National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

November 2002—Number 268

Subject Areas: IIB Pavement Design, Management, and Performance and IIIB Materials and Construction

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Performance of Pavement Subsurface Drainage

This digest summarizes key findings from NCHRP Project 1-34, "Performance of Subsurface Pavement Drainage," conducted by ERES Consultants, Inc. The digest was prepared by Edward T. Harrigan, NCHRP Senior Program Officer, from the contractor's final report.

INTRODUCTION

This digest presents key findings of NCHRP Project 1-34, "Performance of Subsurface Pavement Drainage." It provides a useful summary of the effects of subsurface pavement drainage features on the performance of asphalt concrete (AC) and portland cement concrete (PCC) pavements developed from an extensive body of field project data obtained through 1998. Further, it will serve as a good basis of reference for similar results now being obtained from Special Pavement Studies 1 and 2 in the Long-Term Pavement Performance program. Thus, the digest will be of particular interest to engineers in the public and private sectors with responsibility for the design, construction, and rehabilitation of AC and PCC pavements.

The principal objectives of NCHRP Project 1-34 were to evaluate (1) the overall effect of subsurface drainage of surface infiltration water on the performance of AC and PCC pavements; (2) the specific effectiveness of permeable base and associated edgedrains, as well as traditional dense-graded bases with and without edgedrains; and (3) the specific effectiveness of retrofitted surface drainage on existing pavements.

Project 1-34 was completed in 1998, and its complete final report is available for loan on request from NCHRP. Through 2002, the NCHRP Project Panel 1-34 has commissioned three additional projects to continue the analysis begun in Project 1-34 and to further test its findings. Project 1-34B critically reviewed the results of Project 1-34 and developed an experimental plan to evaluate and test Project 1-34's key findings. Project 1-34C extended the analysis of Project 1-34 to field data from the Long-Term Pavement Performance (LTPP) database for the Special Pavement Studies (SPS)-1 and SPS-2 experiments, supported by the results of a joint FHWA/NCHRP task order effort to physically determine the functionality of the drainage features in SPS-1 and SPS-2 pavement sections. Finally, Project 1-34D will quantitatively test the functionality of the subsurface drainage features in the LTPP SPS-1 and SPS-2 field sections and refine the relationships between subsurface drainage features and pavement performance developed in Projects 1-34 and 1-34C.

Project 1-34 also produced guidelines for the selection and design of subsurface drainage features that are not discussed in this digest. The guidelines have been superseded by those prepared by key members of the 1-34 research team for (1) FHWA in the 1999 publication *Pavement Subsurface Drainage Design—Reference Manual* and (2) NCHRP in Project 1-37A, *2002 Guide for the Design of New and Rehabilitated Pavement Structures*, available in 2003.

SUMMARY OF FINDINGS

Background

It is common practice in many state and provincial highway agencies to incorporate positive subsurface drainage features (e.g., permeable layer and edgedrains) into new flexible and rigid pavements to handle surface infiltration water. The use of such features substantially increases the cost of new and rehabilitated pavements and raises the question whether the increased construction cost is offset by a proportional increase in pavement performance.

Controversy Over Subsurface Drainage

There has always existed a significant controversy over the design and benefits of subsurface drainage. Adding greatly to this controversy is the problematic history of design and construction of features such as permeable bases, longitudinal edgedrains, transverse drains, daylighted permeable bases, and retrofitted edgedrains for existing pavements. Recent surveys suggest that only one-third of the edgedrains in existing pavements are functioning as designed. Other surveys have shown that permeable bases may become infiltrated with fines from underlying layers. Construction difficulties and early cracking supposedly related to permeable bases are also reported, as is settling of retrofitted edgedrains along the edge. Thus, when evaluating the benefits of subsurface drainage, the potential for design-, construction-, or maintenance-related problems must be considered. Essentially, the installation of a subsurface drainage system carries with it a substantial risk that the system will not function properly over the life of the pavement, negating the positive effect of the drainage feature.

Key Questions Addressed

The key questions addressed in Project 1-34 were the following:

- Do the various subsurface drainage design features contribute to improved performance of flexible (AC) and rigid (PCC) pavements?
- Are the features cost-effective, and under what conditions?

A pavement section with a permeable layer is designed to provide much more rapid drainage of free water that infiltrates the pavement structure than do dense-graded pavement structures. In theory, saturation of critical unbound layers or erosion of any layer should not occur in pavement structures with permeable layers. Edgedrains retrofitted into existing pavements are designed (1) to drain water that infiltrates through joints or cracks in the lane or shoulder by shortening the drainage path of excess free moisture along the critical edge of the traffic lane or (2) to drain the interfaces of impermeable layers.

Any design change that provides rapid removal of water from a pavement structure should improve pavement performance. Observations and critical analyses of field sites where positive subsurface drainage features exist are the only way that credible evidence can be gathered concerning the true effects of subsurface drainage on performance. NCHRP Project 1-34 focused on collecting data and analyzing the performance of as many in-service pavements as possible, both with and without subsurface drainage, in major climatic zones in the United States.

