

PERMEABLE BASE DESIGN AND CONSTRUCTION

DANIEL M. MATHIS

Federal Highway Administration
Washington, D.C.

INTRODUCTION

This paper will present the state-of-the-practice in pavement drainage (i.e., permeable bases) for new or reconstructed asphalt concrete (AC) and Portland cement concrete (PCC) pavements.

Rather than using impermeable dense-graded materials many States have gone to using open-graded or "permeable" bases to allow infiltrated moisture to rapidly drain through the base and out from beneath the pavement structure.

Because of the relative unfamiliarity with permeable base pavement structures and with the varying designs in use, this paper synthesizes permeable base pavement systems being used in this country.

BACKGROUND

The pavement structure is the most costly element of the highway system and its premature failure is of major concern. Among the reasons cited for pavement failures, inadequate drainage of the pavement structure has been identified as a primary cause of pavement distress. The newly published AASHTO Guide for the Design of Pavement Structures (1986) addresses this as a problem by including drainage as an essential element of pavement design. Also, the Federal Highway Administration's (FHWA) pavement management and design policy encourages performing a drainage analysis for each new, rehabilitation, and reconstruction pavement design.

In designing pavement sections in the past, the primary function of the base was to provide uniform support. However, with increasing traffic loads, erosion and pumping of the underlying material resulted. This led to construction of what were thought to be strong nonerodible bases (i.e., dense graded aggregate bases, cement treated bases, asphalt concrete bases). These materials were not only impermeable, they were also found to be erodible in many cases. Infiltrated moisture was trapped in the pavement structure and, under the effects of heavy loads, led to a weakening or

erosion of the base, subbase, and/or subgrade often resulting in premature distress of the pavement structure.

A significantly different pavement design philosophy is now receiving a great deal of consideration. Rather than using impermeable dense-graded materials, several States have opted to use open-graded or permeable bases to allow infiltrated moisture to rapidly drain through the base and out from beneath the pavement structure. A permeable base is normally characterized by an open-graded crushed angular aggregate with essentially no fines. Recognizing the problems moisture distress has played on pavements, primarily on PCC pavements, many States are routinely using or experimenting with permeable bases beneath new or reconstructed high-type pavements. A longitudinal edgedrain collector system is commonly used to rapidly drain the moisture that collects in the permeable base. Typical permeable base pavement sections are shown in Figure 1.

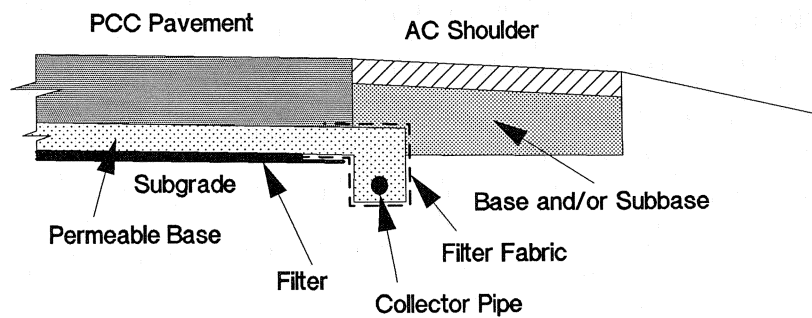
OBJECTIVE

The primary objective of this paper is to synthesize the design and construction of permeable base pavement systems being used in this country. It is the intent to summarize the findings, to communicate the experiences of various States, and to demonstrate that permeable base pavements can be designed and constructed without significant changes to conventional practices.

