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Permeability Behavior of Sand-Kaolin Mixtures through Laboratory Tests

Faheem Junaid Mir[1] and Anuj Sachar[2]

[1]Student, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India
[2]Assistant Professor, Department of Civil Engineering, RIMT University, Mandi Gobindgarh, Punjab, India

Correspondence should be addressed to Faheem Junaid Mir; faheemjunaid1@gmail.com

ABSTRACT- Permeability or Hydraulic conductivity of soil is basic property of soil that needs to be taken into consideration when planning a Civil engineering project. In most of the Civil engineering projects a low permeable soil is desired over high permeable soils. In areas like deserts, the construction industry is facing a number of challenges due to non availability of permeable soils. Kaolin is a naturally occurring fine grained clayey soil that can be obtained in abundance at very low costs. In this study samples with different proportions (0%, 5%, 10%, 15%, and 20%) of sand-Kaolin were tested for the variations in permeability (vertical permeability) of sand. The tests were performed through constant head permeability methods and variable head permeability methods. The main aim of our study was to test the capability of Kaolin to decrease the permeability of sand. The results indicated a steep decrease in permeability of sand till 10% Kaolin clay content, afterwards a gradual decrease was observed. The coefficient of permeability of sand was decreased by 99.3% by increasing Kaolin content to 10% from 0%. This low permeable sand thus obtained could be potentially used as a filler material, vertical backfills to cut off the seepage through sandy soils, low permeable embankments, etc.

KEYWORDS- Permeability, Seepage,Sand- Kaolin mixture, coefficient of permeability, Particle size distribution,

I. INTRODUCTION

The properties of soil keep changing time to time and with location. These properties can be influenced by physical conditions of adjoining areas including the physical features, climate, weather etc. For engineers it is very important to understand the soil of the proposed site when designing a structure because it will affect the way it is designed. It helps geotechnical engineers in designing foundations, retaining walls, dams etc. Without this knowledge the lives are at stake and the investments could be at stake if the projects are not efficient enough. Geotech properties such as particle size distribution, Atterberg limits, maximum and minimum index densities, specific gravity, permeability, soil classification, shear strength and compressibility.

The information about permeability of soil is essential to every project especially where the project has to deal with the water such as dams, reservoirs, river banks, docks, projects in deserts etc. In some places due to the absence of impervious soil like the deserts the permeability of soil is a major issue. In these areas it is impossible to construct a pond or a reservoir without special techniques. In many areas lying below the sea level or water level of a river or a lake the water seeps through the soil and forms stagnant water this water cannot be drained easily as the drainage system is at higher elevation than the ground itself. This ponded water damages crops, orchards and many structures that are susceptible to water damage such as wooden structures or iron structures. In desert areas where water is scarce the seepage loss in long distance canals and reservoirs leaves the construction works ineffective and thus makes it necessary for engineers to go for special techniques to prevent the seepage.

There are many techniques that can be used to prevent this water loss through seepage. Vertical backfills of low permeable soil mixtures can be used to form cutoff walls that prevent the seepage through them. These walls extend to the impervious subgrade and prevent or significantly decrease the flow of water through them to the main land. HDPE lining in combination with concrete has shown highest value of 10.4 : 1. Bentonite, though costly has shown significant results by reducing the seepage losses by 72% to 96% respectively [2]. However some materials seem to increase the permeability instead of decreasing like fly ash due to its irregular particle shapes [6].

Other seepage control methods include: Split curtain grouting, High-pressure jet grouting and anti-seepage, Geomembrane anti-seepage Split curtain grouting and High-pressure jet grouting [11]. Scholars have used many different materials, most often material used is cement since the cement has an average particle size of 200μm to 7μm it decreases the permeability up to a great extend but cement is expensive and it makes soil rigid which reduces the chances of further consolidation of soil. There has not been much research on cement soil permeability, and what ratios to mix [7], [10].

The study envisages investigating the addition of Kaolin clay to decrease the permeability of sand. This study is first of its kind and can open new avenues of soil improvement enhancement and while going a long way towards minimizing the loss of water in the form of seepage. We can use this minimal permeable soil mixture at many places wherever needed such as reservoir lining, river banks, around the subways and any other underground structure where the problem of seepage is persisting. Previous studies have either used Bentonite, fly ash or clay minerals to check the permeability changes. In all cases the change in permeability was notable and effective in some cases. But bentonite being expensive and not that readily available cannot be considered an effective material for the purpose. Also due to lack of data on present study it was necessary to connect the missing links of the chain

The main objective of this study include 'arriving at a suitable particle size distribution curve of sand and sand-kaolin mixtures thus obtained after comprehensive tests, testing the permeability of the sand used in the study and to analyze the permeability of the sand after adding the Kaolin clay in different proportions. Furthermore a comprehensive comparison of permeability among mixtures of different proportions of Sand-Kaolin is done'.

