The Influence of Particle Size on Permeability in an Overburden Dump Material

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Bachelor of Technology

in

Mining Engineering

by

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(19MI33001)

Under the supervision of

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Spring Semester, 2022-23

May 3, 2023

DECLARATION

I certify that

(a) The work contained in this report has been done by me under the guidance of my supervisor.

(b) The work has not been submitted to any other Institute for any degree or diploma.

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DEPARTMENT OF MINING ENGINEERING

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CERTIFICATE

This is to certify that the project report entitled "**The Influence of Particle Size on Permeability in an Overburden Dump Material**" submitted by **Akash Deep** (Roll No. 19MI33001) to Indian Institute of Technology Kharagpur towards partial fulfilment of requirements for the award of degree of Bachelor of Technology in Mining Engineering is a record of bona fide work carried out by him under my supervision and guidance during Spring Semester, 2022-23.

Date: May 3, 2023
Place: Kharagpur

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Contents

Chapter 1

Introduction

1.1 Significance of Permeability Test of Soil

Soils are permeable materials due to the presence of interconnected voids that allow fluid to flow from high energy places to low energy places. A good knowledge of the permeability of the soil is essential to assess the amount of drainage to facilitate underground construction.

Permeability is one of the most crucial soil properties of interest for a geophysical engineer. This is because it affects the settlement rate of saturated soil under hydraulic structures. The earth dam design is based chiefly on the permeability of the soil used and greatly influences the stability of retaining structures and slopes. Soil permeability is also significant for the estimation of underground seepage and for analyzing the strength of earth structures suffering from seepage forces. Various factors affect soil permeability, like void ratio, degree of saturation, and intergranular pore distribution.

Also termed Hydraulic Conductivity, permeability can be measured using several methods. Field permeability can be measured using pump tests, which provide a good measure of aquifer permeability. Pumping tests give the average value of the permeability coefficient at the landfill. For a detailed analysis, laboratory methods can be used to measure permeability, which includes Constant Head and Variable Head tests.

1.2 Mine Dump

Waste overburden and unprofitable mineralized rock is needed to be removed to extract a useful mineral resource in a surface mining operation. In this process, a landfill is formed by disposing of the waste and dumping it in the vicinity. The dump thus formed is known as the mine waste heap. These waste rock dumps are heterogeneous in particle size distribution and structure. Rock fragmentation in a landfill results from various mechanical processes such as drilling, blasting, and ripping. Hence, the dump rock can vary in size from clay particles to boulders.

The permeability of a fill is the measure of the ease with which water flows through its voids. Permeability is the key to successful drainage. Upon placement, it is desirable to drain it as quickly as possible so the fill material can settle and reach its operating density. This process of drainage is dependent upon the permeability of the fill. It is common practice to specify fill permeability in terms of percolation rate. Since the percolation rate is dependent on the fill material, the grain size distribution and the porosity affect the drainage behavior of the fill. As for the fluid flowing through the fill, in this case, water, the viscosity and degree of saturation also influence its dewatering capabilities.

1.3 Objectives

The primary goals of this project is to test the permeability of Overburden dump material using falling head method and the objectives are outlined as given below.

- To segregate the oven-dried sample based on the Unified Soil Classification System (USCS)
- To perform Falling Head Permeability Test on the segregated samples
- To compare and analyse the different results found in samples
- To find the influence of particle size on permeability of samples

Chapter 2

Literature Review

2.1 Factors affecting Permeability

Permeability is a complex property controlled by the physical properties of soil and permeant fluid (DeGroot et al., 2012). At a constant temperature of 20°C, standard room temperature, viscosity, and specific gravity of water remain constant. Therefore, permeability is affected by physical properties such as particle size distribution, density, porosity, texture, and soil structure.

2.1.1 Effect of Grain Size and Grain Size Distribution

Grain size distribution of granular soils affects their permeability (Freeze and Cherry, 1979). There are several ways to characterize grain size distribution of a granular soil. Commonly used indices include coefficient of uniformity, $C_u = \frac{D_{60}}{D_{10}}$ and coefficient of curvature, $C_c = \frac{D_{30}^2}{D_{10}D_{60}}$ where D_{10}, D_{30}, and D_{60} are particle sizes, in mm, of 10%, 30%, and 60%, by weight of soil, passing the respective sieve sizes.

