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MODELLING THE PERMEABILITY CHARACTERISTICS OF AN EARTH RESERVOIR

A. Mohammed[1] and A. Y. Abdulfatah[2,*]
[1, 2,] DEPARTMENT OF CIVIL ENGINEERING, BAYERO UNIVERSITY, KANO, KANO STATE, NIGERIA
E-mail addresses: [1] *trophygroup2010@gmail.com,* [2] *ayabdulfatah.civ@buk.edu.ng*

ABSTRACT

Particle size distribution and void ratio of a soil are considered as the direct information that can be used in a relatively easy manner for hydraulic conductivity estimation. Estimation of hydraulic conductivity from particle size distribution can be used to check permeability values obtained from other methods. Therefore, this paper attempts to relate the particle size distribution to hydraulic conductivity. The study was carried out on 24 soil samples which were collected from the embankment of an earth reservoir and subgrade at the toe. The investigation was carried out in accordance with the standard procedure given in BS1377. A series of hydraulic conductivity tests were carried out on optimum moisture content (OMC) compacted soil samples using the falling head method. The mean sizes of particles in each sample from particle size distribution curves were determined and used to generate regression models for the flow. Linear, exponential, polynomial and logarithmic models were used to test the validity; however, the best was adopted for this study. The findings of this study show that there is variability in the particle sizes of the soil material which in turn results to variation in the hydraulic conductivity. The hydraulic conductivity was found to increase with an increase in mean particle size. The relationship between mean particle size and hydraulic conductivity yielded coefficients of determination (R^2) of stronger correlation when the plastic and non-plastic samples were separately analyzed. However, all values of R^2 (0.9949, 0.9968 and 0.8918 for samples 1 to 16, 17 to 24 and 1 to 24 respectively) can be considered satisfactory. In addition, generalized models for the flow were generated for the plastic, non-plastic and the combined samples. The generated models can be used to predict the hydraulic conductivity of different soil samples.

Keywords: *Model, Hydraulic Conductivity, Mean Particle Size, Earth Reservoir*

1. INTRODUCTION

Seepage through soils may affect the stability of geotechnical structures such as pavements, tunnels, walls, slopes and excavations [1]. In order to solve fluid flow problems associated with soil, different techniques were proposed some of which include the field methods (the pumping-of-wells test, the auger-hole test and the tracer test), laboratory methods (the falling-head test, the constant-head test) and calculations from empirical formulae [2]. Many researchers have made attempts in solving hydraulic conductivity problems in soil. However, published hydraulic conductivity equations based on the porosity and grain-size distribution of sandy sediments are used by researchers to estimate the hydraulic conductivity of well core. These equations are based on empirical studies and the results are not necessarily transferable from one location to another [3]. In addition, some of the formulated models vary in accuracy as was seen in [4] who have recently employed several empirical formulae to specify the hydraulic conductivity of aquifer materials in the field. They stated that the most accurate estimation of the hydraulic conductivity was found using the Terzaghi equation, followed by the Kozeny-Carman, Hazen, Breyer and Slitcher equations respectively.

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* Corresponding author, tel: +234 – 806 – 603 – 1086

Hydraulic conductivity is one of the most important properties of soils [5]. Hydraulic conductivity is affected by pores space, structures and sizes of the soil, however, according to [6] estimation of hydraulic conductivity using particle size distribution is relatively simple and straightforward. Pore size distribution, which is intimately linked to the grain size distribution, is frequently involved in the determination of hydraulic conductivity. In addition, it is widely known that the hydraulic conductivity is related to the particle size distribution of the soil grains [7, 8]. Particle size distribution is considered as the direct information that can be used in a relatively easy manner for hydraulic conductivity estimation [9]. Global studies of hydraulic conductivity of marine sediments have shown that grain size exerts a first-order control on hydraulic conductivity [10, 11]. Estimation of hydraulic conductivity from particle size distribution can be used to check permeability values obtained from other methods. Therefore, this paper attempts to relate the particle size distribution to hydraulic conductivity of soils.

