Low Cost Instrumentation for Testing Permeability of Bituminous Mixes

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***Abstract*—The bituminous mixes are often assumed by many researchers and field engineers as impermeable mixes or mixes with very low permeability. However many drainage problems occurring in pavements, distresses such as stripping, pothole formation are due to presence of water in the bituminous layer of pavements. Hence there is need to assess the permeability of the bituminous mixes with a suitable and low cost instrument. In the present study a permeability mould is fabricated and used along with the permeability apparatus used for testing soils. Tests are conducted to assess the suitability of the equipment in testing permeability of bituminous mixes by constant head and falling head method. Further a comparison is made as to whether the falling head method or the constant head method is more suitable for testing permeability of bituminous mixes**

***Keywords*—Permeability, Bituminous mixes, Permeameter, Constant head method, Falling head method**

I INTRODUCTION

Permeability of Bituminous mixes is a property that is important in defining the durability of the pavement and is also the one which is most neglected with respect to the measurement method and standard specification for quality control. The general opinion is that the pavement surface layer should be impermeable, thus protecting the structure from any surface infiltration. Also some researchers are of the opinion that some permeability is needed to help release the fluid that infiltrates the structure from the side and bottom surfaces. However, there is no quantification of as how to measure the permeability of bituminous mixes and what will be the range of permeability of bituminous mixes. Further the effect of voids, bulk density and gradation on the permeability of bituminous mixes is not clearly quantified. Adding to this is the directional property of permeability which is different in horizontal and vertical direction of flow. Therefore a study is required to develop a low cost instrument to measure the permeability of bituminous mixes in the lab and a suitable methodology for quantifying the range of permeability of the bituminous mixes

II. LITERATURE REVIEW

A. *Permeability*

Permeability can be defined as the ability of a porous medium to transmit fluid. Any material having continuous voids is called permeable media. The flow of water through any medium may be laminar or turbulent. Darcy's law forms the fundamental theory for flow of fluids. It states that " The rate of flow of water is proportional to the hydraulic gradient and area of the sample". The hydraulic gradient is defined as the head loss per unit length. The head loss increases linearly with the velocity of water transmitted through the medium as long as the flow of water is laminar. Once the flow of water becomes turbulent Darcy's law is invalid. Two general approaches are used to measure permeability of porous media – Constant head method and Falling head method.

B. *Permeability in Pavements*

It is generally accepted that the proper compaction of hot bituminous mix is vital for a stable and durable pavement. For dense-graded mixes numerous studies have shown that the initial in-place air void contents should not be below 3 percent or above approximately 8 percent. Low air void content have been shown to lead to rutting and shoving, while high air void content allow water and air to penetrate into the pavement resulting in an increased potential for moisture damage, ravelling and/or cracking. The size and interconnectivity of air voids have been shown to greatly influence pavement permeability.

C. *Critical Permeability Values*

Few research studies have drawn up certain guidelines for categorizing pavement sections according to the permeability values of their representative cores. The university of Arkansas as part of the AHTD's Transportation research project No. 82, "Asphalt mix permeability" categorizes the permeability range as shown in Table 1. The values are based only on the permeability coefficients, irrespective off the NMAS and density. The term 'critical' is used to infer the point at which pavement becomes excessively permeable.

Table 1 Critical Permeability Values by AHTD studies

Permeability Category	Permeability Range
High	$10^{1} – 10^{-4}$
Low	$10^{-4} – 10^{-6}$
Practically Impervious	$10^{-6} – 10^{-9}$

D. *Correlation between lab and field permeability*

It will be interesting to study the correlation between the lab and field permeability values. This is important as the mechanism of percolation of water is different in laboratory and field. In the lab Darcy's law of one-dimensional flow is applicable. However in the field the water flow is three dimensional. Also the degree of saturation, boundary conditions of flow, depth of the layer etc., affect the permeability values. These problems are not discussed in this research. The current research is limited to finding the permeability of the bituminous mix in the lab under one directional flow of water.

E. Method of measuring permeability

Generally there are two most popular methods of measuring permeability of soils. One is the Constant head method and the other is the Falling head method.

