FLEXIBLE PAVEMENT DESIGN CATALOG FOR NON-STATE DOT ROADWAYS

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NAPA
NATIONAL ASPHALT PAVEMENT ASSOCIATION

SR-231 March 2025

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ACRONYMS

AADT	average annual daily traffic
AADTT	average annual daily truck traffic
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
CCPR	cold central plant recycling
CIR	cold in-place recycling
CTB	cement treated base
DCP	dynamic cone penetrometer
DOT	Department of Transportation
ESAL	equivalent single axle load
FDR	full-depth reclamation (recycling)
FHWA	Federal Highway Administration
FWD	falling weight deflectometer
GPR	ground penetrating radar
NAPA	National Asphalt Pavement Association
NCAT	National Center for Asphalt Technology
NMAS	nominal maximum aggregate size
PCI	pavement condition index
PG	performance grade
RAP	reclaimed asphalt pavement

1. INTRODUCTION

As a group, non-state Department of Transportation (DOT) agencies (e.g., counties, cities, Bureau of Indian Affairs, developers; referred to as local agencies in this design catalog) use a variety of methods to formulate pavement thickness design recommendations. These methods may include lower volume pavement design practices established by the state highway agencies, industry design methods, consultant designs, or may simply be a single page, reproduced in each bid document, specifying the minimum pavement thickness. The development of alternative project-specific designs can be frustrating or confusing to local designers (e.g., extremes in the results of the varied methods). For instance, the American Association of State Highway and Transportation Officials (AASHTO) 1993 *Guide for the Design of Pavement Structures* (AASHTO 1993) may recommend 4 inches of asphalt over 3 inches of granular base over compacted subgrade, whereas an alternate design method may recommend 2.5 inches of asphalt over cement treated subgrade. These are very different pavement structures and would perform differently when subjected to the same truck loading, moisture conditions, and/or freeze-thaw cycling. While these pavement structures may meet the design criteria, it is important to understand and capture the impact of material properties, construction requirements, and processes.

To facilitate the development of pavement thickness design recommendations, DOTs and local agencies promote the adoption of "design catalogs," which are collections of structural designs for roads commonly encountered in certain locations. This design catalog was developed to provide local agencies with the ability to quickly identify a recommended pavement design given a desired pavement type and level of traffic.

1.1 BACKGROUND

In November 2021, the Bipartisan Infrastructure Law reauthorized the surface transportation program with an additional investment of $110 billion over 5 years for the repair of roads and bridges. Unlike prior federal highway authorization bills where money flowed through a state highway agency, local agencies have direct access to these funds; however, they must abide by Federal-aid project regulations. The Code of Federal Regulations, Title 23, Part 626, policy on pavement design for Federal-aid projects includes accommodating "…current and predicted traffic needs in a safe, durable, and cost-effective manner." While the regulation does not require a specific method, it defines pavement design as:

> *"…a project level activity where detailed engineering and economic considerations are given to alternative combinations of subbase, base, and surface materials which will provide adequate load carrying capacity. Factors which are considered include: Materials, traffic, climate, maintenance, drainage, and life-cycle costs."*

1.2 OBJECTIVE

The design catalog provides a simple, straightforward approach for new and reconstructed asphalt pavement designs for non-state DOT roadway applications using recognized procedures. This design catalog is timely, not only in meeting recent legislation and federal aid requirements, but also in addressing the local agency needs for developing reasonable and applicable pavement design recommendations.

1.3 REPORT ORGANIZATION

The report is organized into 4 chapters:

- **Chapter 1—Introduction.** Provides background information, objectives, and a summary of the organization of the document.
- **Chapter 2—Pavement Design Methods.** Provides a summary of the design concepts and components of the pavement design method used to develop the design catalog.
- **Chapter 3—Pavement Design Catalog.** Presents the pavement design catalog including the development process, recommended layer thickness, and recommendations for use and implementation.
- **Chapter 4—Use of Overlays for Maintenance and Rehabilitation.** Discusses the use of overlays for maintenance and rehabilitation activities and describes efforts to evaluate existing pavement conditions and overlay design considerations.

2. PAVEMENT DESIGN METHODS

Pavement design methods have evolved from empirical (based on observations of how pavements perform) to mechanistic-empirical (incorporating pavement responses and behavior) methods. Empirical data describing pavement behavior was predominately based on full-scale studies of pavement responses to traffic and environmental conditions. The most notable of these full-scale studies was the American Association of State Highway Officials (AASHO) Road Test, conducted in the late 1950s in Ottawa, IL, which led to the 1972 AASHO *Interim Guide for the Design of Pavement Structures* (AASHO 1972) Over the next 2 decades, the 1972 AASHO Interim Guide was updated to include, for example, drainage considerations, revised methods for assessing truck traffic according to an 18,000 lb equivalent single axle load (ESAL), and expanded considerations for overlay designs. The last published version was released in 1993 as the AASHTO *Guide for Design of Pavement Structures* (AASHTO 1993). The AASHTO 1993 Guide was based on empirical data but introduced subgrade resilient modulus as a mechanistic term in the design process.

The mechanistic component of mechanistic-empirical methods quantifies the pavement's response to traffic and environmental conditions (e.g., moisture, elevated and freezing temperatures). The structural response of flexible pavements is typically modeled using layered elastic analysis and distress prediction (De Jong et al. 1973, Finn et al. 1977, Asphalt Institute 1983). These procedures and analysis tools for pavement materials and structural mechanics continue to be refined and improved and collectively define the current state of the practice for pavement design. Overall, mechanistic-empirical design procedures use structural behavior and statistical modeling of distress prediction to analyze pavement materials and layer thickness. The AASHTO Mechanistic-Empirical Pavement Design Guide is founded on previous empirical and mechanistic-empirical procedures (AASHTO 2021).

Mechanistic-empirical pavement design procedures incorporate sophisticated inputs and analytical methods. To encourage the implementation of these methods, DOTs and local agencies promote the adoption of design catalogs, which presume shared assumptions for traffic, materials, climate, and other structural and material inputs and provide associated structural design recommendations.

PAVEXpress software was used to develop the non-state DOT roadway pavement design catalog. PAVEXpress was originally based on the AASHTO 1993 Guide and has been expanded to include asphalt overlay designs for both flexible and rigid pavements, life cycle cost analysis, layered elastic analysis, and perpetual pavement designs. The following descriptions provide a brief overview of the pavement design methods contained within the PAVEXpress software. The following is not intended to provide details of the software operation or all the details of the pavement design process.

2.1 AASHTO 1993 PAVEMENT DESIGN

The most widely adopted procedure in the United States for non-state DOT roadway pavement design is the AASHTO 1993 Guide. The AASHTO 1993 Guide pavement design process assigns a pavement thickness to achieve the intended service life, which is expressed in a measure of anticipated traffic (i.e., ESALs) over the specified performance period. The AASHTO 1993 Guide includes methods for designing new, reconstructed, and rehabilitated asphalt and concrete pavements. The details of the AASHTO 1993 Guide are not described herein; however, the equation used for the design of new and reconstructed asphalt pavements includes:

$$\log(W_{18}) = Z_R \times S_o + 9.36\log(SN+1) - 0.20 + \frac{\log\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32\log(M_R) - 8.07 \quad \text{(Eq 1)}$$

where:

W_{18} = predicted number of ESALs

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

ΔPSI = difference between the initial design serviceability index (p_o) and the design terminal serviceability index (p_t)

M_R = resilient modulus (psi)

a_i = i^{th} layer coefficient

D_i = i^{th} layer thickness (inch)

m_i = i^{th} layer drainage coefficient

The pavement design scenarios incorporated in the PAVEXpress AASHTO 1993 Guide method include new and reconstructed asphalt pavements, the 1998 AASHTO Supplement for concrete pavements, new porous pavements, asphalt overlays of existing asphalt pavements, and asphalt overlays of existing concrete or composite (asphalt overlay of jointed plain concrete) pavements. The following describes the general design factors included in PAVEXpress using the AASHTO 1993 Guide pavement design methodology.

