International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 2, February 2014

Assessing the Suitability of Various Materials for Improving Subsurface Drainage

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Abstract: ***Indian Road Network has a major problem of drainage. Permeability is the main property for proper drainage. Most of the roads in India deteriorated due to improper drainage. Thus, the present study has been conducted to investigate the variation of permeability (k) with porosity (n) at different depths of various materials used in construction of road. The soil in the study segment stretch has been excavated and replaced with three new layers of materials consisting of sand, gravel sub-base (G.S.B) and wet mix to increase permeability. For the purpose of analysis eleven numbers of samples were collected. Sieve analysis of two excavated soil samples was carried out to give us an idea about the type and gradation of soil. For the rest of the remaining nine samples hydraulic tests was carried out in a permeameter to determine the values of permeability (k) and porosity at different depths of various material used in construction of roads. Specific gravity for different materials was also computed. Numbers of equations were developed to find relationship between permeability (k) and porosity (n). The equations developed can be used to estimate permeability and porosity at different depth. The results from the study indicate high correlation between permeability and porosity.***

Keywords: Hydraulic test, Porosity, Permeability, Road network, Sieve analysis and Specific gravity

1. Introduction

India stands next in line to United States in highways and road networks on the planet, exceeding the total length of 4.7 million kilometers [1]. Indian Road Network has a major problem of drainage. Permeability is the main property for proper drainage. Most of the roads in India deteriorated due to improper drainage. Moisture in the soil subgrade causes considerable lowering of its stability. When load is applied on the road having moisture in the subgrade, cracks appeared on the top of the road surface. The present study has been conducted on a stretch of road 3.5 km long under construction, from junction of sector 73/74 to NH-21 (Chandigarh-Kharar road) to investigate the variation of permeability (k) with porosity (n) at different depths of various materials used in construction of roads. The soil in the study segment stretch has been excavated and replaced with three new layers of materials consisting of sand, gravel sub-base (G.S.B) and wet mix to increase permeability as shown in figure 1.

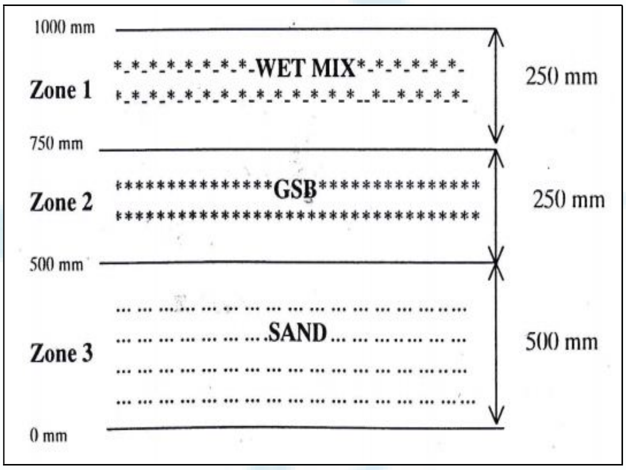

Figure 1: Cross-section of highway

The subgrade is situated in excavation. Site was cleared off all the top soil consisting of grass and other organic matters. To bring the vertical profile of the subgrade to designed camber and grade, grading operation was done. . After this new materials were laid on the subgrade.

Sand was laid in a two layer of 250 mm; Gravel sub base (GSB) and wet mix were also laid, in two layers of 125 mm each. Each layer of new material was compacted with vibrators and the required quantity of water was added at Optimum Moisture Content (OMC). Thus, for the present study 11 numbers of samples were collected from the sight at different levels.

Table 1: Samples collected from the sight

Sample No.	Type of material	Depth (mm)
1	Excavated soil	
2	Excavated soil	
3	Sand Sample	0-200
4	Sand Sample	300-500
5	Sand Sample	200-300
6	GSB	680-750
7	GSB	600-680
8	GSB	500-600
9	Wet Mix	930-1000
10	Wet Mix	750-850
11	Wet Mix	850-930

2. Experimental Setup

The various equipments used in the experimental work are as follows:

2.1 Permeameter

The constant head vertical flow type permeameter were used for hydraulic tests as shown in Figure 2.

