International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

An Empirical Model for Estimation of Permeability of Porous Media based on its Gradation Parameters

MA Lone

***Abstract:** In the present study the hydraulic conductivity of the porous media has been related to its gradation parameters. Nine cohesion-less soils of different gradations were tested in a constant head permeameter. A low head of water, standardised to viscosity at 20°C, was used to avoid the turbulence. It was observed that the hydraulic conductivity varied significantly with respect to the gradation parameters. The empirical model developed on the basis of this study can be helpful for more rational estimation of the flow through non-cohesive porous media on the basis of its gradation characteristics.*

***Index Terms:** Cohesion-less Soils, Gradation, Permeability, Porous Media, Regression.*

I. INTRODUCTION

Soils as particulate media have certain special engineering characteristics and permeability is one of them. The importance of permeability in the field of geotechnical engineering and water resources engineering has been discussed by many investigators. The determination of permeability is essential for rate of settlement of saturated soils under load, the stability of slopes and retaining structures, the design of filters, and the design of earth dams, etc [1]. In view of its importance, large amount of work has been done to understand the flow through porous media and this characteristic is quantified as coefficient of permeability. The most important empirical models for the determination of coefficient of permeability of granular soils were given by some researchers [2-4].

The internal structure of porous media is very complex and there are no definite flow paths as in the case of pipes or channels. Hence a clear understanding and assessment of permeability coefficient has evaded the efforts of many researchers. One of the most widely accepted equation is that of Darcy, which is based on empirical relations wherein gross area of cross section of a specimen is used as flow area.

Manuscript received on January 02, 2020.
Revised Manuscript received on January 15, 2020.
Manuscript published on January 30, 2020.

* Correspondence Author
MA Lone, Professor, Department of Civil Engineering, National Institute of Technology, Srinagar, India.
Email: professorlone@nitsi.net

Efforts have been made by various researchers to relate the various soil parameters such as particle size, particle shape, void ratio, viscosity etc., with the permeability [5-10]. The equations obtained give parabolic relations for permeability with respect to particle size and void ratio. However the approach adopted in actual practice is based only on the Darcy's law.

In the present study, an attempt has been made to estimate the permeability of a non-cohesive porous media based on its gradation parameters. The cohesion-less media considered in the present study ranged from uniformly graded to widely gap-graded soils.

II. MATERIAL

For the purpose of testing nine cohesion-less soils of different gradations were used. The gradation of the test materials varied from uniformly graded to the well graded and the widely gap-gradation. The various gradation parameters of these soils are presented in Table 1(a)-(b). Where, D_x is the size of the protected soil at which x% is finer and C_u is the uniformity coefficient.

Table 1(a): Gradation parameters of Test Material

Material	D_5	D_{10}	D_{15}	D_{50}	D_{85}	D_{95}
M_1	0.13	0.155	0.16	0.45	0.98	1.45
M_2	0.25	0.340	0.41	0.71	1.56	2.25
M_3	0.14	0.190	0.23	1.00	2.3	3.35
M_4	0.26	0.370	0.45	0.96	1.60	1.90
M_5	0.205	0.250	0.30	0.74	1.65	2.50
M_6	0.80	1.10	1.23	1.65	2.0	2.25
M_7	0.30	0.395	0.46	0.98	1.67	2.05
M_8	0.101	0.175	0.22	0.47	1.70	2.00

M_9	0.11	0.125	0.13	1.47	2.45	3.55

Table 1(b): Gradation parameters of Test Material

Material	C_u	Remarks
M_1	3.19	Well Graded
M_2	2.79	Not so well graded
M_3	6.29	Well Graded
M_4	3.11	Well Graded
M_5	4.0	Well Graded
M_6	1.68	Uniformly Graded
M_7	2.66	Not so well graded
M_8	7.43	Narrow Gap Graded
M_9	13.2	Narrow Gap Graded

III. EXPERIMENTAL SETUP

The experimental set up used in the present is shown in Fig 1. It consisted of a 250 mm diameter cylindrical container having 600 mm length with a hopper type base of 80 mm diameter. The two stopcocks were provided at the inlet and outlet for regulating the supply of water. The two air vents and a pressure gauge were provided at the top of the apparatus. A set of seven brass pinch cocks in a row were provided and used for closure and resumption of supply to the piezometer. Rubber tubing's were connected to the pinch cocks to measure the head available with a help of measuring staff rod which was provided adjacent to the apparatus. A flexible pipe of 3.75 cm diameter was connected to hopper base for directing the outflow discharge into the graduated.