2. MATERIALS AND METHOD

The study was carried out on an existing and abandoned earth reservoir 200 m by 200 m. The reservoir with about 120,000 m^3 capacity was constructed for irrigation purpose and is located around Challawa Gorge Dam in Karaye Local Government, Kano-Nigeria. Challawa Gorge Dam is the main source of water for the reservoir. The dam was built by Julius Berger Nigeria between 1990 and 1992 using rock fill construction. It is 42 m high and 7.8 km in length. The dam has a full storage capacity of 904,000,000 m^3. The direct catchment area is 3857 km^2. The reservoir, during the study was virtually empty. Twenty-four (24) disturbed samples were collected from the embankment and subgrade at the toe of the reservoir for laboratory analyses as shown in Figure 1. GPS set to WGS 84 Map datum was used to take the coordinate of the sampling points as shown in Table 1. Samples 1 to 16 were collected from the embankment and 17 to 24 from the subgrade at the toe of the reservoir with 6 samples each representing one side of the rectangular reservoir.

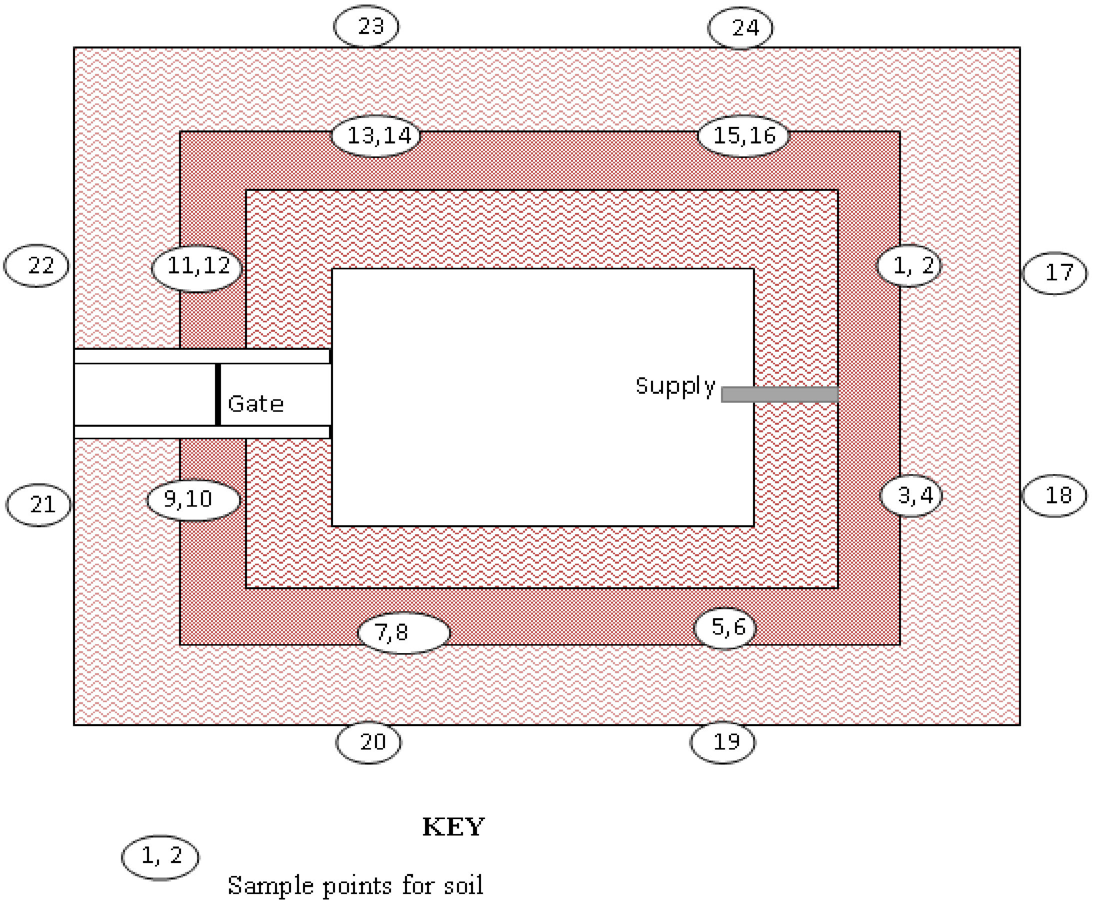

Figure 1: Sampling Points

Table 1: Sampling Points Coordinates and Sample Identification

Samples	Way Points	Coordinates	Depth
1	001	32P 0394128 UTM 1300957	1.5 m from the Top
2	003	32P 0394127 UTM 1300951	2.5 m from the Top
3	002	32P 0394105 UTM 1300975	1.5 m from the Top
4	004	32P 0394108 UTM 1300974	2.5 m from the Top
5	005	32P 0394102 UTM 1301004	1.5 m from the Top
6	007	32P 0394107 UTM 1301007	2.5 m from the Top
7	006	32P 0394129 UTM 1301022	1.5 m from the Top
8	008	32P 0394139 UTM 1301028	2.5 m from the Top
9	009	32P 0394172 UTM 1301041	1.5 m from the Top
10	011	32P 0394172 UTM 1301040	2.5 m from the Top
11	010	32P 0394204 UTM 1300992	1.5 m from the Top
12	012	32P 0394207 UTM 1300999	2.5 m from the Top
13	014	32P 0394204 UTM 1300978	1.5 m from the Top
14	017	32P 0394208 UTM 1300976	2.5 m from the Top
15	013	32P 0394171 UTM 1300948	1.5 m from the Top
16	016	32P 0394174 UTM 1300949	2.5 m from the Top
17	025	Toe of the Reservoir (Ground level below)	1.5 m from the Top
18	024	Toe of the Reservoir (Ground level below)	2.5 m from the Top
19	023	Toe of the Reservoir (Ground level below)	1.5 m from the Top
20	021	Toe of the Reservoir (Ground level below)	2.5 m from the Top
21	020	Toe of the Reservoir (Ground level below)	1.5 m from the Top
22	019	Toe of the Reservoir (Ground level below)	2.5 m from the Top
23	018	Toe of the Reservoir (Ground level below)	1.5 m from the Top
24	015	Toe of the Reservoir (Ground level below)	2.5 m from the Top

The Index and Engineering properties were determined in accordance with the standard procedure given in BS1377. The specific gravity (G_s) was determined using the gas jar method as given in Equation 1.

