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Research Article

FABRICATION OF PERMEAMETER FOR TESTING IN LABORATORY AND EVALUATION OF PERMEABILITY IN BITUMINOUS CONCRETE MIX

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ABSTRACT

Permeability is the hydraulic property of the porous material which is the measure of durability. Since water is the enemy of bituminous topped pavement because when rain water infiltrates and percolate through the pores, break down the bonding between bitumen and aggregate. Ultimately pavement fails before service life. It is well aware that bitumen mixture at different air voids content represents different permeability characteristics for the different composition of bitumen. In order to measure permeability of bituminous mixture, an instrument was fabricated which follows the Darcy's falling head method. Permeameter is designed in such a way that it can consist of Marshall's sample and tested in the lab. This equipment is capable to measure vertical as well as horizontal permeability. It was found that the horizontal and vertical permeability varied largely over the entire range of air voids content. However, relationship between horizontal and vertical permeability ratio and percent air voids was established. Four types of asphalt mixtures for different composition namely BC 20mm aggregates, BC stone dust as filler, BC cement as filler and SDBC was used in the lab test for estimation of permeability. However, Composition of bitumen varied over 4.5%-7.0% and percent of air voids varied over 2%-8% on the basis of laboratory investigation of various asphalt mixtures. Permeability increases with increase of void ratio and found ratio of vertical and horizontal permeability is 1.12.

INTRODUCTION

Indian road transportation infrastructure is rapidly expanding with ambitious development of road networks. In India almost 98% of paved roads are flexible and most are having bituminous layers. The durability and long term satisfactory performance of pavements are always influenced and affected to a greater extent by the employed pavement ingredient materials and their inherent properties. Pavement drainage contributes largely to long-term pavement performance. Pavement undergo surface as well as sub surface egress during prolonged rain events. It is a well-known fact that water is the worst enemy of road pavement, particularly in expansive soil areas. Hence, permeability of the topping material is one of the most important parameter with reference to longer durability of the pavement. A material is said to be porous if it contains interstices. The porous material will be permeable when these interstices are interconnected. Permeability states that it is the property of a material, which permits flow of liquid thorough air voids presence in it.

For newly constructed flexible pavement, rain water infiltrate into the surface course and percolate through the pavement layers that lead to the damage of pavement and reduce the service life. Since average annual rainfall in Bihar is 1000mm to 1200mm. The infiltration of water in asphalt pavements promotes moisture damage primarily through damaging the binder cohesive bond and the adhesive bond between aggregates and binder. The design of bitumen concrete paving mixtures requires a balance between different mixture properties. Some of these mixture properties include permanent deformation, fatigue cracking properties, strength, modulus and durability. There has been extensive work in trying to optimize these different mixture properties to produce a combination of aggregate and bitumen, which will result in the maximum service life for the flexible pavement. Permeability has become a major concern in recent years among the bitumen paving community. It is important to have pavements that possess characteristics of low permeability, which would minimize the effects due to moisture damage and increase the service life of pavements. The first step in addressing the problems caused by the presence of water within pavement systems is quantifying the permeability of bituminous mixtures. Realizing the problem

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occurs in the bituminous mixtures, a laboratory study is initiated for determining permeability to investigate the water permeability characteristics of different bituminous mixtures. The aim of this paper are (i)To fabricate a permeameter based on Darcy's law for determining the permeability of Marshall Sample in the laboratory, (ii)To measure the vertical and horizontal permeability of SDBC and BC mixes, and(iii)To observe the effect of void ratio on permeability of bituminous concrete mixes.

Determination of Permeability

Permeability is a property that is important to pavement's durability. Measuring permeability with density will give a better indication of a pavement's durability besides density alone. The presence of water over the long periods in the pavement is directly or indirectly linked to early deterioration of pavements. Permeability or the hydraulic conductivity of the surface is, defined as the rate of flow of a fluid through a material having unit head, is usually based on Darcy's Law. Darcy had demonstrated experimentally that for laminar flow, in case of homogenous soil the velocity (v) is directly proportional to hydraulic gradient (i) i.e.

