

Perpetual Pavements

A Synthesis



ASPHALT PAVEMENT ALLIANCE

NATIONAL ASPHALT PAVEMENT ASSOCIATION
ASPHALT INSTITUTE
STATE ASPHALT PAVEMENT ASSOCIATIONS



ASPHALT PAVEMENT ALLIANCE

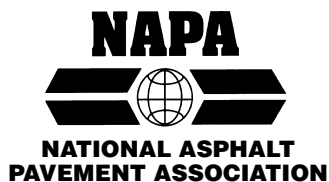
5100 Forbes Boulevard, Lanham, MD 20706-4407

Toll-free: 888-468-6499 Fax: 301-731-4621

publications@AsphaltAlliance.com www.AsphaltAlliance.com

This document was prepared for the Asphalt Pavement Alliance (APA), a coalition of the National Asphalt Pavement Association (NAPA), Asphalt Institute (AI), and State Asphalt Pavement Associations (SAPA). The content of this report reflects the views of the author(s), who are responsible for the facts and accuracy of the data presented herein. The contents do not reflect the decision-making process of NAPA, AI, or SAPA with regard to the advice or opinions on the merits of certain practices. This document does not constitute a standard, specification, or regulation.

The author(s) and the APA do not endorse specific products or manufacturers. Trade or manufacturers' names appear herein because they are essential to this document.



Published 2002 Asphalt Pavement Alliance

Order Number APA 101

1/02

PERPETUAL PAVEMENTS

A Synthesis

Introduction	5
Mechanistic-based Design	6
Foundation	8
HMA Considerations	11
HMA Base Layer	11
Intermediate Layer	12
Wearing Surface	13
Performance Goals	14
Current Perpetual Pavement Efforts	15
California	15
Illinois	16
Michigan	17
Wisconsin	18
Texas	19
Kentucky	19
Ohio and Virginia	20
United Kingdom	20
Summary	21
References	23



ASPHALT PAVEMENT ALLIANCE

5100 Forbes Boulevard
Lanham, MD 20706
888-468-6499
publications@AsphaltAlliance.com

NATIONAL ASPHALT PAVEMENT ASSOCIATION
ASPHALT INSTITUTE
STATE ASPHALT PAVEMENT ASSOCIATIONS



Abbreviations used in this document:

AASHTO	American Association of State Highway and Transportation Officials
AASHO	American Association of State Highway Officials
AI	Asphalt Institute
CBR	California Bearing Ratio
DOT	Department of Transportation
APEC	Asphalt Paving Environmental Council
EAPA	European Asphalt Pavement Association
ESAL	Equivalent Single Axle Load
FWD	Falling Weight Deflectometer
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
IDOT	Illinois Department of Transportation
KTC	Kentucky Transportation Cabinet
LCPC	Laboratoire Central de Ponts et Chasses
MAPA	Michigan Asphalt Paving Association Inc.
Mn/ROAD	Minnesota Road Research Project
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
ODOT	Ohio Department of Transportation
OGFC	Open Graded Friction Course
PAIKY	The Plantmix Asphalt Industry of Kentucky
PG	Performance Grade
SHRP	Strategic Highway Research Program
SMA	Stone Matrix Asphalt
SST	Superpave Shear Test
TxDOT	Texas Department of Transportation
TxHMAPA	Texas Hot Mix Asphalt Pavement Association
TRB	Transportation Research Board
TRL	Transport Research Laboratory
TRRL	Transport and Road Research Laboratory
WSDOT	Washington State Department of Transportation
WisDOT	Wisconsin Department of Transportation
WAPA	Wisconsin Asphalt Pavement Association

Acknowledgements

This synthesis was prepared by Dr. David Newcomb of the National Asphalt Pavement Association.

A number of individuals contributed information contained herein. Dr. Mark Buncher of the Asphalt Institute and Mr. Jim Huddleston of the Asphalt Pavement Association of Oregon both serve on the Asphalt Pavement Alliance resource team for Perpetual Pavements. Dr. Buncher provided valuable insight during the preparation of this work and Mr. Huddleston is to be credited with many of the innovative ideas concerning Perpetual Pavements.

A workshop on Perpetual Pavements was held in October 2000 in Cincinnati. The following attendees discussed many of the topics presented herein:

Mr. Tom Blair – Cadillac Asphalt Paving Co.
Mr. Dean Blake – The Plantmix Asphalt Industry of Kentucky Inc.
Dr. Mark Buncher – Asphalt Institute
Dr. Ray Brown – National Center for Asphalt Technology
Mr. Ron Collins – Pavement Technologies, Inc.
Mr. Bill Fair – Flexible Pavements of Ohio
Mr. Frank Fee – Citgo Asphalt Refining Co.
Mr. Gary Fitts – Asphalt Institute
Dr. Kevin Hall – University of Arkansas
Mr. Kent Hansen – National Asphalt Pavement Association
Mr. Gerry Huber – Heritage Research
Mr. Jim Huddleston – Asphalt Pavement Association of Oregon
Dr. Joe Mahoney – University of Washington
Mr. Jack Mathews – Alabama Asphalt Pavement Association
Dr. Rich May – Koch Materials Co.
Dr. David Newcomb – National Asphalt Pavement Association
Mr. Michael Nunn – Transport Research Laboratory
Mr. Richard Schreck – Virginia Asphalt Association Inc.
Mr. Jim Scherocman – Consulting Engineer
Dr. Marshall Thompson – University of Illinois
Dr. Marvin Traylor – Illinois Asphalt Pavement Association
Mr. Cliff Ursich – Flexible Pavements of Ohio
Mr. Harold Von Quintus – Fugro-BRE Inc.
Mr. Brian Wood – The Plantmix Asphalt Industry of Kentucky Inc.

Credit is due Dr. Joe Mahoney for contributing valuable text concerning the treatment of frost heave and thaw weakening in soils, and to Dr. Marshall Thompson for providing information concerning the practice of treating subgrade soils in Illinois.

The following reviewers gave a great deal of thought and comment on the presentation of the information in this synthesis: Messrs. Byron Lord, John Bukowski and John D'Angelo of the Federal Highway Administration; Dr. Marvin Traylor of the Illinois Asphalt Pavement Association; Mr. John Becsey of the Michigan Asphalt Paving Association Inc.; and Dr. Joe Mahoney of the University of Washington. Their input into this document was invaluable.

Introduction

A Perpetual Pavement is defined as an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement.

The concept of Perpetual Pavements, or long-lasting asphalt pavements, is not new. Full-depth and deep-strength asphalt pavement structures have been constructed since the 1960s, and those that were well-designed and well-built have been very successful in providing long service lives under heavy traffic.

Full-depth pavements are constructed directly on unmodified or modified subgrade soils, and deep-strength sections are placed on granular base courses. One of the chief advantages of these pavements is that the overall section of the pavement is thinner than those employing a thin asphalt layer over thick granular layers. As a result, the potential for traditional fatigue cracking may be eliminated, and pavement distress may be confined to the upper layer of the structure. Both are advantages to Perpetual Pavements. Thus, when surface distress reaches a critical level, an economical solution is to simply remove the very top layer and replace it to the same depth. The pavement material that is removed can then be recycled.

Recent efforts in materials selection, mixture design, performance testing, and pavement design offer a methodology to obtain even longer-lasting performance from

asphalt pavement structures (greater than 50 years) while periodically replacing the pavement surface. The structure, designed for durability, combines a rut-resistant and wear-resistant top layer with a rut-resistant intermediate layer and a fatigue-resistant base layer as shown in Figure 1. By applying the proper structural design and selecting materials appropriate to their placement within the structure, the designer can make the conscious decision to obtain a long-lasting pavement.

This approach can be taken on any pavement structure where it is desirable to minimize rehabilitation and reconstruction costs as well as minimize closures to traffic. While these considerations are especially important for high-traffic-volume roadways and major

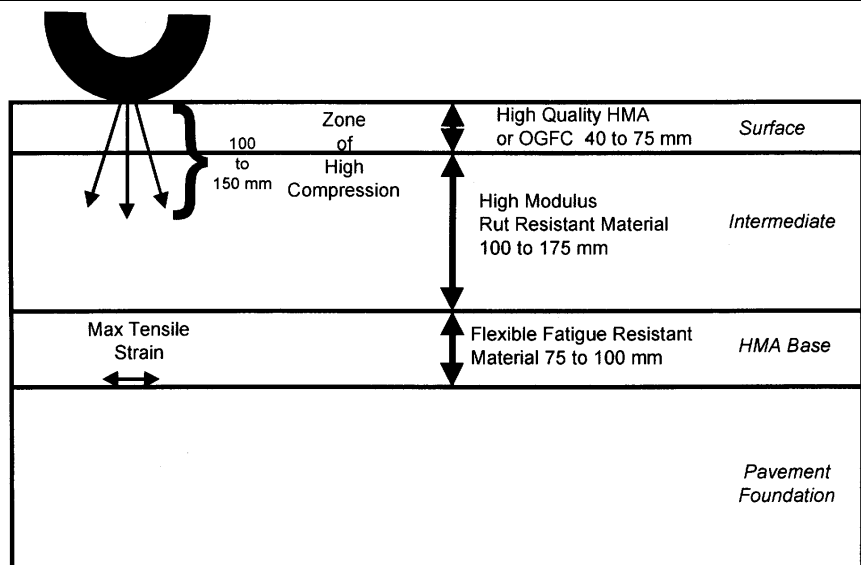
airports where user-delay costs may be prohibitive, they could certainly be applied to lower-volume roads and general aviation airfields where the possibility of future funding cuts may require deferred rehabilitation.

A life cycle cost analysis, including user-delay costs, should be employed to evaluate different pavement strategies. In this process, consideration should be given to the realistic expectation of the availability of future funding. If future funding for rehabilitation is uncertain, then the construction of a thicker pavement initially may preclude the need for costly rehabilitation or reconstruction in the future.