II. MATERIAL AND METHOD

A. Collection of the Samples

The Samples for the experiments were collected locally. The sand was collected from a stream and the samples were tested trough sieve tests for particle size analysis. The over sized and undersized particles were eliminated for precise results. The Kaolin was ordered from sources based in Haryana namely 'Soapytwist', it assured the purity of Kaolin clay as locally obtained does not have surety unless you have a proper method or machinery to extract it from natural sources.

B. Ingredients of mixtures

- Sand Sand is a naturally occurring granular substance composed of finely divided rock and mineral particles. The composition of sand is highly variable, depending on the local rock sources and conditions. Generally most common constituent of sand in inland continental settings and non-tropical coastal settings is silica (silicon dioxide, or SiO_2), usually in the form of quartz. The second most common type of ingredient of sand is calcium carbonate [12]. Sand particles range in diameter from 0.075 mm (or 1⁄16 mm) to 4.75 mm. An individual particle in this range size is termed a sand grain. Sand grains are between gravel (with particles ranging from 4.75 mm up to 80 mm) and silt (particles smaller than 0.075 mm down to 0.002 mm). Sands dark to black in color are rich in magnetite, as are sands derived from volcanic basalts and obsidian.
- Sands used in the experimentation were obtained locally from river Sindh. The sand was passed through 4.75 mm sieve which restricted the particle size to 4.75 mm. A detailed particle analysis was performed on the sand and results thus obtained were noted down in the observations section. The color of sand was found to be grayish black. The specific gravity of sand was found to be around 2.73. The sand from river Sind is free from all sorts of organic impurities.
- Kaolin clay Its name was derived from a hill in China (Kao-ling) where it was mined for centuries. Kaolin is a significant raw material with wide-spread application in industrial arena including cement and ceramics production, as porcelain, water treatment, and equally used as fillers for polymer, paint and rubber. It is fundamental in the manufacture of clean white porcelain. The AlO-H-OSi hydrogen bonds are attached to each two unbroken layers since the Kaolinite layer is neutral [13]. There is a formation of an asymmetric environment of octahedral sheets which have hydroxyl groups on the interlayer surface; however the tetrahedral sheets possess oxide surfaces [9].
- The Kaolin is composed of roughly 1:1 clay mineral $Al_2Si_2O_5(OH)_4$ structure per alumina-silicate producing bulky congested particles of SiO_4 tetrahedral sheets and $AlO_2(OH)_4$ octahedral sheets [9].
- The Kaolin used in the experimentation was obtained from Purenso Global, Indore Madhya Pradesh in powdered form. The color of the Kaolin was white and soft textured. Specific gravity of Kaolin was roughly calculated and found 2.6. After a through particle size analysis detailed in the next chapter was performed.
- Mixture proportioning The Kaolin and Sand were mixed thoroughly and then compacted to their original density. The size of mould was 291 cm3 therefore the quantities were taken to make a mixture near that value. Original specific gravities of Sand and Kaolin were 2.73 and 2.6 respectively. The proportions were taken on the basis of masses, to obtain a final mass around 1 kg. After calculating the specific gravity of the samples appropriate weights were taken for the tests from these samples. The following mixtures were prepared for testing in lab shown in Table 1.

Table 1: Proportions and weights of different ingredients used in experiments

Sample ID	Percentage of Kaolin	Mass of Sand in kg	Mass of Kaolin in kg	Total mass of Sample (kg)
Sample 1	0	1	0	1
Sample 2	5	0.95	0.05	1
Sample 3	10	0.9	0.1	1
Sample 4	15	0.85	0.15	1
Sample 5	20	0.8	0.2	1

C. Testing of the Sand Kaolin mixtures

- **Particle size distributions**

Soil Gradation is vital to examine the type of soil that we are dealing with and what kind of soils will these finding be applicable for. It is an indicator of other engineering properties such as compressibility, void ratio, cohesive forces, shear strength, hydraulic conductivity etc.Table 2 shows the classification of soils:

Table 2: Classification of soils according to Indian Standard Soil Classification System (ISSCS)

Very coarse soils	Boulder size		> 300 mm
	Cobble size		80 - 300 mm
Coarse soils	Gravel size	Coarse	20 - 80 mm
		Fine	4.75 - 20 mm
	Sand size	Coarse	2 - 4.75 mm
		Medium	0.425 - 2 mm
		Fine	0.075 - 0.425 mm
Fine Soils	Silt size		0.002 - 0.075 mm
	Clay size		< 0.002 mm

A mechanical grain size analyses was performed on the samples to see the difference in the soil gradation and volume of voids that can be filled by Kaolin particles.

