International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 6, June-2018

Effect of Shape Factor on Hydraulic Conductivity of Porous Media For Different Sized & Different Proportions Of Material

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Abstract : Hydraulic conductivity is one of the most important physical properties of soil which governs the quantitative evaluation of groundwater resources. It depends upon large number of variables such as particle size, porosity of the packing, shape of the individual particles, size distribution of particles in the packing, arrangement of particles in the bed with respect to each other, particle surface roughness and permeameter walls. In common practice the coefficient of permeability is usually obtained by Constant Head Permeability test as it is easy to apply. It is desirable to predict the Hydraulic Conductivity (Permeability) value of different Shape group particles of different sizes and mixed in some proportions for knowledge of their statistical size and shape distribution. However, a comprehensive study of the effects of Shape factors of sediments on permeability of the porous materials is not available. Hence, to investigate the effect of Shape factors of sediments on hydraulic conductivity through porous media, the present study has been conducted on Constant Head permeameter with appurtenances to measure discharge, pore pressure differences and temperature. Four number of materials such as 6.3 mm White Marble chip, 6.3 mm Crushed Quartzite, 10 mm River Washed Gravel, 16 mm Glass Spherical Glass balls and making a mixture of these above mentioned materials in fixed proportion and then conducting Hydraulic Conductivity tests on it. Four tests namely Sieve analysis test, Specific gravity test, Volume displacement method test and Hydraulic test are conducted.

KEYWORDS ; Hydraulic conductivity, grain size analysis, shape factor, Volume mean diameter

1. Introduction

Permeability must be considered in problems for estimating the quantity of underground seepage under various hydraulic conditions, the design of filters made of soil, to solve problems involving pumping seepage water from construction excavations, to determine spacing and depth of drains for lowering the water table under roads and highways, to conduct stability analyses of earth structures and earth retaining walls when they are subjected to seepage forces (Das, 2008) for making stability analysis of earth dams and earth-retaining structures that are subject to seepage forces, rate of settlement and rate of strength increase with pore pressure dissipation or when conducting a hydro-geological study; hydraulic conductivity is one of the most important parameters, but also a parameter that is difficult to determine. It is also used for modelling the water flow in the soil, both in the saturated and unsaturated zone, and transportation of water-soluble pollutants in the soil. Furthermore, it is of paramount importance in relation to some geotechnical problems, including the determination of seepage losses, settlement computations, and stability analyses (Boadu, 2000).

All these considerations and others make it necessary to study the mechanics of water through soil and to evaluate properties such as hydraulic conductivity (K); one of the most important parameters required for predicting the movement of water through the soil. Hydraulic conductivity is an essential quantitative measure of fluid transmissibility in the linear, pre-linear and post-linear regimes. It depends on both the physical properties of flowing liquid such as density and viscosity at the temperature and pressure involved as well as the characteristics of the transmitting medium such as particle size, porosity of the packing, shape of the individual particles, size distribution of the particles in the bed with respect to each other, particle surface roughness and permeameter walls (Bear, 2013). The hydraulic conductivity is subject to variation in space and time, which means that we must adequately assess a representative value. This is time-consuming and costly, so a balance has to be struck between budget limitations and desired accuracy. As of yet, no optimum surveying technique exists. Much depends on the skill of the surveyor. To find a representative K-value, the surveyor must have a knowledge of the theoretical relationships between the envisaged drainage system and the drainage conditions in the survey area.

Various methods have been developed to determine the K-value of soils. Which method to select for the survey of K depends on the practical applicability, and the choice is limited. Because of the variability of the soil's K-value, it is better to determine it from large-scale experiments (e.g. from the functioning of existing drainage systems), rather than from small- scale experiments. But in-situ determination of K is not always possible due to various constraints such as time, labour and economy. As such, various empirical formulae have been devised along with laboratory tests to overcome these constraints and estimate the value of hydraulic conductivity of different soils with reasonable accuracy.

2. Experimental work

Figure 1 shows the experimental setup

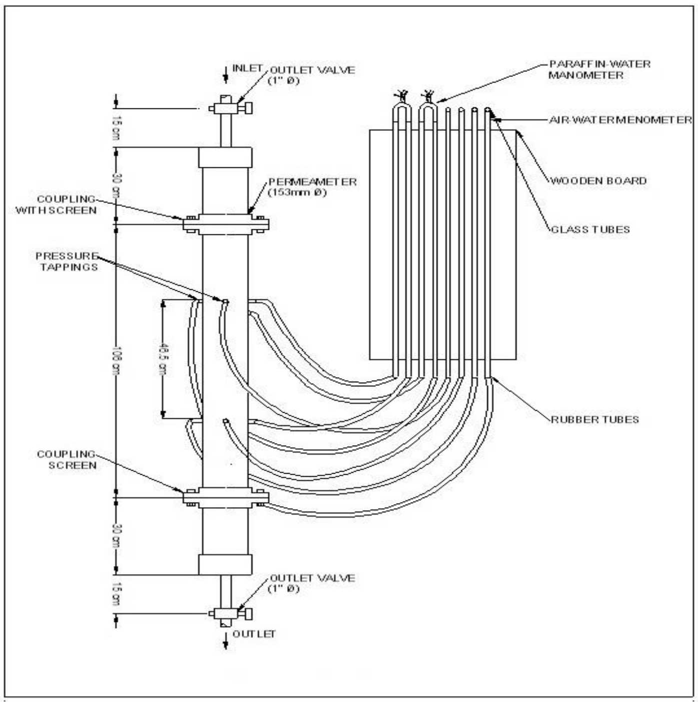

Figure1 : Constant head permeameter

2.1 Experimental Equipment

The experimental equipment consists of the following items:

a) Permeameter

b) Discharge measuring device

c) Weighing Balance

d) Pycnometer

e) Manometer

f) Thermometer

g) Source of supply

h) Oven

a) Permeameter

The constant head vertical flow type permeameter was used for hydraulic tests in this work. The main permeameter section consisted of a 10.16 cm internal diameter GI tube with a total length of 1.06 m and a test length of 46.5 cm.

