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Comparison of Laboratory and Field Permeability of Bitumen Mixes

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ABSTRACT

The primary objective of the present study is to determine general magnitude of permeability of bitumen mixes at different conditions. Additionally, the permeability characteristics of field-prepared field-compacted (FPFC) cored specimens are evaluated and compared with laboratory-prepared laboratory-compacted (LPLC) specimens. Field cores are extracted from on-going paving projects and evaluated for permeability using a fabricated falling head laboratory permeameter. Marshall Mix prepared in the laboratory as per the site specification and compacted with impact compactor at varying compactive efforts, and finally subjected to permeability testing. Results of the study are presented in terms of permeability-air voids relationship of FPFC and LPLC specimens. The findings are also useful to predict field permeability of bituminous mixes using permeability values determined in laboratory. Moreover, the effect of type of compaction is observed from differences in the permeability values of LPLC specimens. An attempt is also made to model permeability-air voids relationships using various models. The variation of the permeability characteristics of pavement in the lateral direction is also included in the scope of the project
Keywords—Permeability; bituminous mixes; compaction; air voids.

I. INTRODUCTION

A. General

India has a total land area of about 2,973,193 sq. km and it is ranked seventh in the world in terms of land area. Being a considerably large country with a huge population spread across its land mass spanning from 37º6'North to 8º4' South latitude and 97º25' East to68º7' West longitude, India has set-up a large road network to cater the transportation needs of such a large population. India has a considerably larger road network of 54 lakh km and which is second largest in the world. The spread and category of the road network in India can be seen in Table 1-1.

Table 1-1 Category of Roads in India as on 31st March 2015 (NHAI, 2015)

Category	Length of Road (km)	Share in total road length (%)
National Highways (NHs)	97,991	1.79
State Highways (SHs)	167,109	3.05
Other PWD (OPWD) Roads	1,101,178	20.12
Rural Roads	3,337,255	61
Urban Roads	467,106	8.54
Project Roads	301,505	5.5
Total	5,472,144	100

Owing to the huge diversities in the geographical terrain, India has a huge diversity of weather and climatic conditions in its regions where the temperature ranges from as high as 50 ºC in Alwar, Rajasthan to a whopping low of -45 ºC in Dras, Ladakh. The precipitation scenario in India also follows the same trend as that of the temperature, some regions receiving no annual rainfall to regions, which have an annual rainfall of about

11,872 mm in places like Mawsynram, Meghalaya that happen to be the wettest places on Earth. This heterogeneous weather and climatic conditions ranging pan India have led to some critical challenges in the field of Engineering. With a population of 1.3 billion, growing at 1.6 per cent per annum, India may have a population of 1.53 billion in the year 2030 (WPP, 2015). To reach out and have a positive effect on the lives of such huge population, India will require an astonishing connectivity for people and freight movement throughout the country. The success of any country depends upon the efficient transportation means, quality and density of the road networks in the country. Indian road transportation infrastructure is rapidly expanding and reaching the corners of the country with the ambitious development of road networks under National Highways Development Programme (NHDP), State Highways Improvement Programmes (SHIPs), Bharat Nirman, Pradhan Mantri Gram SadakYojana (PMGSY) etc. Further, other category roads and airports are being expanded largely. The fast growing Indian economy will further demand road transport network with a high-quality pavement structure as the main corridors are required to cater to very heavy traffic, both in terms of number and axle loading (MoSPI, 2016).

The pavement can be classified into flexible or rigid pavement depending upon the material used for its construction or way in which the load transfer occurs between the pavement layers. Roads network in India is mainly composed of flexible pavements. As the study deals with the bituminous mixes, further discussion will be regarding the flexible pavements only.