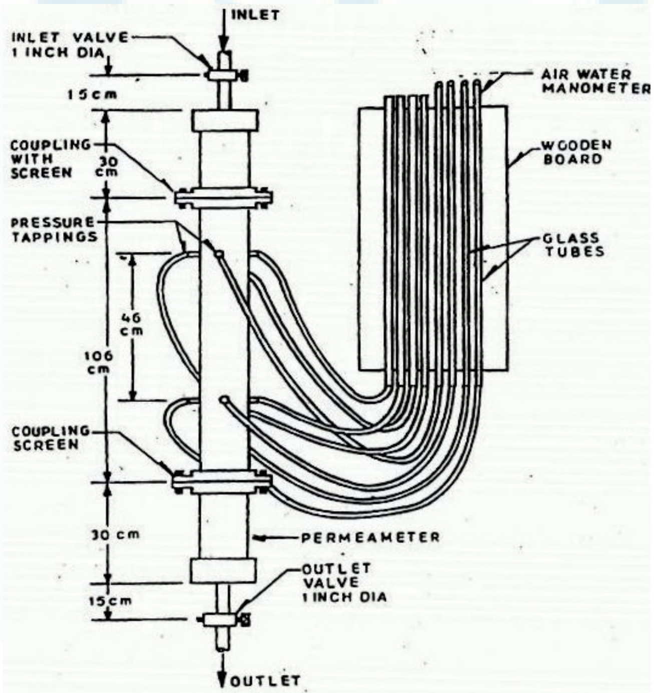

Figure.2: Details of Permeameter set-up

Permeameter with internal diameter (d) 10.16 cm and test length (L) of 46.5 cm were used to perform experimental work. The total length was 1.06m for permeameter. Four, pressure-taping each making an angle of 90° with other was provided along the circumference of permeameter at the starting and end point of test length. This arrangement of tapping points was adopted to ensure the means pressure at section under consideration. Water enters into permeameter through an inlet pipe of 1 inch in diameter. Rate of flow of water through permeameter was regulated with the help of an outlet tap of 1/2 inch diameter. IS 300 mm mesh was used as filter on IS 2 mm mesh screen for resting the test materials. For filling and removing of material, permeameter was detached from its support each time.

2.2 Discharge measuring device

The discharge was measured by volumetric method. The volume of water was collected in a measuring flask for a certain period of time with the help of a stopwatch. The volume of water collected divided by the time gives the discharge.

2.3 Manometers

Simple graduated glass tubes connected with the pressure tapping points on the permeameter with rubber tubes were used as manometers to measure head losses of about 5 cm to 100 cm of water. The manometers have a least count of 5 mm of water.

2.4 Pycnometer

IS Pycnometer was used to carry out the specific gravity tests on the samples.

2.5 Weighing balance

Two types of balances were used

a. Spring Balance- spring balance of 10 kg capacity was used to weigh the sample before placing it in the permeameter.
b. Electronic Balance- electronic balance was used for weighing the fraction of material.

2.6 Thermometer

Mercury based thermometer for a range of temperature 0°C to 80°C was used for temperature recording.

2.7 Source of Supply

The permeameter receives its water supply from an overhead tank at a height of 2.65 m above permeameter out let. The tank receives its supply from a re-circulating tank so that constant head is maintained in the overhead tank [2].

3. Methodology

3.1 Specific Gravity Test

The specific gravity tests were conducted on material to know the porosity of the material to be filled in permeameter for hydraulic test. The tests were carried out using Pycnometer method and following equation was used for calculating specific gravity G_s [3].

$$G_s = \frac{(W2 - W1)}{(W2 - W1) - W3 - W4)}$$

Where,
W_1 - weight of empty Pyconmeter
W_2 - weight of Pycnometer + dry material
W_3 - weight of Pycnometer + material + water
W_4 - weight of Pycnometer + water

3.2 Hydraulic Test

The hydraulic test were conducted to study the resistance to the flow of water offered by a given sample material in a particular diameter of permeameter. The method of carrying out these are as follows:

Each of the samples was tested in 10.16 cm internal diameter vertical flow constant head permeameter. Twelve kilogram of samples was used for each test run. Each time the required quantity of material is weighed in 10 equal parts. Each part of sample is give 20 blows in the permeameter before placing the next layer over it. The height of the sample in the permeameter is noted down. After packing the tool and leveling the top of the material, the coupling was fitted. After fixing the permeameter in vertical position and connecting it to the water supply the inlet and outlet valves were completely opened to make the material fully saturated for about 12 hours. Then outlet valves were slowly closed so that the water entered in the manometer tubes. After this the discharge using the outlet valve and corresponding pressure drop readings for the test length of the sample were recorded from the manometer [4].

3.3 Evaluation of k and n

After conducting all the above steps, values of k and n were calculated and are shown in table 2.

