

Development of a Simple Test for Evaluation of In-Place Permeability of Asphalt Mixes

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Dense graded hot mix asphalt (HMA) mixtures are designed to have low permeability to resist excessive penetration of water and avoid durability problems. With the introduction of Superpave mixes, there is a general concern that the coarse graded mixes are more permeable, at similar void levels, compared to fine graded mixes. However, at present there is a lack of a simple tool for measuring the in-place permeability of asphalt mixes. A simple permeability test was developed to determine the effect of voids and gradation on permeability. The field permeameter was used for testing projects with 9.5 mm, fine and coarse, 12.5 mm coarse, 19 mm coarse, and 25 mm coarse graded mixes. Testing of cores taken from location of field testing were also conducted in the laboratory. The results from the in-place permeability tests were found to be consistent with experience with fine and coarse graded mixes. The results indicated that mixes with different gradations and nominal maximum aggregate size have significant increase in permeability at different voids in total mix content. Field testing showed that 25 mm coarse, 19 mm coarse, 12.5 mm coarse and 9.5 mm coarse mixes show significant increase in permeability at 5, 6, 7 and 8 percent voids in total mix respectively, whereas a 9.5 mm fine mix showed a significant increase in permeability above eight percent voids in total mix. Field permeability of 19 mm and 25 mm coarse graded mixes are significantly higher than laboratory permeability, at similar voids in total mix content, most likely due to presence of horizontal flowpaths and high horizontal permeability. It is recommended that field permeability tests be conducted for all mixes, in order to get the best indication of permeability of these mixes.

Keywords: permeability, HMA, field permeameter, gradation, lift thickness, voids

INTRODUCTION

Permeability is defined as the rate at which pressurized gas or liquid passes through a porous medium,

or simply the ability of a medium to permit flow. In the case of hot mix asphalt (HMA) pavements, the pressurized fluid is water (from rain) and the porous medium is HMA material. The invasion of water into

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a HMA pavement can adversely affect the durability of HMA pavements. The most harmful effect takes place through stripping. Stripping is defined as the breaking of the adhesive bond between the aggregate surface and asphalt binder. The result of stripping is pavement distress in the form of cracking or surface raveling. Also, a combination of excessive water due to a high permeability, and air, can result in premature oxidation of the asphalt binder and disintegration of the pavement. Hence a high permeability which results in percolation of a large amount of air or water into the pavement structure is detrimental for the durability of the pavement (1). It has been reported that in Ontario, HMA mixes are designed with a air voids content of two to three percent to make it almost impervious to water (2).

A recent survey of Superpave pavements in eight states (3) has shown that Superpave mixes tend to be more permeable than conventional mixes. Superpave coarse graded mixes (with gradation passing below the Restricted Zone) contain a higher percentage of coarse aggregate than conventional (fine graded) mixes. Since gradation has a significant effect on permeability of HMA there is some concern among state department of transportation (DOT) engineers and contractors that Superpave coarse graded mixes can be highly permeable compared to conventional mixes. Hence, there is a need to evaluate the permeability of dense graded HMA, specifically to evaluate the factors affecting the permeability of HMA. If the factors were fully understood, then it would become easier for the mix designers to design and construct HMA properly, to avoid excessive permeability. Although laboratory methods have been used for evaluating the permeability of HMA, a simple and effective field test method is needed to understand the flow of water in pavements.

Currently, there is no established field test method for determination of permeability of HMA. There is a need to use field testing device to evaluate the permeability of different types of HMA such as Superpave coarse and fine graded mixes. The results from such a study would help the state DOT engineers and contractors to identify change in gradation needed (if any), and identify proper density levels for mixes with

different nominal maximum size aggregates to avoid permeability problems. This paper reports the results of a study carried out to develop and evaluate the use of a simple in-place permeability test for dense graded HMA.

Objective

The objectives of this study are to develop and evaluate a simple in-place permeability test for dense graded HMA, and determine the effect of gradation and in-place density on permeability of these mixes.

Scope

This study was conducted in two parts: field and laboratory. The field permeameter was developed as a part of this study for conducting permeability testing in the field. A commercially available laboratory permeameter was used for testing permeability in the laboratory. The overall scope of the field study consisted of identification of conventional fine and coarse graded Superpave sections, conducting field permeability tests, and coring. In the laboratory, the cores were tested for density (air voids) and permeability. The theoretical maximum density, asphalt content and gradation data were obtained from project information. The data from field and laboratory testing was analyzed to evaluate the results from the permeability tests, and evaluate the effect of different mix design and construction factors on permeability.

Test Plan

Five dense graded Superpave projects were selected for this study. These projects included 9.5 mm, 12.5 mm, 19 mm, and 25 mm nominal maximum aggregate size (NMAS) mixes. Two 9.5 mm mixes were selected – one with a fine gradation passing above the maximum density line (and the restricted zone), and one with gradation passing below the maximum density line (and the restricted zone). A field permeameter was developed at the Worcester Polytechnic Institute (WPI) lab. This permeameter was

