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DEVELOPMENT OF CRITICAL FIELD PERMEABILITY AND PAVEMENT DENSITY VALUES FOR COARSE-GRADED SUPERPAVE PAVEMENTS

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DISCLAIMER

ABSTRACT

Within the hot mix asphalt (HMA) community, it is generally accepted that the proper compaction of HMA is vital for a stable and durable pavement. Low in-place air voids have been shown to lead to rutting and shoving while high in-place air voids have been shown to reduce a pavement's durability through moisture damage and excessive oxidation of the asphalt binder. Recent research has suggested that coarse-graded Superpave designed mixes are more permeable than conventionally designed pavements at a given air void content. This higher permeability can lead to durability problems. This study was conducted to evaluate at what pavement density coarse-graded Superpave mixes become permeable using a field permeability device. Based upon the data collected, 9.5 and 12.5 mm nominal maximum size mixtures (NMAS) become excessively permeable at approximately 7.7 percent in-place air voids, which corresponded to a field permeability value of 100×10^{-5} cm/sec. Mixtures having a 19.0 mm NMAS became permeable at an in-place air void content of 5.5 percent air voids, which provided a field permeability value of 120×10^{-5} cm/sec. Coarse-graded mixes having an NMAS of 25.0 mm became permeable at 4.4 percent air voids, which corresponded to a field permeability value of 150×10^{-5} cm/sec.

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BACKGROUND

Within the hot mix asphalt community, it is generally accepted that the proper compaction of HMA is vital for a stable and durable pavement. For dense-graded mixtures, numerous studies have shown that initial in-place air void contents should not be below 3 percent or above approximately 8 percent (*1*). Low air voids have been shown to lead to rutting and shoving, while high air voids are believed to allow water and air to penetrate into the pavement resulting in an increased potential for moisture damage, raveling, and/or cracking (*1*).

In the past, it has been thought that for most conventionally designed dense-graded HMA (Hveem and Marshall), increases in in-place air void contents have meant increases in permeability. Zube (*2*) has indicated that dense-graded HMA pavements become permeable to water at approximately 8 percent air voids. This was later confirmed by Brown et al. (*3*).

However, due to problems associated with some coarse-graded Superpave designed mixes in Florida (gradation passing below maximum density line and restricted zone), the size and interconnectivity of the air voids have been shown to greatly influence pavement permeability (*4*). The problems encountered with coarse-graded Superpave mixes in Florida has put a high emphasis on the permeability testing of HMA pavements. This is likely due to permeability giving a better indication of a pavement's durability than density alone (*5*).

Cooley and Brown have reported on a permeability device for HMA pavements that can be used in the field (*6*). Results indicated that the field permeameter was correlated to the laboratory permeameter developed by Florida, repeatable, and easy to use. The selected device consisted of a three-tiered standpipe and used a falling head approach. The standpipe with the smallest diameter was located at the top of the device and the largest diameter standpipe was located at the bottom. This configuration made the field permeameter more sensitive to the flow of water into the pavement. For pavements that were relatively impermeable, the water fell very slowly in the small diameter top tier standpipe. If pavements were relatively permeable, the water level would move quickly through the top tier but slow down when it reached the larger diameter middle tier standpipe.

Cooley and Brown (*6*) presented some preliminary results of testing conducted to relate field permeability to in-place pavement density. Results from five HMA projects indicated that good relationships existed. Coefficient of determination (R^2) values ranged from a low of 0.67 to a high of 0.82 for these five projects.

POTENTIAL FACTORS AFFECTING HMA PERMEABILITY

The literature has suggested several mixture properties that can affect the permeability of HMA pavements. Probably the most prevalent of these factors is in-place air voids (*2*, *3*, *4*, *6*). As in-place air voids increase, permeability also increases. However, other factors also can significantly affect permeability. First, work has suggested that mixtures with different nominal maximum aggregate sizes (NMAS) have different permeability characteristics (*7*). The NMAS has an effect on the size of air voids within an HMA. As the NMAS increases, the size of individual air voids also increase. This increase in air void size leads to an increased potential for interconnected air voids. The existence of these interconnected voids is what leads to permeability within pavements. Interconnected voids are the paths through which water can flow. Therefore, mixes with larger NMAS would be expected to be more permeable, at a given air void content, than mixes with a smaller NMAS size.

Another factor that affects the permeability characteristics is the gradation shape. Gradations that pass below the maximum density line (MDL) should be expected to be more permeable than mixes having gradations that pass above the MDL (*4*). Similar to the NMAS, gradation shape affects the size of air voids within a compacted HMA. Coarser gradations contain a higher percentage of coarse aggregate which results in larger individual air voids and thus a higher potential for interconnected air voids.

Since both NMAS and gradation affect permeability characteristics, it can be surmised that the amount of fine aggregate within an aggregate gradation may control permeability. The literature has suggested that larger NMAS and gradations with higher coarse aggregate contents lead to more potential for permeability. In both instances, less fine aggregate is available to fill the void space between the larger aggregate particles. This results in larger air voids within a given volume and thus a higher potential for permeability.

A construction issue that could also affect permeability is the lift thickness at which a given HMA is placed (*7*). As the lift thickness increases, the potential for permeability likely decreases. Take for instance coarse-graded soils (sands), all voids are interconnected and permeability is not dependent upon thickness. Within normally constructed HMA, all voids are not necessarily interconnected. Voids that are not interconnected do no allow water to flow. As the thickness increases, the chance for voids being interconnected with a sufficient length to allow water to flow decreases. For this reason, thinner pavements may have more potential for permeability.

Because of these factors that can affect the permeability characteristics of HMA pavements, a study was needed to identify both critical permeability and pavement density values for coarse-graded Superpave mixes. This type of information would provide valuable information to agencies that wish to construct impermeable pavements.

OBJECTIVE

The objective of this work was to conduct in-place permeability testing on numerous coarse-graded Superpave designed projects, compare in-place permeability to pavement density, and utilize the collected data to recommend both critical in-place density and permeability values for coarse-graded Superpave designed pavements.

RESEARCH APPROACH

The primary objective of this study was to identify the in-place air void content at which coarse-graded Superpave designed pavements become excessively permeable. Therefore, field permeability tests were conducted at eleven on-going HMA projects. Projects were identified such that four different nominal maximum aggregate sizes (NMAS) were included: 9.5, 12.5, 19.0, and 25.0 mm.

For each project visited, field permeability tests were conducted at a total of fifteen test locations. The test locations were selected in a random manner. When testing at one test location was completed, the next location was selected based upon how far the finish roller had moved forward. Because of the variability in testing time and the variability in the construction process, this manner was considered random. At each test location, three replicate permeability tests were conducted. Because the field permeameter uses a silicone-rubber caulk to help seal the device to the pavement, replicate tests could not be conducted on the same spot of the pavement. Therefore, after the first replicate at a given test location was completed, the device was lifted off the pavement and re-sealed immediately beside the first replicate to conduct the second replicate test. The device was moved longitudinally down the pavement during these replicate tests because density tends to be more uniform longitudinally than transversely. After the second replicate test was completed at a given test location, the device was moved in a similar manner. However, between the second and third replicate tests a space of approximately 25.4 cm (10 in) was left from which a core was cut. The core was used to measure pavement density. Theoretical maximum density values were obtained from quality control testing for the day testing was conducted and used along with each core's density to calculate in-place air void contents.