Data Collected in Project 1-34 and Data Obtained from Other Sources

Project 1-34 used available field performance data from past studies and performance data collected throughout the United States and analyzed by the project team. A major effort was made to identify all experimental sites in the United States and Ontario, Canada, that had multiple test sections with subsurface drainage features, such as a permeable base layer, in conjunction with a non-drained control section.

For flexible pavements, most of the identified experimental sites were included in the subsequent analysis. Information on these sites is presented in Table 1, which summarizes 91 pavement sections at 22 project sites in 10 states and the province of Ontario. (Tables appear at the end of the digest).

For rigid pavements, an extensive amount of data was already available from the FHWA Rigid Pavement Performance and Rehabilitation (RPPR) database; thus, fewer sites were specifically surveyed under this study. Information on these sites is presented in Table 2, which summarizes 46 pavement sections at 16 project sites in 7 states and the province of Ontario.

A large majority of the resources for this project were spent in collecting data from the pavement sections at the sites in Tables 1 and 2. Results for more than 300 additional flexible and rigid pavement sections were obtained from the FHWA RPPR database and from the LTPP database. As noted, many of these latter sections were part of experimental projects constructed by the states where drained and non-drained sections existed adjacent to each other. Because of budget constraints, the performance data were limited primarily to visual distress survey, examination of the outlets of existing underdrains, and some deflection data. It was not possible to core or trench the pavements to determine the condition of the permeable layers or edgedrains. Design, traffic, materials, climate, and other data were obtained from the files of the state and provincial highway agencies.

Analyses Conducted

The first phase of this project was a survey of the literature on pavement drainage and documentation of current state drainage practices. Once the extensive field performance database was developed, a second phase of analysis was carried out to compare the performance of all drained and non-drained sections at a given location. A third phase included an analysis of all the performance data through the development of mechanistic-empirical models for fatigue cracking and rutting of flexible pavements and joint faulting of rigid pavements. Finally, life-cycle cost analyses were conducted to illustrate the relative cost-effectiveness of various subsurface drainage features.

The results of these analyses are summarized in the following sections. Readers are referred to the full, unpublished final report for Project 1-34 for more detail.

Effects of Subsurface Drainage on Flexible Pavements

The following findings were obtained from (1) previous studies on the impact of subsurface drainage, (2) direct comparisons of the performance of drained and non-drained experimental sections in Table 1, and (3) distress predictions from mechanistic-empirical models based on all available performance data:

- Both structural capability (particularly the thickness of dense-graded, asphalt-bound layers) and drainability of the section are important to the performance of flexible pavements. Deficient structural capability or poor section drainage can lead to rutting or fatigue cracking. The design of a flexible pavement with a permeable layer must consider both of these key attributes to provide satisfactory performance.
- For a conventional AC pavement with an unbound dense aggregate base, the addition of edgedrains appeared to reduce fatigue cracking, but not rutting. An earlier study in Minnesota showed that sections of conventional AC pavement that were located in a trench (or "bathtub") did not perform nearly as well as sections that had a daylighted dense-graded base with drainage ditches (Kersten and Skok 1968).
- Asphalt-stabilized permeable bases were effective in reducing rutting when compared with unbound dense-graded aggregate bases.
- Unbound dense-graded aggregate bases showed much more rutting in very cold areas (Freezing Index = 1,000) as compared with warmer areas (Freezing Index = 100), whereas asphalt-stabilized permeable bases appeared to show about the same amount of rutting (lower) when located in either climatic area, illustrating the effect of freeze-thaw on saturated unbound aggregate layers.
- Permeable base sections with edgedrains had significantly less rutting in the inner wheelpath than dense-graded aggregate base sections with edgedrains. Rutting performance in the outer wheelpath was about the same.
- Permeable base sections with edgedrains exhibited fatigue cracking performance comparable to dense-graded aggregate base sections with edgedrains.
- Conventional AC pavement with unbound dense aggregate base showed more fatigue cracking without edgedrains than when edgedrains or permeable bases were added.
- Daylighted permeable base sections (without edgedrains) exhibited better fatigue performance than all other types of evaluated AC pavement sections. Rutting, however, did not show any significant difference. The sample size was very small, and these sections ranged in age only up to 7 years and carried up to 1.7 million equivalent single-axle loads (ESALs), so long-term performance and the effect of heavy traffic were not considered. This tentative finding is interesting and deserves further study, particularly in light of the problematic nature of edgedrains. The effective area of outlet of a permeable base that is daylighted is far greater than the small outlet for an edgedrain, even if much of it becomes layered over with soil over time. In addition, edgedrains cannot be used in areas with very flat grades; daylighted permeable bases may be a practical solution here.
- Clogged edgedrain outlets have a very detrimental effect on the performance of flexible pavement sections containing a permeable base. The inability to drain a permeable layer leads to increased fatigue cracking and rutting; increased stripping may also result.
- Flexible pavement sections in Kentucky with dense AC layers of 12 to 24 inches over a fairly permeable, large-rock layer placed on the subgrade showed relatively low fatigue cracking and rutting. This "large-rock layer" design has also been built in Idaho and Missouri with reportedly good performance; it deserves further study and consideration wherever the rock materials are economically available.
- Cement-treated layers were used as a separation layer between the permeable asphalt-treated base and the subgrade on two projects and appeared to perform well.