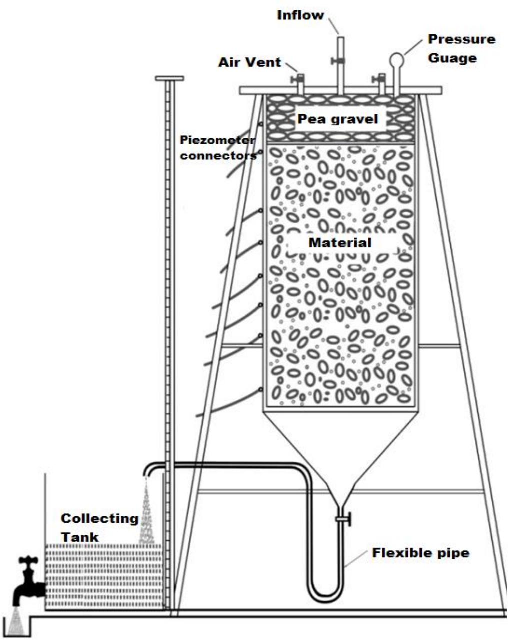

Figure 1. Permeability apparatus

IV. TEST PROCEDURE

The cohesion-less material was placed up to 10 to 15 cm below the top of the cylinder, a wire mesh of 10 mm opening was placed at the top of the cylinder. The direct impact of inflowing water on the test material was prevented by placing pea gravel over the wire mesh. A flexible pipe of 3.75 cm diameter was connected to hopper base through bottom flange for directing the outflow discharge into the graduated measuring tank. Finally, the washer and top flange was placed on the cylinder and tightened. The water was allowed to pass through the main cylinder by regulating the valve at inlet and outlet of the cylinder. The air vents were opened to remove the air from the specimen and then closed. The head measurements along the cohesion-less material, rate of flow through the material and water temperature were measured. The permeability worked out at various temperatures were standardised to the viscosity of water at 20 degree centigrade by the following relation:

$$k_{20} = k_t \left(\frac{\mu_t}{\mu_{20}} \right) \qquad (1)$$

Where, k_{20} and k_t are the coefficients of permeability at 20^0C and t ^{0}C respectively; μ_{20} and μ_t are the viscosities of water at 20^0 C and t ^{0}C respectively.

V. RESULTS AND DISCUSSION

The permeability tests, as described in the preceding section were carried out for all the nine materials. The results of these tests are presented in Table 2.

Table 2 Permeability of the Test Materials

Material Class	Permeability (k) cm/sec
M_1	0.0113
M_2	0.118
M_3	0.033
M_4	0.145
M_5	0.047
M_6	0.260
M_7	0.099
M_8	0.013
M_9	0.023

The permeability values obtained from the testes were related to the various gradation parameters, like D_5, D_{10}, D_{15}; D_{50}; D_{85}; D_{95}; and C_u. The relationships of the permeability with these gradation parameters are shown in Fig 2(a) to 2(g).