- **Sieve tests**

There are two types of sieve tests — Mechanical (dry) and Hydrometer (using water) method.
Mechanical analysis is a method of separating soil particles into different fractions based on particle sizes. The data is then plotted on a graph and is known as particle distribution curve. Mechanical sieve tests were performed on the samples in the research[15]. This test is performed on oven dry soil almost 500g. The soil sample should be beaten to form powdered sample that passes through the sieves easily. It should contain no lumps of cohesive soil[16]. The sieves are assembled in ascending order, placing those with larger openings on top. Sieve no. 4 should be placed at the top and sieve number 200 at bottom. The Soil sample is placed into the top sieve and a lid is placed over it[17]. The stack is placed over a mechanical shaker for 10 minutes. After the procedure is complete the soil material retained on different sieves is weighed separately. A graph is plotted between the particle sizes versus weight of soil retained at each sieve.
Sieves used in the experiment taken as per IS 460 are 4.75 mm, 2.60 mm, 2.00 mm, 1.70 mm, 1.18 mm, 850 µm, 600 µm, 300 µm, 150 µm, 75 µm and53 µm

- **Permeability**

Permeability is the property of soil that permits flow of water through it. In short permeability is the ease with which water can flow through soil[18]. A highly pervious soil allows water to flow easily through it while as in an impervious soil, the permeability is very low and water cannot easily flow through it[19]. However there is no completely impervious soil but a soil is said to be impervious when the permeability is extremely low. Permeability is important property in engineering field as it is important to almost all the civil engineering projects like roads foundation, reservoir construction, subway construction, etc. The flow of water through soil is due to gravitation and depends on the head causing the flow, porosity and viscosity of water.

- **Darcy's law**

The testes performed in the research are based on Darcy's law. Darcy demonstrated an experiment in 1856, and stated that for laminar low in homogeneous soil, the velocity (v) is stated as

$$v = k\,i$$

Where k = coefficient of permeability, i = hydraulic gradient
The discharge Q can be calculated by multiplying the velocity of flow by the total cross sectional area (A) of soil perpendicular to the direction of flow.

$$Q = v\,A = k\,i\,A$$

The area is taken as area of soil sample including solids and voids. The quantity that tells us about the permeable of a particular material is coefficient of permeability which is constant for a material irrespective of hydraulic gradient length or area of cross-section of the soil sample. For a unity hydraulic gradient coefficient of permeability is equal to the velocity of flow. The coefficient of permeability has dimensions of velocity (L/T). It is measured in mm/sec, m/sec, m/day or other velocity units. The quotient of velocity depends on porosity, particle size particle shapes and many other factors. Table 3 shows the coefficient of permeabilities of different soils.

Table 3: Limits of coefficient of permeabilities of different soils

S. No.	Soil Type	Coefficient of permeability (mm/sec)
1.	Clean gravel	10^{1} to 10^{2}
2.	Coarse and medium sands	10^{-2} to 10^{1}
3.	Fine sands, loose silt	10^{-4} to 10^{-2}
4.	Dense silt, clayey silts	10^{-5} to 10^{-4}
5.	Silt clay, clay	10^{-8} to 10^{-5}

Methods to calculate the coefficient of permeability

- Lab methods: In lab coefficient of permeability can be obtained by the following methods:
- Constant head permeability tests
- Variable head permeability tests
- Field methods include:
- Pumping out tests and
- Pumping in tests.
- Indirect methods.
- Computation from the particle size or its specific surface.
- Computation from the consolidation
- **Constant head permeability test** This test is used for the soils that have relatively high permeability and water flows faster through the sample [20]. A constant flow is maintained through the soil sample by constant head reservoir and overflow pipe. The apparatus used to conduct the experiment is known as constant head permeameter shown in Fig.1, it contains a metallic mould. The dimensions of the mould are given in IS: 2720 (Part XVII) as 100 mm internal diameter, 127.3 mm effective height and 1000 ml capacity[21]. The mould has a detachable extension collar that has 100mm dia and 60mm height [8].