Effects of Subsurface Drainage on Rigid Pavements

The following findings on the effects of subsurface drainage on the performance of rigid pavements were obtained from (1) previous studies on the impact of subsurface drainage, (2) direct comparisons of the performance of drained and non-drained experimental sections in Table 2, and (3) distress predictions from mechanistic-empirical models based on all available performance data:

- For properly designed, doweled, jointed concrete pavements, joint faulting in general is fairly low and a permeable base has a relatively small effect on reducing joint faulting further. When a dense-graded base exists, edgedrains were not found to have a significant effect on reducing doweled joint faulting. Dowel bars greatly minimize differential deflections across joints, thus reducing the potential for pumping and erosion.
- For non-doweled, jointed concrete pavements, joint faulting in general is much higher and a permeable base has a significant effect in reducing joint faulting. However, the permeable base must be well designed or it can become contaminated by fines, allowing faulting to develop. The edgedrains must also be maintained properly or they will clog and their beneficial effect will be lost.

- There are several designs of dense-stabilized base with sufficient erosion resistance that can provide good performance, particularly when joints are doweled. Field results from studies in Wisconsin, Georgia, Utah, and Chile indicate that placement of a granular subbase beneath a dense-stabilized base course will reduce pumping and erosion. This layer may also provide a measure of bottom seepage.
- Slab cracking data indicated that when an asphalt-treated permeable base is used with jointed plain concrete pavement (JPCP), the amount of cracking is very low in comparison with other base types. This trend is also shown in early performance data from the LTPP SPS-2 experiment. Overall crack deterioration data indicate that the number of deteriorated cracks in jointed reinforced concrete pavement (JRCP) is lower for permeable base courses than for dense base courses.
- The few sections of continuously reinforced concrete pavement (CRCP) included in the database provide direct comparisons between permeable bases and dense-stabilized bases, as well as between aggregate separation layers and lime-treated subgrade. These sections ranged in age up to 7 years and up to 2 million ESALs. There was no difference in performance between these sections at the time of the analysis in Project 1-34. However, one section of CRCP on I-80 under very heavy traffic included a permeable cement-treated base over a lime-stabilized subgrade that pumped up into the permeable base, causing localized settlements in the CRCP. In addition, for CRCP, the results suggest that a high-strength, cement-treated permeable base should not be used because it may bond strongly to the CRCP (or penetrate significantly into the permeable base), thus increasing the effective pavement thickness so that the crack spacing and width are altered.
- A significant reduction in D-cracking was identified at an experimental site in Michigan that contained a permeable asphalt-treated base (0-, 6-, and 12-percent deteriorated joints on three sections), as compared with sites with dense-graded, asphalt-treated bases and full-depth AC shoulders (79- to 100-percent deteriorated joints on two) (Smith et al. 1990, Smith et al. 1998). When observed over the entire database, concrete sections with permeable bases averaged less than one-half of the deteriorated joints of concrete sections with dense-graded bases. A likely reason is that a concrete slab with a permeable base may be less saturated than with a dense-graded base course, resulting in a lower amount of freeze-thaw during saturation to cause D-cracking. This finding is based on very limited data, but, if valid generally, it would have significant implications for concrete pavements constructed in freeze-thaw areas with aggregates that are susceptible to D-cracking.

Findings for Retrofitted Edgedrains

Previous studies showed some benefits of retrofitted edgedrains for rigid pavements (LaCoursiere et al. 1978, Snyder et al. 1989). However, these findings were based on a very limited number of sections, and a followup to LaCoursiere et al.'s study showed little long-term benefits, perhaps because of lack of maintenance to the edgedrain outlets (DuBose 1995). Limited data were obtained under this study to evaluate retrofitted edgedrains, and the data were inconclusive for slab cracking or joint faulting. Even if retrofitted edgedrains truly had a positive effect when they were maintained in a functioning condition, the fact that they are often not well maintained casts doubt on their reliability. Following are the findings for retrofitted edgedrains:

- A study in Illinois compared the number of punchouts that occurred between CRCP sections with and without retrofit edgedrains when the edgedrains were placed very early in the pavement life. At three different locations where direct comparisons were possible between similar projects, the edgedrains yielded an overall 25-percent average reduction in the number of punchouts (LaCoursiere et al. 1978).
- An FHWA study that included diamond-ground sections of JPCP and JRCP located throughout the United States showed that the joint faulting for non-doweled JPCP was about 50 percent less several years after grinding for sections with retrofit edgedrains. The difference was about 30 percent for doweled JRCP (Snyder et al. 1989). However, after 11 years of additional life, there was no performance difference between JRCP with retrofit edgedrains and JRCP without edgedrains (Rao et al. 1999). The retrofit edgedrains were apparently not maintained and lost effectiveness.
- The Kansas sections evaluated under this study are non-doweled JPCP sections over cement-treated base (CTB) that were retrofitted with edgedrains 4 years after construction, yielding 7 pairs of retrofitted and non-retrofitted edgedrain sections for comparison. Faulting measurements were made after an additional 6 years. All sections exhibited significant faulting, but 3 of the 7 pairs showed reduced faulting with retrofitted edgedrains. Three pairs showed about the same faulting, and the section with the most faulting was also a retrofitted edgedrain section that may not have been functional.

