Determination of Permeability of Spherical Porous Media based on Gradation and Shape Parameters

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Abstract - *The permeability of soil is an important parameter for understanding its various geotechnical engineering properties such as seepage failure, stability of slopes, lowering of ground water table, design of filters in hydraulic structures and settlement of soil under structures. It is particularly necessary to evaluate the permeability properly, while designing and constructing the underground structures. To understand the effect of various factors affecting permeability, numerous research work has been carried out from time to time. In the present study, permeability of spherical porous media has been related to its pore size, gradation and individual shape parameters. For this purpose, spherical porous media has been selected for laboratory testing from river Sindh and its adjoining areas. The gradation parameters (D_{10}, D_{30}, D_{60}, C_u, and C_c) and shape parameters (sphericity, roundness, elongation ratio, and shape factor) of spherical porous media were worked out in this study. The pore size of void network of spherical porous media was determined by using already developed empirical model. The constant head permeability test method has been used for the determination of permeability of spherical porous media. The values of permeability were related with the gradation parameters of spherical porous media and D_{10} was observed to be the most relevant gradation parameter for determination of permeability. Also, the values of permeability were related with the individual shape parameters of porous media and it was observed that individual shape parameters are insignificant for the determination of permeability. Finally, permeability was related with the pore size, D_{10} and individual shape parameters i.e., sphericity, roundness, elongation ratio and shape factor. Empirical models were developed for the determination of permeability based on pore size, D_{10} and individual shape parameters i.e., sphericity, roundness, elongation ratio and shape factor of spherical porous media. The developed empirical models showed significant coefficient of determination ($R^2 > 88\%$). The empirical equations developed in the present study were further validated in laboratory with a different set of porous media.*

Key Words: Permeability, Hydraulic conductivity, Shape parameters, Filter particles, cohesion less soils

1. INTRODUCTION

The permeability of soil is an important parameter for understanding its various geotechnical engineering properties such as seepage failure, stability of slopes, lowering of ground water table, design of filters in hydraulic structures and settlement of soil under structures. It is particularly necessary to evaluate the permeability properly, while designing and constructing the underground structures. To understand the effect of various factors affecting permeability, numerous research work has been carried out from time to time.For instance, Terzaghi (1967) gave a design of a graded filter that consists of coarser filter particles under a layer of finer base, such that there would form an easy passage for the water to come out of the base. However, the design was done in such a way that it would not allow the movement of finer base particles through the filter, that would otherwise fail the whole concept of filtering itself. In most of the investigations, empirical models have been developed for the determination of permeability based on relevant gradation parameters. In the present study, permeability of spherical porous media has been related to its pore size, gradation and individual shape parameters. Permeability studies often comprise of a term “effective size”; permeability coefficient is determined based on the effective size of the sample. Commonly, effective size is taken as D_{10}. It is defined as the diameter of particle or size of particle at which about 10% of the particles are finer than that particular size (Hazen, 1892). The effect of parameters like uniformity coefficient (Cu) and effective diameter (D_{10}) was observed on the permeability of soil by Hazen(1892). Ghabchi (2015) studied the effect of shape and gradation parameters on permeability of aggregate bases. In this particular study, spherical porous media has been selected for laboratory testing from river Sindh and its adjoining areas. The gradation parameters (D_{10}, D_{30}, D_{60}, C_u, and C_c) and shape parameters (sphericity, roundness, elongation ratio, and shape factor) of spherical porous media were worked out in this study. The pore size of void network of spherical porous media was determined by using already developed empirical model. The constant head permeability test method has been used for the determination of permeability of spherical porous media. The values of permeability were related with the gradation parameters of spherical porous media and D_{10} was observed to be the most relevant gradation parameter for determination of permeability. Also, the values of permeability were related with the individual shape parameters of porous media and it was observed that individual shape parameters are insignificant for the determination of permeability. Finally, permeability was related with the pore size, D_{10} and individual shape parameters i.e., sphericity, roundness, elongation ratio and shape factor. Empirical models were developed for the determination of permeability based on pore size, D_{10} and individual shape parameters i.e., sphericity, roundness, elongation ratio and shape factor of spherical porous media. The developed empirical models showed significant coefficient of determination (R^2 > 88%). The empirical equations developed in the present study were further validated in laboratory with a different set of porous media.

2. Test methodology

The following test methodologies have been employed in order to achieve the objectives of this research work:

1. Determination of gradation parameters
2. Determination of shape parameters
3. Determination of pore size
4. Determination of coefficient of permeability

3. Experimental procedure

There are different methods for finding the permeability of filter materials. Some of them are performed in field, while others are performed in laboratory e.g. constant head permeability test, falling head permeability test, pressure tests and slug tests. In this particular study, constant head permeability test was used as it is suitable for coarser material. The material that was used for this study was obtained from river Sindh and adjoining river course. The shape of the particles used for laboratory investigations was close to spherical. However, their size varied from 50 mm to 1 mm. After taking enough amount of aggregates for testing purpose, they were grouped in following size standards : 50 mm, 40 mm, 31.5 mm, 24 mm, 20mm, 18 mm, 16 mm, 12.5 mm, 6.2 mm,4.75 mm , 3.75 mm, 3.36 mm, 2.5 mm, 2 mm, 1.704 mm, 1.404 mm, 1.205 mm and 1mm.