b) Discharge measurement

The discharge was measured by volumetric method. The water was collected in a bucket for a certain period, which was recorded with a stopwatch and collected water was then measured with the help of a 2000 cc capacity glass jar. Volume of water collected at a particular duration will give the discharge.

c) Weighing balance

Electronic weighing balance were used for measuring the weight during specific gravity test

d) Pycnometer

I.S. pycnometer is used in the specific gravity test.

e) Manometer

To cover the desired range of flow, two types of manometer

were used:

(i) Air-water manometer

(ii) Paraffin water manometer

f) Thermometer

I.S. Mercury Thermometer measuring temp from 0^oC to 80^oC was used for measuring the temperature of water.

g) Source of supply

The permeameter receives its water supply from an overhead tank at a height of 2.65 m above the permeameter outlet. The tank receives its supply from a recirculating tank so that a constant head is maintained in the overhead tank.

h) Oven

Oven was used to dry out the soil samples collected from different boreholes before performing the sieve analysis.

2.2. Materials Used

The various materials used in the present study have been listed below:

i) Marble Chips: 6.3mm uniform sizes were used.

ii) Crushed Quartzite: 6.3 mm uniform sizes were used

iii) River washed Gravel: 10 mm uniform sizes were used.

iv) Spherical Glass balls: 16 mm uniform sizes were used.

v) Mixtures of Marble chips, Crushed Quartzite, River washed gravel, and Spherical glass balls in fixed proportions were used

3 Experimental Procedure

3 (a) Sieve Analysis Test

The various materials used in the present investigation are of different sizes and shapes. The materials were sieved according to IS: from bulk material in order to obtain the similar shape for each size, although it is not sure that the shape of separate grain be identical. The Sieves analysis for white marble chip performed in this study has been tabulated in Table 1-3.

Table 1: Sieve Analysis for White marble chip

S. no	**Sieve size(mm)**	**Weight of sieve**	**Weight of sieve+ aggregates**	**Weight retained(gm)**	**% Weight retained**	**Cumulative % weight retained**	**% Finer**
1	8	650	913.25	263.25	5.27	5.27	94.74
2	6.3	890	3927.79	3037.79	60.76	66.02	33.98
3	5.6	720	878.34	158.34	3.17	69.19	30.81
4	4.75	680	782.85	102.85	2.06	71.24	28.76
5	4	700	1898.34	1198.34	23.97	95.21	4.79
6	pan	650	889.43	239.43	4.79	100.00	0.00

Table 2: Sieve Analysis for Crushed Quartzite Sample

S. no	Sieve size (mm)	Weight of sieve	Weight of sieve+ aggregates	Weight retained(gm)	%Weight retained	Cumulative % weight retained	% Finer
1	8	650	889.9	239.9	4.80	4.80	95.20
2	6.3	890	3892.72	3030	60.60	65.40	34.60
3	5.6	720	891.68	171.68	3.43	68.83	31.17
4	4.75	680	800.43	120.43	2.41	71.24	28.76
5	4	700	1798.04	1098.04	21.96	93.20	6.80
6	3.35	650	978.38	328.38	6.57	99.77	0.23
	pan	690	701.57	11.57	0.2314	100	0

Table 3: Sieve Analysis for River Washed Gravel

S. no	**Sieve size(mm)**	**Weight of sieve**	**Weight of sieve+ aggregates**	**Weight retained(gm)**	**% Weight retained**	**Cumulative % weight retained**	**% Finer**
1	12.5	850	980.43	130.43	2.56	2.56	97.44
2	10	810	4248.54	3438.54	67.42	69.98	30.02
3	8	650	1675.87	1025.87	20.12	90.09	9.91
4	6.3	890	970.33	80.33	1.58	91.67	8.33
5	5.6	720	854.87	134.87	2.64	94.31	5.69
6	4.75	680	799.67	230	4.51	98.82	1.18
7	pan	690	749.96	59.96	1.18	100.00	0.00

3 (b)V***olume Displacement Test***

For the size of particles, the Volume mean diameter has been adopted as the representative size in present investigation. Therefore, tests are conducted to determine Volume Mean diameter of various sizes of samples and mixture of samples. This is done by Volume Displacement method. The volume mean diameter is the diameter of an average sphere whose volume times the total number of particles in a sample equals the solid volume in the sample. In present investigation Volume Mean diameter is calculated by Volume Displacement Method. It is determined by determining the volume of liquid displaced and then counting the number of particles in the sample.

$$\frac{\text{Volume of liquid dispalced}}{\text{Number of particles in sample}} = \frac{\pi}{6} d_v^3$$

The Volume Mean diameter obtained for different Sized & different proportions of material are tabulated in Table 4.

Table 4: Volume Mean diameter obtained for different Sized & different proportions of material

S. no.	**Sample**	**Volume Mean Diameter(mm)**
1	6.3 Warble Marble Chip	6.87
2	6.3 Crushed Quartzite	6.87
3	10 mm River Washed Gravel	10.13
4	16 mm Glass Ball	16.17
	Proportion of 6.3 mm White Marble Chip and 10 mm River Washed Gravel	
5	0.5/0.5	8.59
6	0.6/0.4	7.61
7	0.4/0.6	8.44
8	0.3/0.7	9.52
9	0.7/0.3	7.54
	Proportion of 6.3 Crushed Quartzite and 10mm River Washed Gravel	
10	0.5/0.5	8.58
11	0.6/0.4	7.65
12	0.4/0.6	8.54
13	0.3/0.7	9.58
14	0.7/0.3	7.64
	Proportion of 6.3 White Marble Chip and 10 mm Glass balls	
15	0.5/0.5	11.90
16	0.6/0.4	10.88
17	0.4/0.6	13.75
18	0.3/0.7	14.55
19	0.7/0.3	9.01
	Proportion of 6.3 Crushed Quartzite and 10 mm Glass Balls	
20	0.5/0.5	11.88
21	0.6/0.4	10.90
22	0.4/0.6	13.75
23	0.3/0.7	14.55
24	0.7/0.3	9.04
	Proportion of 10 mm River Washed Gravel and 10 mm Glass Balls	
25	0.5/0.5	13.16
26	0.6/0.4	12.37
27	0.4/0.6	14.57
28	0.3/0.7	15.35
29	0.7/0.3	11.74