Bitumen pavements can be defined as the one consisting of a mixture of bitumen or bituminous material and aggregates placed on a bed of compacted granular material of appropriate quality in layers over the subgrade or the natural ground (PavementInteractive, 2016). The flexible pavements support and transfer loads through bearing action between aggregate-bitumen mixtures rather than flexural action as in the case of rigid pavements. Flexible pavements comprise of several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath. The design is such that it ensures proper load transmitted to each successive layer without exceeding the layer's load-bearing capacity. A typical flexible pavement. Flexible pavement are composed of surface course, base course, sub base course, subgrade layers.

Currently, the majority of the Indian roads are flexible pavements, the ones having bituminous layer/s. Initially, there used to be a scarcity of cement and India went for flexible pavements with bituminous toppings. Now, flexible pavement is preferred over cement concrete roads as it has a great advantage, that flexible pavement can be strengthened and improved in stages with the growth of traffic. Another major advantage of these roads is that their surfaces can be milled and recycled for rehabilitation. The flexible pavements are less expensive also with regard to initial investment and maintenance. Bitumen concrete roads constitute the majority of the paved road network in India. With the target of making over 90 percent of Indian roads bituminous, in the year2015 central government has allocated more than 10 percent of its total expenditure on roads development sector (Business-standard, 2015). Bitumen pavements are typically designed for 20 years. However, frequent failures are noticed in such pavements which could be attributed to several causes, such as, improper mix design, increased traffic volume, tire pressure and axle loading and deficiency in specifications. Major distress observed on bitumen pavements are: rutting, fatigue cracking and low temperature cracking. This distress occurs due to high temperatures combined with traffic loading, repeated load applications, aging, moisture damage and thermal stresses occurring due to daily/seasonal temperature cycle.

This template, modified in MS Word 2007 and saved as a "Word 97-2003 Document" for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughoutaconferenceproceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. OBJECTIVE OF STUDY EASE OF USE

The objectives of the study are as follows:

1. Evaluation of the field and laboratory permeability of the bituminous mixes.
2. Comparison of permeability of laboratory compacted bituminous mixes with field compacted mixes in laboratory and field conditions.
3. Developing correlation between various parameters of permeability.
4. Studying the lateral variation of permeability of bitumen pavements in field.

III. EXPERIMENTAL PLAN

A. General

This chapter deals with the experimental procedures adopted for the study.

B. Experimental methodology

The experimental work plan adopted for the study is as follows:

1. Collection of field cores
2. Testing of field cores in laboratory
3. Preparation of Material Mix Samples with approximate Same design as on site
4. Evaluation of lab permeability
5. Statistical analysis & formation.

C. Marshall Mix Preparation

- The coarse aggregates, fine aggregates and the filler material are proportioned in such a way that gradation of the mixture was provided for laying on site.
- The maximum permissible size of coarse aggregates for the preparation of Marshall stability test specimen is 25 mm.
- The aggregates and filler are mixed together in the desired proportion to fulfill the design requirements and the specified gradation.
- In the first attempt approximately 1200 g of the aggregates and filler mix is taken, weighed correctly and heated to a temperature of 175^0C to 190^0C.
- The compaction mould assembly and rammer are cleaned and kept pre-heated at a temperature of 95^0C to 150^0C.
- The bitumen binder is heated to a temperature of 120^0C to 165^0C.
- The required quantity of bitumen is calculated as per the mix design for the project.
- The weighed quantity of heated bitumen is added to the heated aggregate and the mixture is thoroughly mixed at the specified mixing temperature, using a hand mixer with trowel.
- After mixing thoroughly such that the surface of the aggregates are uniformly and fully coated with the binder, the bituminous mix may be allowed to slightly cool down to recommended compacting temperature.
- The mix is placed in the pre-heated mould and is compacted by the rammer at the specified temperature, by applying 75 blows on either side.
- After the compaction the specimen with the mould is allowed to cool down to the room temperature.
- After the bituminous mix with the mould is cooled, the test specimen is carefully extruded from the mould using the specimen extractor.