This synthesis is intended to present discussions pertaining to pavement design, materials and mix design, and construction

Figure 1

Perpetual Pavement Design Concept



relevant to Perpetual Pavements. Since past empirical practices have not recognized the long-life nature of thick Hot Mix Asphalt (HMA) pavements, pavement design is discussed in terms of mechanistic-based design, one of the key considerations being the pavement foundation. Beyond the need for long-term stability, the pavement foundation plays a critical role in providing a

working platform for the placement and compaction of the asphalt layers. HMA materials are addressed in terms of properties needed in the various layers of the pavement. The proper construction for long-lasting pavement performance is discussed because without it the structural design and materials selection processes are incomplete. The performance of demonstrated

long-life HMA pavements is discussed in order to validate the concept that distresses in Perpetual Pavements are confined to the surface, and that deep structural problems are eliminated or minimized. Finally, the experiences of agencies working toward the goal of producing long-life HMA pavement design procedures are presented.

Mechanistic-based Design

The basic premise of obtaining a long pavement life is that an adequately thick HMA pavement placed on a stable foundation will preclude distresses that originate at the bottom of the pavement and that eventually require expensive reconstruction to correct properly. Structurally, the pavement must have the proper combination of thickness and stiffness to resist deformation in the foundation material or the underlying subgrade. Likewise, the HMA layers must be thick enough and have the right properties to resist fatigue cracking originating at the bottom of the structure.

Currently, most pavement design procedures do not consider each pavement layer and its contribution in resisting fatigue, rutting, and temperature cracking in the structure. Since each pavement layer has its own unique part to play in performance, an improved structural design method is needed to analyze each pavement layer. Past empirical methods such as the California Bearing Ratio (CBR) or the

American Association of State Highway and Transportation Officials (AASHTO) structural coefficient procedures cannot consider the contributions by different HMA layers in the pavement, but the mechanistic-empirical approach can.

Mechanistic techniques for asphalt pavement design have been known since the 1960s, although wider development and implementation started in the 1980s and 1990s. States such as Illinois, Kentucky, Minnesota, and Washington are currently adopting mechanistic design procedures, and a research project under the National Cooperative Highway Research Program (NCHRP) is proceeding on the development of a new mechanistically based pavement design guide, which may be adopted by AASHTO.

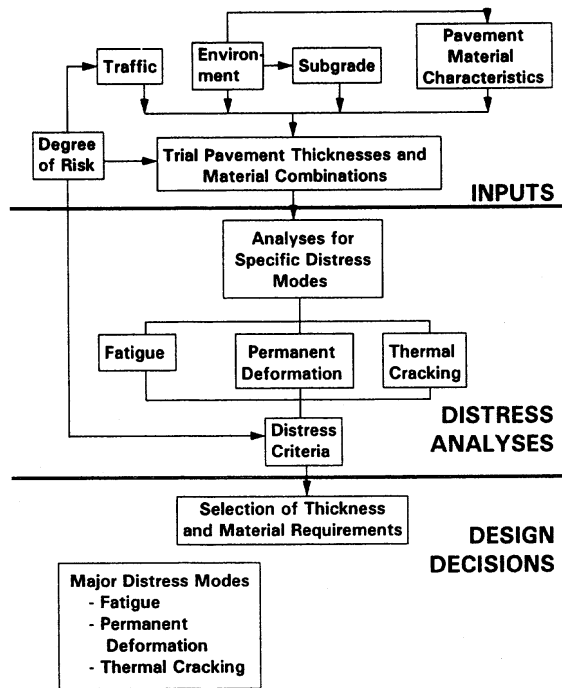
Mechanistic design is much the same as the engineering approaches used for structures such as bridges, buildings, and dams. Essentially, the principles of mechanics are used to determine a pavement's reaction to climate

and loading. Knowing the critical points in the pavement structure, one can design against certain types of failure or distress by choosing the appropriate materials and layer thicknesses. Monismith (1992) thoroughly outlined the mechanistic design approach in his Transportation Research Board (TRB) Distinguished Lecturer paper. His process is shown in Figure 2, wherein the material properties, traffic, climate, and performance are interactively combined in determining the required structural section.

The Washington State Department of Transportation (WSDOT) has been using a mechanistic-empirical design procedure for designing HMA overlays since the late 1980s. The Washington approach uses a fatigue transfer function based on Monismith's laboratory relationship between tensile strain, asphalt mixture modulus, and number of cycles to failure. A shift factor of between 4 and 10 is used to adjust the laboratory fatigue relationship to the field. Their structural rutting transfer function was proposed by

Figure 2

Mechanistic Design Flowchart (Monismith, 1992)



Santucci (1977). In comparing the WSDOT overlay design method with the approach recommended by the AASHTO 1993 pavement design guide, Pierce and Mahoney (1996) found the overlay thicknesses determined by the AASHTO method to be overly conservative.

The Illinois DOT (IDOT) uses a mechanistic approach to pavement design developed at the University of Illinois at Urbana-Champaign (Gomez and Thompson, 1984; Thompson and Cation, 1986; Thompson, 1987). This procedure is based upon the results of finite element analysis using the computer program ILLI-PAVE. A strain-based fatigue equation is used which accounts for HMA proportioning, tensile strength, and field performance. This procedure has been implemented by IDOT.

The state of Minnesota has been developing a mechanistic design procedure based on

information collected from the Minnesota Road Research Project (Mn/ROAD) (Timm et al., 1999). The layered elastic computer program WESLEA (Waterways Experiment Station Layered Elastic Analysis) was used in computing pavement responses to load. Suggestions for seasonal changes in material properties and for performance criteria were obtained from Mn/ROAD data analysis. This procedure is currently being evaluated and modified for use by the Minnesota DOT.

The British used a mechanistic design procedure developed by Powell, et al. (1984) to calculate pavement responses at critical locations in the structure. This early procedure was based upon the assumption of incremental damage occurring in the pavement structure due to repeated loads from commercial vehicles. Thus, regardless of pavement thickness, it was

assumed that cracking or structural rutting would eventually occur. In fact, Nunn and his colleagues (1997) found that in thick asphalt pavements, there is an upper limit to thickness beyond which bottom-up fatigue cracking and structural rutting do not occur in well-constructed pavements. The result was the establishment of a design chart in which the asphalt pavement thickness at 80 million standard axle loads (the same as an equivalent single axle load [ESAL]) does not change. This approach to pavement design is a new paradigm: increasing traffic levels do not automatically necessitate thicker flexible pavement structures. This is because there is a bending strain level at the bottom of the HMA below which fatigue damage will not occur, and any additional HMA thickness to reduce strain will be superfluous. This strain level is known as the fatigue limit.

Mechanistic pavement design is being more readily adopted by various agencies as an improved method for analyzing pavement structures and assessing the impact of changes in traffic and materials. The scheduled completion of the new *Guide for the Design of Pavement Structures* in 2002 should move the implementation of mechanistic design even faster.

Ultimately, whatever mechanistic approach may be adopted, it must recognize the characteristics inherent in the Perpetual Pavement, including the validity of the fatigue limit in bound layers for bottom-up load-related cracking and the preclusion of structural rutting. The mechanistic design process for Perpetual Pavement would conceptually be more of a design for maximum strain than a design for incremental damage.

Foundation

The pavement foundation is critical to the construction and performance of a Perpetual Pavement. During construction, the foundation provides a working platform that supports the dump trucks and laydown equipment placing the HMA layers. It also provides resistance to deflection under the rollers in order that the upper layers of the pavement may be firmly compacted. Throughout the performance period, the foundation is critical in supporting the traffic loads and reducing the variability in support from season to season due to freeze-thaw and moisture changes. Proper design and construction of the foundation are keys to preventing volume change due to wet-dry cycles in expansive clays and freeze-thaw cycles in frost-susceptible soils.

Several northern states incorporate frost design into their pavement structures in areas where the soils and conditions may lead to thaw weakening or non-uniform frost heave. Generally, these states require that the total pavement structure thickness equal or exceed 50 percent of the expected design frost depth. This requirement is generally taken to be a minimum. Results from the American Association of State Highway Officials (AASHTO) Road Test and research in other countries (such as Japan) suggest that a depth of up to 70 percent may be required. Such criteria generally require that the pavement structure be constructed of non-frost-susceptible materials.

A pavement foundation may be comprised of compacted subgrade, chemically stabilized subgrade or granular material, or unstabilized

granular material such as crushed rock or gravel. Regardless of the kind of material employed, the foundation should meet some minimum requirement for stiffness throughout construction as well as during the life of the pavement. Depending upon site conditions and pavement design, this may require the chemical or mechanical stabilization of soils or base course materials. Terrel and Epps (1979) provide excellent guidance on the selection of the stabilization procedures for unbound materials. Furthermore, the site and climate may dictate that drainage features be included in the pavement design, and guidance on subsurface drainage may be found in the Federal Highway Administration (FHWA) manual (Moulton, 1980). The Illinois DOT (IDOT) has put a great deal of emphasis on subgrade soils as detailed in their Subgrade Stability

Manual (IDOT, 1982). From a constructability standpoint, Illinois requires a subgrade to have a minimum California Bearing Ratio (CBR) of about 6 to avoid excessive deformation during the construction of subsequent granular layers; they base this requirement on the graph shown in Figure 3. This graph presents the relationships between soil strength, sinkage, and the tire pressure under a 40-kN load. Figure 4 shows the conditions under which IDOT requires remedial procedures. Remedial action is required if the soil CBR is less than 6, it is optional between a CBR of 6 and 8, and it is considered unnecessary above 8.