Cost-Effectiveness Findings

A very limited study was conducted into the cost-effectiveness of subsurface drainage for flexible and rigid pavements. The results should be considered as only illustrative because both pavement cost and performance are difficult to quantify and vary widely from location to location, as do pavement subsurface drainage designs. The overall findings of this limited study indicated that subsurface drainage features that are properly designed and constructed may decrease the occurrence of key distress types, such as rutting and fatigue cracking of flexible pavements and non-doweled joint faulting of jointed concrete pavements. If so, the initial life of these pavements would be increased and rehabilitation delayed. Permeable base did not, however, have a significant effect on doweled JPCP. Good subsurface drainage may decrease the loss of durability (e.g., D-cracking of concrete) and the deterioration of cracks. Although these benefits were not quantifiable in this study, they may be significant and should be considered on a local basis by the design engineer. However, permeable base layers and edgedrains increase the cost of a project significantly; thus, there are always certain tradeoffs involved.

JPCP

The three widened-lane JPCP designs exhibited a lower life-cycle cost than any of the conventional-lane-width JPCP designs. The lowest life-cycle cost design was a widened-lane, non-doweled, dense-graded aggregate base. However, the other two sections—one of which included dowels with a dense-graded aggregate base, and the other a non-doweled permeable base section—were just slightly more costly.

For regular-lane-width JPCP, the conventional doweled pavement with a dense aggregate base was found to have the lowest life-cycle cost because of lower construction costs and low faulting over the lifetime of the pavement. Although permeable base layers improved non-doweled joint faulting performance, the cost of providing a permeable base layer in addition to the existing structure of the pavement made the drained non-doweled pavement less cost-effective than a conventional doweled pavement. The non-doweled JPCP with the lean concrete base showed the highest life-cycle cost because of its higher construction costs and faulting over time.

The results from this limited analysis did not conclusively answer the question of whether JPCP with a permeable drainage layer is the most cost-effective design. Other design features, such as a widened lane and use of dowel bars have a more significant effect on reducing life-cycle costs. For example, if it is considered essential to use dowel bars on a design (and this is recommended for all heavier trafficked JPCP), then the design with lowest life-cycle cost is the widened lane with dowel bars and dense-graded aggregate base section. However, the next lowest life-cycle cost is with JPCP with a widened lane, dowels, and daylighted permeable base; there was not a large difference in cost between the two designs. A regular-lane-width design with dowel bars and a dense aggregate base is just slightly lower cost than the previous design. This example is for illustration purposes, and similar analysis in another geographical area may show different results.

Other factors, such as reduced erosion, loss of support, better concrete durability in wet-freeze areas, and improved ride over the service life of the pavement, may significantly affect the cost-effectiveness of permeable base sections. These and other factors should be considered at the local level and included in the life-cycle cost analysis through increasing the life of the drained alternative.

AC Pavements

The limited life-cycle cost example conducted for AC pavements also showed some interesting results. The conventional non-drained AC over unbound dense aggregate base course showed development of fatigue cracking, making this the least cost-effective design considered. The placement of an edgedrain on this pavement reduced fatigue cracking and made the design more cost-effective. The incorporation of a permeable layer beneath the dense asphalt-bound layer was even more cost-effective. The section with a daylighted permeable aggregate base resulted in the most cost-effective design of all, assuming similar performance and reduced cost. Again, this example is for illustration purposes, and similar analysis in another geographical area may show different results.

Construction and Maintenance Problems

As previously stated, when considering the benefits of subsurface drainage, the potential of design-, construction-, or maintenance-related problems must also be considered. The life-cycle cost analysis conducted in this project did not consider this issue. The installation of a subsurface drainage system carries with it a risk that the system will not function properly over the life of the pavement, thus possibly negating any positive effect of the drainage feature. In addition, neglecting maintenance of the edgedrains or daylighted sections can lead to more rapid failure of the pavement (see, for example, Christopher 1998).

Discussion of Findings

The results of this limited life-cycle cost study showed that permeable bases (and, in some cases, edgedrains by themselves) have the potential to increase pavement life and, thus, may be cost-effective, depending on the design situation and site conditions. Obviously, the drained section must be structurally adequate over the long term or it may develop structural problems. Also, the drainage layer must be durable and not become unstable over time. This study focused on key distress types that could be quantified, but many others could not be quantified. Thus, local experience is of paramount importance when conducting a life-cycle cost analysis between designs for drained and non-drained sections.

The life-cycle cost analysis also showed that there exist design features that reduce the effects of excess free moisture in the pavement structure. The design features may often be more cost-effective than positive subsurface drainage features. The full report for Project 1-34 provides an approximate life-cycle cost analysis procedure and illustrative examples for rigid and flexible pavements with various drainage features.

