*STATE OF FLORIDA*

# INVESTIGATION OF WATER PERMEABILITY OF COARSE GRADED SUPERPAVE PAVEMENTS

**Research Report**
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STATE MATERIALS OFFICE

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# EXECUTIVE SUMMARY

Water permeability is an important yet often overlooked pavement property. The permeability of a pavement is generally assumed to be proportional to its air void content. However, the lack of void interconnection and size dimensions of the individual voids may result in a watertight pavement of relatively high void content. To date there has not been an accepted standardized testing procedure to determine the potential for water permeability of compacted asphalt mixtures. Thus, there is a need for a simple and effective approach to evaluate this important property of the pavement.

The present study presents the results of an investigation of the water permeability of coarse graded Superpave mixes. The data indicates the importance of proper compaction during placement operations. The report also describes a simple but effective laboratory method, developed during the course of this study, for measuring water permeability. This approach can be used at design verification and during actual asphalt mixture placement to determine the effectiveness of compaction to produce "acceptable" permeability of an asphalt mixture.

## INTRODUCTION

It is well recognized that the air void content of an asphalt mixture is an important factor that affects the performance of the pavement throughout its service life. High air voids in a finished pavement, particularly if the voids are interconnected, will adversely affect its durability and performance in various ways. Air filtration into a permeable pavement accelerates the aging or hardening process of the asphalt binder through oxidation. The penetration of excessive amounts of water into the pavement structure may induce stripping of the asphalt binder from the aggregate surface, leading to potential pavement distresses. This paper deals primarily with air voids and their influence on water permeability of asphalt pavements.

Water permeability is an important yet often overlooked pavement property. The permeability of a pavement is generally assumed to be proportional to its air void content. However, the lack of void interconnection and size dimensions of the individual voids may result in a watertight pavement of relatively high void content. To date there has not been an accepted standardized testing procedure to determine the potential for water permeability of compacted asphalt mixtures. Thus, there is a need for a simple and effective approach to evaluate this important property of the pavement.

The present study presents the results of an investigation of the water permeability of coarse graded Superpave mixes. The data indicates the importance of proper compaction during placement operations. The report also describes a simple but effective laboratory method, developed during the course of this study, for measuring water permeability.

## BACKGROUND

One of the main products of the recently completed Strategic Highway Research Program (SHRP) is a new asphalt mix design procedure, commonly known as Superpave. Superpave represents a significant departure, in terms of material testing and sample compaction techniques, from the traditional Marshall mix design. In 1996, the Florida Department of Transportation (FDOT) made a concerted effort to implement the new Superpave technology to address increasing pavement failures due to rutting, particularly in the northern part of the state *(1)*. During this period, approximately 325,000 tons of Superpave mixes were placed on eight projects throughout Florida. The majority were rehabilitation projects on the Interstate Highway System.

Immediately after construction of a large Interstate project, it was observed that water seemed to be absorbed into the pavements and weeping out at the low side shoulder joint. Initially this phenomenon was assumed to be restricted to the upper surface of the Superpave mixes, where the open texture seemed to be the obvious source. Roadway cores were then drycut to verify the depth to which water was infiltrating the pavement structures. The core holes were closely monitored and it was noted they immediately filled with water that apparently had been trapped in the recently completed Superpave pavement. The water appeared to be passing completely through the Superpave layer until it reached the asphalt rubber membrane interlayer, which serves as a crack relief layer. At that point the water would move laterally through the coarse graded Superpave pavement until it reached the fine-graded Marshall mix that had been placed on the shoulder. With the shoulder acting as a dam, the water would, then, over-flow onto the paved shoulder. Serious technical and practical concerns to FDOT emerged from this finding, as it was felt that it could very likely lead to a premature stripping failure of these multi-million dollar projects. An effective field implementation of Superpave requires addressing such issues.

The present investigation was initiated with the primary objective of (1) developing a procedure for evaluating the water permeability of compacted asphalt mixtures, (2) determining the extent and causes of water permeability of these Superpave projects, and (3) recommending the necessary changes to the FDOT Superpave specifications in order to address this issue.

## PROJECT DESCRIPTIONS

The projects consisted primarily of rehabilitating existing asphalt pavements by milling and resurfacing using Superpave mixes. Two types of coarse graded Superpave mixes were used with respective nominal maximum aggregate sizes of 12.5 and 19.0 mm. An AC-30, which would satisfy the requirements of a PG 67-22, was used for all mixes. Using the volumetric design procedure, most of the mixtures were designed for an average high air temperature of less than 39 $^{o}$C with an $N_{Design}$ value of 109. Further, as illustrated in Figures 1 and 2, all the mixtures would be considered coarse graded (below the 0.45 density line). These mixtures included, depending on the respective geographical location of each project, three aggregate types, namely, (1) Georgia granite, (2) Alabama limestone, and (3) South Florida limestone. In addition, most of the mixes included reclaimed asphalt pavement (RAP). Before resurfacing, the milled surfaces were typically covered with a 10 mm asphalt rubber membrane interlayer (ARMI). The purpose of the ARMI is to act as a moisture barrier and crack relief layer. The Superpave mixes were required to be surfaced with a 15 mm thick open graded friction course. For each project, the mix design characteristics are given in Table 1 and the aggregate gradations are shown in Figures 1 and 2. A detailed description of each of these projects is presented elsewhere *(1)*.

## SAMPLING AND LABORATORY TESTING PROGRAM

An essential step of the study was to provide an effective means for rapidly measuring water permeability of compacted asphalt paving mixtures. To meet this objective, a new test method was developed by FDOT using information that resulted from previous research on the permeability of Portland cement concrete *(2)*.

Following the development of the water permeability test procedure, a sampling and testing plan was initiated to quantify and evaluate the observed water permeability problem. Cores obtained from the Superpave pavement sections were tested for air void content, water permeability, and stripping potential. For comparison purposes, cores were also obtained from well performing Marshall mix pavements and laboratory fabricated samples were prepared. The details of the testing program are given below:

## Field Coring and Test Sample Preparation

A large number of cores, 145 mm in diameter, were obtained from each project by FDOT personnel for water permeability testing. All cores were obtained at the center and in the wheel path (if the section was opened to traffic) of the lane. In addition, groups of six 100 mm diameter cores each were obtained from some of the sections to evaluate their potential for stripping. These cores were taken as close as possible to each other along the same longitudinal alignment. For comparison purposes, cores were also obtained from well performing fine graded Marshall mix pavements and laboratory compacted samples of fine graded Marshall and coarse graded Superpave mixes were prepared. The aggregate gradations of the laboratory compacted Marshall mixes are illustrated in Figure 3, while mixtures similar to those used on the I-10, Columbia County project (see Figures 1 and 2 for aggregate gradations) were used to prepare coarse graded Superpave samples.

The cores were processed at the State Materials Office and cut to separate the layers of the 19 and the 12.5 mm Superpave mixes for the laboratory testing. The cutting was performed with a water-cooled masonry saw equipped with a diamond-tipped blade. After the wet saw cutting, the samples were thoroughly washed to remove any loose fine material resulting from the cutting process. Then the samples were measured and weighed. Three height and two diameter measurements were taken from each sample and averaged. The specific gravities required to compute the air void content of individual test samples, were also determined according to the

Florida test methods FM 1-T 166 *(4)* and FM 1-T 209 *(5)*.

Once the gravimetric measurements were performed, the samples to be tested for water permeability were air dried, then sealed using epoxy. A casting mold, as illustrated in Figure 4, was used in this process which resulted in a sealed edge and a uniform 25 mm wide sealing ring around the sample. The epoxy was allowed to cure for 24 hours before removing the test sample from the mold.