$V \propto i$, when the proportionality sign is removed, a constant k arrive which is known as the constant of permeability i.e. $v = ki$.
Falling head formula for determination of permeability is indicated in eqn.1.

$$k = \frac{aL}{At} \ln \frac{h1}{h2} \quad (1)$$

Where, k = coefficient of permeability in mm/s,L = thickness of the bituminous mix sample in mm, A = cross- sectional area of the test sample in mm^2,a = cross- sectional area of the graduated cylinder in mm^2,t = time in seconds,h_1 = initial head and h_2 = final head. Norambuena-Contreras *et. al. (*2013) propose drange of permeability and their rating (Table 1) along with permeability of different asphalt mixes (Table 2).

Table 1 Description of permeability over different ranges

Permeability Range ($\times 10^{-5}$ cm/s)	Description
0.1 to 1	Very low permeability
1 to 10	Low Permeability
10 to 100	Moderate Permeability
100 to 1000	Permeable to draining
1000 to 10000	Moderate free draining
>10000	Free draining

Table 2 Range and Description of Permeability

Asphalt mixtures	Permeability (in cm/s)				Permeability description as per Table 1
	Average	Standard deviation	Minimum	Maximum	
Dense	5.2×10^{-6}	0.134	1.9×10^{-7}	8.5×10^{-5}	Very low
Semi-dense	1.4×10^{-5}	0.312	2.2×10^{-6}	1.1×10^{-4}	Low
Porous	3.0×10^{-2}	0.271	2.6×10^{-3}	3.8×10^{-1}	Moderate free draining

Fabrication of Permeameter

Permeameter is fabricated using (i) Measuring Cylinder – A measuring cylinder made of transparent plastic having internal diameter 8.5 cm, external diameter 9 cm and volume capacity 2000 ml was installed above the steel rim. The measuring cylinder can be used to measure the initial head of water and then final head of water, (ii) Stand and base – A cylindrical iron stand along with a circular iron base is used to support the permeameter and the bituminous mix sample, (iii) Steel rim and plate–The arrangement of plate and steel rim holds the bituminous sample in position and allows the measuring cylinder filled with water to stand over it,(iv) Paraffin wax – It is not a structural component of the permeameter but it is used to seal the lateral sides of the bituminous sample when the vertical permeability is being determined and vice- versa. Sometimes silicon sealant gel is used to seal any leakage of water between the steel rim and the measuring cylinder,(v)Glass jar – A small, calibrated glass jar of volume capacity 100 ml was used to collect the water that flows through the sample.(Fig.1)

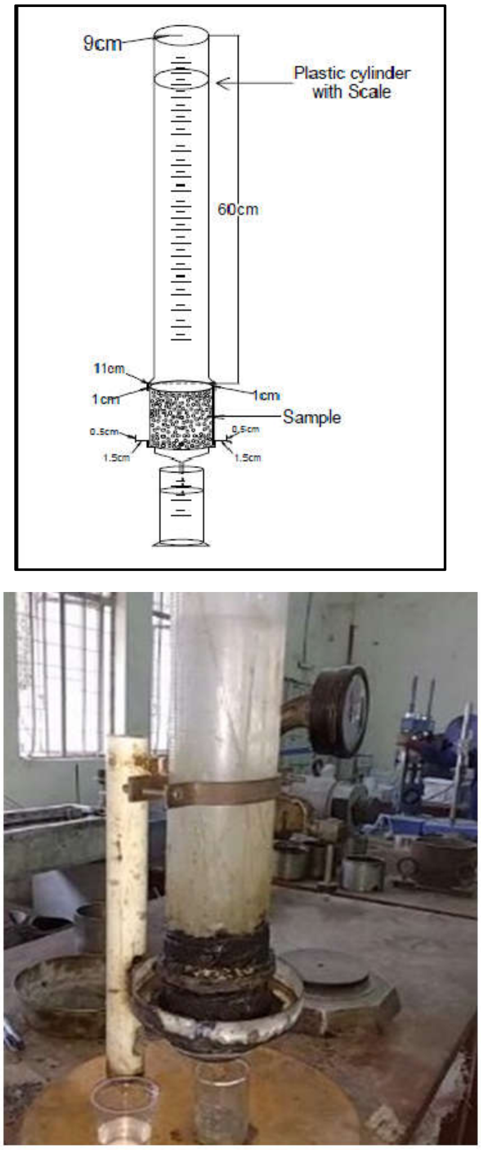

Figure 1 Permeametersketch (left) and actual (right)

MATERIALS AND METHODS

Materials used for preparation of bituminous mix samples are aggregates (20mm down and 10mm down), sand (zone III), PPC cement and stone dust. Cement and stone dust is used as filler and bitumen of VG30 grade is used as a binder. Properties of aggregates and bitumen are shown in Fig.3-4.