For lower-trafficked JPCP where dowels are not used, a widened lane with a dense-graded base was very cost-effective. Adding a permeable base to this non-doweled design increased costs, but was still in the middle cost range of all designs considered. For heavily trafficked JPCP (design traffic has more than 6 million ESALs), dowels are always recommended. For doweled JPCP, both widened lanes and permeable bases were cost-effective. However, there may be other benefits of a permeable base that go beyond joint faulting. These benefits include improving the durability of the concrete slab if the aggregates are susceptible to D-cracking, reducing the faulting of transverse cracks, and reducing the erosion of underlying materials that creates loss of support and increased cracking.

For flexible pavements, thicker layers of asphalt-bound aggregates and full-width paving should be used to prevent moisture from infiltrating from lane or shoulder cracks. The use of non-stripping aggregates is also very important, as is the placement of a granular layer at the bottom of the dense AC layer to avoid a bathtub effect. A Minnesota study showed that daylighting even a dense-graded base can lead to a substantial increase in service life compared with a bathtub design (Kersten and Skok 1968).

Because of the relatively low to moderate levels of traffic on the flexible pavements evaluated in this study, the results may not be directly applicable to heavily trafficked pavements. However, this study showed that the potential benefits of subsurface drainage on flexible pavements, in terms of increased service life, may be substantial, particularly in wet-freeze areas. Further evaluation of the effectiveness of daylighted and permeable bases in improving the performance of flexible pavement is warranted, and construction of test sections for this purpose is recommended. Future results from the LTPP SPS-1 (flexible) and SPS-2 (rigid) experimental sites may also clarify findings in this study; these results are being analyzed and will be reported by NCHRP Projects 1-34C and 1-34D.

Limitations of Findings

The findings prepared from this study are based on the latest information available in 1998 on how subsurface drainage features affect performance of flexible and rigid pavements. These findings were derived from (1) a comprehensive review of findings on subsurface drainage from studies previous to Project 1-34 and (2) the performance of in-service highway pavements with and without subsurface drainage features that were surveyed through 1998 in this project, the FHWA RPPR project, and the LTPP.

However, subsurface drainage design, construction, and maintenance are very complex processes, and the general applicability of the findings is limited by significant conditions. The main conditions include a small sample size, the young age of the majority of field sections included in the analyses, and the unknown functional condition of the subsurface drainage systems in the field sections.

The sample size for flexible pavements was small (sections in 23 states). However, this sample included every experimental site with control sections that was identified by the state highway agencies. The sample should not, however, be considered as nationally representative because there was an insufficient number of sections throughout the country. The sample size for rigid pavements was much larger (27 states and many more sections) and again included every experimental site with control sections that were identified by the state highway agencies. It is important that future studies add to the data collected under this study to build a more comprehensive database for pavements with subsurface drainage systems. The most potentially valuable sources are the LTPP SPS-1 (flexible pavements) and SPS-2 (rigid pavements) experiments. These sources were unfortunately not of sufficient age to include in this study.

Most of the drained (permeable base) pavement sections were relatively young (most were less than 10 years old) and had experienced relatively low traffic. Most flexible pavements carried fewer than 5 million flexible ESALs, with a maximum of 10 million. Most rigid pavements carried fewer than 10 million rigid ESALs, with a maximum of 14 million.

Project resources were not available to conduct trenching, coring, deflection testing, roughness testing, video inspection of edgedrains, and other important pavement evaluation tests. These tests might have clarified the unusual performance of several sections and answered important questions about clogging of the permeable layers and edgedrains.

Finally, it is important to keep in perspective that the sections included in this study were typical of permeable base flexible and rigid sections designed, constructed, and maintained in the United States. Therefore, if some of the edgedrains were malfunctioning, for whatever reason, or if some of the permeable bases were clogged, then this malfunctioning or clogging will be reflected in the results of the analyses. Any product is only as reliable and effective as the cumulative effects of its design, construction, and maintenance. There are risks involved in designing, constructing, and maintaining subsurface drainage systems in pavements, and these activities will always have some associated problems. This point was discussed at great length with the NCHRP project panel, and the research team was instructed not to eliminate sections that had possible functional drainage problems (e.g., clogged drain outlets) because the researchers could not ascertain whether the poor performance of a section was due to some deficiency of design (e.g., instability of drainage layer), construction (e.g., crushing of longitudinal drain pipe), or maintenance (e.g., clogged pipes).

Despite these limitations, the findings still merit consideration by highway agencies to improve design, construction, and maintenance activities and promote more cost-effective and reliable performance. The performance of a drained pavement depends on the quality of design, construction, and maintenance. Unless procedures for each of these factors can be improved to a more reliable level, the performance of a drained pavement will continue to be problematic.