TEST RESULTS AND ANALYSES

Field testing was conducted at a total of eleven different HMA projects for this study and represented Superpave designed mixtures from seven states. Job-mix-formula gradations and asphalt contents for the eleven mixes are provided in Table 1. The NMAS breakdown for the eleven mixes was two-9.5 mm, four-12.5 mm, two-19.0 mm, and three-25.0 mm. Ten of the eleven mixes would be considered coarse-graded with the lone exception being the 25.0 mm NMAS mix from Project 8. This mix had a gradation that passed just above the restricted zone.

Table 1. Mixture Job-Mix-Formula Properties

Project:	1	2	3	4	5	6	7	8	9	10	11
Sieve, mm	Gradation (% Passing)										
37.5					100		100	100			
25.0			100		96		92	97			100
19.0	100		98	100	81		81	90	100	100	98
12.5	96	100	84	96	51	100	67	73	95	94	89
9.5	88	93	69	89	40	94	62	61	83	84	79
4.75	60	56	43	61	28	63	41	45	52	51	48
2.36	35	33	29	41	21	38	27	34	35	32	32
1.18	24	26	22	29	15	21	19	28	25	23	21
0.60	19	20	16	22	10	15	15	23	19	17	13
0.30	14	12	9	13	8	11	12	18	14	12	7
0.15	8	8	6	8	7	8	9	12	9	7	5
0.075	4.8	3.8	4.6	6.1	6	4.9	5	5	4.8	4.1	3.3
NMAS, mm[1]	12.5	9.5	19.0	12.5	25.0	9.5	25.0	25.0	12.5	12.5	19
Asphalt Content	5.2	5.5	4.7	6.2	4.4	5.7	4.8	4.6	4.8	4.6	4.9

[1] NMAS - Nominal Maximum Aggregate Size

Plots of field permeability versus in-place air voids were prepared for all eleven projects. Figures 1 through 3 present three typical plots from the eleven projects. Figure 1 illustrates the permeability-density relationship for Project 2. The mixture from this project was a 9.5 mm NMAS mixture. A good coefficient of determination (R^2=0.67) between permeability and in-place air voids is shown in Figure 1. As in-place air voids increase, permeability also increased. At low air void contents, the pavement is relatively impermeable. However, at higher air void contents small changes in in-place air voids resulted in exponentially increasing permeability.

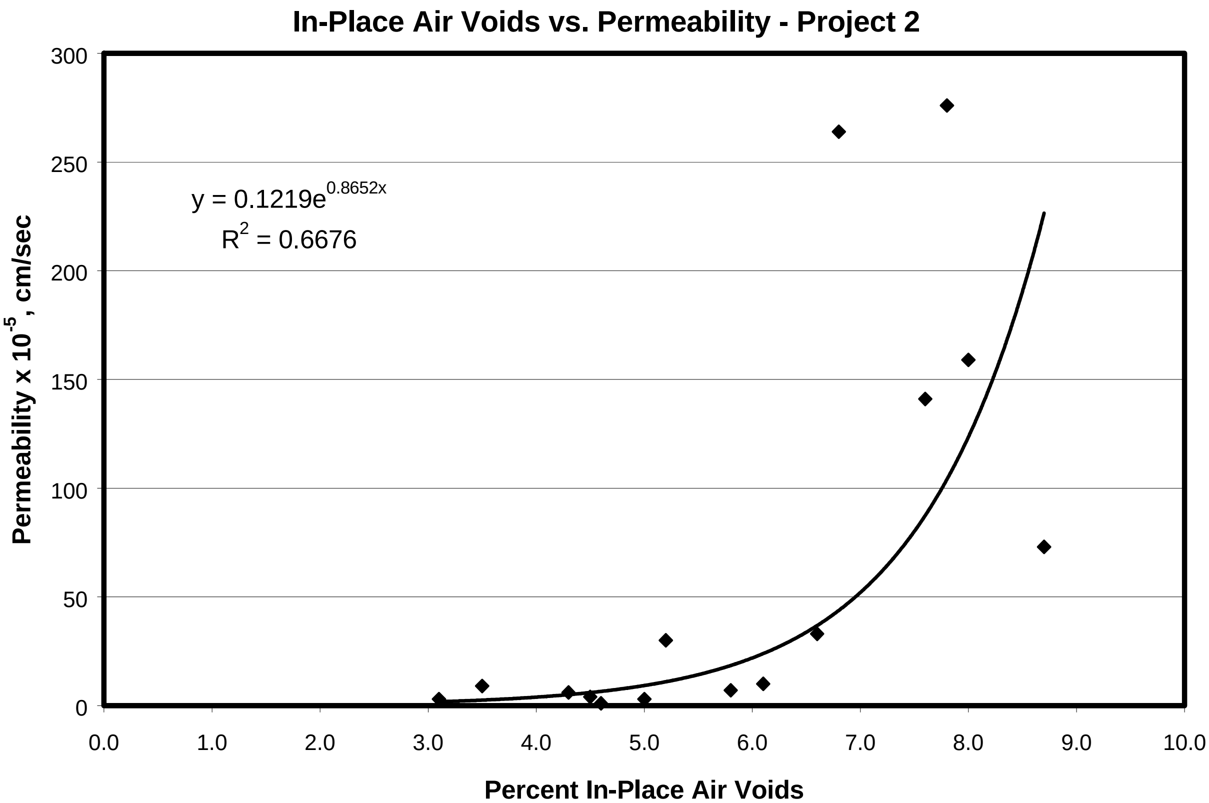

Figure 1. Field Permeability-Density Relationship for Project 2 (9.5 mm NMAS Mix)

Figure 2 presents the permeability-density relationship for Project 5. This project had the lowest coefficient of determination of all eleven projects (R^2=0.33). A 25.0 mm NMAS mixture was utilized on this project. The combination of the gradation being both coarse-graded and the 25.0 mm NMAS likely resulted in many large sized air voids within the pavement and thus an increased potential for interconnected voids. This increased potential for interconnected voids likely resulted in the scatter shown in Figure 2. Examination of the plotted data suggests that most of the scatter occurred in the high air void content region. Within this region the potential for interconnected voids would be highest. A comparison of Figures 1and 2 shows that the 25.0 mm NMAS mixture from Project 5 was much more permeable than the 9.5 mm mix from Project 2 at similar in-place air void contents. For instance, at 6.5 percent voids, the 25.0 mm NMAS mix had a permeability of about 1000×10^{-5} m/sec. By contrast, the 9.5 mm NMAS mix had a permeability value of approximately 40×10^{-5} mm/sec.

Figure 3 presents the relationship between field permeability and in-place air voids for Project 11. Data from this project had one of the better R^2 values at 0.81. This mix had a 19.0 mm NMAS gradation. The regression curve appears to indicate that permeability values tend to significantly increase exponentially at in-place air void contents above about 6 percent.

