FINAL REPORT

INVESTIGATION OF TEST METHODS, PAVEMENTS, AND LABORATORY DESIGN RELATED TO ASPHALT PERMEABILITY

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ABSTRACT

In this study, the permeability of Virginia's Superpave mixtures was tested. A constant head device and a falling head device under development were investigated as aids in measuring asphalt permeability. The effect on permeability of some of the variables associated with the falling head test was also investigated. Falling head permeability tests were performed on pavement cores to determine the general permeability of mixtures being placed, with an emphasis on Superpave mixtures. In addition, the permeability of pavement cores was compared with the permeability of specimens made in the laboratory using mixtures sampled during construction to determine whether laboratory specimens could be used to predict pavement permeability.

The falling head test was found to be more suitable than the constant head test because of its simplicity and the inability of the latter to allow water flow at measurable pressure heads. Sealant was found to be necessary to prevent water flow along the sides of the specimen during the test, and sawing was found to decrease permeability. A large percentage of the field cores had excessive voids, resulting in excessive permeability. Each mixture had a unique voids-permeability relationship; a lower void content was required in mixtures having large aggregates to maintain an acceptable level of permeability. Permeability tests on specimens prepared in the laboratory predicted pavement permeability within acceptable limits in five of six cases. Limited repeat testing by different operators indicated differences among operators that require further investigation.

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INTRODUCTION

The fact that the durability of asphalt concrete is compromised when a pavement has a high air void content has been recognized for many years. Not only do void spaces allow air to enter and oxidize the asphalt cement, but water can also enter and cause freeze-thaw and stripping damage. Brown (cited in Kuennen)[1] indicated that to be waterproof, asphalt pavement must have no more than 8 percent voids for fine mixtures and 6 percent voids for coarse mixtures. In 1996, a field study of Virginia pavements found that pavement voids were higher than desirable and visible stripping damage was significant.[2] In addition, it is not uncommon to see damp spots remaining on the surface of Virginia's asphalt pavements several days after a rain. The Virginia Department of Transportation (VDOT) wanted to know if high voids, stripping, and damp spots indicate permeable pavements and, if so, how permeable the pavements are.

There is also concern about the permeability of Superpave mixtures. A study by the Florida Department of Transportation (FDOT) in 1996-97 indicated that their Superpave mixtures had high permeability at void levels that were reasonable for conventional dense-graded mixtures.[3] Since VDOT is implementing Superpave in 2000, it is important to determine if permeability is a problem with the Superpave mixtures being used in Virginia.

PURPOSE AND SCOPE

The purpose of this investigation was to examine available methods to measure permeability and to determine the general magnitude of permeability for mixtures being used by VDOT, with an emphasis on Superpave mixtures. Tests were also performed on specimens prepared in the laboratory and matching pavement cores to determine whether tests performed on laboratory specimens indicated field permeability.

METHODS

General

The first step in this study was to examine laboratory test methods that appeared to offer the hope of implementation by VDOT. The Texas Transportation Institute used a constant head test similar to that used routinely for soils to evaluate two asphalt mixtures.[4] FDOT used a relatively simple piece of equipment to measure falling head permeability on many field asphalt cores.[3] Both of these tests were examined in the present study. A factorial experimental design was not done because the test methods were constantly examined and changed as experience was gained with the tests. However, the influence of several test variables on test results was studied by using surplus samples of field mixtures collected for other purposes.

The second step was to determine the permeability of asphalt mixtures being used in Virginia. A total of 120 cores were removed from 21 paving projects in 1998 for permeability testing. The cores were grouped according to mixture type for analysis of the results and determination of the maximum void content that could be tolerated in the asphalt concrete while still maintaining acceptable permeability. The number of cores for each mixture type is listed in Table 1.

Table 1. Results of Permeability Tests on Field Cores

Mixture Type	No. Projects	No. Cores	% Cores with Permeability $> 125 \times 10^{-5}$ cm/s	Maximum VTM (%) to Maintain Permeability $< 125 \times 10^{-5}$ cm/s
SM-9.5 cm	2	9	11	8.5
SM-12.5 cm	7	41	66	7.0
SM-19.0 cm	2	11	45	7.0
BM-25.0 cm	2	13	46	5.0
SMA	2	13	62	6.0
SM-2	6	33	94	7.0

For five of the paving projects, mixture was collected during the paving operation and compacted in the laboratory at four or five different void contents ranging from high to low. The relationship between laboratory permeability and voids was determined to see whether the relationship between core permeability and voids was the same. If so, the permeability of the pavement could be predicted from tests of specimens prepared in the laboratory.

Testing

Specimen Preparation and Saturation

Pavement cores were obtained by wet coring, and the layer to be tested was separated by chiseling when necessary. The thickness of the cores was the thickness of the asphalt pavement layer, which was generally 35 to 40 cm. Laboratory specimens were compacted in the SHRP gyratory compactor in accordance with AASHTO Provisional Standard TP4 except that the weight of mixture for each specimen was adjusted to yield the desired void content in the compacted specimen.[5] The laboratory specimens were compacted to a thickness of 63 →5 cm. Voids were determined as described in the next section. The specimen was then placed in a vacuum vessel filled with water and vacuumed at 28 → 2 cm of Hg residual pressure for 15 → 2 minutes. This vacuuming procedure was used for all tests after the test method investigation phase.

Air Voids

The percent air voids in the cores and laboratory specimens was determined in accordance with ASTM D 3203.[6] The bulk specific gravity was determined in accordance with ASTM D 2726.[6] The theoretical maximum specific gravity was determined in accordance with ASTM D 2041.[6] The voids were computed from the specimen bulk specific gravity and theoretical maximum specific gravity by the following formula:

Percent air voids = 100(1 – [Bulk specific gravity of specimen/Theoretical maximum specific gravity of mixture])

Permeability Tests

Constant Head Test

The constant head test with a soils testing setup similar to that described in ASTM D 5084 was used (see Figure 1). The 152-cm-diameter specimen was enclosed in a rubber membrane with porous stones at the top and bottom. The specimen was then placed in a cell, and water was used to apply a confining pressure. Both the inlet pressure and outlet pressure could be controlled on the water as it flowed through the length of the specimen. It was desirable to have low differential pressure so as not to get turbulent flow.

Figure 1. Constant Head Permeameter

The coefficient of permeability was calculated according to the following formula:

$$k = \frac{QL}{Ath}$$

where

k = permeability, cm/s

Q = quantity of flow, cm^3

L = length of specimen, cm

A = cross-sectional area of specimen, cm^2

t = interval of time over which flow Q occurs, s

h = difference in hydraulic head across the specimen, cm.