The remedial procedures provide a working platform adequate to facilitate paving operations, prevent overstressing

Figure 3

Soil Strength for Support of Construction Equipment (IDOT, 1982)

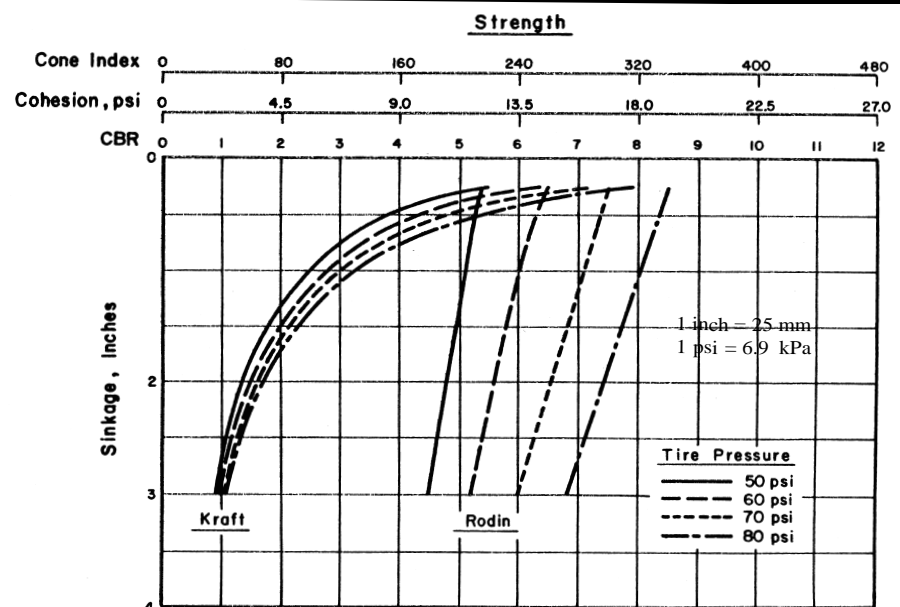
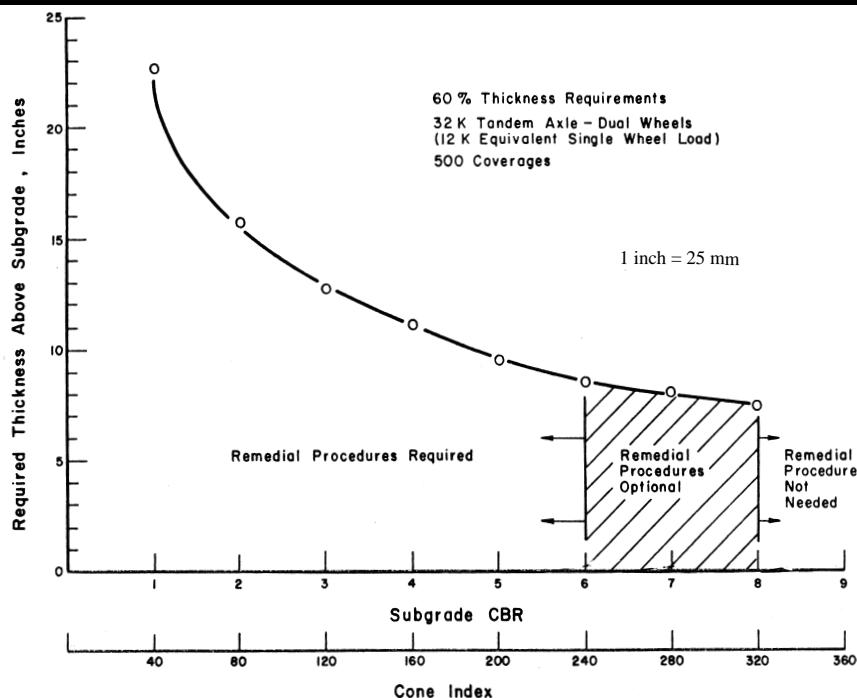


Figure 4

Illinois Granular Thickness Requirement for Foundation
(IDOT, 1982)



the subgrade, and minimize the development of surface rutting from construction traffic.

The most frequently used procedure is to lime-modify (IDOT, 2002) the fine-grained subgrade soils that predominate in Illinois. Undercutting and backfilling with granular material (geo-fabrics are sometimes used) is also a commonly used procedure. The required thickness above the subgrade is typically 300 mm. For subgrade strengths less than a CBR of 4, the thickness is increased as per Figure 4.

If the immediate CBR of the lime-modified soil is less than 10, a granular surface layer may be necessary. The combined thickness of the granular layer and the lime-modified soil is a minimum of 200 mm and should follow the guidelines in Figure 4. The granular material must be adequate in terms of stiffness and strength to accommodate the construction traffic. Highly plastic fines should not be used in base materials.

Table 1 presents layer thickness requirements for lime treatment (IDOT, 2002) of low-strength soils according to various strength and stiffness criteria, including the modulus of subgrade reaction (k), CBR, or Cone Index from the dynamic cone penetration test. This specification is more stringent than IDOT's lime-modified soils specification. The increased strength of lime-stabilized soil mixtures permits a reduction in the lime-treated layer thickness.

Seasonal modulus adjustment factors are used in Washington and Minnesota for subgrade and overlying granular materials to characterize their behaviors during the design life. Seasonal modulus adjustment factors for unbound materials differ between

Table 1

Illinois Requirements for Depth of Lime Modification (IDOT, 1982)

Subgrade Strength ¹			Minimum Lime-Soil Layer Thickness, inches ²	
k , psi/in*	CBR	Cone Index	100 psi ³	200 psi ³
50	2	80	12	9
125	4	160	12	9
150	6	240	9	8
200	8	320	9	8

¹ In-situ subgrade strength

² Strength before opening to traffic

³ Unconfined compressive strength

* Modulus of subgrade reaction

1 inch = 25 mm

1 psi = 6.9 kPa

Table 2

Seasonal Adjustment Factors for Unbound Materials Used in Washington State (Pierce and Mahoney, 1996)

Location	Material	Season			
		Spring	Summer	Fall	Winter
Eastern WA	Base	0.65	1.00	0.90	1.10
	Subgrade	0.90	1.00	0.90	1.10
Western WA	Base	0.85	1.00	0.90	0.75
	Subgrade	0.85	1.00	0.90	0.85

eastern and western Washington State as shown in Table 2 (Pierce and Mahoney, 1996). The seasons in Washington are assumed to be of equal length, and the base season is the summer with a multiplication factor of 1.00. A slightly different approach is taken in Minnesota where the seasons are considered to be of unequal lengths as shown in Table 3, and the base season is the fall. Because the progression of thawing results in different behavior in the upper and lower regions of the pavement, the spring period is divided into early and late spring. Ovik, et al. (1999) determined these seasonal factors from data collected at the Minnesota Road Research Project (Mn/ROAD). The weakest condition for granular base materials is in the early spring, and for the subgrade it is in the late spring. The very high multiplication factors for the winter reflect a frozen condition in the base and subgrade material. In the design of Perpetual Pavements, it is important to know how seasonal changes in the moduli of unbound materials may affect the response of the pavement. In other words, it may be necessary to consider the worst condition in order to preclude undue damage during a given season.

Nunn et al. (1997) encourage the use of in-situ testing for pavement foundation materials. They formulated an end-result specification founded on nuclear density tests and surface stiffness as measured by a portable dynamic plate bearing test. The foundation design practice in the United Kingdom is shown in Table 4 (Nunn). The CBR of the subgrade dictates the thickness of the overlying granular layers called the capping and subbase layers.

Table 3

Seasonal Adjustment Factors for Mn/ROAD (After Ovik, et al.)					
<i>Month</i>	<i>Late Nov, Dec, Jan, Feb</i>	<i>March</i>	<i>April, May</i>	<i>June, July, August</i>	<i>Sept, Oct, early Nov</i>
HMA (120/150 pen asphalt)	2.5	2.1	1.3	0.37	1.0
Granular Base	28	0.65	0.80	1.0	1.0
Subgrade	22	2.4	0.75	0.75	1.0

Table 4

Transport Research Laboratory Foundation Requirements (Nunn, 1997)			
<i>Subgrade CBR</i>	≥ 2	2 – 5	> 5
Subbase Thickness, mm	150	150	225
Capping Thickness, mm	600	350	—

For a subgrade CBR of less than 15, a minimum 150-mm thickness of subbase is required. Capping material may be considered similar in quality to a lower quality base course material in the United States, and the subbase may be considered a high quality base material. Transport Research Laboratory (TRL) set end-result requirements for the pavement foundation, both during and after its construction. Under a falling weight deflectometer (FWD) load of 40 kN, a stiffness of 40 MPa was required on top of the subgrade and 65 MPa was required at the top of the subbase.

The German Ministry of Transportation (1989) requires a minimum subgrade surface modulus of 45 MPa when tested using a static plate-bearing test with a 300-mm diameter plate. At the top of the subbase layer, they require 120 MPa for light traffic conditions and 180 MPa for heavy traffic.

The French (Laboratoire Central de Ponts et Chasses [LCPC],

1992) use an end-result specification for the constructed road foundation. For support of construction traffic, either of the two following criteria must be met: a deflection of less than 2 mm under a 13-ton axle load, or a plate-bearing test modulus of more than 50 MPa. For service conditions, the required subbase stiffness is tied to the strength of the subgrade.

The design and construction of a strong, stable, and consistent foundation is requisite to a Perpetual Pavement. The initial concern is support of construction traffic and a firm layer for providing a reaction to compaction efforts. Long-term support of traffic loads and minimization of volume change are crucial to performance. Thus, guidelines are needed for assessment of stiffness at the time of construction, required stiffness for long-term performance as input to mechanistic design, and provisions to minimize volume change due to expansive behavior or frost heave.

HMA Considerations

Since the Perpetual Pavement is tailored to resist specific distresses in each layer, the materials selection, mix design, and performance testing need to be specialized for each material layer. The mixtures' characteristics need to be optimized to resist rutting or fatigue cracking, depending upon which layer is being considered. Durability is a primary concern for all layers.

HMA Base Layer

The asphalt base layer must resist the tendency to fatigue cracking from bending under repeated traffic loads. One mixture characteristic that can help guard against fatigue cracking is a higher designed asphalt content (Figure 5a). A summary of fatigue research studies by Epps and Monismith (1972) established that this behavior is consistent in many asphalt mixtures. Additional asphalt, up to a point, provides the flexibility needed to inhibit the formation and growth of fatigue cracks. Combined with an appropriate total asphalt thickness, this ensures against fatigue cracking from the bottom layer (Figure 5b). The concept of a "rich" or high-asphalt-content base is being employed in California (Monismith and Long, 1999a) and Illinois (IDOT, 2001).