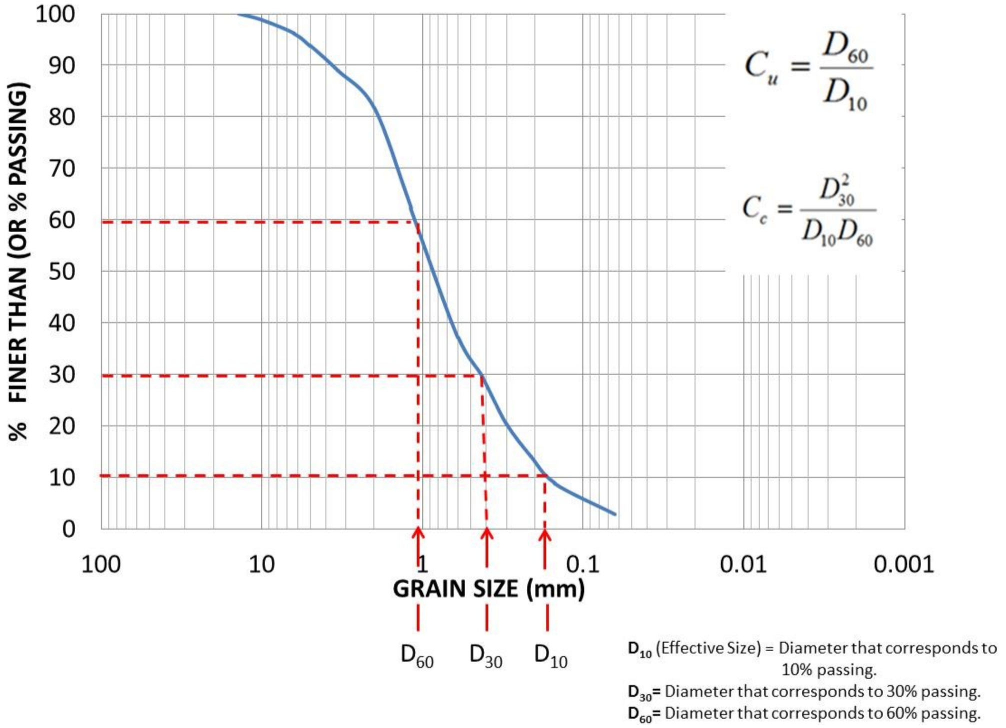


FIGURE 2.1: Typical grain size distribution curve with commonly used grain size indices

C_u is a vital shape factor that represents the soil sorting degree and indicates the slope of the grain size distribution curve (Mitchell & Soga, 2005). Larger C_u values indicate well-graded soils, and smaller C_u values indicate uniformly-graded soils (Holtz et al., 2011). Poorly-graded soils have higher porosity and permeability values than well-graded soils in which smaller grains tend to fill the voids between larger grains. C_c is another important shape factor representing the grain size distribution that considers three points on the grain size distribution curve, reducing the possibility of considering a gap-graded soil as well-graded.

2.1.2 Effect of Density and Void Ratio

Dry density (ρ) is the ratio of the mass of the solids in a soil to its total volume, the sum of the volume of solids and voids. Void ratio (e) is defined as the ratio of the volume of voids to the volume of solids (Das, 2008). The density and void ratio are inversely related. Permeability decreases as density increases or the void ratio decreases.

2.1.3 Effect of Soil Texture and Structure

Texture and structure relate to the size, shape, and arrangement of particles in a soil mass. Particle shape has an essential effect on permeability as it influences the size and shape of interconnection between particles (Figure 2.2). The more angular the grains are, the smaller the voids and the more tortuous the flow paths will be (Figure 2.3). This is because edges and corners of angular grains can fit into voids, i.e., there is a greater degree of interlocking (Holtz et al., 2011).

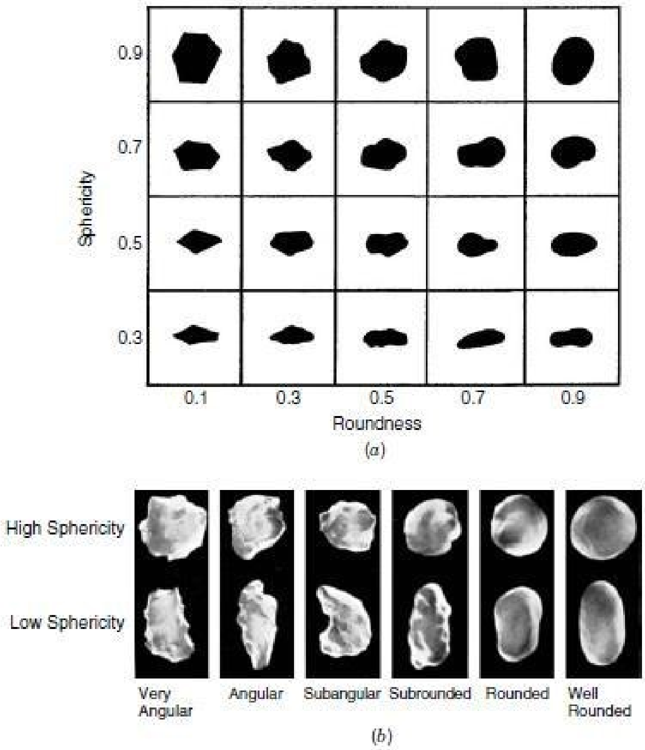


FIGURE 2.2: Particle shape characterization: (a) chart for visual estimation of roundness and sphericity (from Krumbein and Sloss, 1963). (b) Examples of particle shape characterization (from Powers, 1953).

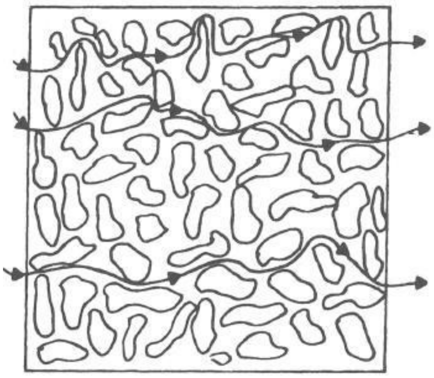


FIGURE 2.3: Diagram showing horizontal flow through grains (From Das, 2008).