Falling Head Test

A falling head permeability test patterned after conventional soils testing was performed using apparatus currently under development (see Figure 2). An ASTM task group in subcommittee D04.23 was refining the procedure and developing a draft test method at the writing of this paper. Some changes in the test procedure are cited in the “Test Investigation” section that follows; however, the following procedure was used in all tests after the test method investigation.

Figure 2. Falling Head Permeameter

The apparatus consists of a metal cylinder with a flexible membrane on the inside of the cylinder to which air pressure can be applied. The cylinder has removable plastic plates at the top and bottom that can be sealed. The top plate has a hole with a graduated cylinder for the introduction of water, and the bottom plate has an outlet hole and valve for the water to flow out. During the project, the manufacturer of the apparatus made several improvements. Subsequently, the manufacturer changed the outlet so that a constant head of water was maintained instead of the situation where water exited vertically from the apparatus.

For the pavement cores, as previously mentioned, the asphalt concrete pavement layer to be tested was separated from the other asphalt layers, when necessary, by chiseling. The circumferential surface of the core or laboratory specimen was coated with a layer of petroleum jelly before being placed in the permeameter to prevent the flow of water along the surface. The specimen was placed on top of the bottom plate, the metal cylinder containing the membrane was placed over the specimen, and the top plate containing the graduated cylinder was placed on top of the specimen. Clamps were then used to compress and seal the bottom and top plates, and the hand pump on the apparatus was used to apply a sealing confining pressure of 96 → 7 kPa to the membrane surrounding the sides of the specimen.

The attached graduated cylinder was filled with water, and the permeameter was tilted and tapped gently to remove air bubbles. Water was then allowed to flow through the specimen by opening the valve on the bottom of the permeameter. The graduated cylinder was refilled to the top mark (approximately 800-cm head), the valve was opened, and the time required for the water to reach the lower mark (approximately 200-cm head) was recorded. The coefficient of permeability was computed according to the following formula. Three tests on the same specimen were performed and averaged. Although the correct engineering term for the quantitative measurement of permeability is *coefficient of permeability,* the term *permeability* is used in this report.

$$k = \left(\frac{\mathrm{A_2L}}{\mathrm{A_1t}}\right)\ln\left(\frac{h_1}{h_2}\right)$$

where

k = coefficient of permeability, cm/s

A_2 = graduated cylinder area, cm^2

L = specimen height, cm

A_1 = specimen area, cm^2

t = time to flow between heads, s

h_1 = initial head of water, cm

h_2 = final head of water, cm.

RESULTS AND DISCUSSION

Test Investigation

Since neither the investigator nor the technician staff had experience in performing permeability tests, preliminary tests were performed to gain experience and confidence in test results. Little published information was available concerning using these tests on asphalt concrete, so there were no standards to follow and particular testing variables needed to be examined.

During the preliminary testing, the confining pressure of the membrane against the outer surface of the specimen appeared to affect the permeability values in the falling head tests. This effect was insignificant for the constant head tests. Even though the confining pressure was identical for both methods, the difference might be related to the incompressible nature of the water for the constant head test versus the compressible properties of air for the falling head test. This observation prompted the ASTM task group to study confining pressure for the falling head test during an initial series of round-robin tests among members (see Table 2, which also provides the sealant results). The table compares the results of falling head tests by the task group (five laboratories), the results of falling head tests by the Virginia Transportation Research Council (VTRC), and the results of the constant head tests by VTRC. Tests were performed on identical specimens made in the VTRC laboratory using asphalt sampled from a construction project. The tests verified that confining pressure did influence permeability for the falling head test. These results indicated that flow was occurring between the specimen and membrane, which led to an overestimation of the permeability of the specimens.

Table 2. Effect of Confining Pressure and Membrane Sealant on Permeability

Source	Test Method	Permeability x 10^{-5} cm/s			
		69 kPa Confining Pressure		96 kPa Confining Pressure	
		No Sealant	With Sealant	No Sealant	With Sealant
VTRC	Falling head	216	3	168	3
ASTM task group (5 labs)	Falling head	216	3	168	3
VTRC	Constant head			13	7

FDOT proposed using a coating of petroleum jelly to help provide a seal between the membrane and specimen.[3] The ASTM task group studied the effect of petroleum jelly as a sealant in the round -robin tests. The results in Table 2 show that the petroleum jelly provided an effective seal against water flowing around the sides of the specimen.

The results showed no practical difference between results of the constant head test with and without sealant. The membrane appeared to produce an adequate seal without sealant. The ASTM task group is also looking at the effect of types of membranes in a second series of tests. The results of the constant head test were comparable with those of the falling head test when sealant was used for the tests with relatively low values of permeability. The constant head test was not operable for moderately permeable mixtures as discussed later.

The saturation of the specimen is important in obtaining consistent results. Two types of saturation procedures were tried on several specimens for the falling head test (Table 3). The permeability was measured on two sets of identical specimens before any saturation. Permeability was then measured on one set after a vacuum was applied to the top of the standpipe of the permeameter allowing water to be drawn from a source below the specimen

Table 3. Effect of Vacuum Methods

Specimen Set	Permeability x 10^{-5} cm/s		
	No Vacuum	Vacuum in Permeameter	Vacuum in Bowl
1	70	90	
2	68		53

through the specimen until the standpipe was filled. The permeability was measured on the second set after a residual pressure vacuum of 20 cm of Hg was applied for 5 minutes in a separate container before they were placed in the permeameter. For the first set with the vacuum applied to the permeameter standpipe, the permeability increased, indicating that more of the flow paths were filled with water. For the second set where the vacuum was applied in a separate container, the permeability decreased for no known reason. The specimens may have lost water after saturation when they were loaded into the testing device. The ASTM task group plans to explore the question concerning the method of saturation in more depth. Future attention needs to be placed on ensuring that the specimen is and remains saturated, which may be checked by measuring the amounts of inflow and outflow water during the test.

Another concern with testing cores is whether the sawing process used to separate layers smears asphalt over the voids, closes water passages, and affects permeability. As part of the ASTM task group testing, the effect of wet sawing to separate layers of field cores was determined. Two mixtures were tested before and after wet sawing 6 cm from the bottom of laboratory specimens 63 cm thick. The task group thought that the sawing of only 6 cm would not affect the results from the standpoint of thickness. One group was sawed at room temperature, and another group was sawed after cooling in an ice bath. The falling head permeability of both groups decreased approximately 50 percent as a result of sawing only the bottom surface (see Table 4). This much decrease is significant.