3 (c) Hydraulic tests

The hydraulic tests were conducted to study the effect of resistance to flow of water in a given sample of material. The method of carrying out these tests are as follows.

Preparation of the Bed: Before filling the permeameter with the material to be tested, the inlet portion of the permeameter was taken off. It was proposed in the present study to keep the porosity constant for all runs of the materials. Therefore, the weight of the material needed to fill the permeameter was calculated as:-

$$W_s = (1\text{-n})\ V_T\ G_S\ \gamma_w$$

Where,

W_s is weight of the material ,n is porosity,V_T is volume of the tube ,G_S is specific gravity of the material ,γ_w is specific weight of the water

TEST RUN: This involved three main operations

1) Measuring the discharge through the permeameter.

2) Reading the pressure drop across the test length of the material.

3) Reading the temperature of water

In all the runs, observations were taken in receding order of magnitude of discharge and hydraulic gradient. The test was started with maximum discharge so that if there was any settlement of the bed due to the impact of the jet of incoming water, it was secured in the beginning. The bed was then checked at the end of each run for settlement, if any. The porosity of the bed was determined after making due allowances for settlement. The discharge was measured by collecting the water in a bucket for a certain period, which was recorded with a stopwatch. The flow was then reduced for the next observation of the run. This operation was continued till the discharge was decreased from maximum to a certain measurable minimum discharge.

4. ANALYSIS OF RESULT

The present study focuses on investigating the effect of shape factor on hydraulic conductivity of porous media. A discussion of results in relation to the different aspects of the studies are presented below

4(a)Variation of Hydraulic Conductivity v/s Volume Mean Diameter

A bar graph plotted between k v/s Volume Mean diameter shows a linear variation which indicates that as the size of material increases the value of K also increases. This may be caused due to a variety of factors such as increase in void space and less friction due to reduced surface area in contact with the liquid layer. The results are shown in Figure 2.

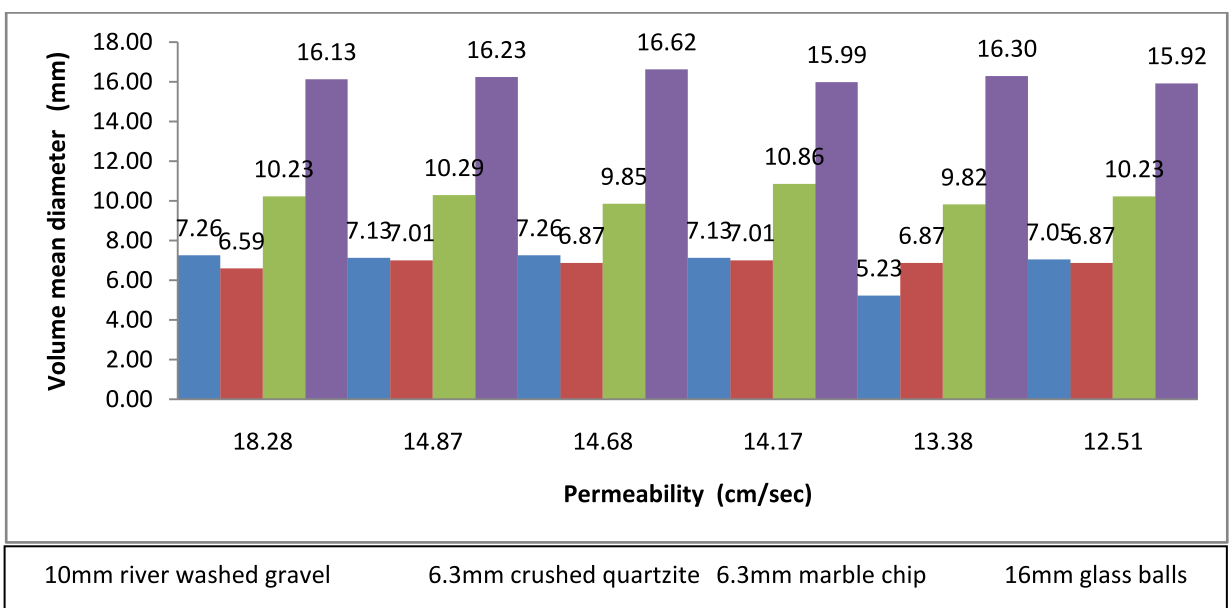

Figure 2: Graph of variation between K and dv for individual material.

