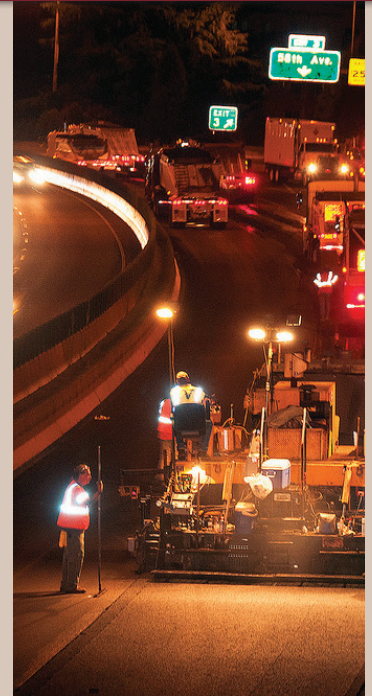




Mechanistic-Empirical Pavement Design Guide

~ A Manual of Practice ~



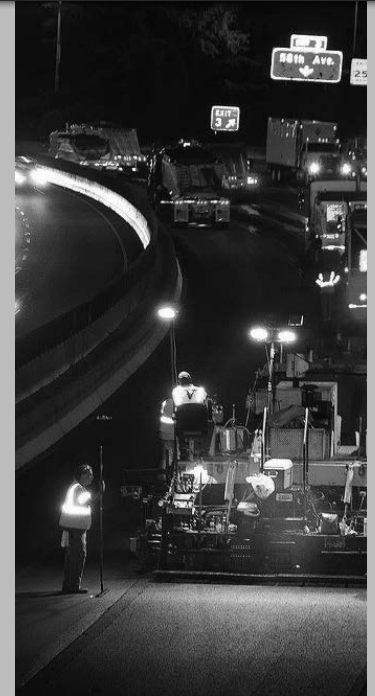
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Preface

This document or manual of practice describes a pavement design methodology that is based on engineering mechanics and has been validated with extensive road test performance data. This methodology is termed mechanistic-empirical (ME) pavement design, and it represents a major change from the pavement design methods in practice today.

Interested agencies have already begun implementation activities through staff training, collection of input data (materials library, traffic library, etc.), acquiring of test equipment, and preparation of field sections for local calibration. This manual, referred to as the Mechanistic-Empirical Pavement Design Guide (MEPDG), presents the information necessary for pavement design engineers to start using the ME-based design and analysis method. The software supporting this method is called Pavement ME Design® and is commercially available through AASHTOWare. The software is referred to in this document as PMED.

Multiple enhancements have been made to the AASHTOWare PMED based on completed research projects sponsored by the National Cooperative Highway Research Program (NCHRP) and the Federal Highway Administration (FHWA). In addition, revisions to the software were based on evaluations performed by State Highway Agencies and others in the Community of Practice. The third edition of the MEPDG Manual of Practice was prepared so the manual was consistent with the enhanced features and models included in the software through 2018.

The following table (Table P-1) summarizes the key differences noted between the format and calibration factors used in the MEPDG version 1.1 software, the AASHTOWare Pavement ME Design software version 2.3.1, and version 2.5.3 software.

Table P-1. Summary of Key Differences in Software Format and Calibration Factors

Format, Transfer Functions, and Calibration Coefficients		MEPDG version 1.1	AASHTOWare Pavement ME Design version 2.3.1	AASHTOWare Pavement ME Design version 2.5.3
Output Format		Excel-based	PDF- and Excel-based	PDF- and Excel-based
Climatic Input Data and if Included in Output Summary		Data from Ground-Based Weather Stations; output summary not included	Data from NARR database for rigid and flexible pavements; output summary included	Data from NARR database for rigid pavements and MERRA2 database for flexible and semi-rigid pavements; output summary included
Axle Configuration Data in Output Summary		Not included	Included	Included
Special Axle Load Configuration		Included	Not included	Not included
Reflection Cracking Transfer Function		Empirical regression equation included	ME-based fracture mechanics model included	ME-based fracture mechanics model included
Coefficient of Thermal Expansion (CTE)		CTE for Basalt of 4.6	CTE for Basalt of 5.2	CTE for Basalt of 5.2
PCC Zero Stress Temperature		PCC Zero Stress Temperature (60°–120°F)	PCC Set Temperature (70°–212°F)	PCC Set Temperature (70°–212°F)
Heat Capacity of Asphalt Pavement		Default value of 0.23 BTU/lb-°F	Default value of 0.28 BTU/lb-°F	Default value of 0.28 BTU/lb-°F
Thermal Conductivity of Asphalt Pavement		Default value of 0.67 BTU/(ft)(hr)(F)	Default value of 1.25 BTU/(ft)(hr)(F)	Default value of 1.25 BTU/(ft)(hr)(F)
Surface Shortwave Absorptivity		Default value of 0.95	Default value of 0.85	Default value of 0.85
Global Model Coefficient for Unbound Materials and Soils in Flexible Pavement Subgrade Rutting Model	Aggregate Base	k_{s1} of 1.673	k_{s1} of 2.03	k_{s1} of 0.965
	Coarse-Grained Soil			k_{s1} of 0.965
	Sand Soil			k_{s1} of 0.635
	Fine-Grained Soil	k_{s1} of 1.35	k_{s1} of 1.35	k_{s1} of 0.675

Continued on next page.

Table P-1. Summary of Key Differences in Software Format and Calibration Factors, *continued*

Format, Transfer Functions, and Calibration Coefficients		MEPDG version 1.1	AASHTOWare Pavement ME Design version 2.3.1	AASHTOWare Pavement ME Design version 2.5.3
Global Local Calibration or Field Adjustment Constant for Unbound Materials and Soils in Flexible Pavement Subgrade Rutting Model	Aggregate Base	1.0	1.0	1.0
	Coarse-Grained Soil			1.0
	Sand Soil			1.0
	Fine-Grained Soil			1.0
Global Laboratory-Derived Model Coefficients in the Fatigue Cracking Prediction Model in Flexible Pavement		k_{s1} of 0.007566	k_{s1} of 0.007566	k_{s1} of 3.75
		k_{s2} of -3.9492	k_{s2} of 3.9492	k_{s2} of 2.87
		k_{s3} of -1.281	k_{s3} of 1.281	k_{s3} of 1.46
Global Local Calibration or Field-Adjustment Constants for Fatigue Cracking Prediction Model in Flexible Pavement		β_1 of 1.0	β_1 of 1.0	AC thickness dependent; see Chapter 5
		β_2 of 1.0	β_2 of 1.0	β_2 of 1.38
		β_3 of 1.0	β_3 of 1.0	β_3 of 0.88
Global Bottom-Up Alligator Cracking Transfer Function Coefficients		C_1 of 1.0	C_1 of 1.0	1.31
		C_2 of 1.0	C_2 of 1.0	AC thickness dependent; see Chapter 5
Global Calibration or Field-Adjustment Coefficient in the Transverse Cracking Model for AC		k_t (Level 1) of 5.0	k_t (Level 1) of 1.5	k_s (Level 1) is Mean Annual Air Temperature (MAAT) dependent; see Chapter 5.
		k_t (Level 2) of 1.5	k_t (Level 2) of 0.5	k_s (Level 2) is MAAT dependent; see Chapter 5.
		k_t (Level 3) of 3.0	k_t (Level 3) of 1.5	k_s (Level 3) is MAAT dependent; see Chapter 5.
Global Laboratory Derived Model Coefficients in the Rut Depth Prediction Model		k_1 of -3.35412	k_1 of -3.35412	k_1 of -2.45
		k_{2r} of 0.4791	k_2 of 1.5606	k_2 of 3.01
		k_{3r} of 1.5606	k_3 of 0.4791	k_3 of 0.22

Continued on next page.

Table P-1. Summary of Key Differences in Software Format and Calibration Factors, *continued*

Format, Transfer Functions, and Calibration Coefficients	MEPDG version 1.1	AASHTOWare Pavement ME Design version 2.3.1	AASHTOWare Pavement ME Design version 2.5.3
Global Local Calibration or Field Adjustment Coefficients in the Rut Depth Prediction Model	β_1 of 1.0	β_1 of 1.0	β_1 of 0.40
	β_2 of 1.0	β_2 of 1.0	β_2 of 0.52
	β_3 of 1.0	β_3 of 1.0	β_3 of 1.36
Calibration Coefficients in the Rigid Pavement Cracking Prediction Model	C_4 of 1.0	C_4 of 0.52	C_4 of 0.52
	C_5 of -1.98	C_5 of -2.17	C_5 of -2.17
Calibration Coefficients in the Rigid Pavement Faulting Prediction Model	C_1 of 1.29	C_1 of 1.0184	C_1 of 0.595
	C_2 of 1.1	C_2 of 0.91656	C_2 of 1.636
	C_3 of 0.001725	C_3 of 0.0021848	C_3 of 0.00217
	C_4 of 0.0008	C_4 of 0.0008837	C_4 of 0.00444
	C_6 of 0.4	C_6 of 0.47	C_6 of 0.47
	C_7 of 1.2	C_7 of 1.83312	C_7 of 7.3
Calibration Coefficient in the Rigid Pavement Punchout Prediction Model	APO of 195.789	C_3 of 107.73	C_3 of 107.73
	α PO of 19.8947	C_4 of 2.476	C_4 of 2.475
	β PO of -0.526316	C_5 of -0.785	C_5 of -0.785
Calibration Coefficients in the Short JPCP Overlay Longitudinal Cracking Prediction Model	Excluded	C_4 of 0.4	C_4 of 0.4
		C_5 of -2.21	C_5 of -2.21

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Introduction

The overall objective of the Mechanistic-Empirical Pavement Design Guide (MEPDG) is to provide the highway community with a state-of-the-practice method for the design and analysis of new and rehabilitated pavement structures, based on mechanistic-empirical (ME) principles. This means that the design/analysis procedure calculates pavement responses (stresses, strains, and deflections) and uses those responses to compute incremental damage over time. The procedure empirically relates the cumulative damage to observed pavement distresses. The flowchart in Figure 1-1 illustrates this ME-based procedure. The AASHTOWare Pavement ME Design® is the commercially available software tool. The AASHTOWare software is referred to in this manual as PMED.