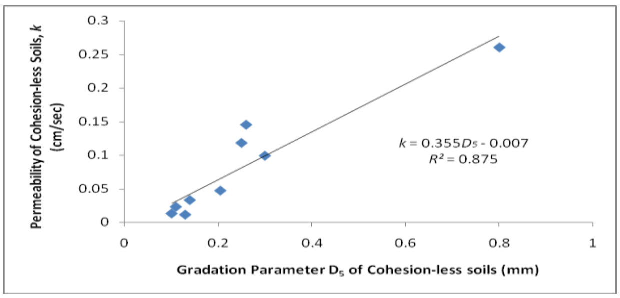

Figure 2(a). Relationship of permeability and D_5 of cohesion-less soils

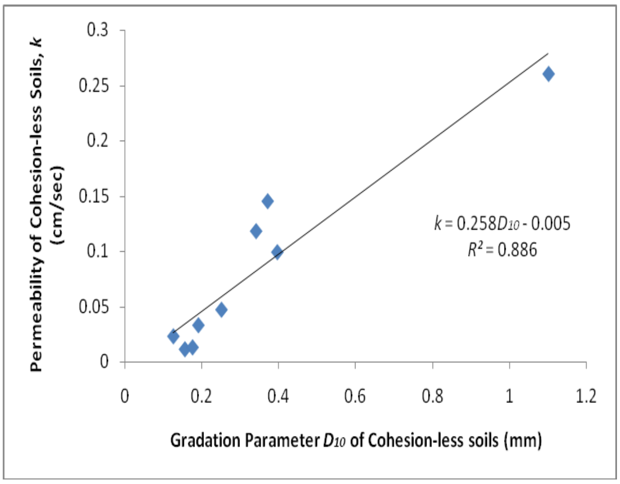

Figure 2(b). Relationship of permeability and D10 of cohesion-less soils

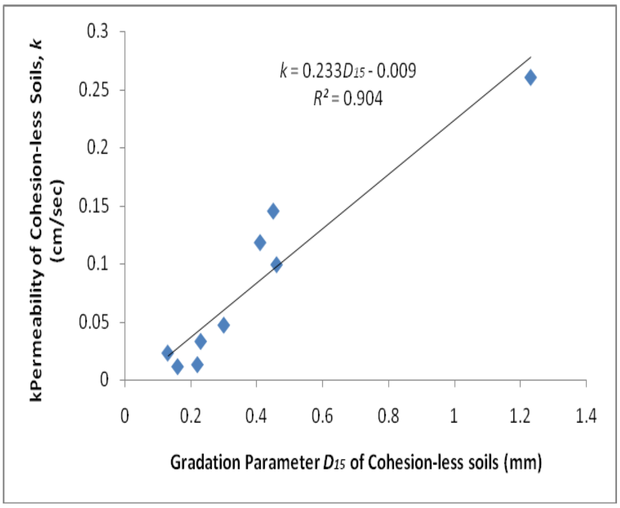

Figure 2(c). Relationship of permeability and D15 of cohesion-less soils

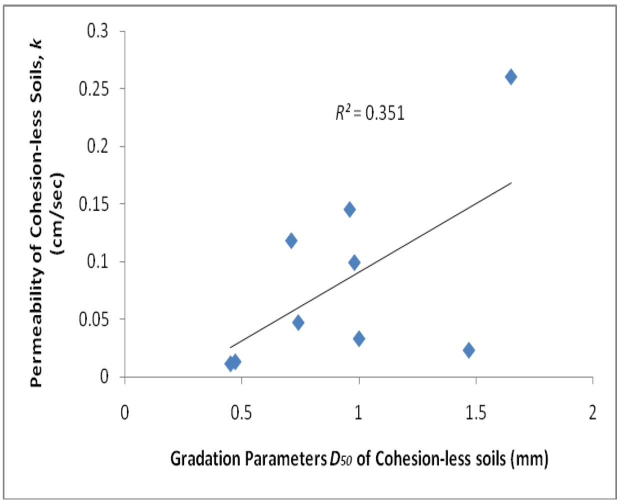

Figure 2(d). Relationship of permeability and D50 of cohesion-less soils

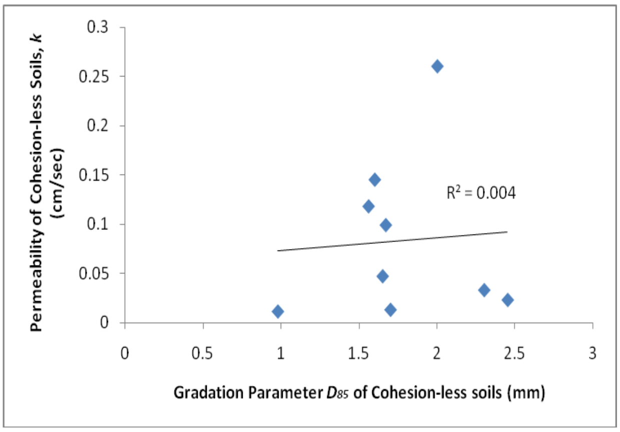

Figure 2(e). Relationship of permeability and D85 of cohesion-less soils

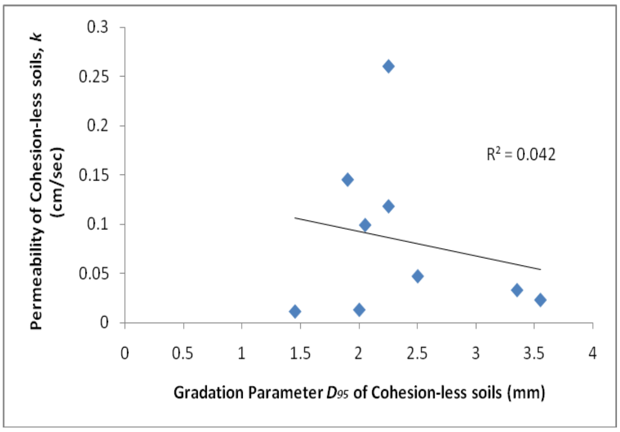

Figure 2(f). Relationship of permeability and D95 of cohesion-less soils

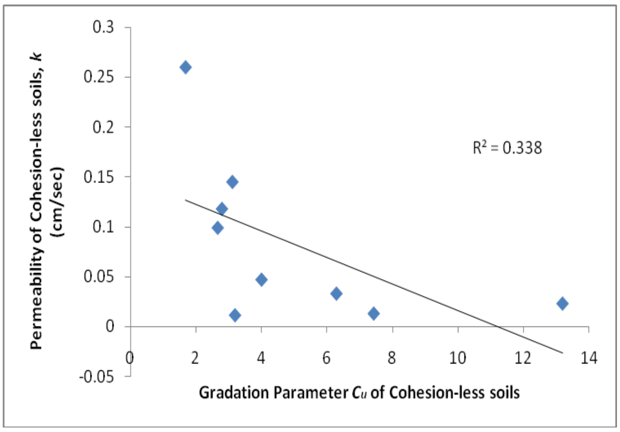

Figure 2(g). Relationship of permeability and Cu of cohesion-less soils

It is seen from the above figures that the effect of finer fractions on the permeability of the soils is significant where the coarser fractions do not show any considerable influence. The regression analysis shows a coefficient of regression of around 0.9 for the gradation parameter of D_5, D_{10} and D_{15}. The multiple regressions for these three parameters were carried out and are represented in Fig 3(a) -3(d).

A better correlation is being observed between these four gradation parameters and the permeability. The empirical model thus evolved for estimation of the permeability of cohesion-less porous media is given below.

$$k = -0.0275 + 0.511D_5 - 1.48D_{10} + 1.23D_{15} \quad (2)$$

R^2 value is 94% and p value of 0.0020.