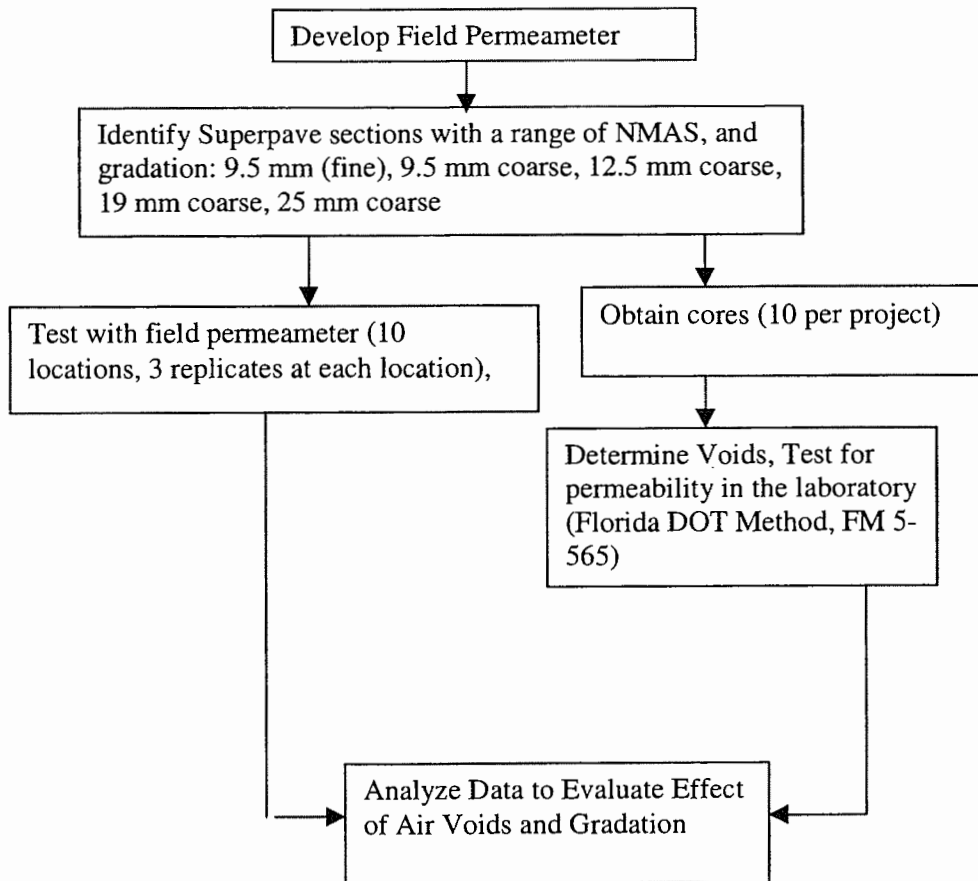


FIGURE 1 Overall Test Plan

used for testing at ten locations per project. Testing was done at random locations, immediately behind the finish roller. One core was obtained at each of these test locations. The cores and the samples were tested for permeability in the laboratory. The overall test plan is shown in Figure 1.

DEVELOPMENT OF FIELD PERMEAMETER

A falling head permeameter was planned for use. Basically, a way of letting water flow through a pavement section, without having water flowing through the sides was sought. Through repeated testing and

evaluation, the final device (Figure 2) was developed with three tiers, a flexible base, and two donut shaped weights. A scale was attached to the top two tiers for reading off the level of water. The three tiers were used for testing pavements with a wide range of permeability, and hence different rates of water flow. A flexible closed-cell sponge rubber was selected as the base because of its non-absorptive nature and its ability to prevent flow of water. The dimensions were selected on the basis of repeated tests on different types of surfaces (HMA and concrete) to ensure practicality, ease of use, and prevent any leakage of water between the permeameter and the base, and the base and the pavement surface. Initially, household caulk-

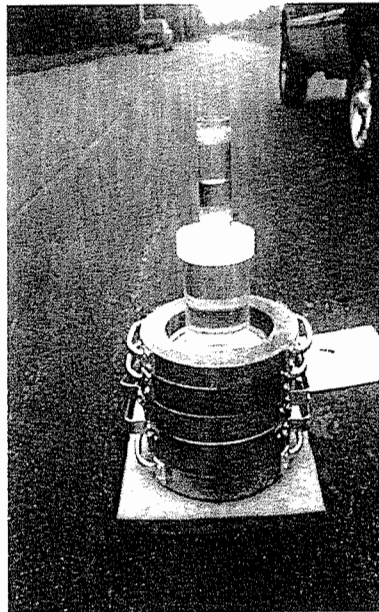
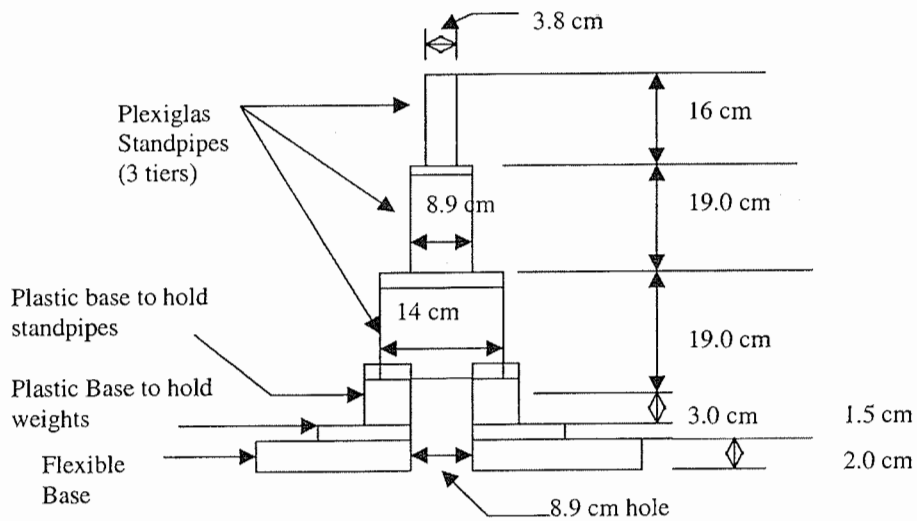


FIGURE 2 Sketch and photo of permeameter

ing used for household need was used between the permeameter and the flexible base, and the flexible base and the pavement to seal water. However, this process involved considerable amount of time (required for repeated caulking at each location) and

also prevented the researchers from obtaining cores at the test location. To solve this problem, three more weights were fabricated, and a total of five weights (total 47 kg) were found to be adequate for sealing off the permeameter without using any caulking. The

final model is shown in Figure 2. Water for the permeameter was supplied by a 50-gallon tank, which was mounted on the back of a pickup truck. The testing setup is shown in Figure 3.

