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ABSTRACT

It can be expected that the life of a permeable pavement would be shorter than that of an impermeable pavement, due to deterioration of mix through water and air infiltration, and subsequent stripping and oxidation and hardening of binder. Recent work has indicated that coarse graded Superpave mixes can be excessively permeable to water at air void levels around 6 percent. The objectives of this study were to evaluate the permeability of Superpave designed mixes used by Maine Department of Transportation and determine the effect of gradation, lift-thickness, and in-place density on the permeability of these mixes. Five Superpave projects were selected for this study. These projects included coarse-graded 9.5 mm, 12.5 mm, 19.0 mm, and 25.0 mm nominal maximum aggregate size (NMAS) mixes and one fine-graded 9.5 mm NMAS mix. Based on the National Center for Asphalt Technology permeameter, a field permeameter was developed at the Worcester Polytechnic Institute (WPI) laboratory. This permeameter was used for testing at ten locations per project. One core was obtained at each of these test locations. The cores were used to determine in-place density at each of the test locations. Field testing was done at random locations, immediately behind the finish roller. Loose mixes were also obtained from each project. The loose mixes were compacted to 5 percent air voids, and to different thickness to evaluate the effect of thickness on permeability. On the basis of results obtained in this study, the following conclusions can be made: 1. Air void content (as measured by voids in total mix) of dense graded HMA has a significant effect on in-place permeability of pavements, 2. There is a significant effect of NMAS on the permeability of coarse-graded Superpave designed mixes. It was shown that at a given in-place air void content the permeability increased by one order of magnitude as the NMAS increased, 3. Samples with different thicknesses showed that there is a decrease in permeability with an increase in thickness. It is recommended that State DOTs consider designing mixes to be placed 100 mm below the pavement surface on the fine side of the maximum density line. By designing base mixes on the fine side of the maximum density line, these mixes could be made less permeable than coarse graded mixes at similar void levels and thus less susceptible to allowing moisture or moisture vapor to propagate upward through the pavement structure. This in turn should reduce the potential for moisture damage within pavement structures.

Key words: Superpave, coarse-graded, permeability, air voids, gradation

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INTRODUCTION

A recent survey of Superpave designed pavements suggested that one of the biggest problems observed was permeability (*1*). This survey stated that coarse-graded Superpave mixes appear to be more permeable than conventional dense-graded mixes at similar air void levels. For conventional dense-graded mixes, work by Zube (*2*) in the 1950s and 1960s indicated that pavements become excessively permeable to water at air void contents above 8 percent. This was later confirmed by Brown et al. (*3*) during the 1980s.

Recent work by the Florida Department of Transportation (DOT) (*4*) has indicated that coarse-graded Superpave mixes can be excessively permeable to water at air void levels around 6 percent. Cooley and Brown (*5*) have also shown that coarse-graded Superpave mixes can be excessively permeable below 8 percent air voids using a field permeability device.

It can be expected that the life of a permeable pavement would be shorter than that of an impermeable pavement (*1*). Infiltration of water or air into a pavement can affect the durability of that pavement. Probably the most harmful effect takes place through the invasion of water into the pavement that results in stripping. Stripping is defined as the breaking of the adhesive bond between the aggregate surface and asphalt binder. Stripping is a very complex mechanism that can be caused by many variables. However, a common factor associated with stripping is moisture within the pavement (*6*). Once a pavement has experienced stripping, pavement distresses such as cracking or surface raveling can be expected. Hence, a pavement that is not constructed in an impermeable manner has the potential for stripping. Another potential problem with permeable pavements is excessive oxidation of the asphalt binder coating aggregate particles. Common sense suggests that if water can penetrate into a pavement so can air. Excessive oxidation of the asphalt binder film can lead to a brittle binder and thus increased potential for cracking of the pavement.

Numerous factors can potentially affect the permeability of HMA pavements. In a study conducted by Ford and McWilliams (*7*), it was suggested that gradation, particle shape, and air void level can affect permeability. Hudson and Davis (*8*) concluded that permeability is dependent on the size of air voids within a pavement, not just the percentage of voids. However, these studies were conducted on conventional fine-graded mixes. Therefore, a study was needed to evaluate factors that can affect the permeability of Superpave designed pavements with coarse-graded mixes.

Objective

The objectives of this study were to evaluate the permeability of Superpave designed mixes used by Maine Department of Transportation (DOT) and determine the effect of gradation, lift-thickness, and in-place density on the permeability of these mixes.

SCOPE

This study was conducted in two parts: field and laboratory. For the field part, a device was developed for conducting permeability testing in the field. Five pavements within Maine were selected for testing with the field permeability device. At each of the five projects cores were obtained at each location that field permeability tests were conducted so that in-place density could be determined. Also, plant produced mix was sampled from each project in order to carry out the laboratory part of this study. In the laboratory, the cores were tested for density (air voids). The loose mix was compacted to different thicknesses at a particular air void level and tested for laboratory permeability. A commercially available laboratory permeameter was utilized.

TEST PLAN

The overall test plan is shown in Figure 1. Five Superpave projects were selected for this study. These projects included coarse-graded 9.5 mm, 12.5 mm, 19.0 mm, and 25.0 mm nominal maximum aggregate size (NMAS) mixes and one fine-graded 9.5 mm NMAS mix. A field permeameter was developed at the Worcester Polytechnic Institute (WPI) laboratory. This permeameter was used for testing at ten locations per project. One core was obtained at each of these test locations. The cores were used to determine in-place density at each of the test locations. Field testing was done at random locations, immediately behind the finish roller. About 100 kg (220 lb) of loose mix was also obtained from each of these projects. Loose mix from each project was used to compact samples, using the Superpave gyratory compactor, to different heights. The exact samples heights were selected based upon the NMAS of the respective mixture. Thickness to NMAS ratios of 2.5, 3.0, 3.5, and 4.0 were investigated. All of the samples were compacted to 5 percent air voids. This value was selected because it is the average specified in-place air voids for Maine DOT. The permeability of all compacted loose mix was determined using the laboratory permeameter.

DEVELOPMENT OF FIELD PERMEAMETER

Based upon work by NCAT (*5*), the primary problem in developing a field permeameter is sealing the device to the pavement surface. This problem arises from the rough surface texture of HMA pavements. The NCAT field permeameter was selected as a model for its simplicity and effectiveness. Through repeated testing and evaluation, a modified permeameter was developed at the Worcester Polytechnic Institute (WPI) pavement laboratory. The final device (Figure 2) was developed with three tiers, a flexible base, and five donut shaped weights. A scale was attached to the top two tiers for reading off the level of water. The three tiers were recommended (*5*) 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 through the macrostructure of the pavement surface. The donut shaped weights (total of 47 kg or 110 lb) were needed to resist the uplift forces exerted by the introduction of water into the device and to keep a good seal with the pavement surface. Use of this sealing system enabled the researchers to take core at the exact spot that testing was conducted. Water for the permeameter was supplied by a 50-gallon tank, which was mounted on the back of a pickup truck.

Field Testing

The field permeameter was used as a falling head device to record the drop in water level in the standpipe over a given time interval. 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. For the most permeable 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

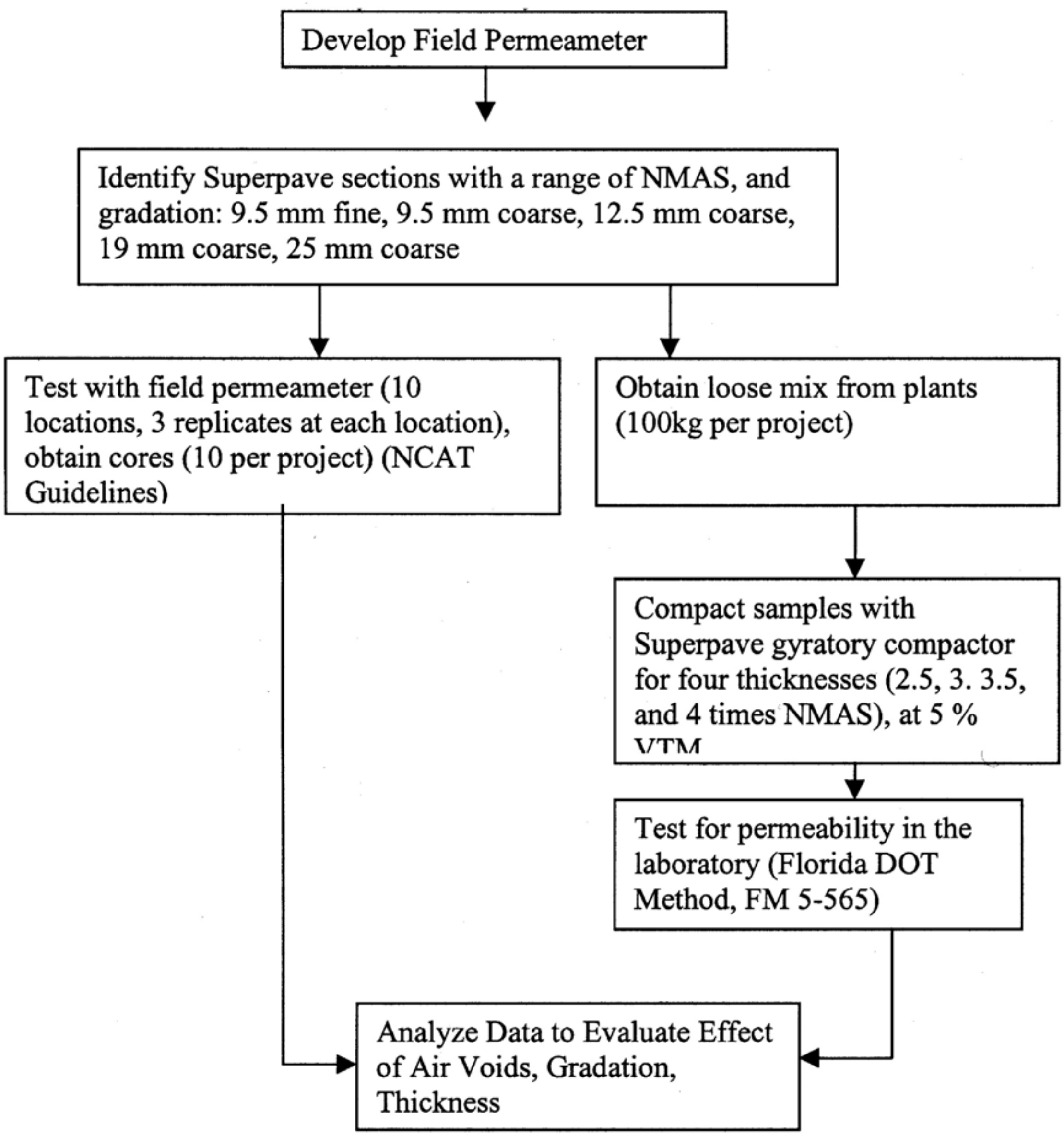


Figure 1. Overall Test Plan

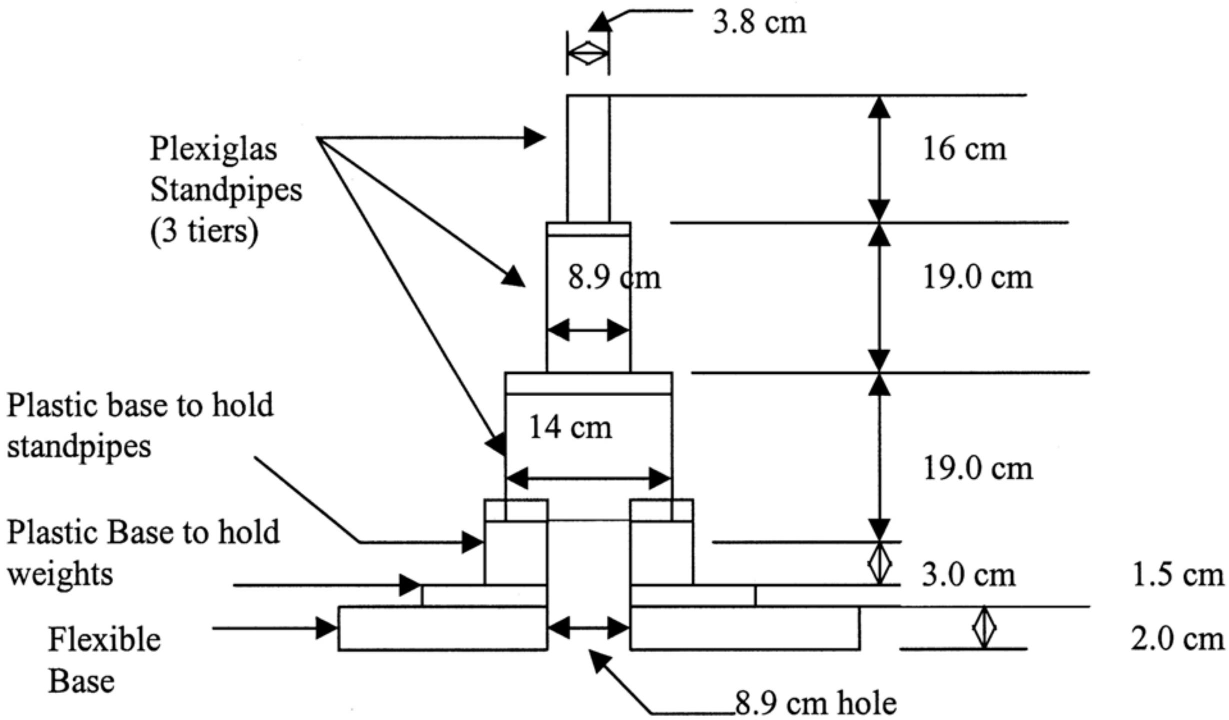


Figure 2. Sketch and Photo of Permeameter

was slow enough for efficient recording of data. For each of the ten locations, three tests were conducted 150 mm apart. For each of the three tests, the average of three individual measurements was used. The standpipe was filled up and the water allowed to fall three times. A core was obtained at the center of the three reading locations.

