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PERMEABILITY OF SUPERPAVE MIXTURES: EVALUATION OF FIELD PERMEAMETERS

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CHAPTER 1 - INTRODUCTION

BACKGROUND

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

In the past it has been thought that for most conventional dense-graded HMA, increases in in-place air void contents have meant increases in permeability for pavements. Zube (*2*) performed an insightful study during the 1950s and early 1960s that indicated dense-graded HMA pavements become excessively permeable to water at approximately 8 percent air voids. This was later confirmed by Brown et. al. (*3*) during the 1980s. However, due to problems associated with Superpave designed mixtures in Florida, the size and interconnectivity of the air voids within the pavement have been shown to greatly influence the permeability of HMA pavements (*4*). A study conducted by the Florida Department of Transportation (FDOT) indicated that Superpave mixtures designed on the coarse side of the restricted zone can be permeable to water at air void contents below 8 percent. As part of this study, the FDOT developed a laboratory permeability device utilizing a falling head concept for cores cut from HMA pavements. FDOT also developed a standard method of test for this laboratory permeameter (*5*).

The question that arises as a result of the experiences of FDOT is “Why are the coarse-graded Superpave mixtures more permeable than conventional dense-graded mixtures?” The probable answer to this question is that the coarse-graded Superpave mixtures have a different void structure than the dense-graded mixtures used prior to Superpave. The 1990 Georgia Department of Transportation gradation band for an “E” mix had as the lower gradation control point on the 2.36 mm (No. 8) sieve 44 percent passing (*6*). Under the Superpave definition of nominal maximum aggregate size (NMAS), this particular mixture would have been either a 19.0 or 12.5 mm NMAS depending on the exact gradation. The Superpave coarse-side control point for a 19 mm nominal maximum aggregate size is 23 percent passing while for the 12.5 mm nominal maximum aggregate size it is 28 percent passing. These values show how much coarser Superpave mixtures can be than those used in the past.

Since the Superpave mixtures are typically coarser, it would be expected that the air voids within the Superpave mixtures are larger in size than the conventional dense-graded mixtures if both are compacted to the same air void content. Since the voids are larger, the chance for interconnected voids is increased. Thus, it would be expected that the Superpave mixtures would have the potential to be more permeable.

PROBLEM STATEMENT

During the last year all of the states within the southeast have placed Superpave designed mixtures. Most have been on the coarse side of the restricted zone. Several states have expressed concerns that the Superpave designed pavements are more permeable than pavements previously designed with the Marshall hammer.

As a result of the work performed by the FDOT, a laboratory permeability device is now available to evaluate the permeability of HMA pavements. However, this test is essentially a destructive test since cores must be cut from the roadway. If a field permeability device could be found that can provide accurate and repeatable results, it would negate the need for cutting cores. A device of this nature would also allow for corrections in pavement construction to be made in the field if permeability values are too high. Therefore a study is needed to evaluate several different field permeameters and to select and standardize a field permeability device.

OBJECTIVE

The objective of this study was to evaluate four field permeameters and select the best device based on correlation with laboratory permeability test results, repeatability, and ease of use. A standard test procedure associated with the selected permeameter should also be developed.

SCOPE

To accomplish the objective of this study, three construction projects were visited. At each of the projects, field permeability tests were conducted on compacted HMA pavements using different field permeameters. Each of these projects was new construction. Also at each of the projects, cores were obtained from which the laboratory permeability was determined. In order to select and standardize one field permeameter, the data from each project was analyzed to determine which permeameter correlated best with the accepted laboratory permeameter, which one was the most repeatable, and which one was easiest to use.

CHAPTER 2 - LITERATURE REVIEW

INTRODUCTION

Permeability can be defined as the ability of a porous medium to transmit fluid. For this study, the porous medium is HMA. This chapter presents brief discussions on the theory of permeability, factors that can influence permeability, the results of previous research on permeability of HMA pavements, and potential problems in measuring the in-place permeability of HMA pavements.

THEORY OF PERMEABILITY

Over one hundred years ago, a French waterworks engineer named Henry Darcy investigated the flow of water through clean sands. Based on his work, the fundamental theory of permeability for soils was established. He showed that the rate of water flow was proportional to the hydraulic gradient and area of a sample by:

$$Q = kiA \qquad \text{Eq. 2.1}$$

where:
- Q = rate of flow
- k = coefficient of permeability (generally called permeability)
- i = hydraulic gradient
- A = total cross-sectional area

The hydraulic gradient is a very important concept when evaluating permeability. It can be defined as the head loss per unit length. The head loss increases linearly with the velocity of water transmitted through a medium as long as the flow of water is laminar. Once the flow of water becomes turbulent, the relationship between head loss and velocity is nonlinear. Thus in a turbulent water flow condition, Darcy's law is invalid (*7*).

In Equation 2.1, permeability is a material property which describes how water flows through the material. In using the equation, several assumptions are made and include:

1. A homogenous material;
2. Steady state flow conditions;
3. Laminar flow;
4. Incompressible fluid;
5. Saturated material; and
6. One dimensional flow.

Two general approaches are used to measure the permeability of a material using Darcy's law: a constant head test and a falling head test. The constant head test involves determining the flow rate of water through a saturated sample while maintaining a constant head of water. The equation derived from Darcy's law for calculating the coefficient of permeability when using a constant head test is as follows:

$$k = \frac{Q\ L}{h\ A\ L\ t} \qquad \text{Eq. 2.2}$$

where:
- k = coefficient of Permeability
- Q = total discharge volume
- L = height of specimen
- h = height of water head on specimen
- A = cross-sectional area of specimen

t = time during which Q is measured

The constant head test is most applicable for materials with relatively high permeabilities (*8*). This is because it can take an extended amount of time to accumulate a significant discharge volume (Q) for relatively impervious materials.

The falling head test involves determining the amount of head loss through a given sample over a given time. This type of test is more suitable for less permeable materials (9). For the falling head test, the coefficient of permeability is calculated as follows:

$$k = \frac{a\ L}{A\ t} \ln\left(\frac{h_1}{h_2}\right) \qquad \text{Eq. 2.3}$$

where: k = coefficient of Permeability
a = area of stand pipe
L = length of sample
A = cross-sectional area of sample
t = time over which head is allowed to fall
h_1 = water head at beginning of test
h_2 = water head at end of test

Since the literature suggests that a falling head permeability test is more appropriate for less permeable materials, permeability tests conducted on dense-graded HMA pavements should most likely be falling head tests. However, for HMA mixtures designed to transmit water (e.g., open-graded friction courses) a constant head test may be more appropriate.

FACTORS INFLUENCING PERMEABILITY OF HMA

In a study conducted by Ford and McWilliams (*10*), several factors were identified that can influence the permeability of HMA and include: particle (aggregate) size distribution, particle shape, molecular composition of the asphalt, air voids (i.e., compaction), degree of saturation, type of flow, and temperature. The particle size distribution and particle shape have an effect on the size and number of air voids present within a mixture. Ford and McWilliams (*10*) suggested that for the most part, permeability decreases as the size and number of voids decrease.

Hudson and Davis (*11*) also concluded that permeability of HMA is dependent on the size of voids, not just percentage of voids. To substantiate, they compacted a fine aggregate HMA to 30-35 percent VMA and a well-graded coarse aggregate to 12-15 percent VMA. Based on their testing, the fine aggregate showed considerably less permeability.

The shape of aggregate particles can also influence permeability (*12*). Irregular shaped particles (angular, flat and/or elongated) can create flow paths which are more tortuous than those created by smooth, rounded aggregates. This can lead to lower flow rates through an HMA.

Without question the degree of compaction affects the permeability of HMA. Pavements compacted to low densities, tend to have more and larger air voids which increases permeability.

The degree of water saturation can greatly affect the permeability of a HMA. Air bubbles trapped within a pavement occupy void space thereby reducing the void volume through which water can pass. Water can not flow through an air bubble (9). Most laboratory permeability tests are performed on saturated samples.

PREVIOUS RESEARCH

As mentioned previously, a significant study was conducted by Zube (*2*) that showed dense-graded HMA pavements become excessively permeable to water at approximately 8 percent in-place air voids. McLaughlin and Goetz (*13*), surmised that permeability actually gives a better measure of a pavement's durability than does density. Permeability provides an indication of how a HMA will transmit water (and therefore give access to air) through the pavement, whereas density is just an indirect measure of in-place air voids.

The most recent work performed that evaluated the permeability of HMA was the previously mentioned work by FDOT (*4*). This study is significant because it evaluated coarse-graded Superpave designed mixes. Results of this study follow the same conclusions derived from the previously mentioned studies, in-place air voids do not specifically identify mixtures that are prone to being permeable. The size, orientation, and interconnectivity of the voids are more important in producing a permeable pavement.

POTENTIAL PROBLEMS MEASURING IN-PLACE PERMEABILITY

The majority of previous work was conducted using cores cut from the roadway in a falling head type permeameter. This is important because Darcy's law is applicable for one dimensional flow as would be encountered in a laboratory test. Measuring the permeability of pavements in-place is theoretically much more difficult, because water can flow in two dimensions. Other potential problems include degree of saturation, boundary conditions of flow, and type of flow.

As stated in a previous section, one of the assumptions in using Darcy's law is that the material being tested is saturated. As the degree of saturation decreases, so does the measured permeability. Unlike laboratory testing, the degree of saturation cannot be accurately determined in the field.

When performing laboratory permeability tests, the sample dimensions are always known. Without cutting a core, the sample thickness has to be estimated when conducting field tests. Also, the effective area of the pavement through which the flow takes place has to be estimated. A typical field permeability test has some type of standpipe that is open on both ends. Water is introduced into the standpipe and the water is allowed to flow into the pavement. Once the water enters the pavement it can flow in any direction and most likely flows outside the area of the standpipe; therefore, the effective area must be assumed.

Another potential boundary condition problem is the flow of water across (through) pavement layers. Without some type of destructive test (e.g., cutting cores) there is no way of knowing whether the water flows across layers.

Darcy's law was based on testing conducted in clean sands. The flow of water was determined to be laminar. Within a pavement, it can not be determined whether the flow of water is laminar or turbulent. Darcy's law is invalid for calculating permeability if the flow of water is turbulent; therefore, water flow must be assumed laminar.

A problem that was experienced by NCAT during the conduct of National Cooperative Highway Research Program Study 9-8, "Designing Stone Matrix Asphalt Mixtures," was that of sealing the field permeameter to the pavement surface. The primary problem comes from the rough surface texture of SMA. Because of the rough surface texture, it was difficult to completely penetrate the surface voids for a water tight seal between the permeameter and pavement. In order to have reasonable repeatability in field permeability measurements, a repeatable method of sealing the permeameter to the pavement must be found.

CHAPTER 3 - RESEARCH APPROACH

The objective of this study was accomplished by evaluating four field permeability devices. Two of these permeameters were developed by a commercial supplier, one was designed by NCAT for use during the NCHRP Study 9-8 “Designing Stone Matrix Asphalt Mixtures”, and the fourth was designed by NCAT specifically for this study. Each of the field permeability devices are described in detail in the next chapter.

Because of the nature of compacted HMA pavements, there may not be a method of determining the true permeability of a pavement (horizontal flow, vertical flow, flow across layers, etc.). Because of the problems measuring in-place permeability discussed in Chapter 2, a theoretical approach to calculating permeability is probably not accurate. However, if a device and test method can be developed that provides a good indication of permeability, is repeatable, and easy to use, it would be of lasting value. The “indication” of permeability should be based on sound engineering assumptions.

Figure 3.1 illustrates the overall research approach in the form of a flow diagram. Three Superpave projects, each from a different state, were visited during the conduct of this project. Two NCAT representatives traveled to each project to perform the field permeability testing. At each project, two pavement sections were selected. Of the two sections, one section was proposed to be compacted to approximately 92 percent theoretical maximum specific gravity (92% G_{mm}) and the other section was proposed to be compacted to approximately 88-90% G_{mm}. This would allow for varying degrees of pavement permeability to be evaluated. In order to obtain the two density ranges, rolling patterns were adjusted. It was proposed to take all measurements 2 feet away from the edge of the mat.

Because all four permeameters require a sealant to seal the devices to the pavement surface, each can not be performed in the same spot. Therefore repeatability was measured by performing ten field permeability tests per field permeameter within each of the two pavement sections for a particular project. This equated to 40 field permeability tests per section (4 field devices x 10 locations). Also from each section, five cores were obtained and brought back to the NCAT laboratory for testing with a laboratory permeability device. Therefore, a total of 45 permeability tests were performed per section (or 90 tests per project).

To ensure the statistical integrity of this methodology, the locations for each of the permeability tests and core locations were determined based on a stratified randomization testing plan. All permeability measurements and coring were on a longitudinal straight line approximately 2 feet from the pavement edge. This test plan was selected because a compacted pavement tends to be more uniform in density longitudinally than transversely. The test location plan is shown in Figure 3.2.