Recall from the test plan that at each of the fifteen test locations, three replicate tests were conducted. For each replicate test, the device was lifted off the pavement and the device set approximately 25 cm away. To provide the reader with an idea of repeatability for the field permeability device, Figure 4 illustrates the three replicate test result at each of the fifteen test locations for Project 3. Based on this figure, at each test location the three replicate tests were

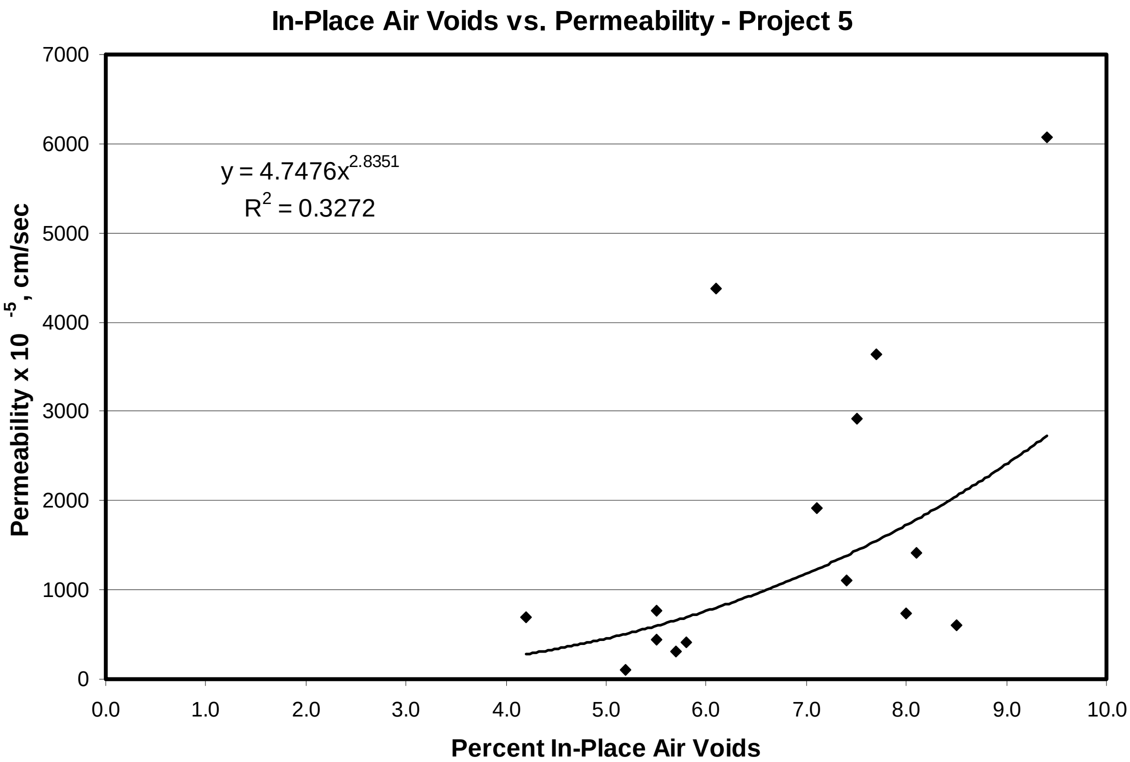

Figure 2. Field Permeability-Density Relationship for Project 5 (25.0 mm NMAS Mix)

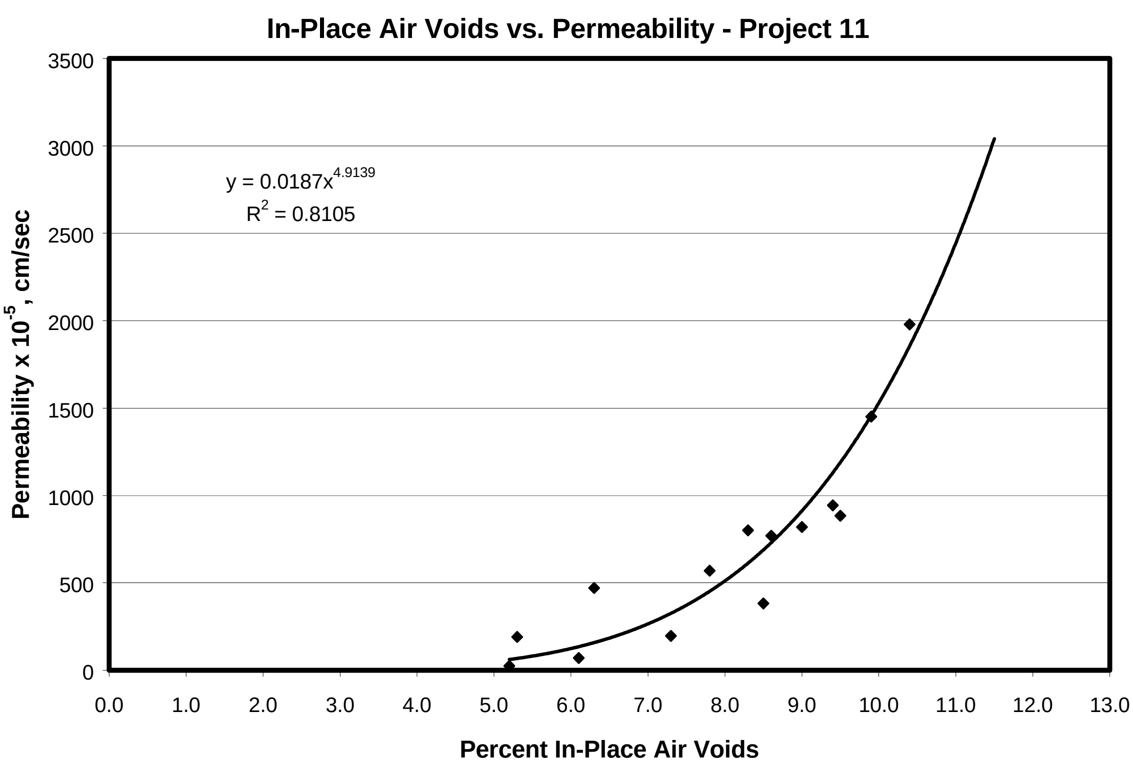

Figure 3. Field Permeability-Density Relationship for Project 11 (19.0 mm NMAS Mix)