The AASHTOWare PMED represents a major change in the way pavement design is performed. AASHTOWare PMED predicts multiple performance indicators (refer to Figure 1-1) and it provides a direct tie between materials, structural design, construction, climate, traffic, and pavement management systems. Figures 1-2 and 1-3 are examples of the interrelationship between these activities for asphalt concrete (AC) and Portland cement concrete (PCC) materials.

1.1 Purpose of Manual

This manual of practice presents information to guide pavement design engineers in making decisions and using AASHTOWare PMED for new pavement and rehabilitation design. The manual does not provide guidance on developing regional or local calibration factors for predicting pavement distress and smoothness. A separate document, *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide*, provides guidance for determining the local calibration factors for both AC and PCC pavement types (2).

1.2 Overview of the Design Procedure

AASHTOWare PMED is a production-ready design tool to support the day-to-day operations of public and private pavement engineers. When analyzing a pavement design project using

AASHTOWare PMED, whether it is new construction, an overlay, or restoration, utilize the following three-step, basic process:

1. Create a trial design for the project.
2. Run AASHTOWare PMED to predict the key distresses and smoothness for the trial design.
3. Review the predicted performance of the trial design against performance criteria, then modify the trial design as needed in order to produce a feasible design that satisfies the performance criteria at the selected reliability level.

Pavement responses (stresses, strains, and deflections) are combined with other pavement, traffic, climate, and materials parameters to predict the progression of key pavement distresses and smoothness loss over time. These outputs are the basis for checking the adequacy of a trial design. AASHTOWare PMED software also includes an automated process or feature to iterate to an optimized pavement thickness for both flexible and rigid pavements.

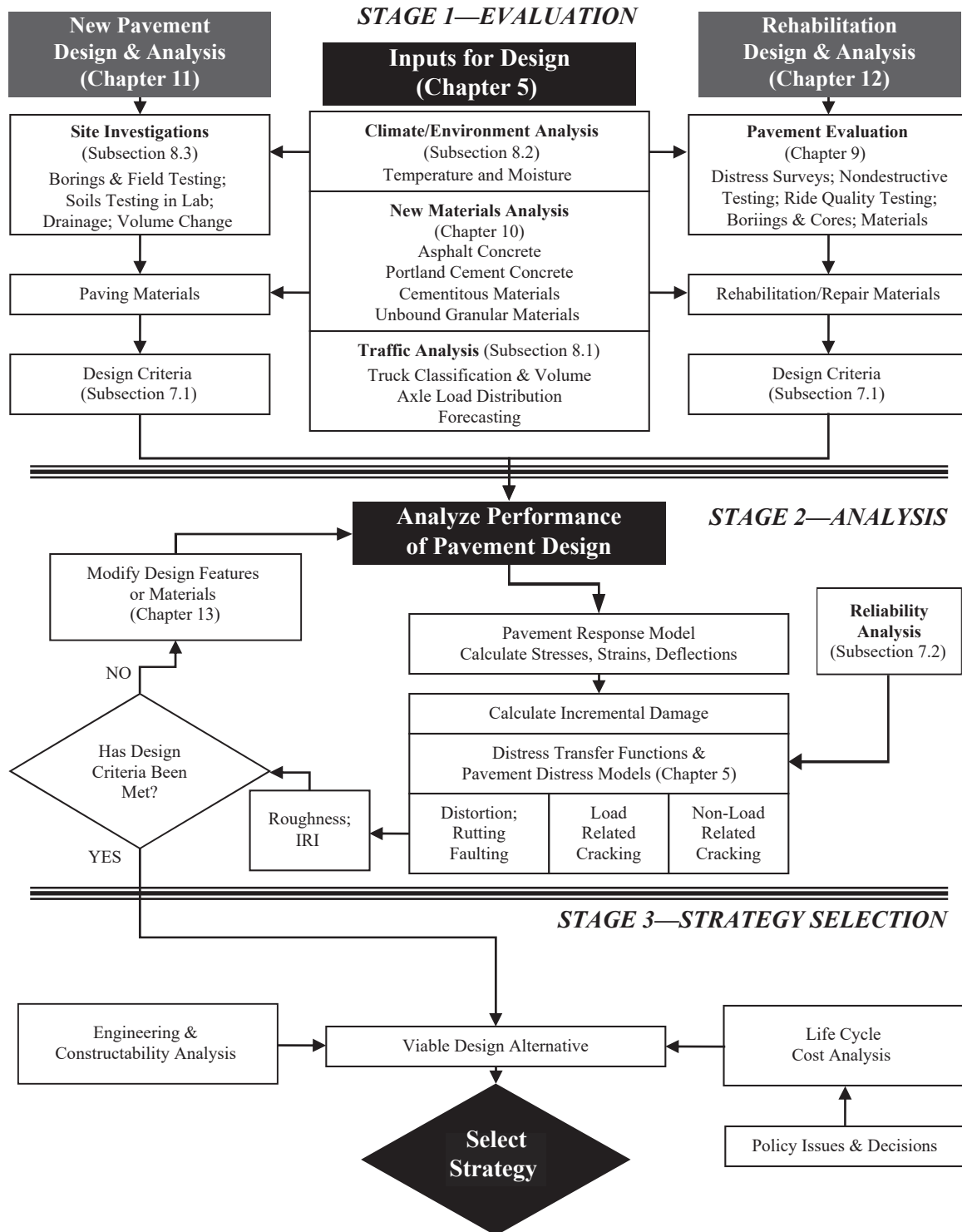


Figure 1-1. Conceptual Flow Chart of the Three-Stage Design/Analysis Process for AASHTOWare PMED

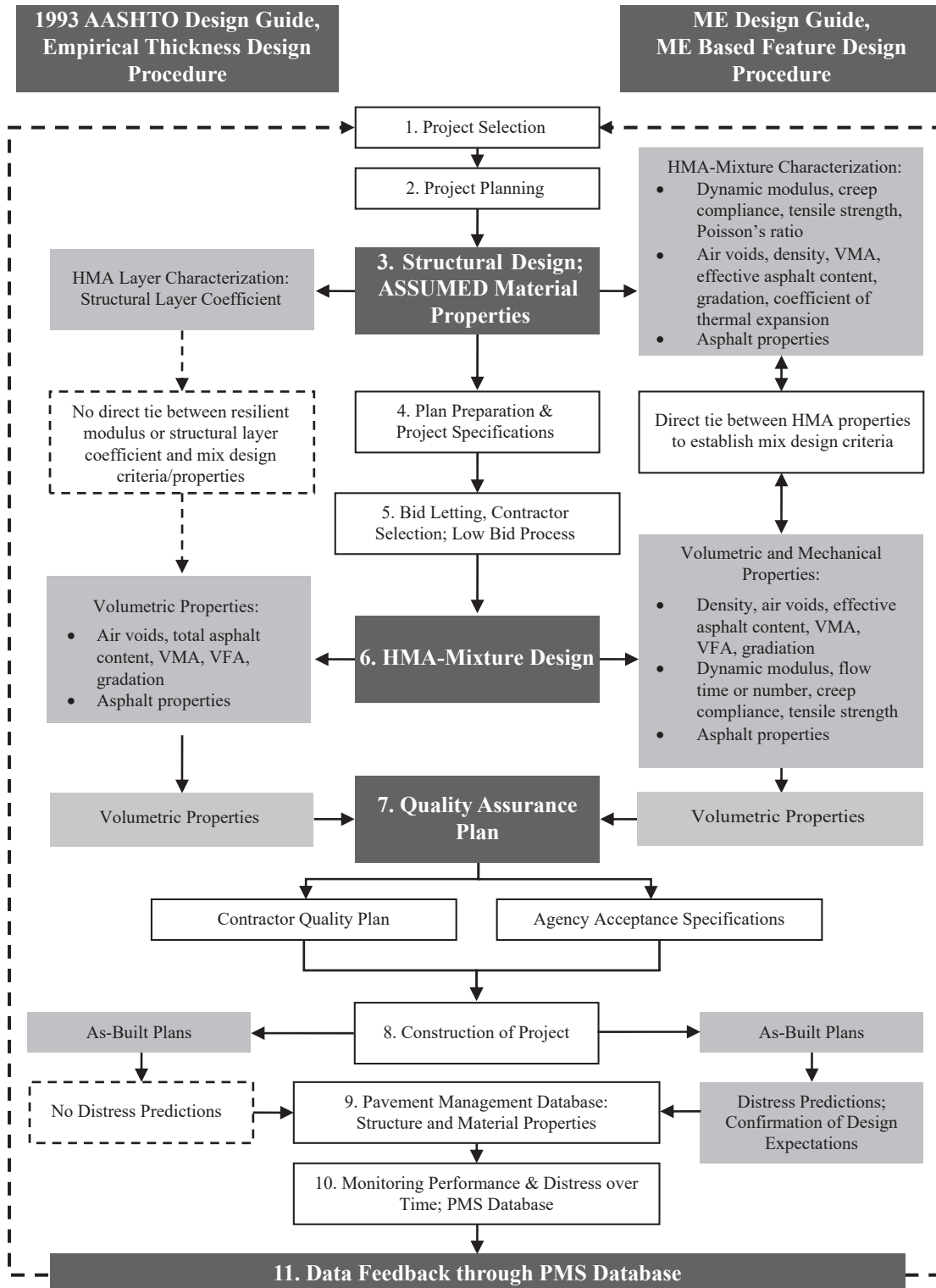


Figure 1-2. Typical Differences between Empirical Design Procedures and an Integrated ME Design System, in Terms of AC Mixture Characterization