- ***Scenario Information:*** Includes fields to describe the paving project (scenario name, scenario description), estimated completion year, roadway classification (parking lot, collector, local, principal arterial, and interstate and other freeways), and state where the project is located (informational only).

- ***Design Parameters:*** Includes inputs for the design period, reliability level, combined standard error of the performance prediction, and the initial and terminal serviceability index.

- ***Traffic and Loading:*** Includes inputs for traffic loading information by annual average daily traffic (AADT) volume estimates or using standard 18-kip ESALs. Note: AADT information is converted to ESALs to correspond with the AASHTO 1993 traffic input requirements.

- ***Pavement Structure:*** Includes inputs for the asphalt layer including layer thickness, layer coefficient, and drainage coefficient. The user can input the asphalt layer as a single layer or in multiple layers.

- ***Substructure:*** Includes supporting layers (e.g., base, subgrade) inputs for layer coefficient, drainage coefficient, and layer thickness. Each layer can be toggled as "Fixed," indicating the layer thickness is unchanged during the analysis.

- ***Design Guidance:*** Provides the required minimum design structural number (required structural number) and confirms the evaluated pavement structure (design structural number) meets the design requirements.

2.2 MECHANISTIC-EMPIRICAL AND PERPETUAL PAVEMENT DESIGN

Mechanistic-empirical pavement designs allow for quantifying pavement performance based on local materials, climatic conditions, and traffic. The mechanistic-empirical pavement design methodology can be used to estimate:

- ***Bottom-up fatigue cracking.*** Cracking due to tensile strain at the bottom of the asphalt layer. Bottom-up fatigue cracking is a function of asphalt materials and layer thickness.

- ***Top-down fatigue cracking.*** Cracking due to tensile strain near the asphalt surface. Top-down fatigue cracking is a function of asphalt binder aging and truck traffic loading.

- ***Rutting.*** Permanent vertical deformation—or rutting—in the asphalt pavement and the supporting base and subgrade layers is generally controlled by the vertical compressive strain. The risk of rutting is compounded by location; the severity of rutting in the asphalt layers increases with increased temperatures.

- ***Thermal cracking.*** Thermal cracking originates at the asphalt surface and is a function of materials and cold temperatures.

PAVEXpress uses a special version of the PerRoad mechanistic-empirical design and analysis method to assess horizontal and vertical strains within the pavement structure (Newcomb et al. 2020). Models for estimating asphalt pavement fatigue cracking and subgrade rutting include:

- Asphalt layer fatigue cracking:

$$\log N_f = 2.83 \times 10^{-6}\left(\frac{1}{\varepsilon_t}\right)^{3.148} \quad \text{(Eq 2)}$$

where:
N_f = loads to failure (ESALs)
ε_t = horizontal tensile strain at the bottom of the asphalt layer (in/in × 10^{-6})

- Subgrade rutting:

$$N_r = 1.077 \times 10^{18}\left(\frac{10^{-6}}{\varepsilon_v}\right)^{4.4843} \quad \text{(Eq 3)}$$

where:
N_r = loads to cause 0.5-inch rutting
ε_v = vertical compressive strain at the top of the subgrade (in/in × 10^{-6})

PerRoad also includes limiting cumulative strain distribution and maximum fatigue ratios for the design of perpetual pavements. Perpetual pavements are designed to prevent bottom-up fatigue cracking, thereby only requiring surface renewal (e.g., mill and overlay) over an extended period of years (50 years or more). The strain value associated with eliminating bottom-up fatigue cracking can range from 60 to 200 microstrain (Thompson and Carpenter 2004, Willis and Timm 2009, Prowell et al. 2010, Tran et al. 2015). In-service asphalt pavements at the National Center for Asphalt Technology (NCAT) Test Track with strain values to the left of the limiting cumulative strain distribution were identified as perpetual pavements (i.e., no bottom-up fatigue cracking), and pavements with strain levels to the right of the limiting cumulative strain distribution were distressed with bottom-up fatigue cracking (**Figure 1**).

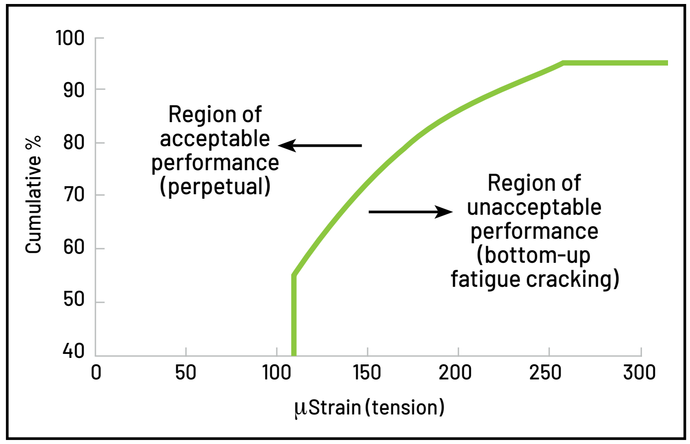


Figure 1. **Cumulative strain distribution.**

PAVEXpress and PerRoad inputs include:

- ***Scenario Info.*** Provides fields to describe the pavement design project. Input fields include scenario name, scenario description, and seasonal conditions (season, mean temperature, and season duration in weeks).

- ***Traffic.*** Allows for the entry of truck traffic volumes and vehicle distribution. Truck traffic volume information includes two-way AADT, percent trucks, percent truck growth, percent trucks in the design lane, and truck traffic directional distribution. To account for axle load distribution, the user is allowed to indicate the roadway functional classification.

- ***Layer Structure.*** Inputs for the pavement structure to be evaluated and include layer material type (e.g., asphalt, aggregate base, subgrade), asphalt layer binder grade, Poisson's ratio, elastic modulus, and layer thickness.

- ***Performance Criteria.*** Performance criteria for assessing the pavement structure. While the criteria are editable, the default values are based on field studies and are recommended for use in the analysis of perpetual pavements. For conventional mechanistic-empirical pavement designs, inputs include asphalt horizontal (fatigue cracking) and vertical (rutting) strain, and unbound layer vertical strain (rutting).

- ***Simulation.*** Layered elastic and perpetual pavement analysis included in PAVEXpress use Monte Carlo simulation in the evaluation of the pavement structure. This area allows the user to input the number of Monte Carlo runs used in the analysis. This area also shows the results of the analysis.

3. PAVEMENT DESIGN CATALOG

3.1 CATALOG DEVELOPMENT

A collection of design scenarios was developed to establish asphalt pavement thickness recommendations for selecting traffic volumes and subsurface conditions for non-state DOT roadways.

3.1.1 Pavement Types

Pavement types in the design catalog include conventional asphalt, asphalt over cement treated base (CTB), full-depth reclamation/recycling (FDR), cold central plant recycling (CCPR) base layers, and full-depth asphalt (**Figure 2**).

Because the design catalog is focused on non-state DOT pavement projects, all projects are "Local" with an associated reliability level of 75%. The difference between the initial and terminal serviceability indices is 2.5. Other default pavement design inputs are a combined standard error of 0.5% for the pavement performance prediction.

The design catalog was developed with the "Fixed" function toggled on (i.e., checked) for all base layers so only the asphalt layer thickness was varied to address the different pavement types, traffic loading, and subgrade conditions.

Conventional

Conventional asphalt pavement is composed of an asphalt layer (minimum thickness of 2.5 inches) placed directly on an unbound aggregate base layer constructed on a prepared subgrade soil.

Cement-Treated Base

Aggregate base layers are often chemically treated to improve stiffness, uniformity of support, and durability. The CTB pavement structure consists of an asphalt layer (minimum thickness of 2.5 inches) placed directly over a CTB layer constructed on a prepared subgrade soil. The selected resilient modulus (i.e., stiffness) of the CTB layer is based on several resources:

- Iowa *Design Manual* recommends a CTB layer coefficient of 0.20 or a design layer modulus of approximately 75,000 psi (Iowa Statewide Urban Design and Specifications 2019).
- Texas DOT *Pavement Manual* recommends a design layer modulus of 50,000 to 250,000 psi for an asphalt-treated base and 80,000 to 150,000 psi for a cement-treated base (Texas Department of Transportation 2018).