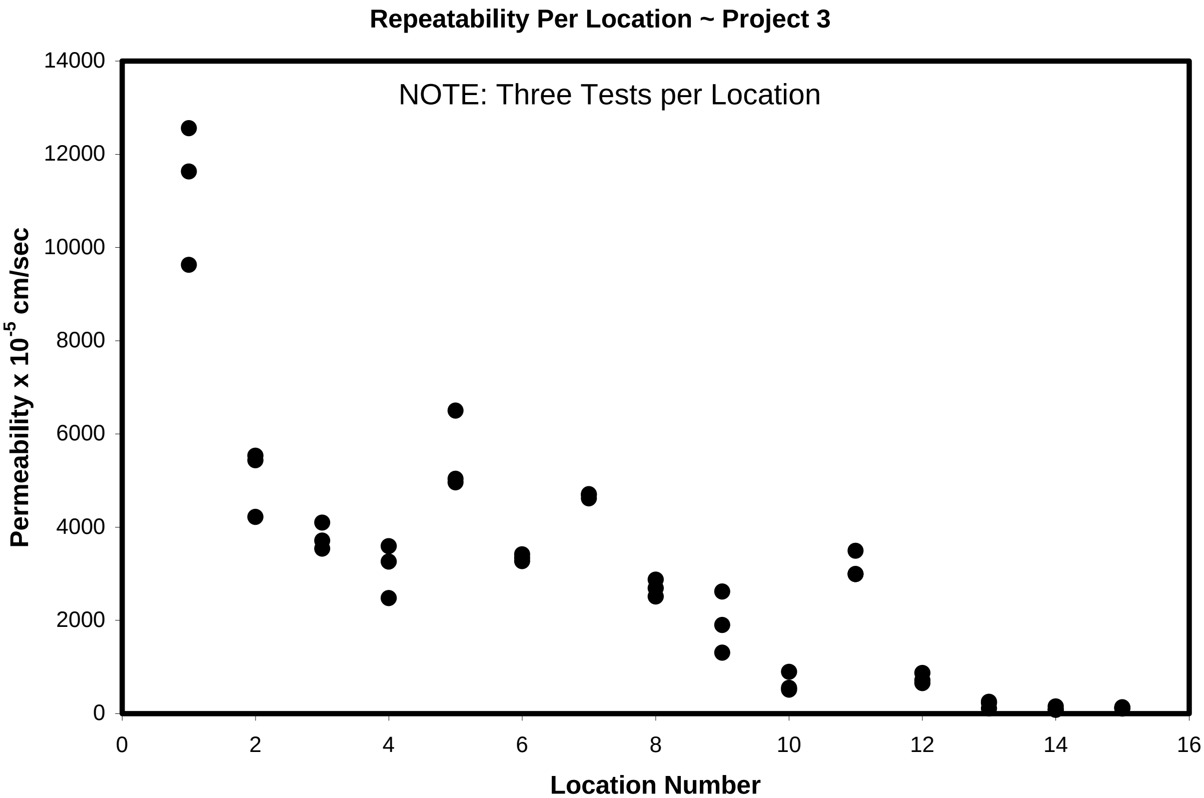

Figure 4. Repeatability of Field Permeameter

similar. An analysis using all data from the eleven projects showed that a coefficient of variation of 17 percent was achieved between the three replicates. This amount of variation is acceptable considering that the typical variation in pavement density and that replicate tests were not conducted in the same exact spot on the pavement.

In order to develop a practical critical value of permeability, a value must be selected that is applicable to more than one mix. In other words, the criteria must be applicable and representative for a wide range of mixes. Based upon work in Florida (4), Maine (7), Virginia (8), and by NCAT (6), it appears that a critical value of permeability should be based upon the NMAS of the mixture. In addition, critical values should likely be different for fine- and coarse-graded mixes even though this study only evaluated coarse-graded mixtures. Figures 5 through 8 present the relationship between in-place air voids and field permeability for all projects grouped by the mixture's NMAS.

Figure 5 shows the permeability-density relationship for the two 9.5 mm NMAS mixes. This figure shows a strong relationship (R^2=0.86). Field permeability was very low at in-place air void contents below 5 percent. From 5 to 7 percent voids, the permeability begins to increase slightly. At air void contents in excess of 8 percent, permeability begins to increase exponentially with small changes in in-place air voids.

Figure 6 illustrates the field permeability versus in-place air voids for the four 12.5 mm NMAS mixes. Again, a strong relationship was observed (R^2=0.77) even though four projects were included. These four pavements were from three different states. The shape of the regression line in Figure 6 is very similar to that shown in Figure 5. At in-place air void contents below 5 percent, field permeability values were relatively low. Between 5 and 7 percent voids,

