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Correlation of Laboratory-Compacted and Field-Compacted Hot-Mix Asphalt Permeability

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16. Abstract

This report presents a summary of results, analysis, and development of a protocol for testing permeability of asphalt specimens prepared in the laboratory or produced from field cores. The objective of the research project was to evaluate the correlation between the laboratory-measured permeability of laboratory prepared specimens and the laboratory-measured permeability of corresponding field cores. Field cores and loose, hot-mix asphalt samples were obtained from six constructed pavements. Four were 9.5-mm Superpave mixes and two were 12.5-mm mixes. Falling head permeability tests were conducted on both field cores and Superpave gyratory compacted (SGC) specimens covering a range of air voids and porosities. These tests indicated that in general permeability increases as the air void or porosity increases. For the 12.5-mm mixes, a porosity level of approximately 7 to 8 percent for both field cores and lab-compacted specimens seems to be a threshold value beyond which permeability begins to increase drastically. For the 9.5-mm mixes, the cores and lab-compacted specimens could be considered practically impervious for porosities lower than 8 percent. In general, laboratory-prepared specimens demonstrated lower permeability compared with field cores at comparable levels of porosity and thickness, even though no unique correlation could be developed between the two. Based on these results, the acceptable maximum permeability for laboratory-prepared specimens was considered lower than that of field cores. Finally, a permeability test protocol was developed based on the results of this investigation. The upper limits of 1.25×10^{-3} cm/sec and 1.5×10^{-3} cm/sec are recommended for SGC specimens and field cores, respectively, assuming specimens have air void and thickness levels established in the test protocol proposed under this research.

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INTRODUCTION

In general, it is desirable to limit the permeability of dense-graded hot-mix asphalt (HMA) pavement to prevent the ingress of water, which potentially could result in premature failure of the pavement. This report summarizes the results from a research project that was initiated by the Pennsylvania Department of Transportation (PennDOT) to address issues concerning hot-mix asphalt permeability, specifically to determine the relationship between the permeability of laboratory-compacted specimens and corresponding field cores. Based on such correlation, PennDOT may utilize permeability tests as part of its specified HMA mix design procedure.

Research Objectives, Approach, and Scope of Work

The main objective of this research project was determination of the permeability of laboratory-prepared specimens and field cores and the correlation between the two. Under this research, work was conducted in two phases. Under Phase I, a series of laboratory permeability tests were conducted and the correlation between permeability of lab-prepared specimens and field cores was investigated. Details of such testing and corresponding analysis are covered in an interim report for Phase I submitted to PennDOT (Solaimanian and Raisi, 2009). In this final report, only a summary of Phase I test results is presented. Under Phase II, included in this report, based on the laboratory test results of Phase I, a laboratory permeability test protocol was developed that may be used as part of the mix design for HMA.

Six mixes were included in the study. Phase I of this project was completed in November 2009 and the corresponding interim report was submitted to PennDOT in December 2009. Two of the mixes tested in Phase I were Superpave mixes with 12.5-mm nominal maximum aggregate size (NMAS). The remaining four mixes were 9.5-mm NMAS Superpave mixes. Phase II included development of the test protocol, as will be discussed in this report.

Test Procedures and Computations

For laboratory permeability testing, for simplicity, a one-dimensional vertical flow through the specimen was utilized (Figure 1). The test results were analyzed and interpreted based on Darcy's Law, which presents the following formula.

$$q = kiA \qquad (1)$$

where

q = flow rate (amount of flow per unit of time)
k = coefficient of permeability (for example, in cm/sec)
i = hydraulic gradient
A = area through which water permeates

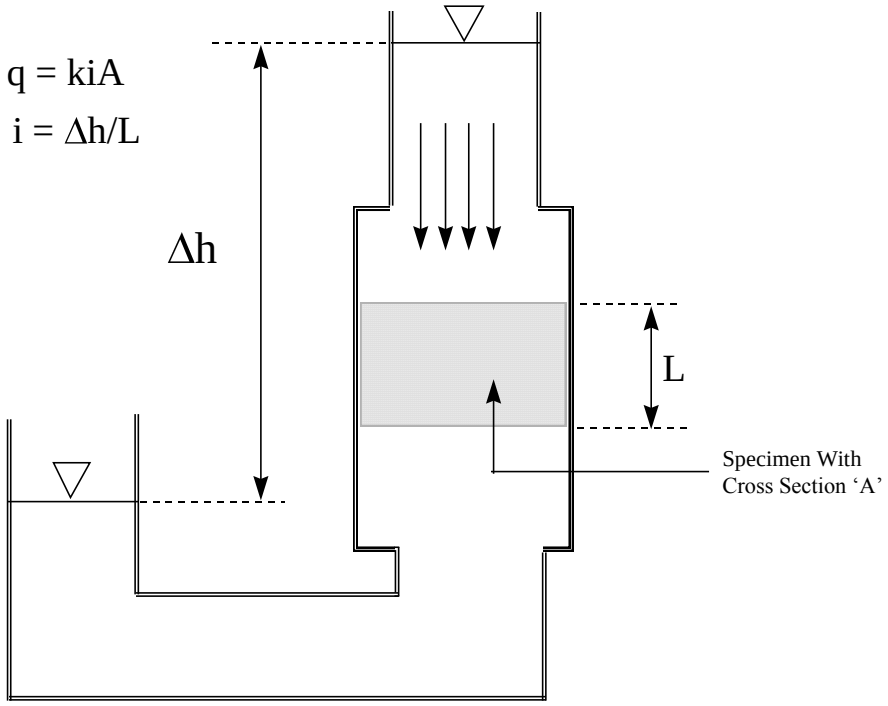

Figure 1 Schematic diagram demonstrating the concept of Darcy's Law

The Karol Warner permeameter was used for this research (Figure 2). Briefly, the equipment consists of a metal cylinder to house the specimen and a graduated cylinder to provide the pressure head required for water to permeate through the specimen. A rubber membrane inside the metal cylinder is pressurized to seal the specimen walls and to prevent water flow around the specimen. The device is equipped with a pressure gage and a hand pump.

Figure 2 Picture of Karol-Warner permeameter used for this research

Permeability tests were conducted under falling water head according to the PennDOT-modified version of the ASTM Test Method PS 129. In the test procedure, first the specimen is subject to vacuum saturation using the procedure explained in ASTM PS 129. To begin the test, the graduated stand is filled with water to a marked level. The water head drops as permeation through the specimen takes place. The rate of vertical flow of water is determined based on the amount of flow within a specific time. In the test, to ensure that water leakage from the specimen sides is prevented, the specimen was confined in a rubber membrane and a constant pressure of approximately 14 psi was applied to the membrane prior to conducting the test. This level of pressure was maintained throughout the test to ensure that side leakage did not occur. The coefficient of permeability was then calculated from Equation 2.

$$k = \frac{al}{At} LN\left(\frac{h_1}{h_2}\right) \qquad (2)$$

where *LN* implies natural logarithm and:

k = coefficient of water permeability, cm/sec
a = inside cross-sectional area of inlet standpipe, cm^2
l = thickness of test specimen, cm
A = cross-sectional area of test specimen, cm^2

t = average elapsed time of water flow between timing marks, sec
h_1 = hydraulic head on specimen at time t_1, cm
h_2 = hydraulic head on specimen at time t_2, cm

Details of test procedures are discussed in the interim report.

SUMMARY OF RESULTS FROM PHASE I INVESTIGATION

Phase I included laboratory testing and analysis of test data. Details of all Phase I tests and corresponding analysis are covered in the interim report. A summary is provided in this report.

Materials

The hot-mix asphalt field cores and loose box samples and the corresponding documentation for this project were received at the Northeast Center of Excellence for Pavement Technology (NECEPT) laboratories according to Table 1.