Table 4. Effect of Sawing on Permeability

Mixture Identification	Falling Head Permeability x 10^{-5} cm/s	
	Before Sawing	After Sawing
Sawed at Room Temperature		
1140	1250	700
1052	110	50
Sawed After Soaking in Ice Bath		
1140	1330	880
1052	170	80

The initial tests with the constant head device (Table 2) yielded low permeability values (less than 100 x 10^{-5} cm/s), which happened to be on rather dense mixtures. Additional testing on more permeable mixtures revealed the inability of the tubing and connections to allow the water to flow freely. The tubing and connections were enlarged as much as feasible, but the flow was still restricted. Therefore, the constant head equipment normally used for soils testing was not suitable to test asphalt mixtures that were more than moderately porous. Suitable equipment would consist of a constant head device without pressure controls but with the pressure applied by a water head that would allow lower pressure differentials between the inflow and outflow. Ideally, a very low pressure differential less than 3 kPa (0.5 psi) was required to obtain measurable flow, and this low differential could not be controlled with the available equipment.

The falling head device was simpler and quicker to use than the constant head device. The flow was probably not laminar when the mixtures were moderately porous, and the test results are thus not a true measure of permeability. However, the test still provides a practical indication of the susceptibility of mixtures to the passage of water. The falling head test device was used in all of the following permeability tests reported herein.

Field Cores

Cores were collected from various field projects in an attempt to determine the general magnitude of permeability for the mixtures in place. The results of the permeability tests on six types of mixtures are illustrated in Figures 3 through 8. There were four types of Superpave mixtures (nominal maximum aggregate size 9.5 cm, 12.5 cm, 19.0 cm, and 25.0 cm); a stone matrix asphalt (SMA) mixture; and an SM-2 mixture; which was Virginia's dense-graded 12.5-cm mixture designed by the Marshall method (see Table 1).

Examination of the scatter plots in Figures 3 through 8 reveals the relationship of individual mixtures to a linear regression and whether the regression differed from mixture to mixture. One would expect the regression of core results to be more variable than a similar regression of tests on specimens made in the laboratory. The connection and sizes of the voids of pavement samples can be affected by construction variables such as segregation, resulting in additional variability. When reaching general conclusions, one should keep in mind the small number of projects available for some mixtures. The semi-log plots of permeability versus pavement voids produced nearly linear regressions. Linearity could have been improved slightly if the plots had been log-log, but a graphic determination of matching permeability-void points on the graphs was easier with semi-log plots. Each project, i.e., mixture, produced a unique regression. If a single maximum allowable air void content were to be specified for each type of mixture (e.g., SM-12.5 cm), the void content corresponding to the most permeable mixture that would likely be encountered would have to be used to prevent pavement failures. Otherwise, every mixture would have to be tested to determine the voids level that would result in acceptable permeability.

FDOT did a similar study in 1996-97 to determine the maximum permeability that could be tolerated in their coarse-graded Superpave mixtures.[3] They determined that the maximum allowable permeability should be 100×10^{-5} cm/s, but they recently increased the value to 125×10^{-5} cm/s to accommodate the prototype ASTM permeameter. This value has been unofficially adopted as the acceptable level of permeability in Virginia for the present time. The percentage of the cores in the study that evidenced a higher permeability is listed in Table 1. Approximately one-half of the Superpave cores, except the 9.5-cm mixture, had permeabilities greater than 125×10^{-5} cm/s. Not only were the Superpave mixtures permeable, but 92 percent of the cores from Virginia's conventional dense-graded SM-2 mixture also had permeabilities