Table 2 Physical properties of aggregates

Property	Result	Method	Specification
Flakiness and elongation Index	24.76%	IS: 2386 (P-1)	< 30%
Toughness	12.66%	IS:2386(P-1V)-1997	< 30%
Hardness	16.42%	IS:2386(P-1V)-1997	< 30%
Strength	24.824%	IS:2386(P-1V)-1997	< 30%
Specific gravity	2.824	IS:2386(P-111)-1997	2.50 - 3.2
Water absorption	1.63%	IS:2386(P-111)-1997	< 2%

Table 4 Properties of bitumen

Properties	Result	Ranges
Penetration value	63mm	63mm
Specific gravity	1.0	0.98-1.02
Softening point	48.25 °C	40-60 °C
Ductility value	77.50 cm	Min 40 cm
Viscosity value	50.1sec	--
Flash Point	280 °C	>65-175 °C
Fire Point	302 °C	

Marshall Mould specimens (10cm diameter and 6cm height)are prepared for Semi dense bituminous concrete (SDBC) and bituminous concrete (BC). Gradation and temperature specified in MORTH is followed for both mixes. To see the effect of voids on permeability, different material combinations are taken into account. The different types of bituminous mix samples are prepared using different constituents namely (i) Aggregates, Sand, Bitumen and Cement,(ii)Aggregates, Sand bitumen and Stone dust and (iii) Aggregates, Sand and bitumen. In addition to the above combinations, different proportions of aggregates, sand and bitumen were also considered.

The paraffin wax coated bituminous mix sample is placed on the plate of the permeameter such that its top surface fits into the steel rim. The measuring cylinder is placed over this steel rim. The gap between the measuring cylinder and the steel rim was sealed with the silicon sealant to prevent any leakage of water. This ensures that water flows only through the bitumen. Water is poured in the measuring cylinder upto a specified height to provide a given head. The amount of water flowing through the bituminous mix sample was noted in every 60 minutes. Three such readings were taken and noted for each specimen; the permeability value is calculated after 60 minutes, 120 minutes, and 180 minutes duration. The above procedure was repeated for the different samples prepared, and the permeability values of these specimens are noted.

RESULT AND DISCUSSIONS

The coefficient of permeability (k) measured by fabricated permeameter for different bituminous mix samples. The fabricated permeameter worked on the principle of Darcy falling head and used to measure in the laboratory. Vertical permeability (k_v) measured after sealing the horizontal surface and horizontal permeability (k_h) measured after sealing the vertical bottom surface of the cylindrical samples. Falling head is measured up to three hours at interval of one hour and permeability is calculated using Eqn.1.Average of three hours is reported as permeability of the samples. It has been seen that there is no significant values obtained after three hours. Since permeability decreases in every hour due to the fall of water head.

The effect of air void on both the types of permeability is investigated for four different bituminous mix samples. Effect of air void on vertical and horizontal permeability for SDBC is shown in Figure 2.It has been observed that vertical permeability is higher than horizontal permeability within air void of 2-5%. Permeability increases with increase of air voids and follow the same trend line. Power trend line is fitted using MS Excel that shows the good fit with R^2=0.851 for k_v and R^2=0.886 for k_h. The transform relationship between air void (V_A) and permeability (mm/sec) is indicated in Eqn.2 and 3.

$$\ln(k_v) = 1.470 \ln(V_A) - 12.710 \quad (2)$$
$$\ln(k_h) = 1.552 \ln(V_A) - 13.122 \quad (3)$$