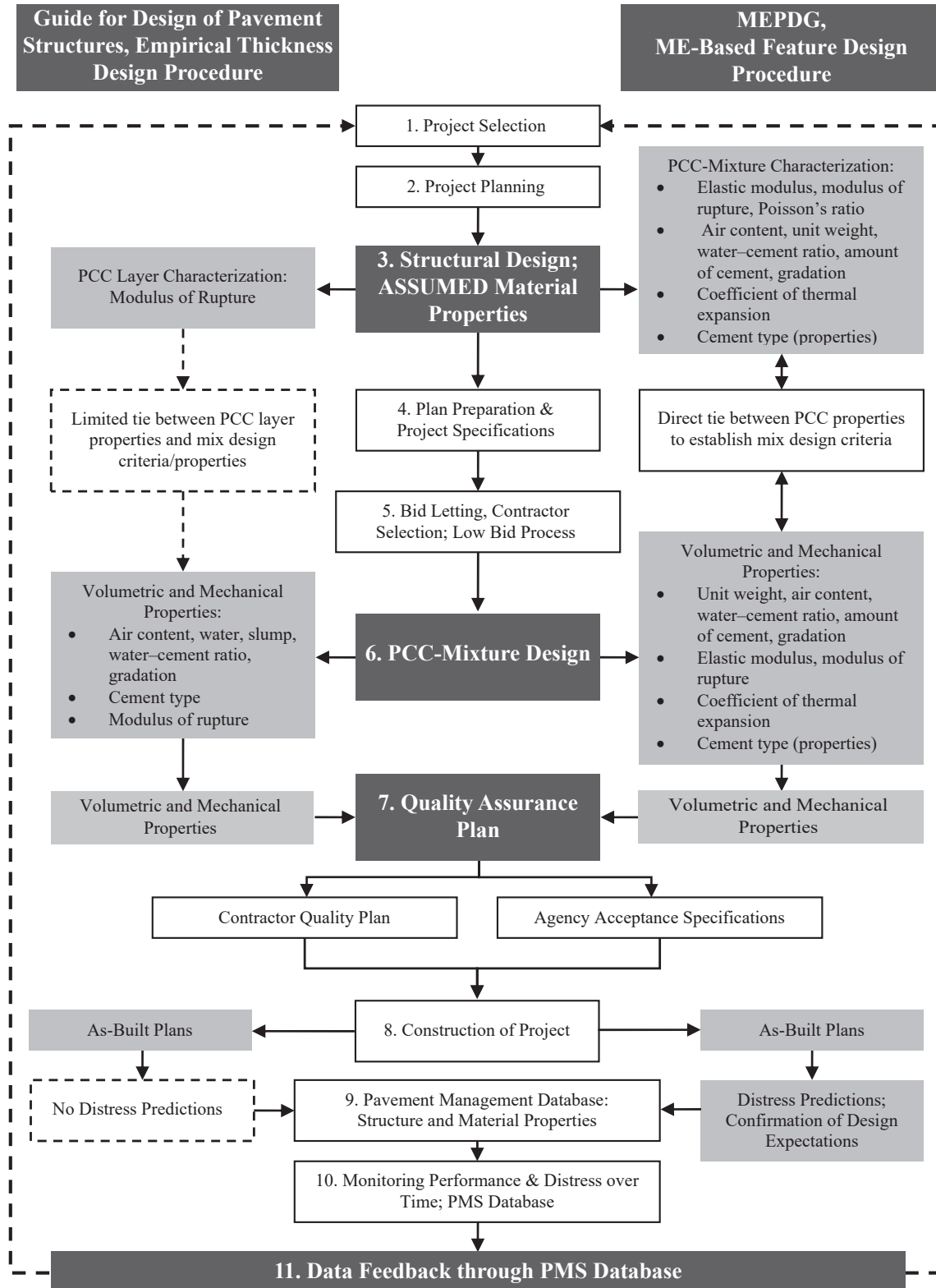


Figure 1-3. Typical Differences between Empirical Design Procedures and an Integrated ME Design System, in Terms of PCC-Mixture Characterization

The ME approach makes it possible to optimize the design and to fully verify that specific distress types will be limited to values less than the failure criteria within the design life of the pavement structure. The basic steps included in the MEPDG are listed below and presented as flow charts in Figures 1-4 and 1-5. The steps shown in Figures 1-4 and 1-5 are referenced to the appropriate sections within this manual of practice.

1. **Select a trial design strategy.** The pavement designer may use an agency-specific procedure to determine the trial design cross section.
2. **Select the appropriate performance indicator criteria (threshold value) and design reliability level for the project.** Design or performance indicator criteria include magnitudes of key pavement distresses and smoothness that may trigger major rehabilitation or reconstruction. These criteria could be a part of an agency's policies for deciding when to rehabilitate or reconstruct. AASHTOWare PMED allows the user to select the performance indicator criteria to be considered. The user can uncheck the box next to the criteria that do not need to be considered. (See Chapter 4.1 for definitions.)
3. **Obtain all inputs for the pavement trial design under consideration.** This step may be a time-consuming effort, but it is what separates the MEPDG from other design procedures. The MEPDG allows the designer to determine inputs using a hierarchical structure in which the effort to quantify a given input is selected based on the importance of the project, importance of the input, and available resources. The required inputs to run the software are obtained using one of three levels of effort that need not be consistent for all of the inputs for a given design. This permits the user to use the “best available” data for all inputs. The hierarchical input levels are defined in Chapters 4 and 5, and are grouped under six broad topics: (1) general project information, (2) design criteria, (3) traffic, (4) climate, (5) structure layering, and (6) material properties (including the design features).
4. **Run AASHTOWare PMED and examine the inputs and outputs for engineering reasonableness.** The software calculates changes in layer properties, damage, key distresses, and the International Roughness Index (IRI) over the design life. The substeps for step 4 include:
 - a. Examine the input summary to verify the inputs are correct. This step should be completed after each run, until the designer becomes more familiar with the program and its inputs.
 - b. Examine the outputs that comprise the intermediate process—specific parameters (such as climate values), monthly load transfer efficiency (LTE) values for rigid pavement analysis, monthly layer modulus values for flexible and rigid pavement analysis to determine their reasonableness, and calculated performance indicators (pavement distresses and IRI). This step may be completed after each run or until the designer becomes more familiar with the program. Review of important intermediate processes and steps is presented in Chapter 13.

- c. Assess whether the trial design has met each of the performance indicator criteria at the design reliability level chosen for the project. As noted above, IRI is an output parameter predicted over time and a measure of surface smoothness. IRI is calculated from other distress predictions (refer to Figure 1-1), site factors, and initial IRI.
 - d. If any of the criteria are not met, determine how this deficiency can be remedied by altering the materials used, the layering of materials, layer thickness, or other design features.
5. **Revise the trial design, as needed.** If the trial design has input errors, material output anomalies, or has exceeded the failure criteria at the given level of reliability, revise the inputs/trial design and rerun the program. An automated process to iterate to an optimized thickness is done by AASHTOWare PMED to produce a feasible design.

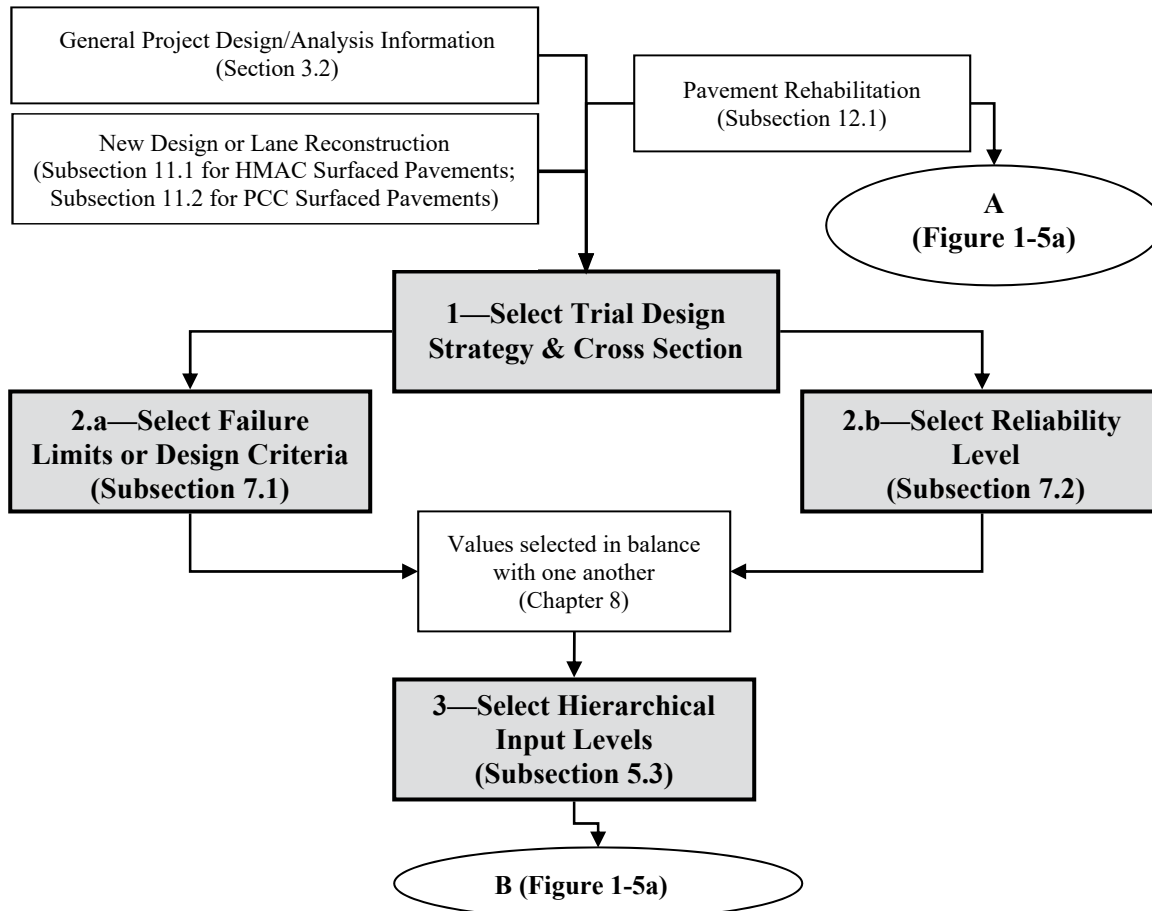


Figure 1-4. Flow Chart of the Steps That Are More Policy Decision Related and Needed to Complete an Analysis of a Trial Design Strategy