Laboratory Sample Preparation and Testing

Loose mix obtained for each project was compacted to 5 percent air voids and at different thicknesses. The different thicknesses were selected so as to give sample thickness to NMAS ratios of 2.5:1, 3:1, 3.5:1 and 4:1. The intent was to evaluate the effect of lift thickness on permeability. These samples were tested for laboratory permeability, using the Karol-Warner laboratory permeameter. Falling head tests were conducted according to Florida DOT test method (FM 5-565). The cores and laboratory samples were saturated before testing by applying a vacuum under water for ten minutes.

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) gradations. Gradation, design asphalt content, and lift thickness of these mixes are shown in Table 1. The 9.5 mm fine mix has a gradation, which passed above the restricted zone and the maximum density line, and the other four mixes had gradations passing below the restricted zone and maximum density line. Results of analyses carried out to answer the different questions about factors affecting permeability of dense-graded HMA are given in the following paragraphs. The term permeability is used for “coefficient of permeability” in the rest of the report.

Results of permeability testing conducted in the field and in the laboratory (on cores) are shown in Table 2. Figure 3 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, 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 aggregate structure and flowpaths in the mixes. 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. For the 9.5 and 12.5 mixes, water was observed to come up through the mat a few cm away from the permeameter. Hence, 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. Hence, laboratory testing with falling head permeameter using vertical flow of water may not give a true indication of permeability of mixes with pronounced horizontal flow paths. The horizontal permeability of some mixes may be much higher and hence of overriding importance in such cases.

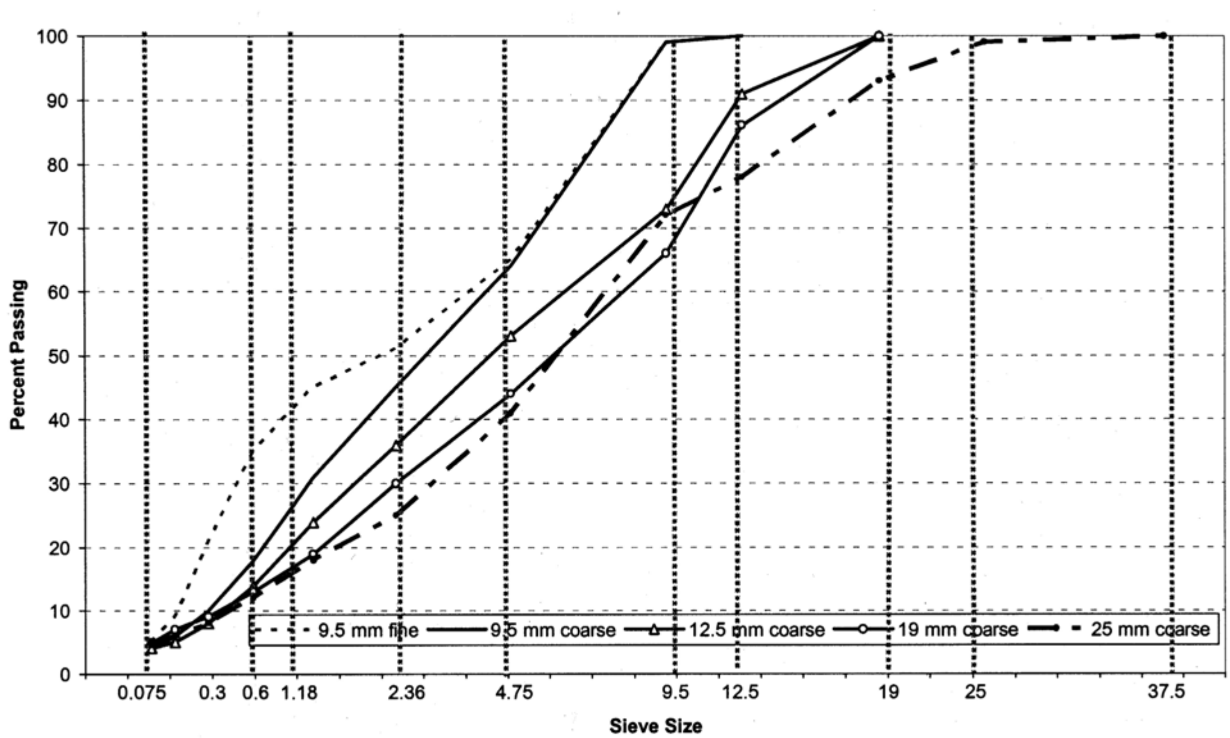
Table 1. HMA Mix Information

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

Table 1. HMA Mix Information

Mix	Gradation Sieve Size (mm)	Gradation Percent Passing	Asphalt Content, %	Lift Thickness, cm
	2.36 1.18 0.6 0.3 0.15 0.075	25 18 12 8 6 5		

Note: Gradation plots shown in figure below



Note: Plots of gradations shown in Table 1.

Table 2. Air Voids and Permeability of Field Cores

Mix	Lift thickness, cm	VTM, %	Field Permeability, cm/s	Lab Permeability, cm/s
9.5 (fine)	4	8.3	1.0838E-03	9.7499E-04
		6.3	1.3443E-04	2.7014E-04
		6.7	2.8635E-04	4.9118E-04
		12.3	6.3481E-03	9.8072E-03
		5.8	1.2072E-04	3.7335E-04
		8.4	1.8246E-04	4.0176E-04
		8.4	6.4517E-04	8.0461E-04
		8.1	6.7204E-04	1.3329E-03
		7.6	4.2636E-04	1.3616E-03
		10.6	3.6161E-03	3.5850E-03
9.5 (coarse)	3	3.1	9.1749E-06	8.0143E-05
		5.4	6.6733E-05	9.0595E-05
		6.3	6.3873E-05	1.1297E-04
		5.5	7.7628E-06	0.0000E+00
		2.9	6.3502E-06	1.3901E-04
		8.1	1.0073E-03	1.8793E-03
		4.7	1.6242E-05	6.5697E-05
		6.3	2.7559E-05	1.4204E-04
		5.5	6.3054E-05	9.4517E-05
		7.4	3.2238E-04	1.3434E-03
12.5 (coarse)	4	3.5	5.7183E-05	0.0000E+00
		8.4	6.5517E-03	6.5916E-03
		6.7	1.1618E-03	1.0851E-03
		4.0	4.8518E-05	0.0000E+00
		4.0	9.4083E-06	5.5650E-05
		2.2	6.0353E-05	9.7985E-06
		4.7	1.3460E-04	1.3835E-04
		5.8	2.9604E-04	1.1175E-03
		3.1	8.4669E-06	0.0000E+00
		7.3	7.7538E-04	1.1588E-03
19	5	6.5	2.3413E-03	0.000132653

Table 2. Air Voids and Permeability of Field Cores

Mix	Lift thickness, cm	VTM, %	Field Permeability, cm/s	Lab Permeability, cm/s
(coarse)				
		6.8	5.5854E-03	0.000717801
		8.4	2.3629E-02	0.006764264
		8.3	1.8440E-02	0.00599689
		7.2	2.3528E-03	0.000461767
		7.9	2.0039E-02	0.004707339
		5.8	1.3512E-03	0.000210647
		Destroyed	5.9815E-04	
		6.4	1.6120E-03	0.001168861
		6.9	5.0150E-03	0.000929873
25 (coarse)	8.9	6.8	0.027677	0
		5.7	0.009455	1.21548E-05
		7.3	0.064893	0.00048978
		7.1	0.016911	2.41046E-05
		5.5	0.007970	2.16938E-05
		8.4	0.027452	0.000518817
		4.8	0.007020	8.68491E-05
		7.0	0.00596775	5.86782E-05
		4.5	0.008018769	0
		9.2	0.122630992	0.000981731

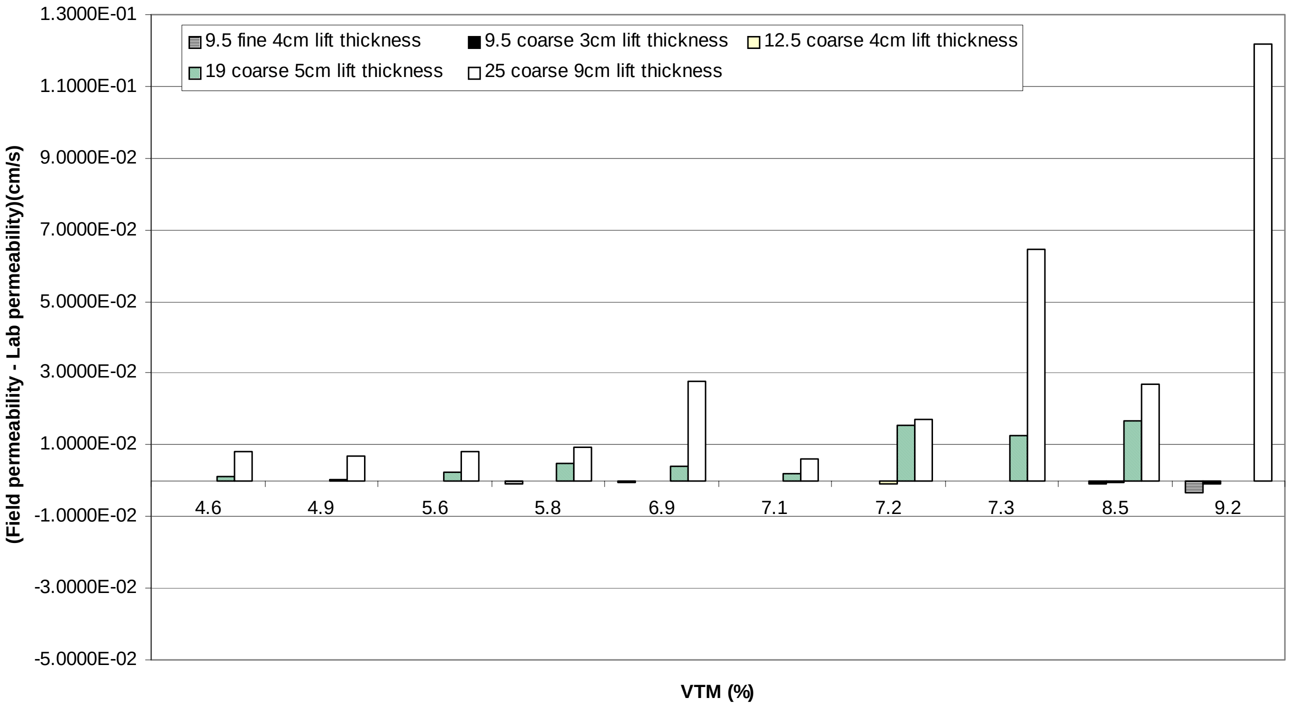


Figure 3 Plot of difference between field and laboratory permeability

The literature suggested that several factors could affect the in-place permeability of HMA pavements. One of the more prominent factors was in-place air void level. Figure 4 illustrates the relationship between in-place air voids and in-place permeability with all projects included. Two data points are not shown on this figure though included in developing the regression line. One data point was located at an air void content of 7.3 percent and permeability of 6480 x 10^{-5} cm/sec while the other was at an air void content of 9.2 percent with a permeability of 12200 x 10^{-5} cm/sec. For Figure 4, the y-axis was reduced so that the relationship between in-place air voids and permeability was clearer.

As was expected, the data shows that as the in-place air voids increase, so does permeability. However, the relationship does not appear strong (R^2 = 0.39). Collectively, the data does suggest that the permeability of the pavements studied increased significantly at an in-place air void content of about 7 percent.

To provide a clearer picture of the permeability characteristics for the projects studied, plots of in-place air voids versus field permeability were prepared for each project (Figures 5 through 9). Figure 5 shows the relationship for the fine graded 9.5 mm NMAS project. As can be seen, the correlation between density and permeability is strong for this project (R^2 = 0.86). Similar to Figure 4, this figure illustrates that as density decreases (or air voids increase) the permeability increases. This figure also shows that this particular mix appears to become excessively permeable at approximately 8.5 percent air voids. At air void contents above 8.5 percent, the permeability increases significantly and becomes very sensitive to a change in air void content. At 8.5 percent voids, the field permeability was approximately 70 x 10^{-5} cm/sec.
Figure 6 presents the relationship between in-place air voids and permeability for the coarse graded 9.5 mm NMAS pavement. Similar to the Figures 4 and 5, increases in in-place air voids resulted in increased permeability. Figure 6 also showed a good correlation (R^2 = 0.75). At first