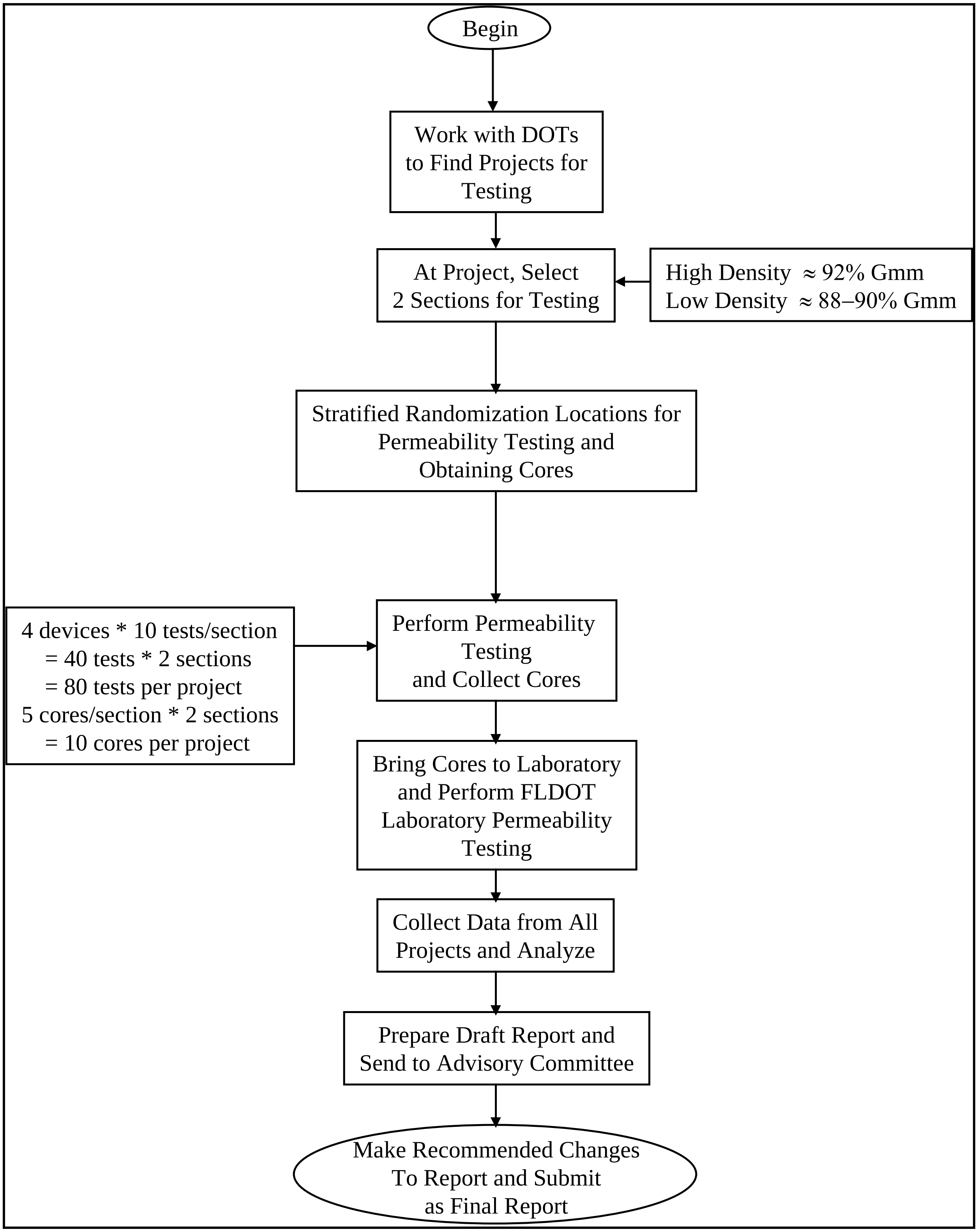

Figure 3.1. Overall Research Approach

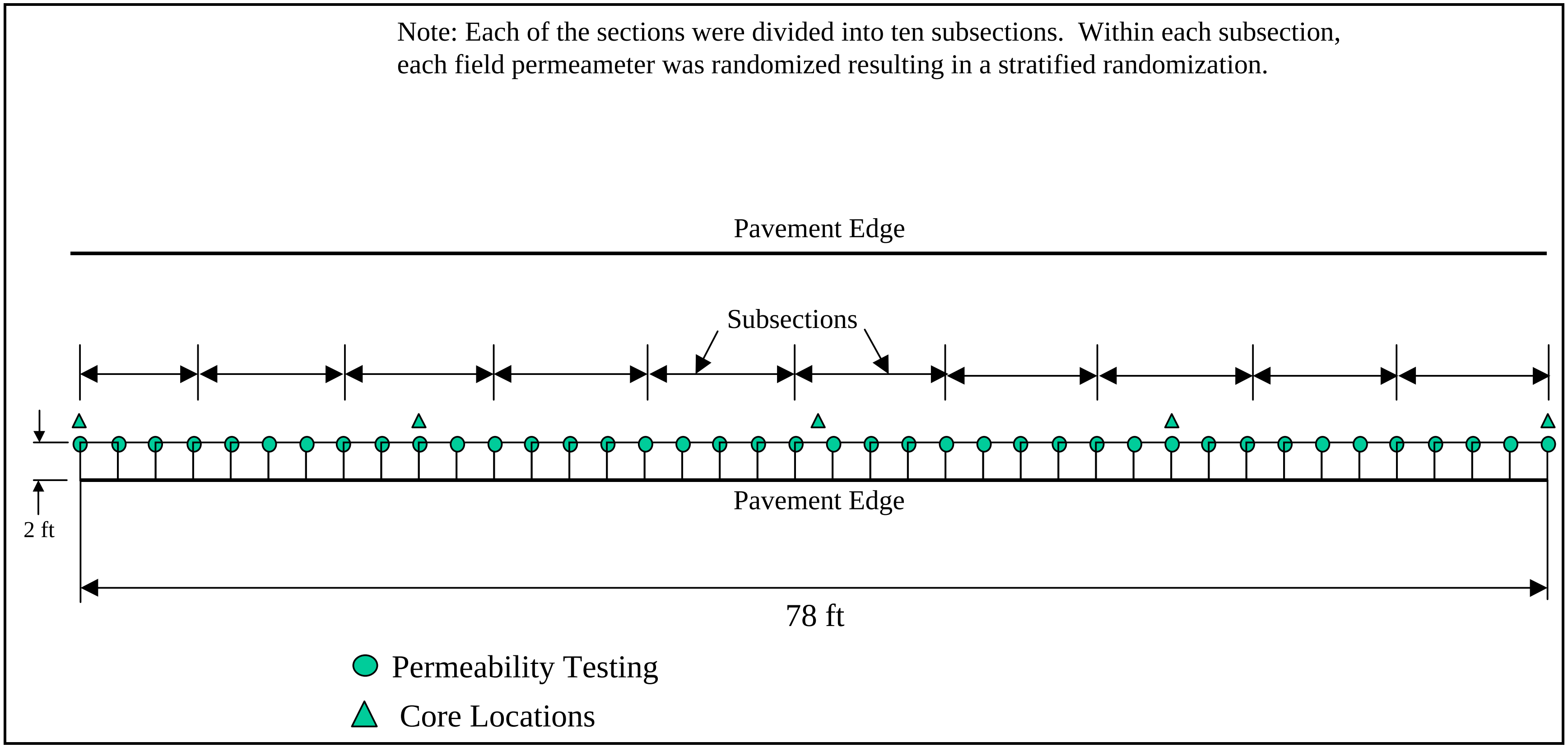

Figure 3.2. Test Location Plan for Each Section of Each Project

CHAPTER 4 - PERMEAMETERS

INTRODUCTION

Four field permeameters were used during the conduct of this study. Each of these permeameters were of the falling head type. Two were provided by a commercial supplier while two were designed by NCAT. As mentioned previously, one major problem in performing field permeability tests is the sealing of the permeameter to the pavement surface. All four permeameters used some type of sealant. Three used a silicone-rubber based caulk and the fourth used paraffin. The actual procedure for estimating permeability with the four devices was very similar. The primary difference was the method of sealing each to the pavement. A standardized procedure for each permeameter was developed and can be found in Appendix A. The coefficient permeability for each field device was calculated using Equation 2.3. This equation is used to calculate permeability based upon a falling head approach. Assumptions used for these calculations included (1): sample thickness was equal to the immediately underlying HMA course thickness; (2) the area of the tested sample was equal to the area of the permeameter from which water was allowed to penetrate into the HMA; (3) one-dimensional flow; and (4) laminar flow of water. The following sections describe each of the four permeameters and the laboratory device used for this study.

Field Permeameter No. 1 (FP1)

FP1 is shown during use in Figure 4.1. This device is similar to the one used by NCAT during NCHRP 9-8, with one modification. The diameter of the base plate located at the bottom of the permeameter was increased in order to help provide a better seal with the pavement surface.

In order to seal FP1 to the pavement surface, a sealant (silicone-rubber caulk) is placed on the bottom of the base plate. The permeameter is then placed onto the pavement surface and pushed

Figure 4.1. Field Permeameter No. 1

down to try and distribute the sealant fully into the surface voids of the pavement. For pavements with a very rough surface texture, it is sometimes necessary to also place some sealant directly onto the pavement surface to ensure the surface voids are completely sealed. Once sealed, a weight was placed onto the base plate to resist the uplift of the device when water is introduced into the standpipe.

Of the four permeameters studied, FP1 was probably the easiest to use. This is based upon the ease of sealing, relative size of the device, and the simple design.

Field Permeameter No. 2. (FP2)

FP2 was one of the two permeameters provided by a commercial supplier. This device (shown in Figure 4.2) essentially consisted of a six-inch Marshall mold, onto which a plastic cap was fitted. The cap had a hole cut into the top for a standpipe to fit. Also shown in Figure 4.2 is a ring that is approximately 50 mm larger in diameter than the Marshall mold. This ring was used while sealing FP2 onto the pavement surface. Heated paraffin was poured between the permeameter and the ring for sealing. Paraffin was selected because in a liquid state it would flow into the surface voids and seal the permeameter to the pavement upon hardening.

This device was probably the most labor intensive. A propane heater was needed in order to melt the paraffin. Once heated to a liquid state, the paraffin had to cool for a period of time. If it was not allowed to cool, it would flow beneath the edges of the permeameter thus potentially closing flow paths. If the paraffin was allowed to cool to a point where it began to "skim over," upon being introduced between the permeameter and ring it would harden quickly.

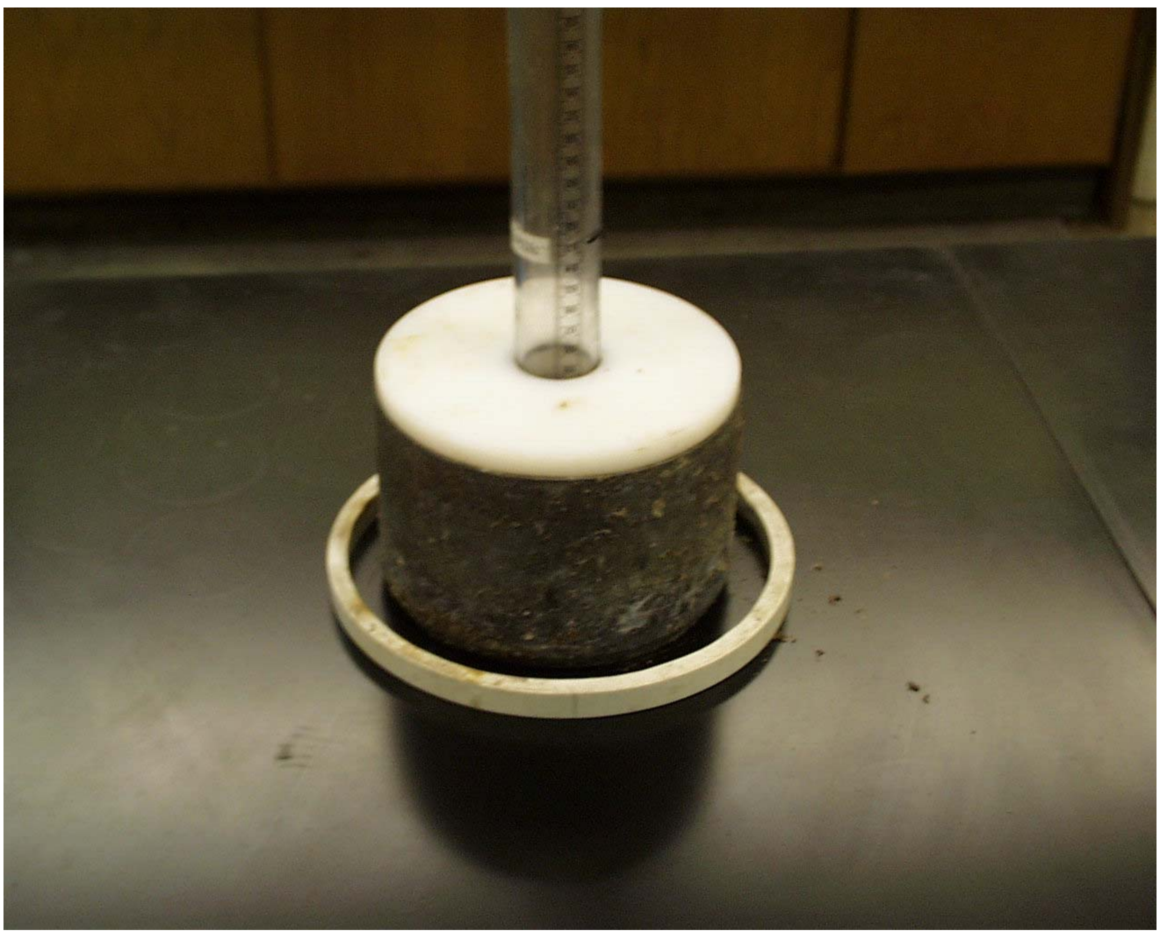

Figure 4.2. Field Permeameter No. 2

Field Permeameter No. 3 (FP3)

FP3 is the second device that was designed and built by NCAT. This device (shown in Figure 4.3) is unique from the other three permeameters because it uses a three tier standpipe. As shown in Figure 4.3, each tier consisted of a standpipe with a different diameter. The standpipe with the smallest diameter is at the top and the largest diameter standpipe is at the bottom. This configuration was designed in an effort to make the permeameter more sensitive to the flow of water into the pavement. For pavements that are relatively impermeable, the water will fall within the top tier standpipe very slowly. Additionally, because of the small diameter of the top tier standpipe, FP3 is very sensitive to small amounts of water draining from the permeameter.