Full-Depth Reclaimed Base

Local agencies are increasingly adopting the use of FDR in the reconstruction and improvement of existing roads. FDR processes involve the pulverization of road materials to typical depths up to 12 inches. These materials—which can be a blend of reclaimed asphalt pavement (RAP), base materials, and subgrade soils—are immediately reused in place as a base layer for a new asphalt pavement. The design catalog presumes the FDR pavement type includes an asphalt layer placed on a 9-inch stabilized FDR base layer on the subgrade.

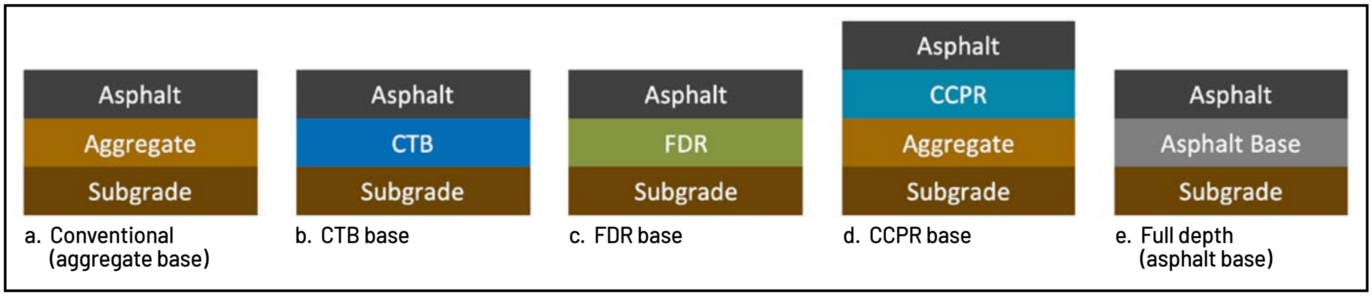


Figure 2. Design catalog pavement types.

While the design catalog does not include the use of a non-stabilized FDR layer, this pavement type can be explored within PAVEXpress given the corresponding design parameters (most notably, layer thickness and stiffness). An unstabilized FDR layer coefficient of 0.18, or layer modulus of approximately 67,500 psi, is recommended (Iowa Statewide Urban Design and Specifications 2019, Zammarchi and Tompkins 2021).

Cold Central Plant Recycled Base

The design catalog includes the use of CCPR or cold in-place recycled (CIR) base materials, which are discussed in resources such as those developed by the Asphalt Recycling and Reclaiming Association (2015). For non-state DOT roadway applications, CCPR and CIR are often constructed at a thickness of 3 to 4 inches. The stiffness and long-term performance of CCPR and CIR base layers can vary significantly based on the age and thickness of the recycled asphalt layer and in the case of CIR, the existing base material. Both CCPR and CIR are stabilized with added bitumen, either in the form of emulsion or foamed asphalt binder. The *Wirtgen Cold Recycling Manual* (Wirtgen 2004) includes moduli ranges for bitumen stabilization based on the material being recycled (**Table 1**). Diefenderfer et al. (2016) suggested using a layer coefficient of 0.36 to 0.39 for CCPR material.

Table 1. Resilient Modulus Ranges of Stabilized Base Materials (Wirtgen 2004)

Material Type	Bitumen Content (%)	Modulus (psi)
100% RAP	1.6 to 2.0	145,000 to 290,000
50-50 blend of RAP and crushed stone	1.8 to 2.5	116,000 to 218,000
Graded crushed stone	2.0 to 3.0	87,000 to 174,000
Natural gravel	2.2 to 4.0	44,000 to 116,000

Full-Depth Asphalt

Full-depth asphalt includes an asphalt surface and asphalt base layers placed directly on a prepared, and possibly treated, subgrade. Full-depth asphalt pavements were presumed to have a single 3-inch asphalt base layer.

3.1.2 Climate

While PAVEXpress allows for the selection of the project location (by state), the project location does not affect the AASHTO 1993 Guide calculated required structural number and final design result for asphalt thickness. Therefore, the design catalog does not account for the effects of climate. The following climate conditions may not affect pavement thickness directly; however, they should be considered since they may impact pavement performance:

- ***Temperature extremes.*** Earlier sections discussed the challenges presented by ambient temperatures, which primarily deal with special materials considerations to limit rutting or low-temperature cracking. Consulting with state resources to anticipate special asphalt mixture needs to accommodate both low and high ambient temperatures is recommended.

- ***Volume changes in subgrade soils.*** Subgrade soil volume change due to moisture absorption/drying (i.e., shrink/swell) or freezing (i.e., frost heave) may compromise pavement support. These issues can be quantified by sampling and testing subgrade soils and consulting with state geotechnical maps and resources.

- ***Flooding.*** While the seasonal saturation of subgrade soils is known to compromise pavement performance in wet-freeze climates, new concerns are emerging for pavements subjected to flooding. Where available, resources should be consulted when planning and designing pavements in flood-risk locations.

Resources for accounting for climate impacts on non-state DOT roadway asphalt pavement designs can be obtained from DOT design manuals and construction specifications. Some agencies maintain special resources for non-state DOT roadway pavement design. These resources can be supplemented with industry resources, including NAPA's library of products, to better design a road for specific environmental concerns.

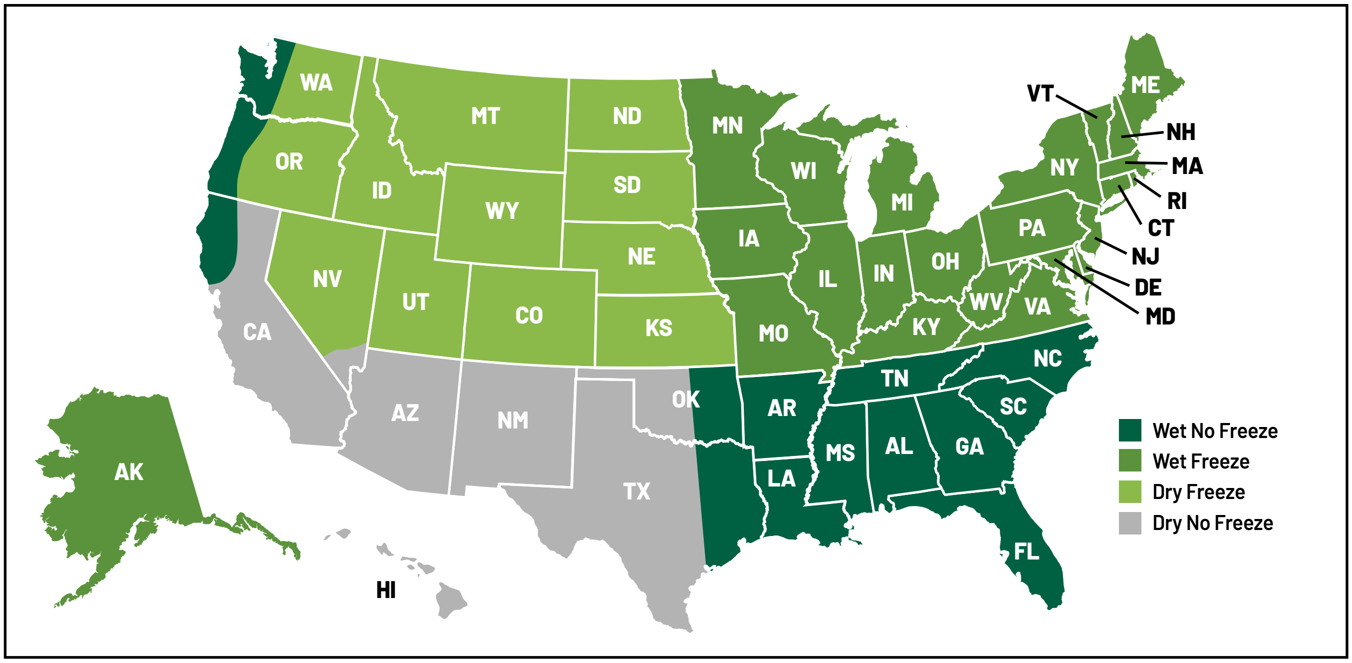


Figure 3. Map of climatic zones.

