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A Laboratory Investigation on Flow Traits in Saturated Clay

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Abstract. The properties of flow through saturated soil are complicated. When the head is low, the flow is virtually linear, and Darcy's rule applies. The flow is nonlinear at the increasing head and is mathematically known as Forchheimer's flow. Several factors, including soil and fluid properties, influence the critical flow velocity for this transition and the corresponding Reynold's number. An experimental examination was carried out in this paper using a falling head permeameter and a locally accessible soft soil sample. The test findings were subjected to a careful analysis and interpretation to identify the linear and nonlinear flow characteristics, and key conclusions were obtained as a result.

Keywords. Aquifer, Groundwater, Saline water intrusion

1. Introduction

Water is extremely important to humanity, and it is also one of the most pressing concerns of our time. Freshwater availability is a major factor in determining a country's population's standard of living [1]. Existing sources of fresh water (lakes, reservoirs, rivers, and so on) must also be developed and managed scientifically to maintain a high level of life and a healthy environment, as the need for freshwater grows daily owing to population growth [2]. The prospects for coping with population demand on the water include groundwater recharge, inter-basin water transfer, and water re-use. In coastal areas, groundwater is the principal supply of freshwater for both household and agricultural purposes. Many hydrological processes are regulated by horizontal and vertical hydraulic conductivity of the soil [3, 4]. Engineers and hydrogeologists will benefit from this research because it will address flow characteristics through saturated soft clay. Basic principles on diverse soil properties are reinforced through a series of experiments to better comprehend the complexity of flow characteristics.

2. Experimentations

2.1. Determination of Specific Gravity

The ratio of the weights of an equal amount of distilled water at the same temperature both weights were taken in the air is known as specific gravity (G). The main goal of this experiment is to get basic information on soil parameters such as degree of saturation, void ratio, and so on. A density bottle is used to determine the specific gravity of soil passing through a 4.75 mm I.S. sieve. The test is carried

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out in accordance with IS-2720 [5]. The specific gravity (G) was found to be 2.51, 2.61, and 2.55. shown in Figure 1.

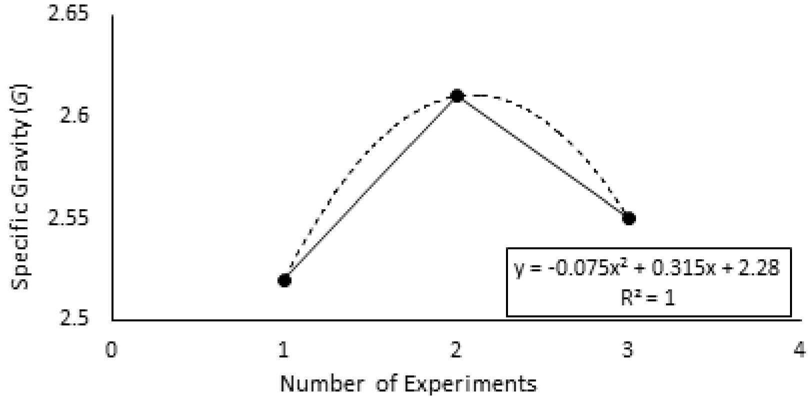

Figure 1. Results of different specific gravity experiments.

2.2. Standard Proctor Test

The standard proctor test is conducted as per IS-2720 [6] to determine the relationship between the moisture content and dry density of the soil sample compacted in a specific mold with a hammer weighing 2.5 kg dropped from a height of 30 cm. the results are shown in Figure 2.

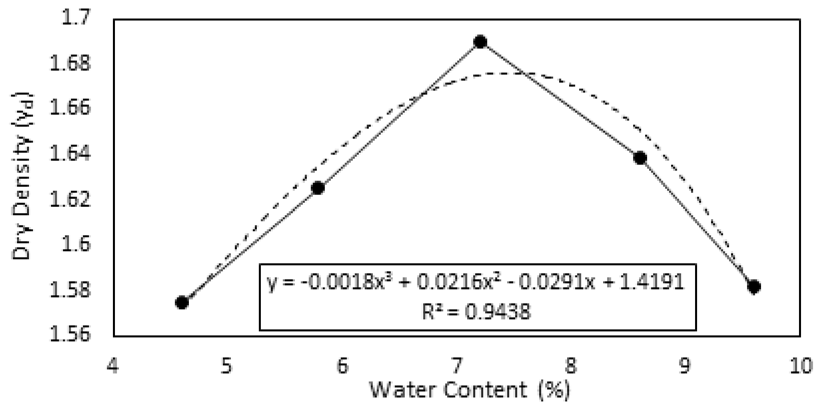

Figure 2. Dry density for Water content

2.3. Liquid Limit

The Liquid Limit of soil is the determination of water content present in the soil due to which there is a small resistance against the flow. This test is done as per IS-2720 [7]. The results are shown in Figure 3.