Figure 4.3. Field Permeameter No. 3

For pavements of "medium" permeability, the water should flow through the top-tier standpipe quickly but slow down when it reaches the larger diameter middle tier standpipe. Likewise, for a very permeable pavement, the water should flow through the top and middle tier standpipes quickly but slow down in the larger diameter bottom tier standpipe.

Sealing FP3 to the pavement surface is similar to the procedure used for FP1. However, a flexible rubber base is used in conjunction with a metal base plate. The rubber base was selected because, being flexible, it would push the sealant down into the surface voids.

FP3 is relatively easy to use. The particular standpipe from which head loss measurements are made must be noted. Head loss measurements obtained across standpipe tiers make the calculation of permeability more complicated. Additionally, sealant has to be applied in two locations: between the steel base plate and the flexible rubber base and between the rubber base and the pavement surface.

Field Permeamater No. 4 (FP4)

As can be seen in Figure 4.4, FP4 is very similar in appearance to FP2. The major difference is that silicone-rubber caulk is used to seal the device to the pavement instead of paraffin. Sealing FP4 to the pavement with the caulk is a little more difficult than for FP1 and FP3. Because the bottom of the permeameter does not have a baseplate, the sealant must be carefully placed. Based on the preliminary work by NCAT with FP4, it was decided that best results were found when sealing along the inside and outside of the permeameter base. Because the top cap of the permeameter is removable, placing the sealant along the inside of the base mold can be achieved. However, because the sealant is placed along the inside of the base mold, the effective area through which water can enter the pavement is slightly reduced.

Figure 4.4. Field Permeameter No. 4

Laboratory Permeameter

The laboratory permeameter used for this study is commercially sold by Karol-Warner. This apparatus is essentially the second generation of the laboratory permeameter developed by FDOT (5). One of the primary differences between the Karol-Warner device and the FDOT permeameter is that the Karol-Warner device uses air pressure exerted onto a rubber membrane to seal flow paths along the sides of a test sample instead of the epoxy used by the FDOT method. Currently no standardized test procedure is available for the Karol-Warner permeameter; however, a task group under the ASTM Subcommittee D 04.23, "Plant-mixed Bituminous Surfaces and Bases" is in the process of developing a standardized test procedure. Both NCAT and FDOT are involved in the task group. A standardized test procedure was developed for this study based partly upon work by the task group. This procedure is provided in Appendix B.

CHAPTER 5 - TEST RESULTS AND ANALYSIS

INTRODUCTION

Field permeability tests were conducted in Mississippi, Virginia, and South Carolina. In each of these states, two separate sections were tested. This resulted in 20 field permeability tests with each permeameter for each state. In addition, five cores were tested for laboratory permeability for each section resulting in 10 laboratory permeability measurements per state. This chapter presents the results of this testing and the analysis of that data.

TEST RESULTS

The first project in which testing was conducted was in Mississippi. Each of the four permeameters were brought for testing. However, it was quickly determined that FP2 could not be used. Recall that FP2 was the device that used paraffin to seal the permeameter to the pavement surface. Apparently, during the heat of the day the pavement surface was hot enough so that even though the paraffin seemed solid, next to the pavement surface the paraffin was still in a semi-liquid state. This resulted in not being able to achieve an adequate seal. The water head within the permeameter would blow the seal. After these problems, FP2 was no longer investigated.

Results of the field permeability testing from Mississippi with the three remaining field devices (FP1, FP3, and FP4) are presented in Table 5.1. This table presents the permeability values for each test location within both sections.

Initial observation of the data seems to indicate that all three field devices are showing similar permeability values. Collectively, the section 1 permeability values are less than those for section 2. Field permeameter No. 1 does however appear to provide larger permeability values, especially for section 2.

In order to evaluate laboratory permeability for these sections, cores were obtained. Results of the laboratory permeability testing on these cores are provided in Table 5.2. Again, this table presents the results based on the section and location from which the cores were obtained.

This laboratory permeability data seems to correlate well with the field permeability values, especially for FP3 and FP4. Figures 5.1 and 5.2 present the field and laboratory permeability values for section 1 and section 2, respectively.

Figure 5.1 indicates that the field permeameters may be slightly underestimating the laboratory permeability. Generally, the laboratory values are higher than the field values; however, neglecting the one low value for FP3 at location 16 most of the test data (laboratory and field) do appear to lie within one order of magnitude. Figure 5.2 shows that the field permeameters overestimated the laboratory results. Field results with FP1 appear to be approximately one order of magnitude higher than the laboratory results. The other two field devices did produce collectively higher permeability values (though less than one order of magnitude) but do seem to correlate with the laboratory results.

The second project visited was in Virginia. Results from the field permeability testing are presented in Table 5.3. For section 1, FP1 and FP3 appear to be showing the same trend in permeability. Both show increasing permeability with the increasing location number. Collectively, all three field permeameters seem to show that section 2 was less permeable than section 1.

Table 5.1. Results of Field Permeability Testing From Sections in Mississippi

FP1			FP3			FP4		
Sect.	Location	Permeability $x10^{-5}$ cm/sec	Sect.	Location	Permeability $x10^{-5}$cm/sec	Sect.	Location	Permeability $x10^{-5}$ cm/sec
1	4	1038	1	1	805	1	2	386
	8	284		5	261		6	648
	9	135		10	278		12	89
	13	380		16	11		14	418
	17	332		18	403		19	392
	23	286		21	405		22	249
	26	393		27	539		25	314
	31	94		30	178		29	801
	33	565		36	853		35	140
	39	418		37	368		40	326
2	3	17354	2	2	4635	2	1	2898
	8	7046		7	1253		5	2005
	10	16314		11	2052		9	4356
	15	4748		16	4742		13	2895
	18	9044		20	4160		17	1372
	21	16241		21	3161		22	2171
	28	13716		27	5334		25	3827
	32	28303		29	4478		31	3907
	34	26993		35	5979		33	4339
	37	24689		39	15263		38	7723

Table 5.2. Results of Laboratory Permeability Testing for Sections in Mississippi

Section	Location	Permeability $x10^{-5}$ cm/sec
1	1	885
	9	1706
	20	582
	31	674
	40	848
2	1	1435
	9	1020
	20	1104
	31	4698
	40	5420

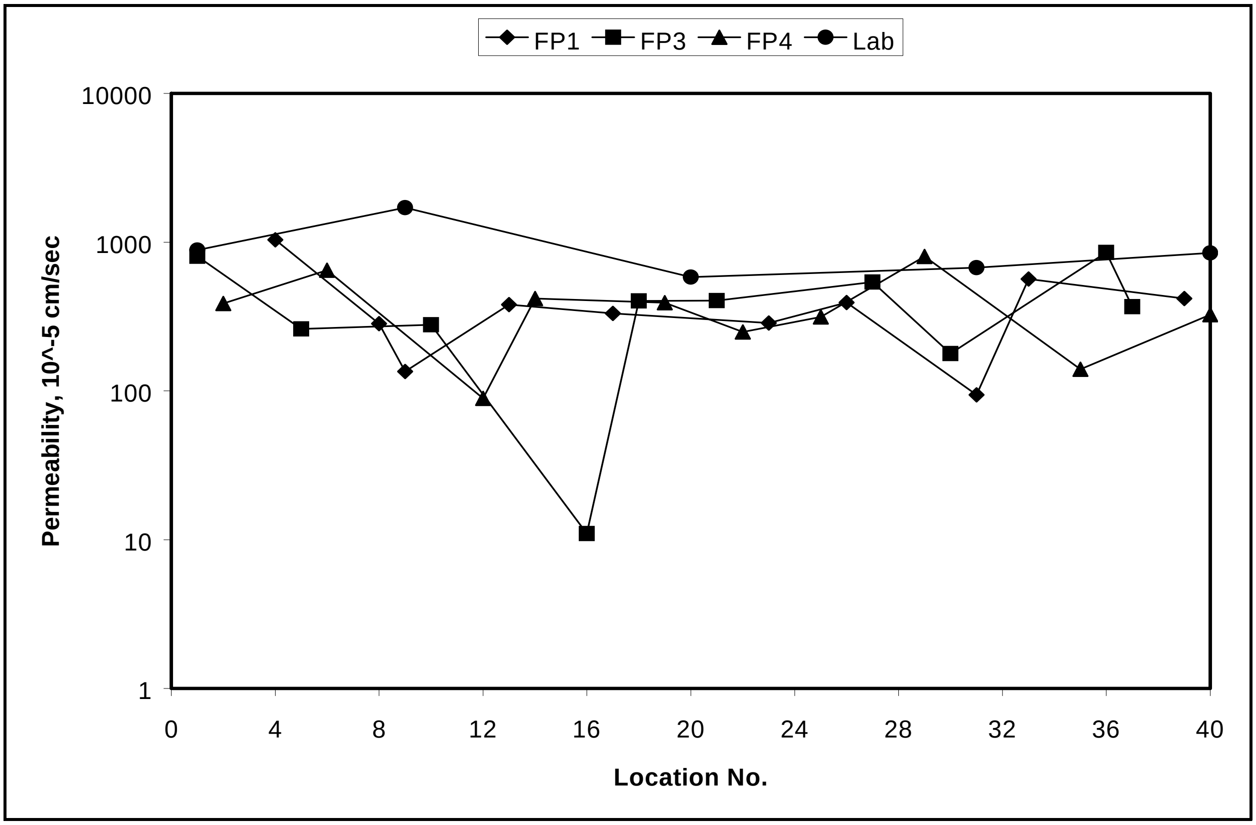

Figure 5.1. Permeability Results for Section 1 in Mississippi

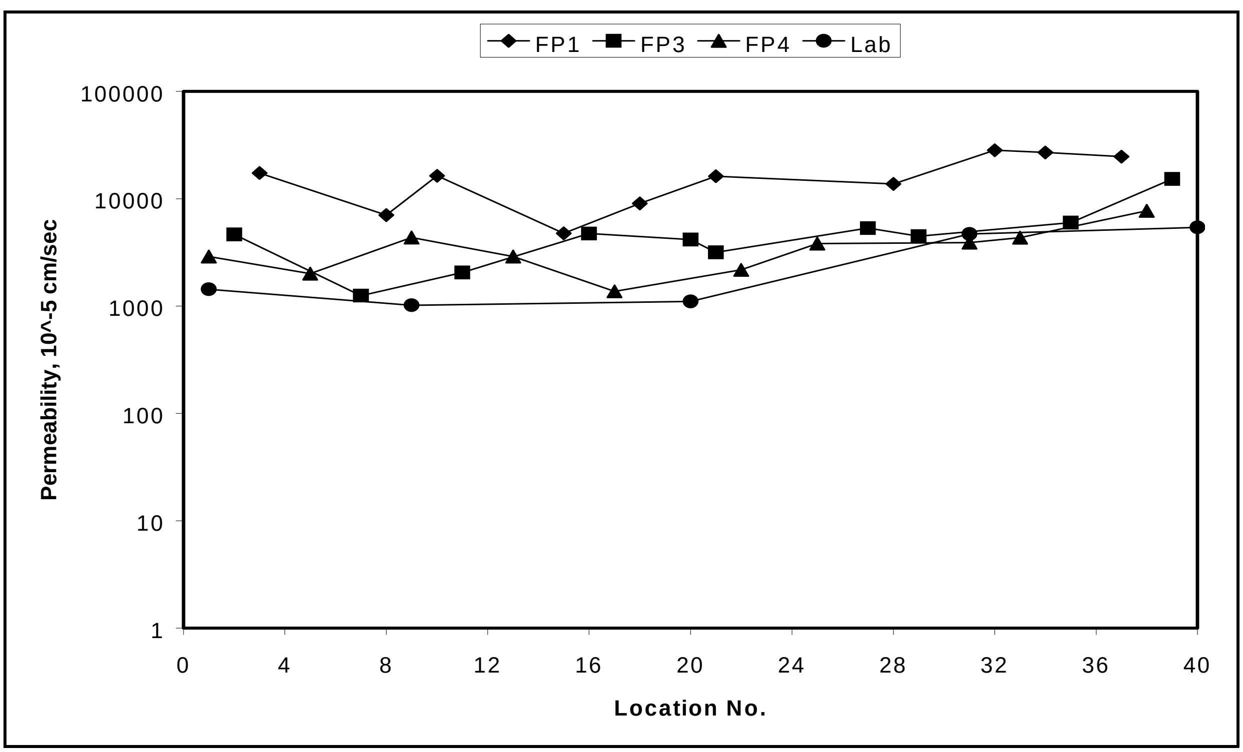

Figure 5.2. Permeability Results for Section 2 in Mississippi

Table 5.3. Results of Field Permeability Testing From Sections in Virginia

FP1			FP3			FP4		
Sect.	Location	Permeability $x10^{-5}$ cm/sec	Sect.	Location	Permeability $x10^{-5}$cm/sec	Sect.	Location	Permeability $x10^{-5}$ cm/sec
1	3	599	1	4	848	1	2	1030
	8	1101		7	672		6	548
	9	746		10	622		12	475
	13	803		15	871		14	370
	19	1126		18	960		17	467
	24	5027		21	1764		23	765
	25	3096		26	2068		28	706
	30	2919		29	2750		32	659
	34	4099		36	2942		33	765
	39	1859		40	2974		38	533
2	2	499	2	4	54	2	1	509
	6	175		5	224		7	260
	10	143		12	115		11	189
	13	582		16	239		15	202
	20	1083		17	259		19	235
	24	380		23	279		21	200
	26	507		28	694		27	498
	32	642		29	694		31	355
	33	1060		34	543		35	353
	38	816		40	442		39	918