$$G_s = \frac{(w_2 - w_1)}{(w_4 - w_1) - (w_3 - w_2)} \qquad (1)$$

Where;
w_1 = weight of empty bottle (g)
w_2 = weight of empty bottle plus soil (g)
w_3 = weight of empty bottle plus soil filled with water (g)
w_4 = weight of bottle filled with water (g)

The liquid limit which represents the moisture content at 25 blows was determined using Cassagrande apparatus. The plastic limit was determined by rolling a ball formed with about 8 to 10 gm of the specimen between the fingers and the glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter of 3mm throughout its length. The plasticity index is taken as the difference between the liquid limit and the plastic limit. BS light compaction was used for the soil compaction test using 2.5 kg rammer and 27 blows in 3 layers in 1000 cm^3 compaction mould. The maximum dry density (MDD) and optimum moisture content (OMC) were taken as the dry density and moisture content corresponding to the peak of the dry density – moisture content plots. The hydraulic conductivity tests were carried out on optimum moisture content (OMC) compacted soil samples using the falling head method as given in Equation 2.

$$k = \frac{2.3aL}{At}.\mathrm{Log}_{10}\frac{h_1}{h_2} \qquad (2)$$

Where;
k = hydraulic conductivity (cm/s)
L = infiltration length (cm)
a = pipe cross-sectional area (cm^2)
A = mould cross-sectional area (cm^2)
t = the measurement time (s)
h_1 = initial head pressure (cm)
h_2 = final head pressure (cm)

The mean sizes of particles in each sample from particle size distribution curves were determined using Equation 3 and used to generate regression model for the flow. The following models; Linear, exponential, polynomial and logarithmic were used to test the validity; however, the best was adopted for this study.

$$D_{mean} = \frac{\Sigma \mathrm{Pd}}{\Sigma \mathrm{P}} \qquad (3)$$

Where; P = Percentage passing (%), d = Particle size (mm)

3. RESULTS AND DISCUSSION

Table 2 shows the maximum dry density (MDD), optimum moisture content (OMC), Plasticity index, relative density and specific gravity of the soil. The results show that the material for the embankment varies with sampling point. This is an indication of variability in seepage through the soil materials. The particle size distribution curves are presented in Figures 2 – 4. The curves show that samples 1, 2, 6, 8, 9, 10, 12, 14 and 15 are clayey sand with gravel; 3 and 13 are clayey gravel with sand; 4, 5 and 7 are silty gravel with sand; 11 is silty sand with gravel; 16 is clayey sand; 17, 22, 23 and 24 are silty sand with gravel and 18, 19, 20 and 21 are silty sand. This classification is based on the unified system of classification.