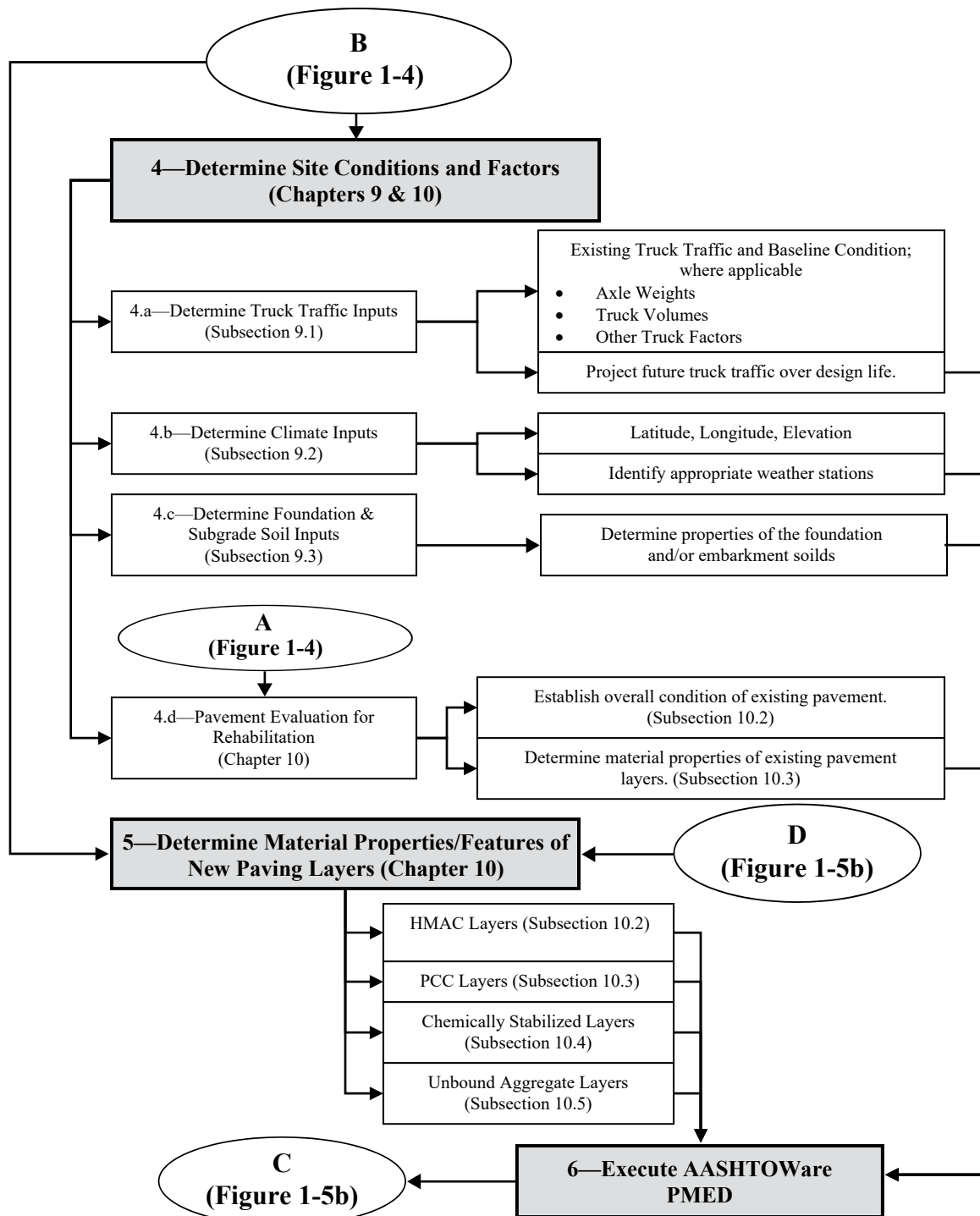


Figure 1-5a. Flow Chart of the Steps Needed to Complete an Analysis of a Trial Design Strategy

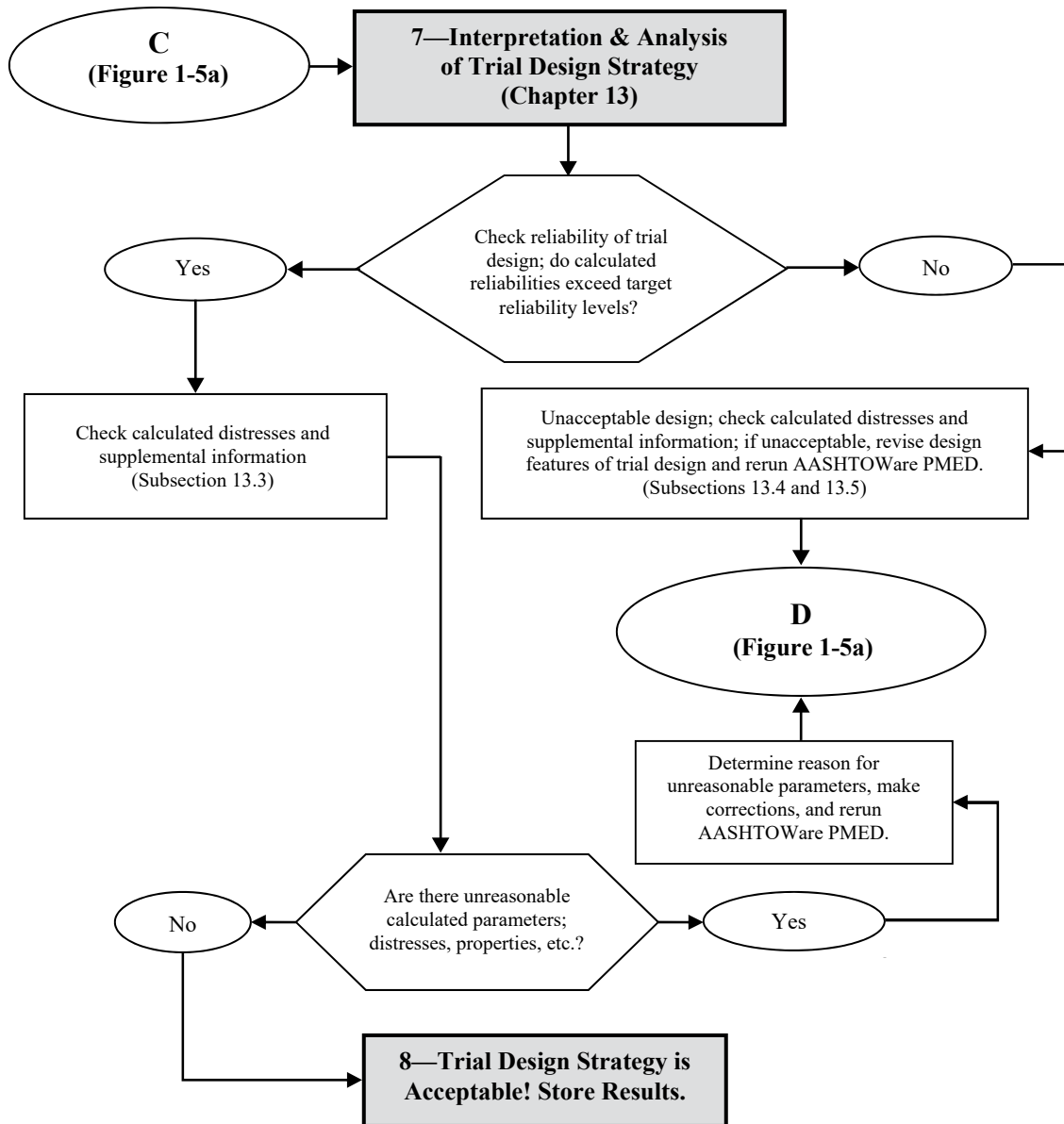


Figure 1-5b. Flow Chart of the Steps Needed to Complete an Analysis of a Trial Design Strategy

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Referenced Documents and Standards

This section includes a listing of the laboratory and field test protocols for different paving materials, recommended practices, material specifications, and the referenced documents needed for using AASHTOWare PMED.

2.1 Test Protocols and Standards

From the test protocols listed in this section, the designer needs to execute only those for the hierarchical input levels selected. Refer to Chapter 4 for a definition of hierarchical input levels. The listing of test procedures is organized into two subsections: Laboratory Materials Characterization and In-Place Materials/Pavement Layer Characterization.

2.1.1 Laboratory Materials Characterization

Unbound Materials and Soils

AASHTO T 88	Particle Size Analysis of Soils
AASHTO T 89	Determining the Liquid Limits of Soils
AASHTO T 90	Determining the Plastic Limit and Plasticity Index of Soils
AASHTO T 99	Moisture-Density Relations of Soils Using a 2.5 kg (5.5 lb) Rammer and a 305-mm (12-in.) Drop
AASHTO T 100	Specific Gravity of Soils
AASHTO T 180	Moisture-Density Relations of Soils Using a 10 lb Rammer and an 18-in. Drop
AASHTO T 190	Resistance R-Value and Expansion Pressure of Compacted Soils
AASHTO T 193	California Bearing Ratio
AASHTO T 206	Penetration Test and Split-Barrel Sampling of Soils
AASHTO T 207	Thin-Walled Tube Sampling of Soils
AASHTO T 215	Permeability of Granular Soils (Constant Heat)
AASHTO T 258	Determining Expansive Soils
AASHTO T 265	Laboratory Determination of Moisture Content of Soils
AASHTO T 307	Determining the Resilient Modulus of Soils and Aggregate Materials

ASTM D2487 Classification of Soils for Engineering Purposes

Treated & Stabilized Materials/Soils

AASHTO T 220 Determination of the Strength of Soil-Lime Mixtures
 ASTM C593 Fly Ash and other Pozzolans for Use with Lime for Soil Stabilization
 ASTM D1633 Compressive Strength of Molded Soil-Cement Cylinders
 ASTM D1635 Flexural Strength of Soil-Cement Using Simple Beam with Third-Point Loading
 ASTM D5102 Unconfined Compressive Strength of Compacted Soil-Lime Mixtures

Asphalt Binder

AASHTO T 49 Penetration of Bituminous Materials
 AASHTO T 53 Softening Point of Bitumen (Ring-and-Ball Apparatus)
 AASHTO T 170 Recovery of Asphalt from Solution by Abson Method
 AASHTO T 201 Kinematic Viscosity of Asphalts (Bitumens)
 AASHTO T 202 Viscosity of Asphalts by Vacuum Capillary Viscometer
 AASHTO T 228 Specific Gravity of Semi-Solid Bituminous Materials
 AASHTO T 315 Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
 AASHTO T 316 Viscosity Determination of Asphalt Binder Using Rotational Viscometer
 AASHTO T 319 Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures

Asphalt Concrete & Asphalt Treated/Stabilized Mixtures

AASHTO T 27 Sieve Analysis of Fine and Coarse Aggregate
 AASHTO T 84 Specific Gravity and Absorption of Fine Aggregate
 AASHTO T 85 Specific Gravity and Absorption of Coarse Aggregate
 AASHTO T 164 Quantitative Extraction of Asphalt Binder from Hot-Mix Asphalt (HMA)
 AASHTO T 166 Bulk Specific Gravity of Compacted Hot-Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
 AASHTO T 209 Theoretical Maximum Specific Gravity and Density of Hot-Mix Asphalt Paving Mixtures
 AASHTO T 269 Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
 AASHTO T 308 Determining the Asphalt Binder Content of Hot-Mix Asphalt (HMA) by the Ignition Method
 AASHTO T 312 Preparing and Determining the Density of Hot-Mix (HMA) Specimens by Means of the Superpave Gyrotory Compactor
 AASHTO T 321 Determining the Fatigue Life of Compacted Asphalt Mixtures Subjected to Repeated Flexural Bending
 AASHTO T 322 Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device

AASHTO T 342	Determining Dynamic Modulus of Hot-Mix Asphalt (HMA)
ASTM D6931-17	Indirect Tensile (IDT) Strength of Asphalt Mixtures

Portland Cement Concrete & Cement Treated/Stabilized Base Mixtures

AASHTO T 22	Compressive Strength of Cylindrical Concrete Specimens
AASHTO T 97	Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
AASHTO T 121M/T 121	Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
AASHTO T 152	Air Content of Freshly Mixed Concrete by the Pressure Method
AASHTO T 196	Air Content of Freshly Mixed Concrete by the Volumetric Method
AASHTO T 198	Splitting Tensile Strength of Cylindrical Concrete Specimens
AASHTO T 336	Coefficient of Thermal Expansion of Hydraulic Cement Concrete
ASTM C469	Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

Thermal Properties of Paving Materials

ASTM D2766	Specific Heat of Liquids and Solids
ASTM E1952	Thermal Conductivity and Thermal Diffusivity by Modulated Temperature Differential Scanning Calorimetry

2.1.2 In-Place Materials/Pavement Layer Characterization

AASHTO T 256	Pavement Deflection Measurements
ASTM D5858	Guide for Calculating In Situ Equivalent Elastic Moduli of Pavement Materials Using Elastic Theory
ASTM D6951	Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications

2.2 Material Specifications

AASHTO M 288	Geosynthetic Specifications for Highway Application
AASHTO M 320	Performance-Graded Asphalt Binder
AASHTO M 323	Superpave Volumetric Mixture Design

2.3 Recommended Practices and Terminology

AASHTO M 145	Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
AASHTO R 13	Conducting Geotechnical Subsurface Investigations
AASHTO R 37	Application of Ground Penetrating Radar (GPR) to Highways
AASHTO R 43/ASTM E1926	Quantifying Roughness of Pavements
AASHTO R 50	Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures

AASHTO R 59	Recovery of Asphalt from Solution by Abson Method
ASTM E1778	Standard Terminology Relating to Pavement Distress
AASHTO LCG-1	Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide

2.4 Referenced Documents

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- (3) Advanced Asphalt Technology, LLC (AAT). *Practitioner's Guide for Using Performance Testing of Resource Responsible Asphalt Mixtures to Support Mechanistic Empirical Pavement Design*, Draft, August 2017.
- (4) Applied Pavement Technology, Inc. *HMA Pavement Evaluation and Rehabilitation—Participant's Workbook*, NHI Course No. 131063. National Highway Institute, Federal Highway Administration, Washington, DC, 2001.a.
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Significance and Use of the MEPDG

The mechanistic portion of the MEPDG refers to the application of the principles of engineering mechanics. The use of engineering mechanics leads to a rational design process, which has three basic elements: (1) the theory used to predict critical pavement responses (strains, stresses, deflections, etc.) as a function of traffic and climatic loading (the mechanistic part); (2) materials characterization procedures that support and are consistent with the selected theory; and (3) defined relationships between the critical pavement response parameter and field-observed distress (the empirical part).

The MEPDG provides a uniform and comprehensive set of procedures for the analysis and design of new and rehabilitated flexible and rigid pavements. More importantly, the MEPDG employs common design parameters for traffic, materials, subgrade, climate, and reliability for all pavement types, and is used to develop alternative designs using a variety of materials and construction procedures. Recommendations are provided for the structure (layer materials and thickness) of new (including lane reconstruction) and rehabilitated pavements, including procedures to select pavement layer thickness, rehabilitation treatments, subsurface drainage, foundation improvement strategies, and other design features.

The output from AASHTOWare PMED is predicted distresses and IRI (smoothness) at the selected reliability level over the design life of a pavement. The thickness optimization tool allows the AASHTOWare PMED to be used not only for analysis, but also for design by evaluating a combination of layer types, layer thickness, and design features for a given set of site conditions and failure criteria at a specified level of reliability over a specified time-period.

3.1 MEPDG Performance Indicators

The MEPDG includes transfer functions and regression equations that are used to predict various performance indicators considered important in many pavement management programs. The following lists the specific performance indicators calculated by AASHTOWare PMED, which were calibrated using data extracted from the Long Term Pavement Performance (LTPP) database. The specific prediction models for all pavement types are presented in Chapter 5.

- ✦ AC-Surfaced Pavements and AC Overlays
 - Total rut depth and AC, unbound aggregate base, and subgrade rutting
 - Non-load related transverse cracking
 - Load related alligator cracking and bottom-up initiated cracks of flexible and semi-rigid pavements
 - Load related fatigue cracking of the cementitious stabilized layer of semi-rigid pavements
 - Load related longitudinal cracking and surface initiated cracks of flexible and semi-rigid pavements (not recommended for use as a design criteria)
 - Reflection cracking of bottom-up fatigue cracks and transverse cracks in AC overlays of cracks and joints in existing flexible, semi-rigid, composite, and rigid pavements
 - Smoothness (IRI)
- ✦ Portland Cement Concrete-Surfaced Pavements and PCC Overlays
 - Jointed plain concrete pavement (JPCP)—mean joint faulting
 - JPCP—joint load transfer efficiency (LTE)
 - JPCP—load related transverse slab cracking (includes both bottom and surface-initiated cracks)
 - JPCP—joint spalling (embedded into the IRI prediction model)
 - Short jointed plain concrete pavement (SJPCP) overlay of flexible pavements—percent cracked slabs, longitudinal cracking. (*Note: The MEPDG does not include or predict faulting and IRI (smoothness) degradation for SJPCP overlays of flexible pavements.*)
 - Continuously reinforced concrete pavement (CRCP)—crack spacing and crack width
 - CRCP—LTE
 - CRCP—punchouts
 - JPCP & CRCP—smoothness (IRI)

3.2 MEPDG General Design Approach

The MEPDG design approach consists of three major stages and multiple steps, as shown in Figures 1-1, 1-4, and 1-5. Stage 1 consists of the determination of input values for the trial design. During this stage, strategies are identified for consideration in the design stage.

A key step of this process is the foundation analysis. For new pavements, the foundation analysis or site investigation consists of resilient modulus determination, and an evaluation of the shrink-swell potential of high plasticity soils, frost heave-thaw weakening potential of frost susceptible soils, and drainage concerns (refer to Subsection 8.3).

The foundation analysis or pavement evaluation for rehabilitation design projects includes recommendations for evaluating the pavement structural condition to identify the types of distresses exhibited and the underlying causes for those distresses (refer to Chapter 9). The procedure focuses on quantifying the strength of the existing pavement layers and foundation using nondestructive deflection basin tests, backcalculation procedures, and destructive sampling and tests (cores and

laboratory tests). Deflection basin tests are used to estimate the damaged modulus condition of the existing structural layers. However, the procedure also includes recommendations for and use of pavement condition survey, drainage survey, and ground penetrating radar (GPR) data to quantify the in-place condition (damaged modulus values) of the pavement layers.

The material, traffic, and climate characterization procedures are also included in Stage 1 of the design approach. Material characterization is an important part of this design procedure, and modulus is the key layer property needed for all layers in the pavement structure. Unbound paving layers and foundation are characterized by resilient modulus whereas AC layers and PCC layers are characterized by dynamic modulus and elastic modulus respectively. Depending on the availability of modulus data, the user has the option through different input levels to either enter appropriate modulus values obtained from testing or use other material property inputs that are converted to modulus values within the software. A more detailed listing of the required material properties for all pavement types is presented in Chapters 9 and 10.

Traffic characterization consists of estimating the axle load distributions applied to the pavement structure (refer to Subsection 8.1). The MEPDG does not use equivalent single axle loads (ESALs) and does not require the development of load equivalency factors.

Another major improvement to pavement design that is included in the MEPDG and embedded in AASHTOWare PMED is the consideration of climatic effects on pavement materials, responses, and distress in an integrated manner (refer to Subsection 8.2). These effects are estimated using the Enhanced Integrated Climatic Model (EICM), which is a tool used to model temperature and moisture within each pavement layer and the foundation. This climatic model considers hourly ambient climatic data through temperatures, precipitation, wind speed, cloud cover, and relative humidity from weather stations across the U.S. for estimating pavement layer temperatures and moisture conditions. The pavement layer temperature and moisture predictions from the EICM are calculated hourly and are used in a variety of applications to estimate the material properties for the foundation and pavement layers throughout the design life.

Stage 2 of the design process (refer to Figure 1-1) is the structural analysis and predictions of selected performance indicators and smoothness. The analysis approach is an iterative one that begins with the selection of an initial trial design. Initial trial designs are created by the designer, obtained from an existing design procedure, or from a general catalog. The trial section is analyzed incrementally over time using the pavement response and distress models. The outputs of the analysis include material properties, accumulated damage (defined in Chapter 4), the amount of distress, and smoothness over time, among other significant process-specific predictions. If the trial design does not meet or exceed the design criteria at the specified level of reliability, modifications are made and the analysis is run until a satisfactory result is obtained.

Stage 3 of the process includes those activities required to evaluate the structurally viable alternatives. These activities include an engineering analysis and life cycle cost analysis of the alternatives. Stage 3 is not covered in this manual of practice.