Table 5.4 presents the laboratory permeability test results for the Virginia project. Similar to the field data, it appears that the laboratory data indicates that section 2 was less permeable than section 1.

Figures 5.3 and 5.4 graphically present the test results from Virginia for section 1 and section 2, respectively. Both figures seem to indicate that all three field devices follow the same trend as the laboratory results. The majority of test results with the field devices fall within one order of magnitude of the laboratory results.

The final project visited was in South Carolina. Results of the field permeability testing for this project are presented in Table 5.5. Results using FP1 appear to be significantly higher than the results from the other two field devices. Table 5.6 presents the results of the laboratory permeability testing. Figures 5.5 and 5.6 present results for the field and laboratory testing for each location. Figure 5.5 illustrates the results for section 1. Based on this figure, FP3 and FP4 appear to provide similar results as the laboratory device. They also appear to follow the same general trend as the laboratory data. Figure 5.6 illustrates the results for section 2. Again, FP3 and FP4 seem to provide similar test results as the laboratory device. However, FP4 appears to follow the trend of the laboratory data better.

Table 5.4. Results of Laboratory Permeability Testing for Sections in Virginia

Section	Location	Permeability x10^{-5} cm/sec
1	1	1598
	9	1316
	20	1067
	31	1501
	40	1218
2	1	1664
	9	529
	20	120
	31	255
	40	314

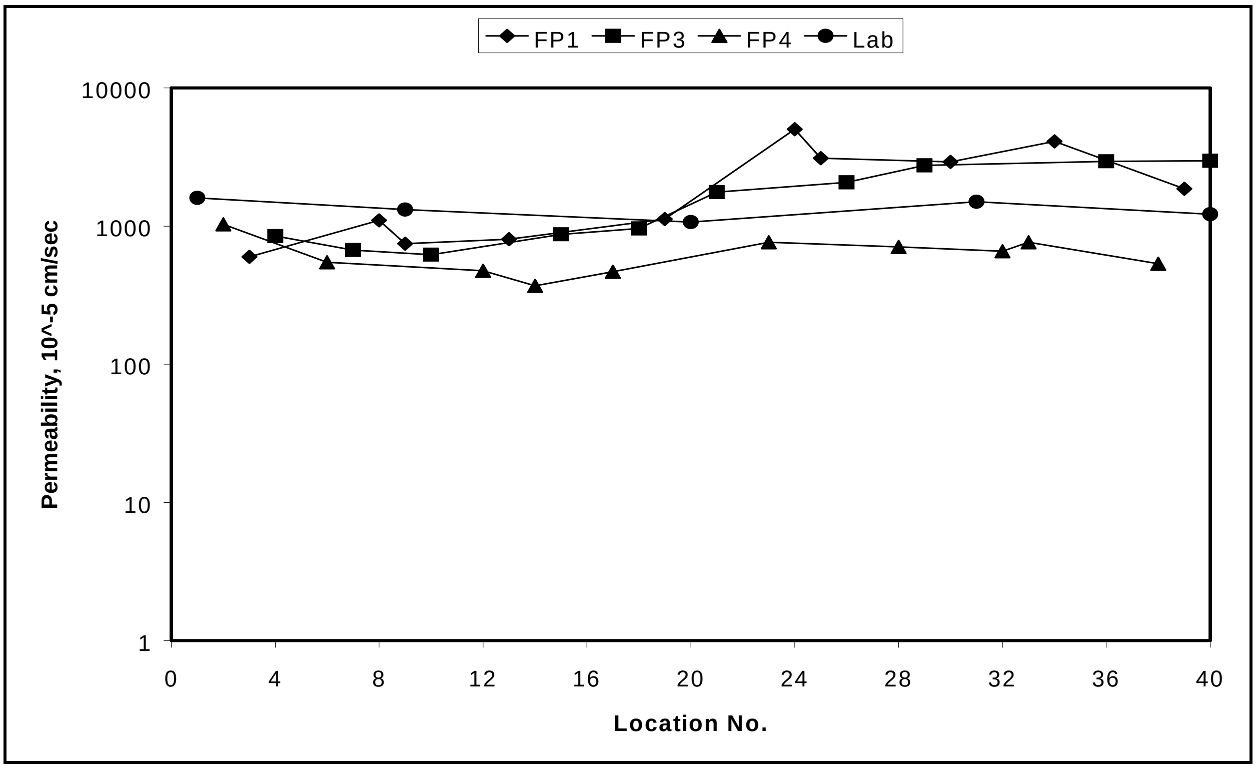

Figure 5.3. Permeability Results for Section 1 in Virginia

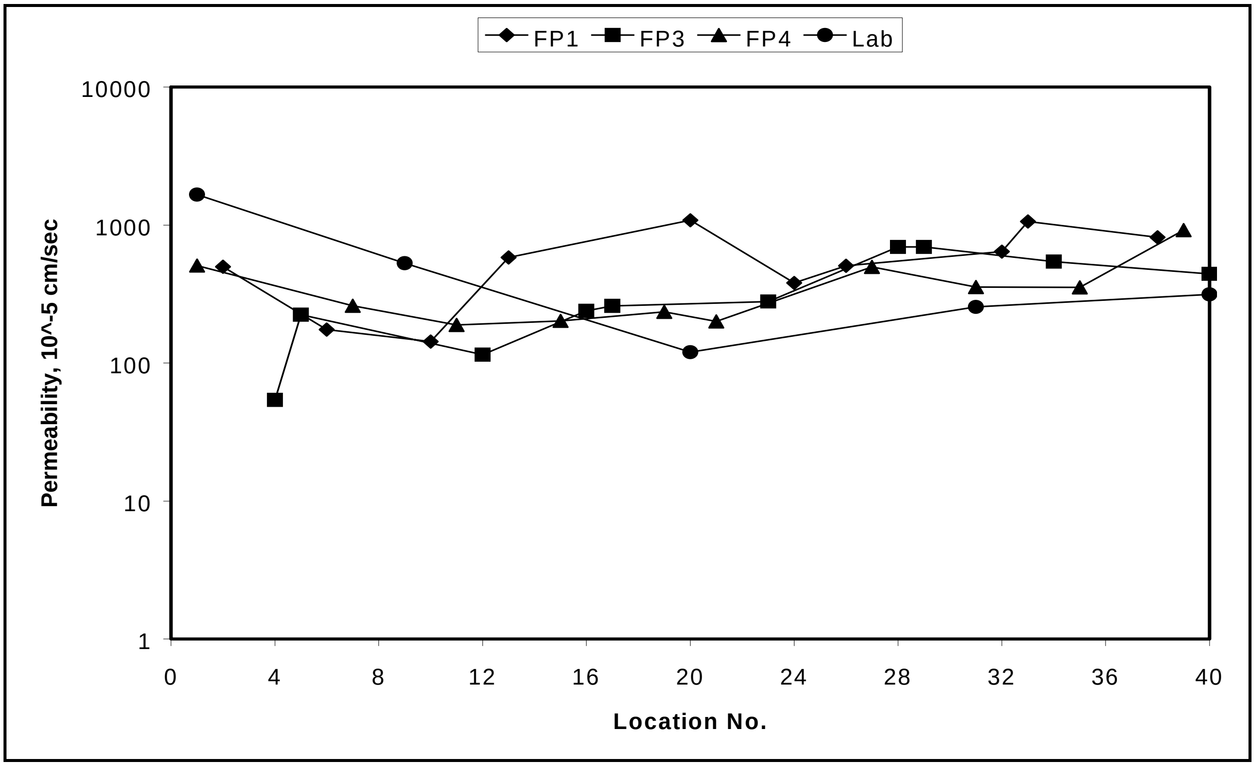

Figure 5.4. Permeability Results for Section 2 in Virginia

Table 5.5. Results of Field Permeability Testing From Sections in South Carolina

FP1			FP3			FP4		
Sect.	Location	Permeability x10^{-5} cm/sec	Sect.	Location	Permeability x10^{-5}cm/sec	Sect.	Location	Permeability x10^{-5} cm/sec
1	3	10839	1	1	7069	1	4	4222
	6	14222		5	4077		7	4207
	9	12425		11	7448		12	4127
	13	8753		16	5183		15	2722
	20	14394		17	3512		18	5396
	23	14232		21	3632		24	1821
	28	10886		26	3744		27	1857
	32	10674		31	2712		30	2122
	33	16583		35	6137		34	1548
	37	10762		38	8354		40	1306
2	4	18660	2	3	3191	2	2	2440
	5	15080		7	3278		6	1921
	12	16221		10	3894		9	1910
	16	8906		15	2313		14	1169
	20	6635		17	2107		19	1148
	23	5188		21	1150		22	1511
	26	1636		25	290		28	2575
	30	966		31	198		29	1441
	35	3253		36	246		34	1447
	38	3129		39	236		37	1473

Table 5.6. Results of Laboratory Permeability Testing for Sections in South Carolina

Section	Location	Permeability x10^{-5} cm/sec
1	1	2645
	9	2203
	20	2836
	31	2602
	40	1540
2	1	1254
	9	1686
	20	1132
	31	733
	40	1065