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GLOSSARY OF ACRONYMS

AC	asphalt concrete
AGG	aggregate base
ATB	asphalt-treated base
CRCP	continuously reinforced concrete pavement
CTB	cement-treated base
ESAL	equivalent single-axle load
JPCP	jointed plain concrete pavement
JRCP	jointed reinforced concrete pavement
LCB	lean concrete base
LTPP	long-term pavement performance
PAGG	permeable aggregate base
PATB	permeable asphalt-treated base
PCC	portland cement concrete
PCTB	permeable cement-treated base
PGED	prefabricated geocomposite edgedrain
RPPR	rigid pavement performance and rehabilitation
SPS	special pavement studies

TABLE 1 Summary of asphalt concrete (flexible) pavement sections analyzed in NCHRP Project 1-34

Location, Age, and Traffic	Section (Base) Types	Other Details	Outlet Conditions	Rutting	Fatigue Cracking
California (dry non-freeze climatic region)					
SR12, San Joaquin Co. (2 sections) 5 years	ATB versus PATB w/edgedrains	Highly organic soil with extremely high fines content	Vegetation, clogged outlets	No significant difference	Excessive fatigue cracking associated with water bleeding at PATB w/edgedrains section
SR36, Tehama Co. (2 sections) 17 years	ATB versus PATB w/edgedrains	A-2 rocky silt loam soil	Good	No significant difference	None observed at either section
Indiana (wet-freeze climatic region)					
I-164, Evansville (1 section) 10 years, 6.7 million ESALs	PATB w/edgedrains	No control section	Good	Moderate	None
US31, Greenwood (2 sections) 6 years, 4.6 million ESALs	PATB w/edgedrains	No control section	Good	Low	Small amount of low-severity fatigue cracking at both sections
Kentucky (wet-freeze climatic region)					
AA Highway, SR546, Northern Kentucky (9 sections) 6–8 years, 0.7–6 million ESALs	a) PATB w/edgedrains b) PATB geotextile w/edgedrains c) PAGG w/edgedrains d) PATB, AGG w/edgedrains e) AGG w/edgedrains f) AGG g) Daylighted PATB h) Daylighted base, 24-in. rock i) AGG, 12-in. daylighted rock	Significantly higher traffic at the first two sections	Good; some vegetation near outlets	The rutting model developed for these sections indicates that permeable bases provide a reduction in rutting, especially if the base is also stabilized; use of a separator layer also improves rutting performance, as does a permeable large-rock layer.	The fatigue cracking model developed for these sections indicates that PATB and AGG perform similarly, with significant reduction in performance in sections with PAGG; permeable large-rock layer and lime-treated subgrade significantly reduce fatigue cracking.

Maryland (wet-freeze climatic region)					
MD-51, Allegany Co. (2 sections) 9 years, 0.39 million ESALs	AGG versus AGG w/edgedrains		Good	Edgedrain section had better rutting performance in the inner wheelpath	Edgedrain section had less fatigue cracking
MD-36, Allegany Co. (1 section) 13 years, 2.4 million ESALs	Edgedrains	Full-depth asphalt pavement	Good	Moderate	Small amount of low-severity fatigue cracking
Minnesota (wet-freeze climatic region)					
TH200/71, Hubbard Co. (4 sections) 12 years, 0.19 million ESALs	AGG versus PATB w/edgedrains	Two replicate sections for each design	Good	No significant difference between designs	Better fatigue performance observed at PATB w/edgedrains section
MnRoad, I-94, Wright Co. (3 sections) 2 years, 1.9 million ESALs	a) AGG (28 in.) b) AGG w/edgedrains c) PATB w/edgedrains	Data from LTPP database		Rutting significantly higher at the PATB w/edgedrains section; attributed to consolidation of the high air voids content of AC layer.	
North Carolina (wet non-freeze climatic region)					
I-40, Johnston Co. (1 section) 7 years, 1.8 million ESALs	AGG w/edgedrains	No control section	Good	Good rutting performance	Extensive low- to medium-severity fatigue cracking
NC-16, Mecklenburg Co. (2 sections) 8 years, 2 million ESALs	AGG versus AGG w/edgedrains		Good	No significant difference	Significantly less fatigue cracking at the edgedrain section, especially less high-severity fatigue cracking

Table continues on next page.