Table 1 Materials tested during Phase I of this research

County	Highway	NMAS, mm	Dates of Receiving Road Cores	Dates of Receiving Loose Box Samples (LSS) or Lab Compacted Specimens (SGC)
Dauphin	SR 0300	12.5	5/22/2007, 10/19/2007	1/7/2008, 2/26/2008 (LSS)
Schuylkill	SR 0081	9.5	8/1/2008	8/1/2008 (LSS)
Lawrence	SR 0079	9.5	10/15/2008	10/15/2008, 11/6/2008 (LSS)
York	SR 2007	12.5	7/16/2009	7/16/2009 (SGC)
Bedford	SR 0026	9.5	7/21/2009	7/21/2009 (SGC)
Somerset	SR 0281	9.5	7/21/2009	7/21/2009 (SGC)

Testing Specimens

Determination of Air Voids and Porosity

Prior to conducting permeability tests, the bulk specific gravity and porosity of both field cores and lab-compacted specimens were measured according to AASHTO T166 and ASTM D6752. Details are covered in the interim report.

Preparation of Laboratory Specimens

Loose materials from boxes of the same project were blended together for uniformity before preparation of individual specimens. Each specimen was prepared from this blended mix to be a better representative of the produced mix in general. Specimens were prepared at a range of air voids (approximately 3 to 10 percent) and two different thicknesses (approximately 60 mm and 100 mm).

Permeability Tests

The permeability test for specimens was conducted according to the PennDOT version of ASTM PS 129. Both field cores and lab specimens were tested in a similar manner, with the exception of one difference in the way the side of the specimen was coated. Following the provisional standard PS 129, petroleum jelly sealant was applied to the sides of the lab-compacted specimens, whereas no sealant was used for the field cores. The purpose of the sealant was to aid in preventing side leakage.

Summary of Results from Laboratory Tests

Table 2 and Figure 3 provide a summary of results from permeability tests for both field cores and SGC lab specimens. It was observed that, in general, field cores had a higher permeability than lab-prepared specimens for a similar range of porosities. The range of porosities for which values are reported range from almost 1 percent to as high as 12 percent. Detailed data for each tested mix are presented in Figures 4 through 13. It should be noted that in these graphs, the same scale is used to present permeability for different mixes. However, for some mixes, specifically those with extremely low permeability, a second graph is included at a narrower range of permeability to more clearly indicate the porosity-permeability relationship.

Table 2 Range of porosity and permeability for the tested mixes

Project	Field Cores		SGC Specimens	
	Porosity Range, %	K Range, cm/sec	Porosity Range, %	K Range, cm/sec
Dauphin SR 300, 12.5-mm mix	1.1 to 10.4	0 to 5.7×10^{-3}	1.9 to 9.8	0 to 4.3×10^{-3}
Schuylkill I-81, 9.5-mm mix	3.1 to 8.2	0 to 5.7×10^{-4}	0.9 to 9.2	0 to 1.05×10^{-3}
Lawrence SR 79, 9.5-mm mix	1.3 to 7.7	0 to 2.4×10^{-4}	2.3 to 8.6	0 to 0.6×10^{-4}
York SR 2007, 12.5-mm mix	1.8 to 6.1	1.9×10^{-5} to 1.5×10^{-4}	5.7 to 11.7	0 to 8.1×10^{-3}
Bedford SR 0026, 9.5-mm mix	2.2 to 8.6	0 to 7.8×10^{-4}	5.2 to 11.7	0 to 6.0×10^{-3}
Somerset SR 0281, 9.5-mm mix	1.3 to 10.0	0 to 1.5×10^{-3}	5.3 to 11.6	0 to 2.8×10^{-3}

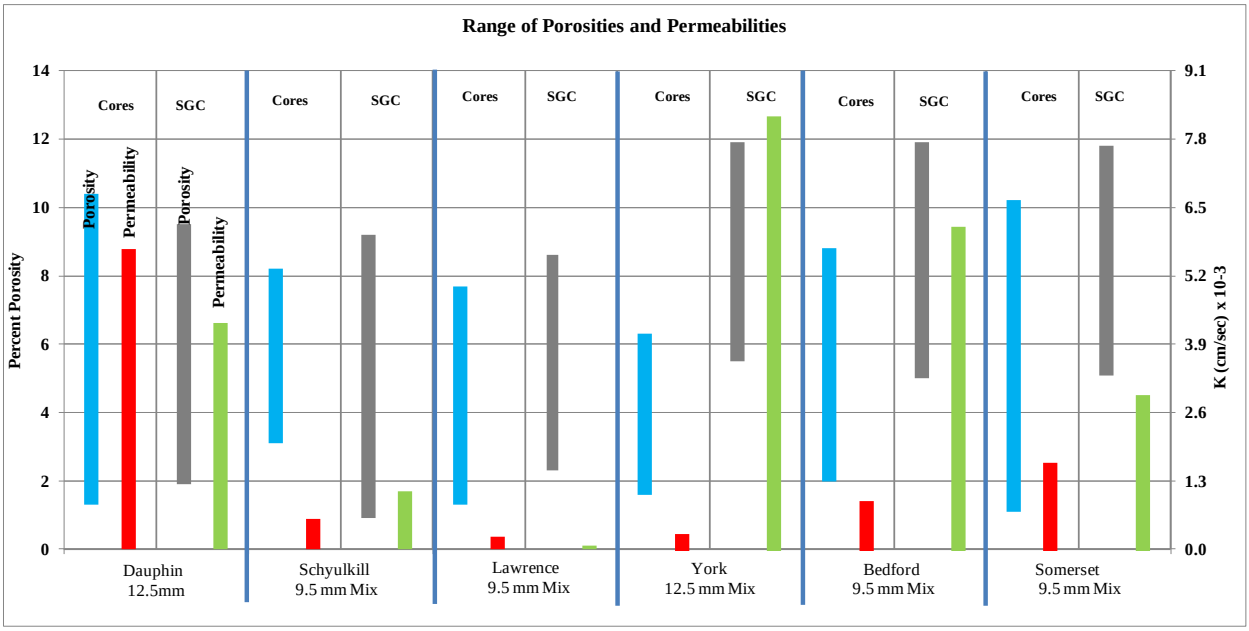

Figure 3 Range of porosity and permeability for the tested mixes

Considering the two 12.5-mm mixes, a comparable range of porosity exists between the field cores and lab-prepared specimens (SGC specimens) for the Dauphin mix but not for the York mix. The latter has a tighter range of porosity for field cores (2 to 6 percent) and a wider range for SGC specimens (6 to 12 percent). This discrepancy in the range of porosities makes it difficult to investigate how the permeability of lab specimens and permeability of field cores compare for the York 12.5-mm mix.

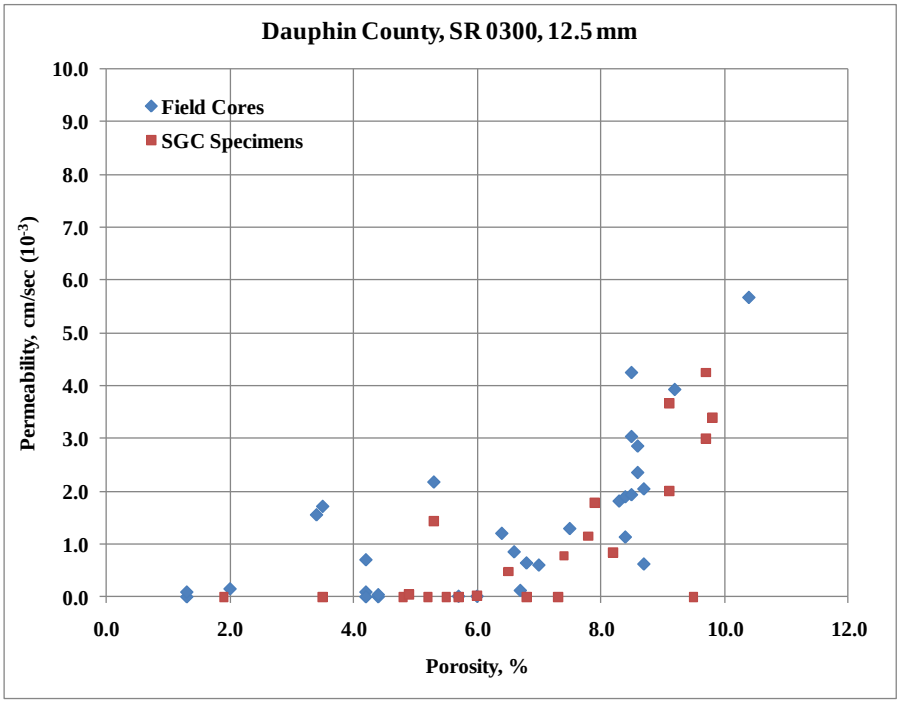

Figure 4 Permeability versus porosity for the 12.5-mm mix of SR 0300, Dauphin County