For the stripping potential test, within each group of six 100 mm diameter specimens, half of the specimens were subjected to accelerated conditioning and the other half were treated as control samples, without any conditioning, in accordance with AASHTO T-283, with some modifications *(6)*. The first group of three samples was vacuum-saturated with water for 30 minutes, then allowed to stand for an additional 30 minutes before being placed inside a sealed plastic bag. The conditioned specimens were put in a freezer at -18 $^{o}$C for 15 hours, and then soaked in a 60 $^{o}$C water bath. After 30 minutes, a small opening was cut in the plastic bags and the samples were left undisturbed for a total of 24 hours. Finally, the specimens were removed from the bags and allowed to reach room temperature undisturbed, then cooled in a 13 $^{o}$C water bath for 3 hours before testing. The control specimens were placed in the refrigerator at 13 $^{o}$C for 3 hours before testing. Both the conditioned and the unconditioned specimens were tested for indirect tensile strength.

## Water Permeability Evaluation

A falling head permeability testing device and a test procedure, both developed by FDOT *(3)*, were used as a means for quantifying the water permeability of water-saturated asphalt samples. A schematic drawing of the device is shown in Figure 5. Water from a graduated buret is allowed to flow through a saturated asphalt sample and the interval of time taken to reach a known change in head across the specimen is recorded. The coefficient of permeability, k, of the asphalt sample is then determined based on Darcy’s law, using the following equation:

$$k = \frac{aL}{At}\ln(h_1/h_2)$$

Where:

k = coefficient of permeability, cm/s;

a = inside cross-sectional area of the buret, $cm^2$;

L = thickness of the test specimen, cm;

A = cross-sectional area of the test specimen, $cm^2$;

t = elapsed time between $h_1$ and $h_2$, s;

$h_1$ = initial head across the test specimen, cm;

$h_2$ = final head across the test specimen, cm;

For each sample, the coefficient of permeability is computed for three runs and averaged. Saturation uniformity was confirmed when the respective recorded times for a change in head from $h_1$ to $h_2$ for three consecutive tests were within 15%.

The measurement provided an indication of water permeability of one sample as compared to those of other asphalt samples tested in the same manner.

### ***Apparatus***

Figure 6 shows a photograph of the basic permeability test equipment used for this study. It consists primarily of a permeability cell  and a 1000 mL graduated glass buret with a stopcock valve.  The cell supports the sample and provides for transmission of water to and from the sample. As seen in Figure 7, it is composed of 300x300x25 mm top and base plates made of PVC.  The top plate is provided with a 9.5x9.5 mm hose barb for water inlet as well as with an air relief valve.  The base place, on which the specimen rests, has a 100 mm diameter central hole for water outlet.  Both plates are sealed to the test sample with 6.35 mm thick rubber O-rings.  The plates along with the

O-rings and the specimen are held together as to create a permeability cell using four 200 mm long bolts.

## Stripping Potential Assessment

The stripping potential was assessed using the modified Lottman test in accordance with AASHTO T 283 with some changes. In this test, three samples within each specimen group are used as a control while the other three are vacuum saturated with water and, then, subjected to one freeze/thaw cycle. The indirect tensile strength test is performed on all samples. A loading rate of 1.65 mm per minute is used. The stripping potential is quantified by comparing the average tensile strength of the conditioned samples with that of the control or reference samples, within each group. It is expressed as the ratio of tensile strength retained (TSR) by a sample after being conditioned using moisture and one freeze-thaw cycle. A minimum TSR of 0.7 to 0.8 is usually specified.

The indirect tensile strength is defined as the maximum stress from a diametral vertical force that a sample can withstand. It is determined using the following equation:

$$Ts = (2000P)/(\pi td)$$

Where: $Ts$ = tensile strength, kPa;

$P$ = maximum load carried by the sample, N;

$t$ = specimen thickness, mm; and

$d$ = specimen diameter, mm.

Once the respective tensile strengths of the conditioned and control samples are determined, the TSR can be expressed as:

$$TSR = Ts_{conditioned} / Ts_{control}$$

Where: $TSR$ = tensile strength ratio;

$Ts_{conditioned}$ = average tensile strength of conditioned samples; and

$Ts_{control}$ = average tensile strength of control or reference samples.

### *Equipment*

An MTS closed-loop servo-hydraulic system was used for loading application. The testing system was linked to a PC computer through an analog-to-digital card that converts the analog voltage signals from the load cell and linear variable differential transducers (LVDT) into a digital voltage output. A data acquisition system was also provided for automatic data collection and processing.

## DATA ANALYSIS

### Water Permeability Evaluation

The general assumption is that the water permeability of a pavement is proportional to its air void content. Thus, the relationship between air void content and permeability was measured on a series of core samples obtained from the various coarse graded Superpave projects. The results, summarized in Table 2, indicated that six of the eight Superpave projects were excessively permeable as compared to existing fine graded Marshall mixes.

One of the projects with relatively lower permeability values was the I-95 project in Brevard County. On this project, the 12.5 mm mix was placed in two 50 mm lifts. The higher density levels, and lower permeability values recorded for this project suggest that increased lift thicknesses, as compared to those used for dense graded Marshall mixes, may be required for coarse graded Superpave mixes to enhance compactibility and reduce permeability. A subsequent meeting with FHWA representatives confirmed that the current FDOT lift thickness criteria of fine-graded Marshall mixes may not be adequate for the coarse graded Superpave mixes. It was recommended, then, to increase the lift thickness of Superpave mixes to a minimum of four times the nominal maximum aggregate size of the mix. Further, the curve for the air void-permeability relationship for coarse graded Superpave mixes, illustrated in Figure 8, seems to indicate that there is no significant change in permeability when the amount of air voids falls below seven percent and that, when the air void content is less than six percent, the pavement is "virtually impermeable" (permeability level is negligible). However, even small increases in void content above the seven percent figure would result in a pronounced increase in permeability. It is, therefore, reasonable to infer that, for coarse graded Superpave mixes, excessive water may infiltrate a pavement if the compaction during construction is not effective in reducing the amount of voids to at least seven percent. The permeability test data collected during this investigation suggests a minimum density level of 94.0 percent of $G_{mm}$ (as determined from cores taken from the completed pavement) be used for coarse graded Superpave mixes.

In addition, Figure 8 shows that a seven percent air void content corresponds to a permeability value of about 60 x $10^{-5}$ cm/s. Acknowledging the difficulty in accurately determining the saturated surface dry (SSD) conditions for relatively porous mixtures (thus, affecting the accuracy of high air void values and possibly the permeability-air void correlation trend), it is suggested, therefore, that a tentative permeability limit not exceeding 100 x $10^{-5}$ cm/s be used when evaluating the permeability of a coarse-graded Superpave mix pavement section. Using a tentative permeability limit of 100 x $10^{-5}$ cm/s, instead of 60 x $10^{-5}$ cm/s, would be low enough to prevent the infiltration of excessive water into the pavement structure and high enough to account for any variability in the density determination of core samples with high air voids. This tentative permeability limit is only a relative test value.

Furthermore, several well performing pavement sections with fine graded Marshall mixes were sampled for comparative purposes. The permeability results summarized in Table 3 tend to indicate that the fine graded mixes are relatively impermeable even at air voids significantly higher than the seven percent air void level needed to make the permeability of the Superpave coarse graded mixes acceptable, as determined in this study. These low permeability values of Table 3 suggest that a larger amount of in-place voids in a fine graded mix are not interconnected as compared to a coarse graded mix. Moreover, as seen in Table 4, the permeability test results on laboratory fabricated coarse graded Superpave samples are also relatively low, even at air void contents above seven percent. This observation seems to indicate that the air void structure in a gyratory compacted sample is not comparable to that of the field compacted core at the same air void level.

Based on all these findings, FDOT decided to construct test sections on I-75 with the 19.0, 12.5, and 9.5 mm coarse graded mixes using a combination of increased lift thicknesses, compactive effort, mat temperature, and running at the lower end of acceptable air voids at the plant during production. The results of the density and permeability tests performed on the cores obtained from these three test sections are given in Table 5. The data shows that the above mentioned modifications in the construction practices resulted in pavements with lower in-place air voids and permeability values as compared to those of the coarse graded Superpave mixes previously placed.

