample it is mixed with distilled water in an evaporating dish. A ball shall be formed with about 8g of this sample and rolled between fingers and glass plate with sufficient pressure so that it may roll into threads of 3mm diameter. If the diameter of the thread becomes smaller than 3mm without any crumbling then the water content is more than the plastic limit. The soil shall be mixed again to form a uniform soil mass and again threads are made. This procedure repeated till the thread crumbles. The water content at which the soil can be rolled into a thread of approximately 3mm in diameter without crumbling is taken as plastic limit. Wet sieve analysis was conducted to determine the percentage of fine particles greater than 75 μ size. One kilogram of soil sample was sieved and washed under a jet of water until the wash water becomes clear through 75 micron sieve. The material retained on the sieve was collected and dried for 24 hours. This sample is again sieved through a set of sieves, 4.75mm, 2.36mm, 1.18mm, 0.60mm, 0.425mm, 0.300mm, 0.150mm and 0.075mm. The material retained on each sieve is collected and weighed. Hydrometer analysis was conducted to obtain percentage of silt and clay separately. A particle size distribution curve, also known as gradation curve, represents the distribution of particles of different sizes in the soil masses. About 50g of dry sample is taken and is thoroughly mixed with 100ml of sodium hexa-meta phosphate and made to 1000ml solution in flask. The hydrometer inserted into the suspension and readings are taken after 0.5minutes, 1,2,4,8,15,30, 60 minutes, 1hr,2hr and 24hr. Particle size D and percentage finer are tabulated The results can be used to draw particle size distribution graph.

For Standard Proctor test, about 3 kg of soil sample is taken and is mixed with some amount of water and is kept for maturing about 15 to 30 minutes. Matured soil sample shall be filled in three layers in the standard mould being given 25 blows with a free fall of 310 mm. The dry densities are plotted against the corresponding moisture content. A smooth curve is drawn through the resulting points and the coordinates of the peak point on this curve (OMC and MDD) are determined.

A soil is highly pervious when water can flow through it easily. In an impervious soil, the permeability is very low and water cannot easily flow through it. For clay being a very less permeable soil, one dimensional consolidation is used for indirect determination of permeability.

3. EXPERIMENTAL RESULTS

Results are shown in Table 1 and 2.

Table 1- Classification of soil samples(ISC system)

Sl No.	Liquid Limit(%)	Plastic Limit(%)	Plasticity index (%)	Specific gravity	%Clay content	Soil classification
1	98	52	46	2.3	53	CH
2	88	48	40	2.3	58	CH
3	83	48	35	2.3	58.2	CH
4	112	59	53	2.4	60.2	CH
5	85	41	44	2.4	55	CH
6	102	52	50	2.3	56	CH
7	98	46	52	2.3	58	CH
8	96	49	47	2.4	52	CH
9	95	48	47	2.3	60.5	CH
10	100	52	48	2.3	60	CH
11	86	46	40	2.4	58	CH
12	93	53	40	2.3	59.6	CH
13	89	44	45	2.4	52	CH
14	118	58	60	2.3	58	CH
15	81	43	38	2.4	52	MH-CH
16	114	54	60	2.4	60	CH
17	86	33	53	2.4	52	CH
18	96	48	48	2.3	58	CH
19	75	39	36	2.4	52	MH-CH
20	97	48	49	2.3	58	CH

Most of the samples are under the category clay of high compressibility (CH). Only two samples fall under CH-MH category.

Table -2: Results of Standard Proctor test and specific surface area analysis

Sl No	Optimum moisture content (%)	Maximum dry density (g/cc)	Specific surface area from BET analysis (m^2/g)	Specific surface area from BJH analysis (m^2/g)	Permeability (10^{-7}cm/s)
1	33	1.25	31.975	17.89	2.81
2	44.5	1.224	38.95	20.44	1.75
3	42	1.3	25.87	16.763	2.696
4	39.5	1.272	28.108	17.14	2.656
5	34	1.245	33.51	18.23	2.147
6	37	1.232	37.5	19.85	1.982
7	34.6	1.175	54.98	24.52	1.59
8	32	1.19	51.59	22.52	1.566