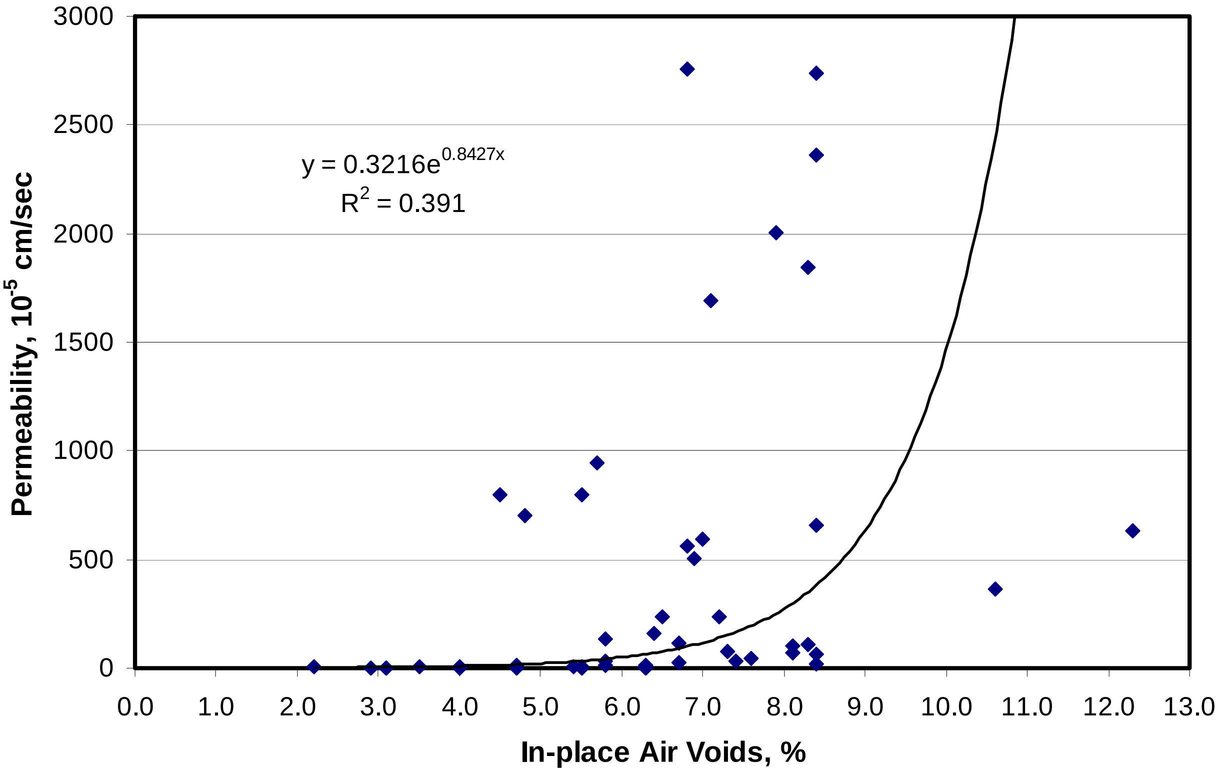


Figure 4. Plot of In-Place Air Voids Versus Permeability For All Data

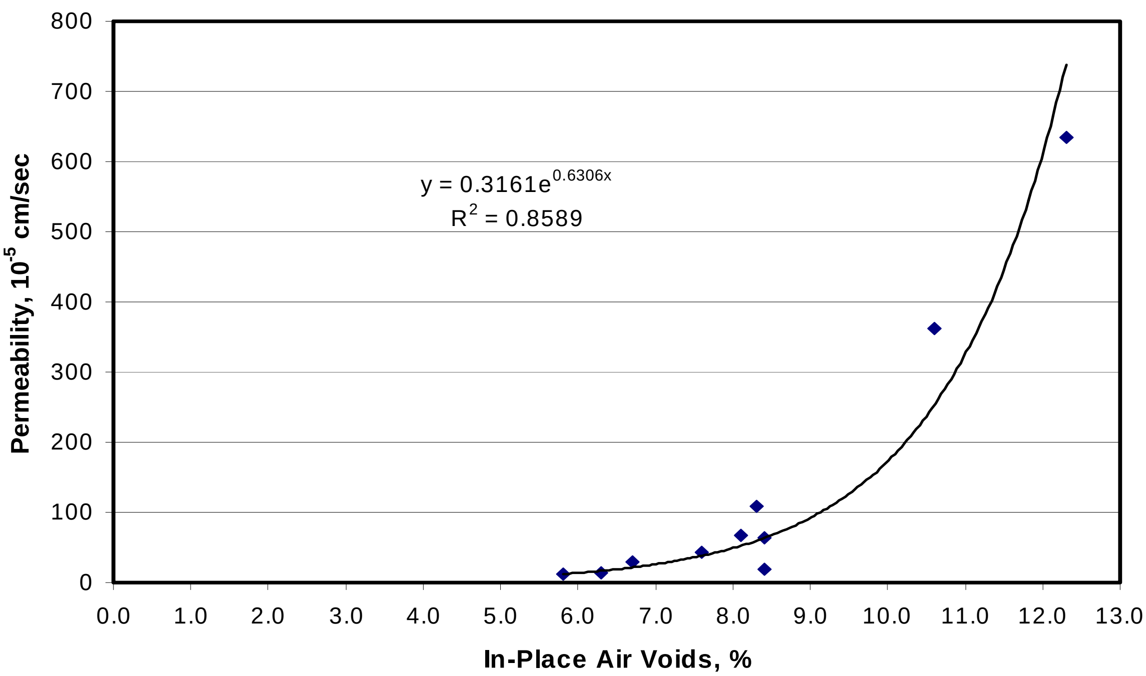


Figure 5. Plot of In-Place Air Voids Versus Permeability For 9.5 mm Fine Mix

glance, it appears that this coarse graded 9.5 mm NMAS becomes permeable at around 6 percent air voids. However, the y-axis scale should be looked at closely. For Figure 6, the maximum y-axis value is only 120 x 10^{-5} cm/sec. By comparison, Figure 5 had a maximum y-axis value of 800 x 10^{-5} cm/sec. Also of interest on Figure 6 were the actual in-place air voids. Only two of the testing locations had in-place air voids in excess of 7 percent while Figure 5 showed that seven of the ten testing locations had in-place air voids in excess of 7 percent. Therefore, the magnitude of permeability values shown in Figure 6 does not appear to be excessive. However, based on the regression line it appears that the pavement depicted in Figure 6 would be excessively permeable at in-place air void contents in excess of 8 percent. Note that the term "excessively permeable" does not refer to any specific permeability value but refers to a point beyond which a slight change in air voids causes a major change in permeability.

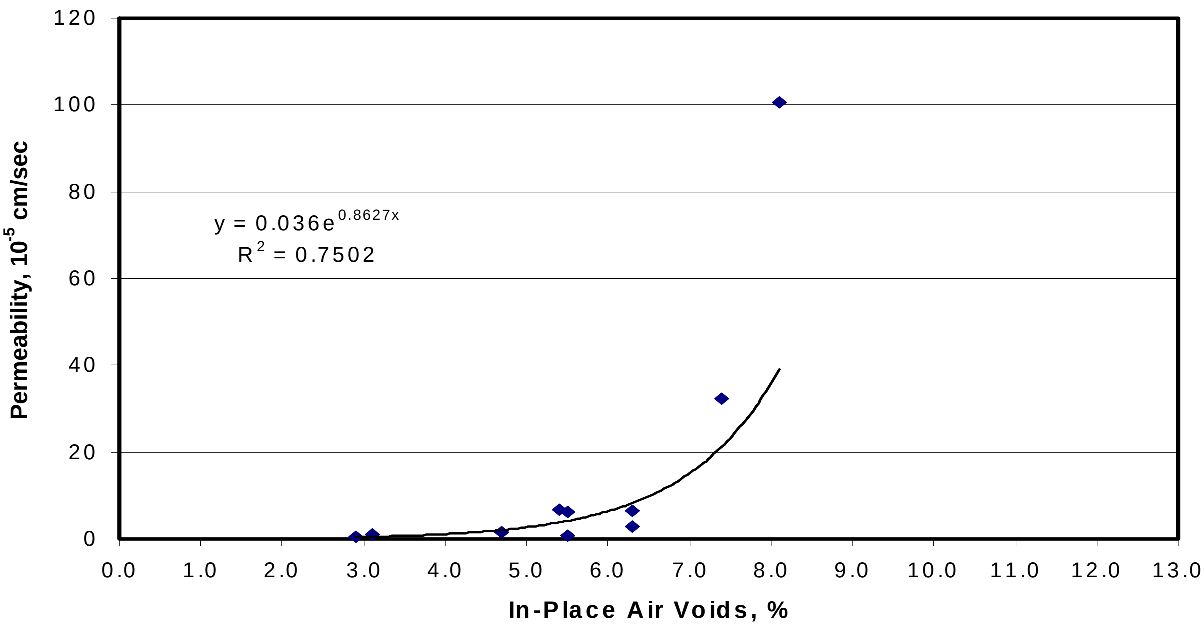


Figure 6. Plot of In-Place Air Voids Versus Permeability for 9.5 mm Coarse Mix

The third project, shown in Figure 7, was a coarse graded 12.5 mm NMAS mix. This figure also shows a strong correlation between in-place density and permeability ($R^2 = 0.79$). For this mix, it appears that the pavement becomes excessively permeable at in-place air void contents above 7 percent. This void level resulted in a permeability value of approximately 100 x 10^{-5} cm/sec.

Figure 8 presents the density and permeability data for the 19.0 mm NMAS coarse graded mix. Again, a very strong correlation was noted for the data ($R^2 = 0.86$). In-place air void contents on this project varied from approximately 6 percent to 8.5 percent. Figure 8 shows that within this range permeability varied greatly. Based on the figure, the pavement became excessively permeable at in-place air void contents greater than approximately 6.5 percent. This void level corresponds to a permeability of about 250 x 10^{-5} cm/sec.

The final project evaluated was a 25.0 mm NMAS coarse graded mix (Figure 9). The range of permeability values shown in Figure 9 is much higher than those shown in Figures 5 through 8. In-place air void contents ranged from approximately 4.5 to 10 percent. Similar to the other projects, decreases in density lead to increased permeability. The correlation shown in Figure 9