2.2 Falling Head Tests

In conventional falling-head tests, we insert a vertical standpipe of a small sectional area into the saturated granular sample from the top. Water is used as test fluid, and a high head is usually desired, which may vary from 0.9 to 4.5 m (Hall 2004). During the test, the water level falls from its initial position, h_o, to a certain height, h_1, over a time interval Δt. The permeability is then calculated as follows (Bear 1972):

$$k = \frac{aL}{A\Delta t} ln(\frac{h_o}{h_1})$$

where a = cross-sectional area of the standpipe; L = vertical length of the specimen; and A = Cross sectional area of specimen. The change in liquid position is usually recorded visually in time.

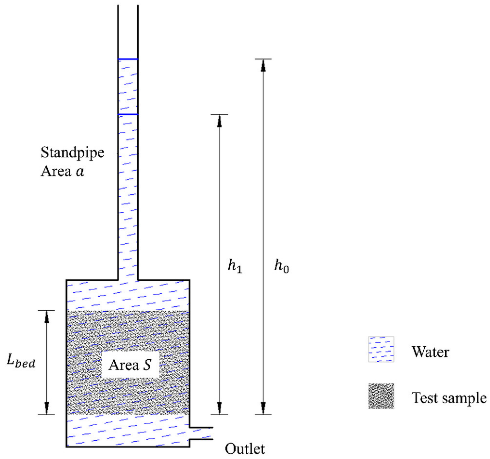


FIGURE 2.4: Schematic diagram of the conventional falling-head test.

2.3 Sieve Analysis

A particle size analysis test is performed to determine the percentage of grains of each size contained in a soil sample, and the test results can be used to plot a grain size distribution curve. The typical particle-size range for sieving is 50 to 2000 µm. Day (1965) indicated that the probability of a particle passing through a sieve in a given time of shaking depends on the nature of the particle, the number of particles of that size, and the properties of the sieve.

FIGURE 2.5: Sieve for sieve analysis.

Chapter 3

Materials and Methodology

3.1 Materials

For this project, dump material was collected from Back Benches 2, 3 and 4 of the Iron Ore Mines, Jindal Steel and Power Limited(JSPL), Tensa, Odisha, India. The other permeability test components used in this study are tap water.

Figure 3.1: Dump Material

3.2 Sample Preparation and Sieve Analysis

The specimens were prepared and segregated at the laboratory as per the Unified Soil Classification System. Sample was initially oven-dried for a period of 24 hours. Then this oven-dried specimen was segregated using Sieve analysis and classified into three groups based on their size as Gravel sized particle, Sand sized particle and Clay sized particle.

(a) Oven-dried Specimen from Back Bench 4

(b) Oven

FIGURE 3.2

Two sets of 3kg oven-dried specimens were analyzed and sieved. The sieves shall be stacked so that those with larger openings (lower numbers) are placed above those with smaller openings (higher numbers). A pan is placed under the last sieve to collect the portion of specimen passing through it. Then the specimen shall be poured from above into the stack of sieves, after which the cover is placed on it. Then the stack is put in the sieve shaker, the clamps are affixed, and the shaker starts and runs for 10 minutes. Mass of each sieve along with retained specimen shall then measured. 16 sieves along with pan were used.

FIGURE 3.3: Sieve

Sieve Size(mm)
4.75
4
3.35
2.8
2.36
2
1.7
1.18
0.85
0.71
0.6
0.5
0.425
0.355
0.3
0.09
pan

TABLE 3.1: Sieve sizes

Particle size analysis is then used to find the median particle diameter D_{50} of both sets of sample. The particles collected from the sieves of both the sets shall then be segregated into Gravel sized, Sand sized, and Clay sized specimen.

FIGURE 3.4: Segregated sample

3.3 Falling Head Test

The falling head permeability test is a common laboratory testing method used to determine the permeability of fine grained soils with intermediate and low permeability such as rocks, silts and clays. This testing method can be applied to an undisturbed sample. This test involves the flow of water through a soil sample. At the top of the sample is a standpipe which provides the water head, and allows measurement of the volume of water passing through the sample. This test is carried out in a permeameter.

Each segregated sample is then tested for determination of Hydraulic Conductivity