Field Testing

The field permeameter was used as a falling head device to record the drop in water level in the standpipe at a specified time. The standpipe was filled up to a specific mark, and the drop in water was noted for 60 seconds. If the pavement was highly permeable, the time to drop a specific interval was taken. For most of such cases, a drop of one inch (2.54 cm) was noted. In a few cases where the pavement was highly permeable, a drop of 2 inch (5 cm) was noted for practicality. In the case of the 25 mm base mix, the permeameter was filled up to the top of the second tier, and the drop was noted in the second tier. Because of the larger diameter, the drop in the tier was slow enough for efficient recording of data. For each location, three measurements were made at 150 mm apart. For each result reported, the average of three individual measurements was used. Each time the water dropped, the standpipe was filled up to the same starting level. In a few cases, due to scarcity of water, the water was let drop through three successive inch mark, and the data was collected without filling up the standpipe to the original level. A typical set of data obtained during field permeability testing is shown in Table I. In most cases, the dropping time (or the drop in 60 seconds) was different for three readings. Usually, the first drop took less time than the second (or the drop was higher for the first reading), and the second drop took less time than the third (or the drop was higher for the second reading compared to the third). One possible explanation is that during the first test, the water fills up the voids, including some which are not interconnected, and during the second and third reading the water cannot go through these non connected voids, and only flows through the interconnected voids. Since in the case of rain-storm, the pavement may not be saturated, and the non-connected voids may not be filled with water, it was decided to use all three readings for specific

measurements. The cores were obtained at the center of the three reading locations. A typical testing and coring location are show in Figure 3.

Laboratory Testing

The field cores were tested for laboratory permeability, using the Karol-Warner laboratory permeameter. Falling head testes were conducted according to Florida DOT specification (FM 5-565). The cores and laboratory samples were saturated before testing by applying a vacuum under water for ten minutes. A typical set of data is shown in Table II. As noted in the case of field permeability testing, the drop in water was faster initially, compared to the drop in successive testing. However, the data did not differ significantly during successive testing of the same sample.

RESULTS AND ANALYSIS

Permeability testing was done in the field for mixes with 9.5 mm fine (surface), 9.5 mm coarse (surface), 12.5 mm coarse (surface), 19 mm coarse (base), and 25 mm coarse (base) mixes. Gradation, design asphalt content, and lift thickness of these mixes are shown in Table III. The 9.5 mm fine mix has a gradation, which goes above the restricted zone and the maximum density line, and the other four mixes have gradations passing below the restricted zone and the maximum density line. The air voids and coefficient of permeability determined from data obtained from field testing and laboratory testing (of cores) are given in Table IV. The term permeability is used for "coefficient of permeability" in the rest of the report.

The flow of water in HMA pavements occur through interconnected air voids. Since there are always some interconnected air voids, there always exists some degree of permeability in a HMA pavement. However, since there is a critical permeability beyond which the pavement lets in excessive amount of water, the question is at what voids in total mix (VTM) do dense graded HMA become highly permeable? There is also a need to define how much permeability is too much.

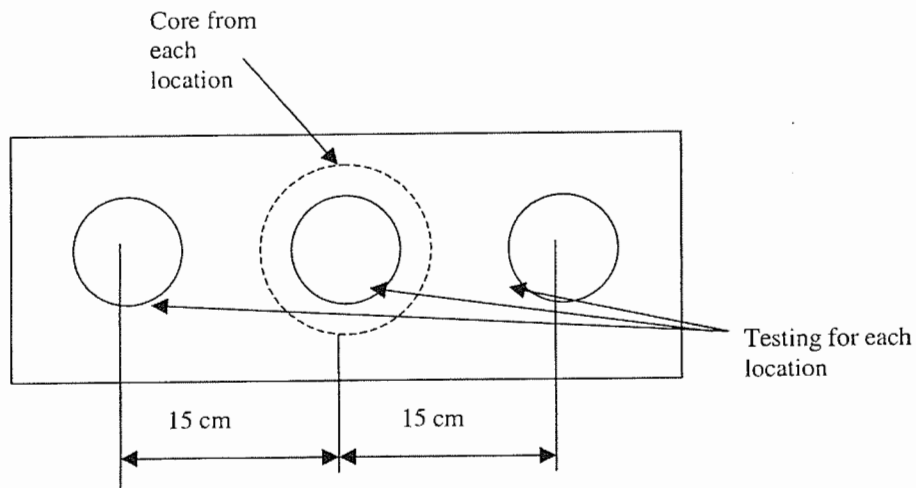
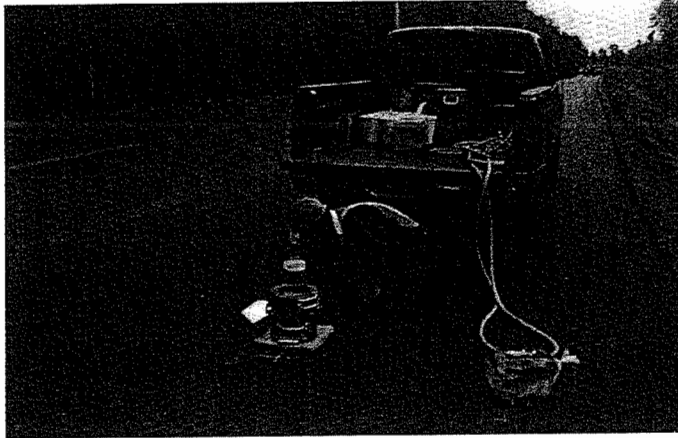


FIGURE 3 Testing and testing location

To answer these questions, Figure 4 is shown with the data of VTM versus field permeability. Figure 4 shows that for the different mixes, permeability increases significantly with VTM beyond a threshold VTM, and that the threshold VTM is dependent on the mix properties. The 25 mm coarse mix shows significantly high permeability (compared to other mixes) at 5 % VTM, the 19 mm coarse mix shows high permeability at 6 % VTM, the 12.5 mm coarse mix shows a significant increase in permeability at VTM greater than 6 %, the 9.5 mm coarse mix shows

a significant increase in permeability at VTM greater than 7 %, whereas the 9.5 mm fine mix shows a significant increase in permeability at VTM greater than 8 %. It seems that coarser the mix, lower is the VTM at which there is a significant increase in permeability. This is logical, since the coarser the gradation the greater likelihood of interconnectivity of air voids. Hence the results indicate that the in-place permeameter seems to give a reasonable indication of permeability of HMA, and a relative comparison of permeability of different mixtures.

