Permeability Measurement of Granular Materials and Development of an Equation

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Abstract

The study of the hydraulic conductivity (K) for flow of water through permeable soil media is important in soil mechanics. It has been recognized that K is statistically related to the grain-size distribution. A series of permeability test were conducted on five types granular soil (denoted by S-1, S-2, S-3, S-4 and S-5) taken from different location of Bangladesh. It has been recognized that K is statistically related to the grain-size distribution. In all, 40 specimens (total 200) of each type of soils were analyzed for grain size distribution, void ratio and hydraulic conductivity according to ASTM code. The experimental values of hydraulic conductivity were then compared to the values calculated using 5 different empirical equations which are commonly used to estimate hydraulic conductivity from grain size analysis. In this study we develop a modified equation that considerably improve the hydraulic conductivity estimates from grain size data. It was found that expected hydraulic conductivity equation reduce the error of estimated values.

Keywords: *Permeability, Grain-Size, Void Ratio, Hydraulic Conductivity.*

1 Introduction

Permeability is defined as the property of porous material which permits the passage or seepage of water or other fluids through its interconnecting voids. Permeability is considered one of the most important parameters in soil mechanics. Permeability is measured by the coefficient of permeability or hydraulic conductivity (K). Basically, it is defined by the quantity of water passing through a soil medium in a certain period, and is determined by in-situ and laboratory tests. In common practice, the permeability coefficient is usually obtained by constant head permeability test, and is utilized in filtration-drainage, settlement, and stability calculations. These problems are extremely important for environmental aspects such as waste water management, slope stability control, erosion, and structural failure related with the ground settlement issues. In this respect, empirical equations are utilized to predict these parameters; however, these equations have certain limitations and uncertainties.

Freeze and Chery, 1979 has been recognized that hydraulic conductivity is related to the grain size distribution of granular porous media. Uma et al., 1985 sampled six soils at seven different locations in the Alabama lower coastal plain and used regression analysis to determine that percentage of clay sized particles was the best predictor of Ks. Rawls and Brakensiek, 1989 used field data across the U.S. to develop a regression equation that relates porosity and percentage of sand and clay sized, particles in the sample to Ks. Jabro, 1992 estimated Ks from grain size and bulk density data. Ahuja et al., 1989 estimated Ks using the generalized form of the Kozeny-Carmen equation. Aiyamani and Sen, 1993 proposed the relation between saturated hydraulic conductivity and soil particles diameters for 32 sandy soil samples.

The objective of this study is to determine the hydraulic conductivity (K) of studied granular materials, compare among the commonly used empirical formulae and finally develop an empirical equation for granular materials from grain size analysis.

2 Results and Discussions

2.1 Grain-size Analysis

In this study five types sandy soils are used in this study which was collected from different location of Bangladesh which is denoted by S-1 (Sample S-1 has been collected from Tista river, Rangpur of Bangladesh which is locally called domer sand from grain size analysis it is found as medium sand), S-2 (Sample S-2 has been collected from Panchagarh, Bangladesh which is locally called panchagarh sand from grain size analysis it is found as medium medium sand), S-3 (Sample S-3 has been collected from Sylhet, Bangladesh which is locally called sylhet sand from grain size analysis it is found as coarse sand), S-4 (Sample S-4 has been collected from Rajsahi, Bangladesh which is locally called local sand from grain size analysis it is found as find sand) and S-5 (Sample S-5 has been collected from Pabna, Bangladesh which is locally called padma sand from grain size analysis it is found as find sand). The grain size distributions curve of soils are shown in Figure 1. By the analysis of this the values of D_5 (grain size corresponding to 5% finer), D_{10} (grain size corresponding to 10% finer), D_{20} (grain size corresponding to 20 % finer), D_{50} (grain size corresponding to 50% finer), D_{60} (grain size corresponding to 60% finer), I_o (intercept of the line formed by D_{10} and D_{50} with the grain size axis), C_u (uniformity coefficient) and FM (fineness modulus) are calculate to evaluate the studied established empirical formulae and proposed empirical formula which are shown in Table 1.