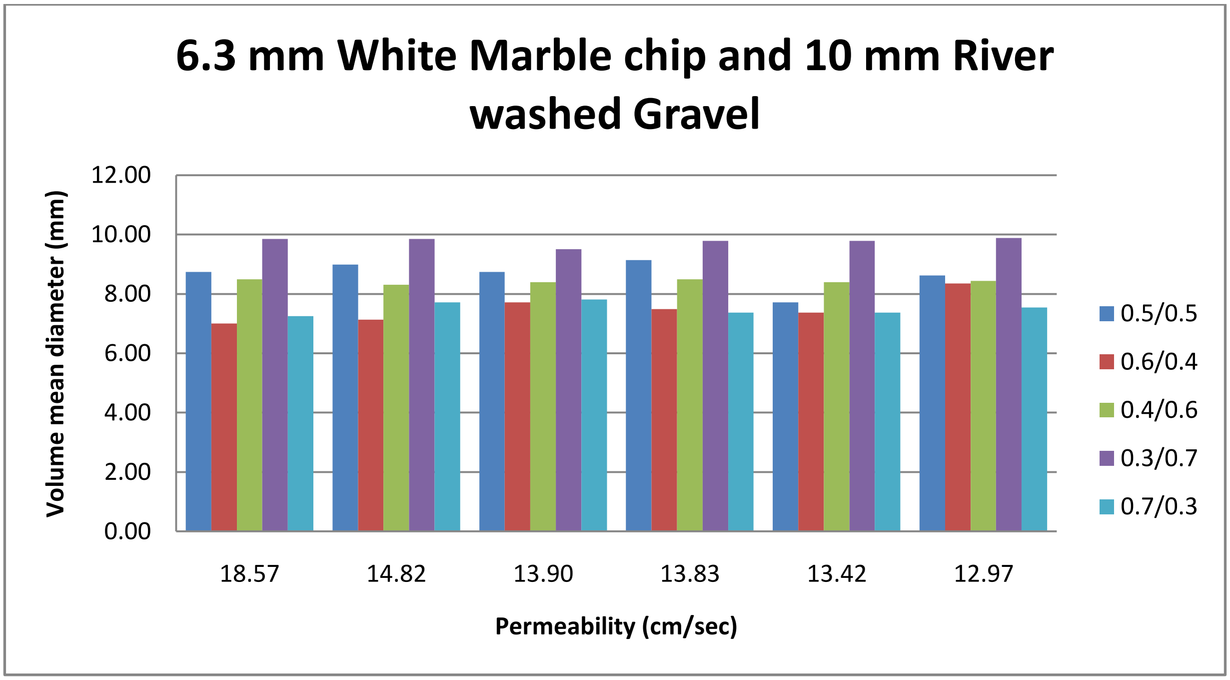

Figure 3: Graph of variation between k & dv for different proportions of 6.3mm White Marble chip & 1.mm River Washed Gravel

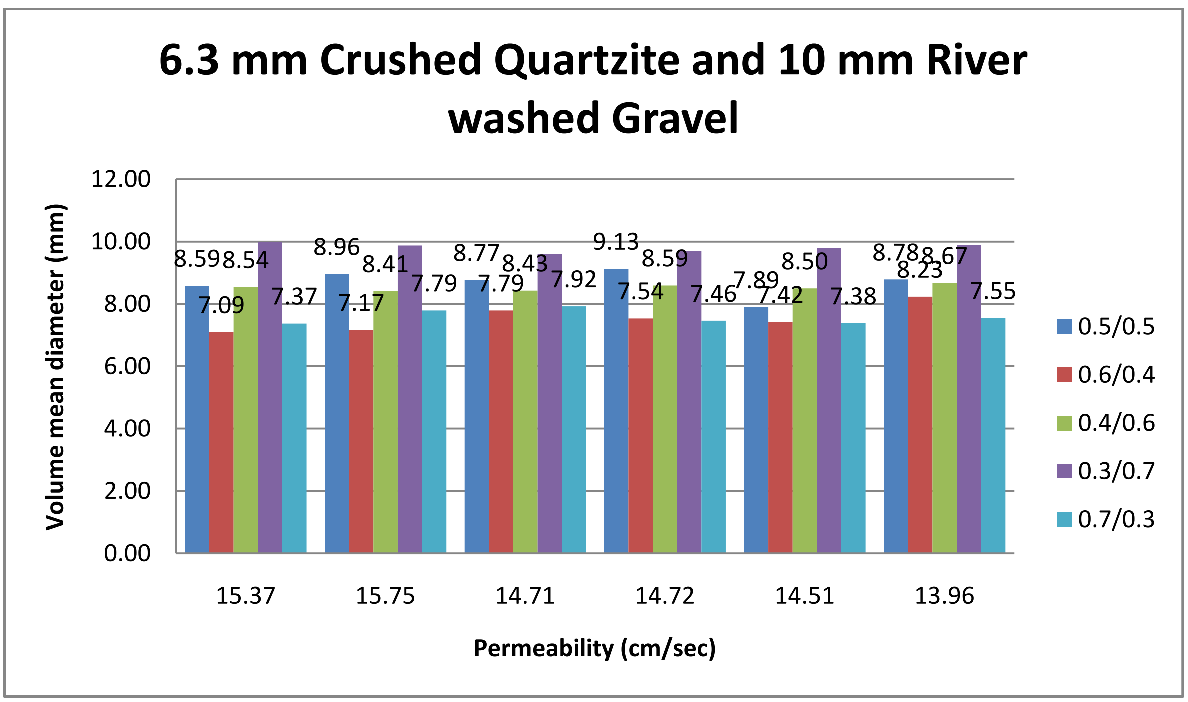

Figure 4: Graph of variation between k & dv for different proportions of 6.3mm Crushed Quartzite & 10mm River washed Gravel