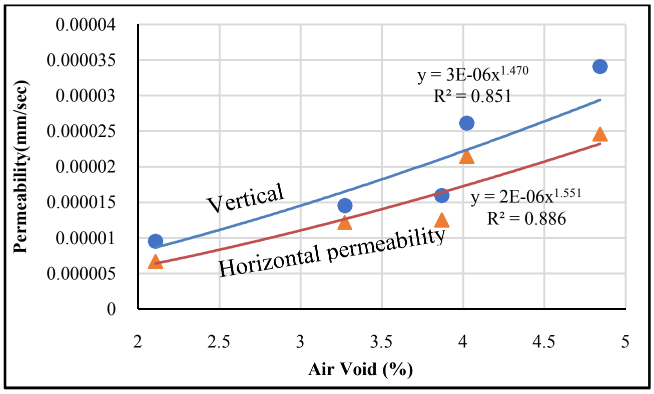

Figure 2 Effect of Air void on vertical and horizontal permeabilityf or SDBC

Effect of air void on vertical and horizontal permeability for BC is shown in Figure 3.It has been observed that vertical permeability is higher than horizontal permeability within air void of 4.5-8.5%. Permeability increases with increase of air voids and follow the same trend line. Power trend line is fitted using MS Excel that shows the good fit with R^2=0.923 for k_v and R^2=0.876 for k_h. The transform relationship between air void (V_A) and permeability (mm/sec) is indicated in Eqn.4 and 5.

$$\ln(k_v) = 1.211 \ln(V_A) - 10.819 \quad (4)$$

$$\ln(k_h) = 1.266 \ln(V_A) - 10.819 \quad (5)$$

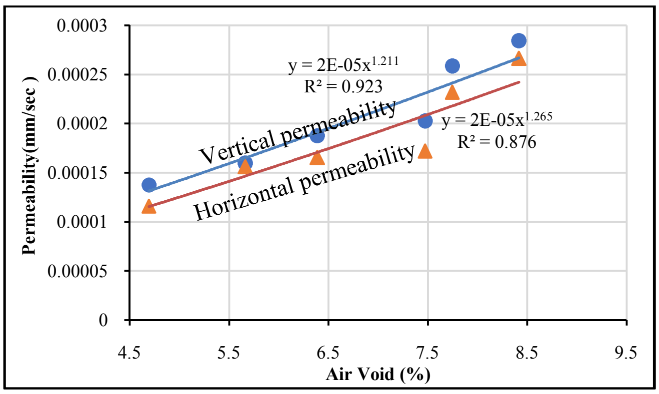

Figure 3 Effect of Air void on vertical and horizontal permeability for BC

Effect of air void on vertical and horizontal permeability for BC with cement as filler is shown in Figure 4.It has been observed that vertical permeability is higher than horizontal permeability within air void of 3.8-7.6%. Permeability increases with increase of air voids and follow the same trend line. But, permeability is same at air void of 3.6% and difference of permeability increases with increase of air void. Power trend line is fitted using MS Excel that shows the good fit with R^2=0.847 for k_v and R^2=0.955 for k_h. The transform relationship between air void (V_A) and permeability (mm/sec) is indicated in Eqn.6 and 7.

$$\ln(k_v) = 1.508 \ln(V_A) - 12.717 \quad (6)$$

$$\ln(k_h) = 1.106 \ln(V_A) - 12.206 \quad (7)$$

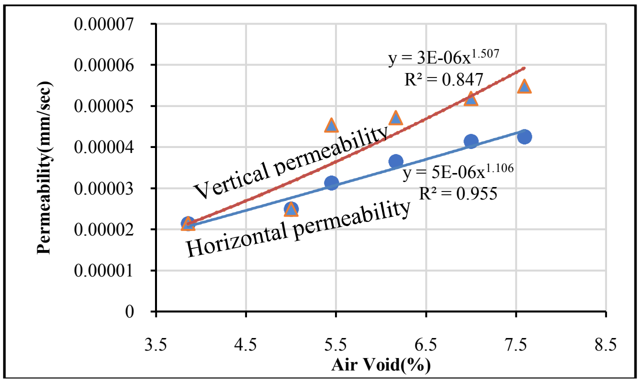

Figure 3 Effect of Air void on vertical and horizontal permeability for BC with cement