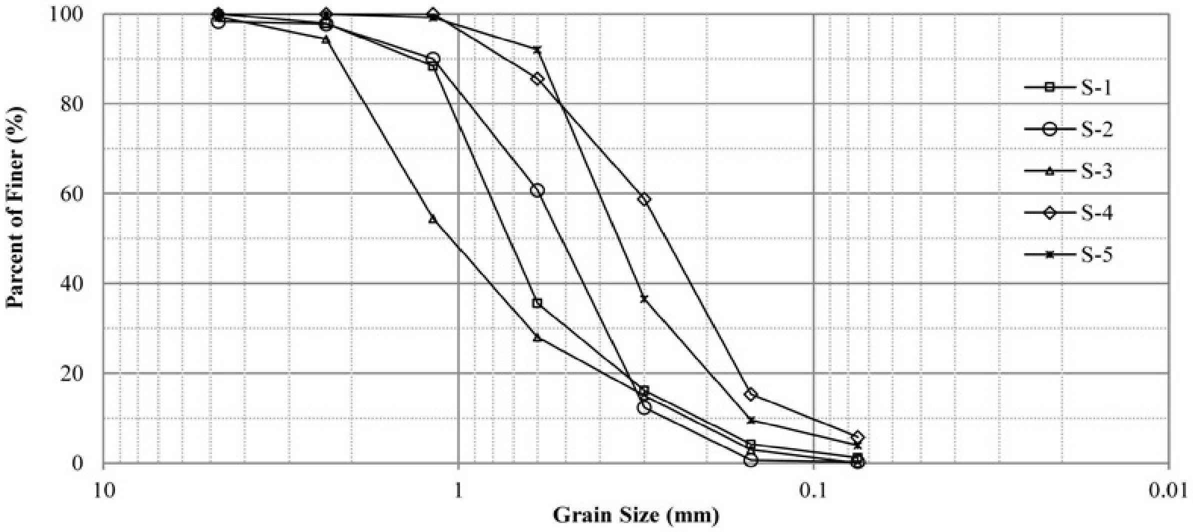

Figure 1. Grain size distribution curve for selected five types of soil samples.

Table 1. Grain-size properties of samples.

Sample ID	D_5 (mm)	D_{10} (mm)	D_{20} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	I_o (mm)	FM
S-1	0.25	0.21	0.31	0.70	0.75	3.57	0.16	2.58
S-2	0.31	0.22	0.32	0.50	0.65	2.71	0.17	2.40
S-3	0.20	0.24	0.40	1.05	1.20	5.45	0.19	3.06
S-4	0.08	0.10	0.18	0.27	0.31	3.10	0.08	1.40
S-5	0.09	0.15	0.20	0.35	0.40	2.67	0.12	1.63

2.2 Basic Properties

Some basic properties are evaluated such as specific gravity, unit weight, OMC, maximum dry density for each sample which is shown in Table 2. OMC and maximum dry density are calculate from the compaction curve shown in Figure 2.

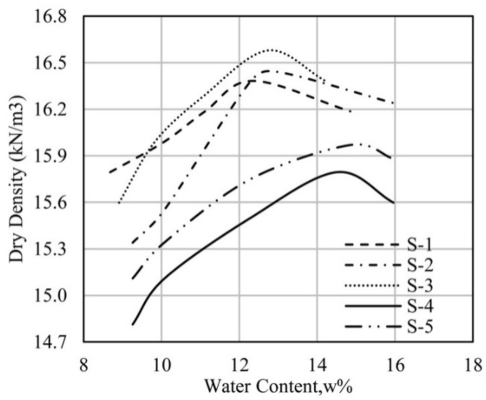

Figure 2. Compaction Curve

Table 2. Basic properties of samples.

Sample ID	Specific Gravity G_s	OMC (%)	MDD (kN/m^3)
S-1	2.71	12.35	16.38
S-2	2.73	13.11	16.44
S-3	2.74	12.73	16.58
S-4	2.67	14.50	15.79
S-5	2.69	14.87	15.97

2.3 Controlling of Void Ration, e

In this study 4 different void ratio (0.70, 0.75, 0.80 and 0.85) are consider. The mold (size: dia. = 10 cm and height = 14 cm) are filled with specified void ratio by the calculated soil mass which is shown in Table 3.

Table 3. Mass of sample for various soil sample

Void Ratio, e	Volume of Mold, V (cm^3)	Volume of Sample, $V_s = \frac{V}{1+e}$ (cm^3)					Mass of the Sample, $M_s = V_s G \rho_w$ (gm)				
		S-1	S-2	S-3	S-4	S-5	S-1	S-2	S-3	S-4	S-5
0.70	1099.56	646.8	646.8	646.8	646.8	646.8	17195.2	17322.1	17385.6	16941.4	17068.3
0.75	1099.56	628.3	628.3	628.3	628.3	628.3	16704.0	16827.2	16888.9	16457.4	16580.7
0.80	1099.56	610.9	610.9	610.9	610.9	610.9	16240.0	16359.8	16419.7	16000.2	16120.1
0.85	1099.56	594.4	594.4	594.4	594.4	594.4	15801.0	15917.6	15976.0	15567.8	15684.4