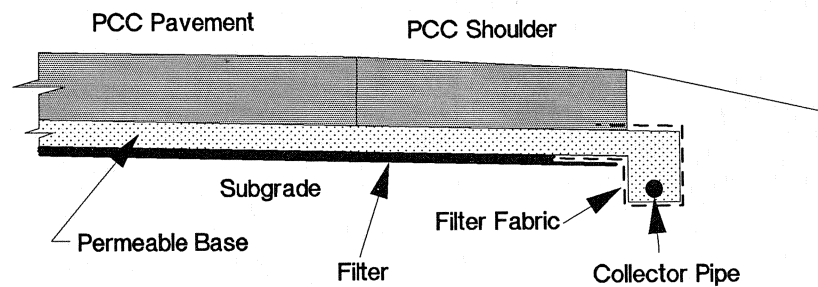
SCOPE

Reviews were conducted in those States that were known to have recently constructed permeable base pavements. States included in the review were California, Iowa, Kentucky, Michigan, Minnesota, New Jersey, North Carolina, Pennsylvania, West Virginia, and Wisconsin. The review included gathering information from each State in design, use, construction, cost, and performance of permeable bases.

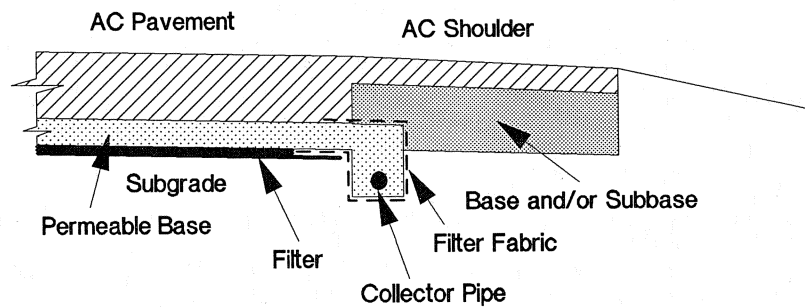
Figure 1. Typical Permeable Base Pavement Sections



PCC Pavement/AC Shoulder Section



PCC Pavement/PCC Shoulder Section



AC Pavement/AC Shoulder Section

FIELD SURVEY RESULTS

In general, the States that are using permeable base pavements can be grouped into two categories-- those that use an untreated permeable base and those that use a treated permeable base. The untreated permeable base materials generally have a lower coefficient of permeability, whereas treated permeable bases have a much higher coefficient of permeability. The untreated permeable base material contains more smaller sized aggregate to give it stability and, thus, it tends to be less permeable. On the other hand, a treated permeable base had a cementing agent, generally 2-3 percent asphalt cement, for stability. The result was a more open material with high permeability.

Summary of State's Philosophy on Permeable Base Pavement Design

The approach to permeable base design varied among the States reviewed with California, Michigan, New Jersey, and Pennsylvania having the most experience. Most of the other States constructing permeable bases investigated the designs used by these States and modified them for their own use. The majority of States are primarily using permeable bases beneath PCC pavements, however, several States are using permeable bases beneath AC pavements as well.

Although the philosophies differ with respect to degree of permeability, the end result is that all States believe that rapid base drainage is extremely important. Some States believed that the highest permeability that could be obtained with readily available materials was best. Whereas, other States believed that a less permeable material which was similar to their existing base material in availability, cost, and stability, but which had some of the fines removed to provide drainability, was sufficient.

Review of Current Permeable Base Pavement Design

Type of Permeable Base

Those States that are predominantly using untreated permeable bases include; Iowa, Kentucky, Michigan, Minnesota, New Jersey, Pennsylvania, and Wisconsin. Iowa's, Minnesota's, and Pennsylvania's permeable base gradation is essentially derived from their conventional dense-graded aggregate base gradation with some of the fines removed. Kentucky's and New Jersey's gradations are based on readily available AASHTO aggregate gradations (i.e., Kentucky uses the AASHTO No. 57 stone and New Jersey uses a 50/50 blend of AASHTO No.'s 57 and 9 stone). Michigan's and Wisconsin's gradations were developed through testing of various permeable gradations. Both Iowa and Michigan allow recycled PCC pavement with some of the fines removed to be used for their permeable base.

Those States that are using treated permeable bases include California, North Carolina, and West Virginia. The predominant material used for stabilization is asphalt cement at approximately 2 percent, although California allows Portland cement at 2-4 bags per cubic yard as an option. Both North Carolina and West Virginia utilize AASHTO's No. 57 stone gradation. California's gradation is similar.