TABLE I Typical data from field permeability testing

Location	Test	Replicate	Initial Head, cm	Final Head, cm	time, s	Area of standpipe, cm ²	Thickness of layer L, cm	Area through which water enters pavement A, cm ²	Permeability Average k, cm/s	Permeability k, average
2	A	1	54.42	46.8	19	11.33	4	62.18	5.79E-03	0.0006552
2	A	2	54.42	46.8	20	11.33	4	62.18	5.50E-03	
2	A	3	54.42	46.8	20	11.33	4	62.18	5.50E-03	
2	B	1	54.42	46.8	12	11.33	4	62.18	9.16E-03	
2	B	2	54.42	46.8	15	11.33	4	62.18	7.33E-03	
2	B	3	54.42	46.8	15	11.33	4	62.18	7.33E-03	
2	C	1	54.42	46.8	17	11.33	4	62.18	6.47E-03	
2	C	2	54.42	46.8	18	11.33	4	62.18	6.11E-03	
2	C	3	54.42	46.8	19	11.33	4	62.18	5.79E-03	

Note: $k = (aL)^3 \ln(h_1/h_2) / (AT)$

TABLE II Typical data from laboratory permeability testing

Core:	2 (Uncut)									
Avg. Height:	35.25 mm									
Weights (gm):	Submerged									
	SSD:									
	Dry:									
BSG:	2.271									

Sample	Area of burette	Thickness of sample	Area of sample	Time between h1 and h2	Initial head	Final head	Temperature correction factor for water	Permeability
(Core)	a	L	A	t	h ₁	h ₂	t _c	K
2	cm ² 7.065	cm 3.525	cm ² 176.625	s 3.9	cm 60	cm 50	1	cm/s 6.59E-03

Note: $k = (aL)^3 \ln(h_1/h_2) / (AT)$

TABLE III HMA Mix Information (from construction records)

<i>Mix</i>	<i>Gradation</i>		<i>Asphalt Content, %</i>	<i>Lift Thickness, cm</i>
9.5 mm fine	12.5	100	5.8	4
	9.5	99		
	4.75	65		
	2.36	51		
	1.18	45		
	0.6	35		
	0.3	21		
	0.15	9		
	0.075	5		
9.5 mm coarse	12.5	100	6.2	3
	9.5	99		
	4.75	64		
	2.36	45		
	1.18	31		
	0.6	18		
	0.3	10		
	0.15	6		
	0.075	4		
12.5 mm coarse	19.0	100	5.5	4
	12.5	91		
	9.5	73		
	4.75	53		
	2.36	36		
	1.18	24		
	0.6	14		
	0.3	8		
	0.15	5		
0.075	4			
19 mm coarse	25.0	100	4.7	5
	19.0	100		
	12.5	86		
	9.5	66		
	4.75	44		
	2.36	30		
	1.18	19		
	0.6	13		
	0.3	9		
0.15	7			
0.075	4.9			
25 mm coarse	37.5	100	5.1	8.9
	25.0	99		
	19.0	93		
	12.5	78		
	9.5	72		
	4.75	41		
	2.36	25		
	1.18	18		
	0.6	12		
0.3	8			
0.15	6			
0.075	5			

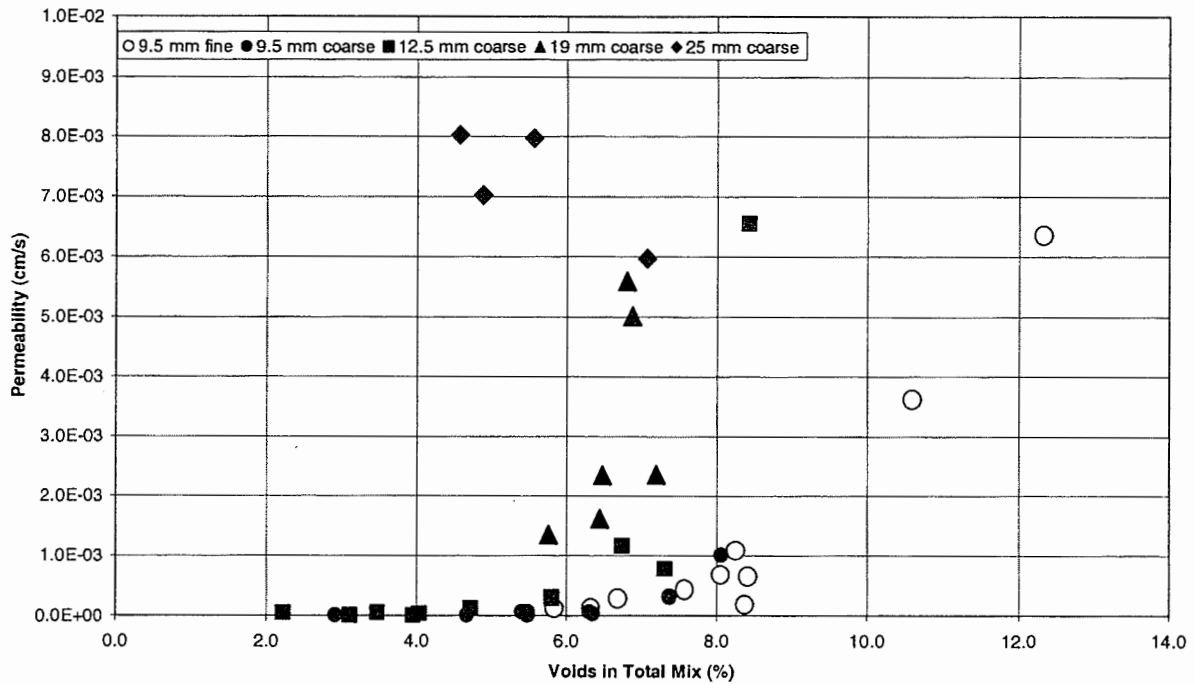


FIGURE 4 Voids in total mix versus field permeability

Selection of a critical permeability value is required for comparison of permeability of different mixes or permeability of same mix at different densities. This criteria needs to be based on a reasonable estimates of what is excessive permeability. Considering mixes that have performed well in the past is the best place to start even though there is no actual in-place permeability data available for these older mixes. The 9.5 mm fine graded mix used in this project is similar in gradation and asphalt content to older Marshall mixes that have often performed very well in resisting permeability-induced damage such as stripping. These Marshall mixes were typically compacted to a density of approximately 92 percent of theoretical maximum density (8 percent air voids). Also, work performed by Zube (4) has shown that dense graded HMA pavements (constructed with fine mixes) become excessively permeable to water at approximately 8 percent air voids. Therefore, the per-

meability of the 9.5 mm fine graded mix at 8 percent air voids can be used to serve as a suitable baseline for comparing the permeability of the other four mixes used in this study. The permeability values between 7.5 and 8.5 percent air voids were averaged, yielding the following:

Field:

$$k_{\text{average}} = 6.02 \times 10^{-4} \text{ cm/s at } 8\% \text{ voids}$$

Laboratory:

$$k_{\text{average}} = 9.75 \times 10^{-4} \text{ cm/s at } 8\% \text{ air voids}$$

Taking the larger of the two numbers, a value of $k = 9.75 \times 10^{-4} \text{ cm/s}$ was selected. This number was rounded to $k = 1.0 \times 10^{-3} \text{ cm/s}$ for simplicity, and selected as a critical permeability. Note that at a permeability level in the order of 10^{-4} cm/s , use of 6 or 9 or 10 does not have a significant effect on the actual numerical value.

TABLE IV Air Voids and Permeability of Field Cores

<i>Mix</i>	<i>Lift thickness, cm</i>	<i>VTM, %</i>	<i>Field Permeability, cm/s</i>	<i>Lab Permeability, cm/s</i>
9.5 (fine)	4	8.3	1.0E-03	9.7E-04
		6.3	1.3E-04	2.7E-04
		6.7	2.9E-04	4.9E-04
		12.3	6.3E-03	9.8E-03
		5.8	1.2E-04	3.7E-04
		8.4	1.8E-04	4.0E-04
		8.4	6.5E-04	8.0E-04
		8.1	6.7E-04	1.3E-03
		7.6	4.3E-04	1.4E-03
		10.6	3.6E-03	3.6E-03
9.5 (coarse)	3	3.1	9.2E-06	8.0E-05
		5.4	6.7E-05	9.0E-05
		6.3	6.4E-05	1.1E-04
		5.5	7.8E-06	0
		2.9	6.4E-06	1.4E-04
		8.1	1.0E-03	1.9E-03
		4.7	1.6E-05	6.6E-05
		6.3	2.8E-05	1.4E-04
		5.5	6.3E-05	9.5E-05
7.4	3.2E-04	1.3E-03		
12.5 (coarse)	4	3.5	5.7E-05	0
		8.4	6.6E-03	6.6E-03
		6.7	1.2E-03	1.1E-03
		4.0	4.9E-05	0
		4.0	9.4E-06	5.6E-05
		2.2	6.0E-05	9.8E-06
		4.7	1.3E-04	1.4E-04
		5.8	2.9E-04	1.1E-03
		3.1	8.5E-06	0
		7.3	7.8E-04	1.2E-03
19 (coarse)	5	6.5	2.3E-03	1.3E-04
		6.8	5.6E-03	7.2E-04
		8.4	2.4E-02	6.8E-03
		8.3	1.8E-02	5.9E-03
		7.2	2.4E-03	4.6E-04
		7.9	2.0E-02	4.7E-03
		5.8	1.4E-03	2.1E-04
		Destroyed	5.9E-04	--
		6.4	1.6E-03	1.2E-03
		6.9	5.0E-03	9.3E-04
25 (coarse)	8.9	6.8	2.8E-02	0
		5.7	9.5E-03	1.2E-05
		7.3	6.5E-02	4.9E-04
		7.1	1.7E-02	2.4E-05
		5.5	7.9E-03	2.2E-05
		8.4	2.7E-02	5.2E-04
		4.8	7.0E-03	8.7E-05
		7.0	5.9E-03	5.9E-05
		4.5	8.0E-03	0
		9.2	1.2E-01	9.8E-04

Note: During laboratory tests with some of the cores, no drop in water in the standpipe was noted within 30 minutes of testing. For these cores, the coefficient of permeability has been reported as zero. It is suspected that either presence of air bubbles or closing of surface voids (for example due to sawing off top layers) is responsible for the zero permeability.