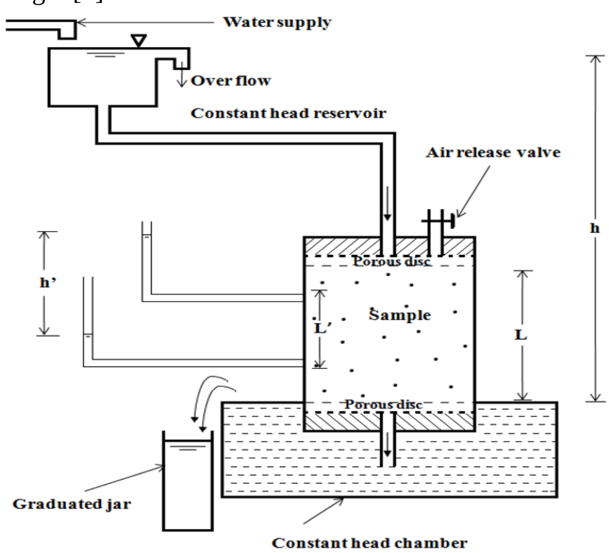

Figure 1: Schematic diagram of Constant head permeameter

A drainage base and cap is fitted with clamps to the mould. The porous discs should not have permeability lesser than ten times the approximate permeability of soil sample. The soil sample should be fully saturated before the tests, to ensure this an upward flow of water from the base expels out all the air in the sample. The saturated soil sample in the permeameter is connected with a constant head chamber. A constant overflow is maintained in the reservoir to maintain a constant head in the input supply.
The water is allowed to flow out of drainage base for some time till the flow is steady and uniform. The mould is kept in another constant head chamber where the extra water overflows into a graduated jar[22]. The difference between the water levels in constant head reservoir and the constant head chamber is the head (h) that causes the flow. If the specimen has a cross-sectional area of A, and length L then the discharge is given by Darcy's Law as

$$q = k\, i\, A$$

or $$q = k \frac{h}{L} A$$

or $$k = \frac{q\,L}{h\,A}$$

Where q is the amount of water collected in the graduated jar. With this equation we can calculate the coefficient of permeability of relatively high permeable soils like sand.

- **Variable head permeability test**

This test is used for relatively less permeable soils, if we use constant head permeability test for low permeable soil the water collected in the graduated jar will be very small and cannot be measured accurately. According to Indian Standard codes, soils with 10% of particles passing through a 75μm sieve are tested with variable head permeameter shown in Fig.2. The mould used is same as constant head permeameter apparatus; the only difference is, instead of a constant head reservoir a stand pipe of known diameter is used. The mould with soil sample (compacted to desired density) is placed in a constant head chamber filled with water to the brim. The sample is deaired by applying vacuum and allowing water to enter in upwards direction. The saturated sample is then ready for the test. The water enters the mould through stand pipe and the level of water decreases in the stand pipe gradually. The time taken for water level to drop from head (h1) to a known final head (h2) is noted down. The coefficient of permeability is measured using the following equation.

$$k = \frac{a\,L}{A\,t} \log_e (h_1/h_2)$$

where, $t = t_2 - t_1$ and a = area of cross-section of stand pipe.
The permeability of first two samples were performed by constant head permeability method as the particle size falling below 75μm is almost 5 % , that is less than 10%. The rest of the samples were tested through the method of variable head permeability tests also known falling head permeability tests.

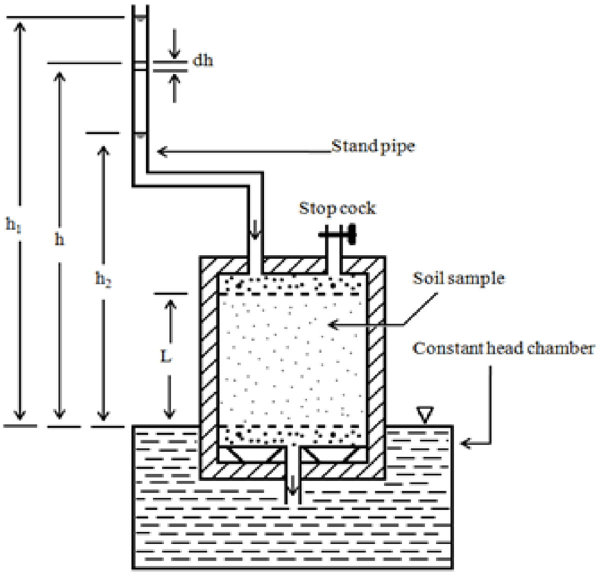

Figure 2: A schematic diagram of Falling head permeameter

III. RESULTS AND DISCUSSION

After primary presentation and performing practical works like preparation of material, discussion mixture proportions, then testing was conducted in the lab and the data was recorded, analyzed and put in proper format for further processing.