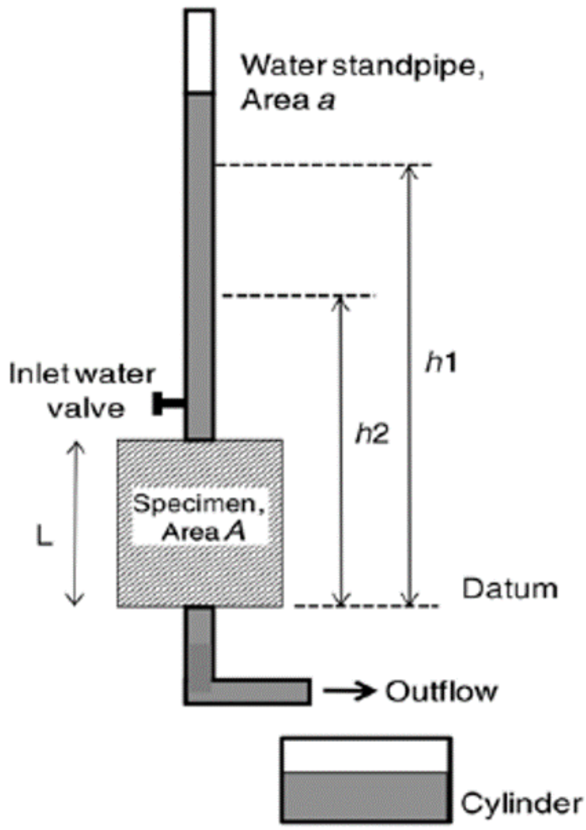


FIGURE 3.5: Test Setup

(K) using this method. The first step is to completely saturate the sample until a constant flow comes from the bottom of the permeameter. Once the sample is saturated and a steady flow of water is achieved, the bottom valve shall be closed (stopping the flow). Then the standpipe shall be refilled with de-aired water, the bottom valve opened, and the test starts. Water will flow while the water head will diminish over time. The test will be complete when the standpipe water reaches a lower predefined level. The time taken for water in the standpipe to drop from the higher to the lower level shall be recorded. This operation shall be repeated three times.

FIGURE 3.6: Falling Head Test using Permeameter

Chapter 4

Results and Discussions

4.1 Particle Size Analysis

The particle size is measured for two sets of the oven-dried specimen of Back Bench 4 using the sieve setup after segregating it on the sieve shaker for 10 minutes and the median diameter, D_{50} is calculated. The below table represents the data for particle size test of both the samples and the graph shows the particle distribution curve.

Sample 1			**Sample 2**	
D30	1.552240437		D30	1.437758621
D10	0.567711599		D10	0.565027322
D50	**4.083333333**		**D50**	**3.268518519**
	Average D50	**3.675925926**		

FIGURE 4.1: D_{50}

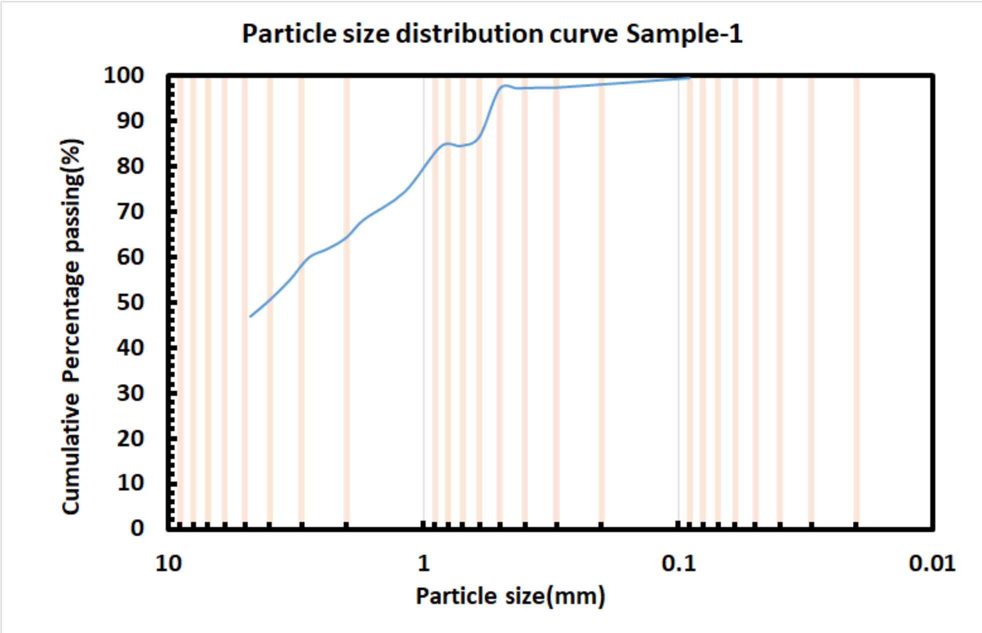
3000	grams	Back Bench 4 Sample 1				
seive size	Empty weight	pan plus sample	weight of sample on sieve	Cumulative weight		passing through a sieve
(mm)	grams	grams	grams	grams	%	%
4.75	1175	2579	1404	1404	46.8	53.2
4	1410	1518	108	1512	50.4	49.6
3.35	1107	1236	129	1641	54.7	45.3
2.8	1129	1283	154	1795	59.83333333	40.16666667
2.36	1208	1267	59	1854	61.8	38.2
2	897	970	73	1927	64.23333333	35.76666667
1.7	1006	1127	121	2048	68.26666667	31.73333333
1.18	925	1108	183	2231	74.36666667	25.63333333
0.85	925	1228	303	2534	84.46666667	15.53333333
0.71	877	880	3	2537	84.56666667	15.43333333
0.6	900	960	60	2597	86.56666667	13.43333333
0.5	847	1166	319	2916	97.2	2.8
0.425	936	939	3	2919	97.3	2.7
0.355	903	907	4	2923	97.43333333	2.566666667
0.3	899	900	1	2924	97.46666667	2.533333333
0.09	851	914	63	2987	99.56666667	0.433333333
pan	1195	1208	13	3000	100	0