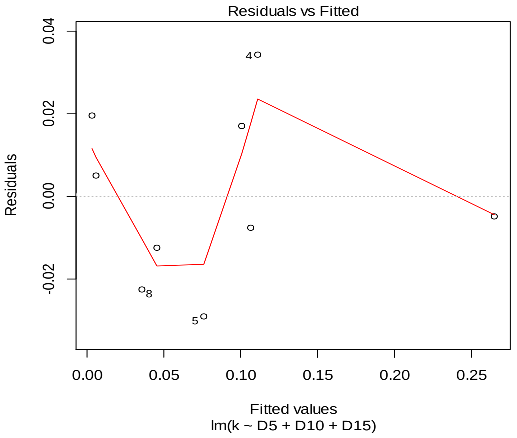

Figure 3(a). Residuals versus fitted values

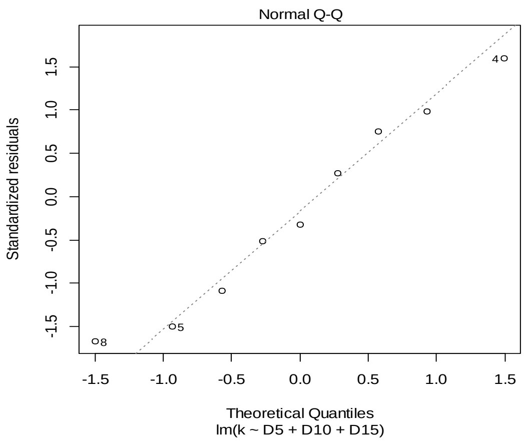

Figure 3(b). Standardized residuals versus quantiles

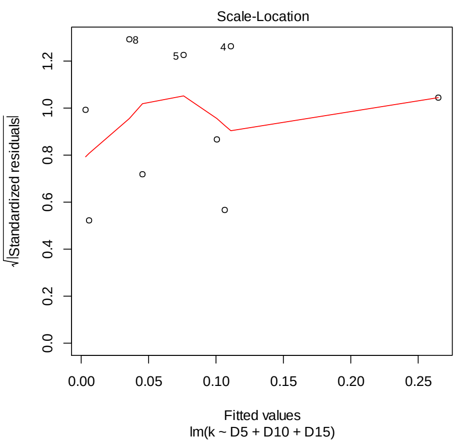

Figure 3(c). Residuals versus fitted values

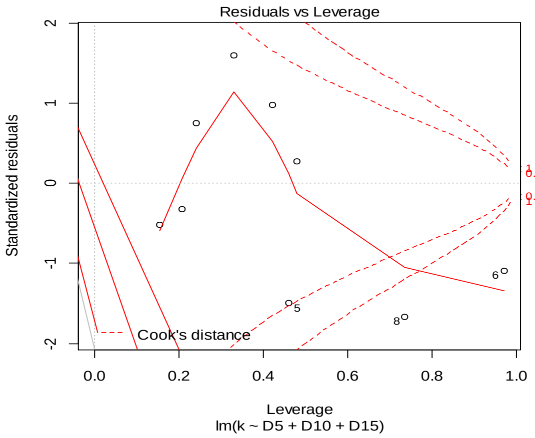

Figure 3(d). Standardized residuals versus Leverage

VI. VALIDATION

The empirical model developed in the present study was further validated by using the data of study carried out by Rather [11]. The gradation parameters and permeability of different cohesion less soils computed by Rather [11] and permeability worked out by using the developed empirical model (Eq. 2) are presented in Table 3(a)-(b). The computed values of permeability and predicted values of permeability are graphically presented in the scatter plot shown in Fig 4. The data points in the plot are close to the 45° line. Hence, the proposed model is promising in terms of predicting the coefficient of permeability.

Table 3(a) Gradation Parameters of Samples used for Validation

Sample	Gradation parameters of materials used for validation		
	D_5 (mm)	D_{10} (mm)	D_{15} (mm)
1	0.176	0.234	0.277
2	0.143	0.192	0.229
3	0.120	0.16	0.185
4	0.115	0.147	0.164
5	0.1905	0.261	0.330
6	0.171	0.237	0.275
7	0.188	0.241	0.279
8	0.200	0.269	0.354
9	0.164	0.21	0.243
10	0.191	0.261	0.321
11	0.151	0.1997	0.229
12	0.185	0.253	0.312

13	0.163	0.213	0.250
14	0.151	0.203	0.233
15	0.153	0.200	0.243
16	0.123	0.155	0.181
17	0.118	0.157	0.181

Table 3(b) Observed and predicted values of permeability

Sample	Permeability computed by Rather [11] (cm/sec)	Permeability predicted by the developed model (cm/sec)
1	0.049	0.0568
2	0.031	0.0431
3	0.024	0.0246
4	0.018	0.0154
5	0.058	0.0894
6	0.051	0.0474
7	0.043	0.0550
8	0.071	0.112
9	0.033	0.0443
10	0.063	0.0786
11	0.03	0.0358
12	0.054	0.0763
13	0.043	0.0480
14	0.039	0.0358
15	0.04	0.0535
16	0.026	0.0286
17	0.017	0.0231