## Stripping Potential Evaluation

The results of the modified Lottman tests are summarized in Table 6. The data seems to indicate that the moisture did not affect the strength of the cores obtained from sections of I-75, Columbia County, and I-10, Suwannee County, which had high in place air voids. However, the after-treatment strength values of core samples from I-10, Columbia county, and A1A, Nassau county, were significantly lower than their corresponding before-treatment strength values. It has to be noted, though, that the specimens from these two latter sections had after-conditioning strength values higher than those of unconditioned samples from I-75. One likely factor that contributed to this difference is the comparatively higher air voids in cores from the I-75 section. Recognizing the severity of the test procedure as compared to the field conditions in Florida and the complexity of the behavior of partially saturated asphalt mixtures under load, it was decided to further monitor these test sections. Using the present strength data as reference, cores will be taken periodically from these sections at the same initial locations to evaluate any significant changes in strength over a period of one year.

## CONCLUSIONS AND RECOMMENDATIONS

This paper presented the results of an investigation of the water permeability of coarse graded Superpave mixes. The data indicated the importance of proper compaction during the placement operations. In addition, a simple test apparatus and a procedure for quantifying the tendency of water to penetrate an asphalt concrete pavement were also presented herein. This approach can be used at design verification and during actual asphalt mixture placement to determine the effectiveness of compaction to produce “acceptable” permeability of an asphalt mixture.

On the basis of this study, the following conclusions can be drawn:

- The permeability test apparatus developed during the course of this study was proven to be effective and convenient for measuring the water permeability of compacted asphalt mixture samples.
- An air void content of 6 percent or less is desired to obtain an impervious coarse graded Superpave pavement.
- An average water permeability value not exceeding 100 x $10^{-5}$ cm/s may be low enough to prevent the infiltration of excessive water into the pavement structure. This value is only a relative test value.

- The present FDOT lift thickness criteria of fine graded Marshall mixes does not seem to be adequate for the coarse-graded Superpave mixes.
- In-place air voids of coarse-graded mixes appear to have a greater amount of interconnection than fine-graded Marshall mixes, based on their respective water permeability levels at the same air void content.
- The air void structure in a gyratory compacted sample may not be comparable to that of a field compacted core at the same air void level.

Based on the findings of this investigation, it is recommended that FDOT increase its density specification for coarse graded Superpave mixes to a minimum of 94.0 percent of $G_{mm}$, as determined from cores taken from the completed pavement. The pavement's permeability should be evaluated if this in-place density is not achieved and falls below 93.0 percent of $G_{mm}$. A tentative permeability limit not exceeding 100 x $10^{-5}$ cm/s is suggested when evaluating the in-place Superpave mix pavement permeability. In addition, it is also suggested that the lift thickness of Superpave mixes be increased, as a rule of thumb, to a minimum of four times the nominal maximum aggregate size of the mix to facilitate compaction.

Florida is still a strong believer in the Superpave technology, but also recognizes that work still need to be done in refining it.

## ACKNOWLEDGMENTS

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3. Florida Department of Transportation, "Florida Method of Test for Water Permeability of Compacted Asphalt Paving Mixtures," February 1997.

4. Florida Department of Transportation, "Florida Method of Test for Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens," September 1993.

5. Florida Department of Transportation, "Florida Method of Test for Maximum Specific Gravity of Bituminous Paving Mixtures," September 1993.

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Table 1 Mix Design Characteristics

| Mix Design Characteristics | Project | | | | | | |
|---|---|---|---|---|---|---|---|
| | I-75 Columbia Co. | I-10 Columbia/ Suwannee Co. | A1A Nassau Co. | A1A Nassau Co. | I-95 Volusia Co. | I-10 Okaloosa Co. | I-95 Brevard Co. |
| Aggregate Type* | GG/RP | GG/RP | GG/RP | GG | FL/RP | AL | FL/RP |
| Nmax | 204 | 174 | 174 | 174 | 174 | 174 | 152 |
| 19.0 mm Mix | | | | | | | |
| AC, % | 4.9 | 5.2 | 5.1 | 5.1 | 5.3 | 4.2 | |
| Gmb @ Ndesign | 2.413 | 2.409 | 2.337 | 2.369 | 2.372 | 2.455 | |
| Lab Density, km/m$^3$ | 2412.4 | | 2371 | 2370 | 2370.7 | 2450.8 | |
| Gmm | 2.514 | 2.505 | 2.487 | 2.481 | 2.482 | 2.557 | |
| Air Voids, % | 4.0 | 3.8 | 4.4 | 4.5 | 4.7 | 4.0 | |
| VMA, % | 13.2 | 13.1 | 14.7 | 15.0 | 14.7 | 13.2 | |
| VFA, % | 69.7 | 71.0 | 70.0 | 70.0 | 68 | 69.7 | |
| Effective AC, % | 3.93 | 4.0 | 4.2 | 4.5 | 4.4 | 3.8 | |
| Dust to Eff. AC Ratio | 1.02 | 1.00 | 0.7 | 0.7 | 0.9 | 1.0 | |
| Gmm @ Ninitial, % | 85.6 | 84.6 | 85.5 | 85.9 | 84.0 | 86.0 | |
| Gmm @ Ndesign | 96.0 | 96.2 | 95.3 | 96.0 | 96.0 | 96.0 | |
| Gmm @ Nmax. | 97.4 | 97.8 | 97.0 | 97.1 | 97.2 | 97.2 | |
| 12.5 mm Mix | | | | | | | |
| AC, % | 5.7 | 5.3 | 5.3 | 5.0 | 5.5 | 4.9 | 7.0 |
| Gmb @ Ndesign | 2.367 | 2.374 | 2.338 | 2.356 | 2.386 | 2.427 | 2.199 |
| Lab Density, km/m$^3$ | 2365.9 | 2372.3 | 2338 | 2356 | 2385 | 2418.8 | 2197.7 |
| Gmm | 2.477 | 2.473 | 2.465 | 2.477 | 2.488 | 2.528 | 2.291 |
| Air Voids, % | 4.2 | 4.0 | 5.2 | 4.9 | 4.1 | 4.0 | 4.0 |
| VMA, % | 14.4 | 14.0 | 15.8 | 15.3 | 14.1 | 14.6 | 14.3 |
| VFA, % | 70.8 | 71.4 | 84.8 | 68 | 70.9 | 72.6 | 72.0 |
| Effective AC, % | 4.4 | 4.3 | 4.6 | 4.6 | 4.3 | 4.5 | 4.8 |
| Dust to Eff. AC Ratio | 0.91 | 1.0 | 0.9 | 0.8 | 0 | 0.9 | 0.7 |
| Gmm @ Ninitial, % | 85.3 | 86.1 | 84.8 | 85.5 | 83.7 | 86.0 | 86.4 |
| Gmm @ Ndesign | 95.8 | 96.0 | 94.8 | 95.1 | 95.9 | 96.0 | 96.0 |
| Gmm @ Nmax. | 97.4 | 97.5 | 96 | 96.2 | 97.2 | 97.9 | 97.9 |

* Aggregate Type:
GG = Georgia granite;
FL = South Florida limestone;
AL = Alabama limestone; and
RP = Reclaimed asphalt pavement.