Another approach to ensuring the fatigue life would be to design a thickness for a stiff structure such that the tensile strain at the bottom of the asphalt layers would be minimized to the extent that cumulative damage would not occur. This would allow for a single mix

design to be used in the base and intermediate layers, precluding the need to switch mix types in the lower pavement structure. This strategy is used in the TRL method proposed by Nunn and his colleagues (1997) as well as the French (EAPA, 1999).

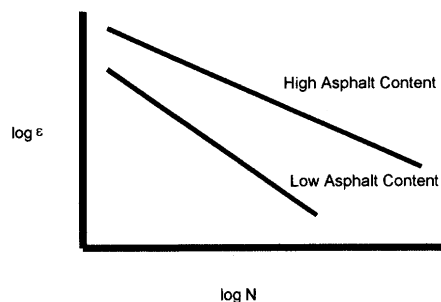
The asphalt content in the base should be defined as that which produces low air voids in place. This ensures a higher volume of binder in the voids in mineral aggregate (VMA), which is critical to durability and flexibility. This concept has been substantiated by Linden et al. (1989) in a study that related higher-than-optimum air void content to reduction in fatigue life. Fine-graded asphalt mixtures have also been noted to demonstrate improved fatigue life (Epps and

Monismith, 1972). The asphalt grade should have the high-temperature characteristics as dictated by the depth of the layer in the pavement. The low-temperature characteristics should be the same as those of the intermediate layer. If this layer is to be opened to traffic during construction, provisions should be made for rut-testing the material to ensure performance during construction, at a minimum. Consideration should be given to fatigue testing this material using the four-point bending method described by Tayebali et al. (1994a and 1994b). This test has been standardized by AASHTO (2001) in its provisional standard TP 8-94. It should be noted that fatigue testing requires substantial equipment and training investment.

Figure 5

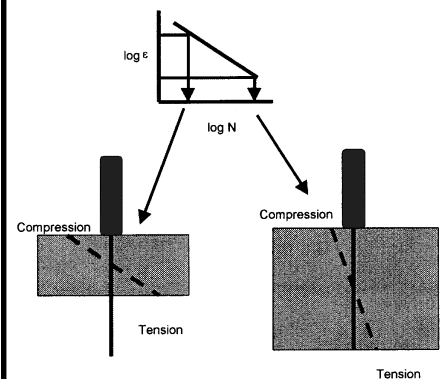
Fatigue Resistant Asphalt Base

Figure 5a



**Improve Fatigue Resistance
with High Asphalt Content Mixes**

Figure 5b



**Minimize Tensile Strain
with Pavement Thickness**

It is important to design pavements so that the bending strain at the bottom of the pavement is less than the fatigue limit of the material. The fatigue limit is the strain below which the material will not fail in fatigue. Japanese researchers (Nishizawa, et al., 1997) have suggested a fatigue limit for asphalt mixtures.

Because this layer is the most likely to be in prolonged contact with water, moisture susceptibility needs to be considered. A higher asphalt content should enhance the mixture's resistance to moisture problems, but it is advisable to conduct a moisture susceptibility test such as AASHTO T 283 (AASHTO, 2000) during the mix design.

Intermediate Layer

The intermediate, or binder, layer must combine the qualities of stability and durability. Stability in this layer can be obtained by achieving stone-on-stone contact in the coarse aggregate and using a binder with an appropriate high-temperature grading. This is especially crucial in the top 150 mm of the pavement where high stresses induced by wheel loads can cause shear failure.

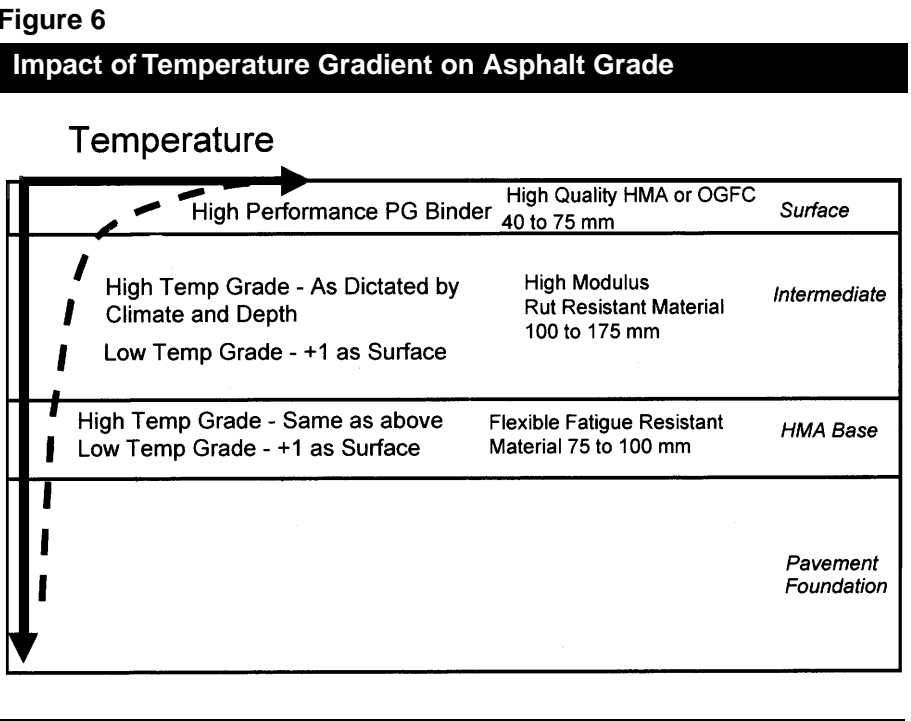
The internal friction provided by the aggregate can be obtained by using crushed stone or gravel and ensuring an aggregate skeleton. One option would be to use a large nominal maximum size aggregate, and guidance for the design of large-stone mixtures can be found in Kandhal (1990) and Mahboub and Williams (1990). For mixtures with a nominal maximum aggregate size up to 37.5 mm, the Superpave mix design approach may be used (Asphalt Institute,

1996b). The same effect could be achieved with smaller aggregate sizes so long as stone-on-stone contact is maintained. One test for evaluating whether this type of interlock exists is the Bailey method (Vavrik et al., 2001). Segregation in coarse aggregate mixtures is an area of concern but proper handling of the material during manufacture, transport, and laydown can prevent the problem (AASHTO, 1997).

The Performance Graded (PG) binder system is used to classify the asphalt according to high and low service temperatures (Asphalt Institute, 1996a). The high-temperature grade of the asphalt should be the same as the surface to resist rutting. However, the low-temperature requirement could probably be relaxed one grade, since the temperature gradient in the pavement is relatively steep and the low temperature in this layer would not be as severe as in the surface layer

(Figure 6). For instance, if a PG 70-28 is specified for the surface layer, a PG 70-22 could be used in the intermediate layer.

The mix design should be a standard Superpave approach (Asphalt Institute, 1996b), and the design asphalt content should be the optimum. Performance testing should include rut testing and moisture susceptibility, at a minimum. Although a test for fundamental permanent deformation properties is currently being developed in a National Cooperative Highway Research Program project, it is recommended that a rut-testing device be used in the interim to evaluate mixtures in order to protect against early rutting. A recent report on performance testing is available from the National Center for Asphalt Technology (Brown et al., 2001). They suggest that the conditions of rut testing need to be selected considering the high-temperature grade of the PG



binder or criteria for the particular device. Another option for performance testing is the Superpave shear test (SST) developed during the Strategic Highway Research Program (SHRP) (Sousa et al., 1994), and standardized in AASHTO test method TP 7-01 (AASHTO, 2001). Currently, most moisture susceptibility testing is performed in accordance with AASHTO test method T 283-89 (AASHTO, 2000).

In adjusting layer moduli for seasonal variations, the Washington State DOT (Pierce and Mahoney, 1996) and the Minnesota DOT (Ovik et al., 1999) use modulus-temperature relationships for asphalt concrete and seasonal multiplication factors based on estimated pavement temperatures. For structural design purposes, the HMA modulus corresponding to the mean monthly pavement temperature is used.

Wearing Surface

The wearing surface requirements would depend on traffic conditions, environment, local experience, and economics. Performance requirements include resistance to rutting and surface cracking, good friction, mitigation of splash and spray, and minimization of tire-pavement noise. These considerations could lead to the selection of Stone Matrix Asphalt (SMA), an appropriate Superpave dense-graded mixture, or Open Graded Friction Course (OGFC). Guidance on mix type selection can be found in the *HMA Pavement Mix Type Selection Guide* by the National Asphalt Pavement Association (NAPA, 2000).

In some cases, the need for rutting resistance, durability, impermeability, and wear resistance would dictate the use of SMA. This might be especially true in urban areas with high truck traffic volumes. Properly designed and constructed, an SMA will provide a stone skeleton for the primary load-carrying capacity and the matrix (combination of binder and filler) gives the mix additional stiffness. Methods for performing SMA mix design are given in NCHRP Report No. 425 (Brown and Cooley, 1999).

The matrix in an SMA can be obtained by using polymer-modified asphalt, with fibers, or in conjunction with specific mineral fillers. Brown and Cooley (1999) concluded that the use of fibers is beneficial to preclude drain-down in SMA mixtures. They also point out the need to carefully control the aggregate gradation, especially on the 4.75-mm and 0.75-mm sieves.

In instances where the overall traffic is not as high, or in cases where the truck traffic is lower, the use of a well-designed, dense-graded Superpave mixture might be more appropriate. As with the SMA, it will be necessary to design against rutting, permeability, weathering, and wear. The Asphalt Institute (1996b) provides guidance on the volumetric proportioning of Superpave mixtures. It is recommended that a performance test of dense-graded mixtures, whether SMA or Superpave, be done during mixture design. At a minimum, this should consist of rut testing (Brown et al., 2001), but more fundamental tests such as the SHRP SST (Sousa et al., 1994) could be employed to estimate the performance of the material.