A. Sieve test results

After 500 grams of the Samples were sieved through different sieves, the following results were recorded and put in tabular form. The sieves were selected as per IS 460 part-I. Table 4, Table5, Table 6, Table 7 & Table 8 shows the sieve analysis of different sample with different percentages of Kaoli

Table 4: Sieve analysis of sample 1: Weight 500g (0% Kaolin)

Sieve as per IS 460	Weight retained (in grams)	Weight passed (in grams)	Percentage weight retained	Percentage weight passed	Cumulative percentage retained
4.75 mm	0	500.0	0.0	100.0	0.0
2.60 mm	6.6	493.4	1.3	98.7	1.3
2.00 mm	13	480.4	2.6	96.1	3.9
1.70 mm	55.2	425.2	11.0	85.0	15.0
1.18 mm	35.4	389.8	7.1	78.0	22.0
850 μm	64.6	325.2	12.9	65.0	35.0
600 μm	245.6	79.6	49.1	15.9	84.1
300 μm	59.4	20.2	11.9	4.0	96.0
150 μm	20.2	0.0	4.0	0.0	100.0
75 μm	0	0.0	0.0	0.0	100.0
53 μm	0	0.0	0.0	0.0	100.0

Table 5: Sieve analysis of Sample 2: Weight 500 g (5% Kaolin)

Sieve as per IS 460	Weight retained (in grams)	Weight passed (in grams)	Percentage weight retained	Percentage weight passed	Cumulative percentage retained
4.75 mm	0	500.0	0.0	100.0	0.0
2.60 mm	6.5	493.5	1.3	98.7	1.3
2.00 mm	12.4	481.1	2.5	96.2	3.8
1.70 mm	52.4	428.7	10.5	85.7	14.3
1.18 mm	33.6	395.1	6.7	79.0	21.0
850 µm	61.2	333.9	12.2	66.8	33.2
600 µm	233.2	100.7	46.6	20.1	79.9
300 µm	56.4	44.3	11.3	8.9	91.1
150 µm	19.2	25.1	3.8	5.0	95.0
75 µm	0.5	24.6	0.1	4.9	95.1
53 µm	1.1	23.5	0.2	4.7	95.3
32 µm	3.5	20.0	0.7	4.0	96.0
25 µm	3	17.0	0.6	3.4	96.6
Pan	17	0.0	3.4	0.0	100.0

Table 6: Sieve analysis of Sample 3 (Kaolin 10 %)

Sieve as per IS 460	Weight retained (g)	Weight passed (g)	Percentage weight retained	Percentage weight passed	Cumulative percentage retained
4.75 mm	0	500.0	0.0	100.0	0.0
2.60 mm	6.2	493.8	1.2	98.8	1.2
2.00 mm	11.7	482.1	2.3	96.4	3.6
1.70 mm	49.6	432.5	9.9	86.5	13.5
1.18 mm	31.8	400.7	6.4	80.1	19.9
850 µm	58.2	342.5	11.6	68.5	31.5
600 µm	221.1	121.4	44.2	24.3	75.7
300 µm	53.4	68.0	10.7	13.6	86.4
150 µm	18.2	49.8	3.6	10.0	90.0
75 µm	1	48.8	0.2	9.8	90.2
53 µm	2.2	46.6	0.4	9.3	90.7
32 µm	7.1	39.5	1.4	7.9	92.1
25 µm	6.4	33.1	1.3	6.6	93.4
Pan	33.1	0.0	6.6	0.0	100.0

Table 7: Sieve analysis of Sample 4 (Kaolin 15%)

Sieve as per IS 460	Weight retained (in grams)	Weight passed (in grams)	Percentage weight retained	Percentage weight passed	Cumulative percentage retained
4.75 mm	0.0	500.0	0.0	100.0	0.0
2.60 mm	5.6	494.4	1.1	98.9	1.1
2.00 mm	11.1	483.3	2.2	96.7	3.3
1.70 mm	46.7	436.6	9.3	87.3	12.7
1.18 mm	30.1	406.5	6.0	81.3	18.7
850 µm	55.0	351.5	11.0	70.3	29.7
600 µm	208.8	142.7	41.8	28.5	71.5
300 µm	50.4	92.3	10.1	18.5	81.5
150 µm	17.2	75.1	3.4	15.0	85.0
75 µm	1.6	73.5	0.3	14.7	85.3
53 µm	3.0	70.5	0.6	14.1	85.9
32 µm	10.5	60.0	2.1	12.0	88.0
25 µm	9.0	51.0	1.8	10.2	89.8
Pan	51.0	0.0	10.2	0.0	100.0