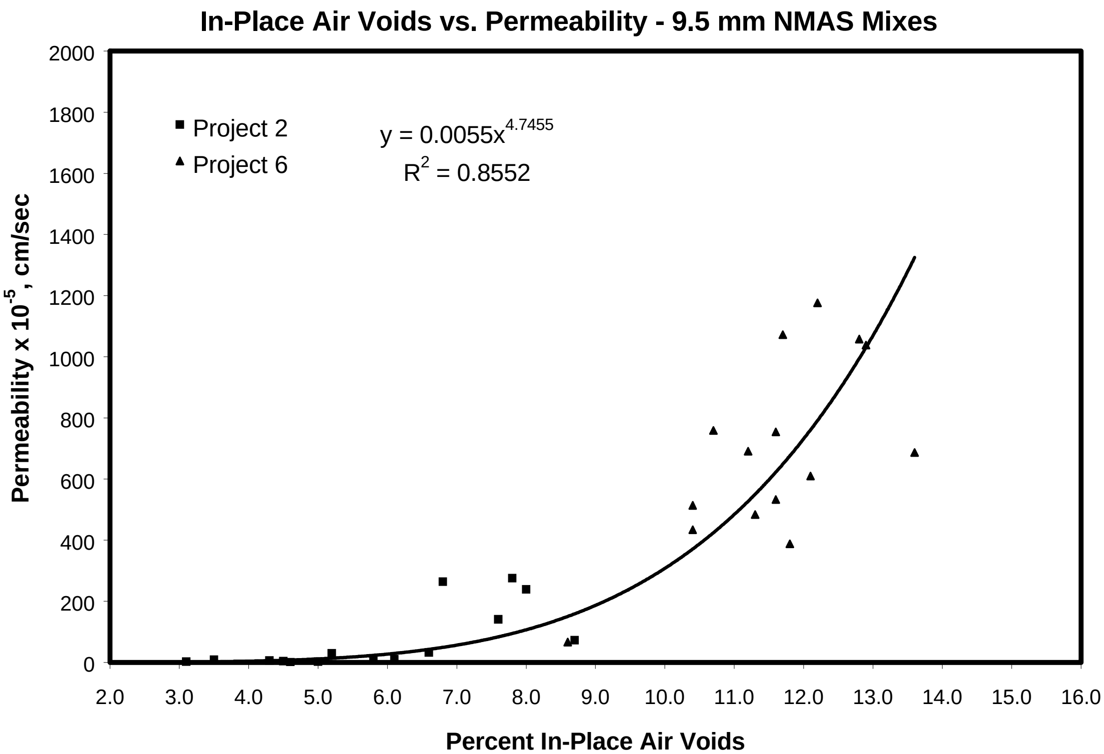

Figure 5. Field Permeability-Density Relationship for 9.5 mm NMAS Mixtures

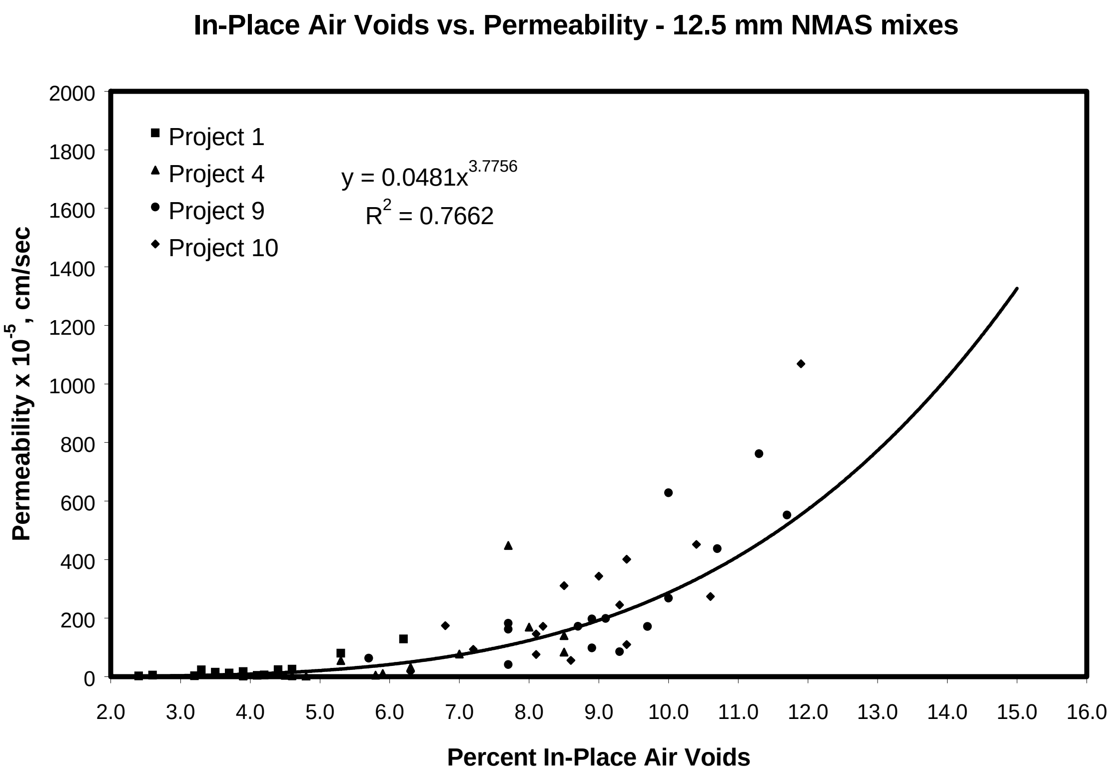

Figure 6. Field Permeability-Density Relationship for 12.5 mm NMAS Mixtures

permeability began to increase at a slightly higher rate. At air void levels above approximately 8 percent, field permeability began to increase significantly with small changes in in-place air voids.

Based on the data shown in Figures 5 and 6, it appears that the relationship between permeability and density is similar for both 9.5 and 12.5 mm NMAS mixes. This really is not unexpected as the percent passing the 2.36 mm (No. 8) sieve is not very different for these mixes. For the six 9.5 or 12.5 mm mixes studied, the percent passing the 2.36 mm sieve ranged from 32 to 41 percent.

The relationship between permeability and in-place air voids for 19.0 mm NMAS mixes is shown in Figure 7. Again, a good relationship was found when the two projects were grouped together (R^2=0.81). This figure illustrates that these 19.0 mm NMAS mixes are more permeable than the 9.5 and 12.5 mm NMAS mixes at similar void levels. These 19.0 mm NMAS mixes do exhibit some permeability at 5 percent voids. Also, permeability increases at a much higher rate between 5 and 7 percent voids than the smaller NMAS mixes. At void levels above 6 to 7 percent, small changes in air void content result in large changes in permeability.

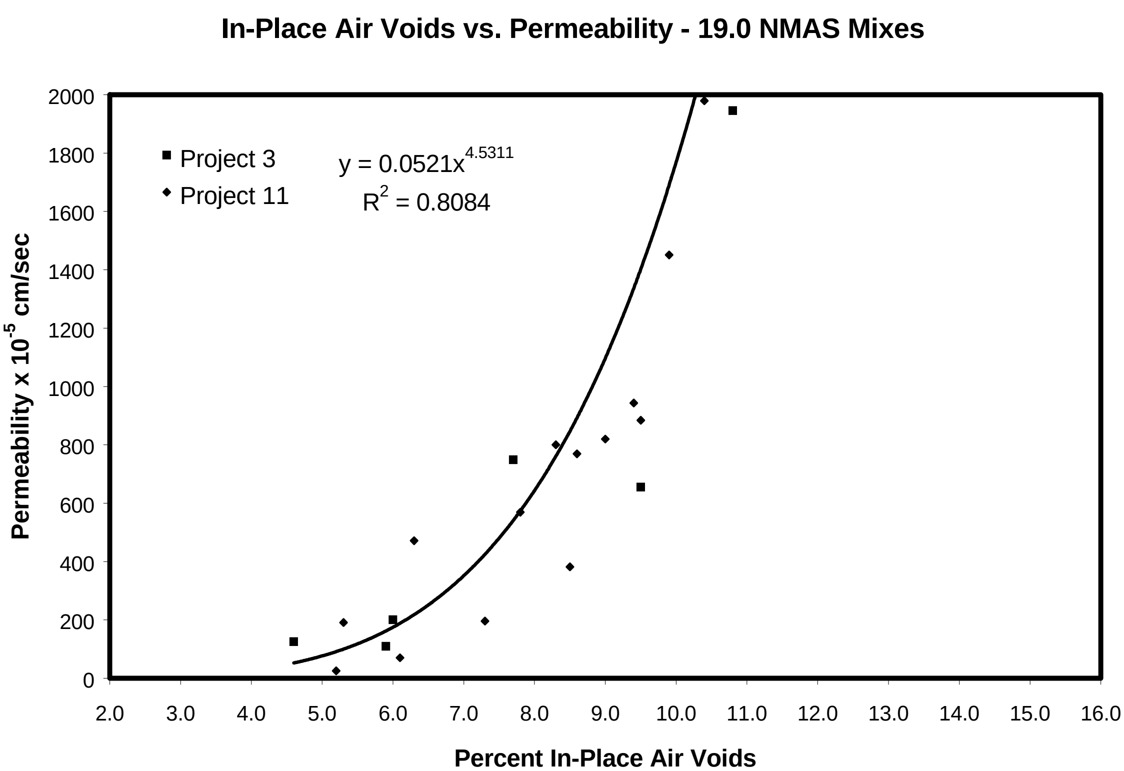

Figure 7. Field Permeability-Density Relationship for 19.0 mm NMAS Mixtures

Similar to Figure 7, Figure 8 shows that 25.0 mm NMAS mixes are much more permeable at lower air void contents that the 9.5 and 12.5 mm NMAS mixes. Figure 8 also shows that 25.0 mm NMAS mixes are more permeable than 19.0 mm NMAS mixes at similar air void contents. The R^2 value in Figure 8 is not as large as for the other NMAS (R^2=0.56); however, recall that Project 8 was actually fine-graded. Based on the plotted data in Figure 8, Project 8 (data points depicted by triangles) appears to be less permeable than the other two projects at similar void levels. This supports the findings by Choubane et al. (4) that fine-graded mixes are less permeable than coarse-graded mixes. Based upon the data in Figure 8, 25.0 NMAS pavements appear to be relatively permeable even at 5.0 percent air voids. Similar results have been reported by Maupin (8).