Table 2 Permeability Test Results

| 19 mm Mix | | | |
|---|---|---|---|
| Project | Sample | Air Voids,% | k, E-5 cm/s |
| 29180-3446<br>I-75<br>Columbia | 5R19 | 4.0 | 0 |
| | 5R19 | 5.4 | 3 |
| | 6R19 | 5.9 | 22 |
| | 3L19 | 6.9 | 526 |
| | 4L | 7.0 | 111 |
| | 5L2B19 | 7.3 | 51 |
| | 6L19 | 7.7 | 270 |
| | 8R19 | 8.2 | 245 |
| | 4R19 | 8.2 | 625 |
| | 2L19 | 8.9 | 741 |
| | 5L19 | 9.0 | 720 |
| | IL19 | 9.4 | 764 |
| | 8L19 | 9.9 | 587 |
| | 2R19 | 10.4 | 1014 |
| | IR19 | 10.9 | 872 |
| | 7L19 | 12.1 | 976 |
| 29170-3405<br>I-10<br>Columbia | 1R19 | 1.9 | 2 |
| | 4R19 | 3.0 | 0 |
| | 7C19 | 3.6 | 0 |
| | 3L19 | 3.7 | 8 |
| | 7R19 | 3.8 | 0 |
| | 1L19 | 4.6 | 50 |
| | 5R19 | 5.0 | 82 |
| | 8R19 | 5.4 | 5 |
| | 4C19 | 5.8 | 301 |
| | 6C19 | 5.9 | 251 |
| | 8C19 | 6.1 | 110 |
| | 5C19 | 6.5 | 262 |
| | 2L19 | 8.4 | 861 |
| | 6R19 | 8.5 | 370 |
| | 3R19 | 8.7 | 638 |
| 48260-3463<br>I-10<br>Escambia | 419 | 6.3 | 13 |
| | 8B19 | 6.6 | 95 |
| | 319 | 6.7 | 25 |
| | 719 | 6.7 | 26 |
| Project | Sample | Air Voids, % | k, E-5 cm/s |
| 48260-3463<br>I-10<br>Escambia<br>(Cont.) | 619 | 7.1 | 1 |
| | 819 | 7.2 | 58 |
| | 219 | 7.3 | 35 |
| | 519 | 7.3 | 3 |
| | 119 | 7.4 | 102 |
| | 5S19 | 8.3 | 125 |
| | 2B19 | 8.9 | 559 |
| | 3B19 | 9.1 | 223 |
| | 5B19 | 9.2 | 84 |
| | 1B19 | 9.6 | 804 |
| | 3S19 | 10.7 | 964 |
| | 4B19 | 11.1 | 533 |
| | 9B19 | 11.6 | 916 |
| | 1S19 | 11.8 | 927 |
| 74040-3529<br>A1A<br>Nassau | 2C19.0 | 2.3 | 0 |
| | 2X19.0 | 4.1 | 1 |
| | 2R19.0 | 4.9 | 1 |
| | 1C19 | 6.6 | 405 |
| | 15R19.0 | 6.8 | 487 |
| | 14C19.0 | 7.2 | 539 |
| 74060-3534<br>A1A<br>Nassau | 4R19 | 4.5 | 25 |
| | 9R19 | 5 | 43 |
| | 10R19 | 6.2 | 117 |
| | 9C19 | 7.2 | 520 |
| | 12R19 | 7.4 | 384 |
| | 6R19 | 8.5 | 385 |
| 57002-3419<br>I-10<br>Okaloosa | 119 | 7.2 | 264 |
| | 519 | 7.2 | 78 |
| | 719 | 7.6 | 116 |
| 37120-3426<br>I-10<br>Suwannee | 7R19 | 6.3 | 121 |
| | 6C19 | 6.7 | 294 |
| | 4R19 | 6.8 | 110 |
| | 3R19 | 7.2 | 205 |
| | 8R19 | 7.8 | 243 |

Table 2 -- Continued

| 12.5 mm Mix | | | | | | | |
|---|---|---|---|---|---|---|---|
| Project | Sample | Air Voids ,% | k, E-5 cm/s | Project | Sample | Air Voids, % | k, E-5 cm/s |
| 70220-3443<br>I-95 Brevard | 2bot12.5 | 3.5 | 0 | 48260-3463<br>I-10<br>Escambia | 9B | 8.1 | 131 |
| | 1bot12.5 | 4.8 | 23 | | 7B | 8.4 | 90 |
| | 1top12.5 | 4.8 | 1 | | 2B12.5 | 8.8 | 184 |
| | 712.5 | 5.1 | 3 | | 3B | 10.4 | 215 |
| | 312.5 | 5.1 | 1 | | 1B12.5 | 11 | 490 |
| | 412.5 | 5.6 | 19 | | 1B | 11.2 | 489 |
| | 2top12.5 | 6.1 | 1 | | 11B | 11.7 | 500 |
| | 812.5 | 6.4 | 50 | 74040-3529<br>A1A Nassau | 2C12.5 | 3.9 | 9 |
| | 612.5 | 6.8 | 5 | | 2R12.5 | 6.9 | 262 |
| | 512.5 | 6.9 | 9 | | 31R12.5 | 7.9 | 458 |
| | 212.5 | 7.0 | 60 | | 3R12.5 | 8.2 | 347 |
| | 112.5 | 8.3 | 107 | | 2X12.5 | 8.8 | 515 |
| 29180-3446<br>I-75<br>Columbia | 5R12.5 | 4.2 | 1 | | 1C12.5 | 9.4 | 384 |
| | 5L2T12.5 | 6.3 | 102 | | 14R12.5 | 9.4 | 463 |
| | 8R12.5 | 8.7 | 546 | | 1X12.5 | 10.5 | 773 |
| | 6R12.5 | 9.3 | 359 | 74060-3534<br>A1A Nassau | 12C12.5 | 4.3 | 0 |
| | 5R12.5 | 9.9 | 444 | | 11R12.5 | 4.9 | 7 |
| | 2L12.5 | 11.0 | 452 | | 7C12.5 | 5.7 | 6 |
| | 4L12.5 | 11.3 | 761 | | 7R12.5 | 5.9 | 5 |
| | 4R12.5 | 11.3 | 591 | | 12R12.5 | 6 | 14 |
| | 7R12.5 | 11.5 | 615 | | 9R12.5 | 7.1 | 109 |
| | 6L12.5 | 12.2 | 919 | | 11C12.5 | 7.3 | 119 |
| | 5L12.5 | 12.5 | 537 | | 6R12.5 | 7.7 | 357 |
| | 8L12.5 | 12.6 | 434 | 57002-3419<br>I-10<br>Okaloosa | 712.5 | 4.5 | 10 |
| | 7L12.5 | 12.6 | 413 | | 112.5 | 4.9 | 8 |
| | 2R12.5 | 12.7 | 722 | | 312.5 | 5.2 | 60 |
| | 3L12.5 | 12.8 | 628 | | 512.5 | 6.3 | 38 |
| | 3R12.5 | 13.6 | 544 | 37120-3426<br>I-10<br>Suwannee | 6C12.5 | 7.5 | 384 |
| | IL12.5 | 13.6 | 598 | | 3C12.5 | 7.7 | 302 |
| | 1R12.5 | 14.6 | 575 | | 2C12.5 | 8.3 | 436 |
| 29170-3405<br>I-10<br>Columbia | 3R12.5 | 2.1 | 0 | | 6R12.5 | 8.4 | 405 |
| | 1L12.5 | 6.8 | 152 | | 5R12.5 | 8.5 | 318 |
| | 4R12.5 | 6.8 | 183 | | 7C12.5 | 8.5 | 575 |
| | IR12.5 | 7.3 | 474 | 79002-3435<br>I-95 Volusia | A9 | 6.1 | 69 |
| | 4C12.5 | 8.2 | 369 | | A12 | 6.5 | 155 |
| | 3L12.5 | 8.4 | 373 | | A11 | 6.9 | 106 |
| | 2L12.5 | 8.5 | 419 | | RLSB12.5T | 7.4 | 36 |
| | 8R12.5 | 8.9 | 381 | | A7 | 7.9 | 306 |
| | 7R12.5 | 9.2 | 469 | | RLSB12.5B | 8.8 | 273 |
| | 7C12.5 | 9.6 | 496 | | A19 | 10.1 | 657 |
| | 5R12.5 | 10.3 | 311 | | A18 | 10.2 | 584 |
| | 6R12.5 | 10.3 | 470 | | A8 | 11.5 | 1002 |
| | 6C12.5 | 10.3 | 360 | | | | |
| | 8C12.5 | 11.8 | 580 | | | | |