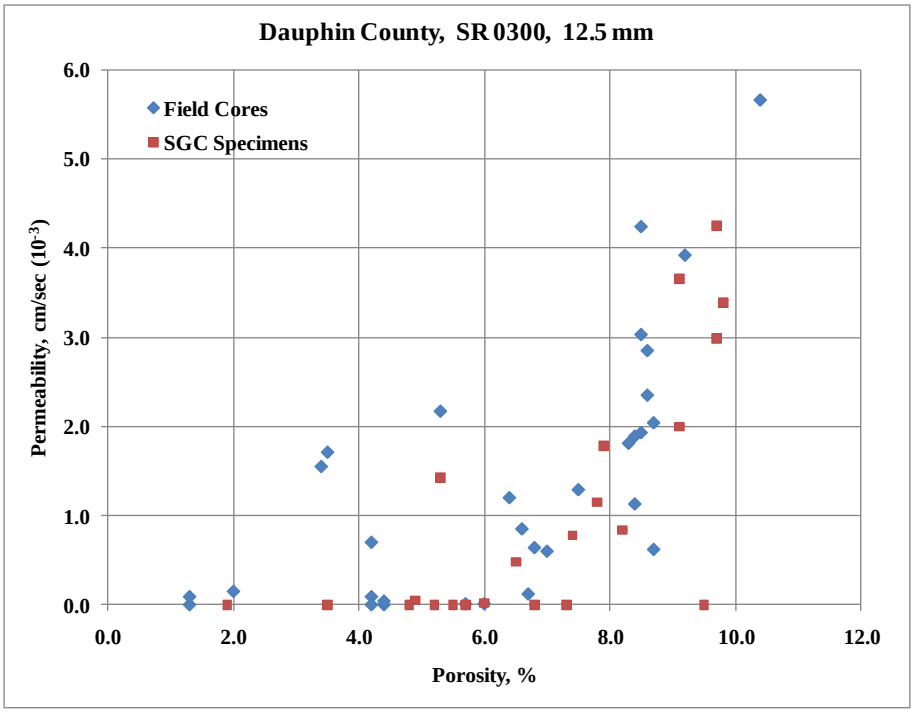

Figure 5 Permeability versus porosity for the 12.5-mm mix of SR 0300, Dauphin County

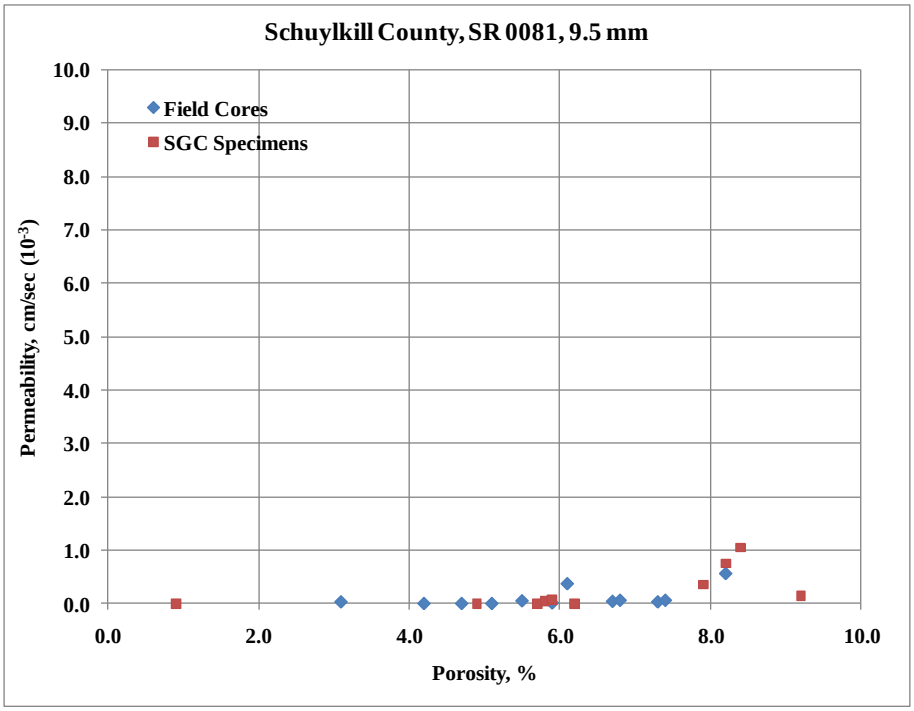

Figure 6 Permeability versus porosity for the 9.5-mm mix of SR 0081, Schuylkill County

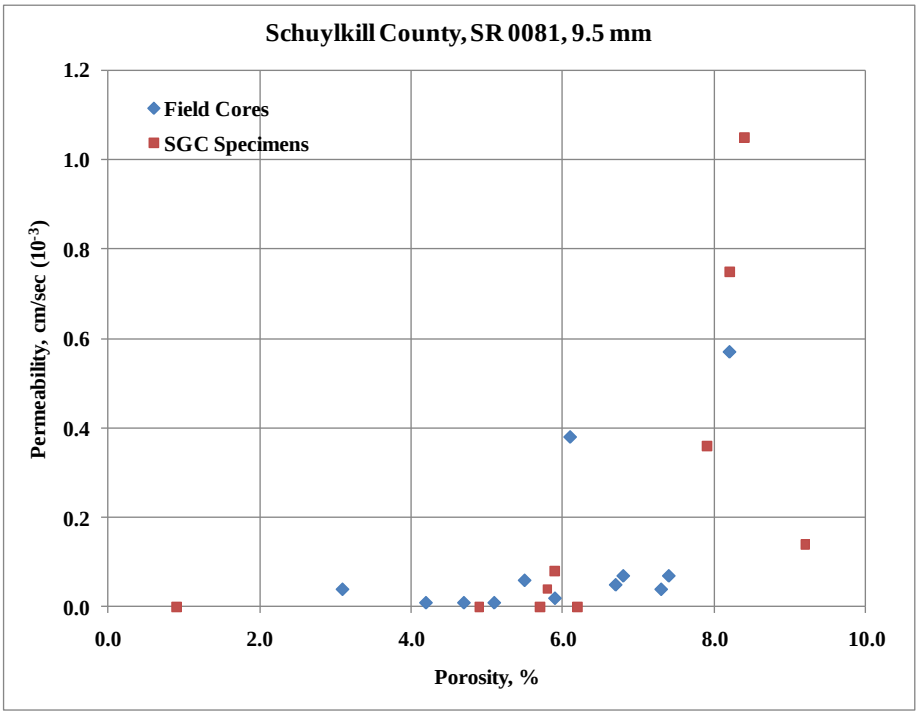

Figure 7 Permeability versus porosity for the 9.5-mm mix of SR 0081, Schuylkill County