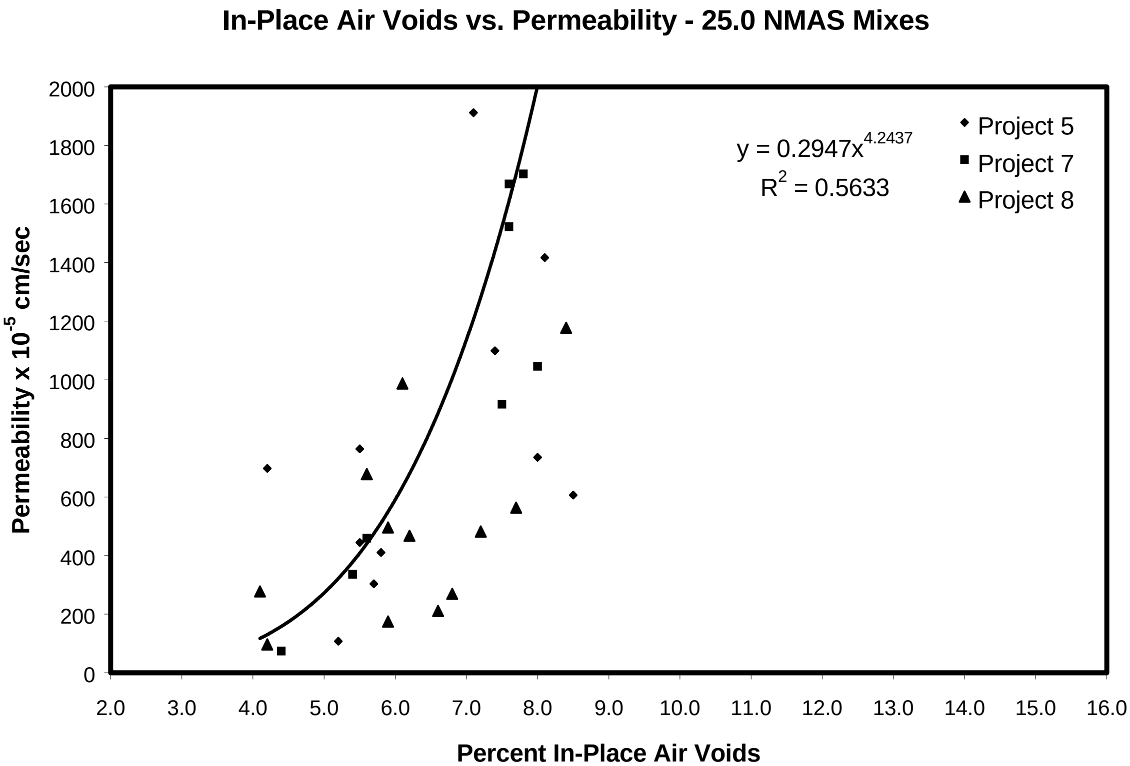

Figure 8. Field Permeability-Density Relationship for 25.0 mm NMAS Mixtures

Before critical in-place air void and permeability values for the different NMAS are presented, the method of determining the critical values is discussed. Figure 9 presents a typical figure when field permeability is plotted versus in-place air voids. The regression line (dotted line) in this figure shows that at low in-place air voids pavements are relatively impermeable. This region of the curve signifies when the air void pockets within the pavement are mostly isolated from each other and thus very few interconnected voids exist. By contrast, the region of the curve with high air voids contains a high percentage of interconnected voids. Because of the high percentage of interconnected voids, small changes in air void content leads to large changes in permeability. The problem with developing a critical value of pavement permeability lies in the middle region depicted in Figure 9 as the typical voids range. Beginning at the left side of the middle region, there are probably more isolated voids than interconnected voids. However, as the percentage of air voids increase within this region the ratio of interconnected voids to isolated voids increases, as does permeability. At some point, this ratio exceeds unity. The method employed in developing a maximum field permeability criteria for this study was to try and identify the point in which the ratio of interconnected voids to isolated voids is unity. Figure 9 also illustrates the method utilized. First, within the low voids range a line was drawn tangent to the regression line. Second, another line was drawn tangent to the regression line within the high voids region. At the intersecting point of these two lines, a bisecting line was then drawn to the regression line. The point at which the bisecting line hits the regression line was defined as the point where the ratio of interconnected voids to isolated voids was unity. From this information, a critical in-place air void content and field permeability value was identified.

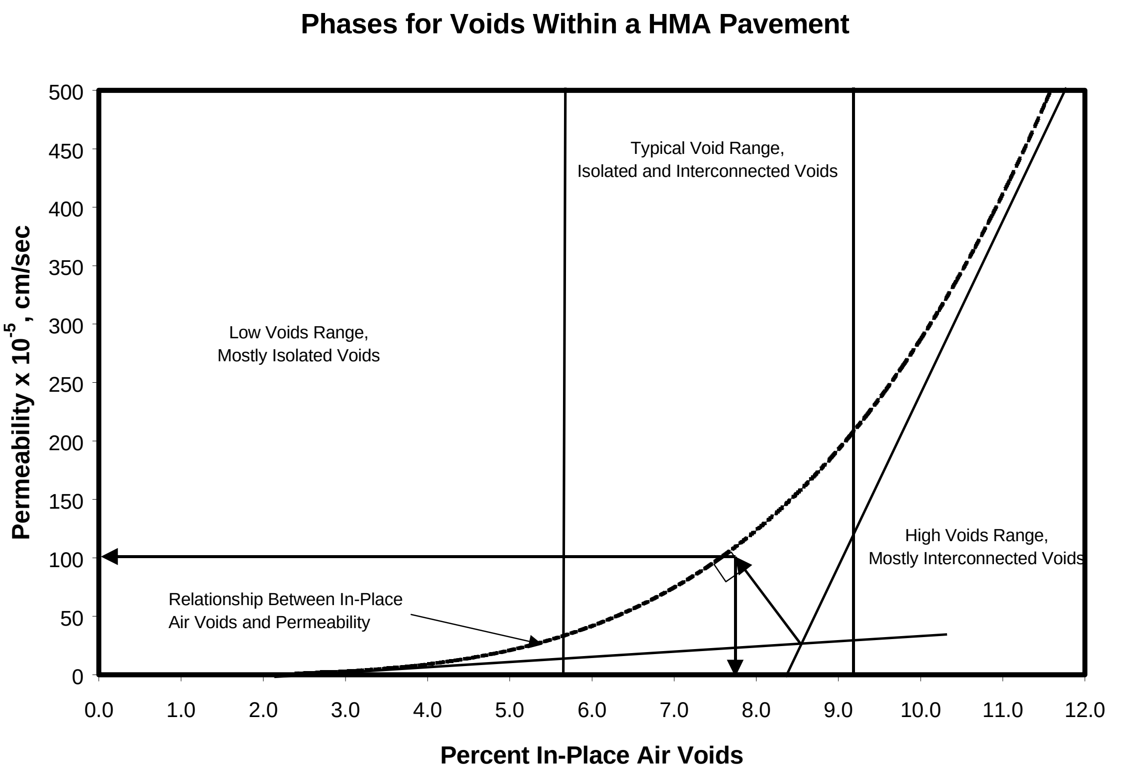

Figure 9. Method for Selecting Critical In-Place Air Voids and Field Permeability