D.Job Mix Formula for Dense Graded Bituminous Macadam(DGBM)

The Job mix formula for proportioning the aggregates to satisfy the required gradation as per, MORTH Revision-2001 Specification is as shown in Table no. 3-1.The correspondence sieve analysis results and the obtained gradation using Job Mix Formula are tabulated in Table no. 3-2.

Table 3-1 Job Mix Formula for DGBM

Sl. No.	Materials	Proportion	Remark
1	26.5 mm down size aggregates, %	23	% by Weight of aggregate Mix
2	13.2 mm down size aggregates, %	12	
3	06 mm down size aggregates, %	26	
4	Crusher Dust	39	

Table 3-2 Sieve analysis and proportioning of aggregate mixture

Sieve Size, in mm	Cumulative Percentage by Weight of Total Aggregate Passing				Obtained Gradation	Gradation Requirement as per Table 500-10of MORTH Specifications (Grading-II)
	26.5 mm down size	13.2 mm down size	6 mm down size	Crusher Dust		
37.5	100	100	100	100	100	100
26.5	84	100	100	100	97	90-100
19	52	100	100	100	86	71-95
13.2	0	100	100	100	70	56-80
4.75	0	6	40	100	42	38-54
2.36	0	0	18	75	32	28-42
0.3	0	0	6	24	15	7-21
0.075	0	0	2	8	3	2-8

Table 3-3 Specific Gravity of Materials

Sl. No.	Materials	Value Obtained
1	26.5 mm down size aggregates,	2.68
2	13.2 mm down size aggregates,	2.70
3	6 mm down size aggregates,	2.71
4	Crusher Dust	2.75

Table 3-4 Volumetric and Marshall Properties

Sl. No	Bitumen %	Wt. in Air	Wt. in Water	G_b	G_t	V_v	V_b	VMA	VFB	Stability, Kgs	Flow mm
1	4.00	1228	703	2.339	2.55	8.23	9.45	17.68	53.45	1108	2.25
2	4.50	1232	706	2.342	2.53	5.26	10.65	15.91	67.86	1152	3.00
3	5.00	1234	708	2.346	2.51	4.02	11.85	15.87	74.67	1140	3.60
4	5.50	1227	703	2.342	2.49	3.26	13.01	16.27	79.96	1106	4.10

Table 3-5 Properties of DGBM Mix at 4.64% Optimum Binder Content

Sl. No.	Test property	Test results obtained by Marshall Method	Requirement of Dense Graded Bituminous macadam as per Table 500-11 of MORTH Specifications
1	Optimum Binder content, %(by weight of mix).	4.64	Minimum 4.5%
2	Bulk Density, gm/cc	2.35	---
3	Voids in Compacted Mix, %	4.26	3.0-6.0
4	Marshall Stability(at 60^0C), Kgs	1125	900
5	Marshall Flow at 60^0C, mm	3.26	2.0-4.0
6	Percentage voids filled with bitumen, %	69.70	65-75

E. Permeability Measurement Apparatus

The permeability of the bitumen mixes was evaluated in the laboratory. The equipment's used for measuring the field and laboratory permeability were fabricated according to the standards specified. The following equipments were used for the study:

F. Laboratory Falling Head Permeameter

Permeability of the bitumen mixes was evaluated in the laboratory using a falling head permeameter as shown in the Figure 3-1. This apparatus works on the principle of falling head.

Figure 3-1 Schematics of Laboratory Permeameter used for the study.

The steps involved in the measurement of the laboratory permeability are mentioned below:

i. The sample is kept for saturation by submerging it under water and applying vacuum pressure for half an hour at 4 KPa absolute pressure.
ii. The saturated sample is taken and the side of the sample is wrapped by a plastic strip or polythene.
iii. The sample is put into the sample holder and moldable putty is applied at the edges to prevent the side drainage.
iv. All the clamps are fastened ensuring no leakage.
v. The stand pipe is filled with water and all the air bubbles from the outlet pipe is removed.
vi. Then the outlet valve is opened and the time required to for the change in head (initial head (h_1) to final head (h_2)) is measured with the help of stopwatch.

vii. The test is repeated minimum three times for each sample.