Table 3  Marshall Mix Permeability Test Results

| Sample | Air Voids, % | k, E-5 cm/s |
|---|---|---|
| Field Samples | | |
| 1 | 5.9 | 14 |
| 2 | 7.7 | 7 |
| 3 | 8.5 | 7 |
| 4 | 9.5 | 32 |
| 5 | 10.9 | 152 |
| 6 | 11.9 | 17 |
| 7 | 6.5 | 1 |
| 8 | 7.0 | 1 |
| 9 | 7.3 | 2 |
| 10 | 8.3 | 52 |
| Laboratory Fabricated Samples | | |
| 1 | 7.1 | 6 |
| 2 | 7.8 | 5 |
| 3 | 7.9 | 8 |
| 4 | 8.4 | 15 |

Table 4  Laboratory Fabricated Superpave Samples Permeability Test Results

| Sample | Air Voids, % | k, E-5 cm/s |
|---|---|---|
| 19 mm Mix | | |
| 1 | 6.5 | 22 |
| 2 | 7.3 | 145 |
| 3 | 8.3 | 124 |
| 12.5 mm Mix | | |
| 6 | 8.2 | 14 |
| 7 | 9.2 | 107 |
| 8 | 6.2 | 11 |
| 9 | 7.0 | 47 |
| | 7.8 | 93 |
| 10 | 8.0 | 120 |
| 9.5 mm Mix | | |
| 11 | 5.1 | 1 |
| 12 | 5.7 | 1 |
| 13 | 8.2 | 8 |
| 14 | 9.0 | 33 |

Table 5  I-75 Superpave Test Sections Permeability Test Results

| Sample | Air Voids, % | k, E-5 cm/s |
|---|---|---|
| 19 mm Mix | | |
| 1 | 3.1 | 0 |
| 2 | 4.5 | 0 |
| 3 | 5.6 | 0 |
| 4 | 5.9 | 24 |
| 5 | 5.6 | 1 |
| 12.5 mm Mix | | |
| 6 | 3.8 | 337* |
| 7 | 4.7 | 0 |
| 8 | 4.0 | 0 |
| 9 | 5.3 | 34 |
| 10 | 4.8 | 1 |
| 9.5 mm Mix | | |
| 11 | 4.8 | 5 |
| 12 | 6.8 | 170 |
| 13 | 7.8 | 203 |
| 14 | 7.9 | 179 |
| 15 | 5.0 | 14 |

* Sample damaged prior to testing

## Table 6 Modified Lottman Test Results

| Site | Average Air Void, % | Average Tensile Strength, kPa |  | TSR (%) |
|---|---|---|---|---|
|  |  | Unconditioned | Conditioned |  |
| Project 29180-3446 I-75 Columbia County |  |  |  |  |
| 19 mm Aggregate Size |  |  |  |  |
| 1 | 7.1 | 357 | 330 | 92.4 |
| 2 | 4.4 | 414 | 468 | 113.0 |
| 3 | 8.5 | 268 | 252 | 94.0 |
| 4 | 8.3 | 357 | 366 | 102.5 |
| 12.5 mm Aggregate Size |  |  |  |  |
| 1 | 10.6 | 284 | 241 | 85.0 |
| 2 | 10.8 | 287 | 276 | 96.2 |
| 3 | 8.5 | 284 | 277 | 97.6 |
| 4 | 9.7 | 291 | 292 | 100.3 |
| Project 29170-3405 I-10 Columbia County |  |  |  |  |
| 19 mm Aggregate Size |  |  |  |  |
| 1 | 4.4 | 551 | 390 | 70.8 |
| 2 | 3.9 | 620 | 470 | 75.8 |
| 12.5 mm Aggregate Size |  |  |  |  |
| 1 | 9.5 | 511 | 351 | 68.7 |
| 2 | 7.5 | 547 | 428 | 78.3 |
| Project 37120-3426 I-10 Suwannee County |  |  |  |  |
| 19 mm Aggregate Size |  |  |  |  |
| 1 | 5.8 | 495 | 562 | 113.6 |
| 2 | 8.0 | 553 | 559 | 101.0 |
| 12.5 mm Aggregate Size |  |  |  |  |
| 1 | 9.4 | 462 | 475 | 102.8 |
| 2 | 8.5 | 558 | 597 | 107.0 |
| Project 74060-3534 A1A Nassau County |  |  |  |  |
| 19 mm Aggregate Size |  |  |  |  |
| 1 | 3.7 | 818 | 670 | 82.0 |
| 2 | 3.8 | 775 | 621 | 80.0 |
| 12.5 mm Aggregate Size |  |  |  |  |
| 1 | 6.7 | 643 | 397 | 61.7 |
| 2 | 9.1 | 508 | 378 | 74.4 |