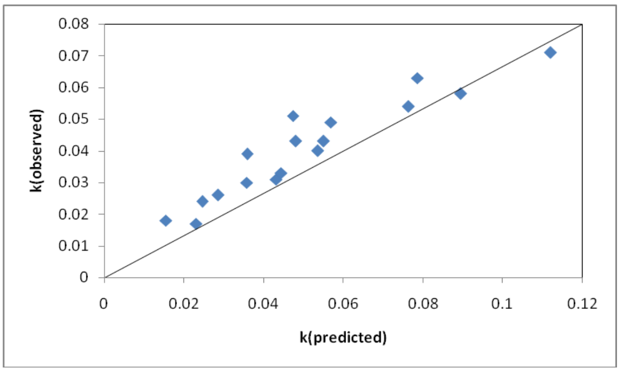

Figure 4. k (predicted) versus k (observed)

VII. CONCLUSION

The present study has shown that the flow through porous media, hence the permeability, is mainly controlled by the finer fraction of the media i.e. mainly up to 15% finer, other coarser factions have a very less effect. The material tested here included the uniformly graded, well graded, narrowly gap-graded and the widely gap-graded materials, to ascertain effect of the overall gradation on permeability, and it was observed that mainly the finer fractions have the effect on the permeability of the material. This is because of the fact that the flow through porous media is through the pore channels of the media whose effective size actually depend on the smaller windows/pores formed between the finer fractions of the media. The pores formed between the coarser fractions also get finally filled with finer fractions, thus having lesser effect on the permeability phenomenon**.** The empirical relation proposed on the basis of present study can be used as a first hand tool for estimation of permeability in the field knowing the gradation parameters of the soil.

REFERENCES

1. B. M. Das, Advanced Soil Mechanics, Taylor & Francis, New York, 2008, pp. 567.
2. A. Hazen, Some physical properties of sands and gravels, Massacheuttes State Board of Health, Annual Report, 1892, pp. 539-556.
3. P. C. Carman, "Permeability of Saturated Sands, Soils and Clays", Journal of Agricultural Sciences, 1939, 29(20), pp 262-273.
4. T. C. Kenney, D. Lau and G. I. Ofoegbu, "Permeability of Compacted Granular Materials", Canadian Geotechnical Journal, 1984, 21(4), pp 726-729.
5. J. Kozeny, Ueber Kapillare Leitung des Wassers im Boden, "Sitzungsber Akad. Wiss., Wien", 1927, 136(2), pp 271-306.
6. D. W. Taylor, "Fundamentals of Soil Mechanics", John Wiley and Sons, New York, 1948.
7. T. W. Lambe and R. V. Whitman, Soil Mechanics, Wiley Eastern Private Limited, 1973.
8. A. Kezdi, Handbook of Soil Mechanics, Soil Physics Akademiai Kaido, Budapest, 1974, 1.
9. P. C. Carman, Flow of Gases through porous media, Academia Press, New York, 1956.
10. J. K. Mitchell, Fundamentals of Soil Behaviour, John Wiley and Sons, Toronto, 1976.
11. N. A. Rather, Protective Filter Design Criteria Based on Particle Shape and Base Gradation Parameters, Ph.D. Dissertation, National Institute of Technology Srinagar, 2016.

AUTHORS PROFILE

MA Lone is a Professor of Civil Engineering at Department of Civil Engineering, National Institute of Technology Srinagar. Prof. Lone has Doctorate in Civil Engineering with specialization in Water Resources Engineering and Hydraulic Structures. With a vast experience in water resources engineering and management, he has been in charge of various survey and development works in the Kashmir Valley closely associated with various agencies. He has guided numerous graduate students and Post graduate and Doctorate Dissertations. Presently, he is also the Head of the Water Resources Management Centre at NIT Srinagar. Prof. Lone is actively involved with the various academic societies and the administrative boards and committees.