3.3 New Flexible Pavement and AC Overlay Design Strategies Applicable to the MEPDG

The AASHTOWare PMED can be used to analyze the expected performance of new and reconstructed AC-surfaced pavements, as well as AC overlays. The AC-surfaced pavement types include the following, which are illustrated in Figures 3-1 and 3-2. (*Note: The minimum total AC layer thickness to derive the calibration coefficients was 4 in. for all new flexible pavements. The minimum total AC overlay thickness to derive the reflection cracking calibration coefficients was 1.5 in.*)

- ✦ **Conventional Flexible Pavements**—Flexible pavements that consist of AC surfaces with less than 6 in. of thick placed over unbound aggregate base layers (crushed stone or gravel, and soil-aggregate mixtures). Many of the pavements used in the global calibration process had multiple aggregate base layers. Conventional flexible pavements may also have a stabilized or treated subgrade layer.
- ✦ **Deep Strength Flexible Pavements**—Flexible pavements that consist of a relatively thick AC surface and a dense-graded AC or asphalt stabilized base mixture totaling over 6 in. and placed over an aggregate base layer. Deep strength flexible pavements may also have a stabilized or treated subgrade layer. Many of the flexible pavements used in the global calibration process had asphalt stabilized base layers and would be defined as deep strength flexible pavements.
- ✦ **Full-Depth AC Pavements**—AC layers placed on a stabilized subgrade layer or placed directly on the prepared embankment or foundation soil. Full-depth flexible pavements were also included in the global calibration process, but there were fewer test sections than for conventional and deep strength flexible pavements.
- ✦ **Semi-Rigid Pavements**—Semi-rigid pavements consist of AC mixtures placed over cement treated base (CTB), lean concrete base (LCB), or cement aggregate mixtures (CAM), with or without an aggregate subbase layer. Cementitious materials may also include lime, lime-fly ash, and Portland cement stabilizers. An aggregate subbase layer is recommended to be included in the design strategy because all of the neural networks for the stress intensity factors for predicting reflection cracks were derived using an aggregate subbase layer. However, some of the test sections included in the calibration process did not include an aggregate subbase layer below the stabilized layer. As such, an aggregate subbase layer is defined as optional in Figure 3-1. The minimum thickness of the aggregate subbase layer is 2 in. This type of pavement is also referred to as composite pavements in the MEPDG. Semi-rigid pavements were included in the updated global calibration process for version 2.5 released in July 2018. The minimum CTB and cementitious soil stabilized layer thickness included in the global calibration was 6 in. (*Note: 31 test sections were included in the global calibration process, which is slightly less than the minimum number recommended in the *Guide for Local Calibration* [2].*)

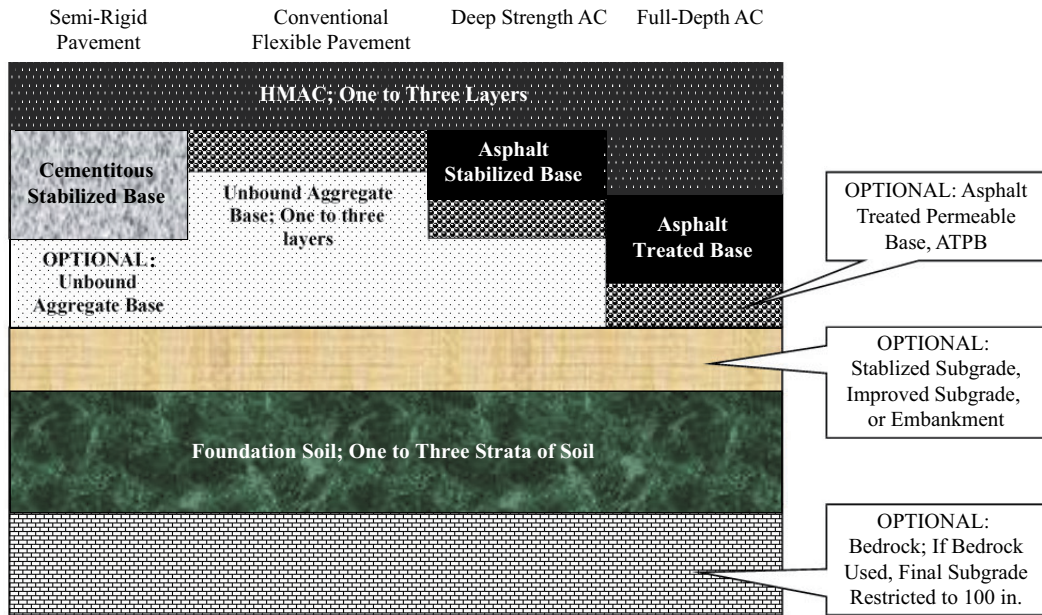
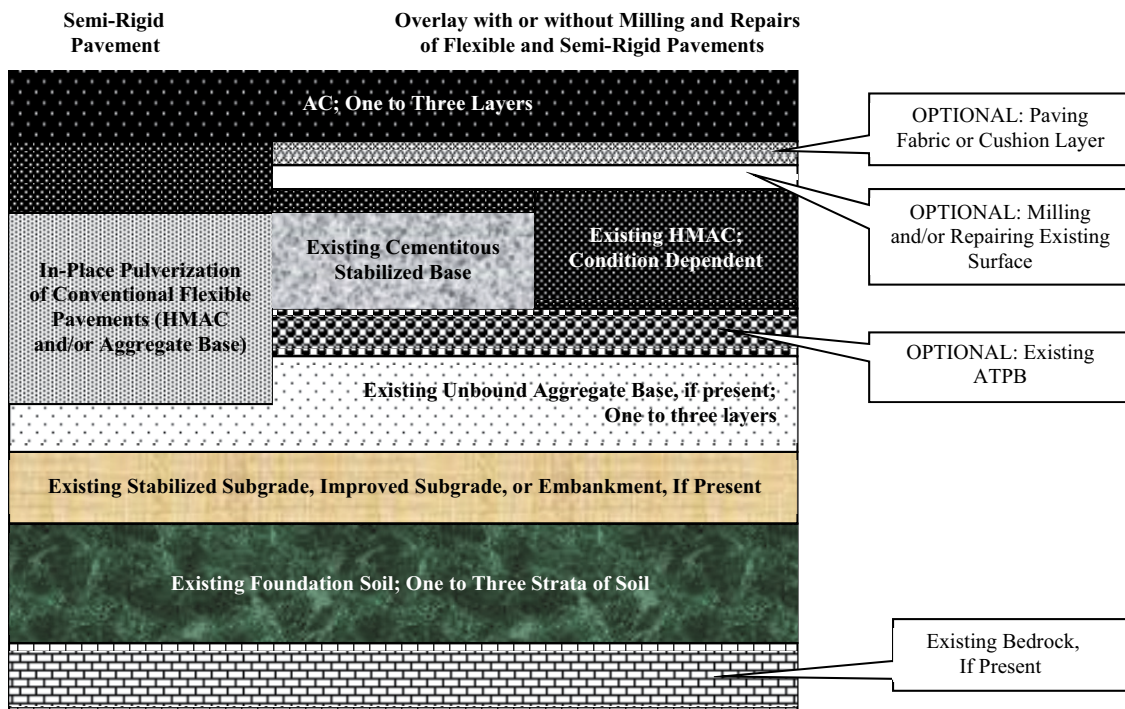


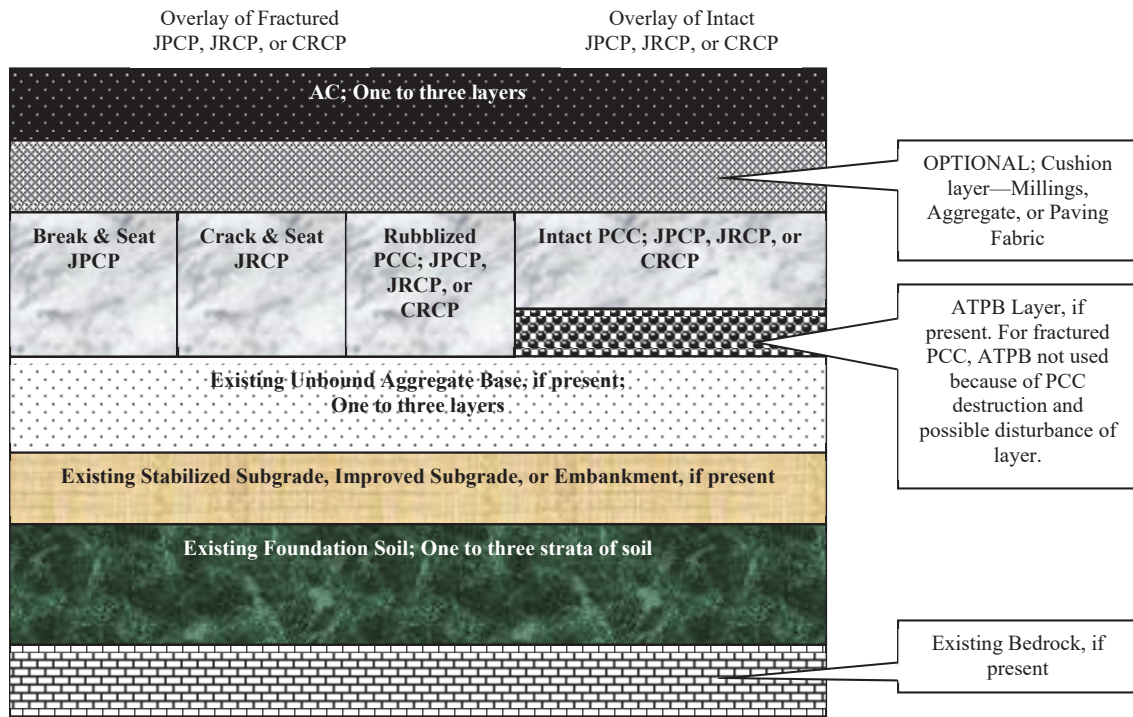
Figure 3-1. New (Including Lane Reconstruction) Flexible Pavement Design Strategies That Can Be Simulated with the AASHTOWare PMED (Refer to Subsection 11.1); Layer Thickness Not to Scale



3-2a. Rehabilitation Options for Existing Flexible and Semi-Rigid Pavements

Figure 3-2. AC Overlay Design Strategies of Flexible, Semi-Rigid, and Rigid Pavements That Can Be Simulated with the AASHTOWare PMED (Refer to Subsection 12.2); Layer Thickness Not to Scale

Continued on next page.