Degree of Permeability

There was a wide range in permeabilities desired. The untreated permeable bases generally had a lower coefficient of permeability -- in the range of 200 to 3,000 feet per day. The treated permeable bases all had a very high coefficient of permeability-- from 3,000 to 20,000 feet per day or higher. The permeabilities were determined using either a falling head or constant head permeameter using standard test procedures. The gradations used by the 10 States reviewed for the treated and untreated permeable bases, respectively, follow.

TREATED PERMEABLE GRADATIONS

Percent Passing

<u>Sieve Size</u>	<u>California</u>	<u>North Carolina/West Virginia</u>
1 1/2-inch	-	100
1-inch	100	95-100
3/4-inch	90-100	-
1/2-inch	35-65	25-60
3/8-inch	20-45	-
No. 4	0-10	0-10
No. 8	0-5	0-5
No. 200	0-2	0-2
Coefficient of Permeability (feet per day)	15,000	20,000

UNTREATED PERMEABLE GRADATIONS

Sieve Size	Percent Passing						
	IA	KY	MI	MN	NJ	PA	WI
2-inch	-	-	-	-	-	100	-
1 1/2-inch	-	100	100	-	100	-	-
1-inch	100	95-100	-	100	95-100	-	100
3/4-inch	-	-	-	65-100	-	52-100	90-100
1/2-inch	-	25-60	0-90	-	60-80	-	-
3/8-inch	-	-	-	35-70	-	35-65	20-55
No. 4	-	0-10	0-8	20-45	40-55	8-40	0-10
No. 8	10-35	0-5	-	-	5-25	-	0-5
No. 10	-	-	-	8-25	-	-	-
No. 16	-	-	-	-	0-8	0-12	-
No. 30	-	-	-	-	-	0-8	-
No. 40	-	-	-	2-10	-	-	-
No. 50	0-15	-	-	-	0-5	-	-
No. 200	0-6	0-2	-	0-3	-	0-5	-
Coefficient of Permeability (feet per day)	500	20,000	1000	200	2000	1000	18,000

Extent of Use

Nine of the 10 States use their permeable base under new or reconstructed high-type PCC pavements. Also, most States have constructed at least one permeable base AC pavement experimentally. Kentucky has only constructed permeable bases under AC pavements to date. It has been within the past 5 years that permeable bases beneath high-type PCC pavements has become standard in these States, with California specifying them beneath AC pavements, as well.

Thickness and Width of Permeable Base

The thickness of permeable bases varied from 3 to 6 inches, with 4 inches being the most common. Although the thickness required for drainage can be calculated, 4 inches seems to provide sufficient capacity, is easily constructed, and provides for construction tolerances. California specifies 0.25-foot (3 inches) for its asphalt cement treated permeable base and 0.35-foot (approximately 4 inches) for its Portland cement treated permeable base. The difference in thickness specified is attributed to the asphalt cement treated permeable material having a higher coefficient of

permeability -- approximately 15,000 feet per day -- than the Portland cement treated material -- approximately 4,000 feet per day.

The width of permeable base, whether treated or untreated, was generally placed 1 to 3 feet outside either pavement edge. In most cases, the tracks of the paver ran on this widened section. Kentucky, New Jersey, and West Virginia carried the permeable base layer out to the edge of either shoulder.

Method Used to Drain Permeable Base

All States reviewed use a longitudinal edgedrain collector system to drain accumulated water from their permeable bases. Seven of the 10 States used an excavated trench design exclusively. Kentucky, West Virginia, and Wisconsin have also used a V-ditch design for the longitudinal edgedrain collector. Both Kentucky and West Virginia noted problems with this design. Not only is constructing and maintaining the V-ditch a problem, but protecting the pipe from crushing under construction traffic was also noted as a problem. Several States that use the excavated trench design also expressed a concern with possible crushing of the pipe, however, there is generally more cover

over the pipe than with the V-ditch design. Both Minnesota and Wisconsin allow the contractor to construct the longitudinal edgedrain collector system either before or after pavement construction. They were concerned with the possible damage to the pipes in the longitudinal trenches and the outlet lateral trenches by construction equipment.