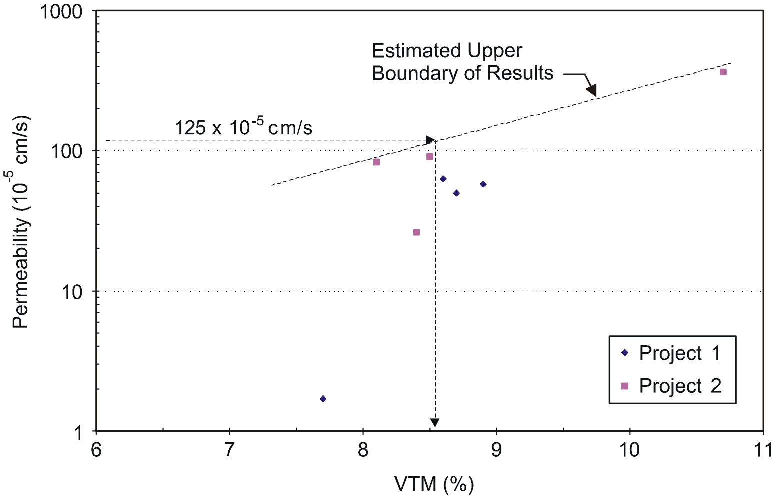

Figure 3. Core Permeability vs. VTM for Two 9.5-mm Projects

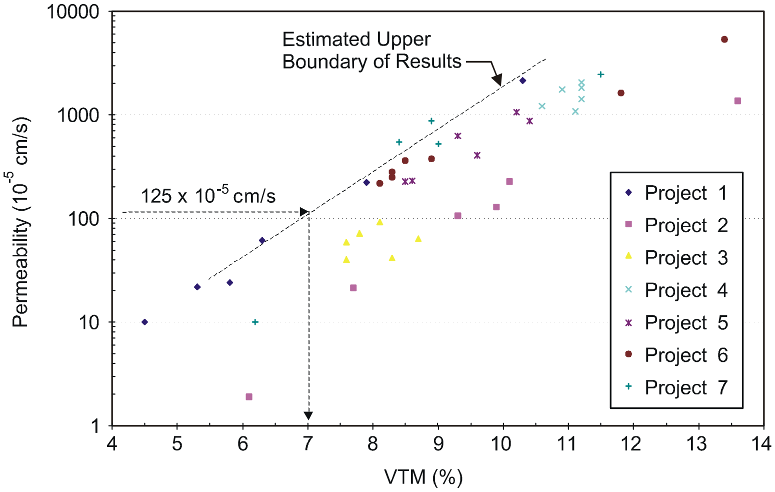

Figure 4. Core Permeability vs. VTM for Seven 12.5-mm Projects

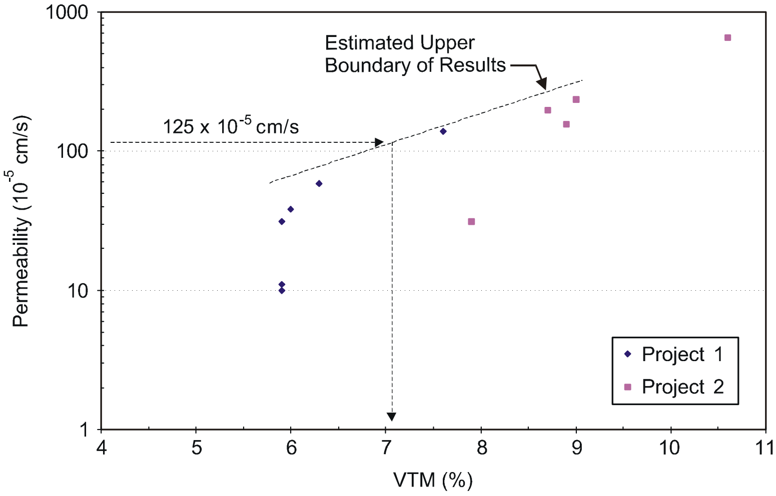

Figure 5. Core Permeability vs. VTM for Two 19.0-mm Projects

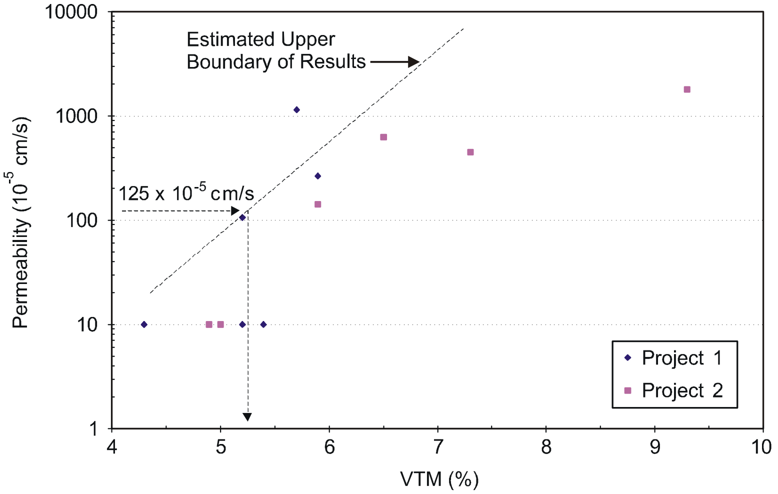

Figure 6. Core Permeability vs. VTM for Two 25.0-mm Projects

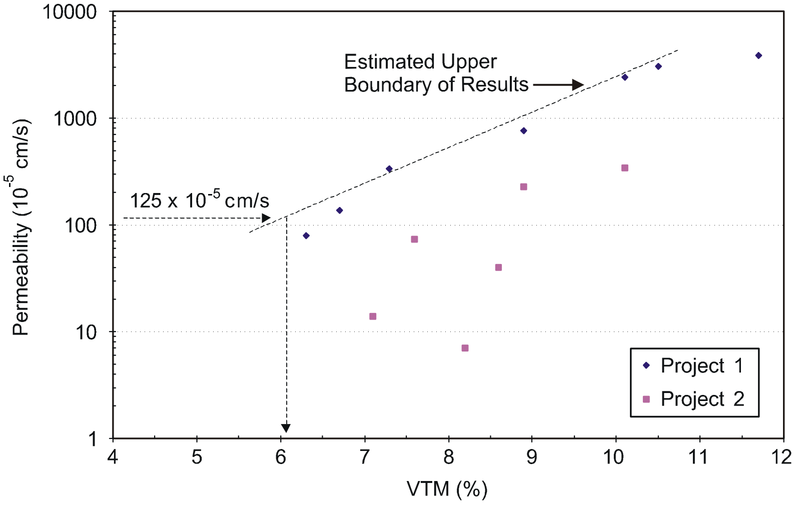

Figure 7. Core Permeability vs. VTM for Two SMA Projects

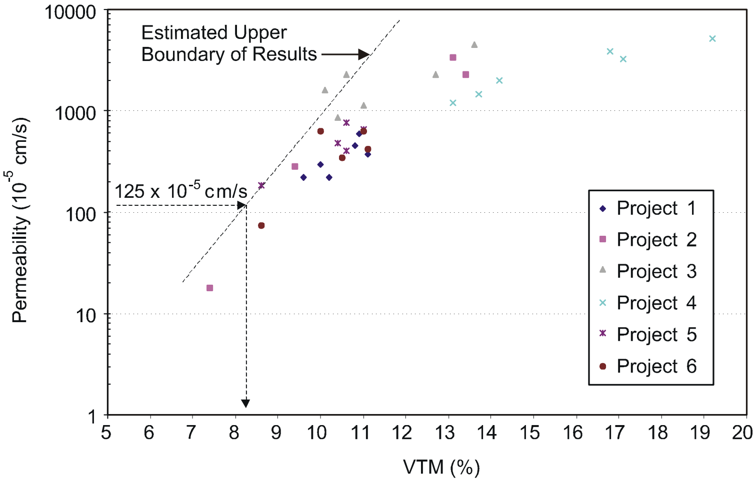

Figure 8. Core Permeability vs. VTM for Six SM-2 Projects

greater than 125 x 10^{-5} cm/s. This indicates that the high voids detected in the previously cited stripping investigation did promote excessive permeability. It is evident from Figures 3 through 8 that voids are higher than desirable.

An upper boundary line of test results was used to estimate the maximum voids content that could be tolerated and still maintain permeability less than 125 x 10^{-5} cm/s for each type of mixture (see Table 1). The author felt that visual estimation was the best method to establish an upper boundary for the type of data collected in this study, and a more rigorous analysis would not have been advantageous. The other alternative would have been to combine and analyze all projects into a single regression, which would not have given a good correlation. As the maximum aggregate size is increased, the void content must be decreased to maintain acceptable permeability. Mixtures with large aggregate particles tend to have larger voids, which probably tend to interconnect more than smaller voids. The Superpave 25.0-cm base mixture should have less than 5.0 percent voids to achieve an acceptable permeability, whereas the 9.5-cm mixture should have less than only 8.5 percent voids to achieve acceptable permeability. A possible complicating factor could be that the void content measured for the mixtures with large aggregate may be less than the actual void content because of difficulties in correctly measuring voids of mixtures with large aggregate. Other aggregate properties such as shape could affect permeability, but making such a determination is beyond the scope of this study.