The above assembly can be used to measure the permeability of high as well as medium porous bitumen mixes, but the setup takes very high amount of time to accurately measure the permeability of dense graded bituminous mixes. To overcome the limitations of the earlier assembly and to quickly and accurately be able to measure the laboratory permeability of the field cored or laboratory compacted dense mixes new assembly was fabricated which was similar to Karol warner falling head permeameter setup.

(a) Application of Binding Tape to Tighten the Apparatus and the Sample

(b) Rapping of Tape around the Sample (c) Pouring of Water in Falling Head Permeameter

Figure 3-2 Schematics of Steps Involved in Laboratory Measurement of Permeability

G. Field permeability measurement:

The selected site for the study was 5.5 m wide and the average thickness of the wearing course was 40 mm. The testing spots were selected on the centre and edges of the pavement. The field cores were taken from the same testing spot after field permeability measurement. These cores were further evaluated for laboratory permeability. The following figure shows the experimental setup for site testing.

(a) Before Laying process (b) After successful completion of laying and compaction

Figure 3-3 Actual Site of Study

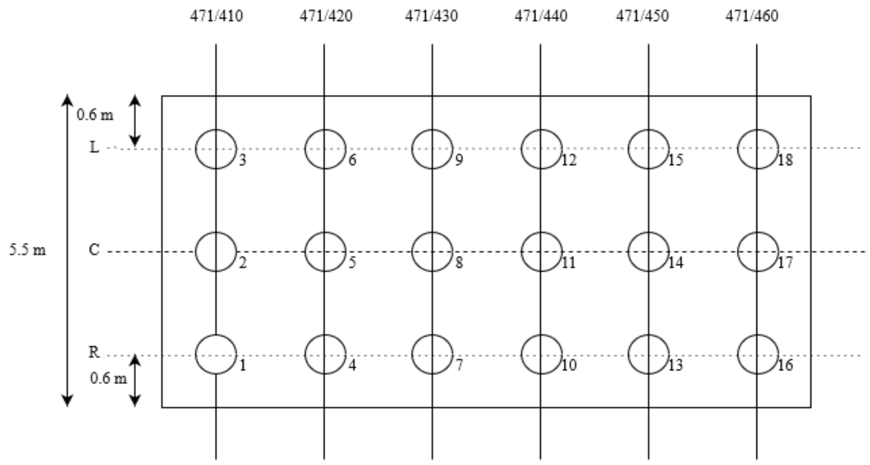
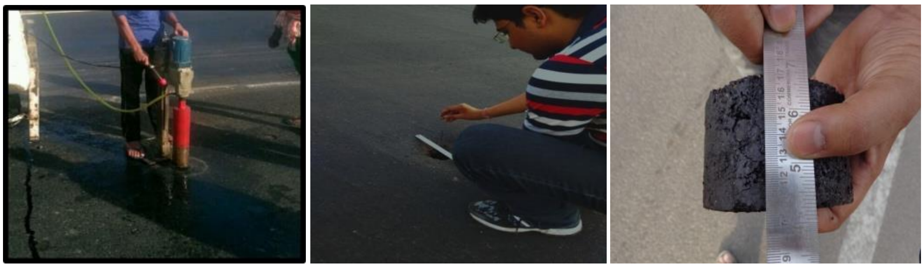


Figure 3-4 Schematics of the Experimental Site Plan Intended for the Study



(a) Field core being driven out **(b) Measurement of in field layer depth** **(c) Cross checking depth of the field cores**

Figure 3-5 Steps Involved in Extraction of Field Cores from Site

H. Determination of properties of laboratory compacted mixes and field cores

The Laboratory compacted mixes and the field core that were taken from both the sites were evaluated for permeability. All the sample taken from the site and from laboratory compacted were tested for permeability in the concerned laboratory.