The PG grade used in the top dense-graded mixture should be bumped to at least one high-temperature grade greater than normally used in an area, consistent with Brown and Cooley's (1999) recommendations. To resist thermal cracking, the low-temperature grade should be that normally used for 95 percent or 99 percent reliability in the area, depending upon availability and cost. With the possible use of polymer-modified asphalts, it will be critical to avoid overheating the binder in the construction process. New industry guidelines have been developed to ensure the proper handling and application of polymer-modified asphalt binders (APEC, 2000).

OGFCs are designed to have voids that allow water to drain from the roadway surface. These are often used in western and southern regions of the United States to improve wet-weather friction. Normally the mixtures are designed to have about 15 percent air voids, but it has been reported that void levels approaching 18 percent to 22 percent provide better long-term performance (Huber, 2000). Fibers are sometimes used to help resist draindown of the asphalt during construction. Huber (2000) also reports that the use of a polymer-modified asphalt will help in providing long-term performance. A mix design method for OGFC has been developed by Kandhal and Mallick (1999) using the Superpave Gyratory Compactor. Guidance regarding the construction and maintenance of OGFC surfaces is found in Kandhal (2001).

Performance Goals

To maintain a Perpetual Pavement and ensure that it performs to its potential, it is necessary to monitor the pavement condition periodically in order to keep all forms of distress in the top of the pavement. Thus, distresses such as top-down fatigue cracking, thermal cracking, rutting, and surface wear must be confined to no deeper than the original thickness of the wearing course. Once the distresses have reached a predetermined level, the resurfacing would be programmed, and an evaluation of the pavement structure would be undertaken. There are a number of studies that support the idea that thick, well-constructed asphalt pavements have distresses confined to their surfaces.

A Dutch study (Schmorak and Van Dommelen, 1995) of 176 pavement sections showed that surface cracking occurred in asphalt structures thicker than

160 mm, with cracks extending about 100 mm down into the asphalt layer. They concluded that conventional fatigue failure was very improbable and that surface cracking would be the main form of distress in thick asphalt pavements.

A 1997 report from the United Kingdom (Lesch and Nunn, 1997) showed that pavement deterioration in thick asphalt structures was much more likely to occur in the wearing course than deep in the pavement. This paper also demonstrated that the structural layers become stronger with time, instead of weakening as is commonly assumed.

In a case study representative of good-performing pavements, a recent review of thick (between 160 and 475 mm) asphalt pavements on I-90 through the state of Washington revealed that none of these sections had ever been rebuilt for structural reasons

(Baker and Mahoney, 2000).

The pavement ages ranged from 23 to 35 years, and thick asphalt pavements on this route comprise 40 percent of the length (about 225 out of 580 km). West of the Cascade Mountains, near Seattle, the average age at resurfacing was 18.5 years. On the eastern side of the state, the average age at first resurfacing was 12.4 years and the average time until second resurfacing was 12.2 years.

The New Jersey DOT recently investigated distresses that developed on a 26-year-old pavement surface on I-287 (Fee, 2001). The structure was a 250-mm-thick asphalt pavement that had received a minimum of maintenance. The surface showed fatigue cracking, longitudinal cracking in the wheelpaths, and ruts deeper than 25 mm. A detailed examination of the pavement structure showed that none of the distresses extended more than 75 mm into the depth of the asphalt. As a result, the decision was made to mill off the top 75 mm and replace it with a total of 100 mm of HMA. This work was done in 1994, and a pavement survey done in 2001 showed no signs of cracking or rutting.

In the event that certain characteristics may have changed, such as a weakening of the underlying soil through increased moisture content, a slight additional thickness may be planned for the resurfacing to ensure the perpetual nature of the structure. The performance goal, however, is to minimize the amount of additional thickness required in future overlays.



Current Perpetual Pavement Efforts

A number of cooperative efforts to develop and implement Perpetual Pavement are currently under way in various states. California, Illinois, Michigan, Texas, Wisconsin, Kentucky, Ohio, Virginia, and the United Kingdom are among those in the process of devising designs and specifications for the construction of Perpetual Pavement.

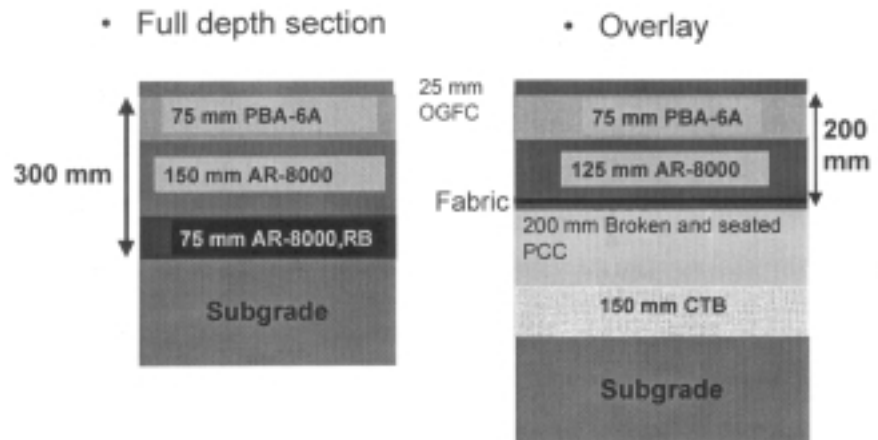
California

At this writing, California is constructing a long-life asphalt pavement on Interstate 710 in Los Angeles County. Known as the Long Beach Freeway, this road has a projected design lane traffic of 100 million to 200 million equivalent single axle loads (ESALs) for a 40-year period. The existing pavement is 200 mm of concrete, over 100 mm of cement-treated material, over 100 mm of aggregate base, over 200 mm of subbase material. The plans call for most of the concrete pavement to be cracked and sealed and overlaid with 200 mm of HMA (Monismith and Long, 1999b), while the concrete pavement and cement-treated material under the bridges will be removed and replaced with 300 mm of HMA. A 25-mm Open Graded Friction Course (OGFC) will be placed over the entire length of the project (Monismith and Long, 1999a).

As shown in Figure 7, the full-depth asphalt section is to be a total of 300 mm thick and will have a fatigue-resistant 75-mm bottom layer in which the asphalt content will be raised by 0.5 percent over optimum to 5.2 percent. This increased binder

Figure 7

California I-710 Sections



content can raise the fatigue life of HMA by up to an order of magnitude (Harvey, et al., 1997). The intermediate 150 mm will be constructed with the same aggregate gradation and binder as the bottom layer, but the asphalt content will be 4.7 percent. The use of a stiff asphalt (AR-8000) in the intermediate layer will help guard against rutting. The upper 75 mm of the pavement structure will be constructed using a polymer-modified binder PBA-6A, and this will be below a 25-mm OGFC. In tests using the California Accelerated Pavement Test Heavy Vehicle Simulator, this material was found to have less than half the rutting of other asphalt mixtures.

The HMA overlay for the cracked and sealed concrete is to be a total of 200 mm thick, and will not have the fatigue-resistant bottom layer. The cracked and sealed concrete should provide a stiff foundation for the asphalt and prevent the excessive bending associated

with bottom-up fatigue cracking. An asphalt-saturated fabric will be placed over a 25-mm leveling course on top of the concrete to guard against reflective cracking. Other than this, the materials to be used in the overlay are the same as those planned for the full-depth pavement. As with the full-depth section, a 25-mm OGFC will be placed on top.

Laboratory testing of the asphalt mixtures included Hveem stabilometer at 60 °C, repeated load simple shear (constant height) at 50 °C and 60 °C, flexural fatigue tests at 10 °C, 20 °C, and 30 °C. Reliability was incorporated into the mixture design by requiring that the performance of the material in laboratory testing surpass the expected demand of the material in the field. This was done by multiplying the expected number of ESALs by a reliability factor, shift factor, and temperature conversion factor.

The structural adequacy of the full-depth pavement sections was checked by limiting the bending strain in the HMA to less than $70\mu\epsilon$ and the vertical strain at the top of the subgrade to less than $200\mu\epsilon$, under an 80-kN single axle. The shear strain near the HMA surface was investigated to ensure that rutting did not occur due to the HMA. The shear strain to produce 5 percent permanent deformation was over 6 times that computed for hot-weather conditions in the field.

Construction of this pavement began in the summer of 2001 and is scheduled to be completed by the summer of 2002.

Illinois

In Illinois, the term Extended Life HMA Pavement is used to denote Perpetual Pavement. The effort in this case was to develop a methodology covering structural design, materials selection, and construction. A panel of IDOT engineers, researchers, contractors, asphalt suppliers, and national specialists gathered to provide input to the development of the procedure. A draft document providing details of the Extended Life HMA Pavement was prepared in December 2000, and a final version should be complete by 2002.

IDOT has decided to use its own mechanistic-empirical approach to pavement thickness design. The typical pavement design in Illinois results in a HMA layer bending strain of less than $60\mu\epsilon$, because the fatigue criterion in the Illinois procedure is conservative. As a result, no changes were made to the IDOT method of pavement design.

The approach to designing the mix for the bottom fatigue-resistant layer is slightly different from California's. In Illinois, the asphalt content to achieve an air void level of 2.5 percent at the design number of gyrations was the benchmark set to obtain a binder-rich mixture. The binder and aggregate gradation would be the same as currently used in Illinois in their approach to Superpave. It is planned that this bottom HMA layer would be constructed in one 100-mm lift.

The intermediate asphalt layer would be constructed using the same binder and mixture specifications currently used for IDOT's dense-graded mixtures. The level of gyrations for design would be set by the requirements for traffic during a 20-year period.

In order to achieve a 20-year life in the renewable surface, the Illinois group decided to use Stone Matrix Asphalt (SMA) for the top layer. The appropriate thickness of SMA was determined by analyzing shear stresses near the surface and reviewing performance relative to rutting and cracking. Most of the problems associated with distresses were found to lie in the top 100 mm of the pavement. Thus, for an extended-life HMA pavement, the thickness of the SMA surface was associated with the expected traffic. For low traffic levels, the SMA thickness is 50 mm, and for medium traffic, it is 100 mm. One hundred-fifty mm of SMA is used for high and very high traffic levels. Although exact definitions for these traffic levels have yet to be determined, it is expected that the high traffic level will start at about 25 million ESAL.