4. Results

Table -1: Gradation parameters of filter material

S_1, S_2, S_3 (mm)	S_4 (mm)	d_5 (mm)	d_{10} (mm)	d_{30} (mm)	d_{60} (mm)	$C_c = (D_{30})^2/(D_{60})(D_{10})$	$C_u = D_{60}/D_{10}$	k(cm/s)
12.5:12.5:12.5	1.875	1.775	8.950	10.054	10.598	1.203	1.022	2.72
16:16:16	2.4	2.250	11.283	12.576	13.337	1.227	1.024	3.25
20:20:20	3	3.025	15.591	16.087	16.957	1.203	1.022	3.65
25:25:25	3.75	3.550	19.321	20.109	21.196	1.203	1.022	4.13
31.5:31.5:31.5	4.725	4.469	23.284	25.141	26.554	1.211	1.022	7.64
40:40:40	6	5.719	31.654	31.685	33.533	1.219	1.023	8.58
50:50:50	7.5	7.550	40.41	40.217	42.391	1.203	1.022	19.53
12.5:20:25	2.75	10.192	11.102	12.115	19.467	2.248	1.352	2.61
16:25:31.5	3.52	12.769	11.88	15.462	24.333	2.255	1.300	3.52
20:31.5:40	4.4	16.308	17.80	19.385	30.633	2.236	1.329	5.70
25:40:50	5.5	20.385	21.001	24.231	38.867	2.248	1.349	7.57
12.5:25:40	3.225	13.667	13.369	25.448	40.698	3.403	0.859	3.09
16:31.5:50	4.128	10.833	19.001	20.345	40.698	4.293	1.065	4.23
12.5:25:50	3.438	10.833	19.234	20.345	32.093	3.419	0.840	3.51

The models yielded from the regression of the values of permeability (k) versus effective diameter (D_{10}), individual shape parameters and pore size (S_4) are presented in Eq. 1-4.

$$k=p/D_{10}(3.7869S_4^{2.4216}) \quad (1)$$
$$k= Q/D_{10}(3.5767S_4^{2.4196}) \quad (2)$$
$$k= \psi/D_{10}(3.669S_4^{24089}), \quad (3)$$

$$k = f/D_{10}(3.9194 S_4^{2.4217}). \quad (4)$$

The above mentioned equations have a significant coefficient of determination.

Table -2: Gradation, shape parameters, observed and predicted permeability of porous media

S_4 (mm)	D_{10}	*P*	*Q*	*Ψ*	*F*	*K (observed)*	K (predicted) As per Eq.1	K (predicted) As per Eq.2	K (predicted) As per Eq.3	K (predicted) As per Eq.4
2.4	11.283	0.751	0.847	0.816	0.689	2.45	2.099	2.236	2.186	2.517
3	15.591	0.763	0.842	0.812	0.700	3.32	2.650	2.762	2.695	3.317
3.75	19.321	0.732	0.839	0.796	0.666	3.75	3.522	3.813	3.650	4.839
4.725	23.284	0.704	0.852	0.776	0.669	4.98	4.919	5.623	5.152	6.566
6	31.654	0.759	0.840	0.799	0.692	6.13	6.957	7.272	6.938	2.707
3.438	19.234	0.734	0.835	0.785	0.666	3.14	2.874	3.0889	2.933	2.700

5. CONCLUSIONS

The present laboratory study was undertaken to investigate the effect of gradation and shape parameters (sphericity, roundness, elongation ratio and shape factor) on the permeability of spherical shaped porous material.

The spherical shaped porous material of different gradation and shape parameters was used for laboratory investigations. The constant head permeability method was used for determination of permeability. On the basis of experimental results, effective diameter (d_{10}) was found to be the most relevant gradation parameter for the determination of permeability of spherical shaped porous media.

The results reveal that there is less effect of individual shape parameters i.e. sphericity, roundness, elongation ratio and shape factor on the coefficient of permeability of spherical material. It was also observed that individual shape parameters with effective diameter (d_{10}) of spherical porous media showed a significant trend with coefficient of permeability.

The main conclusion drawn in the present study are as follows:

- An empirical model was developed for the determination of permeability of spherical porous media based on effective diameter (D_{10})
- Further , four more empirical equations were developed for the determination of permeability of spherical porous media based on the most relevant gradation parameters (d_{10}) & shape parameters(roundness, elongation ratio , sphericity and shape factor) as shown in equation 1-4.

The above mentioned developed equations were further validated in the laboratory with the help of different shaped porous material having the same gradation parameters used for the laboratory testing.

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