Climate inputs for mechanistic-empirical pavement designs using PerRoad require the average seasonal temperature, season duration (i.e., number of weeks), and asphalt layer binder type. Since the design catalog was not developed for a specific location (e.g., city, state, region), an analysis was conducted to determine the seasonal average temperature based on the data contained within the FHWA InfoPave database (https://infopave.fhwa.dot.gov/). InfoPave includes pavement performance data for approximately 2,500 pavement sections across the U.S. and Canada. Figure 3 illustrates the U.S. climatic zones for wet no freeze, wet freeze, dry freeze, and dry no freeze locations.

The InfoPave data were used to determine the average seasonal temperatures and durations for each climatic zone (**Table 2**).

3.1.3 Traffic Loadings

Truck traffic loading is categorized into "low," "medium," and "high" scenarios. Inputs corresponding with each traffic scenario are summarized in **Table 3**. Other relevant parameters not included in **Table 3** are an assumed initial truck equivalency factor of 1.37 and an urban principal arterial vehicle distribution.

3.1.4 Pavement Materials

The AASHTO structural coefficients and corresponding elastic moduli values for the asphalt and base layers and subgrade soils are summarized in **Table 4** through **Table 7**, respectively. The asphalt layer coefficients, shown in **Table 4**, are based on the AASHTO 1993 Guide recommendations and commonly used by many DOTs. Studies have shown

Table 2. Seasonal Temperatures and Duration

Climate Zone	Winter		Spring		Summer		Fall	
	Temp (°F)	Duration (weeks)	Temp (°F)	Duration (weeks)	Temp (°F)	Duration (weeks)	Temp (°F)	Duration (weeks)
Wet freeze	28.4	13.0	48.8	13.0	70.7	13.6	52.1	12.5
Dry freeze	26.3	12.6	47.6	13.4	70.7	13.1	49.4	13.0
Wet no freeze	45.7	12.9	65.7	16.8	79.9	9.5	64.0	13.0
Dry no freeze	49.5	12.9	68.2	16.7	85.1	9.6	67.5	13.0

Table 3. Truck Traffic Inputs

Traffic Category	Target ESAL (millions)	AADT	% Truck Traffic	Initial AADTT*	Volume Growth** (%)	Weight Growth** (%)	% Trucks in Design Lane	Directional Distribution (%)	20-Year ESAL (millions)
Low	< 1	1,000	10	100	2.0	0.5	90.0	50.0	0.58
Medium	1 - 3	3,000	10	300	2.0	0.5	90.0	50.0	1.74
High	> 3	6,000	10	600	2.0	0.5	90.0	50.0	3.48

* *Average annual daily truck traffic*
** *Annual linear growth.*

higher asphalt layer coefficients may be appropriate to reflect advances in materials and construction practices (Timm et al. 2014).

For the PerRoad analysis, the Performance Graded (PG) binder system is used to characterize the asphalt binder according to temperature and truck loading conditions. The PG binder system is based on the average 7-day high pavement temperature (°C) and the low pavement temperature (°C). PG binders are typically specified at 6°C increments (**Table 5**). The high-temperature grade is selected to resist rutting, and the low-temperature grade is to resist thermal (or transverse) cracking.

The high-temperature grade for the asphalt surface layer is typically increased by one grade (e.g., PG 64 to PG 70) for slow-moving truck traffic and increased by two grades for stopped conditions (e.g., PG 64 to PG 76). The low-temperature binder grade for the asphalt base layer may be reduced by one grade compared to the asphalt surface layer.

Table 4. Asphalt Layer Inputs

Layer Type	Thickness (inch)	Modulus (psi)	AASHTO Structural Coefficient
Asphalt surface	---	450,000	0.44
Asphalt base	3	450,000	0.44

Table 5. Typical PG Binder Grades

High Temperature Grade	Low Temperature Grade
PG 46	-34, -40, -46
PG 52	-10, -16, -22, -28, -34, -40, -46
PG 58	-16, -22, -28, -34, -40
PG 64	-10, -16, -22, -28, -34, -40
PG 70	-10, -16, -22, -28, -34, -40
PG 76	-10, -16, -22, -28, -34
PG 82	-10, -16, -22, -28, -34

Asphalt binder grade selection, based on project-specific locations, can be determined using the Federal Highway Administration's LTPPBind web-based tool (https://infopave.fhwa.dot.gov/Tools/LTPPBindOnline) and applicable state highway agency standards for binder specification requirements.

As noted in Section 3.1.2, the design catalog was not developed for specific locations; however, binder grade selection is needed to conduct the PerRoad analysis. A review of the state highway agencies PG binder specifications was conducted and the most common binder grade type in each climatic zone was selected for the analysis. The binder grade used in this design catalog should not supersede the binder types used by any given agency.

The PerRoad analysis included a one-grade high-temperature increase for the high-truck loading category. If the selected PG binder is not included in the design catalog tables, a new design should be conducted using PerRoad.

3.2 DESIGN CATALOG

The design catalog recommendations for low, medium, and high truck traffic volumes are summarized in **Table 8** through **Table 10**, respectively. The design catalog recommendations for weak, moderate, and stiff subgrade modulus by pavement type are included in each of the tables for each base type. The PAVEXpress results are based on the AASHTO 1993 Guide and the PerRoad results are arranged by climatic zone and binder grade. All asphalt surface course thicknesses are expressed in half-inch increments.

Table 6. Base Layer Inputs

Layer Type	Thickness (inch)	Modulus (psi)	AASHTO Structural Coefficient
Aggregate	6	25,000	0.12
Cement treated	6	80,000	0.21
FDR (cement or emulsion)	9	150,000	0.24
CCPR	4	350,000	0.39

Table 7. Subgrade Inputs

Condition	Soil Type	Poisson's Ratio	Modulus
Weak	Clay	0.45	5,000
Moderate	Silty or clayey sand	0.45	10,000
Stiff	Silty or clayey gravel	0.45	15,000

3.3 RECOMMENDATIONS FOR USE AND IMPLEMENTATION

Agencies are encouraged to explore candidate projects by considering issues raised in the design catalog and in other resources, including state DOT resources for design recommendations and guidance. Special considerations in the use of this design catalog are discussed in the following subsections.

3.3.1 Minimum Pavement Thickness

A minimum compacted asphalt layer lift thickness of 2.5 inches has been adopted for the design catalog. The minimum recommended asphalt lift thickness addresses concerns related to:

- ***Variation in mat thickness.*** Areas where the pavement thickness is thinner than design thickness, or "thin spots," at best result in additional distress and, ultimately, lost service life. At worst, these thin spots rapidly deteriorate under combinations of traffic and environmental damage, creating hazardous road debris and directly exposing the supporting layers to further erosion and/or degradation.
- ***Haul traffic tolerance.*** Local roads, particularly in rural areas, run the risk of bearing traffic loads that are beyond those anticipated for design purposes, either in volume or axle load. Instantaneous failures under single-load applications are documented. Minimum values are adopted to decrease the likelihood of immediate failure.
- ***Compaction.*** NCAT studies have shown that permeability is related to the asphalt lift thickness. Sufficient lift thickness ensures proper aggregate alignment during compaction to achieve density and low permeability results. Increasing the lift thickness to allow for a minimum lift thickness (t) to a nominal maximum aggregate size (NMAS) ratio (t/NMAS) of 3.0 is recommended (Asphalt Institute n.d., Cooley et al. 2002).