The Figures 2 – 4 show the variability in the particle sizes of the soil material. This variability was also shown by the mean particle sizes as given in Table 3. The study indicated that the hydraulic conductivity increased with an increase in mean particle size. This variation could be attributed to the variation in particle size contents.

Table 2: Samples MDD, OMC, Plasticity index and Specific gravity

Sample No	MDD (Mg/m^3)	OMC (%)	Plasticity Index (%)	Specific Gravity
1	1.95	13.8	12	2.77
2	1.99	11.13	10	2.72
3	1.96	13.0	12	2.56
4	2.07	11.4	7	2.78
5	2.06	14.7	7	2.87
6	2.01	12.61	8	2.52
7	1.92	11.54	6	2.67
8	1.95	14.66	14	2.66
9	2.05	17.2	10	2.47
10	1.83	16.2	15	2.64
11	1.88	13.47	7	2.74
12	2.04	12.6	15	2.41
13	2.01	12.4	9	2.67
14	1.87	15.6	10	2.73
15	1.81	14.8	18	2.41
16	1.87	15.8	14	2.7
17	2.11	12	NP	2.71
18	1.88	11.2	NP	2.41
19	2.05	11.2	NP	2.51
20	2.06	12.4	NP	2.34
21	1.99	12.5	NP	2.67
22	2.01	10	NP	2.31
23	1.8	12.0	NP	2.55
24	1.94	10.23	NP	2.42