Effect of air void on vertical and horizontal permeability for BC with stone dust as filler is shown in Figure 5.It has been observed that vertical permeability is higher than horizontal permeability within air void of 3.4-7.0%. Permeability increases with increase of air voids and follow the same trend line. But, permeability is almost same at air void of 7% and difference of permeability decreases with increase of air void. Power trend line is fitted using MS Excel that shows the good fit with R^2=0.538 for k_v and R^2=0.865 for k_h. The transform relationship between air void (V_A) and permeability (mm/sec) is indicated in Eqn.8 and 9.

$$\ln(k_v) = 0.304 \ln(V_A) - 10.126 \quad (8)$$

$$\ln(k_h) = 0.874 \ln(V_A) - 11.513 \quad (9)$$

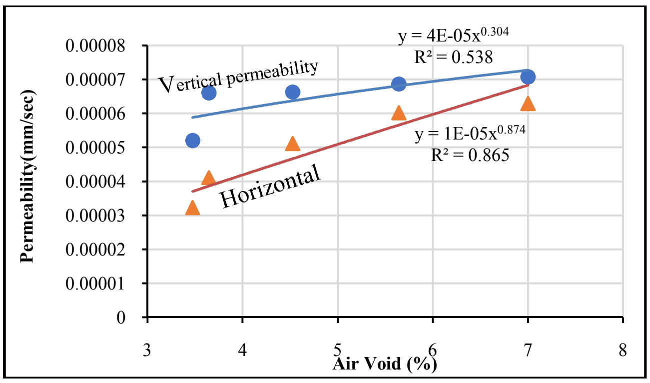

Figure 4 Effect of Airvoid on vertical and horizontal permeability for BC withstone dust

VALIDATION OF RESULTS

Descriptive statistics of measured permeability and predicted permeability is given in the Table 5. In order to validate the results, all the results are combining. So, total number of test data is twenty two. Measured vertical and horizontal permeability, conforming the permeability values obtained by the researchers as shown in Table 1 and 2.Also, permeability predicted by using Eqn. 2-9 for different mixes are combined for descriptive statistics. Minimum value of measured horizontal permeability is slightly more than predicted permeability while predicted vertical permeability is slightly more than measured vertical permeability. Whereas, maximum value follows the vise-versa results. Therefore, measured as well as predicted permeability conform the permeability range sated in the Tables 1 and 2.

Table 5 Comparison between measured and predicted permeability

Descriptive Statistics	Air Void (%)	Measured permeability		Predicted permeability	
		Horizontal (in cm/sec)	Vertical (in cm/sec)	Horizontal (in cm/sec)	Vertical (in cm/sec)
Total numbers of test data	22	22	22	22	22
Minimum value	2.107	0.7×10^{-6}	0.8×10^{-6}	0.6×10^{-6}	0.9×10^{-6}
Maximum value	8.416	2.66×10^{-5}	2.84×10^{-5}	2.96×10^{-5}	2.64×10^{-5}
Average value	5.355	0.76×10^{-5}	0.84×10^{-5}	0.83×10^{-5}	0.86×10^{-5}
Standard deviation	1.704	0.75×10^{-5}	0.83×10^{-5}	0.94×10^{-5}	0.79×10^{-5}

Comparison of vertical to horizontal permeability ratio

The vertical to horizontal permeability ratios for all the mixes are determined as shown in Figure 6.The average vertical to horizontal permeability ratios (k_v/k_h) are 1.24, 1.12, 0.84 and 1.36 for SDBC, BC, BC with cement and BC with stone dust respectively. But, when considered all the data together, the overall average vertical to horizontal permeability ratio is 1.13.It means flow of water in vertical direction is 1.13 times of horizontal direction.