Comparison of Laboratory Specimens and Field Cores

The scatter plots of permeability versus voids for each of six mixtures are shown in Figures 9 through 14. Each plot shows the permeability of laboratory specimens at various void contents and cores of the same mixture extracted from the pavement. The laboratory regressions produced an R^2 ranging from 0.93 to 0.97, which was very good. No regression determinations were made for the field cores because of the small number of cores available for each mixture and the inability to obtain a wide range of void contents per mixture. The plots were visually

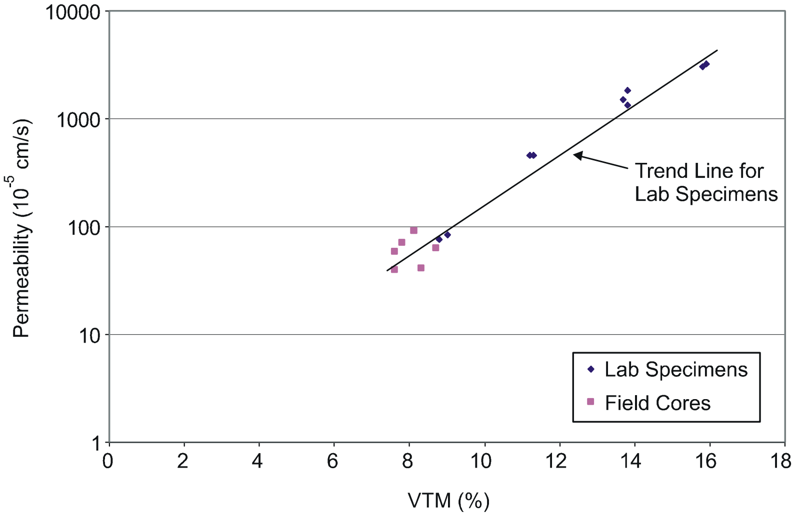

Figure 9. Lab and Core Permeability vs. VTM for Project 1 (12.5 mm)

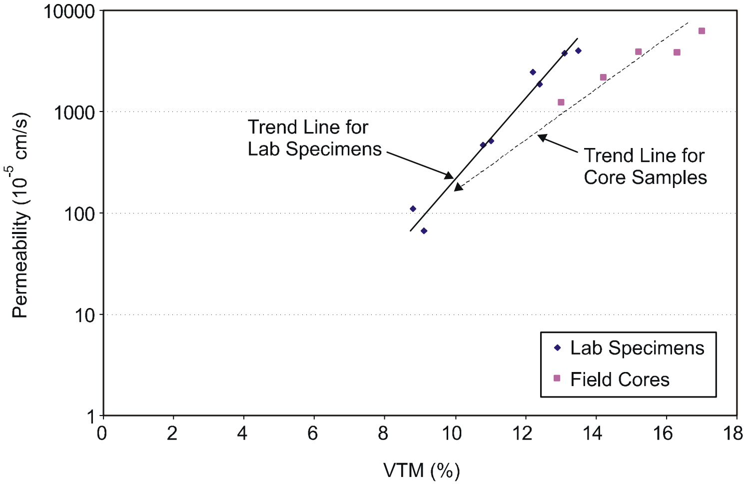

Figure 10. Lab and Core Permeability vs. VTM for Project 2 (SM-1)

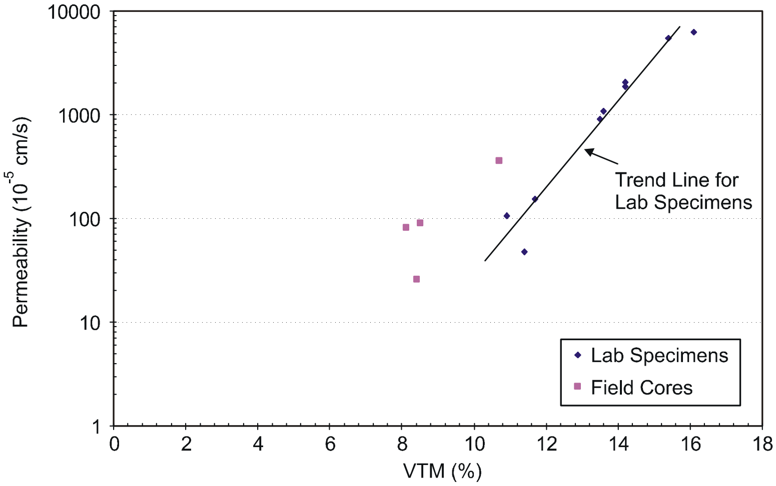

Figure 11. Lab and Core Permeability vs. VTM for Project 3 (9.5 mm)

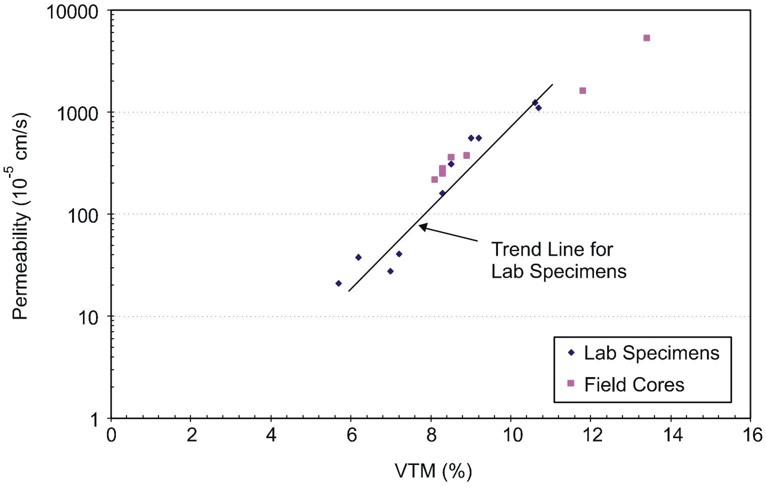

Figure 12. Lab and Core Permeability vs. VTM for Project 4 (12.5 mm)

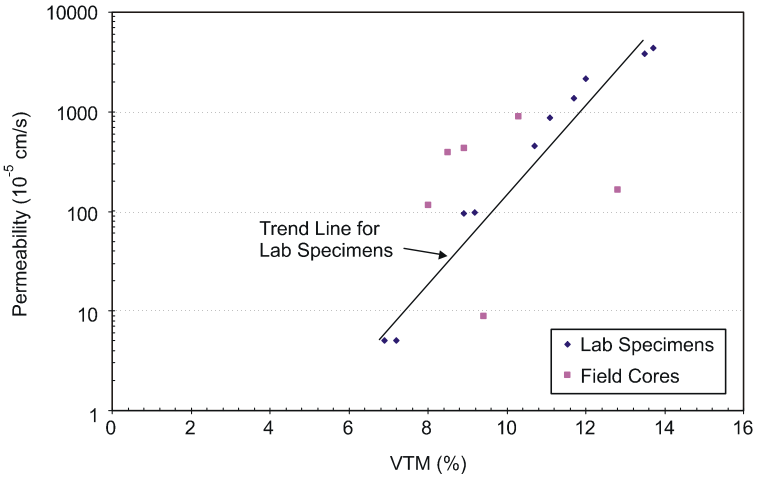

Figure 13. Lab and Core Permeability vs. VTM for Project 5 (12.5 mm)