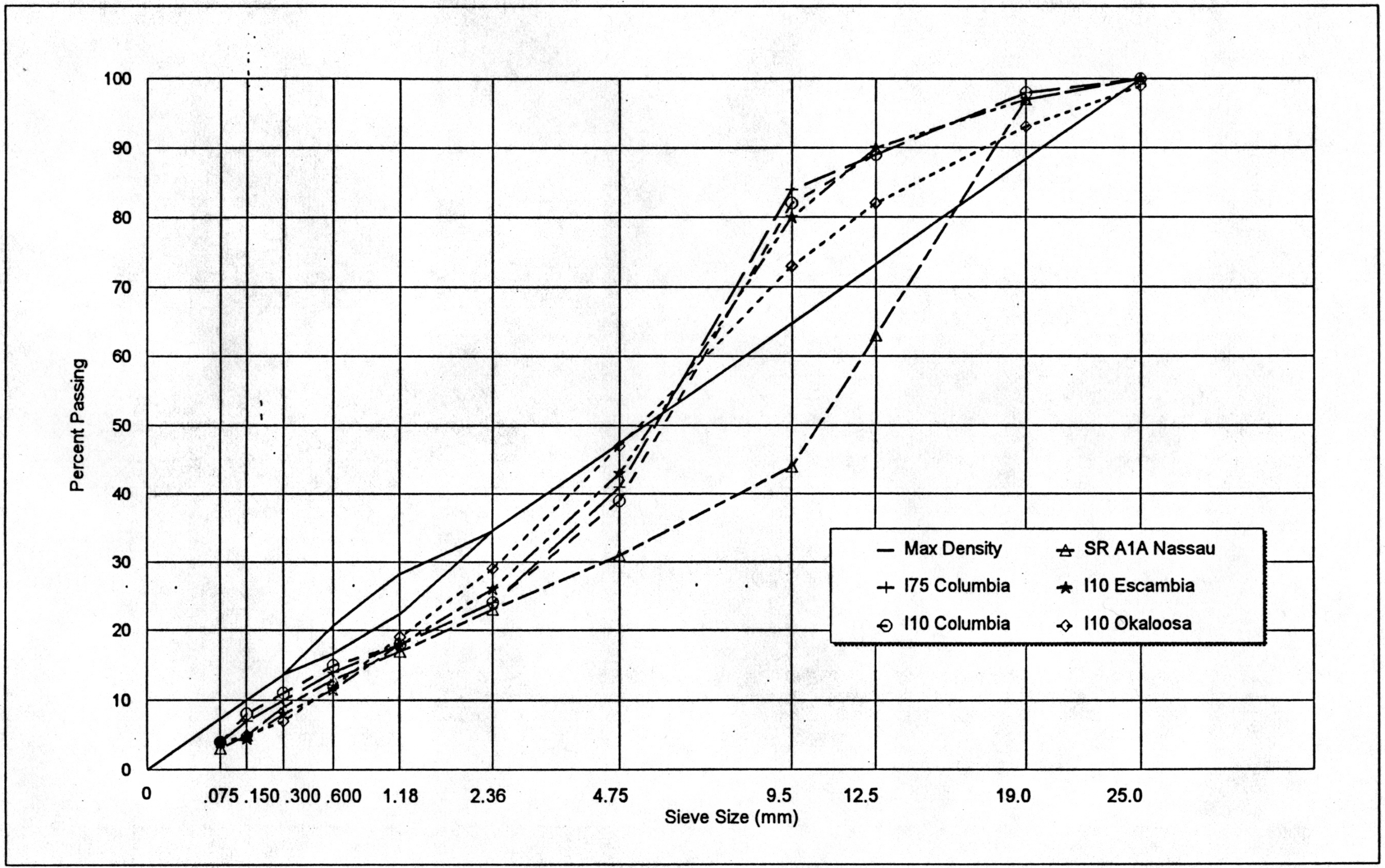

Figure 1 19.0 mm Superpave Mix Aggregate Gradations

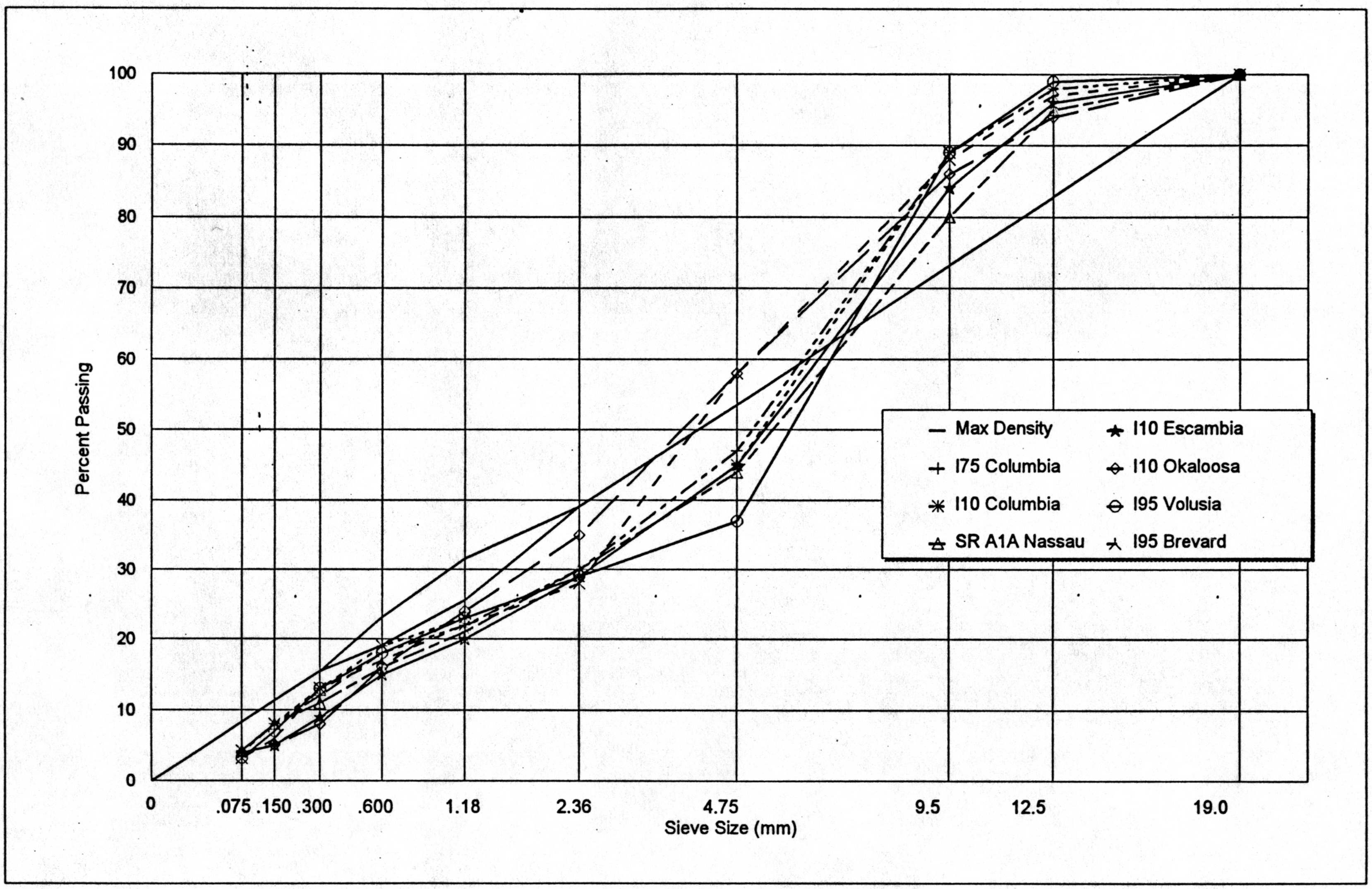

Figure 2 12.5 mm Superpave Mix Aggregate Gradations

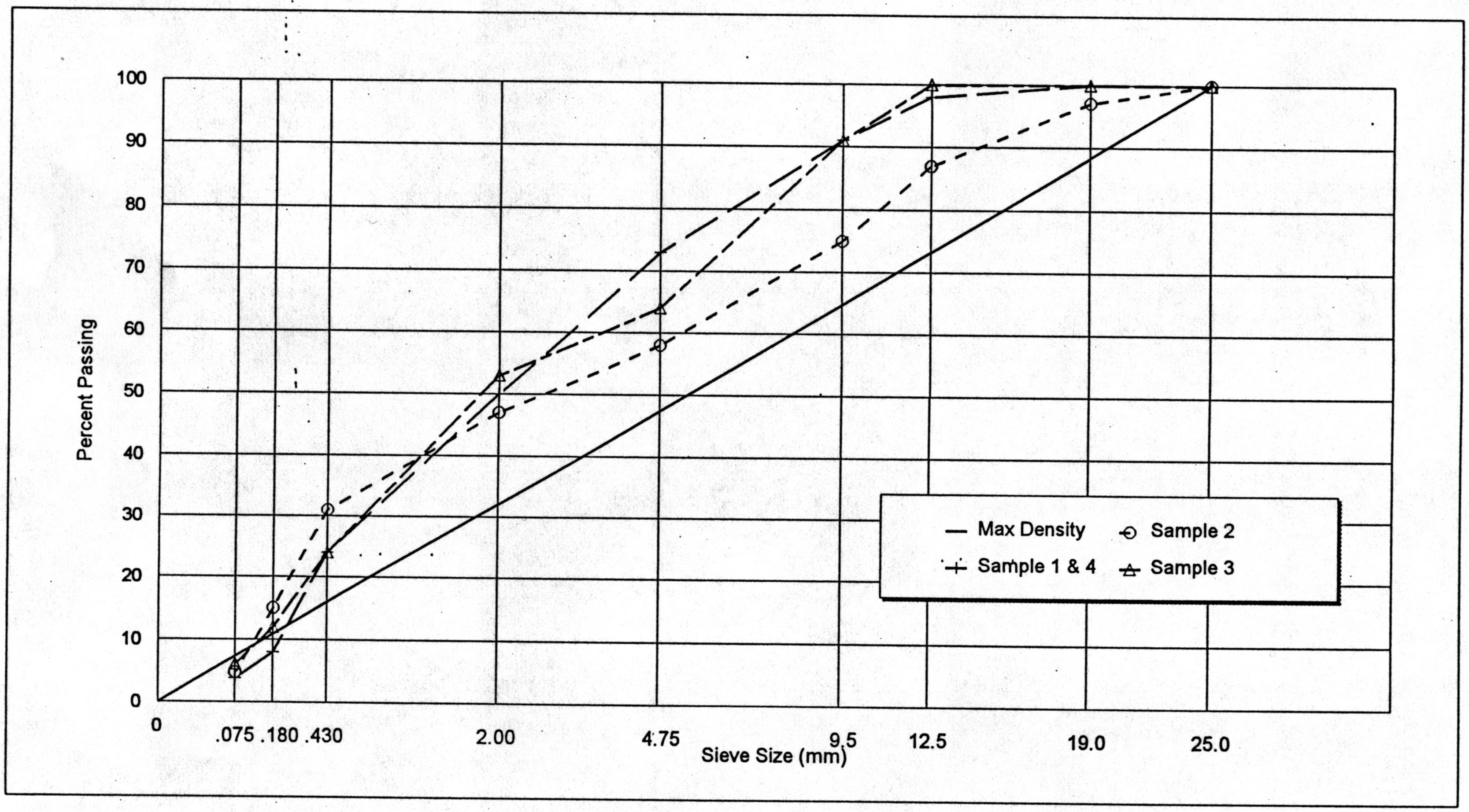