Figure 3-6 Showing the Field Samples and Laboratory Compacted Samples

IV. RESULTS

A. Results

Permeability with respect to field cored samples

The permeability values obtained from various spots and samples were used to formulate the results. Cores were extracted from all locations and testing was performed. The field laboratory permeability values cored samples obtained from the laboratory testing are shown in below Table 4-1 & Figure 4-1.

Table 4-1 Variation of Laboratory Permeability of Cored Samples

S. No	Chainage(m)		Permeability(mm/min.)
1	471/410	Right Edge	4.8
		Center	4.5
		Left Edge	5.1
2	471/410	Right Edge	15
		Center	14.1
		Left Edge	22.2
3	471/410	Right Edge	18
		Center	17.4
		Left Edge	25.5
4	471/410	Right Edge	16.5
		Center	13.2
		Left Edge	22.8
5	471/410	Right Edge	17.7
		Center	16.8
		Left Edge	17.4
6	471/410	Right Edge	19.2
		Center	17.4
		Left Edge	21

The testing was carried out both at the edges at an offset of 0.6m from the pavement edge as well as at the centre. It is clearly observed that the k at the centre locations is lower than at the edges. The reduced permeability at the centre can be attributed to the higher compaction likely to be achieved in the field at the centre due to overlapping during rolling operations.

4.2.2 Permeability of laboratory compacted mixes

The laboratory compacted mixes were prepared at different air voids content by changing the compaction effort given to compact the samples by changing the no of blows of Marshall Impact Compactor. The laboratory compacted samples were further tested for the laboratory permeability and other volumetric properties. The variation of the air voids content and the permeability of the samples can be seen from the Figure 4-2 and There is a decrease in the air voids content as compactive effort increase which is as expected. Since compactive effort decreases and the air voids. On a similar note a decreasing trend can be seen in the case of permeability as result of reduction in the air voids content.