(a) Sample 1

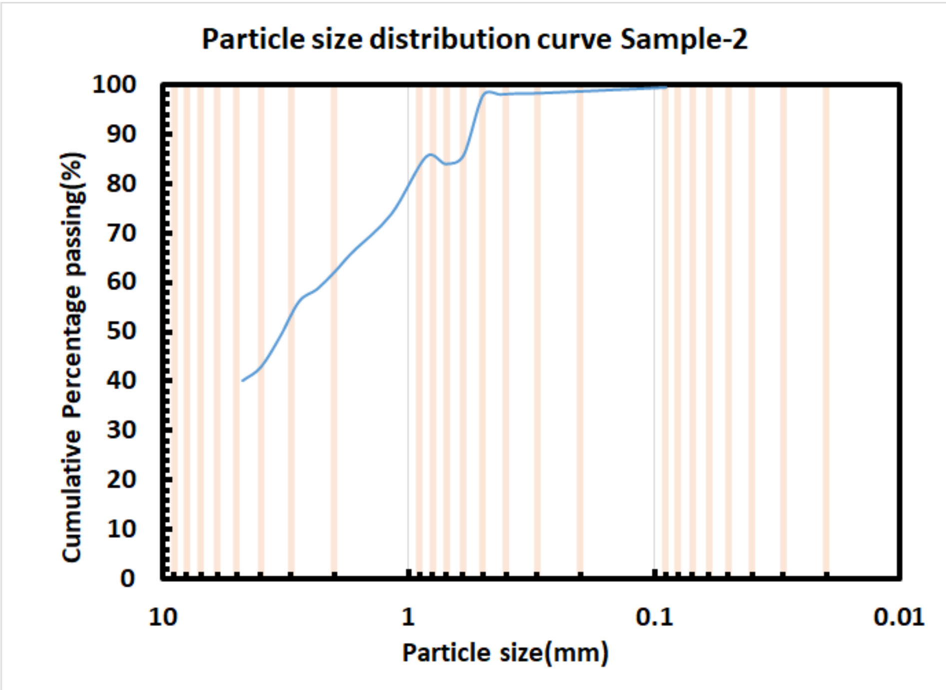
	Back Bench 4 sample 2				3000	grams
seive size	Empty weight	pan plus sample	weight of sample on sieve	Cumulative weight		passing through a sieve
(mm)	grams	grams	grams	grams	%	%
4.75	1175	2377	1202	1202	40.06666667	59.93333333
4	1410	1493	83	1285	42.83333333	57.16666667
3.35	1107	1290	183	1468	48.93333333	51.06666667
2.8	1129	1345	216	1684	56.13333333	43.86666667
2.36	1208	1284	76	1760	58.66666667	41.33333333
2	897	1003	106	1866	62.2	37.8
1.7	1006	1123	117	1983	66.1	33.9
1.18	925	1157	232	2215	73.83333333	26.16666667
0.85	925	1276	351	2566	85.53333333	14.46666667
0.71	877	832	-45	2521	84.03333333	15.96666667
0.6	900	951	51	2572	85.73333333	14.26666667
0.5	847	1213	366	2938	97.93333333	2.066666667
0.425	936	942	6	2944	98.13333333	1.866666667
0.355	903	909	6	2950	98.33333333	1.666666667
0.3	899	900	1	2951	98.36666667	1.633333333
0.09	851	886	35	2986	99.53333333	0.466666667
pan	1195	1209	14	3000	100	0

(b) Sample 2

FIGURE 4.2: **Particle Size Data**



(a) Sample 1



(b) Sample 2

FIGURE 4.3: **Particle Size Distribution**

4.2 Falling Head Test

Falling head permeability tests were conducted at regular intervals for the three segregated specimens of the three back benches. The specimen is kept inside a permeameter and is saturated. After saturation, water is allowed to flow until steady flow is obtained, and then for a fall of head in the standpipe, the time interval is noted. The observed data are shown in the table below:

	Initial Height (H_o) (mm)	Final Height (H_f) (mm)	Time (t) (sec)	$\ln(H_o/H_f)$	Hydraulic Conductivity (K) (mm/s)	Average K (mm/s)	At/aL (sec/mm)	K from graph (mm/s)
Clay Sized Particle	800	700	2630	0.133531393	0.0000172		7747.666914	
	700	600	3040	0.15415068	0.0000172	**0.0000156**	8955.478106	**0.0000141**
	580	480	5220	0.189242	0.0000123		15377.498589	
				0.000000			0.000000	
Sand Sized Particle	900	800	504	0.117783036	0.0000793299		1484.724002	
	800	700	590	0.133531393	0.0000768274	**0.0000778**	1738.069764	**0.000078**
	700	600	678	0.15415068	0.0000771793		1997.307288	
				0.000000			0.000000	
Gravel Sized Particle	900	800	383	0.117783036	0.000104392		1128.272406	
	800	700	436	0.133531393	0.000103964	**0.0000998**	1284.404097	**0.000098**
	700	600	575	0.15415068	9.10044E-05		1693.881550	
				0.000000			0.000000	

(a) Back Bench 2

	Initial Height (H_o) (mm)	Final Height (H_f) (mm)	Time (t) (sec)	$\ln(H_o/H_f)$	Hydraulic Conductivity (K) (mm/s)	Average K (mm/s)	At/aL (sec/mm)	K from graph (mm/s)
Clay Sized Particle	800	700	2718	0.133531393	0.0000167		8006.904438	
	700	600	3222	0.15415068	0.0000162	**0.0000161**	9491.628440	**0.0000160**
	600	500	3989	0.182321557	0.0000155		11751.119133	
				0.000000			0.000000	
Sand Sized Particle	900	800	398	0.117783036	0.0001004580		1172.460620	
	800	700	487	0.133531393	0.0000930763	**0.0000912**	1434.644025	**0.000088**
	700	600	653	0.15415068	0.0000801340		1923.660264	
				0.000000			0.000000	
Gravel Sized Particle	900	800	263	0.117783036	0.000152024		774.766691	
	800	700	316	0.133531393	0.000143444	**0.0001463**	930.898382	**0.000145**
	700	600	365	0.15415068	0.000143363		1075.246549	
				0.000000			0.000000	