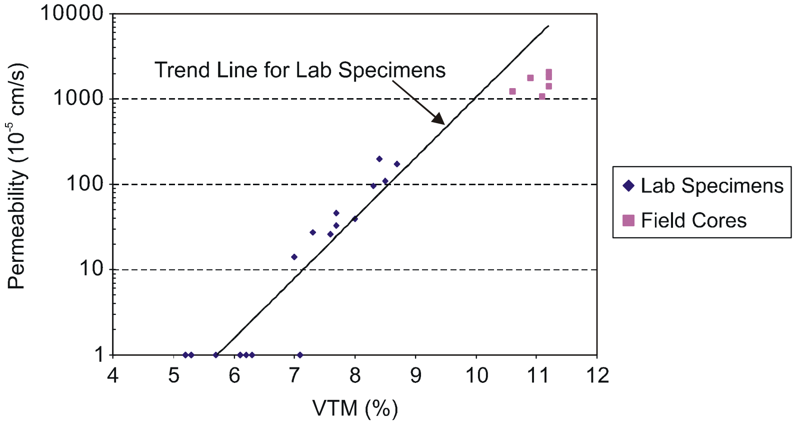

Figure 14. Lab and Core Permeability vs. VTM for Project 6 (12.5 mm)

examined to determine how well the field cores matched the laboratory regressions. The agreement between the laboratory regressions and field core plots of permeability versus air void content is summarized in Table 5.

Table 5. Comparison of Permeability for Laboratory Regressions and Field Cores

Project	Agreement Between Laboratory Regression and Field Cores	Comments
1	Yes	Good agreement
2	Yes	Fair agreement at construction VTM of 8%
3	No	Field cores give higher permeability
4	Yes	Good agreement
5	Yes	Large variability in field cores
6	Yes	Good agreement

The permeability of field cores for project 1 appeared to coincide with the regression of the laboratory specimens. Although all of the cores showed a field permeability that far exceeded acceptable values for project 2, it appears from projected core values that the field and laboratory specimens produced similar results at the typical pavement voids total mix (VTM). The specimens prepared in the laboratory for project 3 were less permeable than field cores with the same void content and could not be used to predict field permeability. The permeability of field cores matched the permeability of specimens prepared in the laboratory at the same void content for project 4. The permeability of field cores for project 5 was so variable it was difficult to determine how well it matched the permeability of laboratory specimens. Although the variability was high, the average permeability of the cores appeared close to the permeability of the laboratory specimens at similar void contents. There were problems with quality control for this mixture in the field, which probably accounted for the permeability variability of field cores. Segregation would be the most logical reason for the variability. The projected laboratory regression line for project 6 fell reasonably close to the average for field cores, indicating agreement between field cores and the laboratory regression. The slope of the line was very steep, indicating that permeability is very sensitive to changes in the VTM of the mix.

Figures 15 and 16 show the gradation and trend lines, respectively, for each laboratory mixture. Each mixture had a unique permeability-voids relationship. Attempts were made to relate gradation to permeability mathematically, with no success. The mixture with the most exaggerated *S*-shaped gradation curve was least permeable. The mixture with the coarsest aggregate (+9.5 cm) was most permeable.

Four of the six mixtures were designed as 12.5-cm mixtures, one was designed as a 9.5-cm mixture, and the SM-1 mixture would have met the 9.5-cm gradation requirements. If only the four 12.5-cm mixtures are examined, there is a range of 510 x 10^{-5} cm/s (i.e., 550 ← 40) for the permeability at 9 percent VTM (Figure 17). Similarly, if the range of void content at the acceptable permeability level of 125 x 10^{-5} cm/s is examined, it is rather high at about 3 percent VTM (i.e., 7.5 ←10.2). This observation indicates that specifying a special void content for a mixture type to achieve a particular permeability level may be difficult.