Table 4-2 Variation of Air Voids with Compactive Effort

S.No.	No. Of Blows	Air Voids (%)
1	45	14
2	55	12.6
3	65	11.4
4	75	10.5
5	85	9.4

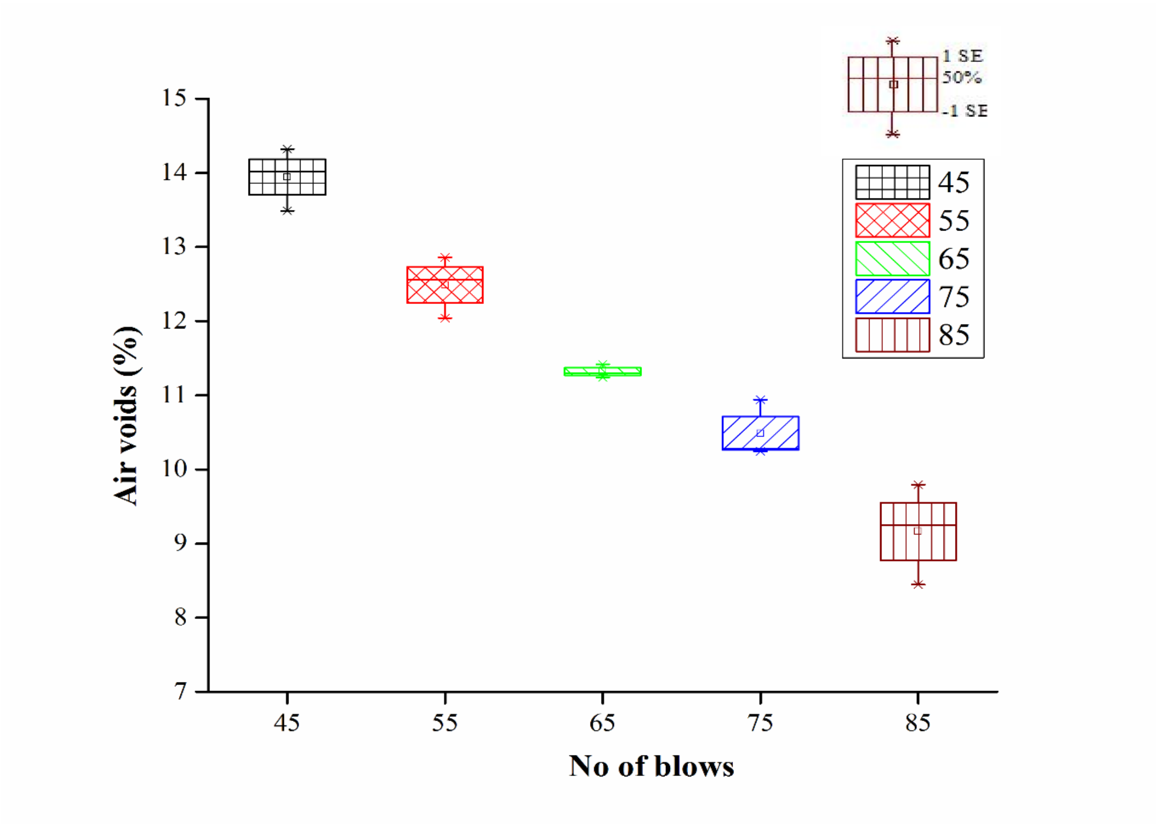


Figure 4-2 Variation of Air Voids with Compactive Effort

Table 4-3 Variation of Permeability with Compactive Effort

S.No.	No. Of Blows	Permeability (mm/min.)
1	45	17.8
2	55	13.1
3	65	11.8
4	75	11.3
5	85	6.2

B. Correlation between field and laboratory permeability

The correlation between the field and laboratory permeability were evaluated using Pearson's coefficient of correlation. The scatter plot for the field and laboratory permeability data is shown in the Figure 4-4. An increasing trend can be seen from the scatter plots. The correlation analysis was performed using the origin software and Pearson's correlation coefficient along with the significance value (p) for the correlation co-efficient at 95% confidence limit. The various statistical output are shown in the Table 44. A strong and significant correlation exists if the r > 0.5 and p<0.05 at 95 % confidence limits. It can be seen that there is a strong and significant correlation between the field and laboratory permeability.