Table 8: Sieve analysis of Sample 5 (Kaolin 20%)

Sieve as per IS 460	Weight retained (in grams)	Weight passed (in grams)	Percentage weight retained	Percentage weight passed	Cumulative percentage retained
4.75 mm	0.0	500.0	0.0	100.0	0.0
2.60 mm	5.3	494.7	1.1	98.9	1.1
2.00 mm	10.4	484.3	2.1	96.9	3.1
1.70 mm	44.2	440.2	8.8	88.0	12.0
1.18 mm	28.3	411.8	5.7	82.4	17.6
850 µm	51.8	360.1	10.4	72.0	28.0
600 µm	196.6	163.5	39.3	32.7	67.3
300 µm	47.4	116.1	9.5	23.2	76.8
150 µm	16.2	100.0	3.2	20.0	80.0
75 µm	2.0	98.0	0.4	19.6	80.4
53 µm	4.0	94.0	0.8	18.8	81.2
32 µm	14.0	80.0	2.8	16.0	84.0
25 µm	12.0	68.0	2.4	13.6	86.4
Pan	68.0	0.0	13.6	0.0	100.0
Total	500	-	100 %		-

Fig.3 to Fig.7 shows the Particle size distribution curves for different samples with different percentages of kaolin.

B. Particle size distributions curves of Samples

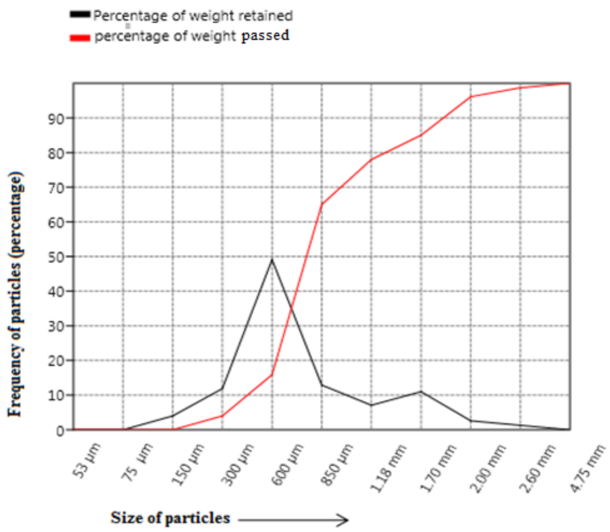

Figure 3: Particle size distribution curve of Sample 1(0% Kaolin)

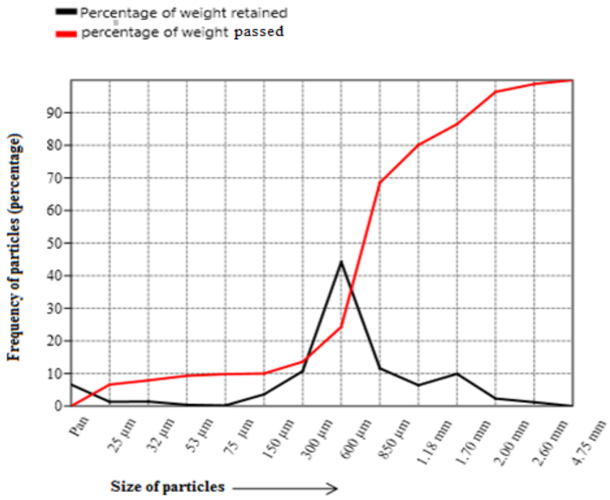

Figure 5: Particle size distribution curve of Sample 3(10% Kaolin)

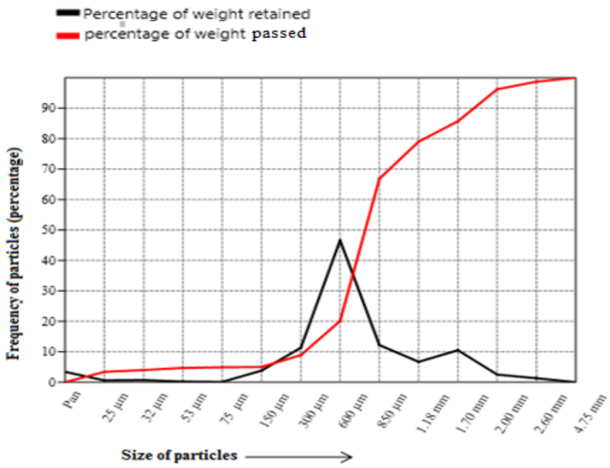

Figure 4: Particle size distribution curve of Sample 2(5% Kaolin)