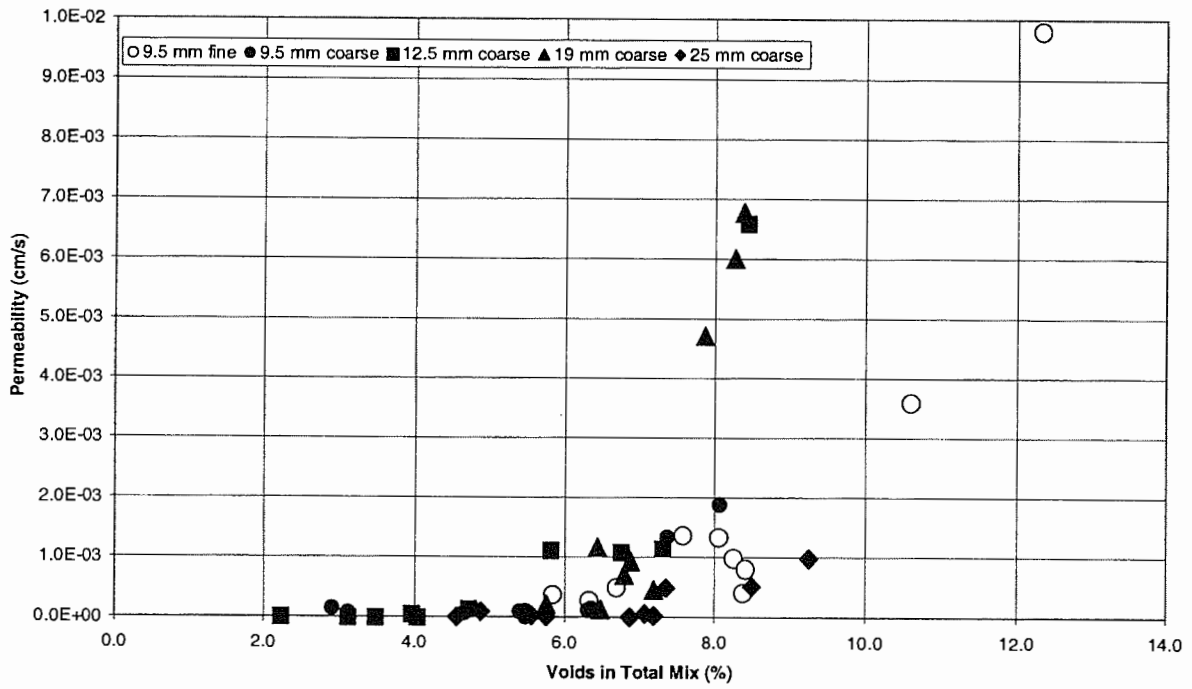


FIGURE 5 Voids in total mix versus laboratory permeability

The results from in-place permeability testing show that the permeability of the 9.5 mm fine graded mix increases significantly above 8 % VTM. This is consistent with experience with fine graded mixes, and hence the in-place permeameter seems to give good indication of permeability of HMA.

From the in-place voids versus permeability results shown in Figure 4, it appears to be that for coarse graded Superpave mixes, the VTM should be less than 6 or 7 to keep the same permeability level as is expected from a fine graded mix at 8 % VTM. Most likely, a VTM of 5 % is desirable for a 25 mm coarse mixes, 6 % is appropriate for 12.5 mm coarse mixes, whereas a VTM level of 7 % is acceptable for a 9.5 mm coarse mix.

Figure 5 shows the results of laboratory permeability testing of cores from different projects. The trend seems to be the same as that shown by the results of field permeability testing – a significant increase in permeability beyond threshold VTM content. How-

ever, there are differences at the levels of VTM at which the permeability increases significantly for the different mixes. The 9.5 mm fine and coarse mixes show a significant increase in permeability beyond 8 % VTM, whereas the 12.5 coarse and the 19 mm coarse mix shows significant increase in permeability beyond 7 % VTM.

The 25 mm coarse mixes does not seem to show a significant increase even beyond 8 % VTM. The question is which method – field or laboratory, gives the best indication of permeability of a mix? Obviously, field testing is more realistic than laboratory testing, even though the ideal conditions, which are assumed for calculation of coefficient of permeability (assuming Darcy’s law of one-dimensional flow), are not present in the field.

Figure 6 shows a plot of difference between field and laboratory (field permeability – laboratory permeability) permeability for the different mixes and for different VTM. For the 9.5 mm fine, 9.5 mm coarse,

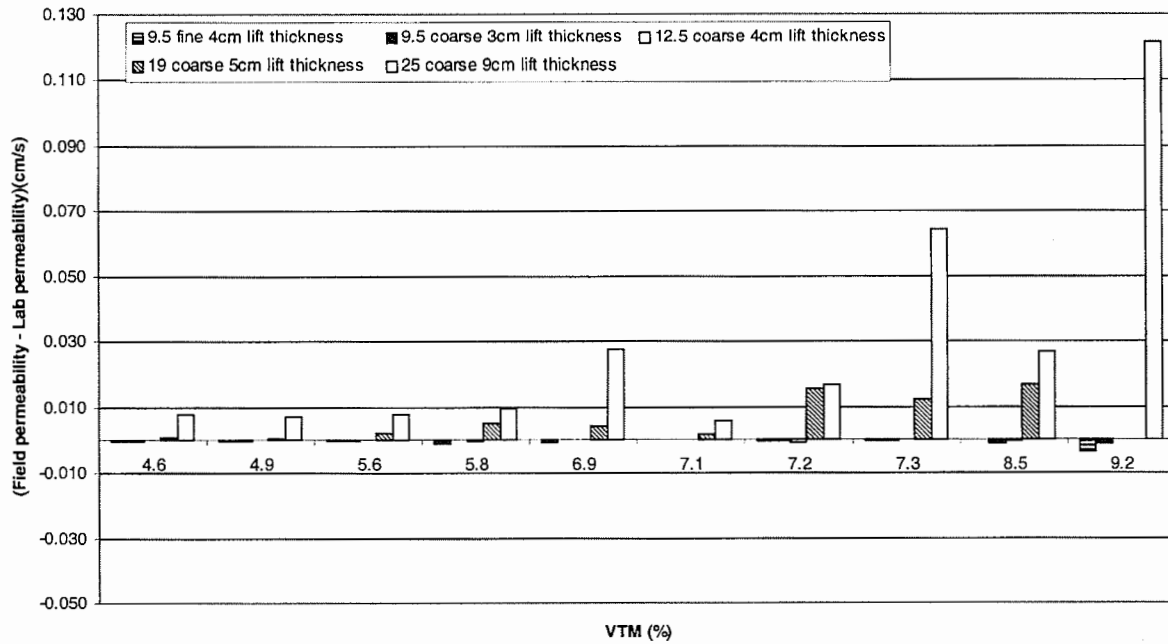


FIGURE 6 Difference between field and laboratory permeability

and the 12.5 mm coarse mixes, the differences are not very significant, and in most cases the laboratory permeability is slightly higher than field permeability. However, for the 19 mm coarse and 25 mm coarse mixes, the differences are very significant, all of the differences are positive (which indicates field permeability is higher), and the differences tend to increase with an increase in VTM. It is believed that permeability is strongly influenced by the macrostructure of the mix. The 19 mm and the 25 mm coarse mixes were 5 and 9 cm thick, respectively, and most likely had horizontal permeability many times more than the vertical permeability. The overall permeability could be approximately equal to the horizontal permeability. The high difference between the field and the laboratory permeability for the 19 mm and 25 mm mixes gives an indication of horizontal permeability, since in the laboratory the flow of water is restricted in the vertical direction. It seems that a large amount of flow in the coarser mixes with thick lifts occurs in the horizontal direction, whereas finer mixes with thinner lifts tend to have more of a vertical flow. For the 9.5 and

12.5 mixes, water was observed to come up through the mat a few cm away from the permeameter (Figure 7). This was not observed in the case of 19 or 25 mm mixes. Hence, laboratory testing with falling head permeameter using vertical flow of water may not give a true indication of permeability of mixes with pronounced macrostructure. The horizontal permeability of some mixes may be much higher and hence of overriding importance in such cases.