3.3.2 Design and Construction Considerations

Most local agencies either maintain agency-specific construction specifications or rely on state DOT specifications for road construction. These records account for planning, evaluation, excavation/earthwork, and other stages involved in pavement construction. The recommendations in this design catalog can be used as a starting point; however, additional considerations to benefit long-term pavement performance include:

- ***Adjusting asphalt layer mix design for special climate concerns.*** Local agencies are encouraged to rely on DOT and asphalt industry association recommendations for binder grade selection to limit distress (e.g., rutting, thermal cracking) due to climate and truck traffic conditions (Garcia and Hansen 2001, Yin and West 2021).
- ***Accounting for locally available materials.*** Local agencies may face challenges with the availability of quality material. DOTs typically maintain records describing local materials and methods to incorporate them into structural designs without sacrificing pavement support and service life. The use of local materials may also be an opportunity for non-state DOT agencies to save on project costs by reducing haul distances and necessary earthwork (Van Dam et al. 2015).

Table 8. Design Catalog – Low Traffic (1,000 AADT, 10% Trucks, 20-year ESAL ~0.6M)

		PAVEXpress (inch)	PerRoad Perpetual Asphalt Layer (inch)					
			Dry Freeze		Dry No Freeze	Wet Freeze		Wet No Freeze
Base Type and Thickness	Subgrade Condition	Asphalt Layer	PG 58-28	PG 58-34	PG 64-22[4]	PG 58-28	PG 64-22	PG 64-22[3,4]
Aggregate (6-inch layer)	Weak	6.0	6.5	6.5	7.0	6.5	5.5	6.5
	Moderate	4.5	6.5	6.5	7.0	6.5	5.5	6.5
	Stiff	3.5	6.0	6.0	7.0	6.5	5.0	6.5
Cement-treated (6-inch layer)	Weak	4.5	4.5	4.5	5.0	4.5	3.5	4.5
	Moderate	3.0	4.5	4.5	5.0	4.5	3.5	4.5
	Stiff	2.5[1]	4.5	4.5	4.5	4.5	3.5	4.5
Full-depth reclamation (9-inch layer)	Weak	2.5[1]	3.5	3.5	4.5	3.5	3.0	4.0
	Moderate	2.5[1]	3.5	3.5	4.5	3.5	3.0	4.0
	Stiff	2.5[1]	3.5	3.5	4.0	3.5	3.0	4.0
Cold central plant recycling (4-inch layer)[2]	Weak	2.5[1]	4.0	4.0	4.5	4.0	3.0	4.5
	Moderate	2.5[1]	4.0	4.0	4.5	4.0	3.0	4.5
	Stiff	2.5[1]	4.0	4.0	4.5	4.0	3.0	4.5
Full depth (3-inch asphalt base)	Weak	5.0	4.5	4.5	5.0	4.5	3.5	5.0
	Moderate	3.5	4.5	4.5	5.0	4.5	3.5	5.0
	Stiff	3.0	4.5	4.0	5.0	4.5	3.5	5.0

[1] Minimum recommended asphalt layer thickness.
[2] Assumes existing 6-inch aggregate subbase.
[3] Many state highway agencies in the Southeastern US use PG 67-22 as a standard binder. PG 67-22 meets the performance criteria for PG 64-22.
[4] In the dry no freeze zone and in the wet no freeze zone, PG58-22/28 binders are generally used when asphalt mixes have higher RAP contents generally more than 25%. In that case PG 64-22 binder should be used in the pavement design.

Table 9. Design Catalog – Medium Traffic (3,000 AADT, 10% Trucks, 20-year ESAL ~1.7M)

		PAVEXpress (inch)	PerRoad Perpetual Asphalt Layer (inch)					
			Dry Freeze		Dry No Freeze	Wet Freeze		Wet No Freeze
Base Type and Thickness	Subgrade Condition	Asphalt Layer	PG 58-28	PG 58-34	PG 64-22[4]	PG 58-28	PG 64-22	PG 64-22[3,4]
Aggregate (6-inch layer)	Weak	7.0	6.5	6.5	7.0	6.5	5.5	6.5
	Moderate	5.5	6.5	6.5	7.0	6.5	5.5	6.5
	Stiff	4.5	6.0	6.5	7.0	6.5	5.0	6.5
Cement-treated (6-inch layer)	Weak	6.0	4.5	4.5	5.0	4.5	3.5	4.5
	Moderate	4.0	4.5	4.5	5.0	4.5	3.5	4.5
	Stiff	3.0	4.5	4.5	4.5	4.5	3.5	4.5
Full-depth reclamation (9-inch layer)	Weak	3.5	3.5	3.5	4.5	3.5	3.0	4.0
	Moderate	2.5[1]	3.5	3.5	4.5	3.5	3.0	4.0
	Stiff	2.5[1]	3.5	3.5	4.5	3.5	3.0	4.0
Cold central plant recycling (4-inch layer)[2]	Weak	3.5	4.0	4.0	4.5	4.0	3.0	4.5
	Moderate	2.5[1]	4.0	4.0	4.5	4.0	3.0	4.5
	Stiff	2.5[1]	4.0	4.0	4.5	4.0	3.0	4.5
Full depth (3-inch asphalt base)	Weak	6.5	4.5	4.5	5.0	4.5	3.5	5.0
	Moderate	4.5	4.5	4.5	5.0	4.5	3.5	5.0
	Stiff	3.5	4.5	4.5	5.0	4.5	3.5	5.0

[1] Minimum recommended asphalt thickness.
[2] Assumes existing 6-inch aggregate subbase.
[3] Many state highway agencies in the Southeastern US use PG 67-22 as a standard binder. PG 67-22 meets the performance criteria for PG 64-22.
[4] In the dry no freeze zone and in the wet no freeze zone, PG58-22/28 binders are generally used when asphalt mixes have higher RAP contents generally more than 25%. In that case PG 64-22 binder should be used in the pavement design.

Table 10. **Design Catalog – High Traffic (6,000 AADT, 10% Trucks, 20-year ESAL ~3.5M)**

		PAVEXpress (inch)	PerRoad Perpetual Asphalt Layer (inch)							
			Dry Freeze		Dry No Freeze		Wet Freeze		Wet No Freeze	
Base Type and Thickness	Subgrade Condition	Asphalt Layer	PG 64-28	PG 64-34	PG 64-22	PG 70-28	PG 64-28	PG 70-22	PG 64-28[3]	PG 70-22
Aggregate (6-inch layer)	Weak	8.0	5.5	5.0	7.0	6.5	5.5	5.5	6.5	6.0
	Moderate	6.0	5.5	5.0	7.0	6.0	5.5	5.5	6.5	6.0
	Stiff	5.0	5.0	5.0	7.0	6.0	5.5	5.0	6.5	6.0
Cement-treated (6-inch layer)	Weak	6.5	3.5	3.5	5.0	4.5	4.0	3.5	4.5	4.0
	Moderate	5.0	3.5	3.5	5.0	4.0	3.5	3.5	4.5	4.0
	Stiff	4.0	3.5	3.5	5.0	4.0	3.5	3.5	4.5	4.0
Full-depth reclamation (9-inch layer)	Weak	4.5	3.0	3.0	4.5	3.5	3.0	2.5	4.0	3.5
	Moderate	2.5	3.0	3.0	4.5	3.5	3.0	2.5	4.0	3.5
	Stiff	2.5[1]	3.0	3.0	4.5	3.5	3.0	2.5	4.0	3.5
Cold central plant recycling (4-inch layer)[2]	Weak	4.5	3.0	3.0	4.5	2.5	3.0	2.5	4.5	3.5
	Moderate	2.5	3.0	3.0	4.5	2.5	3.0	2.5	4.5	3.5
	Stiff	2.5[1]	3.0	3.0	4.5	2.5	3.0	2.5	4.5	3.5
Full depth (3-inch asphalt base)	Weak	7.0	6.5	6.0	6.5	6.5	6.5	6.5	7.0	6.5
	Moderate	5.5	6.0	5.5	6.0	6.5	6.0	5.5	6.5	6.0
	Stiff	4.5	5.5	5.5	5.5	6.0	5.5	5.5	6.5	6.0

[1] *Minimum recommended asphalt thickness.*
[2] *Assumes existing 6-inch aggregate subbase.*
[3] *For Southeastern US PG 76-22 and PG 70-28 are more commonly used.*

- ***Quality control/assurance.*** Local agencies are encouraged to consult resources on acceptance activities for roadway construction projects. These resources will describe contractor quality control requirements, municipal acceptance criteria, and pay items. Many state DOTs provide programs to guide local agencies on acceptance. The FHWA maintains an active website on assurance with resources targeted at non-state DOT roadway projects (FHWA 2023). NAPA maintains resources on quality control for contractors and municipal engineers (Root 1997).