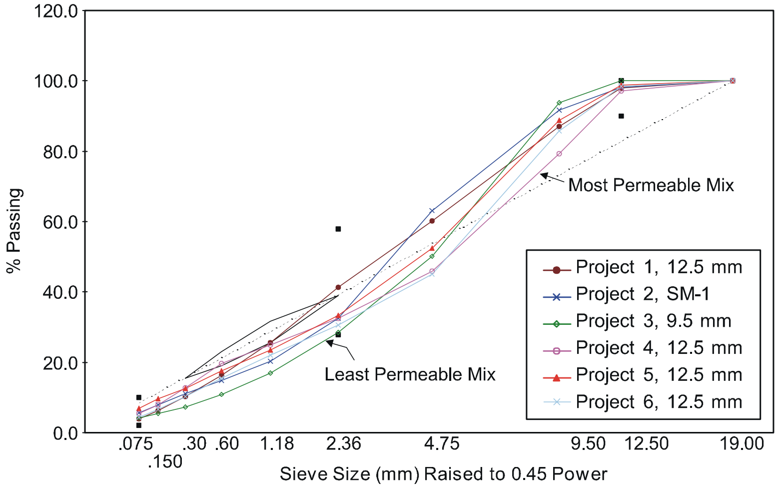

Figure 15. Gradation of Mixtures for Lab Specimens

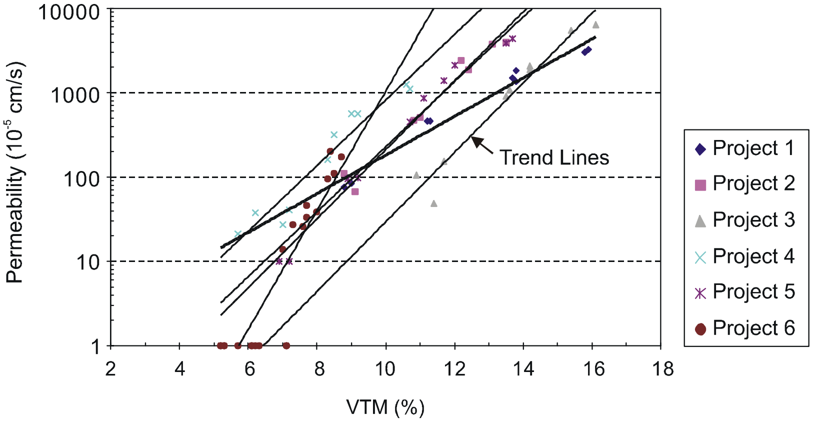

Figure 16. Permeability vs. VTM for Lab Specimens

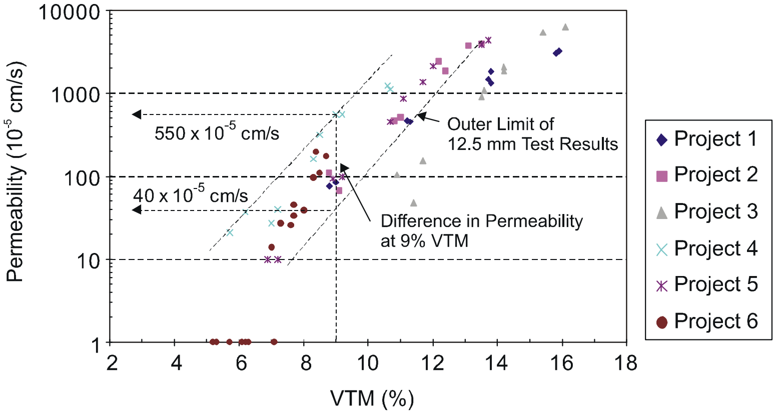

Figure 17. Permeability vs. VTM for Individual Lab Test Results

Test Variability

Field Cores

Sites were selected that had pavement air voids with a standard deviation less than 1.3 percent. A standard deviation of 1.3 was listed as a typical variation for field voids in a 1996 NCHRP synthesis report.[7] The standard deviations and means for each site were plotted and a linear regression was developed to get the coefficient of variation (COV) from the slope of the regression line; i.e., COV = standard deviation/mean (Figure 18). The COV for the 13 sets of data that were selected was 44 percent.

The number of samples required to maintain a particular confidence interval based on sample variance and target values was calculated. Table 6 shows the confidence limits for target

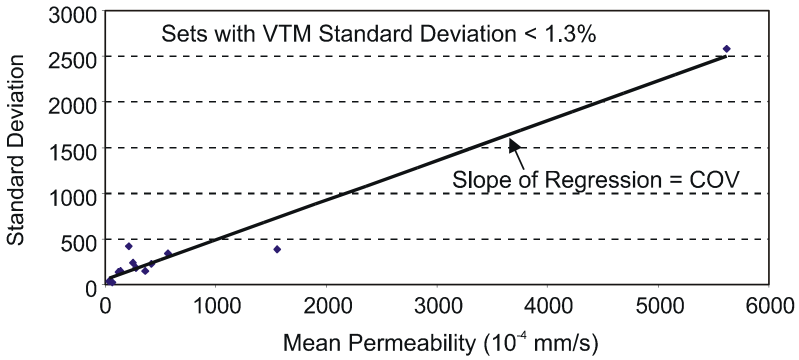

Figure 18. Coefficient of Variation for Projects with a VTM Standard Deviation Less than 1.3%

Table 6. Confidence Limits for Permeability of Cores at Two Acceptance Levels

No. Samples	$t_{0.05}$	Confidence Limits
If the allowable average permeability = 125; *σ = COV(average) = 0.44(125) = 55*		
2	2.920	114
3	2.353	75
4	2.132	59
5	2.015	50
6	1.943	44
7	1.895	39
8	1.860	36
If the allowable average permeability = 50; *σ = COV(average) = 0.44(50) = 22*		
2	2.920	45
3	2.353	30
4	2.132	23
5	2.015	20
6	1.943	17
7	1.895	16
8	1.860	14

Note: Permeability values should be multiplied by 10^{-5} cm/s.

values of 125 and 50 x 10^{-5} cm/s if the standard deviation is based on a COV of 44 percent. The formula for small sample confidence limits for a one-tailed test is:[8]

$$\text{Maximum average permeability} = y + t_{\alpha}(\sigma/\mathrm{sqrt}[n])$$

where

y = target mean permeability value

t_{α} = t distribution values for specific confidence levels

σ = standard deviation

n = sample size.

For instance, if an average permeability of 125 x 10^{-5} cm/s is desirable, then the inherent variability of the testing at a 95 percent confidence level requires that an average of four permeability tests on cores must yield less than 125 + 59 = 184 x 10^{-5} cm/s. Specification limits could be set based on any practical sample size. If the value of 125 x 10^{-5} cm/s is the maximum permissible value for the specification limit, an average of four tests should be set at 125 - 59 = 66 x 10^{-5} cm/s.

Laboratory Specimens

Three SM-12.5-cm mixtures were compacted at various void contents, and three to five samples were tested for permeability at each void content to get an indication of testing variability by a single operator (see Table 7). The COV for each set ranged from 0 to 133 percent. The range of values of any set shows that individual test values can differ significantly, especially at levels above 100 x 10^{-5} cm/s. If average values are targeted around 50 or less, the individual values generally remain below 100 x 10^{-5} cm/s.

Table 7. Variability Data for Laboratory Specimens

Mixture	Average VTM	Permeability x 10^{-5} cm/s		
		Average	Standard Deviation	Range and (Coefficient of Variation)
1102	7.5	3	4	0-8 (133)
	8.8	23	14	7-42 (61)
	11.0	271	269	104-743 (99)
	11.0	302	26	278-339 (9)
	11.4	576	108	454-716 (19)
1122	5.3	0	0	0 (0)
	6.2	0	0	1 (0)
	7.1	10	13	0-27 (130)
	7.8	36	8	26-46 (22)
	8.5	144	50	95-200 (34)
1134	8.5	289	210	71-487 (73)
	9.7	686	196	521-958 (29)
	10.2	1085	251	882-1450 (23)
	10.9	1903	204	1740-2200 (11)
	12.0	3123	383	2690-3620 (32)

Note: Each result indicates an average of 3 to 5 samples. Permeability tests were repeated 3 times per sample.

Repeat Tests by a Different Operator

Two of the mixtures discussed in the previous paragraph had also been tested by a different operator in the part of the investigation that correlated laboratory tests with field core results. Both operator regressions were plotted to determine if there were differences between repeat tests by different operators. The mixture from project 1 shown in Figure 19 produced regressions with different slopes for the two operators. The mixture from project 5 shown in Figure 20 produced regressions with similar slopes but were displaced from each other considerably. In other words, the predicted permeability would differ considerably at the typical constructed pavement void content of 8 percent. Sampling variability associated with obtaining the same mixture from different containers could have caused some of the difference. These attempts to duplicate previous laboratory regressions showed that the repeatability between test series may be a problem. A ruggedness study may be used to identify testing factors that affect results so that they can be more closely controlled.