Generally, the inside edge of the edgedrain trench is located immediately below the longitudinal pavement/shoulder joint (see Figure 1). To avoid settlement or crushing of the collector pipe beneath construction equipment, several States locate the trench 2-3 feet out from the joint beneath the shoulder. Michigan, however, installs the trench beneath the PCC pavement. Most States that construct crowned pavement sections install a longitudinal edgedrain collector system along both the inner and outer pavement edge. This effectively shortens the drainage path and significantly lessens the time for the permeable base to drain.

Most States backfill the edgedrain trench with the same permeable material that is used for the permeable base. A few used a more permeable material as backfill. All 10 States used an outlet pipe to convey the accumulated water from the edgedrain collector to the ditch or other inlet structure. West Virginia tried a fabric wrapped pea gravel outlet system. After several years, these outlets became increasingly difficult to locate because they had become overgrown with vegetation and/or plugged with roadside slope debris. Daylighting of the permeable base to the ditch slope is not recommended because of these reasons.

A number of States had experienced problems with maintaining the proper outlet grade with flexible corrugated plastic pipe and now specify the use of rigid PVC pipe for outlet laterals. Iowa is the only State that does not use a filter fabric lined edgedrain collector trench. The subbase and subgrade material acts as a filter and is compatible with the permeable trench backfill material. Also in Iowa, edgedrains are installed 4 feet below the pavement surface and are generally installed 2-3 years prior to reconstruction, primarily to drain the subbase and subgrade before reconstruction.

Type of Filter Layer Used

Those States that use an untreated permeable base use a filter aggregate layer, which in most cases, is the States's conventional dense-graded aggregate base material. The gradation of this material is compatible with the permeable material to prevent intrusion of fines from the subgrade. Those States that use a treated permeable base predominantly, use a filter fabric (primarily non-woven) to protect the permeable base layer from intrusion of fines. One State, West Virginia, allows the use of a woven fabric. It is interesting to note that research by Penn State University in the use of filter fabrics, found that filter fabrics act as

a wick or blotter actually holding moisture in the material immediately below the filter fabric and may act as an internal source of moisture.(1) California was the only State that used an impermeable aggregate subbase as a separator or filter layer with a treated permeable base.

Structural Value

Five of the seven States that predominantly use an untreated permeable material believe it was structurally equivalent to a dense-graded aggregate base. New Jersey had gyratory shear and repeated load triaxial tests performed on their untreated and asphalt cement treated permeable materials at the Corps of Engineers Waterways Experiment Station (WES). Results indicated that both had bearing capacities similar to dense-graded aggregate base. Also, 1/2 million wheel loads were applied to the same test section which was subject to periodic flooding and it exhibited good performance.(2) Pennsylvania had tests performed on their untreated permeable material at the Penn State University Test Track and found that it provided support similar to a dense-graded aggregate base.(3) Kentucky and Minnesota do not give the untreated permeable material credit in their structural sections.

The three States that used a treated permeable base believed that the permeable material provided support similar to a dense-graded AC base. West Virginia performed a plate load bearing test on their first asphalt treated permeable base. A resultant K-value of 200 pounds per cubic inch (psi).(4) California performed laboratory compressive tests on their asphalt cement treated permeable material and found that it provided more support than dense-graded aggregate material.

Review of Current Permeable Base Construction Practices

Construction Considerations

Overall, construction of permeable base pavements requires more care than unstabilized or stabilized dense-graded aggregate bases. The treated permeable bases have sufficient stability for construction traffic, however, extra care is needed to prevent contamination of the layer. Untreated permeable bases, although sufficiently stable to pave on, are more easily displaced than dense-graded base. Additional care is required by equipment operators and truck drivers when placing and finishing the pavement. Quite often, a roller was used to "dress up" the permeable material immediately in front of the paver.

Most States restrict construction equipment other than the paving and finishing equipment from traversing the permeable base. Also, most States found that when placing an AC pavement on a permeable base, rubber-tired pavers rutted and displaced the permeable material. They now specify tracked pavers which better distribute the load.