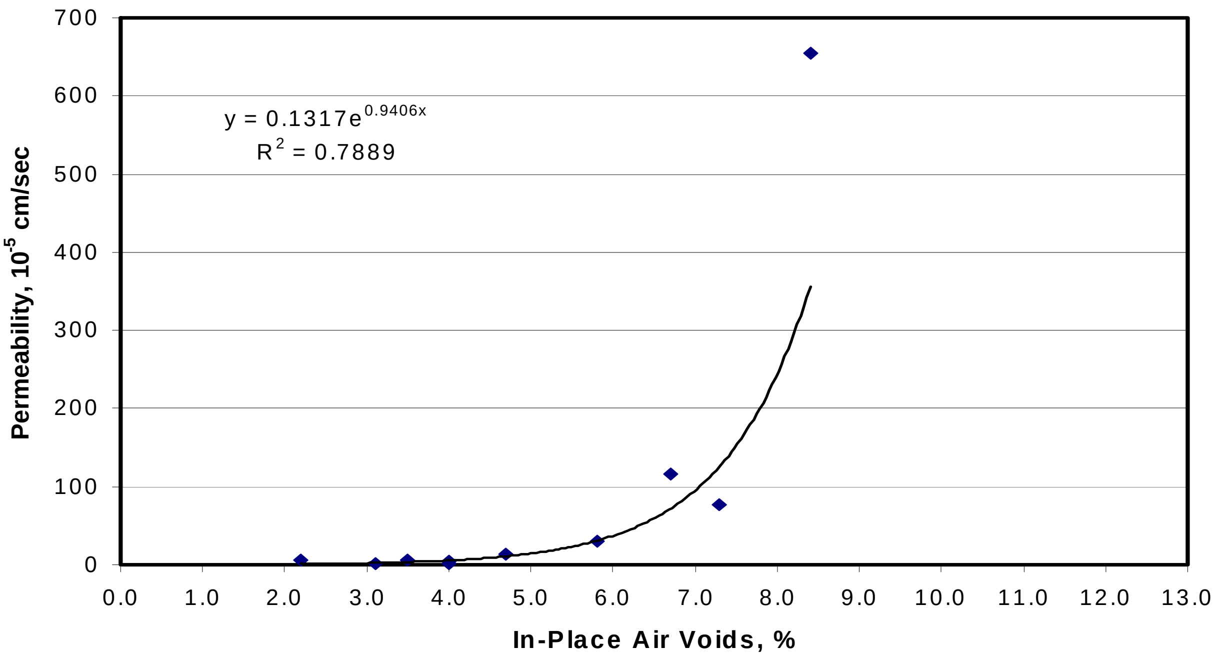


Figure 7. Plot of In-Place Air Voids Versus Permeability for 12.5 mm Coarse Mix

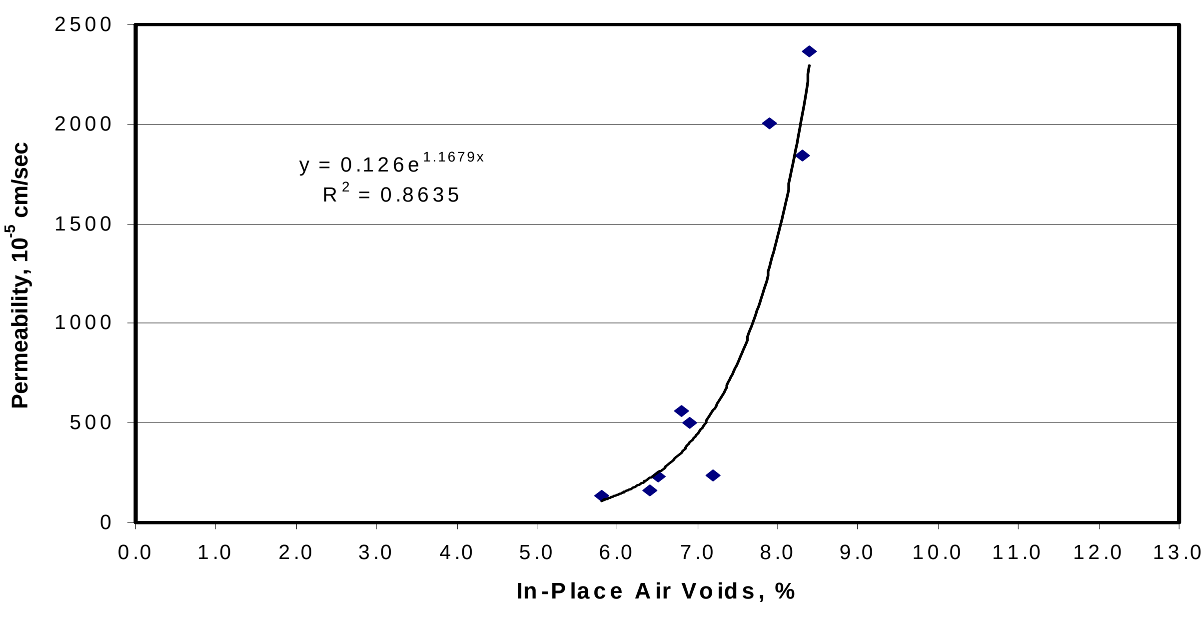


Figure 8. Plot of In-Place Air Voids Versus Permeability For 19 mm Coarse Mix

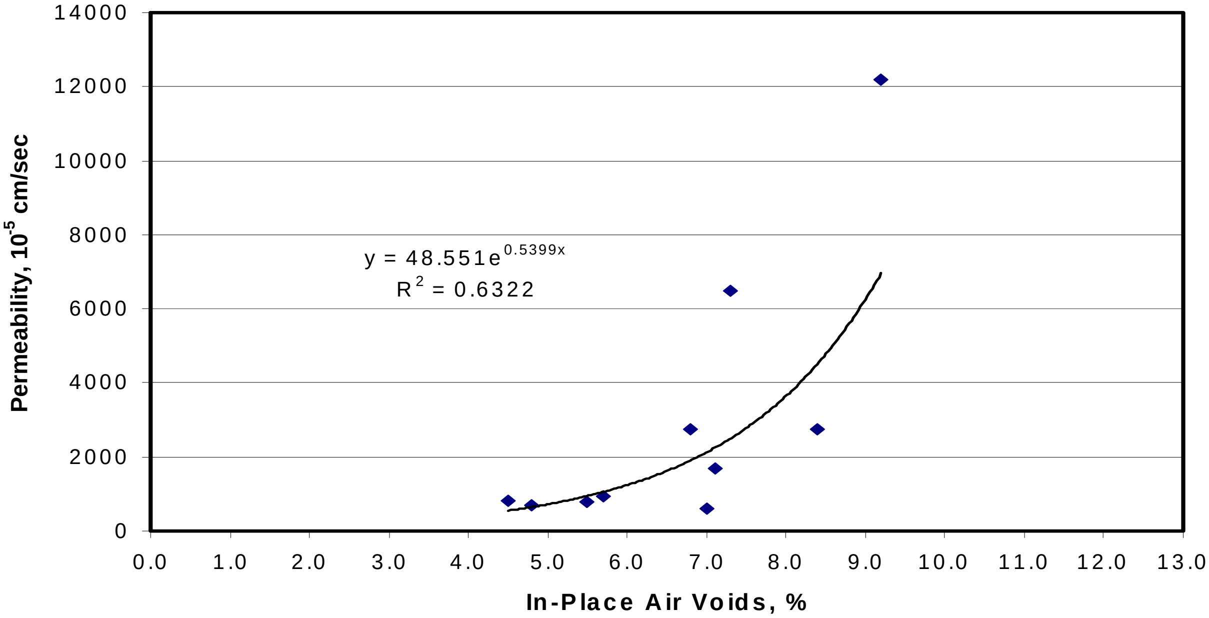


Figure 9. Plot of In-Place Air Voids Versus Permeability For 25 mm Coarse Mix

is not as strong as previous correlations, but is still good (R^2 = 0.63). It appears that this pavement became excessively permeable above 6 percent air voids. Similar conclusion was reported from a study conducted by Maupin (*9*).

Several potential reasons exist for the low correlation exhibited in Figure 4. First is the NMAS of the mixtures. Pavements studied had NMASs ranging from 9.5 to 25 mm. This range of NMAS likely affects the size of air voids within the compacted pavement (*5*). As the NMAS increases, the size of air voids within a pavement also likely increases, especially in coarse-graded Superpave mixes. As the size of voids increase, the potential for interconnected air voids also increase. The in-place permeability of pavements is directly related to the amount of interconnected voids (*4*). Therefore, as the NMAS increases the air void level at which a pavement becomes excessively permeable would be expected to decrease.

Figure 10 illustrates the effect of NMAS on the permeability characteristics of pavements. Of the two 9.5 mm NMAS mixes evaluated, only the coarse graded is shown in Figure 10 as the other mixes shown are also coarse-graded. This figure clearly shows the effect of NMAS. As the NMAS increases, the permeability also increases at a given void level. For instance, at an in-place air void content of 6 percent the following permeabilities were observed for each NMAS:

9.5 mm NMAS » 6 x 10^{-5} cm/sec
12.5 mm NMAS » 40 x 10^{-5} cm/sec
19.0 mm NMAS » 140 x 10^{-5} cm/sec
25.0 mm NMAS » 1200 x 10^{-5} cm/sec

For the mixes evaluated, the permeability increased by an order of magnitude for each NMAS. This data clearly shows that larger NMAS mixes have more potential to be permeable.

Another potential reason for the poor correlation in Figure 4 is the gradation shape. Whether a gradation is fine- or coarse-graded (for a given NMAS) should affect the air void level at which

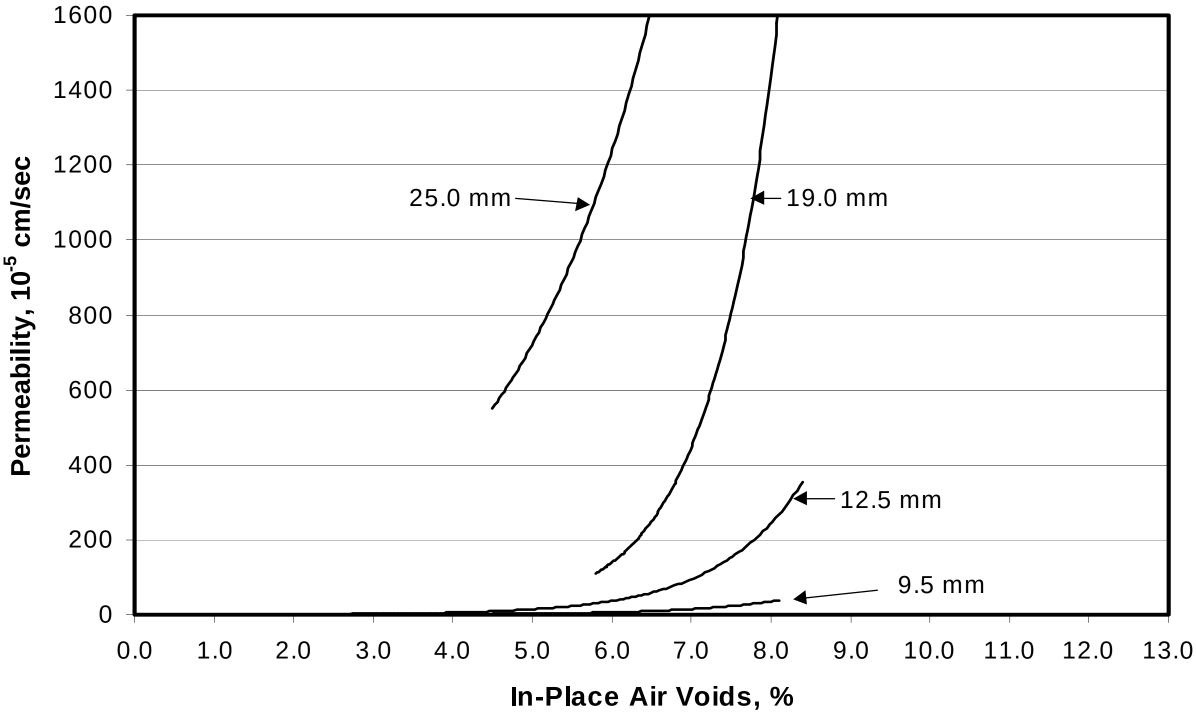


Figure 10. Best Fit Curves For In-Place Air Voids Versus Permeability For Different NMAS

a pavement becomes permeable. Similar to NMAS, the gradation shape should influence the size of voids within a pavement. Coarse graded mixes contain a relatively higher percentage of coarse aggregate than fine graded mixes. This higher percentage of coarse aggregate leads to larger voids within the mix matrix (though by volume fine graded mixes likely have the same amount of voids). The combination of larger voids and less fine aggregate to fill the voids likely results in coarse graded mixes having more interconnected voids.

Figure 11 presents a comparison of the two 9.5 mm NMAS mixtures included in this study. Recall that one was coarse graded and the other fine graded. Based on this figure, it does not appear that a difference in permeability characteristics occurred between the coarse and fine graded mixes. However, it should be cautioned that the coarse graded mix had significantly lower in-place air void contents than did the fine graded mix. The range of air voids for the coarse-graded mix was from 3 to 8 percent . Within this range of voids, one would expect a 9.5 mm NMAS pavement to be impermeable. The range of voids for the fine-graded mix was between 5.5 and 12.5 percent. Whether the mix is fine-graded or coarse-graded, it would be expected that the pavements would be permeable at air void contents above 8 percent (*4*). Therefore, this comparison may not provide the complete picture as to whether coarse-graded mixes are more permeable than fine-graded at similar void levels.

A third potential reason for the poor correlation in Figure 4 is each project utilized different lift thicknesses. As with soils, HMA permeability is directly related to the amount of interconnected voids within the pavement. The interconnected voids are the conduits through which water flows. However, unlike soils all voids within HMA pavements are not interconnected. Take for instance a pavement that is 50 mm thick. A single interconnected air void may exist that allows water to flow through the pavement. If the same pavement is 75 mm thick, it is not necessarily

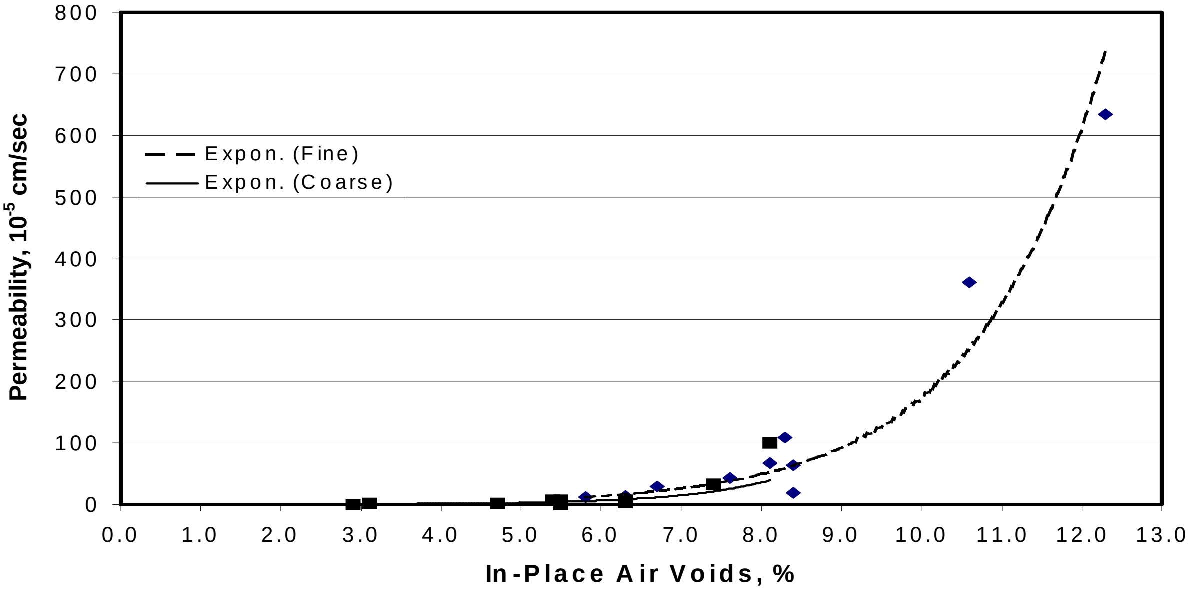


Figure 11. Plot of In-Place Air Voids Versus Permeability For Coarse and Fine Gradations

true that the same interconnected air void will exist throughout the entire pavement since all air voids are not interconnected.

Figure 12 illustrates that the permeability of asphalt pavements is related the thickness of samples. This figure present the results of the laboratory experiment conducted on lab compacted loose mix from three of the five projects. The projects include the coarse graded 9.5 mm, 12.5 mm, and 19.0 mm NMAS mixtures. This figure shows that as the thickness increases (or thickness to NMAS ratio increases), that permeability also decreases. At a thickness to NMAS (t/NMAS) ratio of 2.5, all three mixes exhibit the largest permeability value. Likewise, at the t/NMAS ratio of 4, all mixes had the lowest permeability value. The 12.5 mm NMAS mix did show an anomaly at the 3.5:1 t/NMAS ratio in that the permeability was higher than at the 3 t/NMAS ratio. However, the permeability did again decrease at the t/NMAS ratio of 4. Even with the anomaly, the data clearly shows that thicker pavements should be less permeable.

CONCLUSIONS AND RECOMMENDATIONS

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

1. Air void content (as measured by voids in total mix) of dense graded HMA has a significant effect on in place permeability of pavements.
2. There is a significant effect of nominal maximum aggregate size (NMAS) on the permeability of coarse graded Superpave designed mixes. It was shown that at a given in-place air void content that permeability increased by one order of magnitude as the NMAS increased.
3. Laboratory tests on samples with different thicknesses showed that there is a decrease in permeability with an increase in thickness.