In all pavements, the top 150 mm of Hot Mix, regardless of mix

type, will contain a polymer-modified binder. This is considered necessary to avoid thermal and load-induced cracking in the surface. The PG binder grade to be used in the structure is that required in full-depth asphalt pavements in northern Illinois. Hydrated lime is required in all mixtures used throughout the pavement structure to prevent moisture damage.

The pavement foundation requirements are currently being reviewed, and two approaches are being considered. In one approach, the standard IDOT method of lime modifying the soil for a depth of 300 mm underneath a full-depth pavement is proposed. In the other, a 300-mm granular subbase would be used under the pavement. Additionally, the issue of whether to require longitudinal underdrains at the side of the road is being discussed with respect to structural benefits.

Controls on construction were devised to help ensure the durability of the pavement. These include:

- Specifying a lift thickness of 3 to 6 times the nominal maximum aggregate size to facilitate compaction.
- Requiring positive dust control on the HMA plant.
- Requiring a polymer-modified tack coat between each HMA lift.
- Requiring remixing of materials during laydown of all lifts.
- Revising density testing requirements to ensure uniform density across the mat.
- Revising density requirements for the intermediate layer to obtain 93 percent of theoretical maximum density.

- Longitudinal joint requirements, including:
 - Use of screed extensions and good paving practices.
 - Density tests at two feet from the joint.
 - Use of a polymer-modified tack coat on vertical joint faces.

Michigan

Under a contract with the Michigan Asphalt Paving Association Inc. (MAPA), Fugro-BRE Inc. developed a catalog of structural sections for use as Perpetual Pavement (Von Quintus, 2001a and 2001b). Von Quintus chose to use a mechanistic approach employing the ELSYM5 computer program to calculate stresses and strains in the pavement structure. This approach applied the concept of cumulative damage to determine the appropriate section for a design period of up to 40 years. Von Quintus used this methodology, in the absence of other approaches, as a way of determining a reasonable range of pavement thicknesses for Perpetual Pavements.

The catalog of pavement designs is presented in Table 5 where the structural sections are listed according to the traffic levels expected in the first 20 years of service. The pavement designs and rehabilitation strategies listed at the bottom are intended for a 40-year period.

The pavement foundation in the Michigan procedure consists of one meter of non-frost-susceptible material under crushed aggregate subbase at the 3 million and 10 million ESAL levels (20-year). The higher traffic levels of 20 and 30 million ESAL (20-year) have a crushed stone base course.

Table 5

Design Catalog of Michigan Perpetual Pavement Sections (Von Quintus, 2001a)							
20-Year Traffic Level, ESAL $\times 10^6$		3		10		20	
Total HMA Thickness, mm		290		345		370	
SMA Thickness, mm		—		—		65	
Superpave Thickness, mm		50		50		—	
Binder Course, mm		115	90	140	11	140	125
Base Course, mm		125	150	155	180	165	180
Aggregate Base, mm		—		—		330	
Aggregate Subbase, mm		380		250		—	
Non-Frost Susceptible Soils, mm		345		315		220	
Rehabilitation 1	Year	20		15		15	
	Mill-Overlay, mm	50–50		50–100		65–115	
Rehabilitation 2	Year	32		30		30	
	Mill-Overlay, mm	50-50		50-50		50-50	

Table 5 gives a suggested guide to the types of HMA mixtures to be placed within the pavement structure. The total HMA thickness ranges from 290 to 405 mm for the four traffic levels presented. Von Quintus recommends that the asphalt mixture for the HMA base layer be designed to have 3 percent air voids to mitigate bottom-up fatigue cracking. The surface course mixture is a dense-graded Superpave in the case of the 3 million and 10 million ESAL levels, and an SMA in the case of the 20 million and 30 million ESAL levels (20-year).

For rehabilitation strategies, Von Quintus suggests a straight mill and fill for the lowest level of traffic and mill and strengthening

for the higher levels of traffic. The need for strengthening a given pavement should be investigated at the time of rehabilitation. The strategies presented in Table 5 are for planning purposes only.

Von Quintus (2001b) went through a similar process to develop a Perpetual Pavement design for rubblized concrete pavements. It can be seen in Table 6 that the total HMA thickness for a 40-year analysis period ranges from 215 to 370 mm depending upon the 20-year traffic projection. Again, use of a rich base mixture is recommended along with specifying an SMA surface course at the two highest traffic levels.

Table 6
Design Catalog of Michigan Perpetual Pavement Sections Over Rubblized Concrete
 (Von Quintus, 2001b)

<i>Design Period, Years</i>	<i>20-Year Traffic Level, ESAL X 10⁶</i>	<i>3</i>	<i>10</i>	<i>20</i>	<i>30</i>
20	Total HMA Thickness, mm	150	215	270	290
	SMA Thickness, mm	—	—	65	65
	Superpave Thickness, mm	50	50	—	—
	Binder Course, mm	100	50	75	75
	Base Course, mm	—	115	130	150
	Rehab. Year 20, Mill/Replace, mm	65/130	65/130	65/130	65/130
	Rehab. Year 32, Mill/Replace, mm	50/75	50/90	40/75	40/75
30	Total HMA Thickness, mm	175	255	305	330
	SMA Thickness, mm	—	—	65	65
	Superpave Thickness, mm	50	50	—	—
	Binder Course, mm	50	75	75	75
	Base Course, mm	75	130	165	190
	Rehab. Year 20, Mill/Replace, mm	65/115	65/115	65/115	65/115
	Rehab. Year 32, Mill/Replace, mm	50/50	50/50	50/50	50/50
40	Total HMA Thickness, mm	215	290	330	370
	SMA Thickness, mm	—	—	65	65
	Superpave Thickness, mm	50	50	—	—
	Binder Course, mm	65	100	100	100
	Base Course, mm	100	140	165	205
	Rehab. Year 20, Mill/Replace, mm	50/50	50/50	65/65	65/65
	Rehab. Year 32, Mill/Replace, mm	50/50	50/50	65/65	65/65

Wisconsin

The state of Wisconsin is planning the construction of two test sites for Perpetual Pavement.¹ Five test sections were built on State Trunk Highway 50 in 2000, and two test sections will be constructed at a truck weigh station near Kenosha in 2002. This is a cooperative effort between the Wisconsin DOT (WisDOT) and the Wisconsin Asphalt Pavement Association (WAPA).

¹ Personal communication with Gerald Waelti, Wisconsin Asphalt Pavement Association, July 20, 2001.

The design lane ESAL for the Lake Geneva road is about 2 million for a 20-year period. Three Perpetual Pavement sections will be placed, along with two conventional pavement sections. The sections differ primarily in the binder grades and density requirements as shown in Table 7. There will be two control sections, reflecting normal Wisconsin construction procedures. All pavements in the Lake Geneva site will rest on 100 mm of an open-graded base course over 200 mm of a crushed stone base.

The truck station sections will be subjected to about 75 million ESALs over a design life of 20 years. The structure below the asphalt layers will consist of 100 mm of an open-graded base course over 430 mm of crushed aggregate base course. The traffic conditions will be somewhat worse here than on a mainline highway because the truck traffic will be channelized and moving at slow speed, increasing the potential for rutting.

Table 7

Wisconsin Perpetual Pavement Test Sections					
Test Site	Test Section	Layer	Thickness, mm	Asphalt Grade	In-Place Void Content, %
Lake Geneva	Perpetual Pavement (University of Illinois)	Surface	50	58-28	6
		Binder	90	64-22	6
		Base	90	64-22	4
		Total	230		
	Perpetual Pavement (WisDOT)	Surface	50	64-28	6
		Binder	90	58-28	6
		Base	90	58-28	4
		Total	230		
	Perpetual Pavement (WAPA)	Surface	50	58-28	6
		Binder	90	70-22	6
		Base	90	70-22	4
		Total	230		
	Standard Pavement (9-in. Control)	Surface	50	58-28	
		Binder	90	58-28	
		Base	90	58-28	
		Total	230		
	Standard Pavement (7-in. Control)	Surface	40	58-28	
		Binder	70	58-28	
		Base	70	58-28	
		Total	180		
Truck Station	1	Surface	50	76-28	To Be Determined
		Binder	130	70-22	
		Base	100	58-28	
		Total	230		
	2	Surface	50	70-28	
		Binder	130	70-22	
		Base	100	64-22	
		Total	230		

So, an HMA subbase with 2 percent design air voids was selected. It was also thought that this binder-rich layer would also help to preclude cracking during the early stages of the pavement's life.

The traffic level over a 20-year period is expected to be 48 million ESAL, and the subgrade is classified as clay with a modulus of 82.7 MPa. The total pavement structure, not including an OGFC surface, is about 480 mm. The layers include 50 mm of SMA below the OGFC, over 80 mm of a 19-mm Superpave mixture, over 250 mm of a 25-mm Superpave mixture, with a 100-mm impermeable HMA at the bottom to help maintain a constant moisture content in the underlying clay. Performance testing for the mixtures will include rut testing in the Hamburg and Asphalt Pavement Analyzer devices, Superpave Shear Tester, and Complex Modulus. In-situ testing of the pavement will include dynamic cone penetrometer, falling weight deflectometer, ground penetrating radar, portable seismic analyzer, and profile measurements.

Texas

Construction of a Perpetual Pavement on I-35 near Waco, Texas, began in August 2001.² This project was a joint effort between the Texas Department of Transportation (TxDOT), the Texas Hot Mix Asphalt Pavement Association (TxHMAPA), and the Asphalt Institute. The existing pavement is being removed and replaced due to moisture damage in the lower asphalt layers.

One of the important factors considered in the selection of materials and the pavement design is the presence of highly expansive clays extending to 4.6 m over a limestone bedrock. It is essential to limit changes in moisture content for these materials as that will minimize seasonal movements in the pavement. It was decided that an HMA mixture with low permeability would be required to address this problem.