Addressing these and other concerns early in the planning, design, and construction stages can reduce distress and preserve or possibly extend the intended service life of the pavement.

3.3.3 Use of Pre-Existing Pavement (Including Recycling and Reclamation)

The design catalog includes both FDR and cold-recycled bases supporting the asphalt pavement surface course. Cold-recycled methods, including CCPR, are assumed to use in-place asphalt. The re-use of in-place materials has been an established practice for non-state DOT roadway projects for decades and offers the local owner structural improvement, extended service life, and reduced cost (Asphalt Recycling and Reclaiming Association 2015). Two factors contributing to the quality of FDR and cold-recycled base layers are contractor experience and the use of laboratory mix designs.

- ***Contractor experience.*** Whereas other aspects of paving are familiar to a broader group of contractors, many contractors do not maintain the equipment or have the experience needed to effectively conduct recycling and reclamation construction. The construction bid process should, at a minimum, require past, supported experience for FDR/cold-recycled projects, ideally projects with materials and structural cross-sections resembling those in the bid project.

- ***Laboratory mix designs.*** As FDR bases are assumed to be stabilized with cement or emulsified asphalt, and CCPR/CIR bases are assumed to be stabilized with emulsified or foamed asphalt, local agencies are encouraged to seek out FDR and CIR/CCPR mix designs from a qualified laboratory. Appropriate mix design procedures may include a state DOT procedure or AASHTO procedure (e.g., AASHTO PP 86 or AASHTO PP 94). The value of the mix design procedure extends beyond the final recommendation for stabilizer content. The sampling of road materials for laboratory needs provides an opportunity to evaluate the existing pavement condition and the quality of the in-place materials. The laboratory tests to evaluate the prepared, stabilized base materials provide insight into the strength and layer stiffness. Mix design reports from qualified laboratories will often include guidance on gradation limits, water content, and other important factors to be monitored on-site. Most importantly, the mix design identifies a job-mix formula (i.e., a stabilization target by dry weight of recycled/reclaimed material) to guide the contractor during the construction of the FDR or cold-recycled base.

Additional industry resources are available from the Wirtgen Group (2004), the American Association of Asphalt Recycling (2015), and the Portland Cement Association (Gross and Adaska 2020).

4. USE OF OVERLAYS FOR MAINTENANCE AND REHABILITATION

There are many pavement maintenance, preservation, and rehabilitation activities for extending the pavement service life. These treatments include chip seals, seal coats, and slurry seals. While these (and other) options can slow surface deterioration and the progression of cracking, they do not contribute structurally to the pavement section. Asphalt overlay is an alternative surface treatment that addresses existing distress while potentially improving road structure and extending pavement service life. Asphalt overlays are an integral part of roadway maintenance and rehabilitation. For this reason, asphalt overlays of existing pavements are one of the most common maintenance and rehabilitation strategies for non-state DOT roadway projects (NAPA 2009, Asphalt Recycling and Reclaiming Association 2015). This chapter summarizes generally accepted practices and local considerations for overlay design and factors influencing the long-term performance of asphalt overlays.

4.1 EXISTING PAVEMENT CONDITION ASSESSMENT

One of the most important factors when considering an overlay is the condition of the existing pavement. Pavements in poor condition—or pavements that have not been sufficiently repaired before rehabilitation—will limit the effectiveness of the overlay. All strategies for overlay design begin with a sound engineering evaluation of the existing roadway.

The following is not intended to be a comprehensive guide for assessing existing pavement conditions but instead is intended to describe activities that help quantify existing conditions to ensure the asphalt overlay performs as expected.

4.1.1 Construction Records Review

A review of as-builts, construction records, and other documents may clarify the structural cross-section and pavement materials. This information is often available at little cost and may prevent unnecessary exploration or guesswork in later stages of the evaluation.

4.1.2 Surface Condition Evaluation

State DOTs and local associations maintain rigorous rating systems to evaluate the condition of pavement surfaces. These methods include the pavement condition index (PCI), the PAVER system, and the PASER rating system (Shahin and Walther 1990, Walker 2013, ASTM International 2023). Pavement rating methods help designers quantify pavement conditions and prioritize short- and long-term maintenance and rehabilitation activities. A careful consideration of surface distress may immediately exclude overlays as a rehabilitation strategy or may warrant deeper exploration (e.g., boring/coring). For instance, longitudinal cracking in the wheel path and fatigue cracking may indicate deeper structural issues that would penetrate and jeopardize a new overlay.

4.1.3 Subsurface Sampling and Exploration

Subsurface exploration provides an improved understanding of the existing pavement materials and structures. Methods of exploration include coring, boring, dynamic cone penetrometer (DCP), and ground penetrating radar. Coring provides information on layer thickness, top-down or bottom-up cracking, and material-related distress (e.g., stripping). **Figure 4** shows cores from several pavement locations. **Figure 4b** shows a relatively thick core with wheel path cracking. Without a pavement core, the recommended treatment may have been more extensive (i.e., FDR, reconstruction) than is required; however, the core showed the cracking was limited to the upper 2 inches, suggesting a mill and fill would be appropriate. **Figure 4c** shows stripping and delamination within the asphalt layer and supports the need for more extensive rehabilitation activities.

a. Core barrel.

b. Top-down

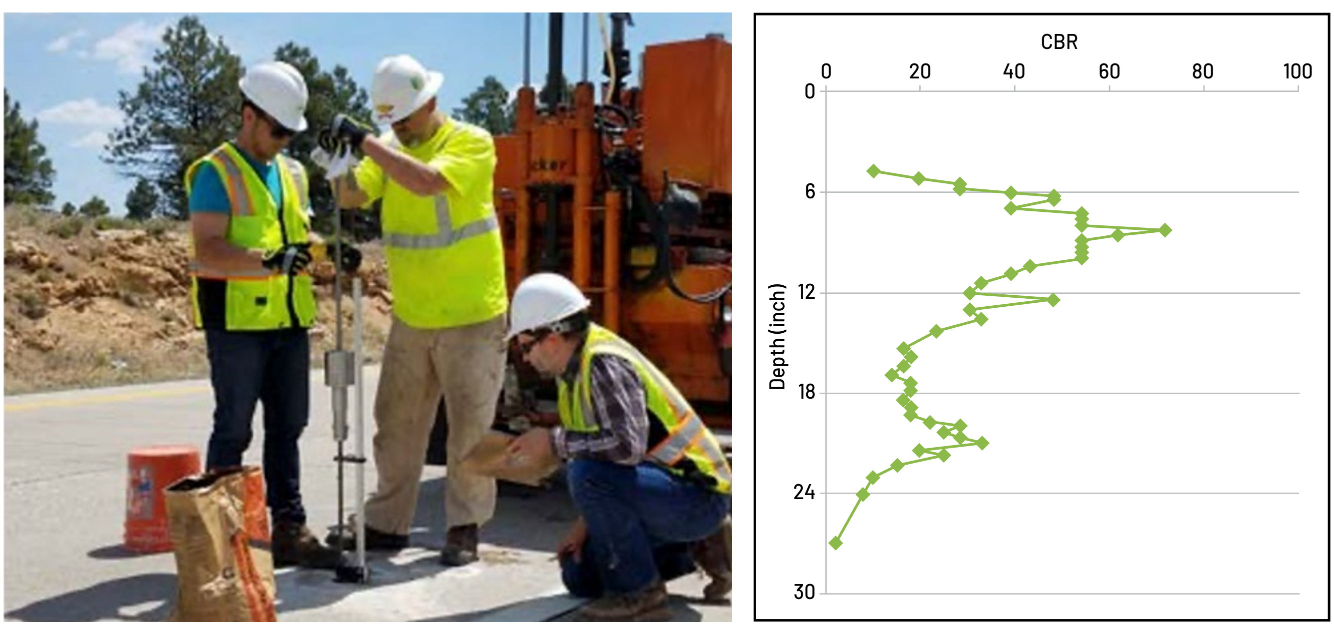
c. Stripping and delamination.