It has been shown in previous studies that rutting in HMA pavements takes place mostly within the top 75 to 100 mm of a pavement structure (*10*). Hence, apart from providing structural support to the pavement structure, the primary concern for the deeper layers (base) should be that

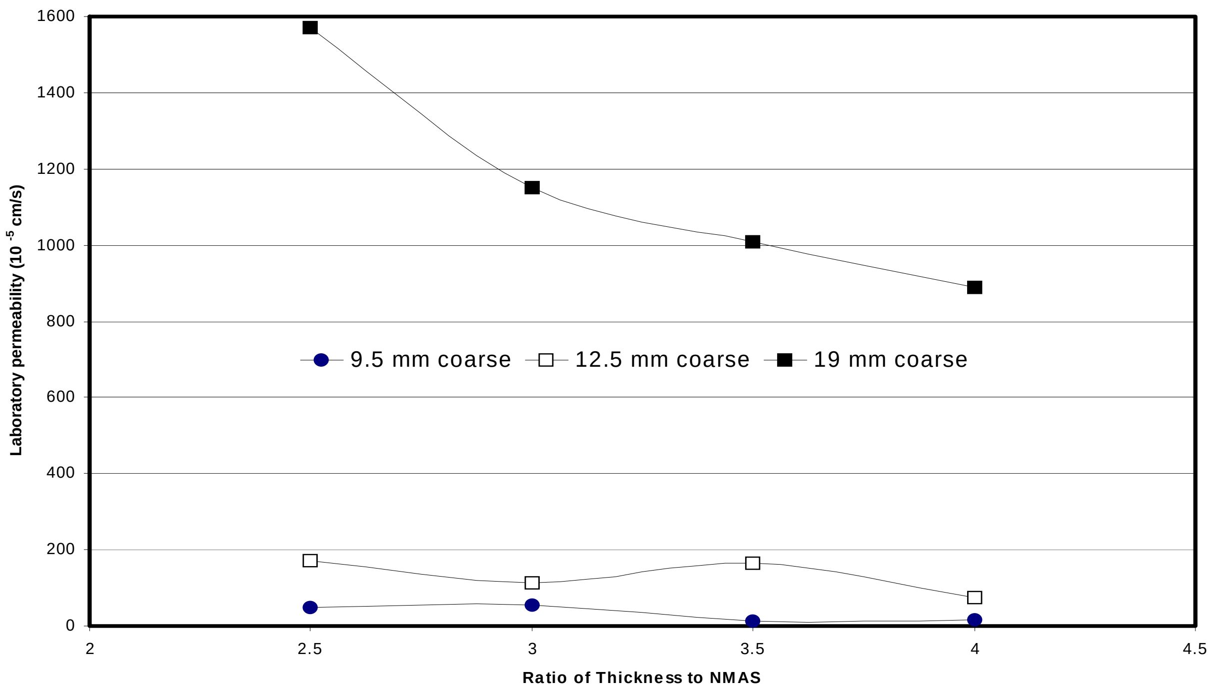


Figure 12. Permeability of Samples With Different Thickness

of durability, particularly moisture damage. This study clearly showed that 19.0 and 25.0 mm NMAS coarse graded mixes are significantly more permeable at similar void levels than typical surface type mixes (9.5 and 12.5 mm NMAS). Hence, it is recommended that State DOTs consider designing mixes to be placed 100 mm below the pavement surface on the fine side of the maximum density line. By designing base mixes on the fine side of the maximum density line, these mixes could be made less permeable than coarse graded mixes at similar void levels and thus less susceptible to allowing moisture or moisture vapor to propagate upward through the pavement structure. This in turn should reduce the potential for moisture damage within pavement structures (assuming the surface layers are impermeable).

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APPENDIX A

Raw Data (Field Testing)

Rt 15, Big Squaw, 9.5 mm fine

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	average k, cm/s
1	A	1	64	56.96	128	54.42	36	-4.30E+00		-1.55E+02	11.33	4	62.18	9.24E-04	0.001084
1	A	2	64	56.96	128	54.42	74	-2.09E+00	-3.00E+00	-1.55E+02	11.33	4	62.18	4.49E-04	
1	A	3	64	56.96	99	55.5709375	60	-2.60E+00		-1.56E+02	11.33	4	62.18	3.00E-04	
1	B	1	64	56.96	128	54.42	18	-8.61E+00		-1.55E+02	11.33	4	62.18	1.85E-03	
1	B	2	64	56.96	128	54.42	29	-5.34E+00	-6.01E+00	-1.55E+02	11.33	4	62.18	1.15E-03	
1	B	3	64	56.96	128	54.42	38	-4.08E+00		-1.55E+02	11.33	4	62.18	8.75E-04	
1	C	1	64	56.96	128	54.42	17	-9.11E+00		-1.55E+02	11.33	4	62.18	1.96E-03	
1	C	2	64	56.96	128	54.42	26	-5.96E+00	-6.54E+00	-1.55E+02	11.33	4	62.18	1.28E-03	
1	C	3	64	56.96	128	54.42	34	-4.56E+00		-1.55E+02	11.33	4	62.18	9.78E-04	
2	A	1	64	56.96	92	55.84875	60	1.19E+00		7.11E+01	11.33	4	62.18	2.39E-04	0.000134
2	A	2	48	57.595	57	57.2378125	60	3.81E-01	6.07E-01	2.29E+01	11.33	4	62.18	7.56E-05	
2	A	3	44	57.75375	50	57.515625	60	2.54E-01		1.52E+01	11.33	4	62.18	5.02E-05	
2	B	1	64	56.96	97	55.6503125	60	1.40E+00		8.38E+01	11.33	4	62.18	2.83E-04	
2	B	2	104	55.3725	120	54.7375	60	6.77E-01	8.18E-01	4.06E+01	11.33	4	62.18	1.40E-04	
2	B	3	128	54.42	137	54.0628125	60	3.81E-01		2.29E+01	11.33	4	62.18	8.00E-05	
2	C	1	56	57.2775	76	56.48375	60	8.47E-01		5.08E+01	11.33	4	62.18	1.70E-04	
2	C	2	80	56.325	92	55.84875	60	5.08E-01	5.64E-01	3.05E+01	11.33	4	62.18	1.03E-04	
2	C	3	96	55.69	104	55.3725	60	3.39E-01		2.03E+01	11.33	4	62.18	6.95E-05	
3	A	1	72	56.6425	123	54.6184375	60	2.16E+00		1.30E+02	11.33	4	62.18	4.42E-04	0.000286
3	A	2	136	54.1025	160	53.15	60	1.02E+00	1.26E+00	6.10E+01	11.33	4	62.18	2.16E-04	
3	A	3	164	52.99125	178	52.435625	60	5.93E-01		3.56E+01	11.33	4	62.18	1.28E-04	
3	B	1	80	56.325	136	54.1025	60	2.37E+00		1.42E+02	11.33	4	62.18	4.89E-04	
3	B	2	144	53.785	170	52.753125	60	1.10E+00	1.38E+00	6.60E+01	11.33	4	62.18	2.35E-04	
3	B	3	176	52.515	192	51.88	60	6.77E-01		4.06E+01	11.33	4	62.18	1.48E-04	
3	C	1	64	56.96	121	54.6978125	60	2.41E+00		1.45E+02	11.33	4	62.18	4.92E-04	
3	C	2	136	54.1025	163	53.0309375	60	1.14E+00	1.47E+00	6.86E+01	11.33	4	62.18	2.43E-04	
3	C	3	168	52.8325	188	52.03875	60	8.47E-01		5.08E+01	11.33	4	62.18	1.84E-04	
4	A	1	64	56.96	128	54.42	3.74	-4.14E+01		-1.55E+02	11.33	4	62.18	8.89E-03	0.006348
4	A	2	64	56.96	128	54.42	4.65	-3.33E+01	-3.64E+01	-1.55E+02	11.33	4	62.18	7.15E-03	
4	A	3	64	56.96	128	54.42	4.48	-3.46E+01		-1.55E+02	11.33	4	62.18	7.42E-03	
4	B	1	64	56.96	128	54.42	4.38	-3.54E+01		-1.55E+02	11.33	4	62.18	7.59E-03	
4	B	2	64	56.96	128	54.42	5.28	-2.93E+01	-3.12E+01	-1.55E+02	11.33	4	62.18	6.30E-03	
4	B	3	64	56.96	128	54.42	5.39	-2.87E+01		-1.55E+02	11.33	4	62.18	6.17E-03	
4	C	1	64	56.96	128	54.42	6.52	-2.38E+01		-1.55E+02	11.33	4	62.18	5.10E-03	
4	C	2	64	56.96	128	54.42	7.43	-2.09E+01	-2.11E+01	-1.55E+02	11.33	4	62.18	4.47E-03	
4	C	3	64	56.96	128	54.42	8.23	-1.88E+01		-1.55E+02	11.33	4	62.18	4.04E-03	
5	A	1	64	56.96	100	55.53125	60	-2.60E+00		-1.56E+02	11.33	4	62.18	3.09E-04	0.000121
5	A	2	108	55.21375	124	54.57875	60	-4.45E+00	-4.11E+00	-2.67E+02	11.33	4	62.18	1.41E-04	
5	A	3	128	54.42	140	53.94375	60	-5.28E+00		-3.17E+02	11.33	4	62.18	1.07E-04	
5	B	1	40	57.9125	56	57.2775	60	-1.61E+00		-9.68E+01	11.33	4	62.18	1.34E-04	
5	B	2	58	57.198125	64	56.96	60	-2.37E+00	-2.26E+00	-1.42E+02	11.33	4	62.18	5.07E-05	
5	B	3	68	56.80125	72	56.6425	60	-2.79E+00		-1.67E+02	11.33	4	62.18	3.40E-05	
5	C	1	76	56.48375	104	55.3725	107	-1.74E+00		-1.86E+02	11.33	4	62.18	1.35E-04	
5	C	2	112	55.055	124	54.57875	60	-4.62E+00	-3.88E+00	-2.77E+02	11.33	4	62.18	1.06E-04	
5	C	3	128	54.42	136	54.1025	60	-5.29E+00		-3.17E+02	11.33	4	62.18	7.11E-05	
6	A	1	72	56.6425	98	55.610625	60	-2.94E+00		-1.76E+02	11.33	4	62.18	2.23E-04	0.000182
6	A	2	104	55.3725	116	54.89625	60	-4.28E+00	-4.06E+00	-2.57E+02	11.33	4	62.18	1.05E-04	
6	A	3	120	54.7375	128	54.42	60	-4.95E+00		-2.97E+02	11.33	4	62.18	7.07E-05	
6	B	1	100	55.53125	140	53.94375	60	-4.10E+00		-2.46E+02	11.33	4	62.18	3.52E-04	
6	B	2	144	53.785	166	52.911875	60	-5.94E+00	-5.72E+00	-3.57E+02	11.33	4	62.18	1.99E-04	
6	B	3	172	52.67375	184	52.1975	60	-7.12E+00		-4.27E+02	11.33	4	62.18	1.10E-04	
6	C	1	84	56.16625	118	54.816875	60	-3.44E+00		-2.06E+02	11.33	4	62.18	2.95E-04	
6	C	2	124	54.57875	144	53.785	60	-5.11E+00	-4.89E+00	-3.07E+02	11.33	4	62.18	1.78E-04	
6	C	3	148	53.62625	160	53.15	60	-6.12E+00		-3.67E+02	11.33	4	62.18	1.08E-04	
7	A	1	64	56.96	160	53.15	60	-2.56E+00		-1.54E+02	11.33	4	62.18	8.41E-04	0.000645
7	A	2	176	52.515	230	50.371875	60	-7.26E+00	-6.59E+00	-4.35E+02	11.33	4	62.18	5.06E-04	
7	A	3	240	49.975	272	48.705	60	-9.94E+00		-5.96E+02	11.33	4	62.18	3.13E-04	

Rt 15, Big Squaw, 9.5 mm fine

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	average k, cm/s
7	B	1	72	56.6425	200	51.5625	60	-2.87E+00		-1.72E+02	11.33	4	62.18	1.14E-03	
7	B	2	104	55.3725	160	53.15	60	-4.25E+00	-4.69E+00	-2.55E+02	11.33	4	62.18	4.98E-04	
7	B	3	168	52.8325	204	51.40375	60	-6.93E+00		-4.16E+02	11.33	4	62.18	3.33E-04	
7	C	1	80	56.325	196	51.72125	60	-3.21E+00		-1.93E+02	11.33	4	62.18	1.04E-03	
7	C	2	212	51.08625	280	48.3875	60	-8.75E+00	-5.41E+00	-5.25E+02	11.33	4	62.18	6.59E-04	
7	C	3	104	55.3725	158	53.229375	60	-4.26E+00		-2.55E+02	11.33	4	62.18	4.79E-04	
8	A	1	64	56.96	160	53.15	60	-2.56E+00		-1.54E+02	11.33	4	62.18	8.41E-04	0.000672
8	A	2	88	56.0075	152	53.4675	60	-3.58E+00	-4.25E+00	-2.15E+02	11.33	4	62.18	5.64E-04	
8	A	3	160	53.15	200	51.5625	60	-6.60E+00		-3.96E+02	11.33	4	62.18	3.68E-04	
8	B	1	44	57.75375	148	53.62625	60	-1.72E+00		-1.03E+02	11.33	4	62.18	9.01E-04	
8	B	2	114	54.975625	184	52.1975	60	-4.66E+00	-4.77E+00	-2.80E+02	11.33	4	62.18	6.30E-04	
8	B	3	192	51.88	236	50.13375	60	-7.93E+00		-4.76E+02	11.33	4	62.18	4.16E-04	
8	C	1	88	56.0075	208	51.245	60	-3.55E+00		-2.13E+02	11.33	4	62.18	1.08E-03	
8	C	2	104	55.3725	184	52.1975	60	-4.24E+00	-5.24E+00	-2.54E+02	11.33	4	62.18	7.17E-04	
8	C	3	192	51.88	248	49.6575	60	-7.92E+00		-4.75E+02	11.33	4	62.18	5.32E-04	
9	A	1	72	56.6425	138	54.023125	60	-2.91E+00		-1.75E+02	11.33	4	62.18	5.75E-04	0.000426
9	A	2	104	55.3725	148	53.62625	60	-4.26E+00	-4.54E+00	-2.56E+02	11.33	4	62.18	3.89E-04	
9	A	3	156	53.30875	188	52.03875	60	-6.44E+00		-3.86E+02	11.33	4	62.18	2.93E-04	
9	B	1	64	56.96	132	54.26125	60	-2.58E+00		-1.55E+02	11.33	4	62.18	5.90E-04	
9	B	2	138	54.023125	184	52.1975	60	-5.68E+00	-5.40E+00	-3.41E+02	11.33	4	62.18	4.18E-04	
9	B	3	192	51.88	220	50.76875	60	-7.94E+00		-4.76E+02	11.33	4	62.18	2.63E-04	
9	C	1	64	56.96	136	54.1025	60	-2.58E+00		-1.55E+02	11.33	4	62.18	6.25E-04	
9	C	2	144	53.785	186	52.118125	60	-5.93E+00	-5.54E+00	-3.56E+02	11.33	4	62.18	3.82E-04	
9	C	3	196	51.72125	228	50.45125	60	-8.10E+00		-4.86E+02	11.33	4	62.18	3.02E-04	
10	A	1	88	56.0075	192	51.88	10.44	-2.04E+01		-2.13E+02	11.33	4	62.18	5.34E-03	0.003616
10	A	2	104	55.3725	192	51.88	10.31	-2.46E+01	-2.81E+01	-2.54E+02	11.33	4	62.18	4.61E-03	
10	A	3	128	54.42	192	51.88	8.03	-3.92E+01		-3.15E+02	11.33	4	62.18	4.34E-03	
10	B	1	64	56.96	128	54.42	9.57	-1.62E+01		-1.55E+02	11.33	4	62.18	3.47E-03	
10	B	2	96	55.69	192	51.88	16.76	-1.39E+01	-1.45E+01	-2.34E+02	11.33	4	62.18	3.08E-03	
10	B	3	64	56.96	128	54.42	11.71	-1.32E+01		-1.55E+02	11.33	4	62.18	2.84E-03	
10	C	1	64	56.96	128	54.42	9.93	-1.56E+01		-1.55E+02	11.33	4	62.18	3.35E-03	
10	C	2	64	56.96	128	54.42	11.62	-1.33E+01	-1.38E+01	-1.55E+02	11.33	4	62.18	2.86E-03	
10	C	3	64	56.96	128	54.42	12.54	-1.24E+01		-1.55E+02	11.33	4	62.18	2.65E-03	