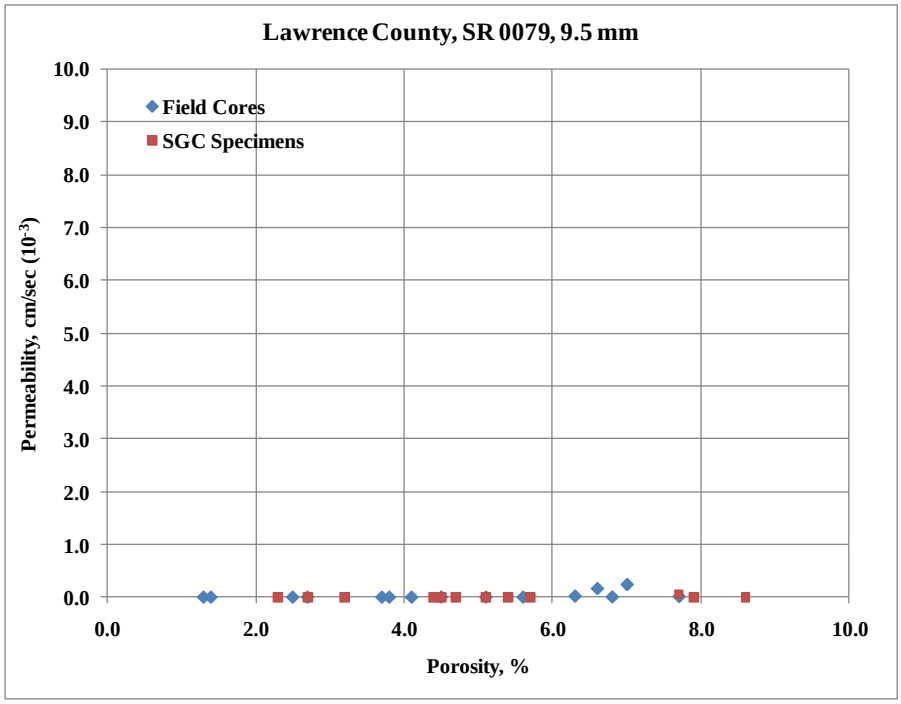

Figure 8 Permeability versus porosity for the 9.5-mm mix of SR 0079, Lawrence County

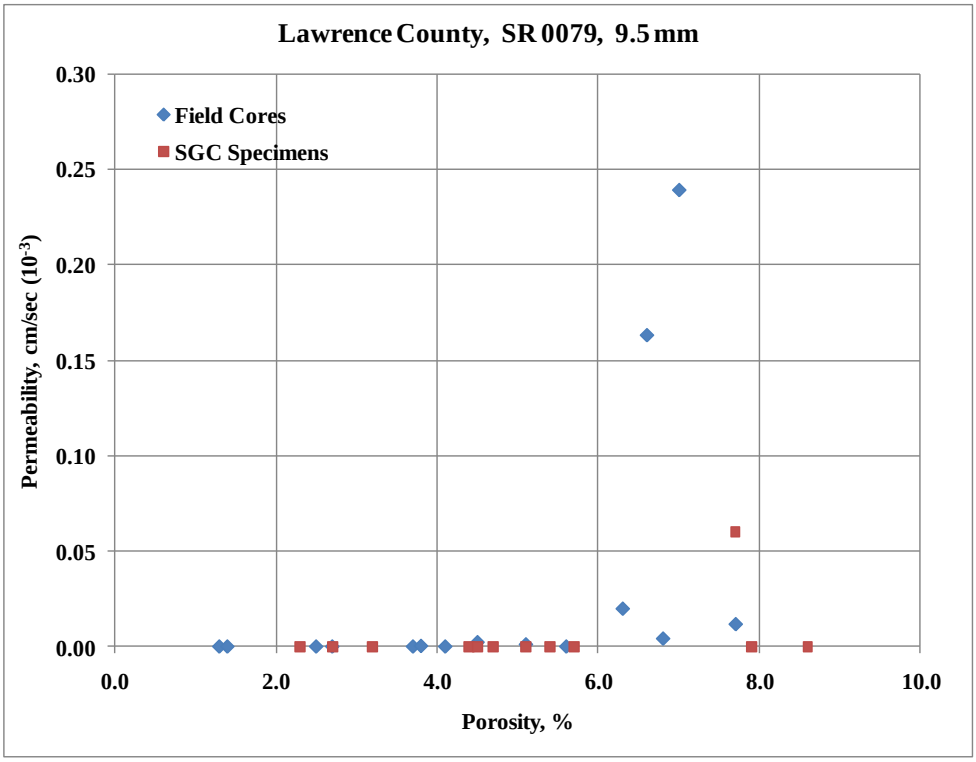

Figure 9 Permeability versus porosity for the 9.5-mm mix of SR 0079, Lawrence County

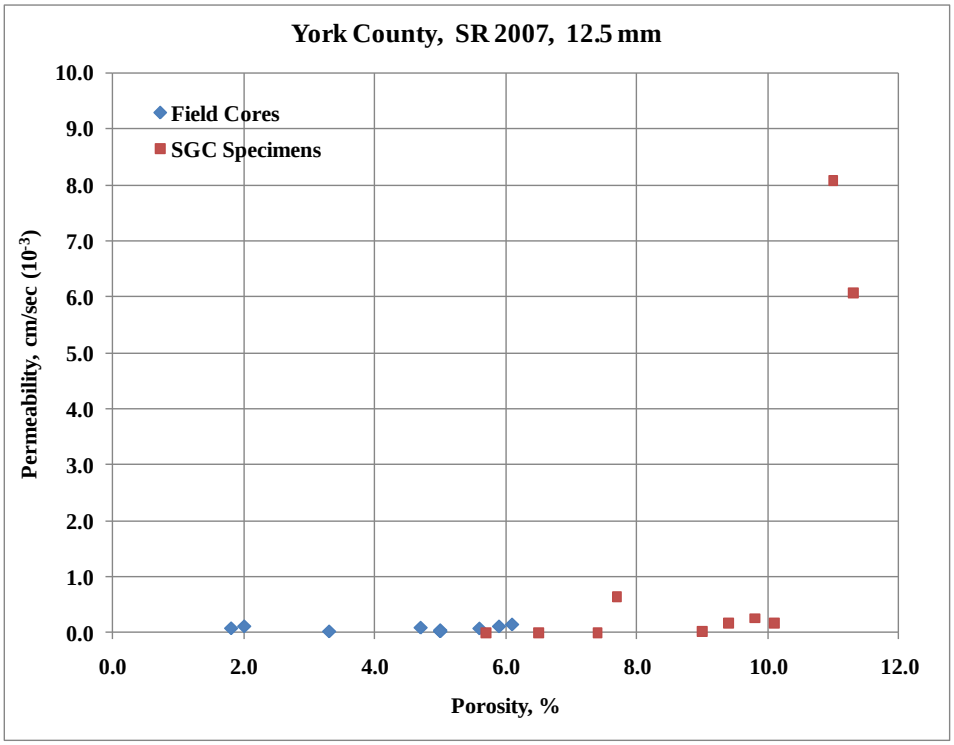

Figure 10 Permeability versus porosity for the 9.5-mm mix of SR 2007, York County

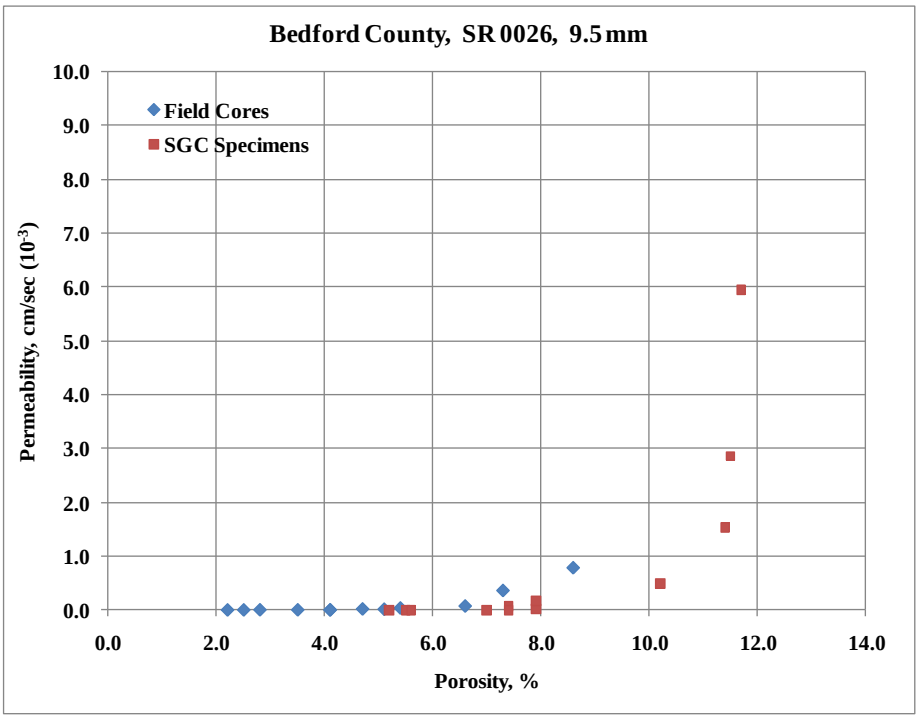

Figure 11 Permeability versus porosity for the 9.5-mm mix of SR 0026, Bedford County