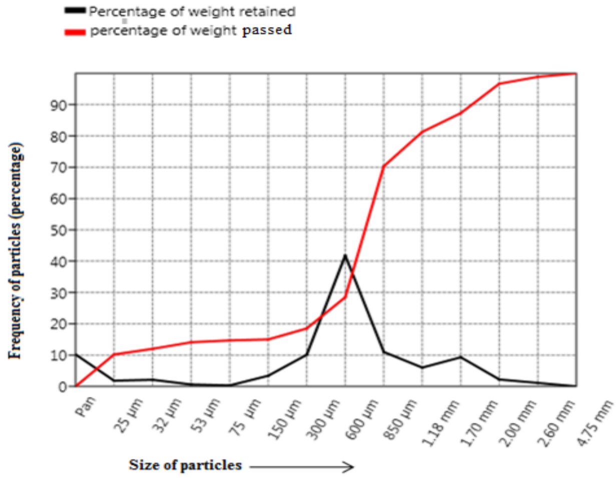

Figure 6: Particle size distribution curve of Sample 4(15% Kaolin)

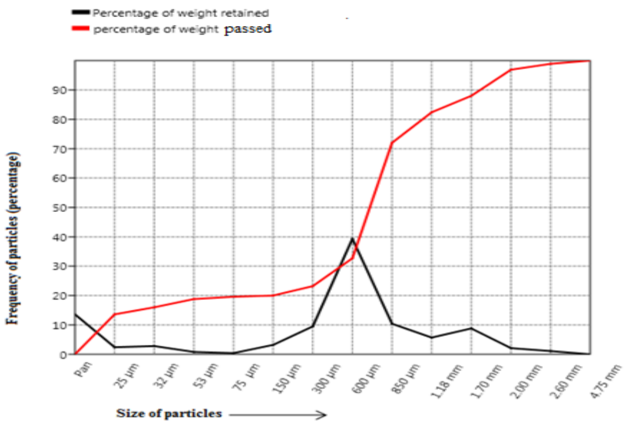

Figure 7: Particle size distribution curve of Sample 5(20% Kaolin)

C. Sieve tests analysis

The particle size distribution gives a clearer picture as to what is happening with the gradation of the soil. The finer particles fill up the voids and thus clogging the passage ways for water. The gradation of sand gets better making it more stable and hydraulically more resistant.

Coefficient of uniformity (Cu) as

$$C_u = \frac{D_{60}}{D_{10}}$$

Where D60 is the grain diameter at 60% passing and D10 is the grain diameter at 10 % passing

The coefficient of uniformity changed from 1.833 in sample 1 to 41.66 in sample 5

This implies the soil goes from poorly graded less than 4 to well graded i.e. more than 6. Measurements have demonstrated that the uniformity coefficient could be responsible for variances up to a value, which is significantly larger than the impact of water viscosity changing due to temperature changes. Possibilities of finding soils with coefficient of uniformity greater than 100 are rare under natural circumstances.

D. Permeability Results

Table 9 shows the calculation of discharge Table 10 & Table 11 shows the Coefficient of permeability.

Constant head permeability test results

Temperature of water was recorded as 20 o C

Table 9: Calculation of discharge

Sample no.	Kaolin content	Attempt	Volume (cm3)	Time taken (s)	Discharge (cm3/s)
Sample 1	0 %	1	648	60	10.8
	0 %	2	673	60	11.21
Sample 2	5 %	1	83.5	60	1.39
	5 %	2	87	60	1.45

E. Calculation of Coefficient of Permeability

- **Variable head or Falling head permeability tests**

The equipment available in Lab had following specification:

Length of sample (L) = 5.8 cm

Area of cross section (A) = 50.28 cm2

Constant head used (h) = 10 cm

Discharge (q) in table

Using the equation of coefficient of permeability $k = \frac{\square\,\square}{h\,\square}$

Table 10: Calculation of coefficient of permeability

Sample no.	Kaolin content	q_1	q_2	Average discharge	Coefficient of permeability (k) cms^{-1}
1	0%	10.8	11.21	11	1.269×10^{-1}
2	5%	1.39	1.45	1.42	1.638×10^{-2}