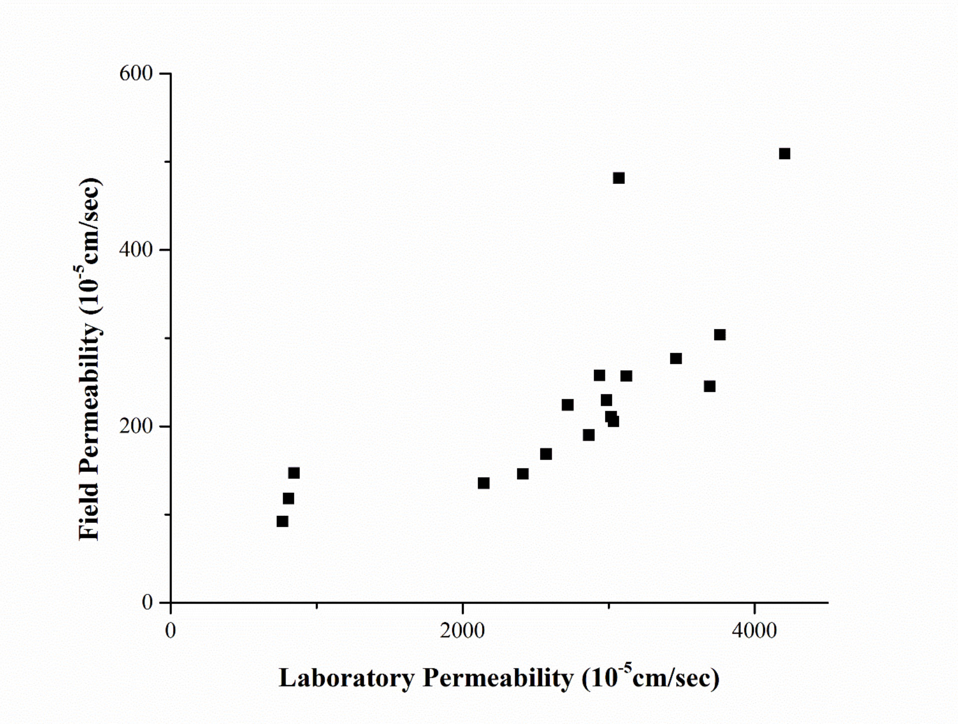


Figure 4-4 Scatter Plot for Field and Laboratory Permeability

Table 4-4 Correlation Analysis Results

Site	Pearson's correlation coefficient (r)	Significance of R at 95% confidence limit
Field k vs Laboratory k	0.72013	0.000751

C. Comparison between the field compacted laboratory evaluated
permeability and laboratory compacted laboratory evaluated

The permeability and air voids data collected from laboratory permeability of site samples and also from the lab compacted mixes during the study were further regressed and multiple models were tried to fit to the data for a better correlation among the parameters air voids and permeability. It was observed that as most of the permeability data showed a positive correlation with the air voids in various models such as linear model, power model, exponential model and hyperbolic model, but the data showed a greater correlation and a better fit with the hyperbolic model for all the data set from various sites. In the hyperbolic model the permeability k, is plotted with ratio of the permeability and air voids (k/Av) as shown in the Eq. (4.1).

$k = \frac{a}{\left(\frac{1}{AV}\right) - b}$ Eq. (4.1)

$\frac{k}{AV} = a + b.k$ Eq. (4.2)

The various scatter plot for the data at various sites with k/Av on the vertical axis is plotted with permeability k and it is shown in the
Figure **4**-5 to **Error! Reference source not found.**7. The R^2 value associated with each fit is also shown in the respective figures. In general the hyperbolic model can be used to the derive the relationship between the air voids and permeability of the study. The model parameters observed in both fit can be further used to have comparison between the field compacted laboratory evaluated permeability and laboratory compacted laboratory evaluated permeability. The model parameters for both the model fit are shown in the Table 4-5

Table 4-5 Comparison of Hyperbolic Model Parameters for Field and Laboratory Compacted Samples

Permeability	Model parameter ($\frac{k}{AV} = a + b.k$)		
	A	B	R^2

Laboratory compacted samples	68.9265	0.05036	0.92114
Field compacted laboratory permeability evaluated samples	47.9923	0.0593	0.81694
Field compacted field permeability evaluated samples	3.92456	0.06125	0.87906