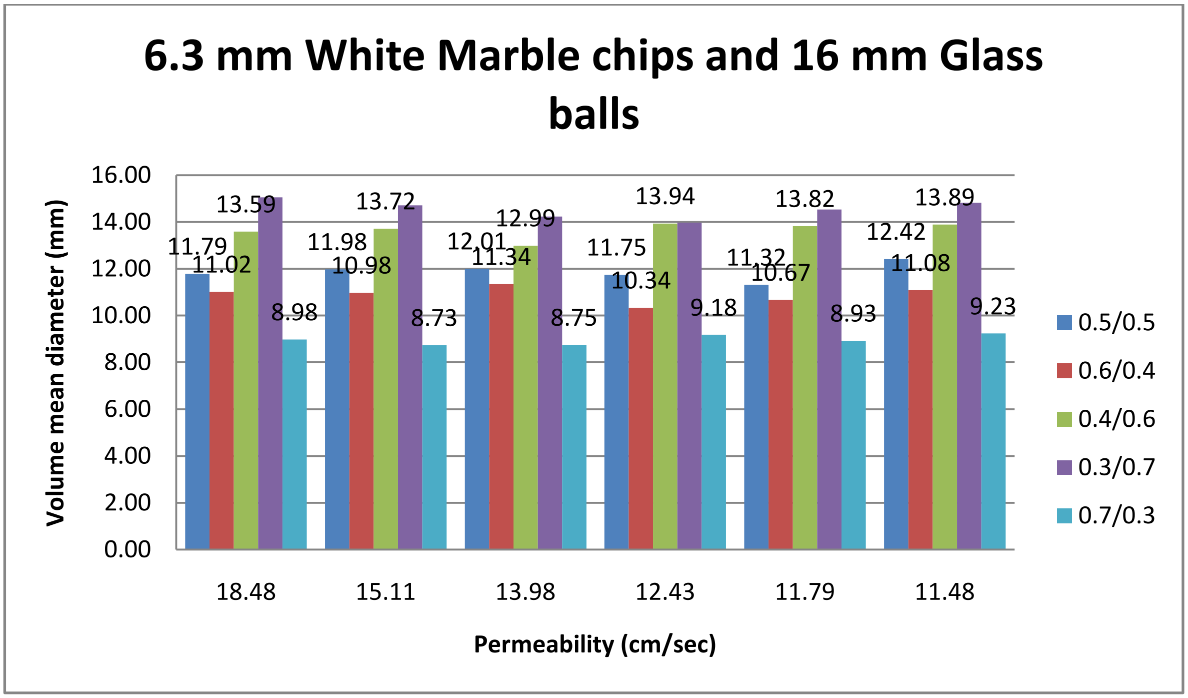

Figure 5: Graph of variation between k & dv for different proportions of 6.3 mm White Marble chips and 16 mm Glass balls

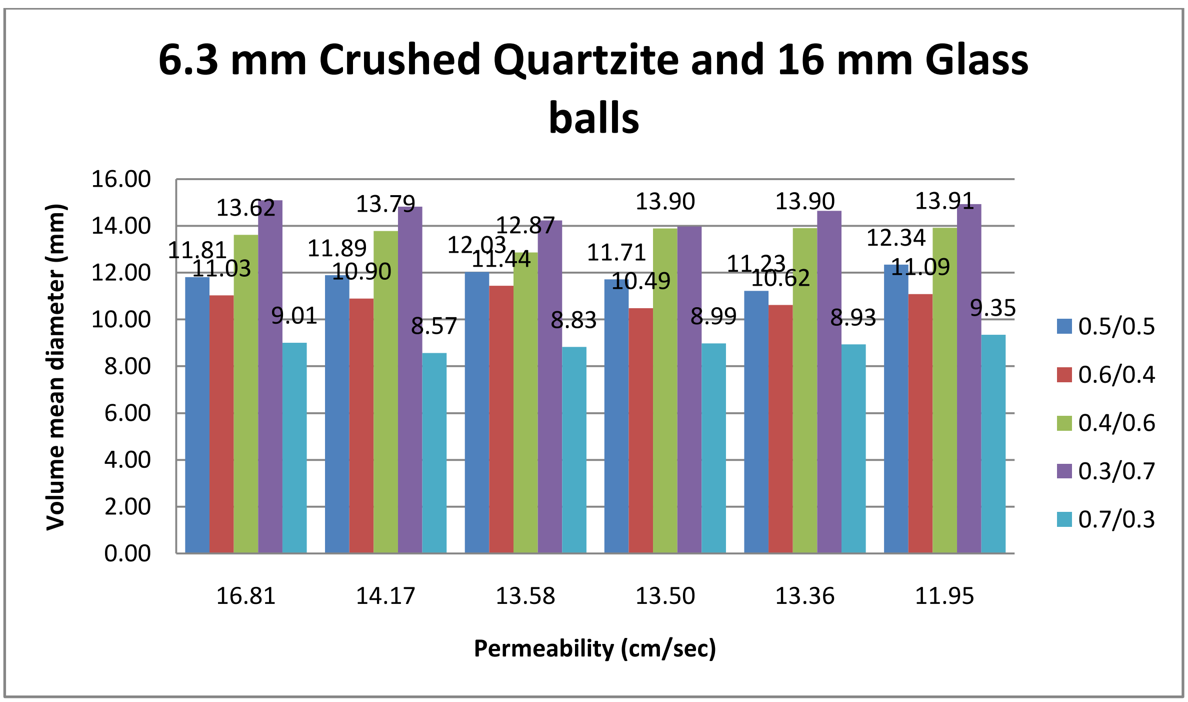

Figure 6: Graph of variation between k & dv for different proportions of 6.3mm Crushed Quartzite and 16 mm Glass balls