Kentucky

Kentucky has a history of using thick asphalt pavements for new construction and rehabilitation that result in long service lives.³ The Kentucky Transportation Cabinet (KTC) currently uses a mechanistic-empirical design method that usually results in relatively thick asphalt pavements.

³ Personal communication with Brian Wood, The Plantmix Asphalt Industry of Kentucky, December 14, 2001.

² Personal communication with Gary Fitts, Asphalt Institute, August 29, 2001.

They often include about 100 mm of dense-graded aggregate (DGA) resting on clayey soils (sometimes chemically modified) beneath the HMA. In rehabilitation projects, broken and seated concrete pavements are often overlaid with a thick layer of asphalt.

Mechanistic analyses have shown that Kentucky's pavement sections have resulted in strains below the 70 $\mu\epsilon$ levels specified in California. Recently, KTC has let several projects where contractors could bid alternate pavement types. As a result, KTC decided to base the designs for these projects on 40-year traffic levels.

In 2000, KTC advertised an alternate bid project on Interstate 64 in Louisville which included the rehabilitation of 5.3 km (two lanes in each direction) of Interstate pavement. The roadway carries about 100,000 vehicles per day with about 10 percent truck traffic. A mechanistic-empirical design process concluded that a 280-mm asphalt overlay would result in less than 70 $\mu\epsilon$. At the same time, KTC found that a 280-mm asphalt section matched their design assuming 1400 MPa for the broken concrete pavement overlay. The successful bidder chose the 280-mm asphalt pavement. The asphalt section consisted of dense-graded Superpave mixtures with polymer-modified asphalt (PG 76-22) in the upper layers.

A similar project on Interstate 65 was recently let which allowed alternate bids on the rehabilitation and widening of an existing concrete pavement near Bowling Green. The successful bidder selected a design that included a 280-mm HMA overlay of the broken and seated concrete and

a 380-mm HMA section for the widened portion of the road. The rehabilitation strategy assumed by KTC in their life cycle cost analysis (which includes a 90-mm overlay in year 20) was amended to include only shallow (40 mm) mill and overlay throughout the 40-year analysis period. This rehabilitation strategy is consistent with the Perpetual Pavement concept in that no additional structure will be needed during the design period. The mixtures specified in the proposal are also dense-graded Superpave mixtures utilizing PG 76-22 in the upper layers. The KTC elected not to use the fatigue layer concept in either the I-64 or the I-65 projects. As in California, the presence of the stiff underlying concrete layer would most likely preclude excessive bending in the HMA layer.

Ohio and Virginia

These states have recently begun devising their approaches to the design, specification, and construction of Perpetual Pavements.

The Ohio Department of Transportation (ODOT) and Flexible Pavements of Ohio have formed a Perpetual Pavement Committee to explore the design and construction of long-life asphalt pavements. The committee is comprised of ODOT personnel, Flexible Pavements staff, academia, and consultants. Subcommittees involved in this effort are addressing concerns in the areas of design, specifications, testing, and project selection. The objective is to identify a project to test the feasibility of constructing a Perpetual Pavement in the next year.

The Virginia DOT is developing its concepts on Perpetual Pavement based upon input provided by industry, represented by the Virginia Asphalt Association and the Asphalt Institute, and by the Virginia Transportation Research Council. Issues being discussed include pavement design, materials selection, and life cycle cost analysis.

United Kingdom

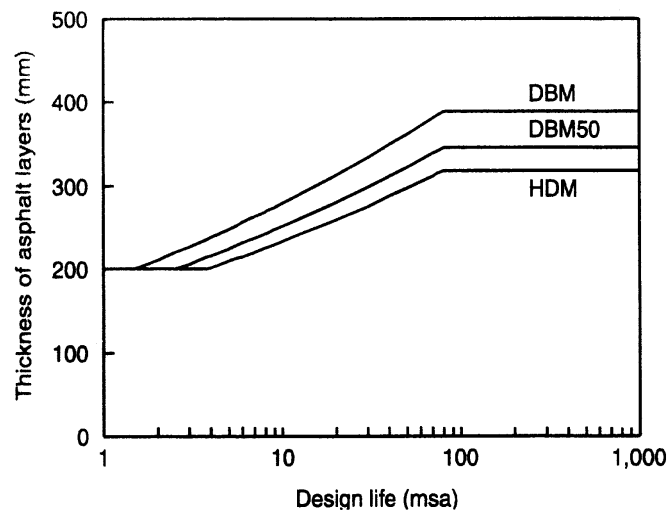
Past practice in the United Kingdom was to design a flexible pavement structure with a life of 40 years, and with a planned structural overlay at 20 years. Recent evidence shows it would be more cost-effective, especially from a user-delay standpoint, to design and build the structure adequate for the 40 years initially (Nunn et al., 1997). Thus, only periodic milling and surface restoration is needed.

The structural section for the Perpetual Pavement in the United Kingdom includes the use of granular base and subbase layers below a thick asphalt pavement. The thickness of the asphalt is such that traditional bottom-up fatigue cracking and structural rutting are avoided. Nunn and his associates have found that pavements having a total asphalt thickness of less than 180 mm are prone to structural rutting, while the rutting in thicker pavements is confined to the top of the structure. Rutting occurs mainly in the top 100 mm of thick asphalt roads in the United Kingdom. The TRL approach allows for an adjustment in asphalt thickness according to the type of mix and stiffness of the binder. The standard dense bitumen macadam base uses a 100-penetration asphalt binder.

Using increasingly stiff binders allows for the design of thinner sections according to the British approach. However, the British researchers placed an upper limit on asphalt thickness based upon observed distresses. Studies of the performance of British roads show that additional pavement thickness, beyond that required for 80 million ESAL, would not provide additional benefit as shown in Figure 8. Nunn and his associates state that the fourth power law, traditionally used for describing the relationship between pavement damage and axle loads, is not appropriate for thick asphalt pavements.

Figure 8

TRRL Design Curve (Nunn et al., 1997)



Summary

The concept of the Perpetual Pavement has been established by the performance of well-constructed, thick asphalt pavements. Although designed to be comparable in performance with more conventional flexible pavements, deep-strength and full-depth asphalt sections have been shown to confine distresses to the upper pavement layers. This allows for periodic removal of the surface layer and replacement with an HMA overlay, minimizing rehabilitation costs and user inconvenience. The pavement material removed from the surface is recycled, conserving natural resources.

A new approach to design is needed to recognize that there is a point beyond which additional thicknesses of HMA offer very little return on investment. Mechanistic methods offer a way to

calculate strains in pavement structures so that, for a given combination of materials, the optimum pavement structure that will not require reconstruction may be defined. Design criteria need to be developed for different mixture characteristics. Work on this has begun in Illinois, California, and the United Kingdom.

The pavement foundation will play a key role in defining the quality of construction and the long-term performance of Perpetual Pavements. Guidance on criteria to use for pavement foundations during design is available from the Transport Research Laboratory (TRL) in the United Kingdom, the Laboratoire Central de Ponts et Chaussées (LCPC) in France, and the Illinois DOT. Seasonal adjustments for considering the behavior of the pavement during its performance

period have been developed by a number of agencies including the Washington State DOT, the Minnesota DOT, and TRL. A combination of in-situ stiffness and density measurements should be made during construction to ensure a good foundation for the pavement.

The Perpetual Pavement offers engineers the ability to design for specific modes of distress in the HMA materials. Resistance to bottom-up fatigue cracking is provided by the lowest asphalt layer having a higher binder content or by the total thickness of pavement reducing the tensile strains in this layer to an insignificant level. The intermediate layer provides rutting resistance through stone-on-stone contact and the durability is imparted by the proper selection of materials. The uppermost structural layer

resists rutting, weathering, thermal cracking, and wear. SMAs or dense-graded Superpave mixtures provide these qualities.

A number of agencies have started investigating and implementing Perpetual Pavement concepts. California is in the process of building such a pavement on the Long Beach Freeway (I-710). Illinois is developing a methodology for extended-life pavements and has set a number of criteria pertaining to construction. The Michigan Asphalt Paving Association Inc. has proposed a design catalog for long-life pave-

ments, both in new design and in the rehabilitation of concrete pavements. The Wisconsin DOT is working with its industry partners to build test sections in that state. The Texas DOT is in the process of building a Perpetual Pavement on I-35 near Waco, utilizing the best available technology in the materials selection and mix design process. The Kentucky Transportation Cabinet is finding that their existing design procedure results in long-lasting HMA pavements. The states of Ohio and Virginia are at the beginning of a process in developing their

approaches to Perpetual Pavements. The Transport Research Laboratory in the United Kingdom has put forward a well-documented approach to the design of long-lasting pavements.

The next step should be the development of national guidelines and procedures to give pavement engineers the tools for successfully designing and constructing Perpetual Pavements. These guidelines should address the rehabilitation of flexible and rigid pavements in addition to new or reconstructed pavements.