Route 9 Edington, 9.5 mm coarse

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	average k, cm/s
1	A	1	64	56.96	67	56.8409375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.91E-05	0.000009
1	A	2	64	56.96	66	56.880625	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	1.27E-05	
1	A	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
1	B	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
1	B	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
1	B	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
1	C	1	64	56.96	66	56.880625	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.27E-05	
1	C	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
1	C	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
2	A	1	64	56.96	68	56.80125	60	1.69E-01		1.02E+01	11.33	3	62.18	2.54E-05	0.000067
2	A	2	64	56.96	65	56.9203125	60	4.23E-02	8.47E-02	2.54E+00	11.33	3	62.18	6.35E-06	
2	A	3	64	56.96	65	56.9203125	60	4.23E-02		2.54E+00	11.33	3	62.18	6.35E-06	
2	B	1	64	56.96	71	56.6821875	60	2.96E-01		1.78E+01	11.33	3	62.18	4.45E-05	
2	B	2	64	56.96	71	56.6821875	60	2.96E-01	2.68E-01	1.78E+01	11.33	3	62.18	4.45E-05	
2	B	3	64	56.96	69	56.7615625	60	2.12E-01		1.27E+01	11.33	3	62.18	3.18E-05	
2	C	1	64	56.96	89	55.9678125	60	1.06E+00		6.35E+01	11.33	3	62.18	1.60E-04	
2	C	2	64	56.96	88	56.0075	60	1.02E+00	9.74E-01	6.10E+01	11.33	3	62.18	1.54E-04	
2	C	3	64	56.96	84	56.16625	60	8.47E-01		5.08E+01	11.33	3	62.18	1.28E-04	
3	A	1	64	56.96	73	56.6028125	60	3.81E-01		2.29E+01	11.33	3	62.18	5.73E-05	0.000064
3	A	2	64	56.96	71	56.6821875	60	2.96E-01	2.82E-01	1.78E+01	11.33	3	62.18	4.45E-05	
3	A	3	64	56.96	68	56.80125	60	1.69E-01		1.02E+01	11.33	3	62.18	2.54E-05	
3	B	1	64	56.96	69	56.7615625	60	2.12E-01		1.27E+01	11.33	3	62.18	3.18E-05	
3	B	2	64	56.96	66	56.880625	60	8.47E-02	1.27E-01	5.08E+00	11.33	3	62.18	1.27E-05	
3	B	3	64	56.96	66	56.880625	60	8.47E-02		5.08E+00	11.33	3	62.18	1.27E-05	
3	C	1	64	56.96	94	55.769375	60	1.27E+00		7.62E+01	11.33	3	62.18	1.92E-04	
3	C	2	64	56.96	76	56.48375	60	5.08E-01	8.61E-01	3.05E+01	11.33	3	62.18	7.65E-05	
3	C	3	64	56.96	83	56.2059375	60	8.04E-01		4.83E+01	11.33	3	62.18	1.21E-04	
4	A	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	0.000008
4	A	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
4	A	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
4	B	1	64	56.96	67	56.8409375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.91E-05	
4	B	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
4	B	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
4	C	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
4	C	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
4	C	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
5	A	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	0.000006
5	A	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
5	A	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
5	B	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
5	B	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
5	B	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
5	C	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
5	C	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
5	C	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
6	A	1	64	56.96	174	52.594375	60	-2.55E+00		-1.53E+02	11.33	3	62.18	7.26E-04	0.001007
6	A	2	64	56.96	144	53.785	60	-2.57E+00	-2.57E+00	-1.54E+02	11.33	3	62.18	5.23E-04	
6	A	3	64	56.96	128	54.42	60	-2.58E+00		-1.55E+02	11.33	3	62.18	4.16E-04	
6	B	1	64	56.96	288	48.07	60	-2.48E+00		-1.49E+02	11.33	3	62.18	1.55E-03	
6	B	2	64	56.96	238	50.054375	60	-2.51E+00	-2.51E+00	-1.51E+02	11.33	3	62.18	1.18E-03	
6	B	3	64	56.96	208	51.245	60	-2.53E+00		-1.52E+02	11.33	3	62.18	9.63E-04	
6	C	1	64	56.96	286	48.149375	60	-2.48E+00		-1.49E+02	11.33	3	62.18	1.53E-03	
6	C	2	64	56.96	240	49.975	60	-2.51E+00	-2.50E+00	-1.50E+02	11.33	3	62.18	1.19E-03	
6	C	3	64	56.96	212	51.08625	60	-2.53E+00		-1.52E+02	11.33	3	62.18	9.92E-04	

Route 9 Edington, 9.5 mm coarse

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	average k, cm/s
7	A	1	64	56.96	66	56.880625	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.27E-05	0.000016
7	A	2	64	56.96	68	56.80125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	2.54E-05	
7	A	3	64	56.96	67	56.8409375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.91E-05	
7	B	1	64	56.96	70	56.721875	60	-2.62E+00		-1.57E+02	11.33	3	62.18	3.82E-05	
7	B	2	64	56.96	66	56.880625	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	1.27E-05	
7	B	3	64	56.96	67	56.8409375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.91E-05	
7	C	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
7	C	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	6.35E-06	
7	C	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	6.35E-06	
8	A	1	64	56.96	68	56.80125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	2.54E-05	0.000028
8	A	2	64	56.96	66	56.880625	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	1.27E-05	
8	A	3	64	56.96	67	56.8409375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.91E-05	
8	B	1	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	3	62.18	5.09E-05	
8	B	2	64	56.96	67	56.8409375	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	1.91E-05	
8	B	3	64	56.96	67	56.8409375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	1.91E-05	
8	C	1	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	3	62.18	5.09E-05	
8	C	2	64	56.96	68	56.80125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	2.54E-05	
8	C	3	64	56.96	68	56.80125	60	-2.62E+00		-1.57E+02	11.33	3	62.18	2.54E-05	
9	A	1	64	56.96	88	56.0075	60	-2.61E+00		-1.57E+02	11.33	3	62.18	1.54E-04	0.000063
9	A	2	64	56.96	73	56.6028125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	5.73E-05	
9	A	3	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	3	62.18	5.09E-05	
9	B	1	64	56.96	76	56.48375	60	-2.62E+00		-1.57E+02	11.33	3	62.18	7.65E-05	
9	B	2	64	56.96	72	56.6425	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	5.09E-05	
9	B	3	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	3	62.18	5.09E-05	
9	C	1	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	3	62.18	5.09E-05	
9	C	2	64	56.96	70	56.721875	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	3	62.18	3.82E-05	
9	C	3	64	56.96	70	56.721875	60	-2.62E+00		-1.57E+02	11.33	3	62.18	3.82E-05	
10	A	1	64	56.96	108	55.21375	60	-2.60E+00		-1.56E+02	11.33	3	62.18	2.84E-04	0.000322
10	A	2	64	56.96	91	55.8884375	60	-2.61E+00	-2.61E+00	-1.56E+02	11.33	3	62.18	1.73E-04	
10	A	3	64	56.96	82	56.245625	60	-2.61E+00		-1.57E+02	11.33	3	62.18	1.15E-04	
10	B	1	64	56.96	116	54.89625	60	-2.59E+00		-1.55E+02	11.33	3	62.18	3.36E-04	
10	B	2	64	56.96	104	55.3725	60	-2.60E+00	-2.60E+00	-1.56E+02	11.33	3	62.18	2.58E-04	
10	B	3	64	56.96	96	55.69	60	-2.60E+00		-1.56E+02	11.33	3	62.18	2.05E-04	
10	C	1	64	56.96	170	52.753125	60	-2.55E+00		-1.53E+02	11.33	3	62.18	6.99E-04	
10	C	2	64	56.96	136	54.1025	60	-2.58E+00	-2.57E+00	-1.55E+02	11.33	3	62.18	4.69E-04	
10	C	3	64	56.96	120	54.7375	60	-2.59E+00		-1.55E+02	11.33	3	62.18	3.63E-04	

Route 1, Ellsworth, 12.5 mm coarse

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	k, average
1	A	1	64	56.96	88	56.0075	70	-2.24E+00		-1.57E+02	11.33	4	62.18	1.76E-04	0.000057
1	A	2	64	56.96	80	56.325	97	-1.62E+00	-1.77E+00	-1.57E+02	11.33	4	62.18	8.42E-05	
1	A	3	64	56.96	80	56.325	108	-1.45E+00		-1.57E+02	11.33	4	62.18	7.57E-05	
1	B	1	64	56.96	80	56.325	112	-1.40E+00		-1.57E+02	11.33	4	62.18	7.30E-05	
1	B	2	64	56.96	72	56.6425	133	-1.18E+00	-1.52E+00	-1.57E+02	11.33	4	62.18	3.06E-05	
1	B	3	64	56.96	72	56.6425	79	-1.99E+00		-1.57E+02	11.33	4	62.18	5.16E-05	
1	C	1	64	56.96	68	56.80125	139	-1.13E+00		-1.57E+02	11.33	4	62.18	1.46E-05	
1	C	2	64	56.96	65	56.9203125	112	-1.41E+00	-1.35E+00	-1.57E+02	11.33	4	62.18	4.54E-06	
1	C	3	64	56.96	65	56.9203125	105	-1.50E+00		-1.57E+02	11.33	4	62.18	4.84E-06	
2	A	1	128	54.42	320	46.8	19	2.57E+01		4.88E+02	11.33	4	62.18	5.79E-03	0.006552
2	A	2	128	54.42	320	46.8	20	2.44E+01	2.48E+01	4.88E+02	11.33	4	62.18	5.50E-03	
2	A	3	128	54.42	320	46.8	20	2.44E+01		4.88E+02	11.33	4	62.18	5.50E-03	
2	B	1	128	54.42	320	46.8	12	4.06E+01		4.88E+02	11.33	4	62.18	9.16E-03	
2	B	2	128	54.42	320	46.8	15	3.25E+01	3.52E+01	4.88E+02	11.33	4	62.18	7.33E-03	
2	B	3	128	54.42	320	46.8	15	3.25E+01		4.88E+02	11.33	4	62.18	7.33E-03	
2	C	1	128	54.42	320	46.8	17	2.87E+01		4.88E+02	11.33	4	62.18	6.47E-03	
2	C	2	128	54.42	320	46.8	18	2.71E+01	2.71E+01	4.88E+02	11.33	4	62.18	6.11E-03	
2	C	3	128	54.42	320	46.8	19	2.57E+01		4.88E+02	11.33	4	62.18	5.79E-03	
3	A	1	64	56.96	168	52.8325	60	4.40E+00		2.64E+02	11.33	4	62.18	9.14E-04	0.001162
3	A	2	64	56.96	128	54.42	59	2.76E+00	3.19E+00	1.63E+02	11.33	4	62.18	5.64E-04	
3	A	3	64	56.96	128	54.42	67	2.43E+00		1.63E+02	11.33	4	62.18	4.96E-04	
3	B	1	64	56.96	256	49.34	53	9.20E+00		4.88E+02	11.33	4	62.18	1.97E-03	
3	B	2	64	56.96	256	49.34	78	6.25E+00	6.70E+00	4.88E+02	11.33	4	62.18	1.34E-03	
3	B	3	64	56.96	256	49.34	105	4.64E+00		4.88E+02	11.33	4	62.18	9.97E-04	
3	C	1	64	56.96	256	49.34	53	9.20E+00		4.88E+02	11.33	4	62.18	1.97E-03	
3	C	2	64	56.96	192	51.88	54	6.02E+00	6.56E+00	3.25E+02	11.33	4	62.18	1.26E-03	
3	C	3	64	56.96	192	51.88	73	4.45E+00		3.25E+02	11.33	4	62.18	9.33E-04	
4	A	1	64	56.96	88	56.0075	82	-1.91E+00		-1.57E+02	11.33	4	62.18	1.50E-04	0.000049
4	A	2	64	56.96	72	56.6425	58	-2.71E+00	-2.31E+00	-1.57E+02	11.33	4	62.18	7.02E-05	
4	A	3	64	56.96	68	56.80125	68	-2.31E+00		-1.57E+02	11.33	4	62.18	2.99E-05	
4	B	1	64	56.96	66	56.880625	60	-2.62E+00		-1.57E+02	11.33	4	62.18	1.69E-05	
4	B	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
4	B	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
4	C	1	64	56.96	74	56.563125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.49E-05	
4	C	2	64	56.96	68	56.80125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	3.39E-05	
4	C	3	64	56.96	68	56.80125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	3.39E-05	
5	A	1	64	56.96	66	56.880625	60	-2.62E+00		-1.57E+02	11.33	4	62.18	1.69E-05	0.000009
5	A	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
5	A	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
5	B	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
5	B	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
5	B	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
5	C	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
5	C	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
5	C	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
6	A	1	64	56.96	69	56.7615625	60	-2.62E+00		-1.57E+02	11.33	4	62.18	4.24E-05	0.000060
6	A	2	64	56.96	67	56.8409375	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	2.54E-05	
6	A	3	64	56.96	69	56.7615625	60	-2.62E+00		-1.57E+02	11.33	4	62.18	4.24E-05	
6	B	1	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	4	62.18	6.79E-05	
6	B	2	64	56.96	72	56.6425	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	6.79E-05	
6	B	3	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	4	62.18	6.79E-05	
6	C	1	64	56.96	75	56.5234375	60	-2.62E+00		-1.57E+02	11.33	4	62.18	9.35E-05	
6	C	2	64	56.96	73	56.6028125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	7.64E-05	
6	C	3	64	56.96	71	56.6821875	60	-2.62E+00		-1.57E+02	11.33	4	62.18	5.94E-05	