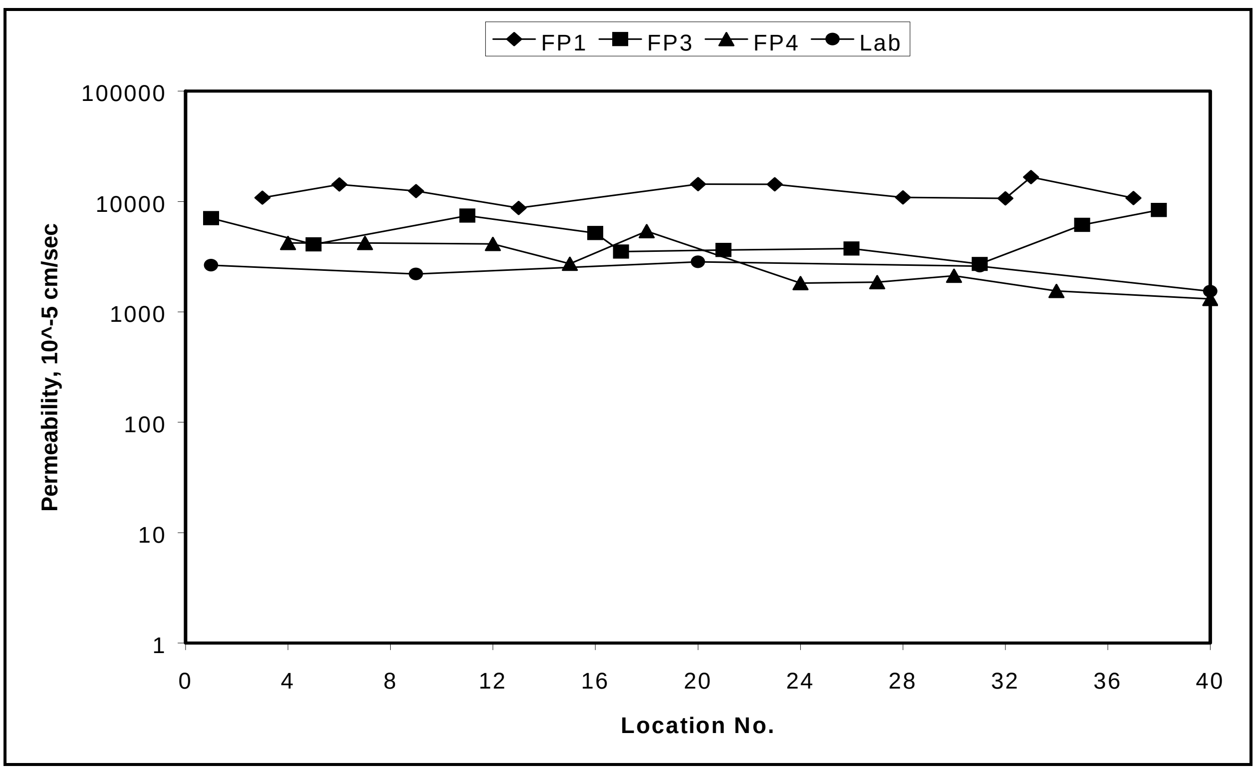

Figure 5.5. Permeability Results for Section 1 in South Carolina

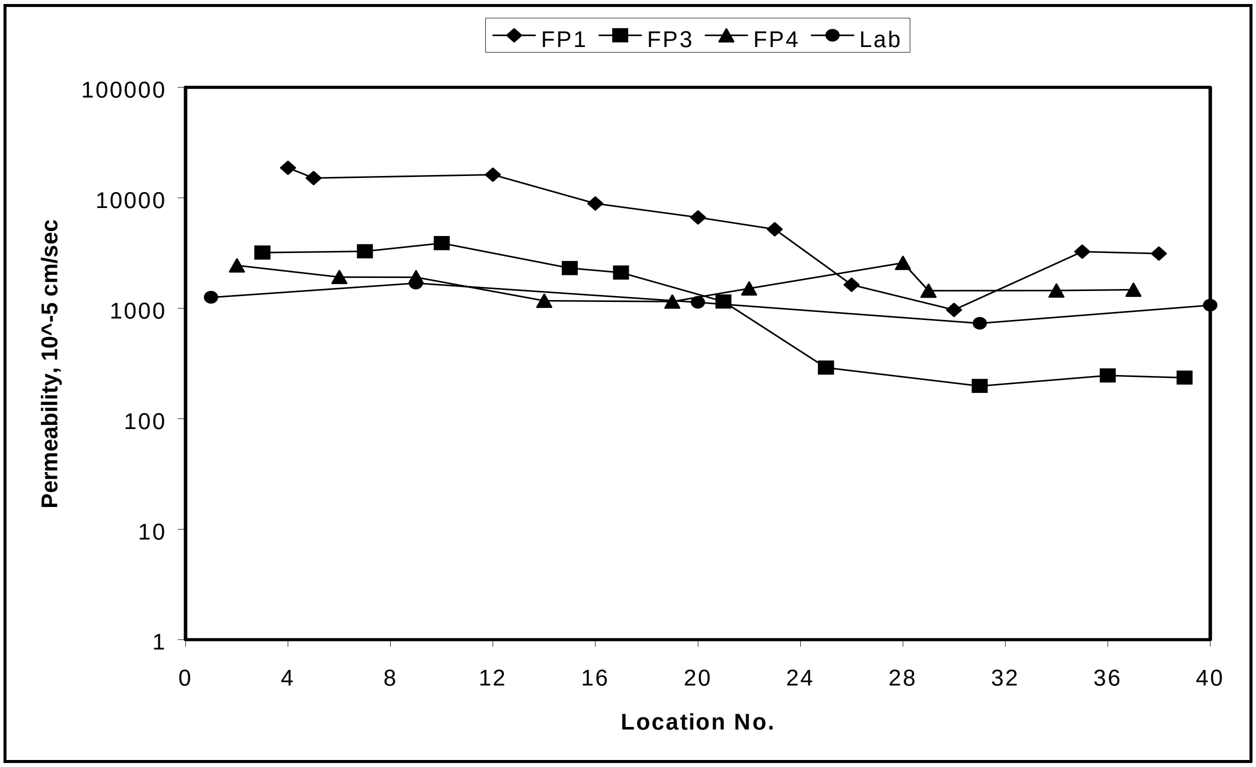

Figure 5.6. Permeability Results for Section 2 in South Carolina

ANALYSIS OF DATA

Based on the field and laboratory test results, one of the four field devices was to be selected based upon three criteria: correlation with the laboratory permeameter, repeatability, and ease of use. The most subjective of these criteria was the ease of use. Clearly, the hardest permeameter to use was FP2 (the one that used paraffin). Not only was it the hardest device to use, it could also not be used in the field, as described previously. The easiest device to use was FP1. To seal FP1 to the pavement surface the sealant was placed onto the bottom plate of the permeameter. The next easiest device was FP3. Sealing this device to the pavement surface was very similar to FP1 but sealant had to be placed on the top and bottom of the rubber base. Though not the most difficult to use, FP4 is relative time consuming compared to FP1 and FP3. The sealant must be very carefully placed on both the inside and outside of the permeameter base. This method took some trial and error in determining the best method of sealing. Based on this discussion, the following ranking of the permeameters for ease of use was obtained. A ranking of 1 suggests the easiest device to use and a ranking of 4 implies the hardest device.

Device	Ranking
FP1	1
FP3	2
FP4	3
FP2	4

The second selection criteria to be discussed is the correlation of the different field permeameters with the laboratory device. Because each of the permeameters used a sealant, cores could not be obtained for laboratory testing at the same location field tests were conducted. Therefore, correlation with the laboratory device was based on significant differences between the data accumulated with the different field permeameters and the laboratory test results. An analysis of variance (ANOVA) was selected to determine the significant differences. For this analysis, all of the data from each state was used, therefore the source of variation was the type permeameter used (the three field and laboratory devices). Table 5.7 presents the results of this analysis.

Table 5.7. Results of ANOVA To Determine Significant Differences

Source	DF	F-stat	Probability > F-stat	Significant Difference?
Permeameter	3	17.22	0.001	Yes

Table 5.7 shows that there were significant differences between the results for the four permeability devices (three field and laboratory). Because of these differences, a Duncan's Multiple Range Test (DMRT) was performed to determine if any of the devices provided test results that were not significantly different. Results of this analysis are presented in Table 5.8.

Table 5.8. Results of DMRT Ranking for All Data

Permeameter	Average Permeability ($x10^{-5}$ cm/sec)	DMRT Ranking*
FP1	6653	A
FP3	2399	B
FP4	1594	B
Lab	1522	B

* Means with the same letter are not significantly different.

Table 5.8 shows that FP1 was significantly different than the other three permeameters. This suggests that permeability tests conducted with both FP3 and FP4 were not significantly different than results obtained with the laboratory device.

To better differentiate whether FP3 or FP4 correlated better with the laboratory device, DMRT rankings were performed for each project section tested. Recall that two sections were tested for each project; therefore, a total of six rankings were performed in this analysis. Because of the significant differences shown in Table 5.8, the FP1 data was not included in this analysis. Table 5.9 presents the results of this analysis.

Table 5.9 shows that significant differences between the three permeameters used in the analysis only occurred for three of the six sections. For section 1 in Mississippi, the laboratory data was significantly different than results for the two field devices. For section 1 in South Carolina, FP3 values were significantly different than the laboratory and FP4 results. For section 1 in Virginia, FP4 results were significantly different than the laboratory and FP3 results. This is interesting because each of the three devices included in the analysis showed significant differences with the other two devices only once. This suggests that both field devices were fairly well correlated with the laboratory permeameter. Based on the analyses performed to determine the correlation between field devices and the laboratory device, it appears that both FP3 and FP4 correlate well. FP1 should not be considered. Referring back to Figures 5.1 through 5.6, this conclusion appears to be correct.

The final selection criteria was the repeatability. Because each of the test locations on which the field devices were tested were randomly selected on a longitudinal line within each section tested, the standard deviations for each device should provide an indication of repeatability. Table 5.10 presents the averages, standard deviations, and coefficient of variations for FP3, FP4, and the laboratory permeameter for each section tested.

Table 5.9. DMRT Rankings for Each Section Using FP3, FP4, and Laboratory Data

Project	Section	Permeameter	Avg. Permeability (x 10^{-5} cm/sec)	Ranking*
MS	1	Lab	939	A
		FP3	410	B
		FP4	376	B
	2	FP3	5106	A
		FP4	3549	A
		Lab	2735	A
SC	1	FP3	5186	A
		FP4	2932	B
		Lab	2365	B
	2	FP4	1703	A
		FP3	1690	A
		Lab	1174	A
VA	1	FP3	1647	A
		Lab	1340	A
		FP4	631	B
	2	Lab	576	A
		FP4	372	A
		FP3	354	A

* Means with the same letter are not significantly different.

When evaluating the repeatability of the different field devices, the standard deviation of the laboratory permeability test results must be considered. Ideally, the standard deviation of the field devices would be identical to the lab device. The COV was included in Table 5.10 to normalize the standard deviations. Coefficient of variation is defined as the standard deviation divided by the average and expressed as a percentage. Based on the COVs presented in Table 5.10, it is unclear which field permeameter shows similar repeatability to the laboratory test results. For some sections the COV for FP3 is closer to the laboratory COV while for some FP4 is closer. Therefore, it appears that FP3 and FP4 have approximately the same repeatability.

Table 5.10. Averages and Standard Deviations on Permeameters for Each Section

Project	Section	Permeameter	Avg. Perm. (x 10^{-5} cm/sec)	St. Dev.	COV
MS	1	FP3	410	263	64
		FP4	376	215	57
		Lab	939	446	48
	2	FP3	5106	3853	75
		FP4	3549	1788	50
		Lab	2735	2142	78
SC	1	FP3	5187	1951	38
		FP4	2933	1431	49
		Lab	2365	516	22
	2	FP3	1690	1448	86
		FP4	1704	496	29
		Lab	1174	345	29
VA	1	FP3	1647	975	59
		FP4	632	194	31
		Lab	1340	214	16
	2	FP3	354	228	64
		FP4	372	225	61
		Lab	576	626	109

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on the analysis of the data accumulated during the conduct of this study, the selection of a field permeameter that correlates best to the laboratory permeability device, is repeatable, and is easy to use basically comes down to FP3 and FP4. Neither of these permeameters showed significant differences with the laboratory device and both had approximately the same repeatability. Therefore, the selection criteria that must be used for the selection of a field permeameter is ease of use. Based on this criteria, FP3 is selected. Based on the experiences with the three field permeameters, FP3 was the second easiest to use. FP1 was the easiest but did not correlate with the laboratory device. A standard procedure for using FP3 is provided in Appendix A.

RECOMMENDATIONS

Based upon the results of this study a field permeameter was selected that was correlated to laboratory test results, repeatable, and easy to use. It is recommended that several minor modifications be made to the selected permeameter and another field study be performed to determine what factors influence the permeability of Superpave designed pavements. One modification envisioned is to make the rubber base plate permanent on the bottom of the permeameter. This would negate the need for applying sealant in two places. Another possible modification would be to increase the mass of the weight used with this device. Because of the rubber base plate utilized with this device, the added mass would better push the sealant into the pavement surface voids leading to a more repeatable seal.

The field study should have two main objectives. First, factors should be identified that influence the permeability of Superpave designed pavements. Tentatively, factors such as gradation type (above, below, or through the restricted zone), nominal maximum aggregate size, air void content, roller type (static steel wheel, vibratory, or pneumatic tire), lift thickness, etc. should be evaluated. Secondly, using the information obtained from the field study, it should be determined at what air void content Superpave designed pavements become excessively permeable. This type of information would be valuable in evaluating current density requirements.

At the conclusion of the field study, each participating state should receive the final version of the selected field permeameter. This will allow each state to evaluate particular points of interest concerning the permeability of pavements. In addition, a set of detailed blue prints of the selected field device should be included in the final report. This will allow commercial vendors to build the device.

ACKNOWLEDGMENTS

The author would like to thank the member states of the Southeastern Superpave Center. Without their participation, this study could not have been accomplished.

REFERENCES

1. Roberts et.al, Hot Mix Asphalt Materials, Mixture Design, and Construction, NAPA Education Foundation, Lanham, Maryland, Second Edition, 1996.
2. Zube, E., "Compaction Studies of Asphalt Concrete Pavements as Related to the Water Permeability Test," Highway Research Board, Bulletin 358, 1962.
3. Brown, E.R., R. Collins, and J.R. Brownfield, "Investigation of Segregation of Asphalt Mixtures in the State of Georgia," Transportation Research Record 1217, 1989.
4. Choubane, B., G.C. Page, and J.A. Musselman, " Investigation of Water Permeability of Coarse Graded Superpave Pavements," Preprint, Annual Meeting and Technical Sessions of the American Association of Asphalt Paving Technologists, March 16-18, 1998.
5. Florida Department of Transportation, "Florida Method of Test for Water Permeability of Compacted Asphalt Paving Mixtures," February 1997.
6. Georgia Department of Transportation, Standard Specifications for Road and Bridge Construction, 1993 Edition.
7. Holtz, R.D. and W.D. Kovacs, An Introduction to Geotechnical Engineering, Prentice Hall, Englewood Cliffs, New Jersey, 1981.
8. Das, B.M., Advance Soil Mechanics, Hemisphere Publishing Corporation, 1983.
9. Olson, R.E. and D.E. Daniel, "Measurement of the Hydraulic Conductivity of Fine-Grained Soils," Permeability and Groundwater Containment Transport, ASTM STP 746, T.F. Zimmie and C.O. Riggs, Eds., American Society for Testing and Materials, 1981.
10. Ford, M.C. and C.E. McWilliams, "Asphalt Mix Permeability," University of Arkansas, Fayetteville, Arkansas, 1988.
11. Hudson, S.B. and R.L. Davis, "Relationship of Aggregate Voidage to Gradation," Association of Asphalt Paving Technologists, Volume 34, 1965.
12. James, J.M., "Asphalt Mix Permeability," FHWA/AR-88/003, September 1965.
13. McLaughlin, J.F. and W.H. Goetz, "Permeability, Void Content, and Durability of Bituminous Concrete," Proceedings, Highway Research Board, Volume 34, 1955.