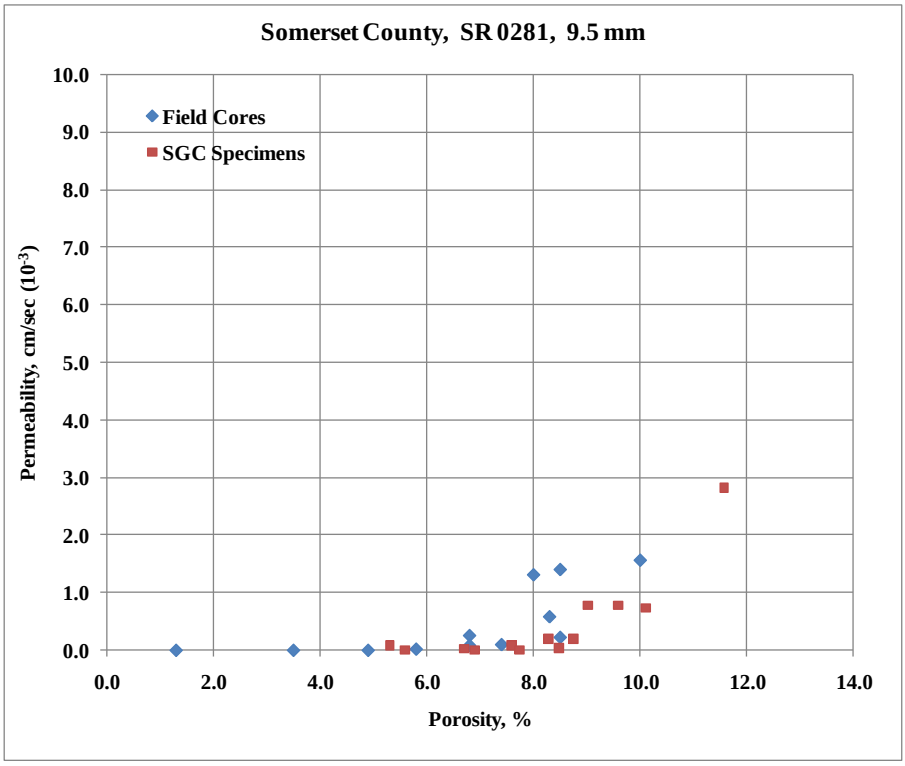

Figure 12 Permeability versus porosity for the 9.5-mm mix of SR 0281, Somerset County

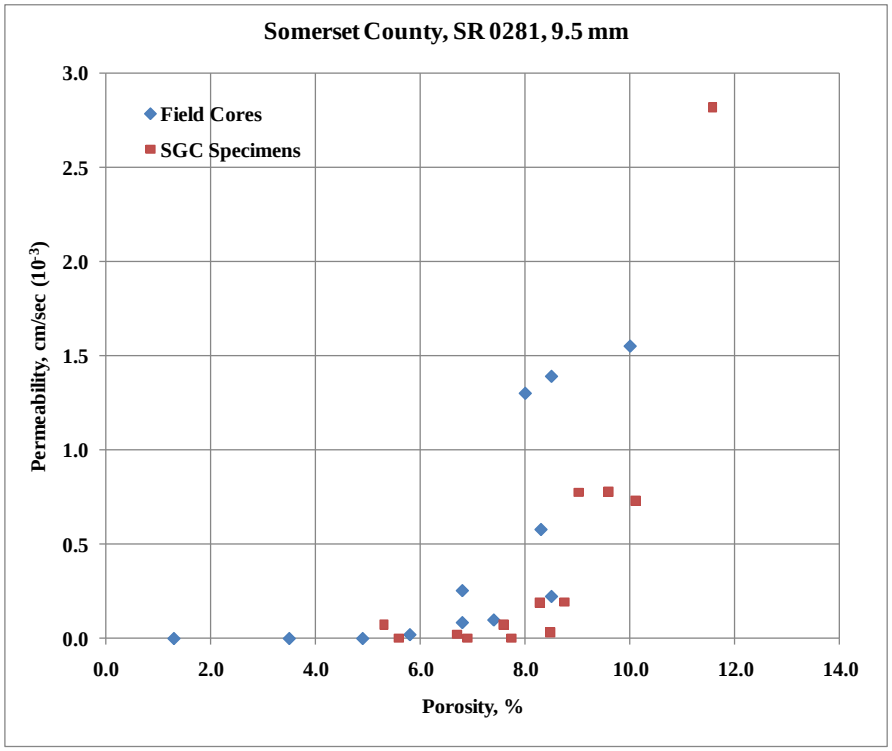

Figure 13 Permeability versus porosity for the 9.5-mm mix of SR 0281, Somerset County

The obvious conclusion from these measurements was that, in general, permeability increases as the air void level or porosity increases. For the Dauphin 12.5-mm mix, a porosity level of approximately 8 percent for both field cores and lab-compacted specimens seems to be a threshold value beyond which permeability begins to increase drastically. For the York 12.5-mm mix, field cores did not have porosities exceeding 6 percent and all specimens delivered low permeability. No definite conclusion could be drawn for permeability at higher porosity levels for this mix. The SGC specimens of this 12.5-mm mix indicated a sudden increase in permeability once porosity exceeded 10 percent.

Through this research, a reasonable relationship was developed between laboratory-compacted specimens and field cores for the Dauphin 12.5-mm mix. This relationship, with an R^2 =0.85, could be defined as $K_{field} = 0.00052 + 0.875\ K_{lab}$. The York 12.5-mm mix did not provide a sufficiently large spread of air voids to make investigation of the relationship between permeability of field cores and lab specimens possible. Similarly, no correlation could be established between permeability of field cores and permeability of lab-prepared specimens for the 9.5-mm mixes.

The effect of thickness of specimens on permeability was also investigated during Phase I. Laboratory specimens were prepared at 60-mm and 100-mm thicknesses. It was found that the thickness of lab-prepared specimens had a major effect on measured permeability at porosity levels higher than about 8 percent. In most cases, for porosity levels lower than 8 percent, the permeability was sufficiently low (less than $1x10^{-3}$ cm/sec) and was not highly affected by the thickness of the specimens.

ESTABLISHING ACCEPTABLE PERMEABILITY LEVELS

A literature review indicates that the permeability of HMA pavement has been investigated to a large extent both in the field and in the laboratory. There is a large amount of information on the range of permeability obtained from both field and laboratory measurements. However, what seems to be missing is systematic scientific research on acceptable levels of permeability for dense-graded mixes. In attempts made so far to establish such criteria, most of the supporting information was obtained from random investigations and sporadic anecdotal evidence. Therefore, while information exists as to what should be considered as the limiting value of permeability, such criteria are not supported by definitive scientific or experimental evidence.

During the early stages of this research project, a survey was conducted of eight states

(Alabama, Arkansas, Florida, Georgia, Minnesota, New Hampshire, Texas, and Virginia) to determine their approach in dealing with the issue of permeability. Results of that survey were submitted to PennDOT in early 2008 (Solaimanian and Chehab, 2008). Two of the surveyed states (Georgia and Virginia) used HMA permeability measurement as part of their mix design. Other states were focusing on density as a measure of controlling permeability. The acceptable upper limit for permeability varies from state to state, but they are all in the range of $1x10^{-3}$ cm/sec to $1.5\ x10^{-3}$ cm/sec. The Florida Department of Transportation is currently using permeability testing of field cores as a quality-control measure but is not using it for mix design. Originally a limiting value of $1x10^{-3}$ cm/sec was used by FDOT, even though the acceptable value was later increased to $1.25x10^{-3}$ cm/sec, as reported by Maupin, of the Virginia Transportation Research Council (Maupin, 2000). The Virginia Department of Transportation currently considers a permeability cap of $1.5\ x10^{-3}$ cm/sec at 7.5 percent air voids as part of its mix design. Westerman (1998) investigated a number of Superpave mixes in Arkansas and developed Table 3 based on permeability test results. However, later a limiting value of $1x10^{-3}$ cm/sec was proposed for use by the Arkansas State Highway and Transportation Department (Williams, 2006). The Georgia Department of Transportation considers an upper limit of $1.25x10^{-3}$ cm/sec at the mix design stage for Superpave mixes at an air void range of 6±1%. Mogawer et al. (2002) did an extensive study on permeability of Superpave mixes for the New England Transportation Consortium and suggested an upper limit of $1x10^{-3}$ cm/sec for permeability.