TABLE 1 Continued

Location, Age, and Traffic	Section (Base) Types	Other Details	Outlet Conditions	Rutting	Fatigue Cracking
Ohio (wet-freeze climatic region)					
US33, Bellefontaine (5 sections) 3 years, 2.5–2.9 million ESALs	a) PATB w/edgedrains b) PCTB w/edgedrains c) PAGG (NJ-type) w/edgedrains d) PAGG (IA-type) w/edgedrains e) AGG w/edgedrains	All permeable base sections have 4-in. AGG layer beneath the base course	Good	Most rutting in PAGG (IA-type) section; least rutting in PATB w/edgedrains section	Small amount of fatigue cracking at the PAGG (IA-type) section; no fatigue cracking at any other section
LTPP SPS-1, US23, Delaware (2 sections) 0.04 million ESALs	AGG versus PATB w/edgedrains		Good	Significantly higher in the conventional AGG base section	None
Oklahoma (wet non-freeze climatic region)					
SR-199, Carter Co. (2 sections) 5 years, 0.9 million ESALs	Daylighted PCTB versus PCTB w/edgedrains		Good; dead vegetation	No significant difference	None in either section
US64, Noble Co. (2 sections) 7 years, 1.4 million ESALs	Daylighted PATB versus PATB w/edgedrains	Geocomposite edgedrains	Good; dead vegetation	Significantly less in both wheelpaths of PATB w/edgedrains	Extensive low-severity fatigue cracking in both sections
Ontario (wet-freeze climatic region)					
Highway 16N, Ottawa (2 sections) 12 years, 3.7 million ESALs	PATB w/edgedrains versus AGG	No drainage trench; improper edgedrain design	Clogged; vegetation	More in PATB w/edgedrains section	Extensive in both sections
Tennessee (wet non-freeze climatic region)					
SR396, Maury Co. (2 sections) 6 years, 1 million ESALs	Daylighted PATB versus PATB w/edgedrains	CTB layer beneath PATB	Clogged	Low in both sections	None

SR397, Williamson Co. (2 sections) 7 years, 0.3 million ESALs	Daylighted PATB versus PATB w/edgedrains	AGG and CTB layers beneath PATB	Good	More rutting at daylighted section in inner wheelpath	Small amount at daylighted section
SR111, Putnam Co. (2 sections) 5 years, 0.8 million ESALs	Daylighted PATB versus PATB w/edgedrains		Good	More at edgedrain section	More at edgedrain section
SR290, Putnam Co. (1 section) 5 years, 0.037 million ESALs	PATB w/edgedrains	No control section	Good	Good rutting performance	None
Wisconsin (wet-freeze climatic region)					
STH167, Washington Co. (2 sections) 5 years, 1 million ESALs	AGG w/transverse drains versus PAGG w/edgedrains		Fair; partially blocked	Slightly more in the inner wheelpath of the transverse drains section	More observed at the transverse drains section
STH60, Washington Co. (4 sections) 5 years, 0.9–1.0 million ESALs	a) PATB w/edgedrains b) PAGG (WI-type) w/edgedrains c) AGG w/edgedrains d) PAGG (67-type) w/edgedrains	PAGG (67-type) more open than PAGG (WI-type)	Outlets for PATB in poor condition; outlets for PAGG (67-type) below ditch line	AGG base section had highest rutting in inner wheelpath, but lowest rutting in outer wheelpath	AGG base section had least fatigue cracking; PATB and PAGG (67-type) sections had greatest fatigue cracking

AC = asphalt concrete
AGG = aggregate base
ATB = asphalt-treated base
CTB = cement-treated base
ESAL = equivalent single-axle load
LTPP = long-term pavement performance
PAGG = permeable aggregate base
PATB = permeable asphalt-treated base
PCTB = permeable cement-treated base

TABLE 2 Summary of portland cement concrete (rigid) pavement sections analyzed in NCHRP Project 1-34

Location, Age, and Traffic	Section (Base) Types	Other Details	Outlet Conditions	Faulting	Cracking
		Jointed Plain Concrete Pavement (JPCP)			
		Kansas (wet-freeze climatic region)			
K7, Johnston Co. (8 sections) 10 years, 0.8 million ESALs Retrofitted edgedrains at 6 years	a) CTB w/PGED1 b) CTB c) CTB w/PGED2 d) CTB w/pipe edgedrain e) CTB w/AGG trench f) CTB w/PGED1 g) CTB w/pipe edgedrain h) CTB w/PGED2	9-in. JPCP, 15-ft spacing Non-doweled 4 sections in NB direction, 4 sections in SB direction, very low traffic volume	Good	All sections had severe faulting. Most faulting may have accumulated prior to edgedrain retrofit. In the NB direction, the section with no edgedrains had more faulting than the three edgedrained sections combined. In the SB direction, the section with the aggregate trench had more faulting than the other drained sections.	None observed
		Minnesota (wet-freeze climatic region)			
TH212, McLeod Co. (1 section) 22 years, 2 million ESALs	AGG w/edgedrains	9-in. JPCP, 20-ft spacing, non-doweled, tied shoulders, and surface planing 11 years prior.	Good	Severe from pumping and erosion of the base course; no apparent benefit from edgedrains	Very little transverse cracking; no longitudinal cracking
		North Carolina (wet non-freeze climatic region)			
I-40, Johnston Co. (1 section) 7 years, 3.2 million ESALs	PATB w/edgedrains	10-in. JPCP, 18-19-21-22-ft spacing, doweled	Good	None	None
I-40, Johnston Co. (2 sections) 12 years, 11.7 million ESALs Retrofitted edgedrains at 8 years	LCB w/edgedrains	11-in. JPCP, 19-18-25-23-ft spacing, doweled	Good	None; unable to assess effects of edgedrains	Very little transverse cracking; small amounts of longitudinal cracking