- Permeability (k)

v = k. i

Where,

k = coefficient of permeability
v = one dimensional velocity of flow
or v = Q / A

Where, A (area) = πr^2 = 81.07cm^2 and Q = Discharge per unit time

i = hydraulic gradient = (Avg. of upper head - Avg. of lower head)/L

- Porosity (n)

$$n = 1 - \frac{W}{\gamma V G s}$$

Where,

W = Total weight of sample
γ = unit weight of water = 1000 kg / m^3
G_s = specific gravity

Table 2: Value of k and n with relation to depth (D)

SN.	Samples	Average Specific gravity (G_s)	Permeability, k (mm/sec)	Porosity, n (%)	Depth, D (mm)	Avg. Depth (mm)
1	Sample No. 3	2.219	0.15	0.1598	0-200	100
2	Sample No. 4	2.29	0.0764	1.26	300-500	400
3	Sample No. 5	2.415	0.0923	0.133	200-300	250
4	Sample No. 6	2.29	0.6875	0.0853	680-750	715
5	Sample No. 7	2.225	0.705	0.107	600-680	640
6	Sample No. 8	2.3275	0.125	0.15	500-600	550
7	Sample No. 9	2.2	0.9175	0.143	930-1000	965
8	Sample No. 10	2.435	0.99	0.186	750-850	800
9	Sample No. 11	2.223	0.09275	0.152	850-930	890

4. Results and Discussion

Based upon the calculated values of k, n and D in table 2, various graphs were plotted as shown in Figure 3, 4 and 5 below. Numbers of equations were developed to find relationship between permeability (k), porosity (n) and depth (D) as shown in table 3. The equations developed can be used to estimate permeability and porosity at different depths. The results from the study indicate high correlation between permeability and porosity.