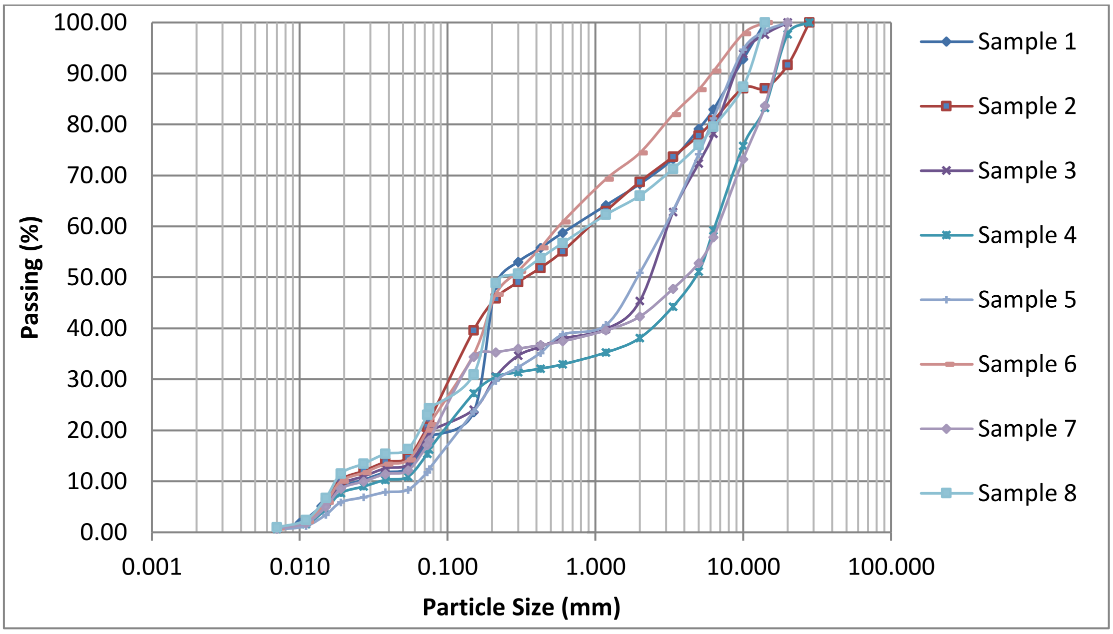

Figure 2: Particle size distribution curve for samples 1 to 8

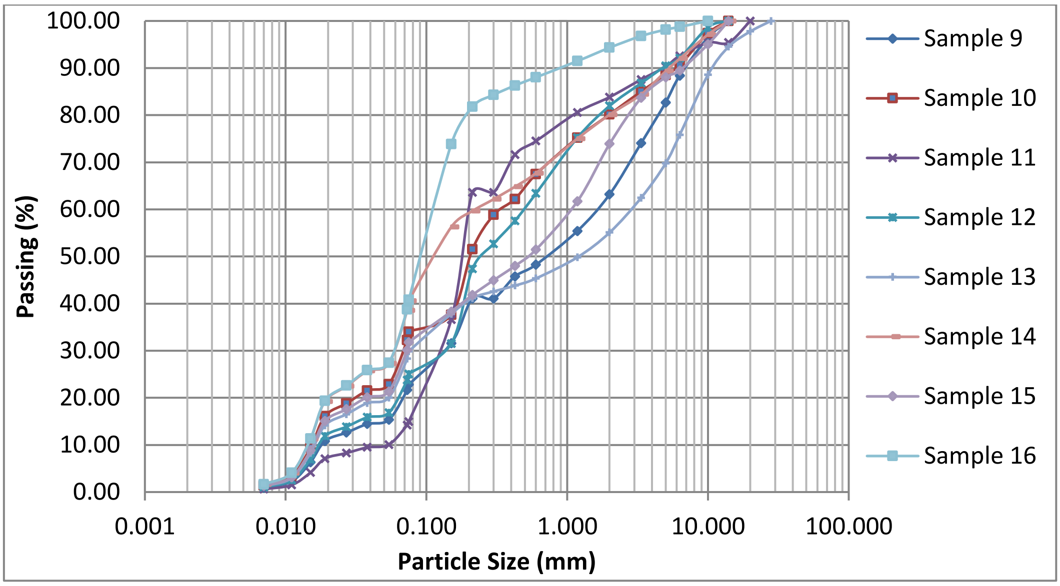

Figure 3: Particle size distribution curve for samples 9 to 16

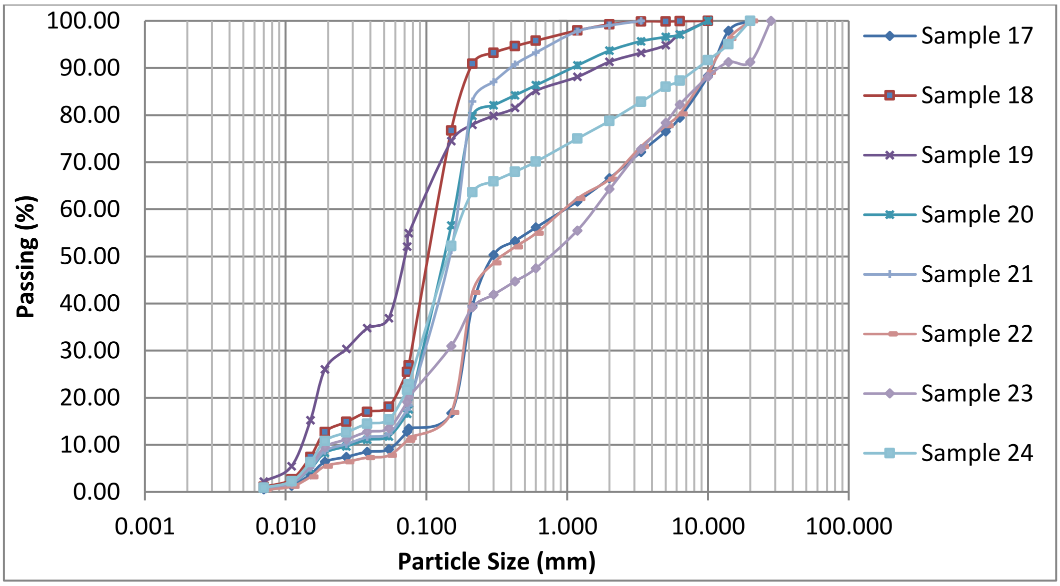

Figure 4: Particle size distribution curve for samples 17 to 24

Figures 5 – 7 are plots showing the relationship between mean particle size and hydraulic conductivity. The coefficients of determination (R^2) are 0.9949, 0.9968 and 0.8918 for sample 1 to 16, 17 to 24 and 1 to 24 respectively. This shows that there is a good correlation between particle mean size and hydraulic conductivity among the samples analyzed in this study. However, a stronger correlation were noticed when the plastic and non-plastic samples were separately analyzed. The findings of this study corroborated [3] that mean grain size, the Kruger effective diameter, and effective diameters ranging from D_{10} to D_{20} have high correlation coefficients with measured permeability. In addition, generalized models for the flow were generated as given in Equations 4-6. These Equations represent the models for plastic, non-plastic and the combined samples respectively.