2.4 Permeability Test Program and Procedure

A series of 200 constant head permeability tests were carried out on 5 soil samples referred to as sample S-1, S-2, S-3, S-3 and S-5. 40 tests were performed for 4 different void ratio (0.70, 0.75, 0.80 and 0.85) on each sample. 10 test were done for each void ratio and average value of this 10 permeability test is considered. To carry out these tests, a permeameter was placed on a table in the laboratory. After removing the air in the flexible rubber tubing connecting the tube, the outlet tube of the constant head tank was connected to the inlet nozzle of the permeameter. The hydraulic head was measured by a meter scale from the bottom outlet of the permeameter to the water surface in the overhead tank. Stop watch was started and at the same time a beaker was put under the outlet of the permeameter. The test was run for some convenient time interval. The quantity of water collected in the beaker was measured during that time. The test was repeated twice more under the same head and for the same time interval. The temperature of the room was measured by the thermometer.

2.5 Proposed Empirical Equation

The main reason of this study to develop an empirical formulae for hydraulic conductivity (K) based on grain size distribution. For this reason 200 permeability test were carried out in laboratory and compere these test result with various parameters from grain-size distribution analysis. Here to develop an empirical formula for hydraulic conductivity we consider hydraulic conductivity is the function of void ratio, D_{10}, D_{60}, C_u, and fineness modulus. Mathematically,

$$K = f(e, D_{10}, D_{60}, F_m, C_u) \quad (1)$$

By this study, proposed empirical formula

$$K = 5 \times 10^{-5} \times e \times Exp(\sqrt{F_m}) \times \log \frac{500}{C_u} \quad (2)$$

Where K= hydraulic conductivity (m/sec.), e = void ratio, F_m = fineness modulus and C_u = uniformity coefficient (C_u= D_{60}/D_{10}, D_{10} and D_{60} represent grain size in mm corresponding to 10% and 60% finer respectively.

2.6 Comparison with Test Result

After conducting laboratory test our result is compared with another five empirical formulae and our proposed equation. In this study to compare our result we consider empirical formulae which was developed by Hazen, Kozeny-Carman, Terzaghi, Vukovic and Soro, Breyer. Table 4 shows the details about these five established formulae.

Table 4. Empirical equations manifested for permeability prediction of soils

Researcher	Equation	Limitations, Advantages/Disadvantages
Hazen (1892)	$K = C_H d_{10}^2$	Effective diameter changes between 0.1 and 30 mm (Hazen, 1892; Carrier III, 2003).
Kozeny-Carman (1956)	$K = \frac{g}{\nu} \times 8.3 \times 10^{-3} [\frac{n^3}{(1-n)^2}] d_{10}^2$	d_{10}<3 mm, for granular soils, the inertia term is not taken into account (Carrier III, 2003).
Terzaghi (1964)	$K = \frac{g}{\nu} \times C_t \times \left(\frac{n - 0.13}{\sqrt[3]{1-n}} \right)^2 d_{10}^2$	The selected average value of 0.0084 is actually a classification coefficient typically ranging between 0.0061 and 0.00107
Breyer (1998)	$K = \frac{g}{\nu} \times 6 \times 10^{-4} \log \frac{500}{U} d_{10}^2$	C_u= 1~20, d_{10}= 0.06~0.6 mm.
Alyamani and Sen (1993)	$K = 1300 \times [I_o + 0.025(d_{50} - d_{10})]^2$	The method is more accurate for well-graded sample (Odong, 2008).

Table 5 shows the variation of the value of hydraulic conductivity estimated from grain-size analysis with respect to laboratory test results. From this table we show that the estimated value using proposed equation is near with laboratory test results compared to other established formulae.

Table 5. Comparison of the hydraulic conductivity from test result using various empirical formulae.