3-2b. Rehabilitation Options for Existing Rigid Pavements

Figure 3-2. AC Overlay Design Strategies of Flexible, Semi-Rigid, and Rigid Pavements That Can Be Simulated with the AASHTOWare PMED (Refer to Subsection 12.2); Layer Thickness Not to Scale, *continued*

- ✦ **Full Depth Reclamation (In-Place Pulverization of Conventional Flexible Pavements)** is the cold in-place recycling of the AC and existing aggregate base layers, and hot in-place recycling of AC. Cold in-place recycling as a rehabilitation strategy is considered reconstruction under the MEPDG design/analysis process and would be defined as a new flexible pavement. Hot in-place recycling as a rehabilitation strategy is considered mill and fill with an AC overlay of the existing flexible pavement. The thickness of the hot in-place recycled material is considered part of the AC overlay, as well as the thickness of the milled material. Full depth reclamation, however, was not included in the global calibration of AASHTOWare PMED.
- ✦ **AC Overlays** of all types of flexible and intact rigid pavements, with or without pavement repairs and surface milling. Pavement repairs and milling of the existing surface layer is considered by the AASHTOWare PMED. The expected milling depth is an input value, and pavement repairs are considered by entering the condition of the pavement prior to overlay placement. The thickness of the existing AC layer considered by AASHTOWare PMED is the AC thickness prior to overlay (existing AC thickness minus the depth of milling). AASHTOWare PMED is also used to design AC overlays of fractured PCC slabs (break and seat [applicable to JPCP] and rubblization

[applicable to all PCC pavements]). AC overlays of fractured PCC slabs, however, were not included in the global calibration process.

- Preventive maintenance strategies applied to flexible pavements can be considered within the design period by resetting the predicted distress and performance measure. The preventive maintenance strategies applicable to flexible pavements are assumed to provide no increase in structural value and include scratch layer with other treatments, micro-surface, ultra-thin overlays, and surface hot in-place recycling with a seal coat. The assumptions when considering preventive maintenance treatments within the design period include the aging of the existing AC layers does not change, there is full bond between the existing AC layer and the treatment strategy, and the strategy has no impact on fatigue damage accumulation.

3.4 New Rigid Pavement, PCC Overlay, and Restoration of Rigid Pavement Design Strategies Applicable for Use with the MEPDG

The AASHTOWare PMED can be used to analyze the expected performance of new and re-constructed PCC surfaced pavements, as well as PCC overlays and concrete pavement restoration (CPR). The PCC-surfaced pavement types include the following, which are illustrated in Figures 3-3 and 3-4.

- **JPCP:** The minimum thickness of JPCP modeled in the software is 6 in. In this type of PCC pavement, the minimum joint spacing is 10 ft. The transverse joints are spaced relatively close (e.g., ranging from 10–20 ft) in order to minimize transverse cracking from temperature gradient and drying gradient shrinkage stresses. This pavement contains no distributed steel to control random cracking and may or may not contain transverse joint load transfer devices (e.g., dowels). JPCP may have tied or untied longitudinal joints. However, most of the test sections included in the global calibration process had tied longitudinal joints. The effect of tied or untied longitudinal joints would need to be defined and considered through the local calibration process. The base (layer directly beneath the PCC slab) and subbase layers consist of a wide variety of unbound aggregates, asphalt stabilized granular, cement stabilized, lean concrete, crushed concrete, lime stabilized, reclaimed asphalt pavement (RAP), and other materials. The base layer may be dense-graded or permeable drainage layers.
- **CRCP:** The minimum thickness of CRCP modeled in the software is 7 in. In this type of PCC pavement, longitudinal reinforcement at or above mid-depth designed to hold shrinkage cracks tightly closed. Transverse joints exist only for construction purposes and to separate on-grade structures. Transverse reinforcement may or may not exist. Longitudinal joints exist similar to other types of concrete pavements. The base (layer directly beneath the PCC slab) and subbase layers consist of a wide variety of unbound aggregates, asphalt stabilized granular, cement stabilized, lean concrete, and crushed concrete, lime stabilized RAP, and other materials. The base layer may be dense-graded or permeable drainage layers.

- ✦ The MEPDG includes an input feature to allow the consideration and use of widened slabs for JPCP and CRCP. The use of widened slabs reduces the edge stress condition and reduces the predicted transverse or mid-slab cracks for JPCP and punchouts for CRCP. There is a limit, however, on the width of the widened slabs, which is not considered by the MEPDG. Slabs can be widened to a width where a different cracking mechanism (longitudinal cracks) becomes the control, which is not simulated in the MEPDG. PCC slabs of 13 ft wide have been used with success. It is recommended that slabs greater than 14 ft in width not be used without local calibration to verify the success of this slab width.
- ✦ **JPCP Overlays:** JPCP placed over existing rigid pavements, composite pavements, and flexible pavements. Composite pavements consist of AC placed over PCC, lean concrete, or a cement stabilized base (including roller compacted concrete). Composite pavements are the same as semi-rigid pavements (defined in Subsection 3.3), as used in AASHTOWare PMED.
- ✦ Short Jointed Plain Concrete Pavement (SJPCP) is defined specifically as bonded concrete overlay placed over an existing asphalt pavement. These relatively thin (4–8 in.) concrete overlays are bonded to the existing asphalt pavement surface and have short joint spacing (5x5, 6x6, 7x7, and 8x8 ft). These overlays have also been referred to in the literature as Bonded Concrete Overlays of Asphalt pavements (BCOA).
- ✦ **CRCP Overlays:** CRCP placed over existing rigid pavements, composite pavements, and flexible pavements.
- ✦ **Restoration of JPCP.** Work performed on an existing JPCP that includes diamond grinding of the surface. Other work includes dowel bar retrofit, joint reseal, edge drains, slab replacement, full depth repair, spall repair, and shoulder replacement.
- ✦ Preventive maintenance strategies applied to rigid pavements (JPCP or CRCP) can be considered within the design period by resetting the predicted distress and performance measure. The preventive maintenance strategies applicable to rigid pavements are assumed to provide no increase in structural value and include diamond grinding and ultra-thin AC overlays (less than 1 in. thick). The assumptions when considering the use of ultra-thin overlays within the design period include a full bond between the existing PCC slab and ultra-thin overlay and that there is no impact on fatigue damage accumulation.

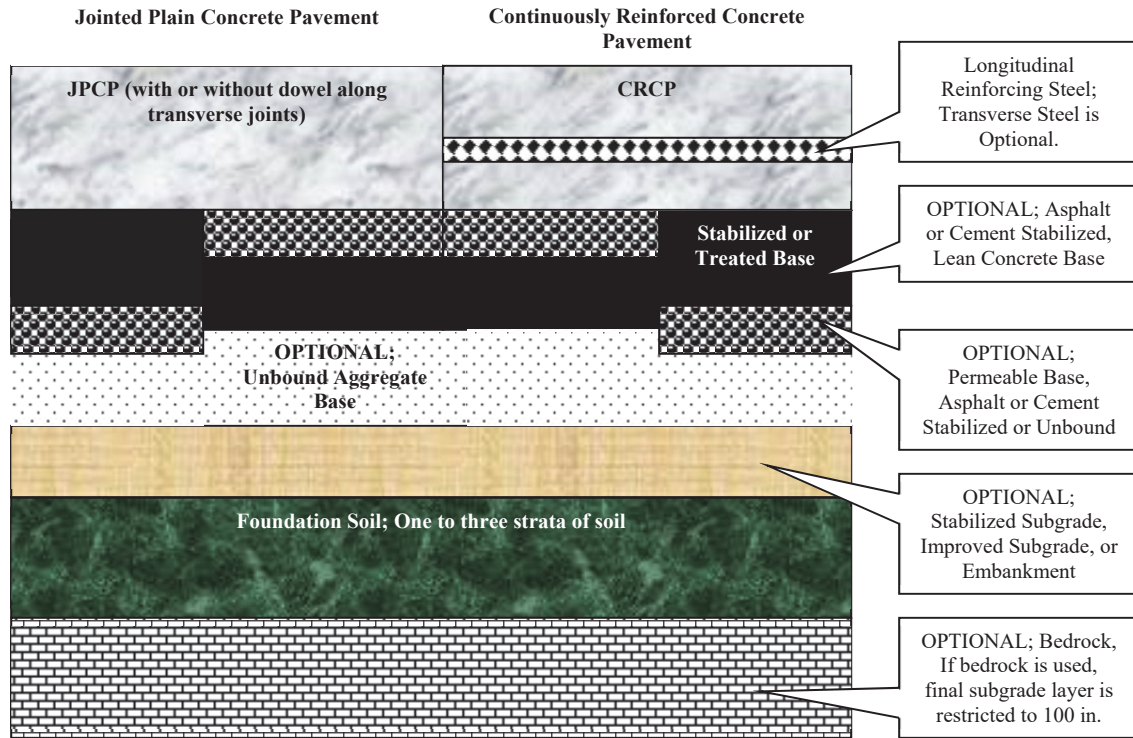


Figure 3-3. New (Including Lane Reconstruction) Rigid Pavement Design Strategies That Can Be Simulated with the AASHTOWare PMED (Refer to Subsection 11.2); Layer Thickness Not to Scale