References

- American Association of State Highway and Transportation Officials (1997) Segregation: Causes and Cures for Hot Mix Asphalt, Washington, DC.
- American Association of State Highway and Transportation Officials (2000) Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II – Tests, 20th Ed., Washington, DC.
- American Association of State Highway and Transportation Officials (2001) AASHTO Provisional Standards, Interim Edition, Washington, DC.
- Asphalt Institute (1996a) Performance Graded Asphalt, SP-1, Lexington, Kentucky.
- Asphalt Institute (1996b) Superpave Mix Design, SP-2, Lexington, Kentucky.
- Asphalt Institute (1981) Thickness Design – Asphalt Pavements for Highways and Streets, MS-1, Lexington, Kentucky.
- Asphalt Paving Environmental Council (APEC) (2000) Best Management Practices to Minimize Emissions During HMA Construction, Report No. EC-101, National Asphalt Pavement Association, Lanham, Maryland.
- Baker, M.J. and J.P. Mahoney (2000) Identification and Assessment of Washington State Pavements with Superior and Inferior Performance, Report No. WA-RD 437.1, Washington State Department of Transportation, Olympia.
- Brown, E.R. (1993) Experience with Stone Mastic Asphalt in the United States, Report No. 93-4, National Center for Asphalt Technology, Auburn University, Alabama.
- Brown, E.R. and L.A. Cooley, Jr. (1999) Designing Stone Matrix Asphalt Mixtures for Rut-Resistant Pavements, Report No. 425, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC.
- Brown, E. Ray, Prithvi S. Kandhal, and Jingna Zhang (November, 2001) Performance Testing for Hot Mix Asphalt, Report No. 2001-05, National Center for Asphalt Technology, Auburn University, Alabama.
- Epps, J.A. and C.L. Monismith (1972) "Fatigue of Asphalt Concrete Mixtures – Summary of Existing Information," STP 508, American Society for Testing and Materials, Conshohocken, PA.
- European Asphalt Pavement Association (EAPA) (1999) "High Modulus Asphalt," Breukelen, The Netherlands.
- Federal Ministry of Transport (1989) Guidelines for the Standardization of the Upper Structure of Traffic Bearing Surfaces, RS+O 86, Bonn, Germany.
- Fee, F., (July-August, 2001), "Extended-Life Asphalt Pavement," TR News, No. 215, Transportation Research Board, Washington, DC.
- Gomez, M. and M.R. Thompson (1984) Mechanistic Design Concepts for Full Depth Asphalt Concrete Pavements, Transportation Engineering Series No. 41, Civil Engineering Studies, Department of Civil Engineering, University of Illinois at Urbana-Champaign.
- Harvey, John T., John A. Deacon, Akhtar A. Taybali, Rita B. Leahy and Carl L. Monismith (1997) A Reliability-Based Mix Design and Analysis System for Mitigating Fatigue Distress, Proceedings, Eighth International Conference on Asphalt Pavements, University of Washington, Seattle.
- Huber, G. (2000) Performance Survey on Open-Graded Friction Course Mixes, NCHRP Synthesis 284, Transportation Research Board, Washington, DC.
- Hughes, C. (1999) Designing and Constructing SMA Mixtures – State-of-the-Practice, QIP 122, National Asphalt Pavement Association, Lanham, Maryland.
- Kandhal, P.S. (1990) "Design of Large-Stone Mixes to Minimize Rutting," Transportation Research Record No. 1259, Transportation Research Board, Washington, DC.
- Kandhal, P.S. (2001) Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses, Quality Improvement Series IS-115, National Asphalt Pavement Association, Lanham, Maryland.
- Kandhal, P.S. and R.B. Mallick (1999) Design of New-Generation Open-Graded Friction Courses, Report No. 99-3, National Center for Asphalt Technology, Auburn University, Alabama.
- Illinois Department of Transportation (IDOT) (1982) Subgrade Stability Manual, Policy MAT-10, Springfield.
- Illinois Department of Transportation (IDOT) (2001) "A Guide Specification for HMA Extended Life Pavements," Draft Version, Springfield.
- Illinois Department of Transportation (IDOT) (2002), Standard Specifications for Road and Bridge Construction, Illinois Department of Transportation, Springfield.
- Laboratoire Central de Ponts et Chasses and Service D'Etudes Techniques des Route et Autoroutes (1992) Realisation des Remblais et des Couches de Forme, Ministere de l'Equipment du Logement des Transports, Paris, France.
- Lecsh, D. and M.E. Nunn (1997) "Deterioration Mechanisms in Flexible Pavements," Proceedings, 2nd European Conference on the Durability and Performance of Bituminous Materials, University of Leeds, Leeds, UK.
- Linden, Robert N., Joe P. Mahoney, and Newton C. Jackson (1989) "Effect of Compaction on Asphalt Concrete Performance," Transportation Research Record 1217, Transportation Research Board, Washington, DC.

- Mahboub, K. and E.G. Williams (1990) "Construction of Large-Stone Mixes (LSAM) in Kentucky," Transportation Research Record No. 1282, Transportation Research Board, Washington, DC.
- Monismith, C.L. (1992) Analytically Based Asphalt Pavement Design and Rehabilitation: Theory to Practice, 1962-1992, 1992 TRB Distinguished Lecture, Transportation Research Record 1354, Transportation Research Board, Washington, DC, 1992.
- Monismith, C.L. and F. Long (June 1999a) Mix Design and Analysis and Structural Section Design for Full Depth Pavement for Interstate Route 710, Technical Memorandum TM UCB PRC 99-2, Pavement Research Center, Institute for Transportation Studies, University of California, Berkeley.
- Monismith, C.L. and F. Long (September 1999b) Overlay Design for Cracked and Sealed Portland Cement Concrete (PCC) Pavement – Interstate Route 710, Technical Memorandum TM UCB PRC 99-3, Pavement Research Center, Institute for Transportation Studies, University of California, Berkeley.
- Monismith, C.L. and J.A. Epps (1969) Asphalt Mixture Behavior in Repeated Flexure, Transportation and Traffic Engineering, University of California, Berkeley.
- Moulton, L.K. (1980) Highway Subdrainage Design, Report No. FHWA-TS-80-224, Federal Highway Administration, Washington, DC.
- National Asphalt Pavement Association (NAPA) (2000) HMA Pavement Mix Type Selection Guide, Information Series 128, Lanham, MD.
- Nishizawa, T., S. Shimeno, and M. Sekiguchi (1997) "Fatigue Analysis of Asphalt Pavements with Thick Asphalt Mixture Layer," Proceedings, 7th International Conference on Asphalt Pavements, University of Washington, Seattle.
- Nunn, M.E., A. Brown, D. Weston and J.C. Nicholls (1997) Design of long-life flexible pavements for heavy traffic, Report No. 250, Transportation Research Laboratory, Berkshire, United Kingdom.
- Ovik, J., B. Birgisson, and D.E. Newcomb (1999) "Characterizing Seasonal Variations in Flexible Pavement Material Properties," Transportation Research Record 1684, Transportation Research Board, Washington, DC, 1999.
- Pierce, L.M. and J.P. Mahoney (1996) "Asphalt Concrete Overlay Design Case Studies," Transportation Research Record 1543, Transportation Research Board, Washington, DC.
- Powell, W.D., J.F. Potter, H.C. Mayhew and M.E. Nunn (1984) The Structural Design of Bituminous Roads, TRRL Report No. LR 1132, Transport and Road Research Laboratory, Crowthorne, England.
- Santucci, L.E. (1977) "Thickness Design Procedure for Asphalt and Emulsified Asphalt Mixtures," Proceedings, 4th International Conference on the Structural Design of Asphalt Pavements, Grosvenor House, London, UK, Volume 1, pp. 550-567.
- Schmorak, N. and A. Van Dommelen (1995) "Analysis of the Structural Behavior of Asphalt Concrete Pavements in SHRP-NL Test Sections," Proceedings, International Conference on the Strategic Highway Research Program and Traffic Safety, Prague.
- Sousa, J.B., J.A. Deacon, S. Weissman, J.T. Harvey, C.L. Monismith, R.B. Leahy, G. Paulson and J.S. Complantz (1994) Permanent Deformation Response of Asphalt-Aggregate Mixes, Report No. SHRP-A-415, Strategic Highway Research Program, Transportation Research Board, Washington, DC.
- Tayebali, A.J., J. Deacon, J. Coplantz, F. Finn, and C. Monismith (1994a), Fatigue Response of Asphalt-Aggregate Mixes, Part II – Extended Test Program, Report No. SHRP-A-404, Strategic Highway Research Program, Transportation Research Board, Washington, DC.
- Tayebali, A.J., J. Deacon, J. Coplantz, J. Harvey, and C. Monismith (1994b), Fatigue Response of Asphalt-Aggregate Mixes, Part I – Test Method Selection, Report No. SHRP-A-404, Strategic Highway Research Program, Transportation Research Board, Washington, DC.
- Terrel, R.L. and Jon A. Epps (1979) Soil Stabilization in Pavement Structures – A Users Manual, Vols. I and II, Report No. FHWA-IP-80-002, Federal Highway Administration, Washington, DC.
- Thompson, M.R. (1987) ILLI-PAVE Based Full-Depth Asphalt Concrete Pavement Design Procedure, Proceedings, 6th International Conference on Structural Design of Asphalt Pavements, Ann Arbor.
- Thompson, M.R. and K. Cation (1986) A Proposed Full-Depth Asphalt Concrete Thickness Design Procedure, Transportation Engineering Series No. 45, Civil Engineering Studies, Department of Civil Engineering, University of Illinois at Urbana-Champaign.
- Timm, David H., David E. Newcomb and Bjorn Birgisson (January 1999) Mechanistic-Empirical Flexible Pavement Thickness Design: The Minnesota Method, Report No. MN/RC-P99-10, Minnesota Department of Transportation, St. Paul.
- Vavrik, W.R., W.J. Pine, G. Huber, S.H. Carpenter, and R. Bailey (2001) "The Bailey Method of Gradation Evaluation: The Influence of Aggregate Gradation and Packing Characteristics on Voids in the Mineral Aggregate," Asphalt Technology, vol. 70, Association of Asphalt Paving Technologists, St. Paul, MN.
- Von Quintus, Harold L. (December 2001a) Pavement Structural Design Study – A Simplified Catalog of Solutions, Report No. 3065, for the Michigan Asphalt Pavement Association, Fugro-BRE, Inc., Austin, Texas.
- Von Quintus, Harold L. (December 2001b), HMA Overlay Design Study for Rubblization of PCC Slabs, Report No. 3066, for the Michigan Asphalt Pavement Association, Fugro-BRE, Inc., Austin, Texas.



Mission Statement

The Asphalt Pavement Alliance is a coalition of the Asphalt Institute, the National Asphalt Pavement Association, and the State Asphalt Pavement Associations.

The Asphalt Pavement Alliance's mission is to further the use and quality of Hot Mix Asphalt pavements.

The Alliance will accomplish this through research, technology transfer, engineering, education, and innovation.

ASPHALT PAVEMENT ALLIANCE

5100 Forbes Boulevard, Lanham, MD 20706-4407 ■ Toll-free: 888-468-6499 ■ Fax: 301-731-4621
publications@AsphaltAlliance.com ■ www.AsphaltAlliance.com