At this time there is no good method for determination of horizontal permeability of HMA in the laboratory. Because of the sealing effect of drill during coring operation, it is not possible to have water flow through the sides of HMA cores in the laboratory. A similar problem arises with testing of laboratory prepared samples, in which case the sides are sealed off by kneading effect during compaction with a Superpave gyratory compactor. However, one possible approach for estimating horizontal permeability that can be suggested is to conduct a permeability test on a constructed in-place pavement, and then saw of one side to observe the flow of water. This method,

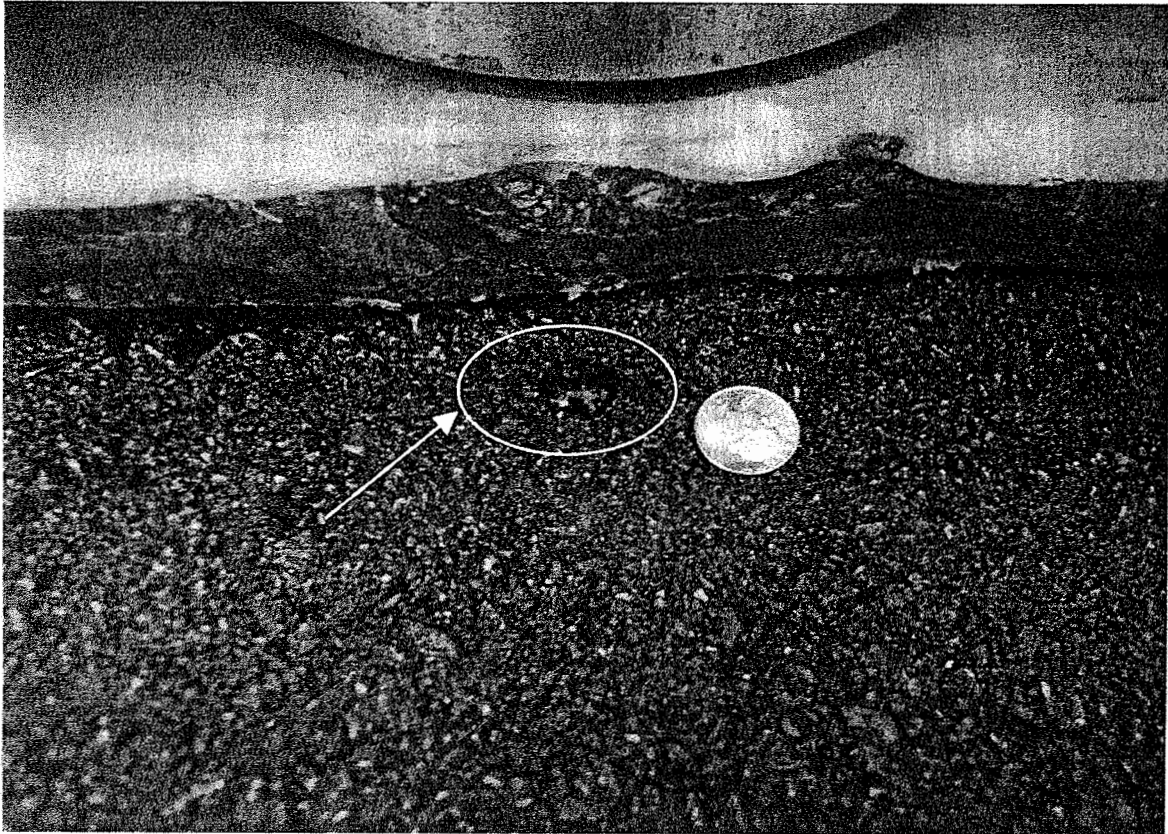


FIGURE 7 Water popping up near permeameter during field testing

although time consuming, can help in avoiding the sealing effect of a core drill. The flow of water through the cut face can be measured to get an approximate estimation of horizontal permeability of the in-place mix.

Limitations of Permeability Test

The limitation of the in-place permeability test that was developed and used in this project is that the conditions, which are assumed to be valid in order to calculate the coefficient of permeability from Darcy's law, are not valid. For example, Darcy's law is valid for one dimensional flow, whereas the flow of water through a pavement is partly horizontal and partly vertical. Hence, it is difficult to compare or correlate

permeability values that are obtained in the field to the permeability values that are obtained from laboratory testing. However, it must be noted that it is impossible to meet Darcy's law condition during in-place permeability testing, and in the absence of "ideal" conditions, Darcy's law can still be used to get an estimation of water flow through pavements, and more importantly, to make a comparison of permeability of different HMA mixes.

The laboratory test method has less limitations in the sense that the flow conditions are more similar to those assumed for application of Darcy's law, and hence calculating coefficient of permeability.

The use of the in-place permeability test, as indicated in this report, is best suited for comparative evaluation of permeability of different mixes, and

same mixes with different properties, such as in-place density. Since the limitations of in-place testing will be present in each and every test, as long as a similar equipment and a consistent procedure is maintained, the results should be good enough for comparative evaluation purpose. A suggested method for in-place permeability testing is given in Appendix A.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of results obtained in this study, the following conclusions can be made:

1. The in-place permeameter developed in this study is a simple method for obtaining a reasonable indication of the permeability of asphalt mixes. The results obtained from this test are consistent with expected results from mixes with different air voids and gradations. The test is quick, and gives a good indication of inter-connectivity of air voids in asphalt mixes.
2. Air void content (as measured by voids in total mix) of dense graded HMA has a significant effect on permeability of HMA. The permeability of dense graded HMA increases significantly at VTM greater than a critical VTM, which is dependent on type of mix.
3. There is a significant effect of gradation on permeability of dense graded HMA. For a coarser mix, there is a significant increase in permeability at a lower VTM, compared to a finer mix. Coarse graded mixtures with 25 mm, 19 mm, 12.5 mm and a 9.5 mm nominal maximum aggregate size showed significant increase in permeability at 5, 6, 7 and 8 % VTM, respectively. In contrast, a 9.5 mm fine mix showed significant increase in permeability at VTM greater than 8 percent.
4. A field permeability of 0.001 cm/s appears to be critical permeability of dense graded HMA.
5. The difference between field and laboratory density is significant at higher VTM for 19 mm nominal maximum aggregate size and 25 mm nominal maximum aggregate size coarse mixes, but not significant for the 9.5 mm nominal maximum aggregate size fine, 9.5 mm nominal maximum aggregate size coarse and 12.5 mm nominal maximum aggregate size coarse mixes. 19 mm and 25 mm nominal maximum aggregate size mixes seem to have a large number of horizontal flow-paths, and hence significantly high horizontal permeability. The field permeability of these mixes seems to be determined by the horizontal permeability.

Based on the conclusions, the recommendations are:

1. As quality control procedures, regular field permeability testing of coarse graded mixes should be done to ensure proper watertightness of the mix.
2. For coarse graded mixes similar to those discussed in this paper, DOTs should specify in-place construction VTM of less than 7 % for 9.5 mm and 12.5 mm nominal maximum aggregate size mixes.
3. For 19 mm and 25 mm nominal maximum aggregate size coarse graded mixes, construction VTM should preferably be kept around 5 percent.
4. Laboratory tests can be substituted for field test for 9.5 mm and 12.5 mm nominal maximum aggregate size mixes. However, field testing must be done for 19 mm and 25 mm nominal maximum aggregate size mixes in order to get a true indication of permeability of these mixes.

References

1. The Asphalt Institute. Principles of Construction of Hot Mix Asphalt Pavements. *Manual Series No. 22 (MS-22)*, 1983.
2. Fromm, H. J., The Mechanisms of Asphalt Stripping from Aggregate Surfaces. *Association of Asphalt Paving Technologists*, Volume 43, 1974.
3. Brown, E. Ray, Dale Decker, Rajib B. Mallick and John Bukowski, Superpave Construction Issues and Early Performance Evaluations. *Journal of Asphalt Paving Technologists*, Volume 68, 1999.
4. Zube, E. Compaction Studies of Asphalt Concrete Pavements as Related to the Water Permeability Test. Highway Research Board, *Bulletin 358*, 1962.

APPENDIX A: IN-PLACE PERMEABILITY TESTING PROCEDURE**Test Method for Determining In-Place Permeability**

1. **Scope**
 - 1.1 This test method covers the in-place estimation of the water permeability of a compacted hot mix asphalt (HMA) pavement. The estimate provides an indication of water permeability of a pavement.
 - 1.2 The values states in metric (SI) units are regarded as standard. Values given in parenthesis are for information and reference purposes only.
 - 1.3 This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.
2. **Summary of Test Method**
 - 2.1 A falling head permeability test is used to estimate the rate at which water flows into a compacted HMA pavement. Water from a graduated standpipe is allowed to flow into a compacted HMA pavement and the interval of time taken to reach a known change in head loss is recorded. The coefficient of permeability of a compacted HMA pavement is then estimated based on Darcy's Law.
3. **Significance and Use**
 - 3.1 This test method provides a means of estimating water permeability of compacted HMA pavements. This estimation of water permeability is based upon assumptions that the sample thickness is equal to the immediately underlying HMA pavement course thickness; the area of the tested sample is equal to the area of the permeameter from which water is allowed to penetrate the HMA pavement; one-dimensional flow; and laminar flow of the water. It is assumed Darcy's Law is valid.
4. **Apparatus**
 - 4.1 Field Permeameter – A field permeameter made to the dimensions and specifications shown in Figure 1.
 - 4.2 Gasket – A gasket made of ethyl vinyl acetate (or similar, suitable, closed cell material) to be used for sealing the field permeameter to the pavement surface,
 - 4.3 Weights – Cylindrical weights, a total of 120 lb, constructed to fit over the permeameter and rest on the permeameter base, to aid in sealing the gasket to the pavement surface.
 - 4.4 Timing Device – A stopwatch or other timing device graduated in divisions of 1.0 seconds.
5. **Test Procedure**
 - 5.1 Permeameter Setup
 - 5.1.1 Ensure that both sides of the gasket are free of debris.
 - 5.1.2 Place the gasket on the pavement surface over the desired testing location.
 - 5.1.3 Place the permeameter on the gasket, ensuring the holes in each are properly aligned
 - 5.1.4 Place the cylindrical weights over the permeameter, letting them rest on the base flange of the permeameter.
 - 5.2 Permeability Test

5.2.1 Fill the standpipe to just above the desired initial head.

Note 1: For most applications, enough water should be introduced to bring the water level to the top of the top tier standpipe.

5.22 When the water level has fallen to the desired initial head, start the timing device. (See Note 2) Stop the timing device when the water level within the standpipe reaches the desired head, (See Note 3) Record the initial head, final head, and time interval between the initial and final head

Note 2: For relatively impermeable pavements, the water level will drop very slowly within the top tier standpipe. Therefore, the initial head should be taken within the top tier standpipe. For pavements of "medium" permeability, the water level will drop very quickly through the top tier standpipe. Therefore, the initial head should be taken within the middle tier standpipe. For very permeable pavements the water level will drop very quickly through the top and middle tier standpipes but slow down when it reaches the bottom tier standpipe. Therefore, the initial head should be taken in the bottom tier standpipe.

Note 3: The initial and final head determinations should be made within the same standpipe tier.

6. Calculation

6.1 The coefficient of permeability, k , is estimated using the following equation:

$$k = \frac{a L}{A \Delta t} * \ln(h_1/h_2)$$

where: k = coefficient of permeability

a = area of stand pipe

L = length of sample

A = cross-sectional area of sample

Δt = time during which the change in head is measured

h_1 = water head at beginning of test

h_2 = water head at end of test

6.2 Report results for k to the nearest whole units, in cm/s, using scientific notation.