Another concern with the untreated permeable aggregate material was the possible segregation of the material during placement and degradation of the aggregate under construction traffic. Several States specify that untreated permeable aggregate be placed at a certain percent moisture to reduce segregation.

The grade of the treated permeable materials was more difficult to modify once it had been placed and compacted. High and/or low spots at the longitudinal joint between asphalt cement treated paving passes was common and some method of modifying the grade (i.e., trimming with a blade or autograder) was required. Also, keeping the highly permeable base material clean and free from contamination was a concern. Both North Carolina and West Virginia require that the filter fabric between the subgrade and permeable base layer be wrapped or lapped up around both edges of the permeable base. California required sufficient filter fabric to line the edgedrain collector trench and to wrap up and over the low side of the permeable base layer.

Equipment Modifications

Only very minor equipment modifications are required to more easily construct permeable base pavements. One modification noted in a couple States was the use of wider rubber tires on the reinforcing mesh cart (for jointed reinforced concrete pavements (JRCP)) to distribute the load over a larger area of the permeable base, thereby, reducing the potential displacement of the untreated material. Also, as mentioned previously, when placing an AC pavement use of tracked pavers on untreated permeable bases in lieu of rubber-tired pavers was specified. In addition, use of longer pins to hold dowel baskets in place was necessary on permeable bases.

Stability

No stability problems were observed or indicated by any of the States that were reviewed. Many State and contractors' personnel expressed reservations regarding the paving on the more open-graded permeable treated or untreated base materials on their initial contact with it. However, in all cases, after working with the material the doubts vanished. All States required at least 85 percent crushed material which provided additional stability through aggregate interlock.

There were no problems noted with stability of the asphalt cement treated permeable materials under construction equipment even under high ambient air temperatures. All three States used a conventional paving grade asphalt cement as the stabilizing material. California noted a problem on one project where the asphalt treated permeable base did not set up properly and took up to a week to provide sufficient stability to pave on. The State attributed this to the permeable aggregate temperature not being in the 275-375 degree F range

specified at the time the asphalt cement was introduced.

As expected, stability was more of a concern with untreated permeable materials. Although stability varied from state to state and gradation to gradation, all untreated permeable materials were stable under paving equipment. However, many States did not allow any equipment other than that needed to place and finish the paving to traverse the material. Those States that did allow construction traffic on the untreated base, required a roller in front of the paving operation to compact and smooth out any disturbance to the material from trucks hauling on the base. Both Minnesota and Pennsylvania require a minimum coefficient of uniformity (D_{60}/D_{10}) of 4 to ensure a stable gradation.

Performance of Existing Permeable Base Pavements

Performance information available to date indicates that properly designed and constructed permeable bases virtually eliminate pumping, faulting, and cracking. There is no long-term performance data available (in excess of 15 years). However, based on a comparison of the performance of existing permeable base sections to undrained sections, States anticipate a 50 percent increase in PCC pavement service life.

California continues to evaluate their permeable base pavements versus those that are not drained. On PCC, they found that in terms of percent cracked slabs, the permeable base (drained) sections had significantly lower rates of slab cracking. Of the four permeable base sections evaluated, three of which were constructed in 1980, two of the permeable base sections had no cracking, whereas the undrained control sections had 18 and 47 percent cracking. A drained section constructed in 1965 had 5 percent cracking compared to 10 percent for the undrained section. One project with both a permeable base and an undrained section had exhibited no cracking yet. A 500-foot section of AC pavement on a logging road was reconstructed in 1967 using a highly permeable open-graded base drainage layer after it had failed twice in just a few years. The State conducted a review in 1986 and found that the original pavement was still in excellent condition with no patching, whereas, the adjoining pavement had been extensively patched. The 19-year service life of this section (to date) is well beyond the normal 12-year life of AC pavements in California. Studies performed by California suggest a minimum service life increase of 33 and 50 percent, respectively, for AC and PCC pavements constructed on a permeable base.(5)

Iowa has performed a substantial amount of nondestructive testing (NDT) with a Road Rater on their PCC pavements. They indicated that permeable base pavements provide greater structural support than undrained pavements. The support on undrained pavement sections deteriorates for approximately 5 years, whereas support on permeable base sections does not deteriorate. They felt the constant support of the permeable base sections was

equivalent to 3 to 5 inches of effective pavement. In addition, crack surveys which are performed every 2 years revealed that permeable base pavements have virtually no cracks, unlike conventional undrained pavements of the same age.