Ontario (wet-freeze climatic region)					
Highway 115, Peterborough (3 sections) 6 years, 0.9 million ESALs	a) PCTB w/edgedrains b) PATB w/edgedrains c) PAGG w/edgedrains	7.9-in. JPCP, 12-13-19-18-ft spacing, doweled	Outlets clogged	Very low; PAGG section had the greatest of the three	More, especially longitudinal, in PAGG than PCTB or PATB
Pennsylvania (wet-freeze climatic region)					
SR-30, Bedford Co. (2 sections) 16 years, 1.7 million ESALs Retrofitted w/edgedrains at 10 years	Daylighted PAGG versus PAGG w/edgedrains	9-in. JPCP, 20-ft spacing, doweled, geocomposite edgedrains	Good	Low; no significant difference between daylighted and edgedrained sections	No cracking or spalling
I-70, Washington Co. (1 section) 7 years, 12.4 million ESALs	PAGG w/edgedrains	13-in. JPCP, 20-ft spacing, doweled, geocomposite edgedrains		Very little	Very little
Wisconsin (wet-freeze climatic region)					
STH14, Dane Co. (3 sections) 8 years, 2.1 million ESALs	a) AGG w/edgedrains b) AGG c) PATB/AGG w/edgedrains	8-in. JPCP, 13-11-17-19-ft spacing, non-doweled	Standing water along ditches	Greatest amount at AGG section; 25% reduction at AGG w/edgedrains section, 75% reduction at PATB w/edgedrains section	Substantially greater at AGG section
STH18/151, Dane Co. (5 sections) 8 years, 2.2 million ESALs	a) PCTB w/edgedrains b) PATB w/edgedrains c) PAGG w/edgedrains d) AGG e) AGG	9-in. JPCP, 12-13-19-18-ft spacing, doweled	Fair	None	None

Table continues on next page.

TABLE 2 Continued

Location, Age, and Traffic	Section (Base) Types	Other Details	Outlet Conditions	Faulting	Cracking
			Jointed Reinforced Concrete Pavement (JRCP)		
			Illinois (wet-freeze climatic region)		
I-39, McClean Co. (2 sections) 7 years, 1.5 million ESALs	LCB w/edgedrains versus PCTB w/edgedrains	10.8-in. JRCP, 45-ft spacing, 15-ft saw space, doweled	Good	Very low	None
			Minnesota (wet-freeze climatic region)		
TH15, Martin Co. (3 sections) 13 years, 1.4 million ESALs	a) AGG w/edgedrains b) PATB w/edgedrains c) AGG	8-in. JRCP, 27-ft spacing, doweled	Good; dead vegetation	Sections with edgedrains showed less faulting	Significantly less transverse cracking at PATB w/edgedrains section than at sections with AGG base
			Pennsylvania (wet-freeze climatic region)		
SR3-30, Bedford Co. (2 sections) 16 years, 3.5 million ESALs Retrofitted w/edgedrains at 10 years	Daylighted PAGG versus PAGG w/edgedrains	9-in. JRCP, 64-ft spacing, doweled, geocomposite edgedrains	Good	Very low; no significant difference between two sections	Identical cracking, but daylighted section had severe spalling
			Continuously Reinforced Concrete Pavement (CRCP)		
			Illinois (wet-freeze climatic region)		
I-39, Woodford Co. (2 sections) 4 years, 1.7 million ESALs	PCTB/AGG w/edgedrains versus PCTB w/edgedrains	10-in. CRCP	Good	No significant difference	No significant difference
I-39, LaSalle (8 sections) 6 years, 1.5 million ESALs	a) 4-in. LCB b) 4-in. PATB c) 5-in. PATB d) 4-in. PATB, AGG e) 4-in. LCB f) 4-in. PCTB, AGG g) 5-in. PCTB h) 4-in. PCTB	10-in. CRCP, all sections edgedrained, PATB sections NB, PCTB sections SB	Some partially clogged; standing water at some sections	All sections performing fairly well. In NB direction, LCB had least number of deteriorated cracks, while PATB/AGG had highest number. No significant difference between 4-in. and 5-in. PATB. In SB direction, 5-in. PATB had least number of deteriorated cracks, the PCTB/AGG section had greatest number. The 4-in. PCTB section performed similarly to the LCB section.	

I-57, Champaign Co. (1 section) 25 years, 7.4 million ESALs Retrofitted w/edgedrains at 6 years	AGG w/edgedrains	8-in. CRCP	Poor	Most transverse cracks have deteriorated. Effect of retrofitted edgedrains could not be assessed.
Oklahoma (wet non-freeze climatic region)				
SR-74, Oklahoma Co. (2 sections) 6 years, 2.5 million ESALs	Daylighted PATB versus PATB w/edgedrains	10-in. CRCP	Good	Both sections are performing identically well.

AGG = aggregate base
CRCP = continuously reinforced concrete pavement
CTB = cement-treated base
ESAL = equivalent single-axle load
JPCP = jointed plain concrete pavement
JRCP = jointed reinforced concrete pavement
LCB = lean concrete base
NB = northbound
PAGG = permeable aggregate base
PATB = permeable asphalt-treated base
PCTB = permeable cement-treated base
PGED = prefabricated geocomposite edgedrain
SB = southbound