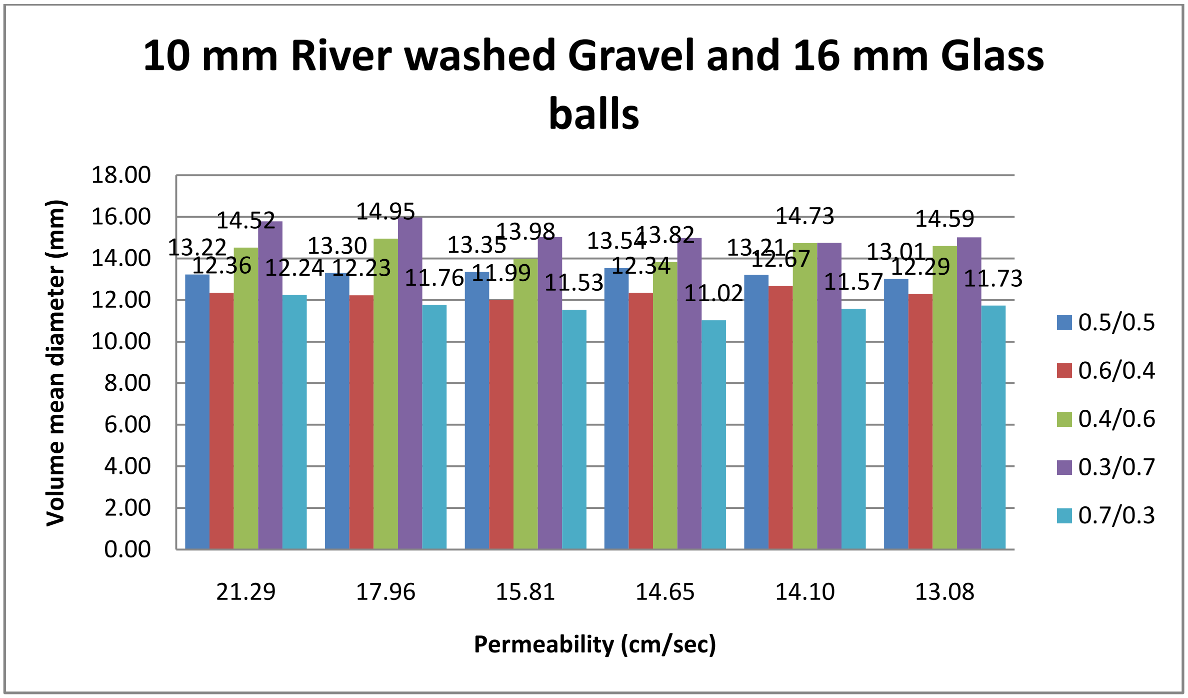

Figure 7: Graph of variation between k & dv for different proportions of 10 mm River washed Gravel and 16 mm Glass balls

4 (b) Variation of Hydraulic Conductivity vs % voids

There samples used in the present investigation have wide range of % voids. It becomes important to study relationship between hydraulic conductivity and % voids. Fig. 8-13 shows the variation of Hydraulic conductivity vs % voids.

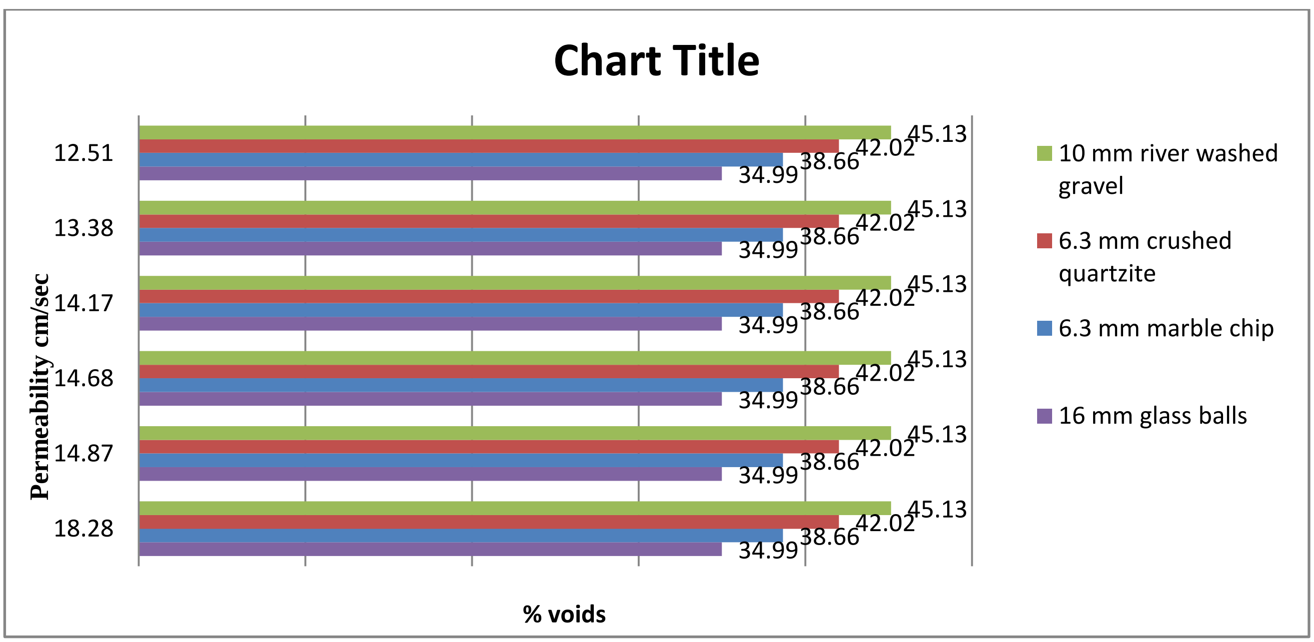

Figure 8: Graph of variation between K and % voids for individual material.