The constant head method works on the principle that the hydraulic head causing flow is maintained constant, the quantity of water flowing through a soil specimen of known cross-sectional area and length in a given time is measured. Although the method can be used for any type of soil, it is most suitable for relatively pervious soils. The permeability is obtained by the equation given below,

$$k = \frac{Q\,l}{t\,h\,A} \qquad \text{Equation (1)}$$

The falling head method works on the principle that water level in the stand-pipe falls continuously as water flows through the soil specimen. Observations should be taken after a steady state of flow has reached. The permeability is obtained by the equation given below,

$$k = \frac{2.303\ a\ L}{A(t_1 - t_0)} \log\left(\frac{h_0}{h_1}\right) \qquad \text{Equation (2)}$$

III. EXPERIMENTAL INVESTIGATIONS

The present investigation is aimed at fabricating mold assembly for permeability measurement, arriving at suitable methodology for measuring permeability of bituminous mixes in the lab and comparison of resultsmeasured by constant head and falling head methods

F. Fabrication of Mold assembly

The specimens generally prepared and tested in the lab are the Marshall specimens having diameter 101.6mm and standard height 63.5mm. These specimens are used for determining OBC, Indirect tensile strength, Tensile strength ratio as well as Fatigue resistance of bituminous mixes. Hence it will be logical to test the permeability of the same sample size. Hence, a permeameter mold of inner diameter 101.4mm and height 75mm was fabricated as shown below.

Figure 1: Mold for measuring permeability

This mold is fitted with permeability apparatus used for testing of soils. The final setup will be as shown below.

Figure 2: Final setup for testing permeability

G. Physical properties of materials used

The aggregates and bitumen used were obtained from a nearby Hot mix plant. The materials are tested for their suitability and the results are shown below.

TABLE 1: TEST RESULTS ON AGGREGATES

Sl. No	Property	Measured value	Specification as per MoRT&H
1	Aggregate Crushing value	24.03%	-----
2	Aggregate Impact value	23.12%	24% Max.
3	Combined Index	27.5%	30% Max.
4	Specific Gravity		
	Coarse aggregate	2.652	------
	Fine aggregate	2.70	-----
	Filler (cement)	3.01	-----

TABLE 2: TEST RESULTS ON 60/70 BITUMEN

Sl. No	Property	Measured value	Specification as per IS 73: 2002
1	Penetration at 25° C, 0.1,,	66.3	60 – 70
2	Softening Point, °C	53	40 – 55
3	Ductility at 27°C, mm	85	Min. 75
4	Flash point, °C	265	Min. 175
5	Fire point, °C	290	-----
6	Specific gravity	1.01	0.97 – 1.02

H. Gradation adopted

Bituminous concrete of nominal aggregate size 13.2mm is adopted for the mix as shown below

TABLE 3: ADOPTED GRADATION FOR MIX DESIGN (BC – 2)

Sieve size, mm	% Passing
19	100
13.2	79 – 100
9.5	70 – 88
4.75	53 – 71
2.36	42 – 58
1.18	34 – 48
0.60	26 – 38
0.30	18 – 28
0.15	12 – 20
0.075	4 – 10

I. Testing of Specimen – density voids analysis

The Marshall specimens are fabricated using standard Marshall methodat the lower, upper and mid limit of the above mentioned gradation. The specimens are prepared with varying compaction levels and allowed to cool for 24 hrs. After cooling period they are extracted, the height is measured at four places and averaged. The weight in air and weight in water are measured. Using these values the density voids analysis is carried out i.e., finding G_b, $\%V_v$, %VMA, %VFB. The results are presented below.

TABLE 4: DENSITY-VOIDS ANALYSIS OF MARSHALL SPECIMENS

NO	GRADATION	NO. OF BLOWS	BULK DENSITY g/cc	% VOIDS	% VOIDS IN MINERAL AGGREGATES	% VOIDS FILLED WITH BITUMEN
1	Lower limit	35	2.268	8.08	20.43	60.46
		50	2.288	7.29	19.75	63.09
		65	2.341	5.15	17.89	71.22
		75	2.360	4.37	17.22	74.60
2	Mid limit	35	2.281	7.56	19.98	62.17
		50	2.303	6.66	19.21	65.30
		65	2.336	5.35	18.07	70.40
		75	2.354	4.62	17.43	73.50
3	Upper limit	35	2.292	7.11	19.59	63.71
		50	2.314	6.22	18.82	66.96
		65	2.347	4.88	17.67	72.37
		75	2.361	4.34	17.2	74.77

J. Preparation of Specimen – Permeability testing

The Marshall specimens are prepared as per design gradation and binder content. The specimens are then sealed on the outside by a impervious membrane and then inserted into the mold. Any gap in between the specimen and the mold is sealed off with adhesive such that water flows vertically through the specimen. The mold with specimen is fitted with base plate and collar assembly and connected to water inlet pipe for testing.