APPENDIX A

Field Estimation of Water Permeability of Compacted Asphalt Paving Mixtures Field Permeameter No. 1

1. Scope

1.1 This test method covers the in-place estimation of the water permeability of a compacted hot mix asphalt (HMA) pavement. The estimate provides an indication of water permeability of a pavement location as compared to those of other pavement locations.

1.2 The values stated in metric (SI) unit are regarded as standard. Values given in parenthesis are for information and reference purposes only.

1.3 This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Summary of Test Method

2.1 A falling head permeability test, as shown in Figure 1, is used to estimate the rate at which water flows into a compacted HMA pavement. Water from a graduated standpipe is allowed to flow into a compacted HMA pavement and the interval of time taken to reach a known change in head loss is recorded. The coefficient of permeability of a compacted HMA pavement is then estimated based on Darcy's Law.

3. Significance and Use

3.1 This test method provides a means of estimating water permeability of compacted HMA pavements. The estimation of water permeability is based upon assumptions that the sample thickness is equal to the immediately underlying HMA pavement course thickness; the area of the tested sample is equal to the area of the permeameter from which water is allowed to penetrate the HMA pavement; one-dimensional flow; and laminar flow of the water. It is assumed that Darcy's law is valid.

4. Apparatus

4.1 *Hand broom* - A broom of sufficient stiffness to sweep a test location free of debris.

4.2 *Timing Device* - A stopwatch or other timing device graduated in divisions of 1.0 seconds.

4.3 *Sealant* - A silicone-rubber caulk to seal the permeameter to the pavement surface.

4.4 *Field Permeameter* - A field permeameter made to the dimensions and specifications shown in Figure A.1.

5. Preparation of Pavement Surface

5.1 Prior to conducting the test, a broom should be used to remove all debris from the pavement surface. Debris left on the pavement surface can hinder the sealing of the permeameter to the pavement surface.

6. Test Procedure

6.1 Permeameter Setup

6.1.1 Turn the permeameter upside down so that the bottom of the plastic, circular base plate is facing upwards. Place sealant onto the bottom plastic, circular baseplate.

6.1.2 Invert the permeameter and place onto the pavement surface. Push the permeameter onto the pavement surface in order for the sealant to penetrate the surface voids of the pavement.

6.1.3 Place the weight over the standpipe onto the plastic, circular base plate.

6.1.4 Allow one minute for the sealant to partially set up.

6.2 Pavement Saturation

6.2.1 Fill the standpipe approximately half full with water.

6.2.2 Allow the water to remain in the standpipe for not less than one minute. It may be necessary to add water to keep the water leel approximately half full within the standpipe.

6.3 To start the test, introduce water into the standpipe to just above the desired initial head.

6.4 When the water level is at the desired initial head, start the timing device. Stop the timing device when the water level within the standpipe reaches the desired final head. Record the initial head, final head, and time interval between the initial and final head.

7. Calculation

7.1 The coefficient of permeability, k, is estimated using the following equation:

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

Where: k = coefficient of permeability, cm/sec
a = inside cross sectioned area of standpipe, cm^2
L = thickness of underlying HMA course, cm
A = cross-sectioned area of permeameter through which water can penetrate the pavement, cm^2
t = elapsed time between h_1 and h_2
h_1 = initial head on the pavement location, cm
h_2 = final head on the pavement location, cm

7.2 Report results for k to the nearest whole units x 10^{-5} cm/s.

Figure A.1: Field Permeameter No. 1

Field Estimation of Water Permeability of Compacted Asphalt Paving Mixtures Field Permeameter No. 2

1. Scope

1.1 This test method covers the in-place estimation of the water permeability of a compacted hot mix asphalt (HMA) pavement. The estimate provides an indication of water permeability of a pavement location as compared to those of other pavement locations.

1.2 The values stated in metric (SI) unit are regarded as standard. Values given in parenthesis are for information and reference purposes only.

1.3 This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Summary of Test Method

2.1 A falling head permeability test, as shown in Figure 1, is used to estimate the rate at which water flows into a compacted HMA pavement. Water from a graduated standpipe is allowed to flow into a compacted HMA pavement and the interval of time taken to reach a known change in head loss is recorded. The coefficient of permeability of a compacted HMA pavement is then estimated based on Darcy’s Law.

3. Significance and Use

3.1 This test method provides a means of estimating water permeability of compacted HMA pavements. The estimation of water permeability is based upon assumptions that the sample thickness is equal to the immediately underlying HMA pavement course thickness; the area of the tested sample is equal to the area of the permeameter from which water is allowed to penetrate the HMA pavement; one-dimensional flow; and laminar flow of the water. It is assumed that Darcy’s law is valid.

4. Apparatus

4.1 *Hand broom* - A broom of sufficient stiffness to sweep a test location free of debris.

4.2 *Timing Device* - A stopwatch or other timing device graduated in divisions of 1.0 seconds.

4.3 *Sealant* - Paraffin to seal the permeameter to the pavement surface.

4.4 *Heating Unit* - A propane or similar heating unit used to melt the sealant.

4.5 *Container* - A container is needed for heating the sealant. The container should be of sufficient size to melt enough sealant for the test.

4.6 *Ladle* - A ladle or similar device is needed to dip the heated sealant from the container and pour the sealant onto the pavement surface.

4.7 *Field Permeameter* - A field permeameter made to the dimensions and specifications shown in Figure A.2.

5. Preparation of Pavement Surface

5.1 Prior to conducting the test, a broom should be used to remove all debris from the pavement surface. Debris left on the pavement surface can hinder the sealing of the permeameter to the pavement surface.

6. Test Procedure

6.1 Permeameter Set Up

6.1.1 Ensure the base mold is free from debris

6.1.2 Place the base mold onto the pavement surface.

6.1.3 Place the outside ring onto the pavement surface around the base mold. Care should be taken to center the base mold within the outside ting.

6.1.4 Heat the paraffin wax to a liquid state and pour between the base mold and outside ring. (See Note 1) The paraffin should be placed in at least three layers (See Note 2).

Note 1: For best results allow the paraffin to cool prior to pouring between the base mold and outside ring. The paraffin has sufficiently cooled when it begins to skim over at the top.

Note 2: The first layer of paraffin should be placed around the entire circumference between the base mold and outside ring. This layer should be just thick enough to cover the surface voids of the pavement. Subsequent layers of paraffin should be placed in approximately equal lifts.

6.1.5 Place weight over the standpipe onto the top cap.

6.1.6 Allow the paraffin to cool for not less than one minute. The paraffin should be stiff with a touch of the finger.

6.2 Pavement Saturation

6.2.1 Assemble the permeameter including, top cap, and standpipe.

6.2.2 Fill the standpipe to just above the top cap of the permeameter.

6.2.3 Allow the water to remain in the standpipe for not less than one minute. It may be necessary to add water to keep the water level above the top cap of the permeameter.

6.3 To start the test, introduce water into the standpipe to just above the desired initial head.

6.4 When the water level is at the desired initial head, start the timing device. Stop the timing device when the water level within the standpipe reaches the desired final head. Record the initial head, final head, and time interval between the initial and final head.

7. Calculation

7.1 The coefficient of permeability, k, is estimated using the following equation:

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

Where: k = coefficient of permeability, cm/sec
a = inside cross sectioned area of standpipe, cm^2
L = thickness of underlying HMA course, cm
A = cross-sectioned area of permeameter through which water can penetrate the pavement, cm^2
t = elapsed time between h_1 and h_2
h_1 = initial head on the pavement location, cm
h_2 = final head on the pavement location, cm

7.2 Report results for k to the nearest whole units x 10^{-5} cm/s.

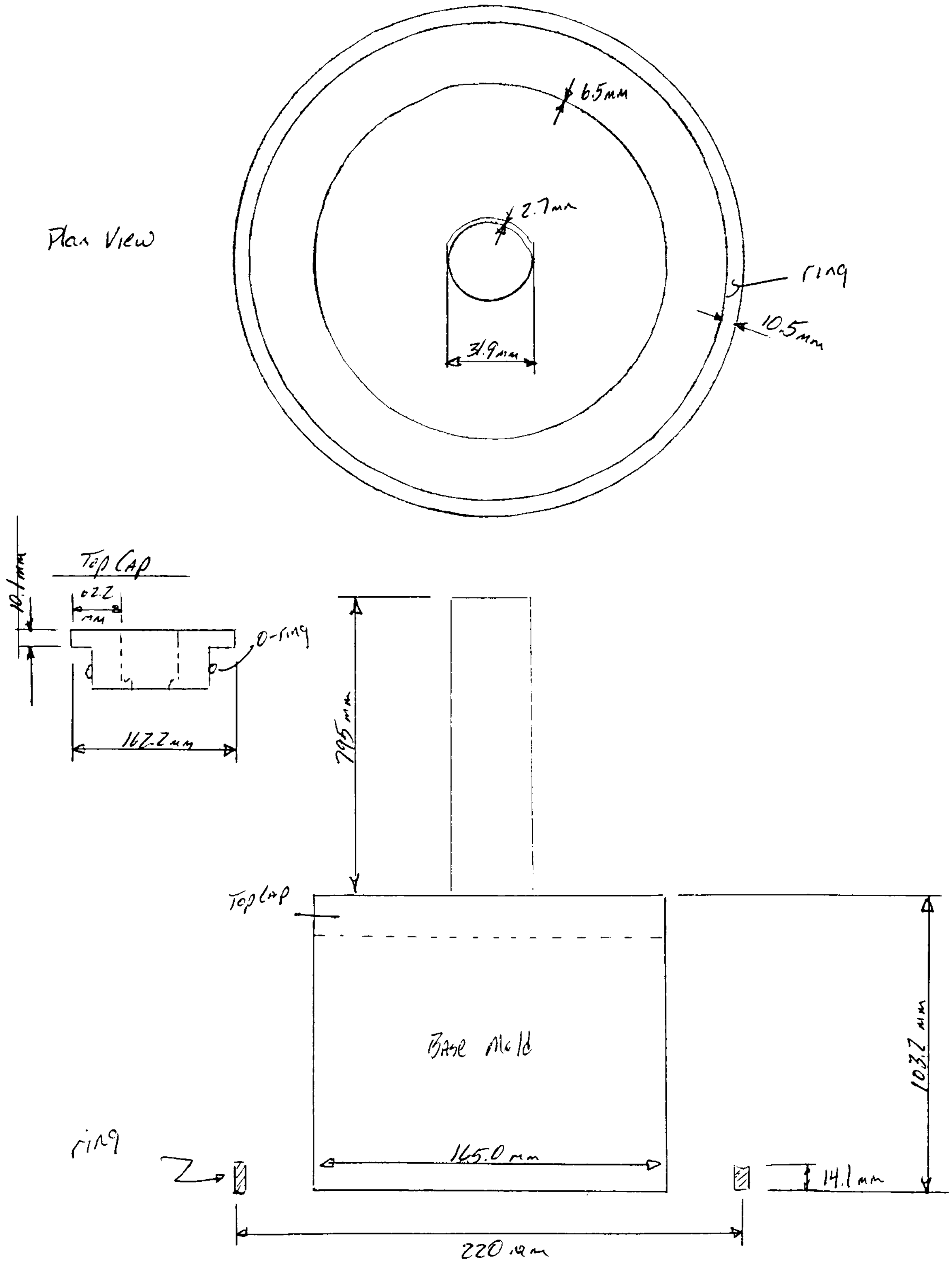

Figure A.2: Field Permeameter No. 2

Field Estimation of Water Permeability of Compacted Asphalt Paving Mixtures Field Permeameter No. 3

1. Scope

1.1 This test method covers the in-place estimation of the water permeability of a compacted hot mix asphalt (HMA) pavement. The estimate provides an indication of water permeability of a pavement location as compared to those of other pavement locations.

1.2 The values stated in metric (SI) unit are regarded as standard. Values given in parenthesis are for information and reference purposes only.

1.3 This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Summary of Test Method

2.1 A falling head permeability test, as shown in Figure 1, is used to estimate the rate at which water flows into a compacted HMA pavement. Water from a graduated standpipe is allowed to flow into a compacted HMA pavement and the interval of time taken to reach a known change in head loss is recorded. The coefficient of permeability of a compacted HMA pavement is then estimated based on Darcy's Law.