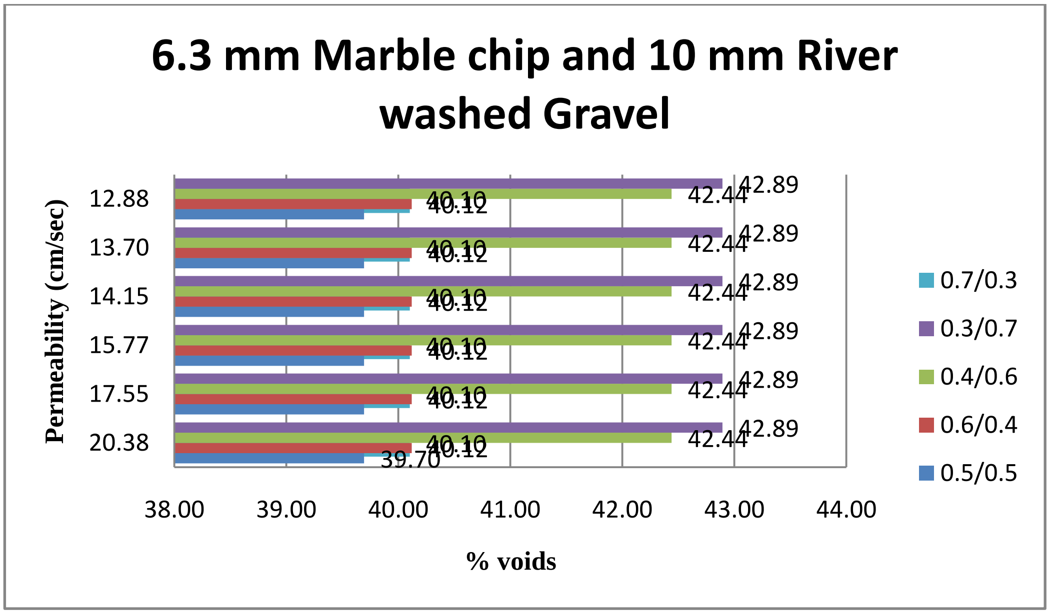

Figure 9 : Graph of variation between k & % voids for different proportions of 6.3mm White Marble chip & 10.mm River Washed Gravel .

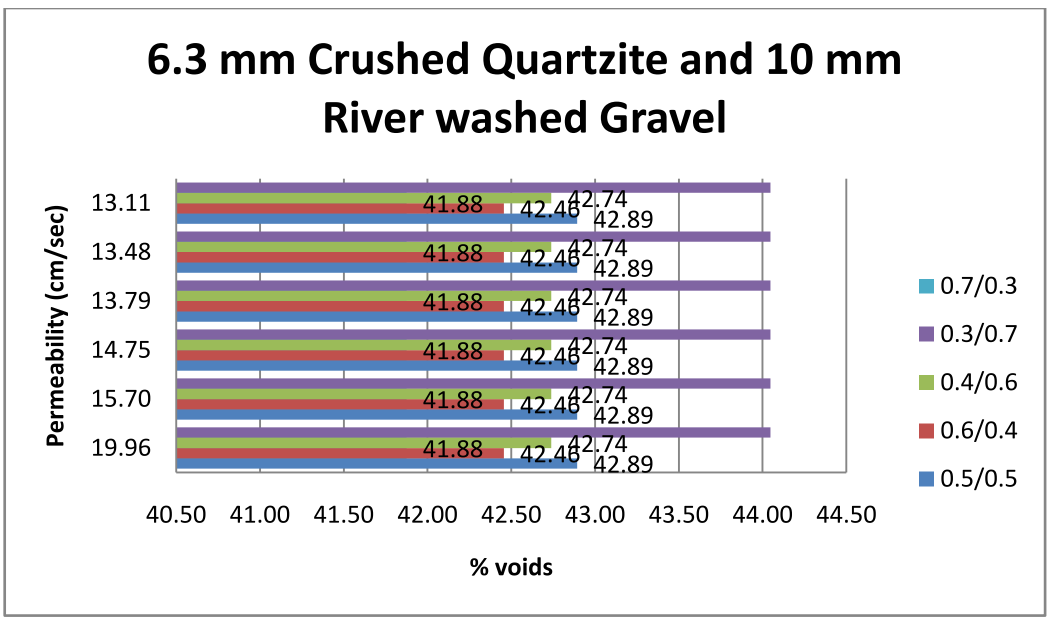

Figure 10: Graph of variation between k & % voids for different proportions of 6.3mm Crushed Quartzite & 10mm River washed Gravel

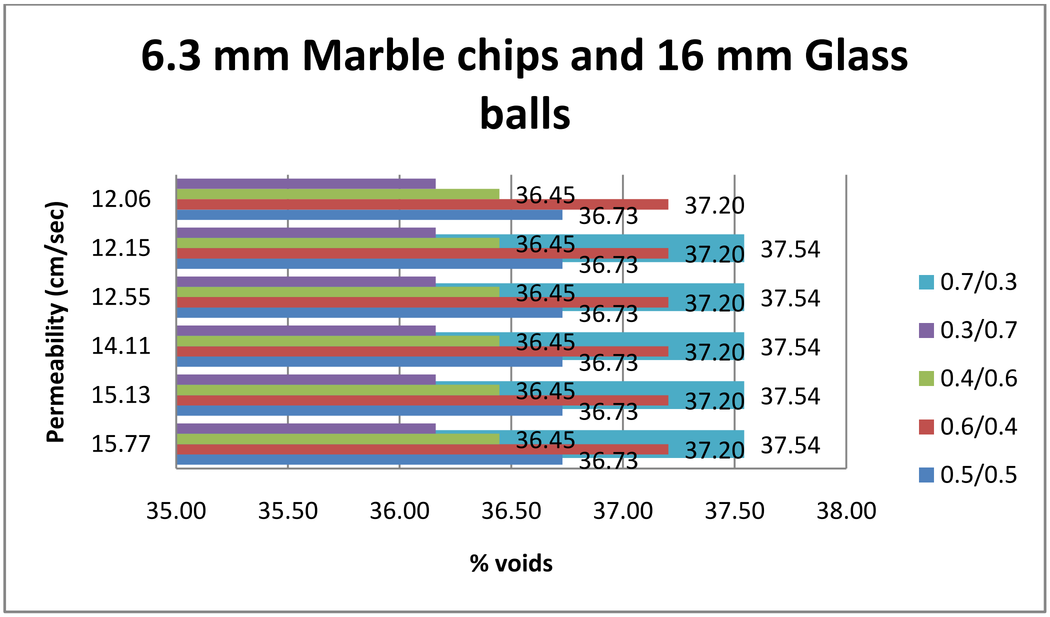

Figure 11: Graph of variation between k & % voids for different proportions of 6.3 mm White Marble chips and 16 mm Glass balls