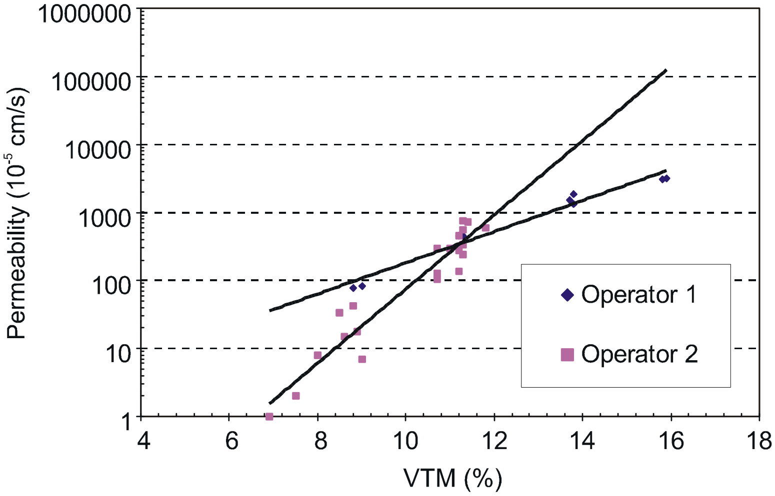

Figure 19. Lab Regressions by Different Operators for Project 1 (12.5 mm)

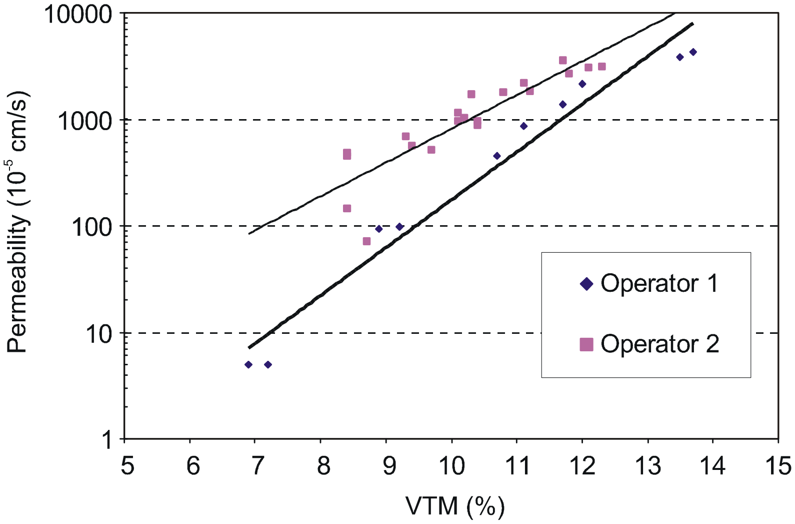

Figure 20. Lab Regressions by Different Operators for Project 5 (12.5 mm)

Use of Regression as a Prediction Tool

Figure 21 shows a regression plot of project 5 from the laboratory results by the first operator. This is shown as an example of the type of plot that may be used during the design phase to ensure that the mixture will be impervious. The regression would be developed by making and testing the mixture at several void contents, and the maximum allowable void content would then be selected at the specified allowable permeability value. The predicted maximum allowable void content would be used as a minimum target void content for field compaction to ensure pavement imperviousness. Just for illustration, Figure 21 shows the 95 percent confidence interval for the regression line and the 95 percent confidence interval for predicted values. For this plot, the prediction interval appears to be approximately →1 percent VTM; therefore, it is evident that there is an inherent uncertainty involved in obtaining a target void content. This variation must be considered when specifications are developed for the design procedure.

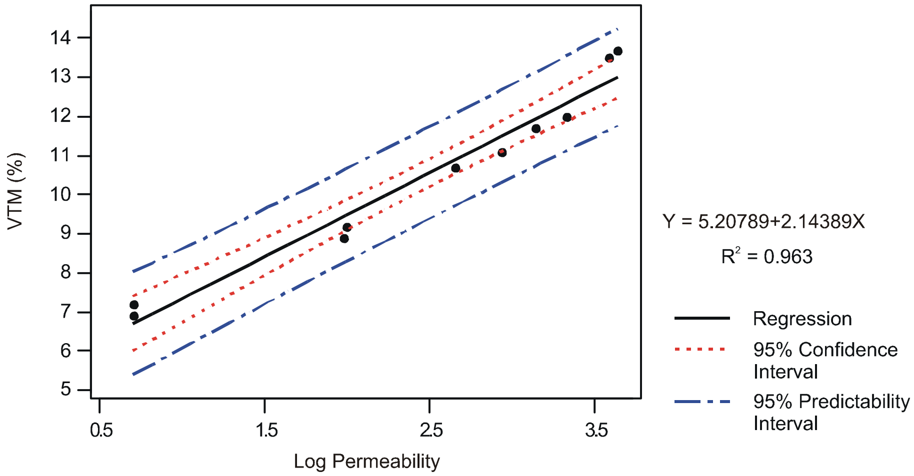

Figure 21. Typical Lab Regression

FINDINGS AND CONCLUSIONS

- For asphalt mixtures, the falling head test apparatus is better suited than the constant head test apparatus used in this study. The constant head apparatus did not allow the low-pressure differentials necessary to measure water flow in semiporous mixtures.

- A sealant is needed to prevent water flow along the sides in the falling head test.

- Sawing decreases permeability significantly; therefore, alternative methods of separating layers should be sought.

- A large number of the field cores tested had excessive permeability.

- All of the mixtures had unique permeability-voids relationships. The minimum voids required to achieve acceptable permeability varied even within the Superpave 12.5-cm gradation band.
- Generally, fine mixtures (small maximum aggregate size) tend to be less permeable than coarse mixtures.
- Permeability tests on laboratory specimens indicated general field permeability in five of six cases. Further work in using laboratory design to predict field permeability is warranted.
- Limited repeat tests for laboratory regressions by different operators indicated differences that need to be investigated with further ruggedness testing.

FUTURE RESEARCH AND TEST IMPLEMENTATION

The falling head test continues to be improved by the ASTM task group and individuals using the test. It is currently useful as a rough design tool to minimize water flow in asphalt mixtures; however, additional testing is needed to make it useful as a mixture design tool. It may not be prudent to set specification limits for field cores until a laboratory design test method is available. The following steps are recommended:

1. Some VDOT district materials laboratories should purchase the falling head equipment so that the variation among operators and laboratories can be determined. This would also allow VDOT districts to begin running the test as a guide in analyzing mixtures.
2. A ruggedness study should be conducted if excessive variability is evident from the district variability study.
3. A study to determine the feasibility of designing mixtures for minimum permeability should be undertaken to determine if acceptable permeability can be achieved and other design parameters, such as rutting, can be controlled.

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