9	32.8	1.189	55.464	25.63	1.27
10	38.5	1.17	60.81	28.76	0.999
11	37.778	1.162	58.98	26.52	1.18
12	40	1.15	62.665	30.23	0.952
13	48	1.07	55.525	25.82	1.267
14	44	1.122	71.256	34.67	0.4703
15	40	1.136	54.422	24.12	1.536
16	37	1.15	63.18	31.85	0.912
17	40	1.148	63.278	31.98	0.874
18	40.96	1.12	71.872	34.95	0.421
19	40.2	1.15	63.42	31.15	0.824
20	38	1.14	54.295	24.23	1.413

4. REGRESSION ANALYSIS

Linear regression is done in this study. A linear regression model between a single study variable and single explanatory variable is termed as simple linear regression model.

A. Regression analysis between Maximum dry density(MDD in g/cc) and Specific surface area(SSA in m^2/g) from BET analysis

SSA = -255.3 MDD + 354

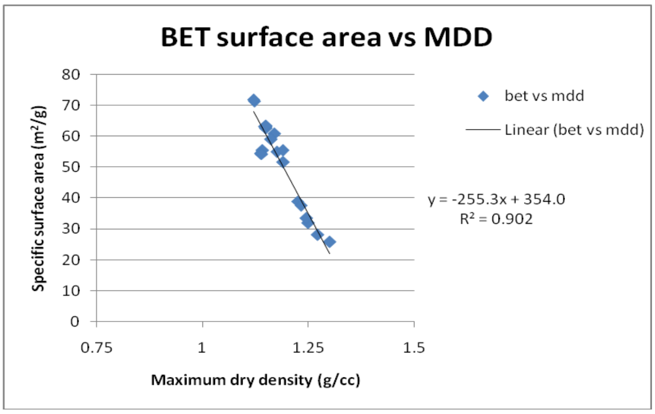

Chart -1: Regression plot for SSA (BET) vs MDD

B. Regression analysis between Maximum dry density(MDD in g/cc) and Specific surface area(SSA in m^2/g) from BJH analysis

SSA = -97.02 MDD + 140.1

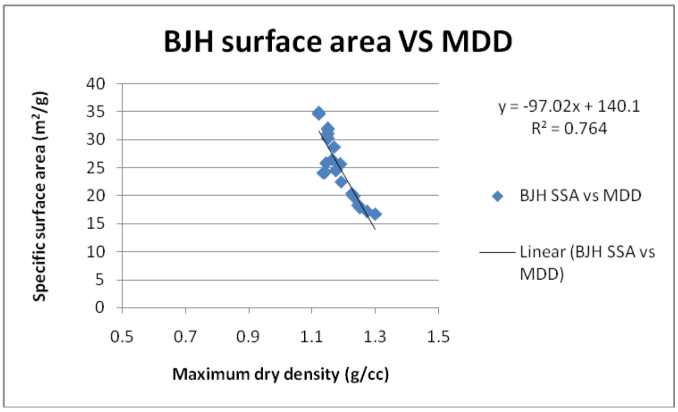

Chart -2: Regression plot for SSA (BJH) vs MDD

C. Regression analysis between Optimum moisture content(%) and Specific surface area(SSA in m^2/g) from BET analysis

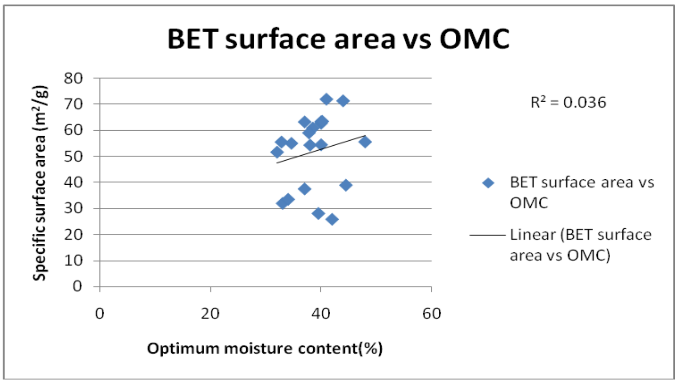

Chart -3: Regression plot for SSA (BET) vs OMC

A poor correlation is obtained between specific surface area from BET analysisand optimum moisture content.