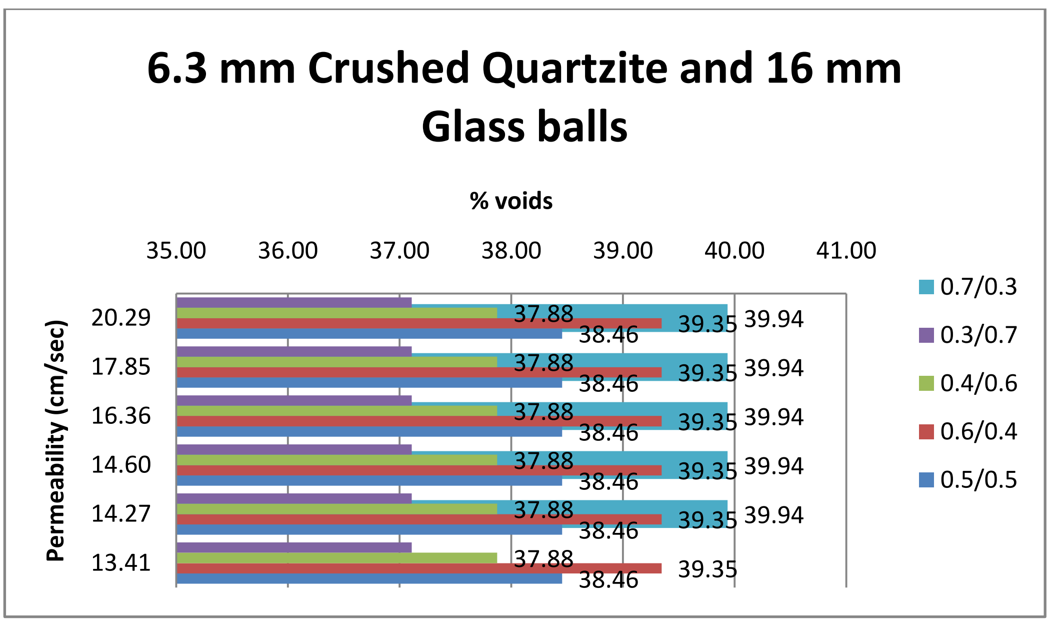

Figure 12: Graph of variation between k & % voids for different proportions of 6.3mm Crushed Quartzite and 16 mm Glass balls

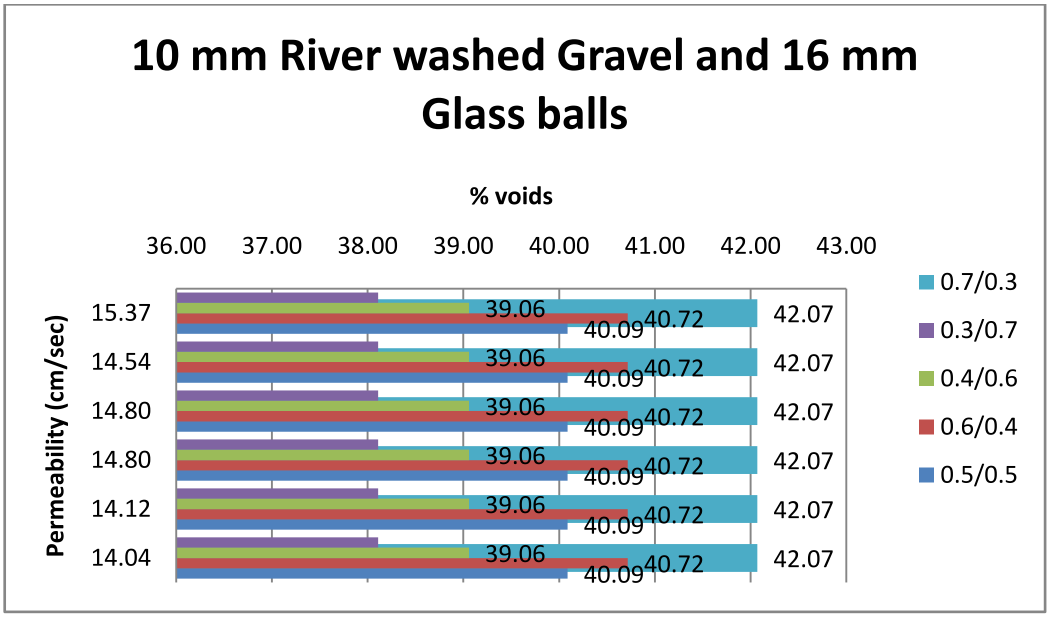

Figure 13: Graph of variation between k & % voids for different proportions of 10 mm River washed Gravel and 16 mm Glass balls

5. Conclusions

The present study has been conducted with an aim to study the effect of shape factor on hydraulic conductivity of porous media. Hydraulic resistance decreases as Volumetric mean diameter increases thus increasing the hydraulic conductivity. Hydraulic resistance decreases as the porosity increase thus increasing the hydraulic conductivity. A bar graph plotted between these two parameters shows a linear variation which indicates that as the % voids of material increases the value of K also increases. This may be caused due to a variety of factors such as increase in void space and less friction due to reduced surface area in contact with the liquid layer. The range of dv of the samples used in the present investigation varies from 6 mm to 16 mm. A bar graph plotted between k v/s Volume Mean diameter shows a linear variation which indicates that as the size of material increases the value of K also increases. This may be caused due to a variety of factors such as increase in void space and less friction due to reduced surface area in contact with the liquid layer.

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