Figure 4. Example of coring.

Boring and DCP provides an accurate view of layer cross-sections and materials. DCP is defined by ASTM D6951-03 as a device used to assess the in-place strength of soils or compacted materials. Results from DCP testing can be used to estimate the thickness of the unbound layers and in situ California Bearing Ratio (CBR) (**Figure 5**).

Samples of the unbound pavement layers (i.e., base, subbase, subgrade) can be obtained and provided to laboratory facilities for further testing and analysis.

GPR surveys are conducted per ASTM D4748-10 (2020) and can be used to determine asphalt, concrete (and the presence of reinforcing steel),



a. Testing equipment.

b. Analysis results.

Figure 5. Example of DCP testing equipment and analysis.

Figure 6. Example of GPR equipment.

and unbound layer thickness. Data are typically collected at posted speeds, at 1-foot intervals, with geo-spatial location information (**Figure 6**).

Pavement layer thickness is determined by viewing the GPR data and identifying the significant layers. In the example shown in **Figure 7**, the analysis showed the asphalt layer was approximately 4 inches thick over approximately 6 inches of aggregate base and 6 inches of aggregate subbase. As shown, the distortion in the GPR image indicated the location of an asphalt patch.

Figure 8 illustrates an example of the benefits of GPR testing. On this local agency project, the client requested limited pavement coring (only in the inside lane of a 4-lane roadway); however, the variability of the core thickness caused concerns during the pavement design phase of the project. Three cores were extracted, one indicating a thinner asphalt layer around station 150 and a thick asphalt layer at approximately stations 450 and 1750. GPR testing was conducted in lane 1 (inside lane) and lane 2 (outside lane) and showed that the asphalt layer in lane 2 was considerably thinner than indicated by coring (the average asphalt layer thickness for lane 1 is 14.2 inches and for lane 2 is 7.0 inches).

Based on only the core information, the pavement structural capacity would have been considered adequate, requiring only a mill and overlay. However, the GPR data indicated lane 2 was considerably thinner than observed in the core and would have been structurally inadequate with only a mill and overlay treatment. With this knowledge, the pavement design was modified to reconstruct lane 2 to meet structural requirements. Without this knowledge, distress (i.e., bottom-up fatigue cracking) would likely have occurred sooner than expected in lane 2.

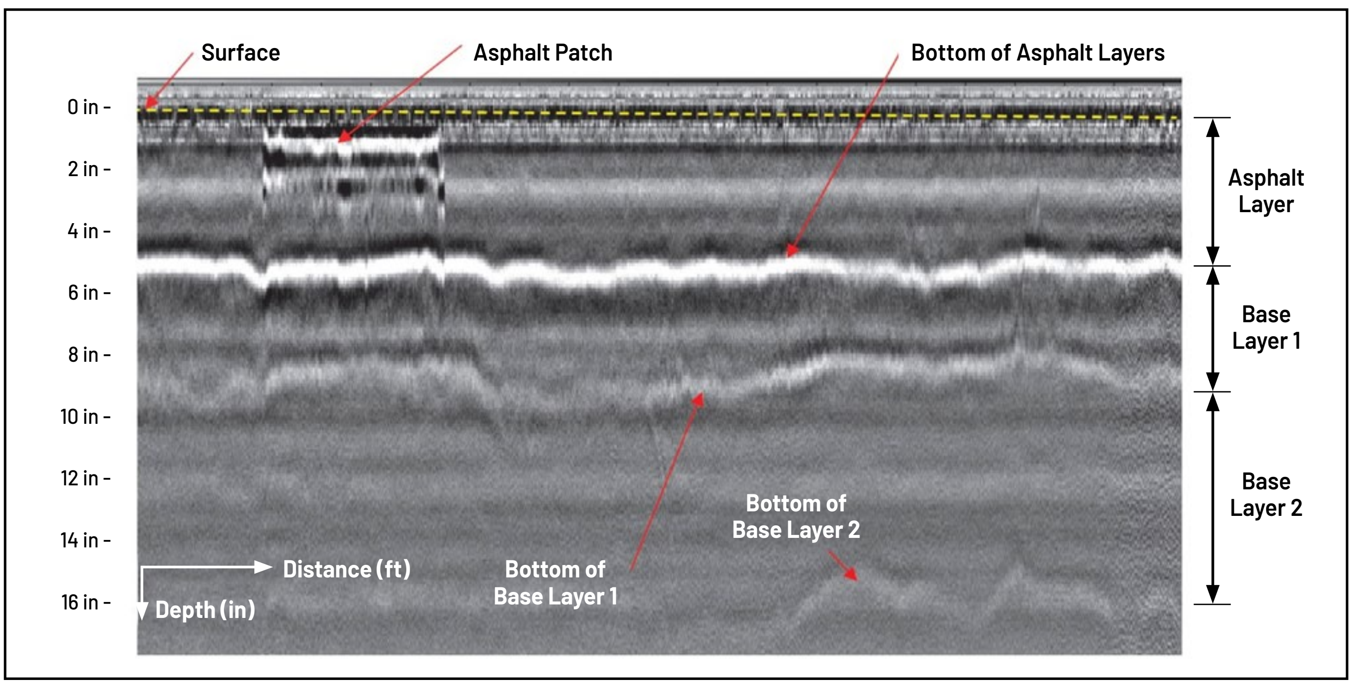


Figure 7. Example of raw GPR data (Source: Infrasense).

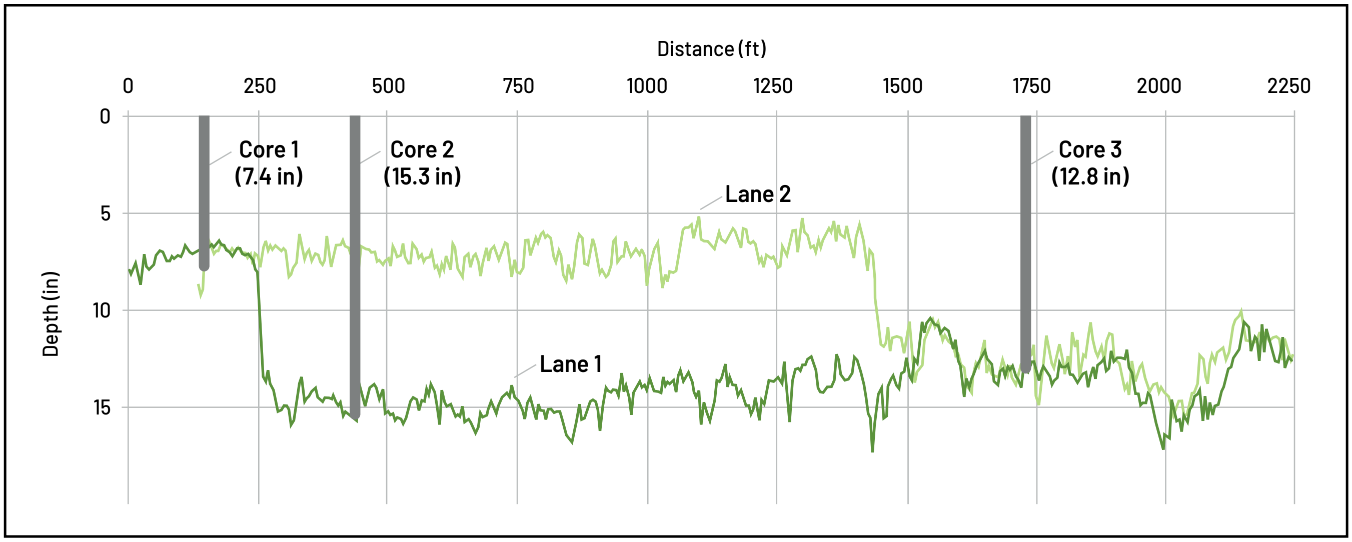


Figure 8. Comparison of core and GPR results.