Route 1, Ellsworth, 12.5 mm coarse

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	k, average
7	A	1	64	56.96	73	56.6028125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	7.64E-05	0.000135
7	A	2	64	56.96	73	56.6028125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	7.64E-05	
7	A	3	64	56.96	71	56.6821875	60	-2.62E+00		-1.57E+02	11.33	4	62.18	5.94E-05	
7	B	1	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	4	62.18	6.79E-05	
7	B	2	64	56.96	75	56.5234375	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	9.35E-05	
7	B	3	64	56.96	72	56.6425	60	-2.62E+00		-1.57E+02	11.33	4	62.18	6.79E-05	
7	C	1	64	56.96	96	55.69	60	-2.60E+00		-1.56E+02	11.33	4	62.18	2.74E-04	
7	C	2	64	56.96	97	55.6503125	60	-2.60E+00	-2.60E+00	-1.56E+02	11.33	4	62.18	2.83E-04	
7	C	3	64	56.96	89	55.9678125	60	-2.61E+00		-1.56E+02	11.33	4	62.18	2.13E-04	
8	A	1	64	56.96	128	54.42	60	-2.58E+00		-1.55E+02	11.33	4	62.18	5.54E-04	0.000296
8	A	2	64	56.96	120	54.7375	60	-2.59E+00	-2.59E+00	-1.55E+02	11.33	4	62.18	4.83E-04	
8	A	3	64	56.96	113	55.0153125	60	-2.59E+00		-1.56E+02	11.33	4	62.18	4.22E-04	
8	B	1	64	56.96	98	55.610625	60	-2.60E+00		-1.56E+02	11.33	4	62.18	2.91E-04	
8	B	2	64	56.96	97	55.6503125	60	-2.60E+00	-2.60E+00	-1.56E+02	11.33	4	62.18	2.83E-04	
8	B	3	64	56.96	94	55.769375	60	-2.60E+00		-1.56E+02	11.33	4	62.18	2.57E-04	
8	C	1	64	56.96	78	56.404375	60	-2.62E+00		-1.57E+02	11.33	4	62.18	1.19E-04	
8	C	2	64	56.96	80	56.325	60	-2.61E+00	-2.61E+00	-1.57E+02	11.33	4	62.18	1.36E-04	
8	C	3	64	56.96	78	56.404375	60	-2.62E+00		-1.57E+02	11.33	4	62.18	1.19E-04	
9	A	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	0.000008
9	A	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
9	A	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
9	B	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
9	B	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
9	B	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
9	C	1	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
9	C	2	64	56.96	65	56.9203125	60	-2.62E+00	-2.62E+00	-1.57E+02	11.33	4	62.18	8.47E-06	
9	C	3	64	56.96	65	56.9203125	60	-2.62E+00		-1.57E+02	11.33	4	62.18	8.47E-06	
10	A	1	64	56.96	152	53.4675	60	-2.57E+00		-1.54E+02	11.33	4	62.18	7.69E-04	0.000775
10	A	2	64	56.96	123	54.6184375	60	-2.59E+00	-2.58E+00	-1.55E+02	11.33	4	62.18	5.10E-04	
10	A	3	64	56.96	120	54.7375	60	-2.59E+00		-1.55E+02	11.33	4	62.18	4.83E-04	
10	B	1	64	56.96	176	52.515	60	-2.55E+00		-1.53E+02	11.33	4	62.18	9.87E-04	
10	B	2	64	56.96	146	53.705625	60	-2.57E+00	-2.57E+00	-1.54E+02	11.33	4	62.18	7.15E-04	
10	B	3	64	56.96	136	54.1025	60	-2.58E+00		-1.55E+02	11.33	4	62.18	6.25E-04	
10	C	1	64	56.96	192	51.88	60	-2.54E+00		-1.52E+02	11.33	4	62.18	1.13E-03	
10	C	2	64	56.96	168	52.8325	60	-2.56E+00	-2.55E+00	-1.53E+02	11.33	4	62.18	9.14E-04	
10	C	3	64	56.96	160	53.15	60	-2.56E+00		-1.54E+02	11.33	4	62.18	8.41E-04	

Note: a = area of stand pipe, A = area through which water enters pavement, L = thickness of pavement layer, t = time of flow

I-95, Carmel, 19 mm coarse

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	average K, cm/s
1	A	1	64	56.96	128	54.42	37	-4.19E+00		-1.55E+02	11.33	5	62.18	1.12E-03	0.002341
1	A	2	128	54.42	192	51.88	48	-6.56E+00	-5.36E+00	-3.15E+02	11.33	5	62.18	9.07E-04	
1	A	3	128	54.42	192	51.88	59	-5.34E+00		-3.15E+02	11.33	5	62.18	7.38E-04	
1	B	1	64	56.96	128	54.42	13	-1.19E+01		-1.55E+02	11.33	5	62.18	3.20E-03	
1	B	2	192	51.88	256	49.34	15	-3.17E+01	-2.38E+01	-4.75E+02	11.33	5	62.18	3.05E-03	
1	B	3	192	51.88	256	49.34	17	-2.79E+01		-4.75E+02	11.33	5	62.18	2.69E-03	
1	C	1	64	56.96	128	54.42	13	-1.19E+01		-1.55E+02	11.33	5	62.18	3.20E-03	
1	C	2	192	51.88	256	49.34	14	-3.39E+01	-2.23E+01	-4.75E+02	11.33	5	62.18	3.27E-03	
1	C	3	128	54.42	192	51.88	15	-2.10E+01		-3.15E+02	11.33	5	62.18	2.90E-03	
2	A	1	64	56.96	128	54.42	5	3.25E+01		1.63E+02	11.33	5	62.18	8.31E-03	0.005585
2	A	2	64	56.96	128	54.42	6	2.71E+01	2.89E+01	1.63E+02	11.33	5	62.18	6.93E-03	
2	A	3	64	56.96	128	54.42	6	2.71E+01		1.63E+02	11.33	5	62.18	6.93E-03	
2	B	1	64	56.96	128	54.42	15	1.08E+01		1.63E+02	11.33	5	62.18	2.77E-03	
2	B	2	64	56.96	128	54.42	15	1.08E+01	1.08E+01	1.63E+02	11.33	5	62.18	2.77E-03	
2	B	3	64	56.96	128	54.42	15	1.08E+01		1.63E+02	11.33	5	62.18	2.77E-03	
2	C	1	64	56.96	128	54.42	6	2.71E+01		1.63E+02	11.33	5	62.18	6.93E-03	
2	C	2	64	56.96	128	54.42	7	2.32E+01	2.58E+01	1.63E+02	11.33	5	62.18	5.94E-03	
2	C	3	64	56.96	128	54.42	6	2.71E+01		1.63E+02	11.33	5	62.18	6.93E-03	
3	A	1	128	54.42	256	49.34	3	1.08E+02		3.25E+02	11.33	5	62.18	2.98E-02	0.023629
3	A	2	128	54.42	256	49.34	2	1.63E+02	1.44E+02	3.25E+02	11.33	5	62.18	4.46E-02	
3	A	3	128	54.42	256	49.34	2	1.63E+02		3.25E+02	11.33	5	62.18	4.46E-02	
3	B	1	64	56.96	192	51.88	5	6.50E+01		3.25E+02	11.33	5	62.18	1.70E-02	
3	B	2	64	56.96	192	51.88	5	6.50E+01	6.50E+01	3.25E+02	11.33	5	62.18	1.70E-02	
3	B	3	64	56.96	192	51.88	5	6.50E+01		3.25E+02	11.33	5	62.18	1.70E-02	
3	C	1	64	56.96	192	51.88	6	5.42E+01		3.25E+02	11.33	5	62.18	1.42E-02	
3	C	2	64	56.96	192	51.88	6	5.42E+01	5.42E+01	3.25E+02	11.33	5	62.18	1.42E-02	
3	C	3	64	56.96	192	51.88	6	5.42E+01		3.25E+02	11.33	5	62.18	1.42E-02	
4	A	1	64	56.96	192	51.88	5	-3.05E+01		-1.52E+02	11.33	5	62.18	1.70E-02	0.018440
4	A	2	64	56.96	192	51.88	5	-3.05E+01	-3.05E+01	-1.52E+02	11.33	5	62.18	1.70E-02	
4	A	3	64	56.96	192	51.88	5	-3.05E+01		-1.52E+02	11.33	5	62.18	1.70E-02	
4	B	1	64	56.96	192	51.88	4	-3.81E+01		-1.52E+02	11.33	5	62.18	2.13E-02	
4	B	2	64	56.96	192	51.88	4	-3.81E+01	-3.81E+01	-1.52E+02	11.33	5	62.18	2.13E-02	
4	B	3	64	56.96	192	51.88	4	-3.81E+01		-1.52E+02	11.33	5	62.18	2.13E-02	
4	C	1	64	56.96	192	51.88	5	-3.05E+01		-1.52E+02	11.33	5	62.18	1.70E-02	
4	C	2	64	56.96	192	51.88	5	-3.05E+01	-3.05E+01	-1.52E+02	11.33	5	62.18	1.70E-02	
4	C	3	64	56.96	192	51.88	5	-3.05E+01		-1.52E+02	11.33	5	62.18	1.70E-02	
5	A	1	64	56.96	192	51.88	29	-5.26E+00		-1.52E+02	11.33	5	62.18	2.93E-03	0.002353
5	A	2	64	56.96	192	51.88	34	-4.48E+00	-4.58E+00	-1.52E+02	11.33	5	62.18	2.50E-03	
5	A	3	64	56.96	192	51.88	38	-4.01E+00		-1.52E+02	11.33	5	62.18	2.24E-03	
5	B	1	64	56.96	192	51.88	28	-5.44E+00		-1.52E+02	11.33	5	62.18	3.04E-03	
5	B	2	64	56.96	192	51.88	33	-4.62E+00	-4.85E+00	-1.52E+02	11.33	5	62.18	2.58E-03	
5	B	3	64	56.96	192	51.88	34	-4.48E+00		-1.52E+02	11.33	5	62.18	2.50E-03	
5	C	1	64	56.96	192	51.88	42	-3.63E+00		-1.52E+02	11.33	5	62.18	2.03E-03	
5	C	2	64	56.96	192	51.88	48	-3.18E+00	-3.21E+00	-1.52E+02	11.33	5	62.18	1.77E-03	
5	C	3	64	56.96	192	51.88	54	-2.82E+00		-1.52E+02	11.33	5	62.18	1.58E-03	
6	A	1	64	56.96	192	51.88	6	-2.54E+01		-1.52E+02	11.33	5	62.18	1.42E-02	0.020039
6	A	2	64	56.96	192	51.88	7	-2.18E+01	-2.30E+01	-1.52E+02	11.33	5	62.18	1.22E-02	
6	A	3	64	56.96	192	51.88	7	-2.18E+01		-1.52E+02	11.33	5	62.18	1.22E-02	
6	B	1	64	56.96	192	51.88	4	-3.81E+01		-1.52E+02	11.33	5	62.18	2.13E-02	
6	B	2	64	56.96	192	51.88	4	-3.81E+01	-3.81E+01	-1.52E+02	11.33	5	62.18	2.13E-02	
6	B	3	64	56.96	192	51.88	4	-3.81E+01		-1.52E+02	11.33	5	62.18	2.13E-02	
6	C	1	64	56.96	192	51.88	3	-5.08E+01		-1.52E+02	11.33	5	62.18	2.84E-02	
6	C	2	64	56.96	192	51.88	3	-5.08E+01	-4.66E+01	-1.52E+02	11.33	5	62.18	2.84E-02	
6	C	3	64	56.96	192	51.88	4	-3.81E+01		-1.52E+02	11.33	5	62.18	2.13E-02	
7	A	1	64	56.96	128	54.42	40	-3.87E+00		-1.55E+02	11.33	5	62.18	1.04E-03	0.001351
7	A	2	64	56.96	128	54.42	49	-3.16E+00	-3.15E+00	-1.55E+02	11.33	5	62.18	8.48E-04	
7	A	3	64	56.96	128	54.42	64	-2.42E+00		-1.55E+02	11.33	5	62.18	6.49E-04	
7	B	1	64	56.96	128	54.42	18	-8.61E+00		-1.55E+02	11.33	5	62.18	2.31E-03	