3. Significance and Use

3.1 This test method provides a means of estimating water permeability of compacted HMA pavements. The estimation of water permeability is based upon assumptions that the sample thickness is equal to the immediately underlying HMA pavement course thickness; the area of the tested sample is equal to the area of the permeameter from which water is allowed to penetrate the HMA pavement; one-dimensional flow; and laminar flow of the water. It is assumed that Darcy's law is valid.

4. Apparatus

4.1 *Hand broom* - A broom of sufficient stiffness to sweep a test location free of debris.

4.2 *Timing Device* - A stopwatch or other timing device graduated in divisions of 1.0 seconds.

4.3 *Sealant* - A silicone-rubber caulk to seal the permeameter to the pavement surface.

4.4 *Field Permeameter* - A field permeameter made to the dimensions and specifications shown in Figure A.3.

5. Preparation of Pavement Surface

5.1 Prior to conducting the test, a broom should be used to remove all debris from the pavement surface. Debris left on the pavement surface can hinder the sealing of the permeameter to the pavement surface.

6. **Test Procedure**

6.1 Permeameter Setup

6.1.1 Ensure that both sides of the square, rubber base and the bottom of the square, metal base plate are free of debris.

6.1.2 Apply sealant to one side of the square, rubber base.

6.1.3 Place the side of the square, rubber base containing the sealant onto the pavement surface. Evenly apply pressure to the top of the square, rubber base with hand pressure to force the sealant into the surface voids.

6.1.4 Apply sealant onto the bottom of the square, metal base plate.

6.1.5 Place the base mold onto the square, rubber base ensuring that the hole within the square, metal base plate lines up with the hole in the square, rubber base. Apply hand pressure onto the top cap of the base mold to force adhesion between both sides.

6.1.6 Place weight over standpipes and base mold onto square, metal base plate. Apply have pressure to weight tho finalize sealing.

6.2 Pavement Saturation

6.2.1 Fill the standpipe to just above the top cap of the permeameter.

6.2.2 Allow the water to remain in the bottom of the standpipe for not less than one minute. It may be necessary to add water to keep the water level above the top cap of the permeameter.

6.3 To start the test, introduce water into the standpipe to just above the desired initial head. (See Note 1)

Note 1: For most applications, enough water should be introduce to bring the water level to the top of the top tier standpipe.

6.4 When the water level is at the desired initial head, start the timing device. (See Note 2) Stop the timing device when the water level within the standpipe reaches the desired final head. (See Note 4) Record the initial head, final head, and time interval between the initial and final head.

Note 2: For relatively impermeable pavements, the water level will drop very slowly within the top tier standpipe. Therefore, the initial head should be taken within the top tier standpipe. Tor pavements of "medium" permeability, the water level will drop quickly through the top tier standpipe. Therefore, the initial head should be taken within the middle tier standpipe. For very permeable pavements the water level will drop very quickly through the top and middle tier standpipes but slow down when it reaches the bottom tier standpipe. Therefore, the initial head should be taken in the bottom tier standpipe.

Note 3: The initial and final head determinations should be made within the same standpipe tier.

7. Calculation

7.1 The coefficient of permeability, k, is estimated using the following equation:

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

Where: k = coefficient of permeability, cm/sec
a = inside cross sectioned area of standpipe, cm^2
L = thickness of underlying HMA course, cm
A = cross-sectioned area of permeameter through which water can penetrate the pavement, cm^2
t = elapsed time between h_1 and h_2
h_1 = initial head on the pavement location, cm
h_2 = final head on the pavement location, cm

7.2 Report results for k to the nearest whole units x 10^{-5} cm/s.

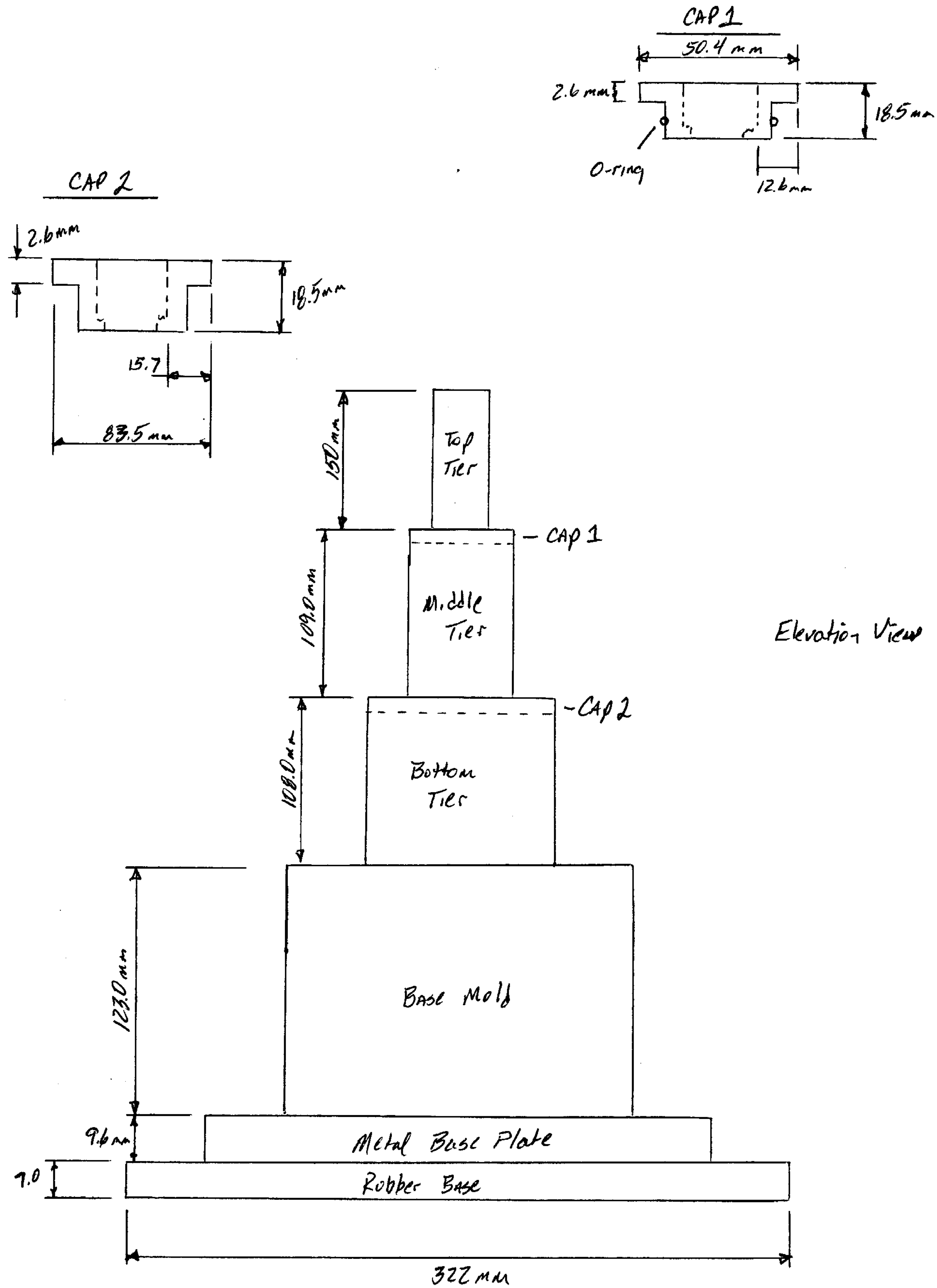

Figure A.3: Elevation View of Field Permeameter No. 3

Figure A.3 (cont.): Plan View of Field Permeameter No. 3

Field Estimation of Water Permeability of
Compacted Asphalt Paving Mixtures
Field Permeameter No. 4

1. Scope

1.1 This test method covers the in-place estimation of the water permeability of a compacted hot mix asphalt (HMA) pavement. The estimate provides an indication of water permeability of a pavement location as compared to those of other pavement locations.

1.2 The values stated in metric (SI) unit are regarded as standard. Values given in parenthesis are for information and reference purposes only.

1.3 This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Summary of Test Method

2.1 A falling head permeability test, as shown in Figure 1, is used to estimate the rate at which water flows into a compacted HMA pavement. Water from a graduated standpipe is allowed to flow into a compacted HMA pavement and the interval of time taken to reach a known change in head loss is recorded. The coefficient of permeability of a compacted HMA pavement is then estimated based on Darcy's Law.

3. Significance and Use

3.1 This test method provides a means of estimating water permeability of compacted HMA pavements. The estimation of water permeability is based upon assumptions that the sample thickness is equal to the immediately underlying HMA pavement course thickness; the area of the tested sample is equal to the area of the permeameter from which water is allowed to penetrate the HMA pavement; one-dimensional flow; and laminar flow of the water. It is assumed that Darcy's law is valid.

4. Apparatus

4.1 *Hand broom* - A broom of sufficient stiffness to sweep a test location free of debris.

4.2 *Timing Device* - A stopwatch or other timing device graduated in divisions of 1.0 seconds.

4.3 *Sealant* - A silicone-rubber caulk to seal the permeameter to the pavement surface.

4.4 *Field Permeameter* - A field permeameter made to the dimensions and specifications shown in Figure A.4.

5. Preparation of Pavement Surface

5.1 Prior to conducting the test, a broom should be used to remove all debris from the pavement surface. Debris left on the pavement surface can hinder the sealing of the permeameter to the pavement surface.

6. Test Procedure

6.1 Permeameter Setup

6.1.1 Ensure the sides of the base mold are free from debris.

6.1.2 Remove the top cap from the base mold and p;ace the base mold onto the pavement surface.

6.1.3 Place a thin bead of sealant along the inside edge of base mold at the pavement surface. Use a finger to push the sealant into the surface voids of the pavement and to evenly distribute the sealant along the bottom of the base mold. (See Note 1)

Note 1: Care should be taken not to apply too much sealant along the inside of the base mold. Any sealant along the inside edges of the base mold reduces the effective area through which water can penetrate the underlying pavement.

6.1.4 Reassemble permeameter including the top cap and the standpipe.

6.2 Pavement Saturation

6.2.1 Fill the standpipe with water till the water level is just above the top cap.

6.2.2 Allow the water to remain in the standpipe for not less than one minute. It may be necessary to add water to keep the water level above the top cap.

6.3 To start the test, introduce water into the standpipe to just above the desired initial head.

6.4 When the water level falls to the desired initial head, start the timing device. Stop the timing device when the water level within the standpipe reaches the desired final head. Record the initial head, final head, and time interval between the initial and final head.

7. Calculation

7.1 The coefficient of permeability, k, is estimated using the following equation:

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

Where: k = coefficient of permeability, cm/sec
a = inside cross sectioned area of standpipe, cm^2
L = thickness of underlying HMA course, cm
A = cross-sectioned area of permeameter through which water can penetrate the pavement, cm^2
t = elapsed time between h_1 and h_2
h_1 = initial head on the pavement location, cm
h_2 = final head on the pavement location, cm

7.2 Report results for k to the nearest whole units x 10^{-5} cm/s.

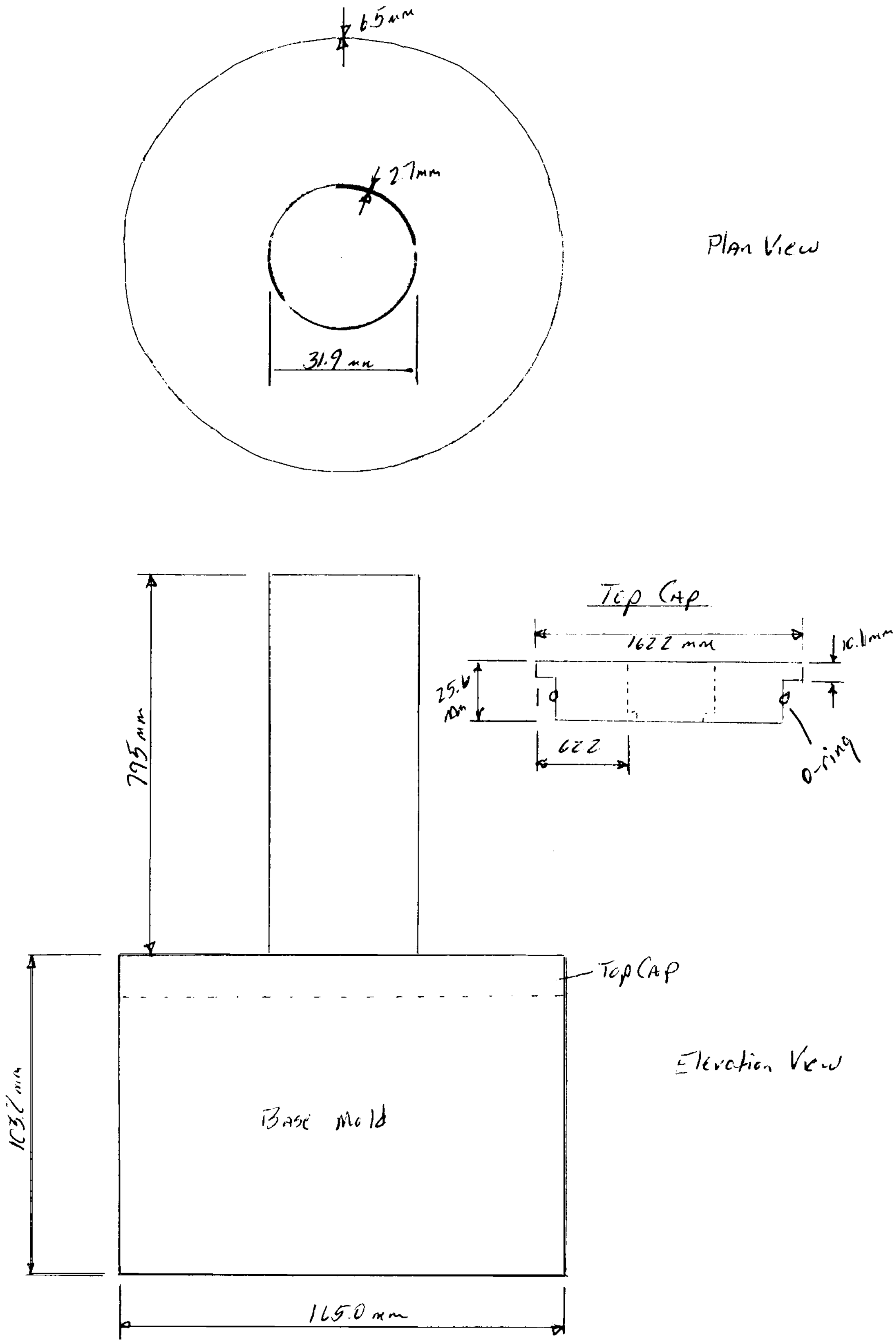

Figure A.4: Field Permeameter No. 4

Appendix B

Measurement of Water Permeability of Compacted Asphalt Paving Mixtures Using the Karol-Warner Flexible Wall Permeameter