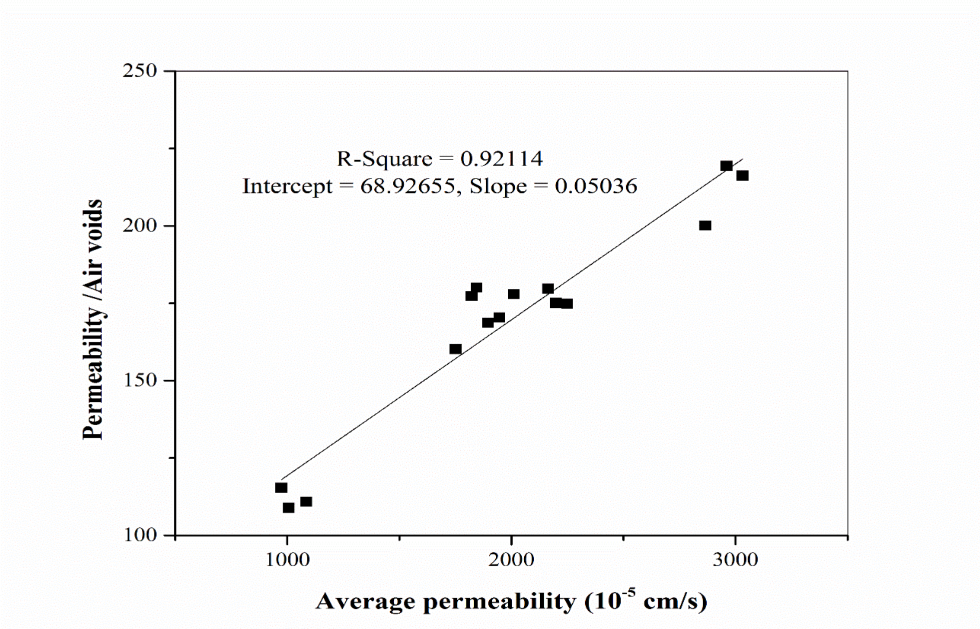


Figure 4-5 Hyperbolic Model Fitted to Laboratory Compacted Laboratory Evaluated Permeability vs Air Void Data

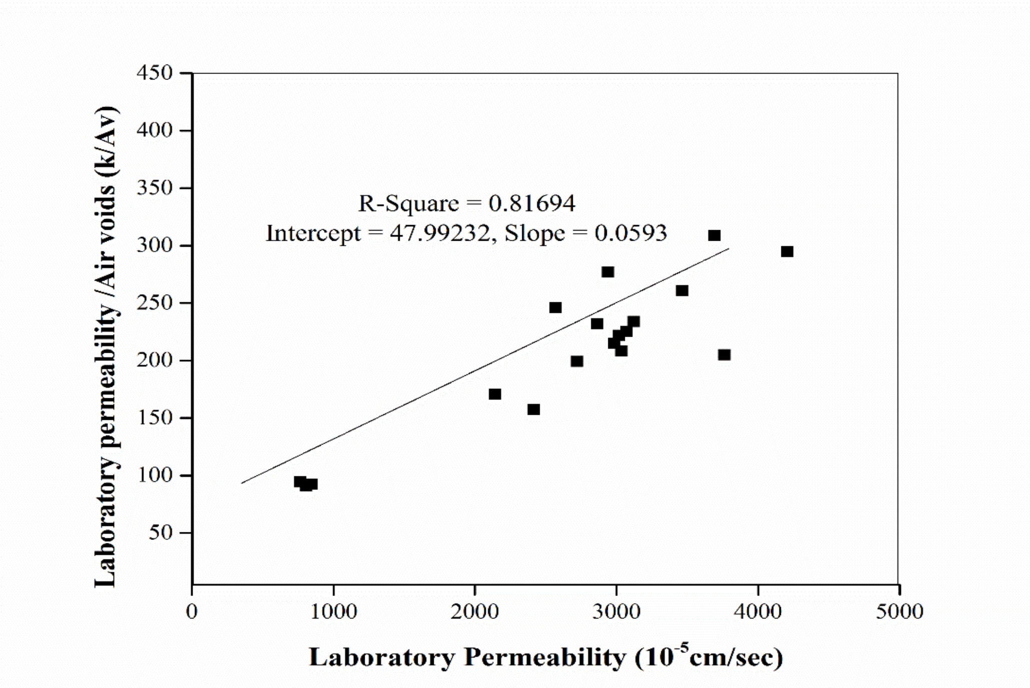


Figure 4-6 Hyperbolic Model Fitted to the Laboratory Permeability and Air Voids Data

V. CONCLUSIONS

The objectives of the study were achieved by the desired experimental plan and the various conclusions based on the observation during testing are listed below. The various conclusions that can be derived from the study are as follows:

- The field and laboratory permeability showed an increasing trend with the increase of the air voids content.
- There was a strong correlation between the field and laboratory permeability.
- Hyperbolic model was best suited to depict the behavior of the permeability in relation to air voids.
- The study conducted to test the variability of the field permeability values with the lateral position at the testing spot showed a good correlation. It can be concluded that the permeability values are statistically different and lower at the center of the pavement then at the edges. The permeability at the left and right edges showed an insignificant statistical difference in their values.
- Variability in permeability of field compacted samples is more than the laboratory.

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