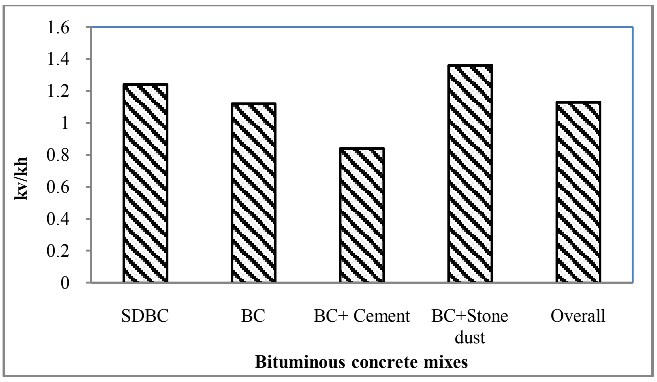

Figure 5 Comparison of kv/kh

Total Permeability

The total permeability value is a representation of the field permeability values. Total permeability (cm/sec) is represented based on horizontal permeability (k_h) in cm/sec and vertical permeability (k_v) in cm/sec as stated in Eqn.10.

$$k = \sqrt{k_v^2 + k_h^2} \quad (10)$$

Descriptive statistics for calculated total permeability value is shown in Table 6.This is compared with the formula proposed by researcher Jian-Shiuh Chen *et al*. (2004) as stated in Eqn.11. There is a significant difference was found. This may be due to the quality of material, gradation and void ratio in the mix.

$$\ln(\mathrm{k}) = 0.432(\mathrm{V_A}) - 13.386 \qquad (11)$$

Table 6 Comparison of permeability values

Descriptive Statistics	Air Void (%)	Permeability using Eqn.10 k (in cm/sec)	Permeability using Eqn.11 k (in cm/sec)
Total numbers of test data	22	22	22
Minimum value	2.107	1.0×10^{-6}	2.0×10^{-6}
Maximum value	8.416	3.89×10^{-5}	0.40×10^{-5}
Average value	5.355	1.14×10^{-5}	0.30×10^{-5}
Standard deviation	1.704	1.11×10^{-5}	0.15×10^{-5}

The effect of air void on total permeability is shown in Figure 7 and relationship established between them as indicated in Eqn.12. The coefficient of determination (R^2) is little bit less so reliable sufficient data are required.

$$\ln(k) = 2.253\ln(V_A) - 13.122 \qquad R^2=0.5998 \qquad (12)$$

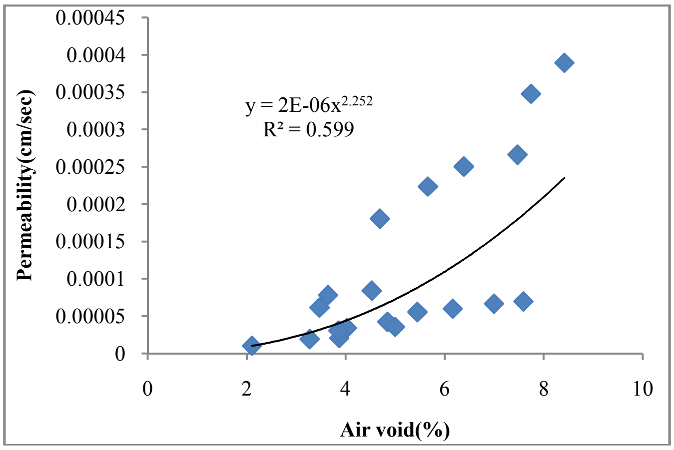

Figure 6 Permeability v/s air void

CONCLUSIONS

The permeameter is fabricated based on Darcy's law for falling head method to determine the vertical and horizontal permeability of the bituminous mix of marshal sample in the laboratory. The permeability obtained is validated using the table prescribed by Norambuena-Contreras et. al. (2013) and the correlation given by the Jian-Shiuh Chen *et al*. (2004).

It was found that permeability shows the good agreement. Vertical and horizontal permeability increases with increase of air-void. It is observed that vertical permeability is higher than the horizontal permeability. The permeability value lies in the air-void range 2-8%, indicates very low permeability for bituminous concrete mixes. It means pavement surface shallim pervious. The ratio of overall average vertical permeability and horizontal permeability is found to be 1.13.For determination of total permeability a relationship has been established in terms of air voids in percentage. The equipment for permeability testing of bituminous concrete sample is capable for measuring horizontal and vertical permeability in the laboratory. It is low cost and easy to operate and portable equipment. But, it required paraffin wax for sealing the sample surfaces or joint during measurement.

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