1. Scope

1.1 This test method covers the laboratory determination of water permeability of a compacted asphalt paving mixture sample. The measurement provides an indication of water permeability of that sample as compared to those of other asphalt paving samples tested in the same manner.

1.2 The procedure uses either laboratory compacted or field cut core cylindrical specimens.

1.3 The values stated in metric (SI) units are regarded as standard. Values given in parentheses are for information and reference purposes only.

1.4 This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Reference Documents

2.1 AASHTO Standards
T166 Bulk Specific Gravity of Compacted Bituminous Mixtures
T209 Maximum Specific Gravity of Bituminous Paving Mixtures
T283 Resistance of Compacted Bituminous Mixtures to Moisture Induced Damage

3. Summary of Test Method

3.1 A falling head permeability test is used to determine the rate of flow of water through a saturated specimen. Water from a graduated standpipe is allowed to flow through the saturated asphalt paving mixture sample and the time interval to reach a known change in head is recorded. The coefficient of permeability of the compacted paving mixture is then determined based on Darcy's Law.

4. Significance and Use

4.1 This test method provides a means for determining the water permeability of water-saturated samples. It applies to one-dimensional, laminar flow of water. It is assumed that Darcy's Law is valid.

5. Apparatus

5.1 Vacuum container, Type E from T209, and vacuum pump, from T209 including manometer.

5.2 Spacer - A specimen spacer similar to that used in T283.

5.3 Balance from T166.

5.4 Supply of distilled water at 23 ± 2° C.

5.5 Sealant - petroleum jelly.

5.6 Karol-Warner laboratory permeameter shown in Figure B.1.

5.7 Timing device - A stopwatch of other timing device graduated in divisions of 1.0 seconds.

5.8 Meterstick - A measuring device graduated in 0.1 centimeters.

6. **Saturation of Test Specimens**

6.1 Determine the bulk specific gravity of the sample in accordance with T166.

6.2 Place the specimen in a horizontal position in the vacuum container supported above the container bottom by the spacer. Fill the vacuum container with distilled water so that the specimen is covered by at least 25 mm (1 inch) of water.

6.3 Remove trapped air and saturate the specimen by applying a gradually increased vacuum until the residual pressure manometer reads 28 ± 2 mm of Hg. Maintain the residual pressure for 15± 2 minutes. Manually agitate the container holding the specimen during the vacuum period by applying 12 taps of a rubber mallet (3 taps at each of 4 different location around the perimeter of the container) at 2 minute intervals.

6.4 At the end of the vacuum period, release the vacuum by slowly increasing the pressure.

6.5 Allow the specimen to stand within the vacuum container, still covered with water, for 5 to 10 minutes.

6.6 Determine and record the saturated surface dry (SSD) mass of the specimen according to T166.

6.7 After determining the SSD mass, return the specimen to the vacuum container similar to that described in 6.2.

6.8 Calculate the degree of saturation for the specimen as follows:

$$\%\ Saturation = \frac{SSD - M}{M\left(\dfrac{1}{G_{mb}} - \dfrac{1}{G_{mm}}\right)} * 100$$

Where: SSD = SSD mass of sample after vacuum conditioning, grams
M = dry mass of sample, grams
G_{mb} = bulk specific gravity of compacted specimens
G_{mm} = maximum theoretical specific gravity of specimen (T209).

6.9 If the degree of saturation is not greater than or equal to 95 percent, repeat 6.2 through 6.8 except maintain the residual pressure for 7 ± 2 minutes. Repeat these steps until 95 percent saturation is achieved

Note 1: Because of potential problems with measuring the SSD mass of coarse graded mixtures, step 6.9 should only be performed a maximum of two times.

7. Permeameter Calibration/Verification

7.1 With the permeameter completely assembled as shown in Figure 1, use the meterstick to measure a distance of 10 cm from the bottom of the outlet pipe and place a mark onto the standpipe. This mark will be designated as the lower timing mark.

7.2 Establish an upper timing mark by using the meterstick to measure a distance of 30 cm from the bottom of the outlet pipe. Place a mark at 30 cm on the standpipe.

8. Testing Procedure

8.1 Disassemble the permeameter by removing the clamp assembly and cap assembly.

8.2 Connect the pressure line on the permeameter to the vacuum quick connect. Using the pressure/vacuum pump, apply a vacuum to the sealing tube to remove entrapped air and collapse the membrane to the inside diameter of the cylinder.

8.3 Remove the specimen to be tested from the vacuum container filled with water and quickly apply a light coating of sealant to the perimeter of the specimen. Care should be exercised so that no sealant gets onto the top or bottom of the specimen.

8.4 Place the specimen onto the pedestal at the bottom of the permeameter.

8.5 Expeditiously reassemble the permeameter making sure all connections are tight.

8.6 Disconnect the pressure line from the vacuum quick-connector and connect to the pressure quick connect.

8.7 Apply a confining pressure of 117 ± 13.8 kPa (17 ± 2 psi).

8.8 Place a tared pan or measure having a minimum capacity of 1000 ml underneath the outlet pipe in order to catch the water exiting the outlet pipe.

8.9 Fill the permeameter standpipe to the upper timing mark with distilled water. Exercise care when filling to minimize the incorporation of air bubbles. Use of rubber tubing and a clamp will facilitate the filling operation.

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

8.11 Commence the water flow by opening the valve on the base of the outlet pipe. Allow water to flow until it begins to exit the outlet pipe. Once the water begins to exit the outlet pipe, close the valve on the base of the outlet pipe.

8.12 Refill the standpipe to the upper timing mark. Remove water from tared pan or measure and replace.

8.13 Commence the flow of water by opening the valve on the base of the outlet pipe. Simultaneously start the timing device.

8.14 Observe the water flow through the standpipe and record the time needed for the water level to fall from the upper timing mark to the lower timing mark. Once the water reaches the lower timing mark immediately close the valve at the base of the outlet pipe.

8.15 Determine the mass of water captured in the tared pan or measure. Determine the volume of water flowing through the sample as follows:

$$Volume\ of\ water\ =\ \frac{\pi\ d^2}{4}\ *\ D$$

Where: d = diameter of standpipe, cm
D = distance between upper and lower timing mark, cm

8.16 Determine the beta factor by determining the percent of water flowing through the sample that was captured in the tared pan or measure as follows:

$$\mathrm{B}\ Factor\ =\ \frac{W_t}{W_f}\ *\ 100$$

Where: W_t = water captured in the tared pan or measure, gram
W_f = water flowing through sample, cm^3

8.17 If the beta factor is below 95 percent, the specimen is not saturated sufficiently. If below 95 percent repeat 8.12 through 8.16. If the beta factor is below 95 percent again, go back to section 6 and repeat through 8.16.

8.18 If the beta factor is 95 percent or above, repeat 8.12 through 8.14 three additional times. Use the average time of three consecutive tests to compute permeability.

9. Calculation

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

$$k\ =\ \frac{al}{At}\ \ln\left(\frac{h_1}{h_2}\right)$$

Where: k = coefficient of permeability, cm/s
a = inside cross-sectional area of standpipe, cm^2
L = thickness of test specimen, cm
A = cross-sectioned area of test specimen, cm^2
t = average elapsed time water flowed between timing marks, s
h_1 = initial head at upper timing mark, cm
h_2 = final head at lower timing mark, cm

10. Report

10.1 For each sample, the coefficient of permeability is reported in whole units x 10^{-5} cm/s.

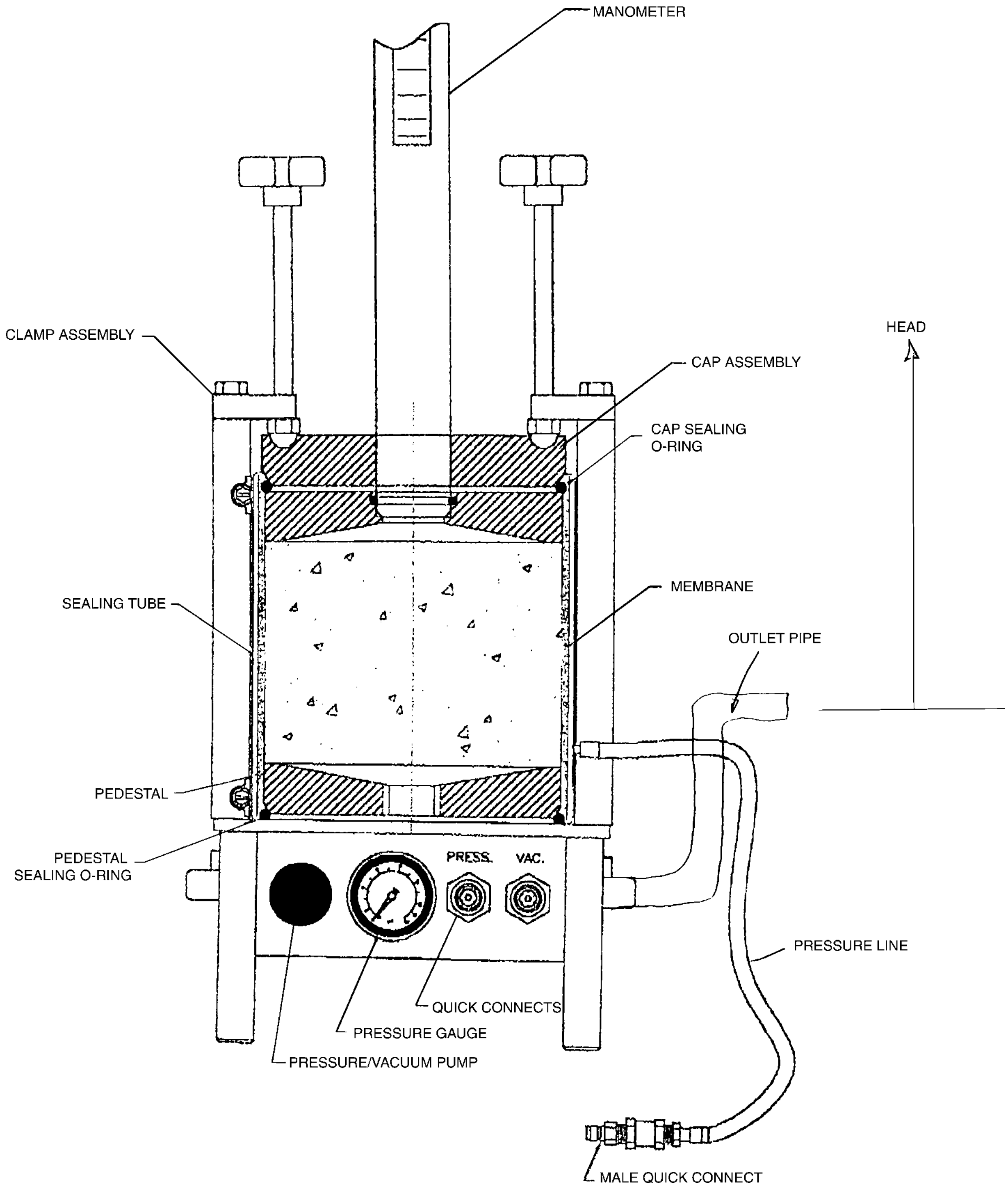

Figure B.1: Karol-Warner Flexible Wall Permeameter