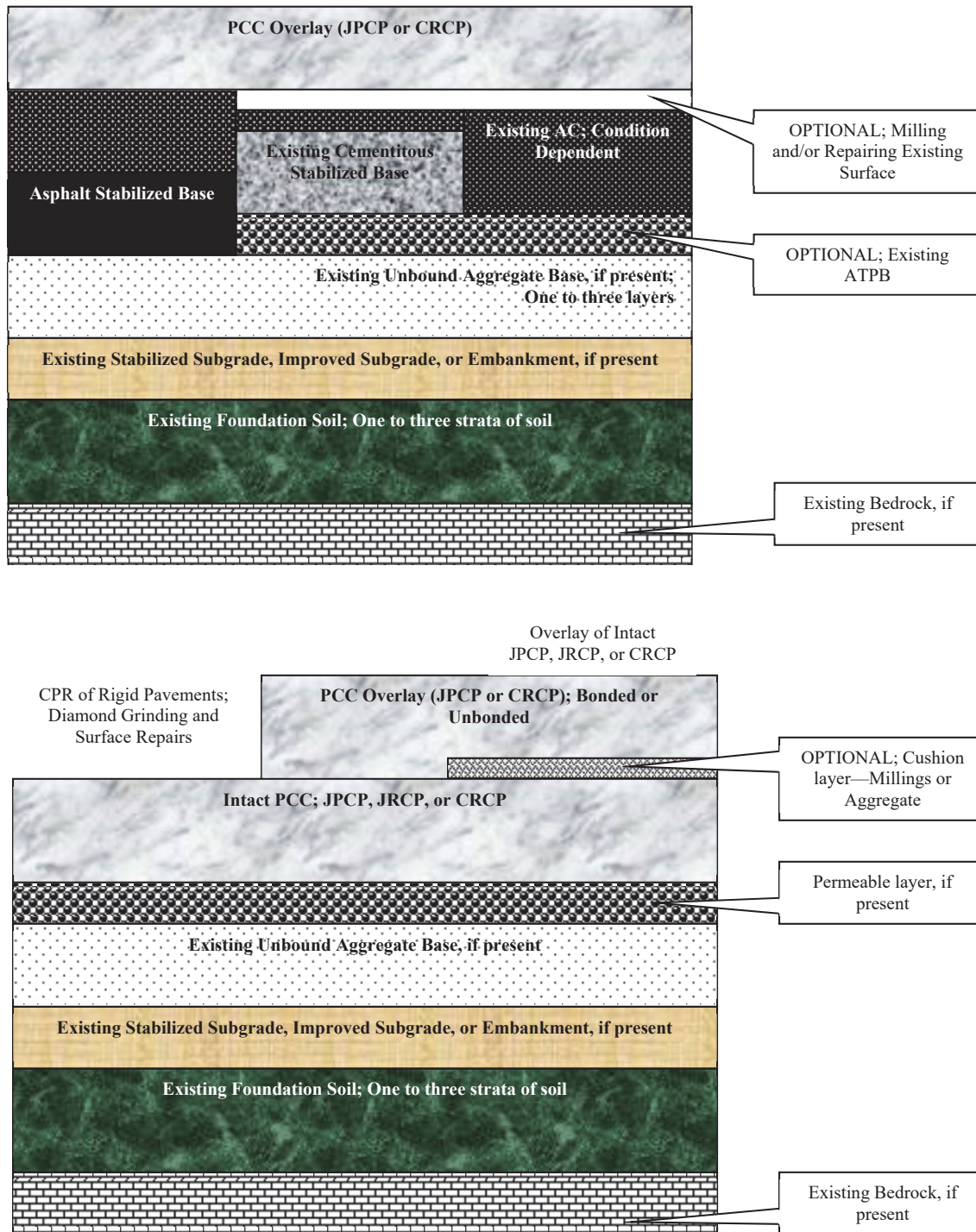


Figure 3-4. PCC Overlay Design Strategies of Flexible, Semi-Rigid, and Rigid Pavements That Can Be Simulated with the AASHTOWare PMED (Refer to Subsection 12.3); Layer Thickness Not to Scale

3.5 Design Features and Factors Not Included within the MEPDG Process

The intent of this subsection is to identify the features and distress prediction models that have not been calibrated for lack of adequate data, theoretical basis for modeling, and other possible reasons. The user should take this into account when using such prediction models. If such models are considered important for a given agency, effort could be expended during local calibration to ensure that they are valid for the conditions under which they are intended to be used. A standard practice is available that agencies may use in completing a local calibration effort (2). Some items not explicitly considered in the MEPDG are listed below.

- ✦ **Thin-Surfaced New AC Pavements:** Conventional flexible AC pavements were defined under Section 3.3 as flexible pavements with an AC surface less than 6 in. thick and placed over a high quality crushed stone or aggregate base materials. Thin-surfaced AC pavements are those where the tensile strains at the bottom of the AC layer are in or nearly in compression, so the traditional bottom-up fatigue cracking mechanism does not apply. Thin in this case would be AC layers less than 3 in. of total AC thickness. AASHTOWare Pavement ME Design can simulate this design strategy as long as the AC thickness is greater than 1 in. However, no thin-surfaced AC pavement section was included in the global calibration process. More importantly, the horizontal strains calculated at the bottom of the lower AC layer in flexible pavements with a total AC layer thickness of less than 3 in. can decrease and even become positive or in compression for layer thicknesses less than 2 in. Horizontal strains in compression means bottom-up fatigue cracks will never occur. As such, the thin-surfaced AC pavement design strategy should not be used without calibration.
- ✦ **Friction or Skid Resistance and Noise:** The AASHTOWare PMED does not predict the loss of surface characteristics related to skid resistance and noise attenuation. The designer needs to consider historical data and experience in evaluating the surface layer's capability to retain minimum skid resistance and noise attenuation values through the materials' specifications external to the AASHTOWare PMED.
- ✦ **Single and Super-Single Tires:** The AASHTOWare PMED assumes that all axles within the truck traffic mix have dual tires; however, the software does have the capability to simulate a super-single tire loading by superimposing two dual tires. In other words, the spacing between the dual tires is set to "0."
- ✦ **Durability and Mixture Disintegration:** The AASHTOWare PMED does not have the capability to predict mixture durability and surface disintegration distresses, such as raveling and stripping of AC mixtures, spalling and alkali silica reactivity (ASR), or D-cracking of PCC layers. Mixture durability issues are addressed during the mixture design process or by the material specifications for a project, external to the AASHTOWare PMED. The spalling of PCC joints, however, is modeled empirically as a function of water/cement ratio, air content, strength, and other parameters.

- **Volume Change in Problem Soils:** The AASHTOWare PMED does not have the capability to predict the volume change potential from frost susceptible soils (frost heave potential) or expansive-highly plastic clay soils (shrink-swell potential; AASHTO T 258). When problem soils are encountered along the project, appropriate subgrade improvement and strengthening techniques could be used to minimize the detrimental impact of these problem soils on pavement performance.
- **Asphalt Treated Permeable Base (ATPB):** Flexible pavement sections with an ATPB were omitted from the global calibration process of flexible pavements but were included in many rigid pavement sections used for global calibration. These ATPB layers below the PCC surface were treated as asphalt treated materials with high air void contents and low asphalt contents.

If these layers are included in the trial design just below the lowest AC dense-graded layer of an AC-surfaced pavement, AASHTOWare Pavement ME Design calculates the tensile strain at the bottom of the ATPB for use in predicting alligator cracking. The high air void content and low asphalt content of this drainage layer significantly reduces the fatigue life of the flexible pavement. The reduction in fatigue life was found to be inappropriate for design of flexible pavements based on performance findings from LTPP SPS-1 test sections (2).

As an option for its use, the ATPB layer may be treated as a high quality aggregate base layer when analyzing the trial design. The representative resilient modulus (resilient modulus remains constant throughout the design period) considered appropriate for this simulation is 65 ksi, but could be verified through expanded local calibration efforts that include flexible pavements with an ATPB layer.

- **Geogrids, Geotextile Fabrics, and Other Reinforcing Materials:** These materials cannot be directly simulated in the AASHTOWare PMED at this time. These materials can be indirectly simulated by modifying the resilient modulus of the unbound layers and/or through the calibration process. None of the test sections included in the global calibration process, however, contained geogrids, geotextile fabrics, or other reinforcing materials included in the pavement structure.
- **Semi-Rigid Pavements:** Semi-rigid pavements consist of AC mixtures placed over a cement treated base (CTB), lean concrete base (LCB), or cement-aggregate mixtures (CAM), with an aggregate subbase layer. The AASHTOWare PMED can analyze this pavement type, but the software does not predict the spacing of transverse shrinkage cracks in the cementitious stabilized layer. The spacing of shrinkage cracks is an input to the software.
- **Pavement Preservation Programs:** Non-structural pavement preventive maintenance or preservation programs and strategies are policy decisions. Pavement preservation strategies or treatments are not simulated in Pavement ME Design, while preventive maintenance strategies can be included in the distress predictions within the design

period of the pavement by resetting selected distress/performance measures (refer to sections 3.3 and 3.4). Non-structural preventive maintenance strategies or treatments are assumed to be those providing no structural value to the structure and are less than 1 in. thick. These strategies can include a scratch layer with other treatments, micro-surfacing, ultra-thin overlays, and surface hot in-place recycling with seal coat. The impact of the non-structural preventive maintenance treatments is limited to those for which the existing surface of the pavement is redefined or releveled, so some of the distresses are reset to the condition right after placement (e.g., rut depth, faulting, IRI).

Pavement preventive maintenance treatments applied to the surface of AC layers early in their life, however, have an impact on the performance of flexible pavements and AC overlays. As an example, there is less hardening or aging of the asphalt binder, but this impact is not considered throughout the design period after the treatment is applied. The pavement designer needs to consider the impact of these programs in establishing the local calibration coefficients or developing agency specific values—primarily for load and non-load related cracking. This pavement preventive maintenance and preservation issue is discussed in more detail in the *Calibration Guide* (2) for determining the regional or agency specific calibration factors. Preservation is also considered in JPCP design only in the ability to design a restoration project.

- ✦ **Staged Construction:** The AASHTOWare PMED does not have the capability to evaluate staged construction events that are offset by extended periods of time. When staged construction is planned for a project, the designer enters a traffic open month and year that the final pavement layer has been placed. Subsection 6.2 provides more discussion on staged construction events.
- ✦ **Ultra-Thin PCC Overlays:** Ultra-thin PCC overlays (e.g., less than 4 in. or less than 5 ft of joint spacing) cannot be designed with the MEPDG. Short Jointed Plain Concrete (SJPCP) bonded overlays of flexible pavements can be designed between 4–8 in. with joint spacing of 5–8 ft. The conventional full lane width JPCP overlays over existing asphalt or concrete pavement have a minimum thickness of 6 in. and joint spacing is also limited to a minimum of 10 ft. The minimum thickness of CRCP overlays is 7 in.
- ✦ **JRCP:** These pavements were not directly considered in the MEPDG development and cannot be designed using the MEPDG procedure.
- ✦ **Early-Age PCC Opening to Traffic:** The minimum time for opening of PCC pavements, as provided in the AASHTOWare PMED, is 28 days.
- ✦ **Interface Friction of AC Overlays of PCC Pavements:** The AASHTOWare PMED excluded the capability to vary the interface friction between the AC overlay and existing PCC pavement. Interface friction, however, is considered between all AC layers of flexible pavements and AC overlays of flexible pavements, and between the JPCP and base layer. Subsection 9.2.7 provides more discussion on the use of interface friction between bound layers. Full bond was assumed in all cases, with the exception of CTB bases, for the global calibration effort (20).