Figure 3 Aggregate Gradations of the Laboratory Compacted Marshall Mix Samples

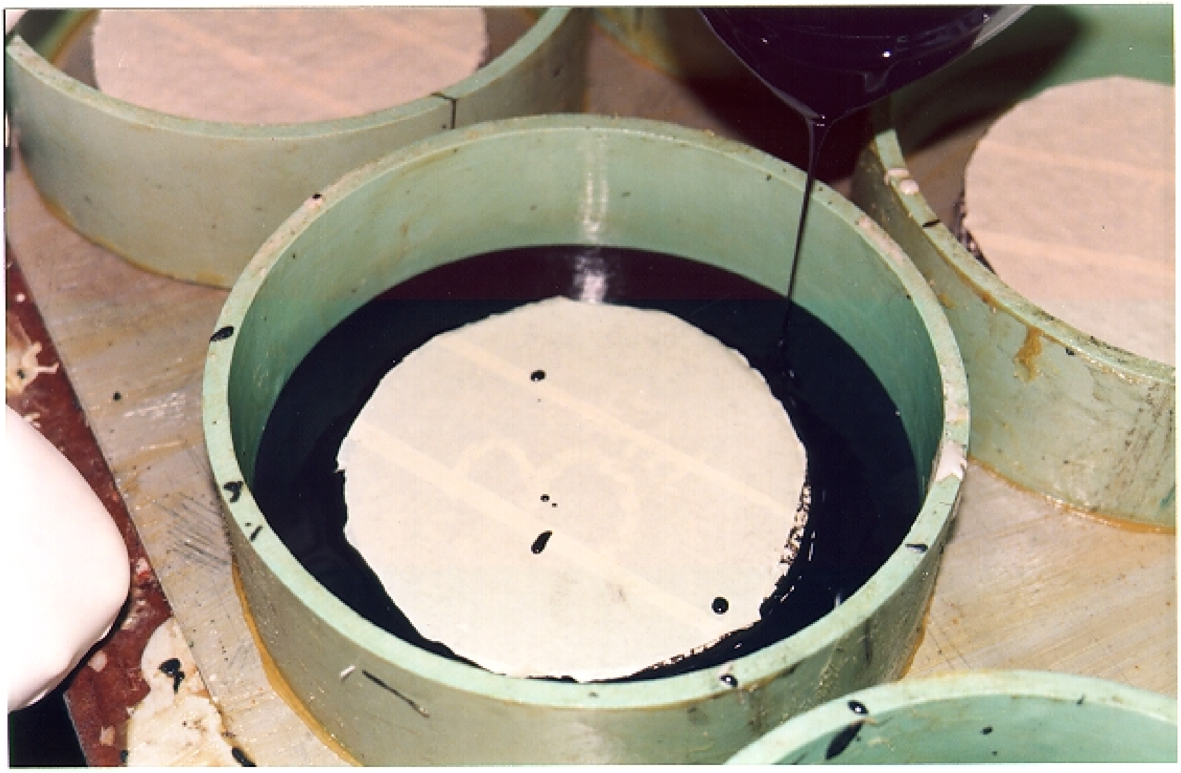

Figure 4  Specimens Epoxy Sealing Mold

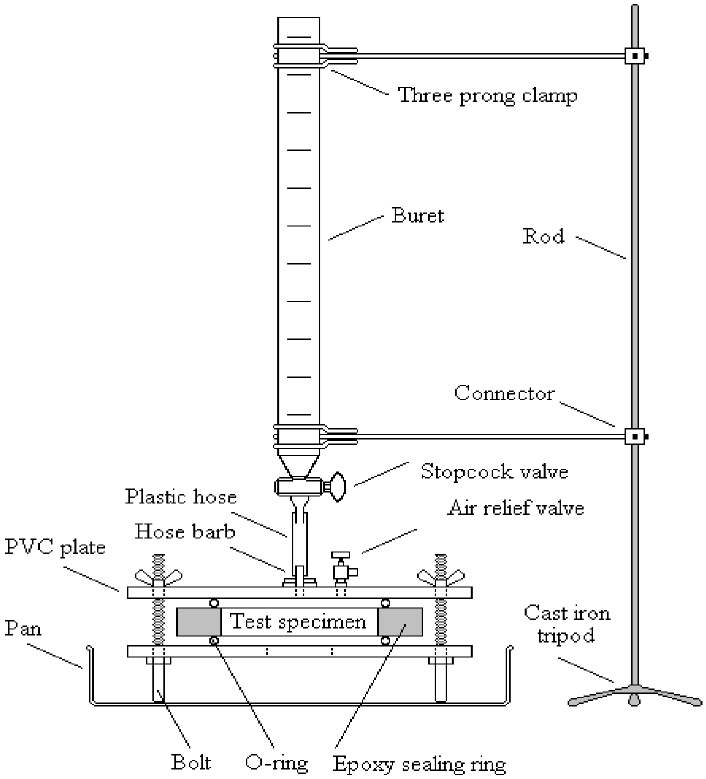

Figure 5 Schematic Drawing of the Water Permeability Test Apparatus (not to scale)