(b) Back Bench 3

	Initial Height (H_o)	Final Height (H_f)	Time (t)	ln(H_o/H_f)	Hydraulic Conductivity (K)	Average K	At/aL	K from graph
	(mm)	(mm)	(sec)		(mm/s)	(mm/s)	(sec/mm)	(mm/s)
Clay Sized Particle	800	700	2630	0.133531393	0.0000172	0.0000156	7747.666914	0.0000141
	700	600	3040	0.15415068	0.0000172		8955.478106	
	580	480	5220	0.189242	0.0000123		15377.498589	
				0.000000			0.000000	
Sand Sized Particle	900	800	504	0.117783036	0.0000793299	0.0000778	1484.724002	0.000078
	800	700	590	0.133531393	0.0000768274		1738.069764	
	700	600	678	0.15415068	0.0000771793		1997.307288	
				0.000000			0.000000	
Gravel Sized Particle	900	800	383	0.117783036	0.000104392	0.0000998	1128.272406	0.000098
	800	700	436	0.133531393	0.000103964		1284.404097	
	700	600	575	0.15415068	9.10044E-05		1693.881550	
				0.000000			0.000000	

(c) Back Bench 4

FIGURE 4.4: Falling Head Test Data

Graph is plotted to determine the hydraulic conductivity (K) of the specimen and it is used to find the coefficient of permeability of the sample (k). The comparison of the hydraulic conductivities of clay, sand and gravel sized particles also is shown in the below graph.

Hydraulic Conductivity (K)	Permeability Coefficient (k)
(mm/s)	(mm^2)
0.0000141	1.4399E-09
0.000078	7.96541E-09
0.000098	1.00078E-08

(a) Back Bench 2

Hydraulic Conductivity (K)	Permeability Coefficient (k)
(mm/s)	(mm^2)
0.000016	1.63393E-09
0.000088	8.98661E-09
0.000145	1.48075E-08

(b) Back Bench 3

Hydraulic Conductivity (K)	Permeability Coefficient (k)
(mm/s)	(mm^2)
0.0000141	1.4399E-09
0.000078	7.96541E-09
0.000098	1.00078E-08