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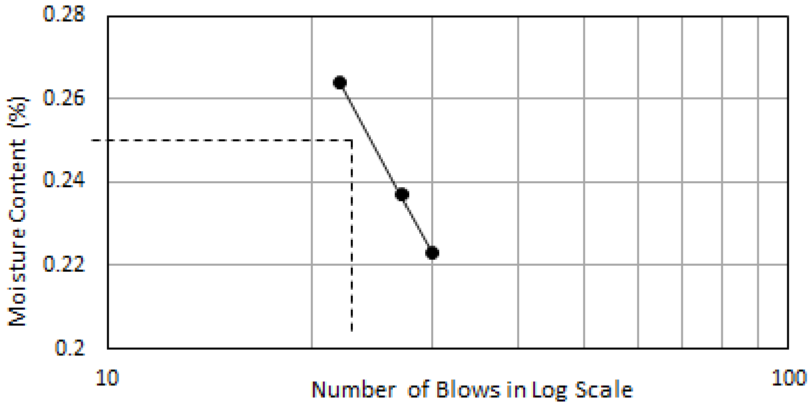

Figure 3. Comparison of water content with the number of blows

2.4. Plastic Limit

The limit of water content at which soil loses its plasticity is defined as the Plastic limit. The difference between liquid limit and plastic limit is defined as the plasticity index, which is considered as one of the major indexes of soil. The experiment is performed as per IS-2720 [7] Observations are Moisture content of sample 1 is 16.8 %, Moisture content of sample 2 is 16.2 % and Moisture content of sample 3 is 14.8 %. (Moisture content is determined using an Infrared moisture meter).

2.5. Falling Head Permeability Test

A falling head permeability test is done to obtain knowledge about hydraulic gradient and coefficients of permeability. These two properties of soil play a very important role in solving the problem related to seepage control, the yield of water-bearing strata, and coastal groundwater management. The test was performed as per IS-2720 [8]. The results are shown in Figure 4.

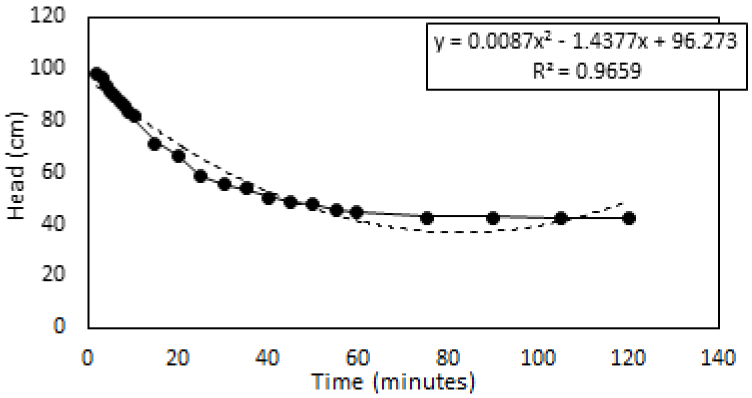

Figure 4. Falling of head for the time

Now the average flow velocity through soil can be calculated by using this expression. $v = \frac{h_{j-1} - h_{j+1}}{t_{j+1} - t_{j-1}}$. Where h is the true head expressed in meter and t is the time expressed in second. Table 1 shows the results of average flow velocity.

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Table 1. The calculation for average flow velocity

Time in minutes	Time in second, t = T x 60	Apparent head in cm, (H)	True head in m, h=(H–42.5)/100	Hydraulic Gradient, i= h/L	Average flow velocity through soil in m/s,
2	120	98.5	0.560	4.39906	
3	180	96.2	0.537	4.21838	0.000400
4	240	93.7	0.512	4.02200	0.000392
5	300	91.5	0.490	3.84918	0.000367
6	360	89.3	0.468	3.67636	0.000342
7	420	87.4	0.449	3.52710	0.000325
8	480	85.4	0.429	3.36999	0.000325
9	540	83.5	0.410	3.22074	0.000333
10	600	81.4	0.389	3.05577	0.000333
15	900	71.5	0.290	2.27808	0.000247
20	1200	66.6	0.241	1.89317	0.000218
25	1500	58.4	0.159	1.24902	0.000182
30	1800	55.7	0.132	1.03692	0.000082
35	2100	53.5	0.110	0.86410	0.000085
40	2400	50.6	0.081	0.63629	0.000078
45	2700	48.8	0.063	0.49489	0.000048
50	3000	47.7	0.052	0.40848	0.000052
55	3300	45.7	0.032	0.25137	0.000052
60	3600	44.6	0.021	0.16496	0.000023
75	4500	42.9	0.004	0.03142	0.000010
90	5400	42.8	0.003	0.02357	0.000002
105	6300	42.5	0.000	0.00000	0.000002
120	7200	42.5	0.000	0.00000	0.000000

3. Conclusion

The flow characteristics through the soil under the variable head are quite complex. For the lower hydraulic gradient, the flow pattern is linear. On the other hand, the flow pattern for higher hydraulic gradient exhibits nonlinear features. To carry out an in-depth study on the linear and nonlinear flow characteristics, a set of laboratory experimentations have been conducted with locally available saturated soil. The study reveals that the hydraulic gradient gradually reduced following a curvilinear pattern with increasing time with ascending slope and diminished at 4500 s. At lower hydraulic gradients, a linear correlation between the parameters *i* and *v* were served, which implies Darcy's flow. For higher values of hydraulic gradients, a parabolic correlation of the order of 2 was noted, conforming to Forchheimer's flow. The value of the critical Reynolds Number was evaluated as 1.11×10^{-2}.

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Conflicts of Interest
The authors declare no conflict of interest.

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