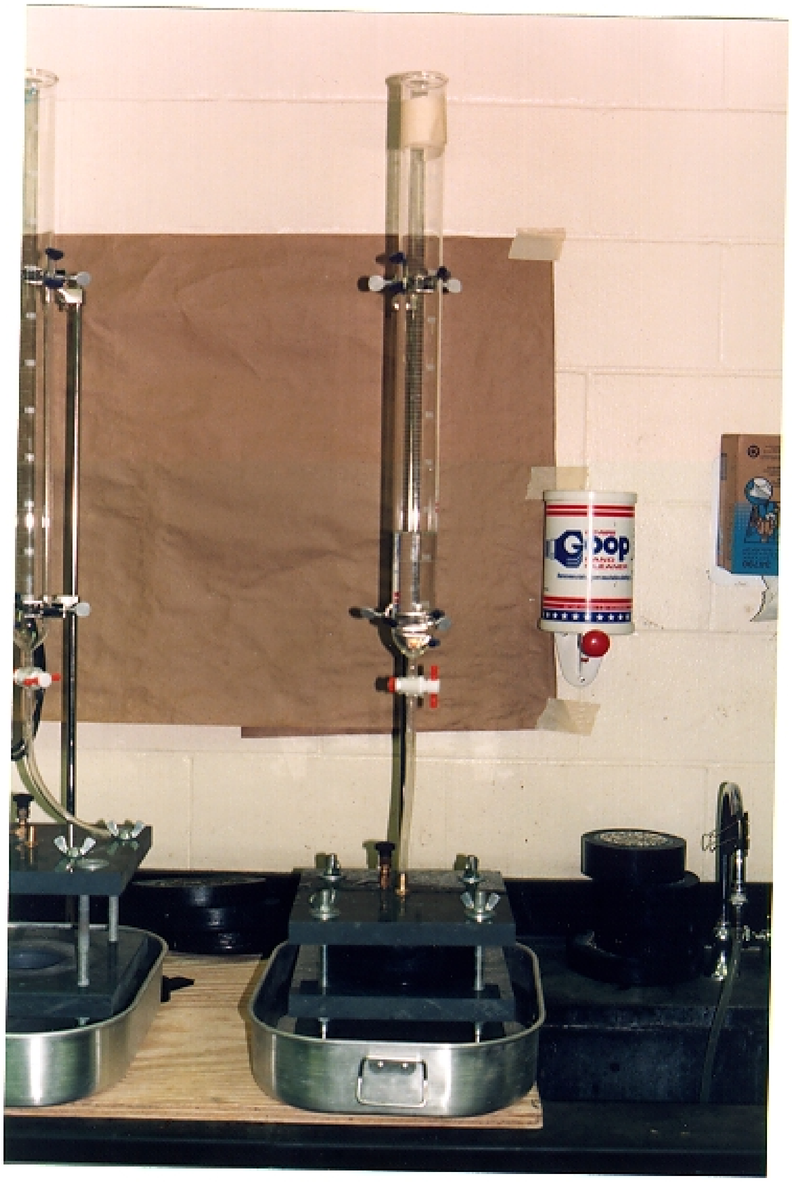

Figure 6  Photograph of the Water Permeability Test Apparatus

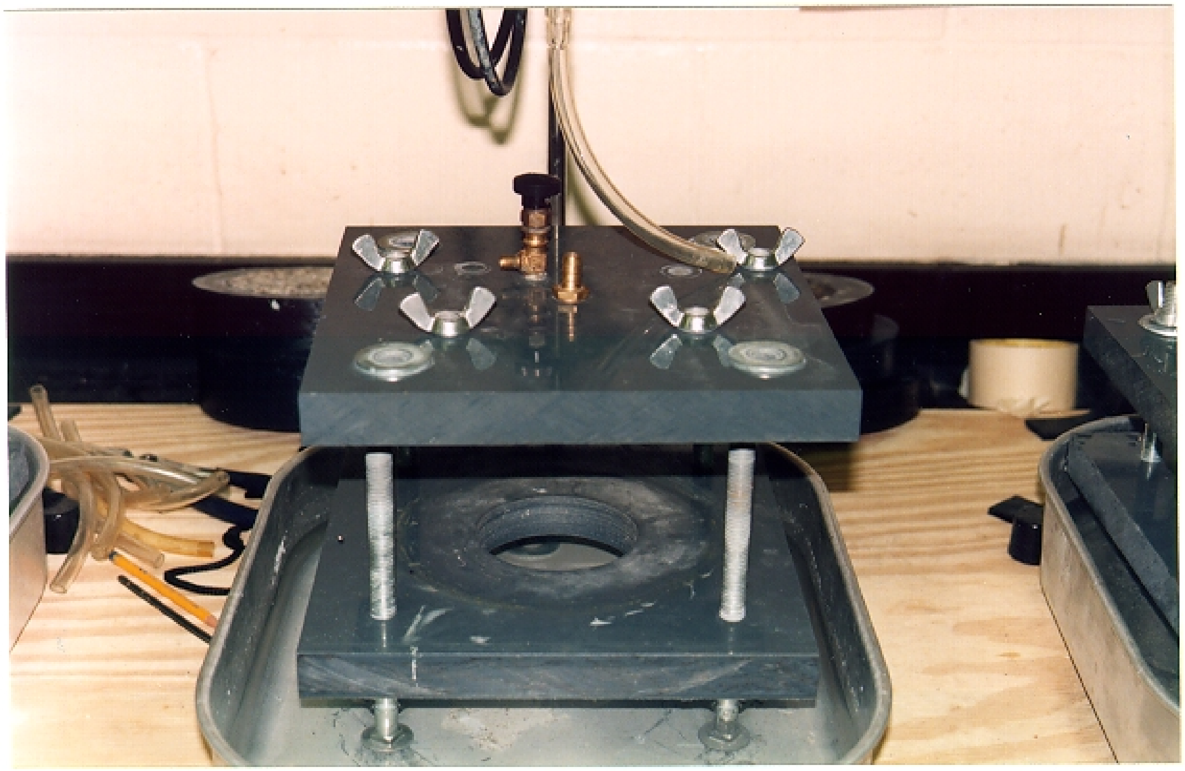

Figure 7  Permeability Cell

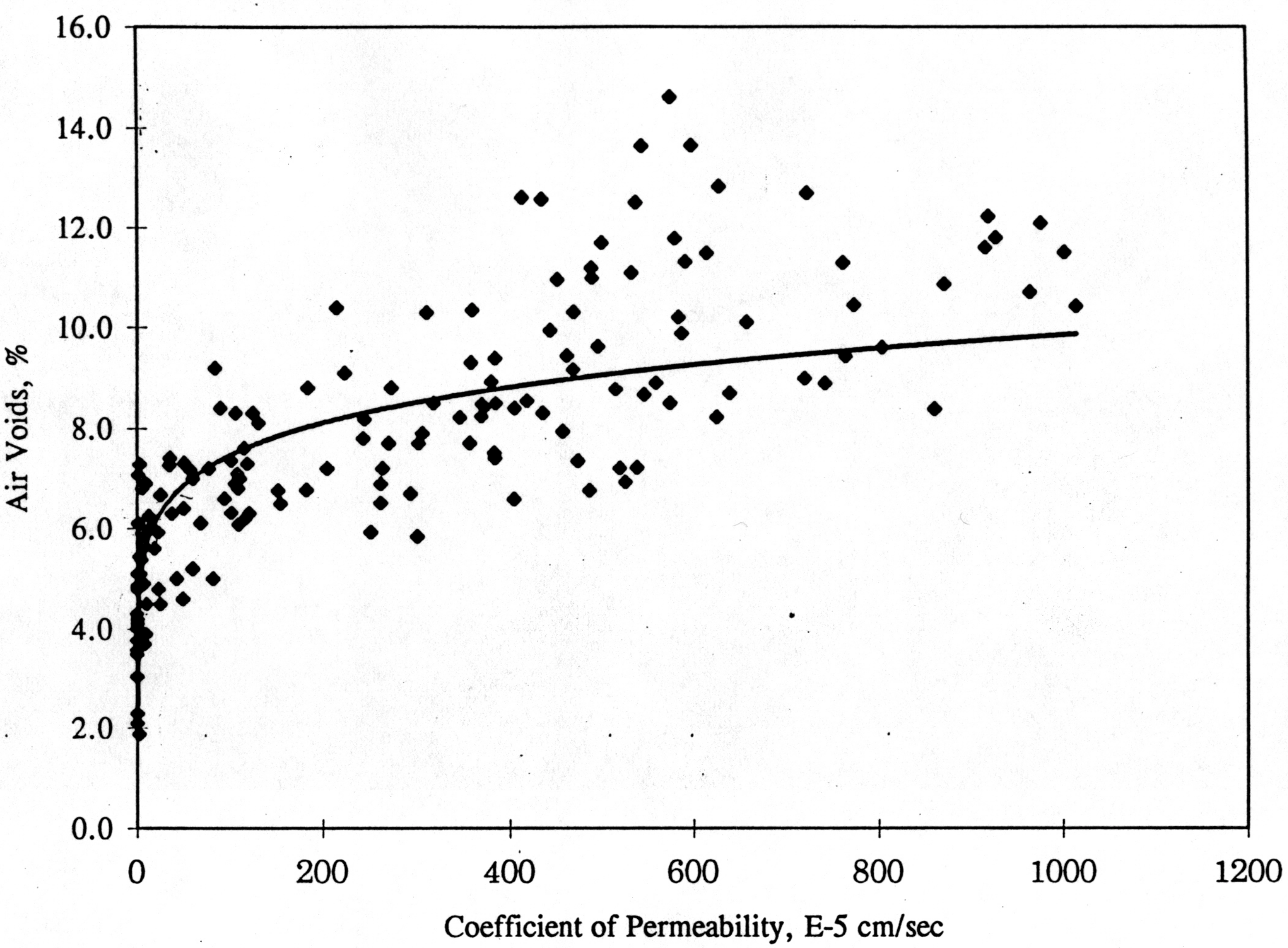

Figure 8 Permeability-Air Void Content Relationship