Table 3 Classification of HMA permeability (Westerman, 1998)

Permeability Category	Permeability Rate (cm/sec)
High Permeability	10^{1} - 10^{-4}
Low Permeability	10^{-4} - 10^{-6}
Practically Impervious	10^{-6} - 10^{-9}

The following recommendations for acceptable levels of permeability for Pennsylvania mixes are put forward in light of the preceding discussion on levels of permeability used by other states and the results of permeability tests conducted under this research.

It was previously mentioned that in general, SGC specimens yielded lower permeability compared with field cores at the same level of air voids or porosity. At low air void levels, no water

permeation was recorded for SGC specimens of mixes tested for this study. Based on overall analysis of data and criteria used by some other states, it is recommended that $1.25x10^{-3}$ cm/sec and $1.5x10^{-3}$ cm/sec be considered as the upper limits of permeability for SGC specimens and field cores, respectively. This is assuming that testing will be conducted on specimens under air void levels and specimen thicknesses established in the test protocol discussed later in this section.

For the 9.5-mm mixes, the cores and lab-compacted specimens could be considered impervious, as they yielded permeability levels significantly lower than $1.25x10^{-3}$ cm/sec for porosities lower than 8 percent. For the 9.5-mm mixes, the general conclusion is that for porosity levels under 8 percent, the permeability of field cores remains below the threshold value.

DEVELOPMENT OF TEST PROTOCOL

The principal activity under Phase II of this research project was the development of a test protocol in the format of a Pennsylvania Test Method. ASTM PS 129 was used as the basis for the development of this protocol. The following areas were included.

- Referenced Documents
- Assumptions
- Significance and Use
- Apparatus
- Sampling
- Preparation of Test Specimens or Pavement Cores
- Calibration/Standardization
- Permeameter Setup
- Testing Procedure
- Calculation
- Report

The developed protocol is presented in the appendix of this report.

SUMMARY AND CONCLUSIONS

This research project was initiated in June 2007 and completed in September 2010. The project was aimed at investigating the correlation between the permeability of field cores and permeability of laboratory prepared specimens (SGC specimens). The project was conducted in two phases. During Phase I, specific gravity, porosity, and permeability tests were conducted on field cores and laboratory-prepared specimens of six Superpave mixes. Two of the mixes were with 12.5-mm nominal maximum size aggregate and the remaining four were 9.5-mm mixes. Phase II was

focused on the development of a test protocol.

Out of the six tested mixes, some level of correlation could be developed between permeability of field cores and that of lab-prepared specimens for one of the 12.5-mm mixes. For other mixes, no correlation could be found because of either extremely low permeability levels or because the cores and SGC specimens had different ranges of air voids. However, it was concluded that in general, SGC specimens yield lower permeability compared to field cores at the same porosity, and it was found that there was a level of air void or porosity below which permeability was of no concern.

Based on the tests conducted under this research, it is recommended that 1.25×10^{-3} cm/sec and 1.5×10^{-3} cm/sec be considered as the upper limits of permeability for SGC specimens and field cores, respectively.

As a general conclusion, for most practical applications, as long as the in-place air void levels of 9.5-mm and 12.5-mm mixes remain under approximately 7.5 to 8 percent, permeability is not a concern. For cases where air voids exceed this level, tests may be needed to ensure the compacted mix is sufficiently impermeable (i.e., permeability does not exceed 1.25×10^{-3} cm/sec for SGC specimens and 1.5×10^{-3} cm/sec for field cores). Specimens at high air void content are of concern, and permeability testing of such specimens will be required to ensure that permeability remains below the recommended limits mentioned above.

11.2 Roadway Pavement Cores

11.2.1 Dimensions of Pavement Cores: While it is recommended that laboratory specimens not be gyratory compacted below 50-mm (2.0-in.) height, it is expected that some of the field pavement cores will have heights of 38 mm (1.5 in.) or smaller. Table 2 provides dimensions of pavement cores needed for permeability testing. Measuring the permeability of pavement cores thicker and thinner than the dimensions presented in Table 2 is feasible but adjustments to results would be needed, as thickness affects permeability.

Table 2 Dimensions of roadway pavement cores needed for the permeability test

Nominal Maximum Aggregate Size (NMAS) mm (in)	Height of Road Cored Specimen mm (in)	Diameter of Road Cored Specimen mm (in)
9.5 (3/8)	48±12 (1.9±0.5)	150±3 (5.95±0.1)
12.5 (1/2)	48±12 (1.9±0.5)	150±3 (5.95±0.1)
19.0 (3/4)	80±20 (3.2±0.8)	150±3 (5.95±0.1)
25.0 (1.0)	80±20 (3.2±0.8)	150±3 (5.95±0.1)
37.5 (1.5)	100±20 (4.0±0.8)	150±3 (5.95±0.1)

11.2.2 Preparation of Roadway Pavement Cores: In some cases, roadway cores consist of two or more layers. In such cases, the layers shall be separated with the aid of a circular saw at the interface of the layers. Care should be taken during sawing to prevent deforming the sawed surface of the core. Such deformation could affect the results of permeability tests. After sawing, the core layers shall be washed to remove debris that might have accumulated during sawing. The washed cores could be allowed to dry and be used for permeability testing at a later time, or they could be immediately conditioned according to section 12.

11.2.3 Dimension Measurements of Roadway Pavement Cores: Using the caliper, measure and record the height and diameter of each roadway pavement core to the nearest 0.5 mm (0.02 in.) or better. Individual height measurements shall be taken at four different locations and the two diameter measurements shall be taken perpendicular to each other. The four individual height measurements shall not vary by more than 5 mm (0.2 in.). Cores not meeting this requirement shall not be tested for permeability.

12. VACUUM SATURATION OF TEST SPECIMENS OR PAVEMENT CORES

12.1 Place the specimen or pavement core in a horizontal position in the vacuum container, supported above the container bottom by the spacer.

12.2 Fill the container with water at room temperature so that the specimen or pavement core has at least 25 mm (1.0 in.) of water above its surface.

12.3 Remove trapped air and saturate the specimen or pavement core by applying increased vacuum gradually until the residual pressure manometer reads 90 ± 2 mm (3.55 ± 0.1 in.) of Hg. Maintain this residual pressure for 15 ± 2 minutes.

12.4 At the end of the vacuum period, release the vacuum by slowly increasing the pressure. Allow the specimen or pavement core to stand undisturbed for a minimum of 5 minutes. The specimen or pavement core may be tested after this time or quickly transferred to another container where it will remain submerged until ready for testing.

13. CALIBRATION/STANDARDIZATION

13.1 Side leakage must be checked at the beginning of each project before actual testing of specimens. The following items shall be checked to ensure proper sealing of the permeameter.

13.1.1 Check the flexible latex membranes visually for any signs of holes, punctures, and tears. Avoid using membranes that have lost their flexibility.

13.1.2 Use an impermeable cylindrical specimen, 150 mm (5.9 in.) in diameter and 50 to 75 mm (2.0 to 3.0 in.) in height, and use it as a specimen installed in the permeameter and conduct a test according to section 15. The specimen could be made of aluminum, rubber, or an asphalt concrete known to be impermeable.

13.1.3 Monitor pressure and water flow for at least 2 hours. If the pressure drops more than 6.9 kpa (1 psi) from the original setting, or the water head drops more than 1 millimeter (0.05 in.), the equipment shall be checked for any leakage of pressure or membrane and the process repeated until the leakage check requirements are satisfied.