- **Variable head or Falling head permeability tests**

Following the parameters taken before the experiments

Temperature of water was recorded 20 oC

Area of cross section of sample (A) = 50.24 cm2

Length of sample (L) = 5.8 cm

Area of cross section of standing pipe (a) = 1 cm2

t* The time taken (t) for the head in standing pipe to fall from 90 cm to 50 cm was recorded

The coefficient of permeability k* was calculated by

$$k = \frac{aL}{A\,t} \log_e (h1/h2)$$

Table 11: Calculation of coefficient of permeability

Sample no.	Kaolin percent	Attempt	Time taken (t*) s	Coefficient of permeability (k*) cms-2	Average coefficient of permeability k cms-2
Sample 3	10%	1	32	9.06 × 10-4	9.205 × 10-4
		2	31	9.35 × 10-4	
Sample 4	15%	1	236	1.23 × 10-4	1.24 × 10-4
		2	232	1.25 × 10-4	
Sample 5	20%	1	535	5.42 × 10-5	5.4 × 10-5
		2	539	5.38 × 10-5	

Fig. 8 shows the variation of permeability with kaolin and Fig. 9 shows the logarithmic variation.

F. Permeability results

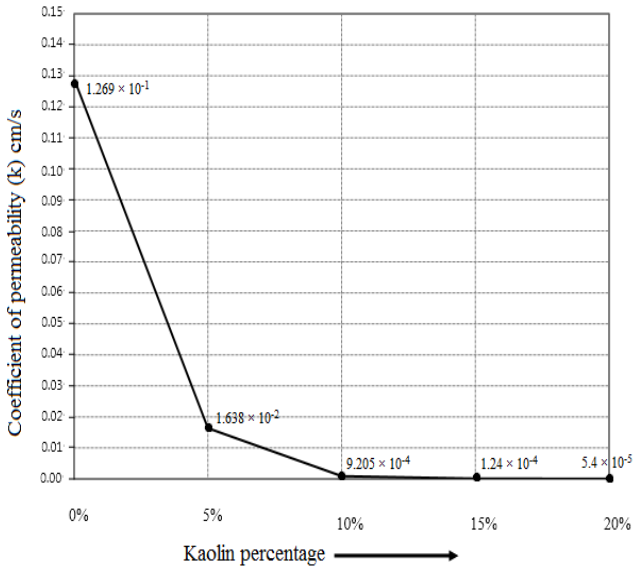

Figure 8: Variation of coefficient of permeability with Kaolin content

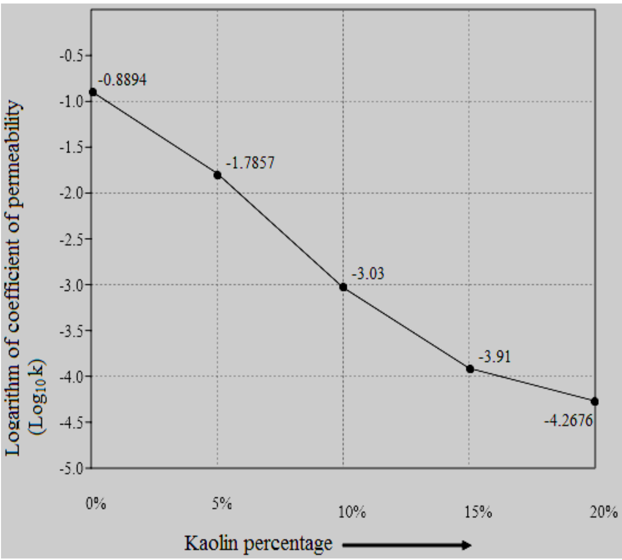

Figure 9: Logarithmic variation of coefficient of permeability with Kaolin content

IV. CONCLUSION

Based on the analysis and interpretation of experimental investigations on sand- Kaolin mixtures, the following statements can be concluded:

- With the increase in the Kaolin content the gradation of soil gets better, with improvement in all the characteristics related to the particle size, such as cohesion between particles which makes soil more stable to stresses.
- With the increase in Kaolin content a steep decrease in the hydraulic conductivity of sand was observed upto a Kaolin content of 10% (Fig. 8).
- It can be concluded that by adding just 10% of Kaolin clay the hydraulic conductivity could be reduced by 99.3%.
- Beyond 10% Kaolin content the variation in hydraulic conductivity was found to be marginal.
- The logarithmic graph (Fig 9) shows us the exponential change in the permeability of sand. The graph is gradually flattening, which means further increase in Kaolin will result in milder changes in the permeability of sands, and can prove economically unsuitable.

CONFLICTS OF INTEREST

We hereby declare there is no conflict of interest among the authors

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