Figure 10 illustrates the selection of the critical permeability value for 9.5/12.5 mm NMAS mixes. These two NMAS mixes were grouped because they indicated similar permeability characteristics. The bisecting line crosses the regression line at approximately 92.3 percent density (7.7 percent air voids) and a permeability of 100×10^{-5} cm/sec. Therefore, both 9.5 and 12.5 mm NMAS coarse-graded mixes should be compacted in the field to at least 7.7 percent air voids. However, one observation about Figure 10 is that seven pavement locations having in-place air voids less than 7.7 percent still had field permeability values in excess of the 100×10^{-5} cm/sec critical value. Also, six pavement locations having in-place air voids in excess of 7.7 percent but permeability values less than 100×10^{-5} cm/sec are shown in Figure 10. The highest in-place air void content meeting the critical permeability value was 9.3 percent. These observations were not unexpected because any data used to create a regression line will show scatter. However, these observations do bring up an interesting point. If a density specification is utilized for a particular 9.5 or 12.5 mm NMAS HMA paving project and the maximum allowable in-place air void content is 7.7 percent, small portions of the pavement would likely be permeable. By contrast, if a permeability specification of 100×10^{-5} cm/sec was utilized instead of density, then small portions of the pavement would have lower density than has typically been specified. The question that an owner agency must answer is whether small portions of the pavement can be permeable or whether slightly lower densities than previously allowed are acceptable. From the slightly lower density standpoint, since the pavement is impermeable to water it is also likely impermeable to air and thus excessive oxidation would not be a concern. However, additional consolidation of the mix in this small portion of pavement would be expected, and would make the mix reasonably impermeable.

Figure 11 presents the selected critical density and permeability values for 19.0 mm NMAS coarse-graded pavements. The bisecting line crosses the regression line at approximately 94.5 percent density (5.5 percent air voids) and permeability value of 120×10^{-5} cm/sec. It should be