Sample ID	Void Ratio, e	Average (10) value of K (Laboratory Test)	Estimated Value of Hydraulic Conductivity, K (m/s)					
			Proposed Equation	Hazen	Kozeny-Carman	Terzaghi	Breyer	Alyamani and Sen
S-1	0.70	3.79E-04	3.74E-04	4.85E-04	5.32E-04	4.11E-04	5.57E-04	4.46E-04
	0.75	4.07E-04	4.01E-04	4.85E-04	6.36E-04	4.70E-04	5.57E-04	4.46E-04
	0.80	4.35E-04	4.28E-04	4.85E-04	7.51E-04	5.32E-04	5.57E-04	4.46E-04
	0.85	4.76E-04	4.55E-04	4.85E-04	8.76E-04	5.94E-04	5.57E-04	4.46E-04
S-2	0.70	3.85E-04	3.73E-04	5.18E-04	6.95E-04	5.37E-04	7.68E-04	4.69E-04
	0.75	4.30E-04	4.00E-04	5.18E-04	8.31E-04	6.14E-04	7.68E-04	4.69E-04
	0.80	4.55E-04	4.27E-04	5.18E-04	9.80E-04	6.94E-04	7.68E-04	4.69E-04
	0.85	4.90E-04	4.53E-04	5.18E-04	1.14E-03	7.76E-04	7.68E-04	4.69E-04
S-3	0.70	3.93E-04	3.95E-04	4.36E-04	5.84E-04	4.51E-04	5.59E-04	6.68E-04
	0.75	4.08E-04	4.23E-04	4.36E-04	6.98E-04	5.16E-04	5.59E-04	6.68E-04
	0.80	4.49E-04	4.51E-04	4.36E-04	8.24E-04	5.84E-04	5.59E-04	6.68E-04
	0.85	4.75E-04	4.80E-04	4.36E-04	9.61E-04	6.52E-04	5.59E-04	6.68E-04
S-4	0.70	2.29E-04	2.61E-04	1.58E-04	1.74E-04	1.34E-04	1.94E-04	1.06E-04
	0.75	2.49E-04	2.80E-04	1.58E-04	2.08E-04	1.54E-04	1.94E-04	1.06E-04
	0.80	2.72E-04	2.99E-04	1.58E-04	2.45E-04	1.74E-04	1.94E-04	1.06E-04
	0.85	2.98E-04	3.17E-04	1.58E-04	2.86E-04	1.94E-04	1.94E-04	1.06E-04
S-5	0.70	2.56E-04	2.85E-04	2.48E-04	2.72E-04	2.10E-04	3.01E-04	2.35E-04
	0.75	2.66E-04	3.06E-04	2.48E-04	3.25E-04	2.40E-04	3.01E-04	2.35E-04
	0.80	2.78E-04	3.26E-04	2.48E-04	3.83E-04	2.71E-04	3.01E-04	2.35E-04
	0.85	3.10E-04	3.46E-04	2.48E-04	4.47E-04	3.03E-04	3.01E-04	2.35E-04

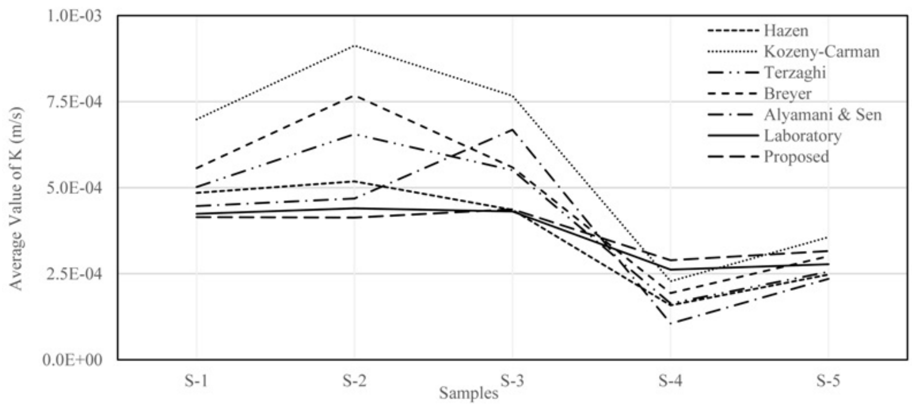

Figure 3. Variation of Hydraulic Conductivity (K) of Each Sample for Various Empirical Formula.

By the graphical representation (Figure 3) we show that the variation of value of K for proposed equation is less in compared to other empirical formulae for all samples.

3 Conclusion

Estimating the hydraulic conductivity of soils in terms of grading characteristics can relatively lead to underestimation or overestimation unless the appropriate method is used. For the studied samples, and consequently may be for a wide range of soil type, the best overall estimation of permeability is reached based on Alyamani & Sen for S-1 & S-2, Hazen for S-3, Kozeny-Carman for S-4 and Breyer for S-5. Alyamani and Sen formula is very sensitive to shape of the grading curve and as such should be used with care. The new suggested formulae give the better estimation in compared to other formulae. This study is done only for sandy type soil so this new proposed empirical formula is applicable only for sand.

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