(c) Back Bench 4

FIGURE 4.5: Coefficient of Permeability

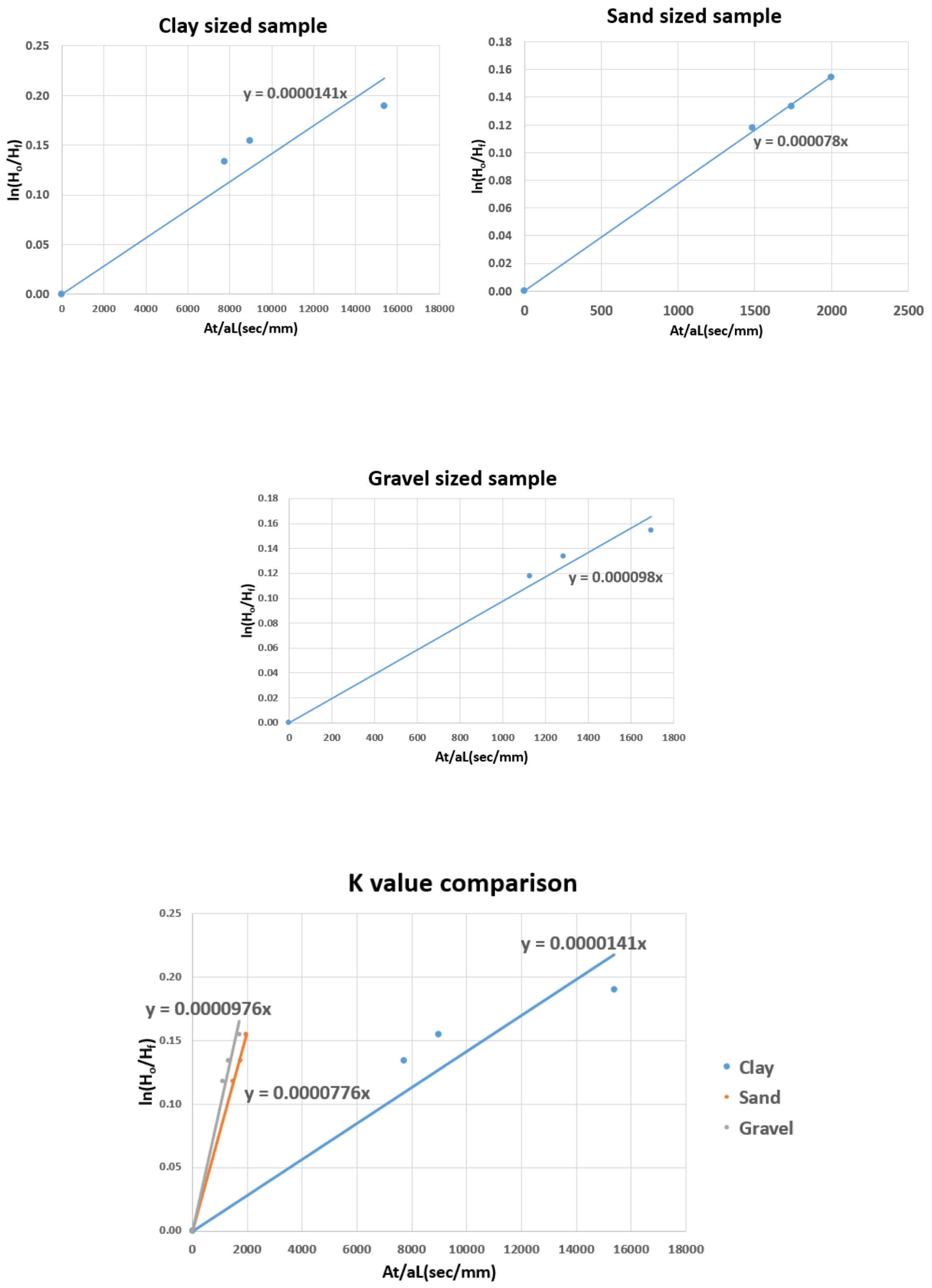


FIGURE 4.6: **Back Bench 2**

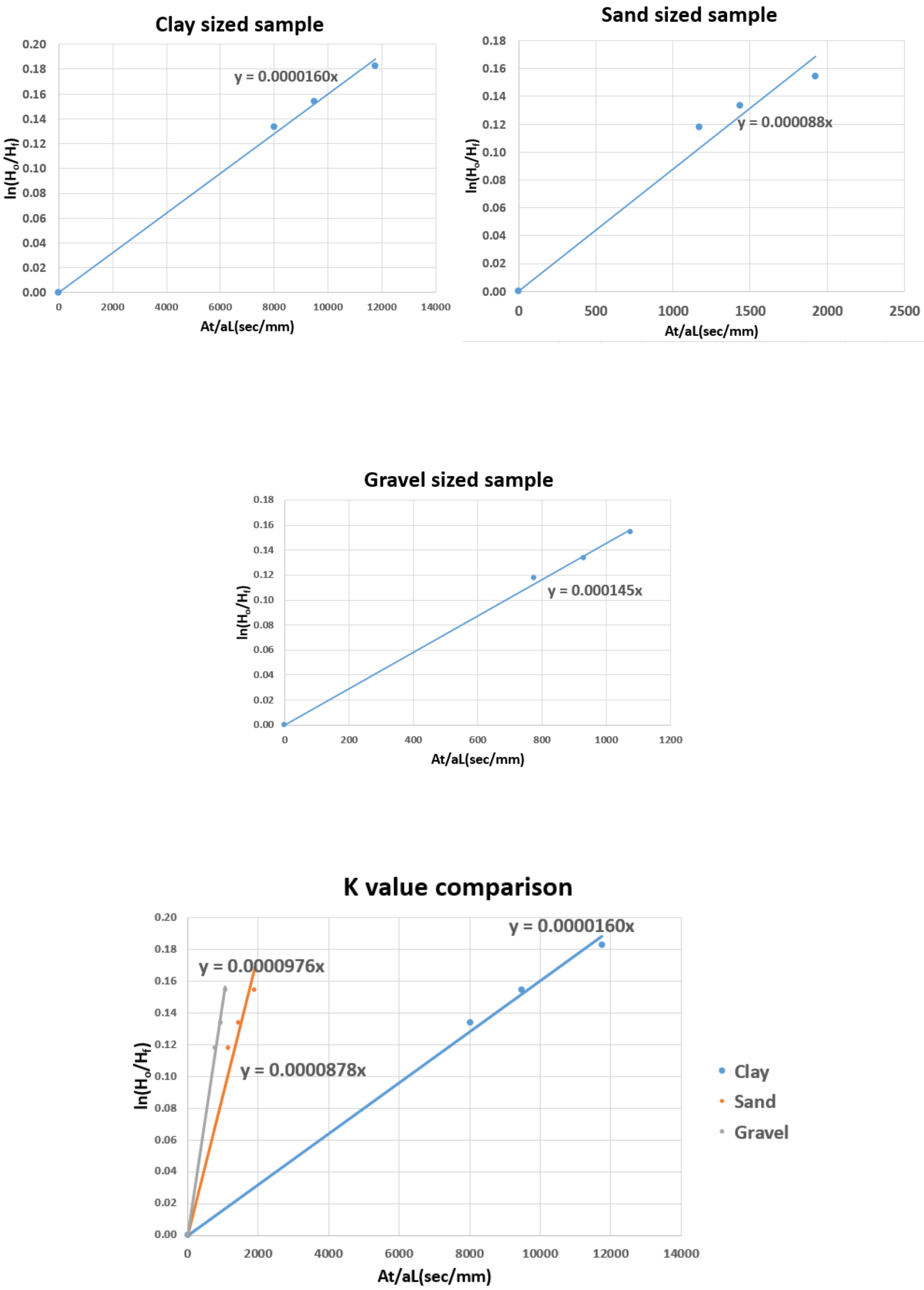


FIGURE 4.7: **Back Bench 3**

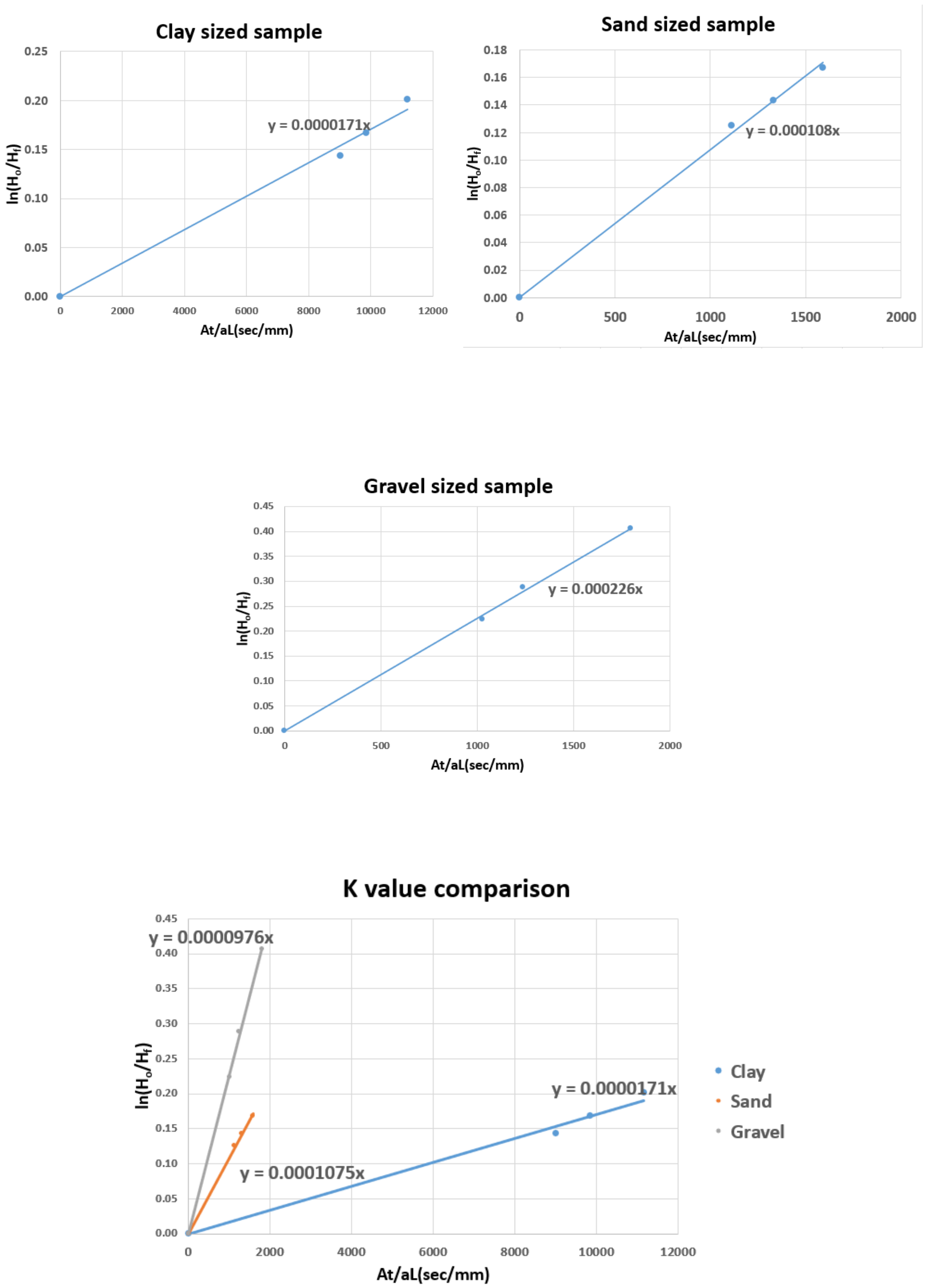


FIGURE 4.8: **Back Bench 4**

Chapter 5

Conclusion

In this study, permeability of dump material and particle size were analyzed and the following inferences were drawn.

1. Using sieve analysis, the D_{50}, D_{30} and D_{10} of the specimen from Back Bench 4 were found to be 3.676 mm, 1.495 mm, and 0.566 mm, respectively, implying that 50% of the sample had a mean size above 3.676 mm.

2. The falling head permeability test results substantiate that the hydraulic conductivity is highest for gravel-sized particles and least for clay-sized particles.

   (a) For Back Bench 2, Sand-sized particles had a hydraulic conductivity of 5.53 times that of clay-sized particles, whereas gravel-sized particles had a hydraulic conductivity of 6.95 times that of clay-sized particles.

   (b) For Back Bench 3, Sand-sized particles had a hydraulic conductivity of 5.5 times that of clay-sized particles, whereas gravel-sized particles had a hydraulic conductivity of 9.06 times that of clay-sized particles.

   (c) For Back Bench 4, Sand-sized particles had a hydraulic conductivity of 6.32 times that of clay-sized particles, whereas gravel-sized particles had a hydraulic conductivity of 13.22 times that of clay-sized particles.

3. As we go deeper below the surface, i.e., from Back Bench 2 to Back Bench 4, there is a gradual increase in the hydraulic conductivity of clay, sand, and gravel-sized particles each.

4. Clay is the most porous sediment but is the least permeable. Clay usually acts as an aquitard, impeding the flow of water. Gravel and sand are both porous and permeable, making them good aquifer materials. Gravel has the highest permeability.

Chapter 6

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