14. PERMEAMETER SETUP

14.1 Assemble the permeameter empty (with no specimen), such that the upper cap is fully compressed against the base (Figure 2[a]).

14.2 Use the meter stick to measure a distance of 10.0 cm (3.9 in.) from the cap assembly of the permeameter and place a mark onto the standpipe. This mark will be designated as the lower timing mark.

14.3 Measure the vertical distance (dh) from the bottom of the outlet pipe opening to the lower timing mark on the graduated standpipe. During actual testing, once a sample of thickness L is assembled (Figure 2[b]), the vertical distance between the lower timing mark and the bottom of the outlet pipe will be $D = L + dh$.

14.4 Use the meter stick to establish a mark on the graduated cylinder at a distance of 63.1 cm (24.8 in.) from the lower timing mark. This shall be designated as the upper timing mark.

NOTE 4 - Additional "upper" timing marks may be established (for example, at 10.0 cm [3.9 in.] intervals) in order to facilitate the testing of mixtures having a wide range of permeability values.

NOTE 5 - If the permeameter's graduated cylinder has manufacturer-established timing marks, steps 14.2 through 14.4 should be done to verify that the timing marks have been properly positioned.

NOTE 6 - The permeameter setup described will produce a starting hydraulic gradient of approximately 17 and an ending hydraulic gradient of approximately 3 at the lower timing mark, for a 50-mm-thick specimen. The hydraulic gradient is a function of both water head and specimen thickness. Tests using other hydraulic gradients may be conducted to verify the validity of Darcy's Law.

15. TESTING PROCEDURE

15.1 Disassemble the permeameter specimen cylinder from the permeameter base.

15.2 Connect the pressure line of the permeameter to the vacuum side of the pump. Using the pump, apply a vacuum to the flexible wall to remove entrapped air and collapse the membrane to the inside diameter of the cylinder. This will facilitate loading of the specimen.

15.3 With the flow control valve open, fill the outlet pipe with water until the taper in the base plate pedestal overflows.

15.4 For laboratory-compacted specimens, it is necessary to apply a thin layer of petroleum jelly to the sides of the specimen to achieve a satisfactory seal between the membrane and the specimen. This shall be accomplished using a spatula or similar instrument. Sealant shall be applied only to the sides of the specimen. Remove the specimen from the vacuum container filled with water, apply the petroleum jelly sealant to the sides, and then quickly place the specimen on the pedestal of the permeameter. For roadway core specimens, remove the specimen from the vacuum container filled with water, and then quickly place the specimen on the pedestal of the permeameter.

NOTE 7 - Petroleum jelly shall not be used on roadway cores.

NOTE 8 - Petroleum jelly has the potential to damage the latex membrane if the membrane is repeatedly used in the tests and petroleum jelly is applied. Therefore, each membrane should be thoroughly checked before each usage. An alternative is to apply a thin layer of bentonite paste to the sides of the specimen to fill the voids and provide a smooth surface.

15.5 Expeditiously reassemble the permeameter, making sure that all connections and clamps are tightened.

15.6 Disconnect the pressure line from the vacuum side of the pump and connect it to the pressure side.

15.7 Apply a confining pressure of 96.5 ± 7.0 kPa (14 ± 1 psi).

NOTE 9 - Watch for fluctuations in confining pressure, since these may be the result of an insufficient seal or a hole in the flexible membrane. Care should be exercised to ensure that the confining pressure remains constant throughout the test.

15.8 Fill the permeameter graduated cylinder until water begins to flow from the outlet tube. Exercise care when filling to minimize the incorporation of air bubbles.

15.9 Close the flow control valve.

15.10 Carefully lean the permeameter from side to side to allow the escape of any entrapped air. Continue this operation until all entrapped air has been removed.

15.11 Fill the graduated cylinder above the upper timing mark.

15.12 Commence the water flow by opening the flow control valve of the permeameter. Allow the water to flow through the specimen from the upper timing mark to the lower timing mark to help ensure that all air is removed from the apparatus and specimen.

15.13 Refill the graduated cylinder and start the timing device when the bottom of the meniscus of the water reaches the upper timing mark. At this point, the water pressure head will be h_1. Allow water to flow until the water level reaches the lower timing mark. At this point the water pressure head will be h_2. Once the water level reaches the lower timing mark, stop the timing device and close the valve. Record the elapsed time to the nearest second.

15.14 Saturation of the specimen and removal of air may require several test runs. Therefore, step 15.13 must be repeated. As a minimum, the test shall be conducted on the same specimen three times. The specimen is considered sufficiently saturated when a measurement does not differ by more than 10% from the preceding measurement. The test is repeated as many times as needed until this requirement is satisfied. Once saturation has been verified, the final time measured shall be recorded as the test time and subsequently used in the calculations.

NOTE 10 - If after 30 minutes the water has not reached the lower timing mark, then the test shall be terminated at the nearest cm mark corresponding to the 30 minutes elapsed time. Make a record of the time to the nearest second and a record of the water level to the nearest millimeter (or nearest 0.05 in.). The test should then be repeated according to sections 15.13 and 15.14.

15.15 Measure and record the temperature of the permeating water in the system to the nearest 0.5 ºC (1 °F).

15.16 After three successful runs meeting the repeatability criteria of 10% have been performed, release the pressure from the permeameter and remove the clamp assemblies, upper cap, and specimen. Wipe clean any excess sealant from the latex membrane.

NOTE 11 - Before running road cores, the latex membrane should be replaced to ensure that no sealant will damage the road core or affect subsequent mixture test results.

16. CALCULATION

16.1 The coefficient of water permeability, *k*, is determined using the following equation:

$$k = \frac{a.l}{A.t} \ln(\frac{h_1}{h_2}) \quad (2)$$

where:
k = coefficient of water permeability, cm/sec (inches/sec)
a = inside cross-sectional area of inlet standpipe, cm^2 (in^2)
l = thickness of test specimen, cm (in)
A = cross-sectional area of test specimen, cm^2 (in^2)
t = average elapsed time of water flow between timing marks, seconds (sec)
h_1 = hydraulic head on specimen at time t_1, cm (in)
h_2 = hydraulic head on specimen at time t_2, cm (in)

16.2 Correct the calculated permeability to that for 20 °C (68 °F) , k_{20}, by multiplying *k* by the ratio of the viscosity of water at the test temperature to the viscosity of water at 20 °C (68 °F), R_T, from Table 1, as follows:

$$k_{20} = R_T k \quad (3)$$

17. TESTING STAGE AND LIMITING VALUE OF PERMEABILITY

17.1 Preparation of permeability test specimens and execution of the permeability test is conducted after completion of mix design and parallel to the stage where moisture damage resistance of the designed mix is evaluated.

17.2 It is recommended that permeability for SGC specimens not exceed $125x10^{-5}$ cm/sec and permeability of field cores not exceed $150x10^{-5}$ cm/sec at the thickness and air void levels established under this test protocol.

18. REPORT

18.1 Report the following information:

18.1.1 Specimen identification

18.1.2 Mixture type/description

18.1.3 Sample type (i.e., lab prepared or roadway core)

18.1.4 Sample air voids

18.1.5 Sample porosity

18.1.6 Water temperature

18.1.7 Coefficient of water permeability

18.1.7.1 For the case of single air void measurements: coefficient of water permeability is reported to two decimal places x 10^{-5} cm/sec (ft/day). The following shall be reported.

- Water permeability, porosity, and air void of each tested specimen; and
- Average water permeability, average air void, and average porosity for the three replicate specimens.

18.1.7.2 For the case of multiple air voids: coefficient of water permeability is reported to two decimal places x 10^{-5} cm/sec (ft/day). The following shall be reported.

- Water permeability and air void of each tested specimen;
- Average permeability, average air void, and average porosity for the three replicates at each air void level; and
- Plot of average permeability versus average porosity to include three air void levels considered.