D. Regression analysis between Optimum moisture content(%) and Specific surface area(SSA in m^2/g) from BJH analysis

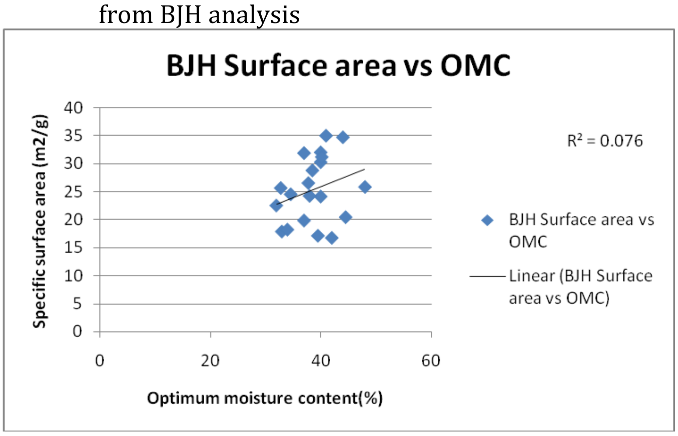

Chart -4: Regression plot for SSA (BJH) vs OMC

As above, a poor correlation is obtained between specific surface area from BJH analysis and optimum moisture content but with a higher correlation coefficient.

E. Regression analysis between Permeability (k in 10^{-7} cm/s) and Specific surface area(SSA in m^2/g) from BET analysis

$$SSA = -19.62\ k + 80.65$$

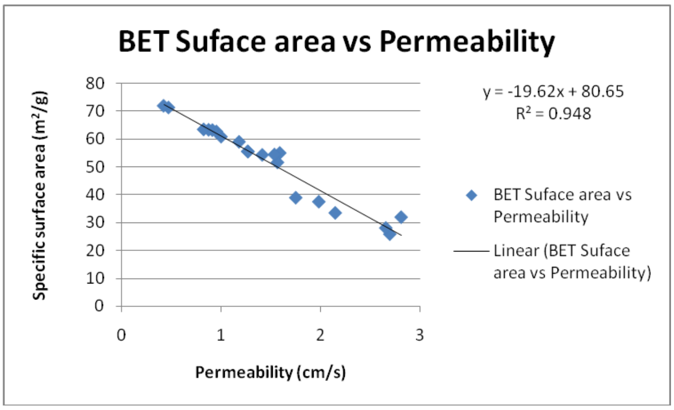

Chart -5: Regression plot for SSA (BET) vs k

F. Regression analysis between Permeability (k in 10^{-7} cm/s) and Specific surface area(SSA in m^2/g) from BJH analysis

$$SSA = -8\ k + 37.09$$

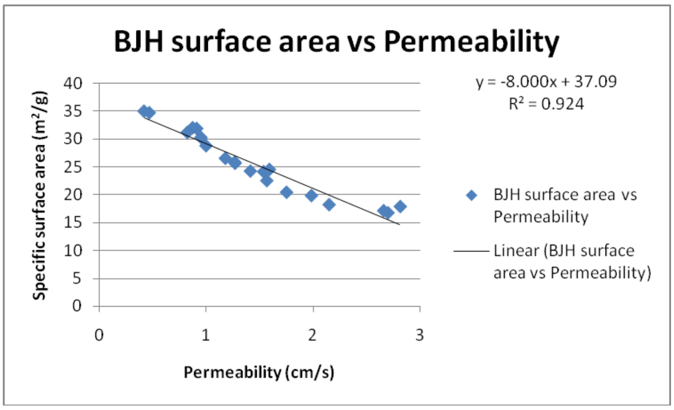

Chart -6: Regression plot for SSA (BJH) vs k

5. CONCLUSIONS

This study was done to develop correlations between compaction characteristics of clayey soil and soil specific surface area. Based on the analysis carried out following conclusions were made:

- Specific surface area determined from BET analysis correlates more with engineering properties. This agrees with the established fact that BET analysis is the more preferred method for specific surface area determination.
- Maximum dry density correlates with specific surface area with higher R squared value. A negative correlation exists between MDD and SSA.
- Optimum moisture content shows poor correlation with specific surface area.
- Permeability shows good correlation with specific surface area as in coarse grained soil.
- Prediction of specific surface area from maximum dry density and permeability is possible thus eliminating the need for highly sophisticated instrument and more time.

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