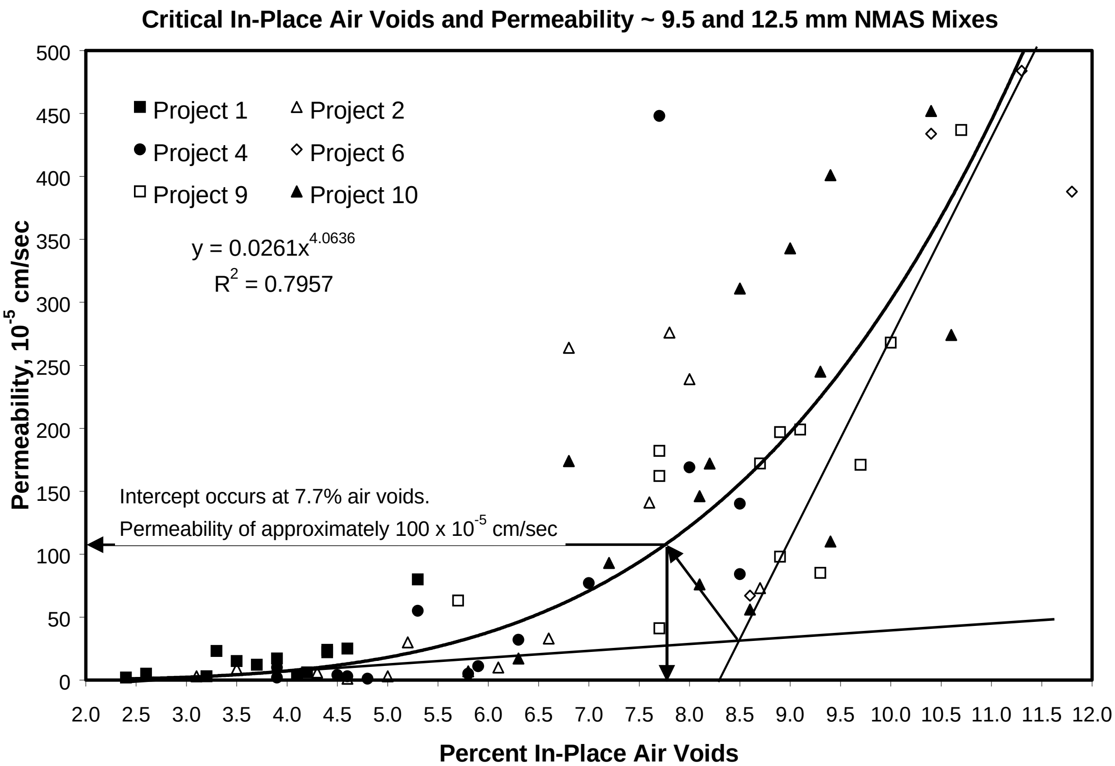

Figure 10. Selection of Critical Values for 9.5 and 12.5 mm NMAS Mixes

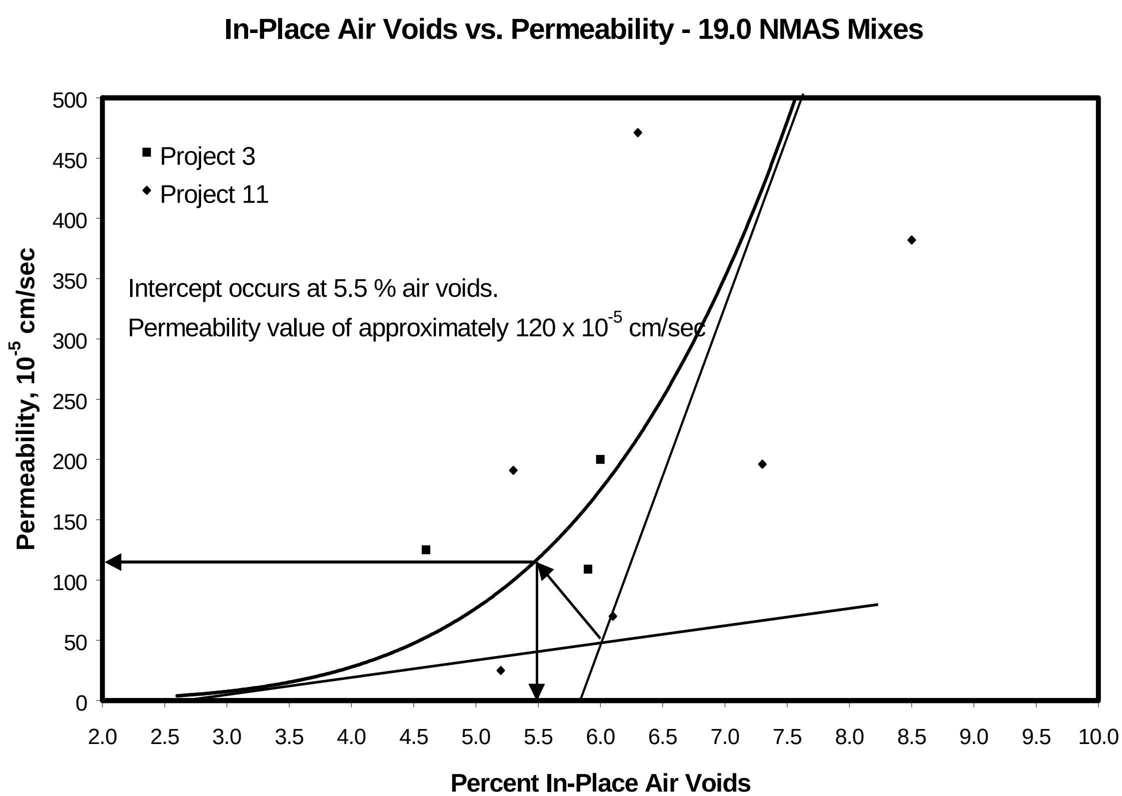

Figure 11. Selection of Critical Values for 19.0 mm NMAS Mixes

noted that the regression line was projected backward in order to find the tangent at the lower air void contents. As expected, the critical air void content decreased as the NMAS increased. Surprisingly, only one data point would meet both the critical density and permeability values. In fact, only three data points would meet the critical in-place air void content and three would meet the critical permeability value. The data shows that small changes in air voids resulted in exponentially increasing values of permeability.

Selection of critical density and permeability values for the 25.0 mm NMAS pavements is shown in Figure 12. Based on this figure, coarse-graded 25.0 mm NMAS pavements become permeable at approximately 95.6 percent density (4.4 percent in-place air voids). A critical permeability value of 150×10^{-5} cm/sec was selected. Similar to the 19.0 mm data, the regression line shown in Figure 12 had to be projected backward to find the tangent within the low air void range. From Figure 12, only two data points meet the critical in-place air void content of 4.4 percent. Of the two data points only one meets the critical permeability value. Three data points meet the permeability criteria.

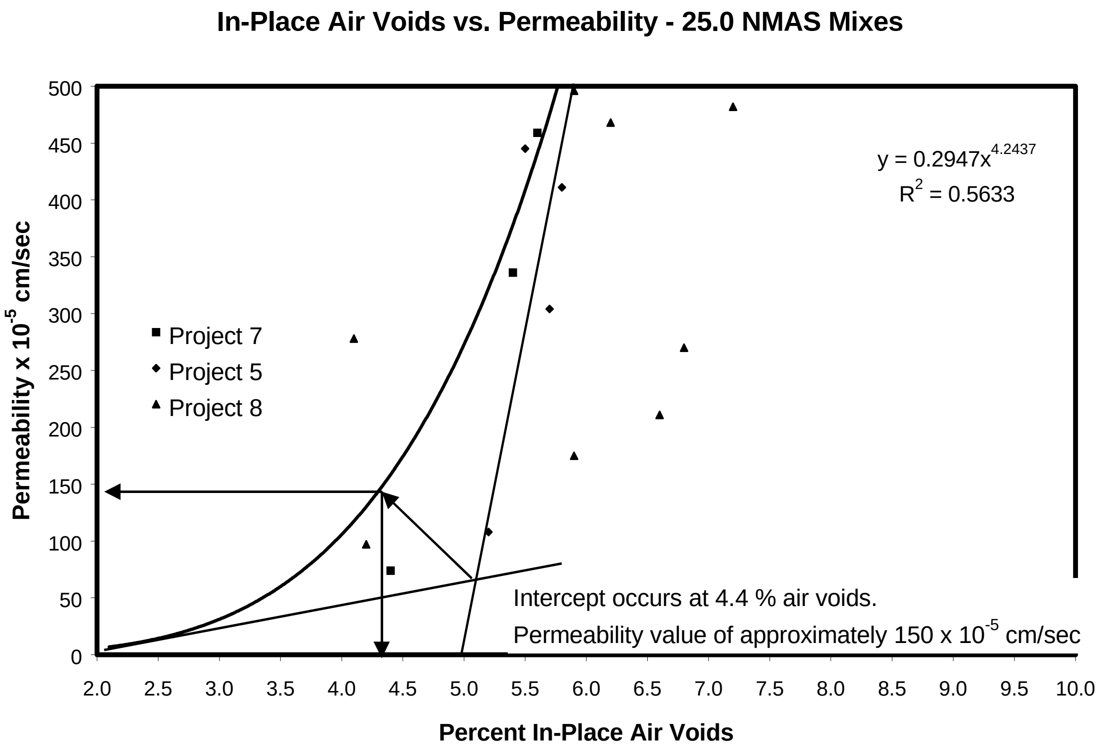

Figure 12. Selection of Critical Values for 25.0 mm NMAS Mixtures

The data for the coarse-graded 19.0 and 25.0 mm NMAS pavements is somewhat disturbing. These pavements were excessively permeable at in-place air void contents much lower than is typically specified. Most density specifications allow in-place air void contents between 7 and 8 percent. This data suggests some remedial action is needed to reduce the permeability of these larger NMAS mixes. Several options are available. First, use a field permeability device during construction as a quality control tool to prevent permeable pavements. Secondly, increase minimum density requirements such that the resulting pavements are impermeable. Thirdly, allow gradations for these larger NMAS mixes to pass above the maximum density line and restricted zone (fine-graded). Of these three options, the first and third are probably the most realistic. Using a field permeability device for the control of density would allow corrections in construction techniques to be made in the field to keep pavements impermeable. For regions of the U.S. that use the 19.0 and 25.0 mm NMAS mixes as binder and base courses, fine-graded mixes would likely be acceptable as rutting typically takes place in the top 75 to 100 mm of the pavement structure (*9*).

CONCLUSIONS

Based on the results of this study, the following conclusions are provided:

1. Strong relationships were observed between field permeability and in-place air void contents for coarse-graded Superpave designed pavements.
2. A mixture's nominal maximum aggregate size greatly affects the permeability characteristics of a pavement.
3. The permeability characteristics of coarse-graded 9.5 and 12.5 mm NMAS pavements are similar. These types of pavements become excessively permeable at approximately 92.3 percent density. A critical field permeability value of 100×10^{-5} cm/sec was selected.
4. Coarse-graded mixtures having a NMAS of 19.0 mm become excessively permeable 94.5 percent density. This density related to a critical field permeability value of approximately 120×10^{-5} cm/sec.
5. Coarse-graded mixes having a NMAS of 25.0 became excessively permeable at 95.6 percent density. A critical field permeability value of 150×10^{-5} cm/sec was selected for 25.0 NMAS mixes.

The term "critical" used in this study infers the point at which a pavement becomes excessively permeable. For the larger NMAS mixes, some permeability may be acceptable as long as the upper courses are impermeable.

Based on the conclusions of this study, it is recommended that field permeability be used as quality control for some selected HMA construction projects. This testing should likely shadow current density specifications to determine its usefulness in preventing permeable pavements.

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