K. Measurement of permeability – Constant and Falling head method

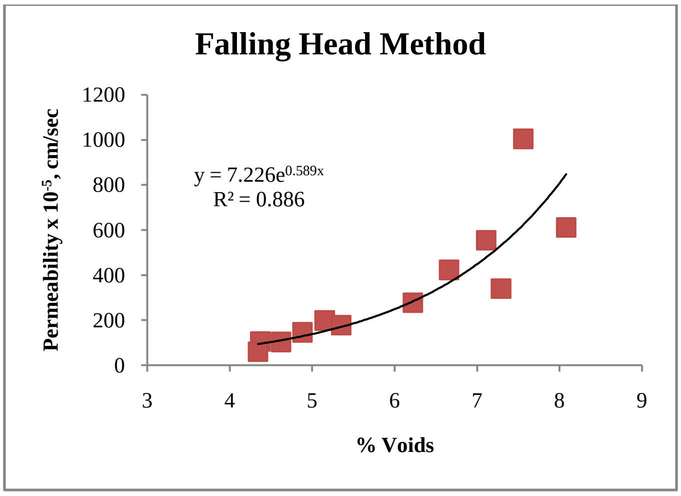
Once steady flow was established permeability readings were taken by both constant head and falling head method. Three trials were made and averaged for determining coefficient of permeability, cm/sec. the results are presented below.

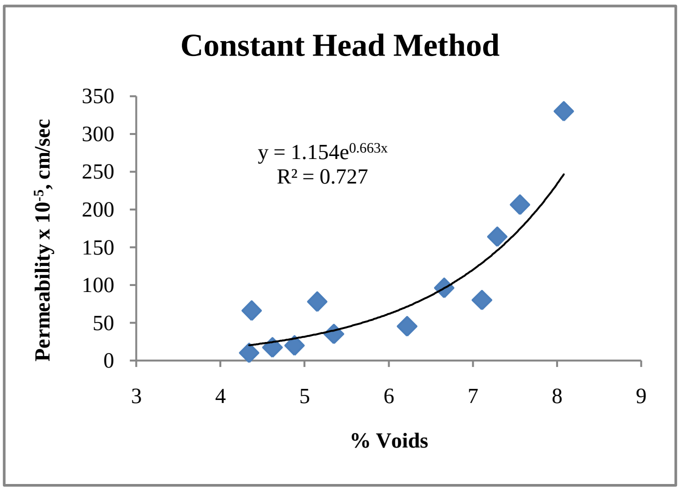
TABLE 4: PERMEABILITY VALUES OF SPECIMENS

NO.	% VOIDS	COEFFICIENT OF PERMEABILITY, x 10^{-5} cm/sec	
		FALLING HEAD METHOD	CONSTANT HEAD METHOD
1	8.08	610.83	329.93
2	7.29	339.63	164.13
3	5.15	198.04	77.77
4	4.37	105.4	65.94
5	7.56	1004.46	206.2
6	6.66	422.9	96.02
7	5.35	177.52	35.36
8	4.62	103.13	17.3
9	7.11	554.07	80.15
10	6.22	276.66	45.19
11	4.88	145.73	19.81
12	4.34	59.57	10.43

L. Comparison of Constant and Falling head method

From the above table it is found that both the methods give good results of permeability of bituminous mixes. It can be seen that as the voids ration decreases, the permeability values reduces in both cases. A graph is plotted as shown below.





It can be seen that the permeability varies exponentially with increase in air voids. This may be due to the fact that at higher voids, the interconnectivity between voids increases as result a more definite channel is established for flow of water in the bituminous mixes. Also it is found that Falling head method (R^2 = 0.886) is more useful in measuring permeability as compared to Constant head method (R^2 = 0.73).

IV. CONCLUSIONS

From the above study the following conclusion can be arrived at

1. The fabricated mold assembly can be used for testing permeability of Marshall specimens in the laboratory
2. Proper care has to be taken to seal the gap in between specimen and the mold such that water flows vertically through the specimen
3. The permeability increases exponentially with increase in air voids
4. The falling head method has higher correlation coefficient than constant head method for testing permeability of bituminous mixes

REFERENCES

[1] Kunnawee kamitpong, Robert Schmidt, Hussain bahla, Jeffrey Russell "Comparison of laboratory and field permeability of HMA mixtures" TRB 83 annual meeting

[2] G.W. Maupin Jr, "Investigation of test methods, pavements and laboratory design related to asphalt permeability" Virginia transportation research council, June 2000

[3] Bituminous materials in Road construction, HMSO publications

[4] Kevin D. Hall "Comparison of falling head and constant head techniques for estimating field permeability of HMA pavements" TRB 2004 annual meeting.

[5] Jørn Raaberg, Hans Bendtsen "Permeability of double-layer porous asphalt pavement" Danish Road Institute, Atkins Denmark.

[6] L. Allen Cooley Jr. E. Ray Brown Saeed Maghsoodloo "Development of critical and pavement density values for coarse graded pavements" NCAT report, Sep 2001