$$K = -0.0429d^3 + 0.7233d^2 - 1.7613d + 0.5832 \quad (4)$$

$$K = 0.2365d^2 + 0.1722d + 0.1335 \quad (5)$$

$$K = -0.0736d^3 + 1.2372d^2 - 4.2467d + 4.7249 \quad (6)$$

Where;

K = hydraulic conductivity (cm/s)

d = mean particle size (mm)

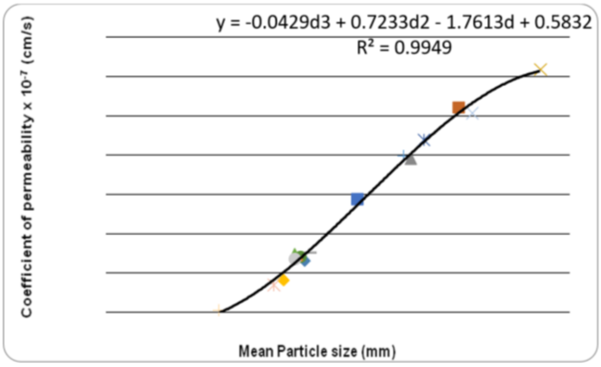

Figure 5: Mean particle size and Hydraulic conductivity curve for samples 1 to 16

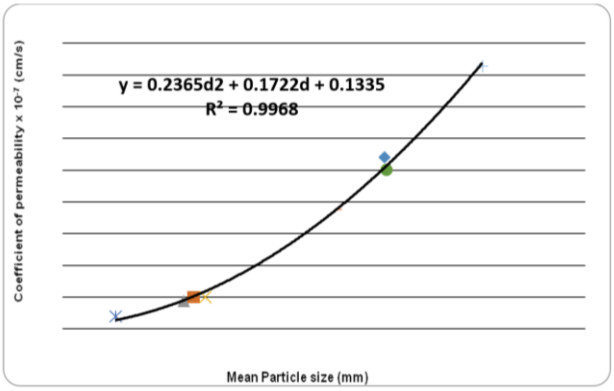

Figure 6: Mean Particle size and Hydraulic conductivity curve for samples 17 to 24

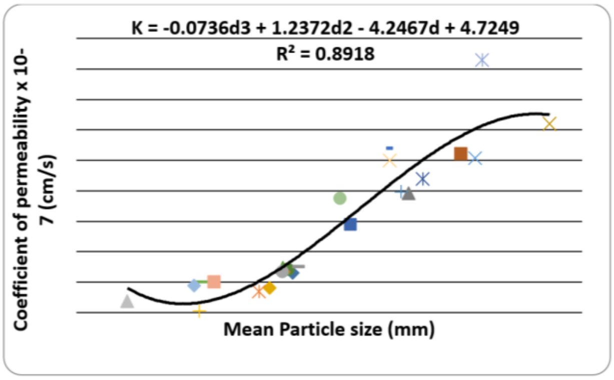

Figure 7: Mean particle size and Hydraulic conductivity curve for samples 1 to 24

4. CONCLUSIONS

Measured hydraulic conductivity was correlated with a number of particle-size parameters. The generated plots from this study were compared with the measured hydraulic conductivity and mean particle sizes. The study concluded that there was a strong correlation between hydraulic conductivity and mean particle size of the soil samples used. However, this correlation was stronger when the plastic and non-plastic samples were jointly examined. The generated models can be used to predict the hydraulic conductivity of different soil samples.

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