Michigan's oldest permeable base sections are on the Clare test road (US 10) constructed in 1975. An inspection of the three 1/2-mile permeable base test sections in comparison to the other sections was conducted during the review. There was no faulting or cracking and less apparent D-cracking on the permeable base sections than on the other two base types (i.e., bituminous base and dense-graded aggregate base). The dense-graded bituminous base sections were the worst performing in terms of pavement distress (i.e., faulting, cracking, D-cracking, and spalling). Pumping was noted on these sections as well. Some spalling of the longitudinal joints was noted on all test sections, but was noticeably worse on the bituminous base sections.

Minnesota's oldest permeable base pavement section, a 1600-foot section of JRPC with 27-foot skewed dowelled joints on Trunk Highway 15 near Fairmont constructed in 1983, was evaluated. After 5 years, only one of the 59 permeable base slabs had a mid-panel crack, whereas the undrained JRPC with conventional dense-graded aggregate base adjacent to either end of the pavement was found to have approximately 50 percent mid-panel cracking. The section adjacent to the south had 15 of 33 slabs that exhibited mid-panel cracks and the section north had 5 of 10 slabs with mid-panel cracks.

New Jersey reported the performance of their experimental permeable base pavement sections constructed in 1979-1980 at the 1988 Transportation Research Board Meeting. Their initial observations/findings on the AC sections were that the thinner sections were performing as well as the thicker sections with rutting being about the same. On PCC pavement sections, there was less deflection, no faulting or pumping, and substantially reduced frost penetration.

Pennsylvania rated the performance of their experimental permeable base sections constructed in 1980 much better than dense-graded aggregate base sections. Based on the positive interim results of these sections, a permeable base layer between the PCC pavement and dense-graded aggregate subbase became the State standard in 1983.(3)

Rideability

All of the States indicated that the rideability of permeable base pavements was no different than that on dense-graded bases. This was substantiated in California and North Carolina (asphalt cement treated) and Michigan (untreated). The rideability of some recently constructed PCC pavements in these States had been measured using the California and Rainhart profilographs at 0-5 inches per mile. In general, those States using a stringline for both horizontal and vertical control had a substantially better ride quality than those that did not. Also,

those States that had incentives/disincentives for rideability had projects with very good ride quality.

Cost

Bids for permeable base materials were generally found to have slightly higher costs per unit weight than the impermeable dense-graded materials they replaced. Five of the seven States that used an untreated permeable base found that they were slightly more costly per unit measure than conventional dense-graded aggregate bases while two States, Iowa and Michigan, indicated that the unit costs for their permeable base material were the same or sometimes less.

As expected, the treated permeable base materials were two to three times more costly per unit measure than conventional dense-graded aggregate bases. However, all three States that predominantly used treated permeable base material found that the unit costs for it were about the same as those for dense-graded AC base. In addition, all three noted that because of the higher void content of the permeable material, the yield was 15-30 percent higher than dense-graded AC. California found that asphalt cement treated permeable base was generally less costly per unit measure than cement treated base (CTB) and lean concrete base (LCB). The material unit costs were the same or slightly more than asphalt concrete base but because of the large void content the yield was 20 percent higher. Kentucky, which had used some asphalt treated permeable base within the past year, also found that its material unit costs were about the same as the dense-graded bituminous base, but the permeable base material had 25-30 percent higher yield.

SUMMARY

A review of current design and construction practices has proven that permeable base pavements can be designed and constructed to rapidly drain moisture that infiltrates the pavement surface without significant changes to conventional practices.

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