I-95, Carmel, 19 mm coarse

Location	Test	Replicate	Initial reading, inch mark	Initial Head, cm	Final reading, 64th of inch	Final Head, cm	time, s	loss, cm/sec	Average of replicates	Loss (h1-h2), cm	a, cm2	L, cm	A, cm2	k, cm/s	average K, cm/s
7	B	2	64	56.96	128	54.42	22	-7.04E+00	-7.37E+00	-1.55E+02	11.33	5	62.18	1.89E-03	
7	B	3	64	56.96	128	54.42	24	-6.46E+00		-1.55E+02	11.33	5	62.18	1.73E-03	
7	C	1	64	56.96	128	54.42	29	-5.34E+00		-1.55E+02	11.33	5	62.18	1.43E-03	
7	C	2	64	56.96	128	54.42	34	-4.56E+00	-4.59E+00	-1.55E+02	11.33	5	62.18	1.22E-03	
7	C	3	64	56.96	128	54.42	40	-3.87E+00		-1.55E+02	11.33	5	62.18	1.04E-03	
8	A	1	64	56.96	128	54.42	57	-2.72E+00		-1.55E+02	11.33	5	62.18	7.29E-04	0.000598
8	A	2	64	56.96	128	54.42	89	-1.74E+00	-1.99E+00	-1.55E+02	11.33	5	62.18	4.67E-04	
8	A	3	64	56.96	128	54.42	103	-1.50E+00		-1.55E+02	11.33	5	62.18	4.04E-04	
8	B	1	64	56.96	128	54.42	75	-2.07E+00		-1.55E+02	11.33	5	62.18	5.54E-04	
8	B	2	64	56.96	128	54.42	99	-1.57E+00	-1.62E+00	-1.55E+02	11.33	5	62.18	4.20E-04	
8	B	3	64	56.96	128	54.42	127	-1.22E+00		-1.55E+02	11.33	5	62.18	3.27E-04	
8	C	1	64	56.96	128	54.42	38	-4.08E+00		-1.55E+02	11.33	5	62.18	1.09E-03	
8	C	2	64	56.96	128	54.42	57	-2.72E+00	-3.08E+00	-1.55E+02	11.33	5	62.18	7.29E-04	
8	C	3	64	56.96	128	54.42	63	-2.46E+00		-1.55E+02	11.33	5	62.18	6.60E-04	
9	A	1	64	56.96	128	54.42	27	-5.74E+00		-1.55E+02	11.33	5	62.18	1.54E-03	0.001612
9	A	2	64	56.96	128	54.42	38	-4.08E+00	-4.37E+00	-1.55E+02	11.33	5	62.18	1.09E-03	
9	A	3	64	56.96	128	54.42	47	-3.30E+00		-1.55E+02	11.33	5	62.18	8.84E-04	
9	B	1	64	56.96	128	54.42	61	-2.54E+00		-1.55E+02	11.33	5	62.18	6.81E-04	
9	B	2	64	56.96	128	54.42	60	-2.58E+00	-2.43E+00	-1.55E+02	11.33	5	62.18	6.93E-04	
9	B	3	64	56.96	128	54.42	71	-2.18E+00		-1.55E+02	11.33	5	62.18	5.85E-04	
9	C	1	64	56.96	128	54.42	12	-1.29E+01		-1.55E+02	11.33	5	62.18	3.46E-03	
9	C	2	64	56.96	128	54.42	14	-1.11E+01	-1.12E+01	-1.55E+02	11.33	5	62.18	2.97E-03	
9	C	3	64	56.96	128	54.42	16	-9.68E+00		-1.55E+02	11.33	5	62.18	2.60E-03	
10	A	1	64	56.96	128	54.42	9	-1.72E+01		-1.55E+02	11.33	5	62.18	4.62E-03	0.005015
10	A	2	64	56.96	128	54.42	11	-1.41E+01	-1.47E+01	-1.55E+02	11.33	5	62.18	3.78E-03	
10	A	3	64	56.96	128	54.42	12	-1.29E+01		-1.55E+02	11.33	5	62.18	3.46E-03	
10	B	1	64	56.96	128	54.42	8	-1.94E+01		-1.55E+02	11.33	5	62.18	5.20E-03	
10	B	2	64	56.96	128	54.42	9	-1.72E+01	-1.79E+01	-1.55E+02	11.33	5	62.18	4.62E-03	
10	B	3	64	56.96	128	54.42	9	-1.72E+01		-1.55E+02	11.33	5	62.18	4.62E-03	
10	C	1	64	56.96	192	51.88	12	-1.27E+01		-1.52E+02	11.33	5	62.18	7.09E-03	
10	C	2	64	56.96	192	51.88	14	-1.09E+01	-1.12E+01	-1.52E+02	11.33	5	62.18	6.08E-03	
10	C	3	64	56.96	192	51.88	15	-1.02E+01		-1.52E+02	11.33	5	62.18	5.67E-03	

Route 11, Oxbow, 25 mm coarse

Location	Test	Replicate	Initial Head, cm	Final Head, cm	time, s	a, cm2	L, cm	A, cm2	k, cm/s	average k, cm/s
1	A	1	38.96	36.42	21	62.18	8.9	62.18	2.86E-02	0.027677
1	A	2	38.96	36.42	22	62.18	8.9	62.18	2.73E-02	
1	A	3	38.96	36.42	21	62.18	8.9	62.18	2.86E-02	
1	B	1	38.96	36.42	26	62.18	8.9	62.18	2.31E-02	
1	B	2	38.96	36.42	26	62.18	8.9	62.18	2.31E-02	
1	B	3	38.96	36.42	26	62.18	8.9	62.18	2.31E-02	
1	C	1	38.96	36.42	17	62.18	8.9	62.18	3.53E-02	
1	C	2	38.96	36.42	19	62.18	8.9	62.18	3.16E-02	
1	C	3	38.96	36.42	21	62.18	8.9	62.18	2.86E-02	
2	A	1	38.96	36.42	41	62.18	8.9	62.18	1.46E-02	0.009455
2	A	2	38.96	36.42	48	62.18	8.9	62.18	1.25E-02	
2	A	3	38.96	36.42	49	62.18	8.9	62.18	1.22E-02	
2	B	1	38.96	36.42	60	62.18	8.9	62.18	1.00E-02	
2	B	2	38.96	36.42	65	62.18	8.9	62.18	9.23E-03	
2	B	3	38.96	36.42	73	62.18	8.9	62.18	8.22E-03	
2	C	1	38.96	36.42	79	62.18	8.9	62.18	7.60E-03	
2	C	2	38.96	36.42	105	62.18	8.9	62.18	5.71E-03	
2	C	3	38.96	36.42	121	62.18	8.9	62.18	4.96E-03	
3	A	1	38.96	36.42	9	62.18	8.9	62.18	6.67E-02	0.064893
3	A	2	38.96	33.88	19	62.18	8.9	62.18	6.54E-02	
3	A	3	38.96	33.88	19	62.18	8.9	62.18	6.54E-02	
3	B	1	38.96	33.88	20	62.18	8.9	62.18	6.22E-02	
3	B	2	38.96	33.88	20	62.18	8.9	62.18	6.22E-02	
3	B	3	38.96	33.88	20	62.18	8.9	62.18	6.22E-02	
3	C	1	38.96	33.88	18	62.18	8.9	62.18	6.91E-02	
3	C	2	38.96	33.88	19	62.18	8.9	62.18	6.54E-02	
3	C	3	38.96	33.88	19	62.18	8.9	62.18	6.54E-02	
4	A	1	38.96	36.42	50	62.18	8.9	62.18	1.20E-02	0.016911
4	A	2	38.96	36.42	48	62.18	8.9	62.18	1.25E-02	
4	A	3	38.96	36.42	52	62.18	8.9	62.18	1.15E-02	
4	B	1	38.96	36.42	24	62.18	8.9	62.18	2.50E-02	
4	B	2	38.96	36.42	26	62.18	8.9	62.18	2.31E-02	
4	B	3	38.96	36.42	27	62.18	8.9	62.18	2.22E-02	
4	C	1	38.96	36.42	35	62.18	8.9	62.18	1.71E-02	
4	C	2	38.96	36.42	39	62.18	8.9	62.18	1.54E-02	
4	C	3	38.96	36.42	45	62.18	8.9	62.18	1.33E-02	
5	A	1	38.96	36.42	64	62.18	8.9	62.18	9.38E-03	0.007970
5	A	2	38.96	36.42	70	62.18	8.9	62.18	8.57E-03	
5	A	3	38.96	36.42	75	62.18	8.9	62.18	8.00E-03	
5	B	1	38.96	36.42	64	62.18	8.9	62.18	9.38E-03	
5	B	2	38.96	36.42	76	62.18	8.9	62.18	7.89E-03	
5	B	3	38.96	36.42	80	62.18	8.9	62.18	7.50E-03	
5	C	1	38.96	36.42	80	62.18	8.9	62.18	7.50E-03	
5	C	2	38.96	36.42	85	62.18	8.9	62.18	7.06E-03	
5	C	3	38.96	36.42	93	62.18	8.9	62.18	6.45E-03	
6	A	1	38.96	36.42	18	62.18	8.9	62.18	3.33E-02	0.027452
6	A	2	38.96	36.42	18	62.18	8.9	62.18	3.33E-02	
6	A	3	38.96	36.42	20	62.18	8.9	62.18	3.00E-02	
6	B	1	38.96	36.42	33	62.18	8.9	62.18	1.82E-02	
6	B	2	38.96	36.42	33	62.18	8.9	62.18	1.82E-02	
6	B	3	38.96	36.42	38	62.18	8.9	62.18	1.58E-02	
6	C	1	38.96	36.42	18	62.18	8.9	62.18	3.33E-02	
6	C	2	38.96	36.42	18	62.18	8.9	62.18	3.33E-02	
6	C	3	38.96	36.42	19	62.18	8.9	62.18	3.16E-02	
7	A	1	38.96	36.42	62	62.18	8.9	62.18	9.68E-03	0.007020
7	A	2	38.96	36.42	69	62.18	8.9	62.18	8.70E-03	

Route 11, Oxbow, 25 mm coarse

Location	Test	Replicate	Initial Head, cm	Final Head, cm	time, s	a, cm2	L, cm	A, cm2	k, cm/s	average k, cm/s
7	A	3	38.96	36.42	71	62.18	8.9	62.18	8.45E-03	
7	B	1	38.96	36.42	55	62.18	8.9	62.18	1.09E-02	
7	B	2	38.96	36.42	60	62.18	8.9	62.18	1.00E-02	
7	B	3	38.96	36.42	60	62.18	8.9	62.18	1.00E-02	
7	C	1	38.96	38.325	74	62.18	8.9	62.18	1.98E-03	
7	C	2	38.96	38.325	81	62.18	8.9	62.18	1.81E-03	
7	C	3	38.96	38.325	88	62.18	8.9	62.18	1.66E-03	
8	A	1	38.96	36.42	78	62.18	8.9	62.18	7.69E-03	0.005968
8	A	2	38.96	36.42	86	62.18	8.9	62.18	6.98E-03	
8	A	3	38.96	36.42	92	62.18	8.9	62.18	6.52E-03	
8	B	1	38.96	36.42	87	62.18	8.9	62.18	6.90E-03	
8	B	2	38.96	36.42	95	62.18	8.9	62.18	6.32E-03	
8	B	3	38.96	36.42	93	62.18	8.9	62.18	6.45E-03	
8	C	1	38.96	36.42	123	62.18	8.9	62.18	4.88E-03	
8	C	2	38.96	36.42	148	62.18	8.9	62.18	4.05E-03	
8	C	3	38.96	36.42	153	62.18	8.9	62.18	3.92E-03	
9	A	1	38.96	36.42	70	62.18	8.9	62.18	8.57E-03	0.008019
9	A	2	38.96	36.42	71	62.18	8.9	62.18	8.45E-03	
9	A	3	38.96	36.42	68	62.18	8.9	62.18	8.82E-03	
9	B	1	38.96	36.42	77	62.18	8.9	62.18	7.79E-03	
9	B	2	38.96	36.42	86	62.18	8.9	62.18	6.98E-03	
9	B	3	38.96	36.42	104	62.18	8.9	62.18	5.77E-03	
9	C	1	38.96	36.42	65	62.18	8.9	62.18	9.23E-03	
9	C	2	38.96	36.42	73	62.18	8.9	62.18	8.22E-03	
9	C	3	38.96	36.42	72	62.18	8.9	62.18	8.33E-03	
10	A	1	38.96	33.88	7	62.18	8.9	62.18	1.78E-01	0.122631
10	A	2	38.96	33.88	8	62.18	8.9	62.18	1.55E-01	
10	A	3	38.96	33.88	8	62.18	8.9	62.18	1.55E-01	
10	B	1	38.96	33.88	12	62.18	8.9	62.18	1.04E-01	
10	B	2	38.96	33.88	13	62.18	8.9	62.18	9.56E-02	
10	B	3	38.96	33.88	13	62.18	8.9	62.18	9.56E-02	
10	C	1	38.96	33.88	11	62.18	8.9	62.18	1.13E-01	
10	C	2	38.96	33.88	12	62.18	8.9	62.18	1.04E-01	
10	C	3	38.96	33.88	12	62.18	8.9	62.18	1.04E-01	

Note: a = area of stand pipe, A = area through which water enters pavement, L = thickness of pavement layer, t = time of flow