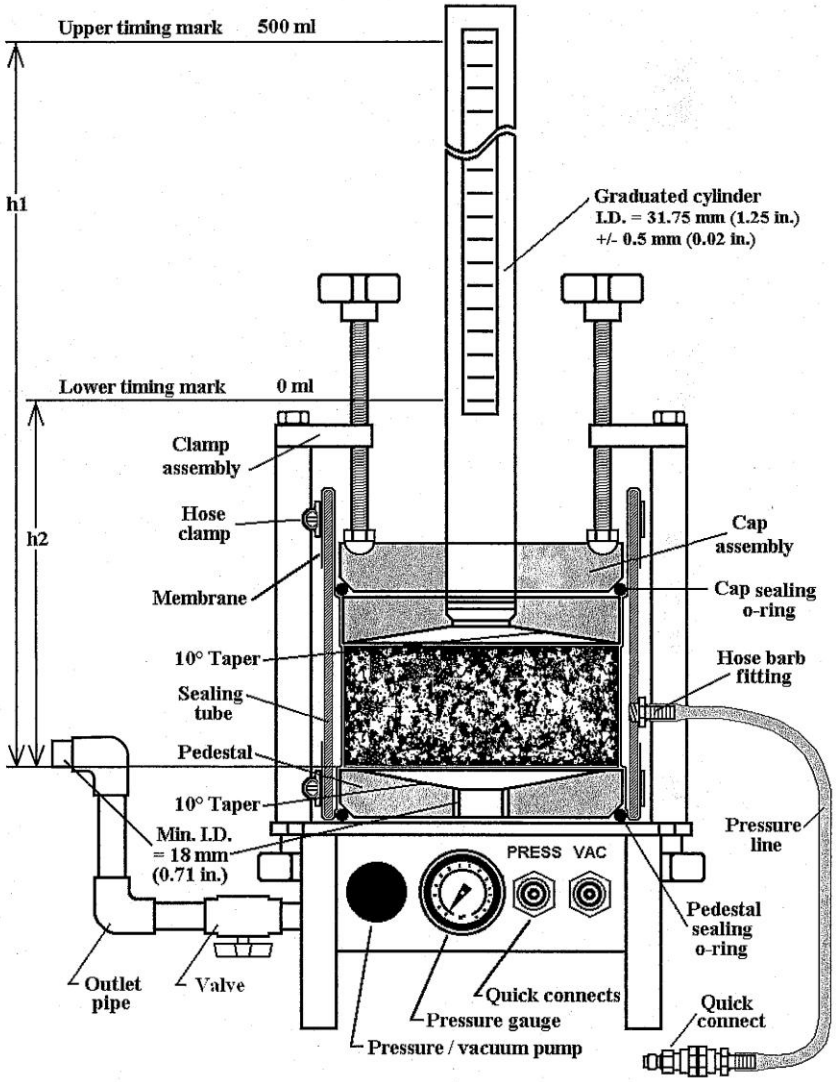

Figure 1 Schematics of a Falling Head Permeameter.

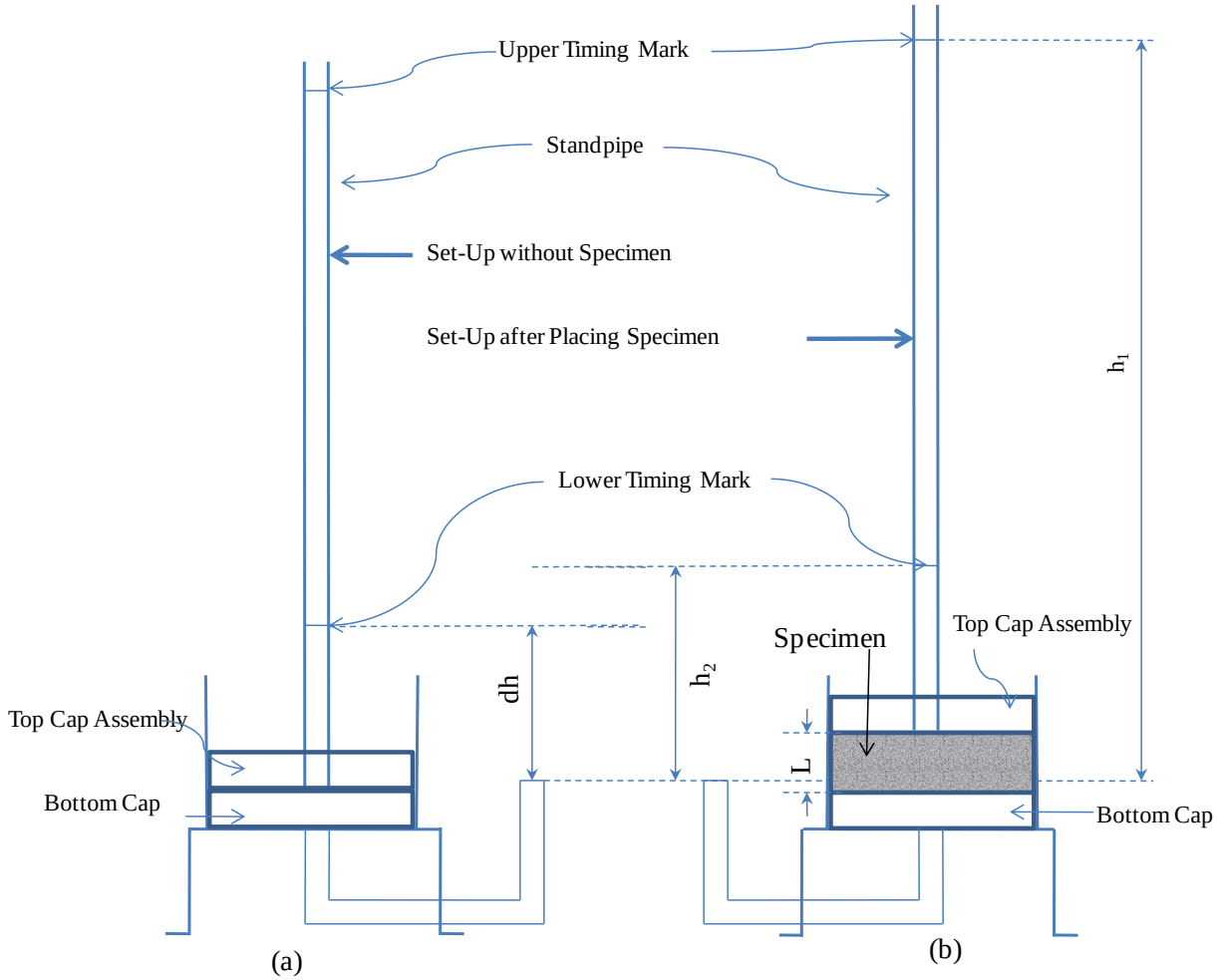

Figure 2 Schematics indicating approach in establishing the lower timing mark position.

Table 3. Correction factor, R_T, for viscosity of water at various temperatures

Temperature °C (°F)	R_T		Temperature °C (°F)	R_T
15.0 (59.0)	1.135		25.0 (77.0)	0.889
15.5 (59.9)	1.121		25.5 (77.9)	0.879
16.0 (60.8)	1.106		26.0 (78.8)	0.869
16.5 (61.7)	1.092		26.5 (79.7)	0.860
17.0 (62.7)	1.077		27.0 (80.6)	0.850
17.5 (63.5)	1.064		27.5 (81.5)	0.841
18.0 (64.4)	1.051		28.0 (82.4)	0.832
18.5 (65.3)	1.038		28.5 (83.3)	0.823
19.0 (66.2)	1.025		29.0 (84.2)	0.814
19.5 (67.1)	1.013		29.5 (85.1)	0.805
20.0 (68.0)	1.000		30.0 (86.0)	0.797
20.5 (68.9)	0.988		30.5 (86.9)	0.789
21.0 (69.8)	0.976		31.0 (87.8)	0.780
21.5 (70.7)	0.965		31.5 (88.7)	0.772
22.0 (71.6)	0.953		32.0 (89.6)	0.764
22.5 (72.5)	0.942		32.5 (90.5)	0.757
23.0 (73.4)	0.931		33.0 (91.4)	0.749
23.5 (74.3)	0.921		33.5 (92.3)	0.741
24.0 (75.2)	0.910		34.0 (93.2)	0.733
24.5 (76.1)	0.900		34.5 (94.1)	0.725