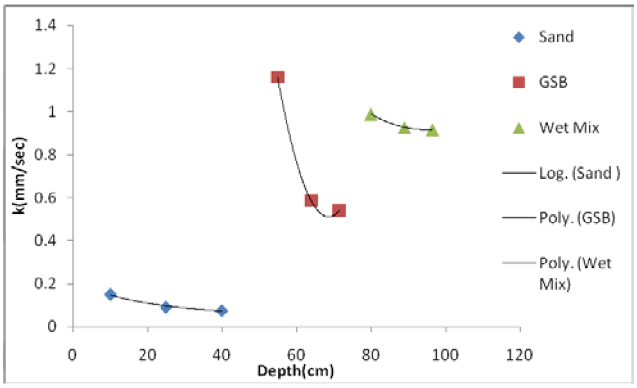

Figure 3: Plot between Depth and k

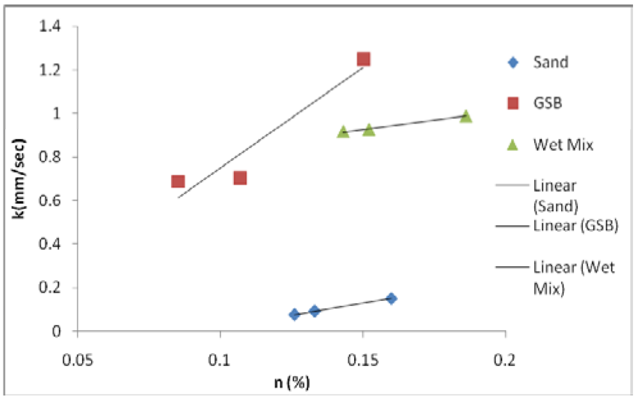

Figure 4: Plot between n & k

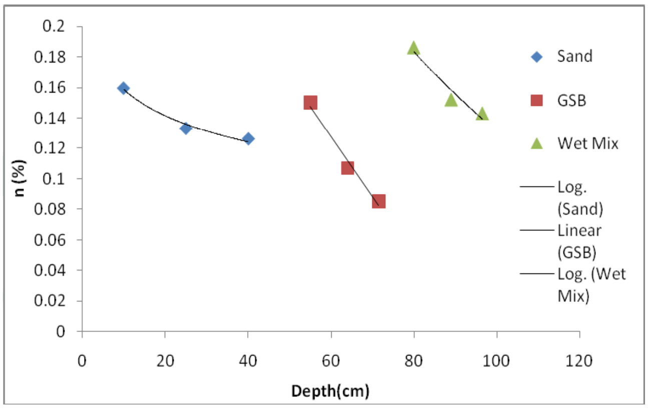

Figure 5: Plot between Depth & n

Table 3: Statistics of Model fitted

SN.	SAMPLES	MODEL FITTED	EQUATIONS	STATISTICS		REMARKS
				r	R^2	
1	k vs. Depth (D) in sand samples Nos. (3,4,5)	a) Linear b)Logarithmic c) Polynomial d) Power	$k = -0.0025\ D + 0.1676$ $k = -0.0544\ \ln(D) + 0.2734$ $k = 9E - 0.5\ D^2 - 0.0071D + 0.2117$ $k = 0.4623\ D^{-0.4926}$	0.9747 0.9955 1 0.9989	0.9029 0.9824 1.0 0.9958	Logarithmic model is fitted
2	k vs. Depth (D) in GSB samples Nos. (6,7,8)	a) Linear b)Logarithmic c) Polynomial d) Power	$k = -0.0386x + 3.2135$ $k = -2.459\ln(D) + 10.953$ $k = 0.0035D^2 - 0.4805\ D + 17.001$ $k = 19980\ D^{-3.025}$	0.9503 0.9583 1 0.9754	0.8458 0.8715 1.0 0.8919	Polynomial model is fitted
3	k vs. Depth (D) in wet mix samples Nos. (9,10,11)	a) Linear b)Logarithmic c) Polynomial d) Power	$k = -0.0045\ D + 1.3413$ $k = -0.3969\ \ln(D) + 2.7233$ $k = 0.0003\ D^2 - 0.0644\ D + 3.9668$ $k = 6.0935\ D^{-0.4182}$	0.2839 0.9747 1 0.9754	0.0065 0.9028 1.0 0.9055	Polynomial model is fitted
4	k vs. Porosity (n) in sand samples Nos. (3,4,5)	a) Linear b)Logarithmic c) Polynomial d) Power	$k = 2.1707\ n - 0.1968$ $k = 0.3109\ \ln(n) + 0.72$ $k = -3.5042\ n^2 + 3.179n - 0.2685$ $k = 25.109\ n^{2.7895}$	0.9999 0.998 1 0.9991	0.9999 0.994 1.0 0.9968	Linear model is fitted
5	k vs. Porosity (n) in GSB samples Nos. (6,7,8)	a) Linear b)Logarithmic c) Polynomial d) Power	$k = 9.2543\ n - 0.1751$ $k = 1.0444\ \ln(n) + 3.1762$ $k = 183.43\ n^2 - 34.467\ n + 2.2929$ $k = 9.6722\ n^{1.1085}$	0.9761 0.9630 1 0.9649	0.9079 0.8603 1.0 0.8671	Linear model is fitted
6	k vs. Porosity (n) in wet mix samples Nos. (9,10,11)	a) Linear b)Logarithmic c) Polynomial d) Power	$k = 1.728\ n + 0.6679$ $k = 0.282\ \ln(n) + 1.4671$ $k = 16.91\ n^2 - 3.8773\ n + 1.1262$ $k = 1.6319\ n^{0.2977}$	0.9986 0.9976 1 0.9783	0.9948 0.9908 1.0 0.9916	Linear model is fitted
7	Porosity (n) vs. Depth (D) in sand samples Nos. (3,4,5)	a) Linear b)Logarithmic c) Polynomial d) Power	$n = -0.0011\ D + 0.1678$ $n = -0.025\ \ln(D) + 0.2165$ $n = 4E - 0.5\ D^2 - 0.0033\ D + 0.1887$ $n = 0.2379\ D^{-0.1754}$	0.5586 0.9949 1 0.9963	0.8974 0.9799 1.0 0.9854	Logarithmic model is fitted
8	Porosity (n) vs. Depth (D) in GSB samples Nos. (6,7,8)	a) Linear b)Logarithmic c) Polynomial d) Power	$n = -0.0039D + 0.3649$ $n = -0.2488\ln(D) + 1.145$ $n = 0.0001D^2 - 0.0184D + 0.8148$ $n = 845.2D^{-2.156}$	0.9954 0.9975 1 0.9996	0.9818 0.9903 1.0 0.9994	Linear model is fitted
9	Porosity (n) vs. Depth (D) in wet mix samples Nos. (9,10,11)	a) Linear b)Logarithmic c) Polynomial d) Power	$n = -0.0026D + 0.3944$ $n = -0.234\ln(D) + 1.2084$ $n = 0.0002D^2 - 0.0302D + 1.6006$ $n = 95.383D^{-1.427}$	0.9815 0.9849 1 0.9877	0.9281 0.9412 1.0 0.952	Logarithmic model is fitted

5. Conclusion

As permeability being one of the important properties of drainage, numbers of relationship between permeability (k), porosity (n) at various depths of different new materials in the subgrade has been determined. Thus, results from the study indicate that the in-situ materials comprising mostly of clay layers need to be replaced with sand, gravel sub base and wet mix which offers adequate drainage.

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