Table 11 provides a summary and comparisons of coring and GPR testing benefits and limitations.

4.1.4 Structural Condition Assessment

Falling-weight deflectometer (FWD) testing and analysis is an effective method to assess the structural pavement response to loading. FWD testing is particularly valuable when performed in conjunction with the activities outlined above, as an understanding of pavement layer thicknesses and materials allows for the determination of structural contributions of each pavement layer. For instance, regular FWD testing (typically in 0.1-mile intervals) may identify areas of compromised base or subgrade support. The addition of FWD tests can also provide valuable information if other, more extensive options, such as CIR, are considered alongside overlays.

4.1.5 Laboratory Testing

While the existing asphalt layer can be tested and evaluated, especially if it fails prematurely, most local agencies use laboratory testing to characterize the unbound base layer and/or subgrade soils. Laboratory testing of the extracted unbound base and subgrade soils may include gradation, Atterberg limits, soil classification (e.g., AASHTO soil classification).

4.2 IDENTIFYING AREAS FOR PRE-OVERLAY REPAIR

Proper identification and application of pre-overlay repair activities improve the performance of the asphalt overlay. The selection of pre-overlay treatments may be a function of several factors including existing pavement conditions, variations in the pavement structure and subgrade strength,

Table 11. Benefits and Limitations of Coring and GPR Testing.

Device	Benefits	Limitations
Coring	▪ Visual identification of layer thickness and type ▪ Observe distress (e.g., depth of cracking, presence of stripping)	▪ Requires traffic control ▪ May require permits and utility location ▪ May not capture the location of thickness change ▪ Exposes the operators to traffic
GPR	▪ Data collection at posted speed ▪ Layer thickness on 1-foot intervals	▪ Typically, 1 to 2 cores to confirm layer thickness ▪ Requires software training for analysis

Table 12. Potential Pre-Overlay Treatments (adapted from Tenison and Hanson 2009)

Distress Type	Severity	Not Needed	Patching	Mill and Overlay	Full-Depth Repair
Fatigue cracking	Moderate			✓	
	High				✓
Block cracking	Moderate			✓	
	High			✓	
Longitudinal cracking	Moderate	✓			
	High			✓	
Transverse cracking	Moderate	✓			
	High			✓	
Patch and patch deterioration	Moderate	✓			
	High				✓
Pothole	Moderate	✓			
	High		✓		
Rutting and shoving	All			✓	
Bleeding	High			✓	
Raveling	All	✓			
Polished aggregate	All	✓			
Roughness	Moderate	✓			
	High			✓	

agency funding and performance expectations, and cost. Pavement condition evaluation should be coupled with other roadway observations, including drainage conditions and performance, cross-slope, shoulder condition, and grade restrictions. **Table 12** summarizes potential pre-overlay treatments based on existing asphalt pavement distress.

Crack sealing (and filling) is integral for maintaining and preserving asphalt pavements; however, the timing of the crack sealing activity can impact the performance of the asphalt overlay. Crack sealing performed too close to the placement of the overlay can result in swelling of the crack seal material (due to the heat of the asphalt overlay material) causing a significant bump in the surface of the asphalt overlay. Ideally, crack sealing is conducted to allow sufficient time (typically, 1 to 3 years) for the crack sealant material to harden before placement of the asphalt overlay (Decker 2014).

4.3 OVERLAY DESIGN

Industry associations and state DOTs maintain guidelines for asphalt overlay design for local roads. The most common design approach in the U.S. is asphalt overlays of existing asphalt pavements based on the procedure described in the AASHTO 1993 Guide (AASHTO 1993). The AASHTO design approach for asphalt overlays resembles the procedure for new or reconstructed asphalt pavements using structural coefficients and structural number concepts. The AASHTO 1993 asphalt overlay design requires an estimate of the effective structural number of the existing pavement. This overlay design method amends deficient pavement thickness with adequate overlay thickness to meet structural requirements for future traffic levels. The AASHTO 1993 asphalt overlay design approach is included in PAVEXpress. Local agencies are encouraged to initiate and explore overlay designs using PAVEXpress and other online resources (NAPA 2024).

4.3.1 Local Considerations for Overlay Designs

The following information may assist with planning, designing, constructing, and monitoring asphalt overlays on non-state DOT roadways.

- ***Materials.*** One important factor for asphalt overlays is the selection of an appropriate mixture type (e.g., dense, open, gap-graded) and asphalt binder. DOT and local asphalt association recommendations can inform asphalt overlay mix design to ensure materials conform with regional needs (FHWA 2019).
- ***Structural design parameters.*** Characterize the structural pavement layers to conform with DOT practices. DOT rehabilitation guidelines typically include rehabilitation recommendations for non-state DOT roadways. Local agency structural design parameters can be compared to DOT recommendations for use in PAVEXpress (or other methods) for determining a final overlay thickness.
- ***Estimating traffic effects beyond traffic counts.*** DOT traffic divisions can provide traffic data for most local roads. Local transportation consultants can perform limited, short-term traffic studies, or reach out to local businesses and residents along the road to learn more about daily traffic conditions.
- ***Finished road elevation, shoulders, and drainage.*** Overlay design and construction provide an opportunity to improve other project aspects, including reshaping shoulders, assuring positive drainage away from the pavement section, and correcting intersections and approaches to improve drainage and load support and pavement edges.
- ***Rehabilitation and maintenance cost considerations.*** The costs associated with traditional mill and fill overlays and alternatives such as CIR are becoming more comparable as reclamation and recycling technologies become more widely adopted and contractors become more experienced with reclamation equipment. Local agencies are encouraged to investigate these costs during the design stage of the project.

Finally, active inspection, quality control, and acceptance are proven low-cost measures to improve pavement performance. These items can be included in the bid package, and working with the contractors, to ensure the project includes, for example, requirements for pavement repair, surface cleaning, adequate tack coat application, asphalt placement and compaction, and planning to reduce construction delays.

4.3.2 Long-Term Performance of Overlays

Asphalt overlays can be part of a successful approach to rehabilitation with active monitoring and considerate evaluation of the existing pavement. Some important factors contributing to long-term overlay performance include:

- ***Sound and appropriate repairs.*** Confirm pavement repairs and milling operations are of sufficient depth to repair distress. Deeper distresses should be localized and repaired appropriately. If there is evidence of deeper distress (e.g., rutting beyond 0.5 inches, full-depth fatigue cracking), more substantial treatment (e.g., CIR, FDR, reconstruction) should be used. The existing pavement must be brought into a structurally sound condition before it is overlaid.
- ***Surface preparation.*** Asphalt overlays should be placed on a properly milled, cleaned, and tack-coated surface.
- ***Understanding traffic and environment.*** Overlays should be sufficiently thick to meet the anticipated future traffic loading conditions (in volume or nature of loading). Traffic studies can help anticipate future traffic loadings to ensure the required overlay thickness meets the design intent.

5. SUMMARY

This design catalog is based on the AASHTO 1993 empirical pavement design method, automated through PAVEXpress, and supplemented with a mechanistic-empirical pavement design method (PerRoad) to determine appropriate layer thickness for specific pavement types to accommodate specified traffic and climate conditions. The PerRoad analysis recommended asphalt layer thickness to minimize bottom-up fatigue cracking resulting in a longer-life pavement structure requiring only surface rejuvenation (e.g., mill and overlay).

This asphalt pavement design catalog has been prepared based on more common pavement types and materials. If unique conditions warrant different materials or traffic conditions additional analysis may be conducted using PAVEXpress and PerRoad (https://PAVEXpress.com/).

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