CTDOT Pavement Design Handbook

FINAL REPORT

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School of Engineering

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Transportation Supervising Planner

Disclaimer

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Acknowledgments

This report was prepared by the University of Connecticut, in cooperation with the Connecticut Department of Transportation and the United States Department of Transportation, Federal Highway Administration. The opinions, findings and conclusions expressed in the publication are those of the authors and not necessarily those of the Connecticut Department of Transportation or the Federal Highway Administration. This publication is based upon publicly supported research and is copyrighted. It may be reproduced in part or in full, but it is requested that there be customary crediting of the source.

Several pavement design manuals and references published by other agencies were obtained and reviewed during the development of Connecticut's handbook. It should be noted that a few of the state design manuals, in particular, were utilized extensively for the preparation of this CTDOT handbook. Most noteworthy are materials used from the California Department of Transportation, the Delaware Department of Transportation, and the Ohio Department of Transportation. A number of other states' documents are also quoted, and these are listed in the Reference section, as well.

Standard Conversions

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Technical Report Documentation Page

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16. Abstract
This document presents the process and methodology for pavement designs in conformance with CT DOT design practices including new construction, rehabilitation, and preservation. Types of pavements addressed include flexible [asphalt concrete] pavements, rigid [Portland cement concrete] pavements, and composite pavements. This document addresses design process and submission requirements, material selection, and design data requirements. Additional special conditions include pavement designs for Major Traffic Generators (MTGs), bridge deck overlays, and widening.

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1 Introduction

1.1 Overview of the Handbook

This pavement design handbook has been assembled to provide general guidance and promote consistency in the development and submittal of pavement designs for roadways managed by the Connecticut Department of Transportation (CTDOT). It is meant to be a practical guide that informs and directs both consultants and CTDOT in-house staff about the process used for pavement designs in Connecticut. The handbook provides a similar opportunity to assist Connecticut municipalities with pavement design guidance. This handbook can also be found online at http://www.ct.gov/dot/cwp/view.asp?a=3609&q=430362

The handbook is arranged to provide an overview of pavement design. It outlines the processes and design methods used for pavement preservation, rehabilitation, widening, resurfacing, new construction, and reconstruction of flexible, rigid, and composite pavement structures. It provides a list of supporting documents for designers to include in their design folders. The specific details of the pavement design process are found in other referenced documents, such as the **1993 AASHTO Guide for the Design of Pavement Structures (1993 AASHTO Guide)**, the CTDOT Pavement Preservation Program, and CTDOT's various publications used in roadway geometric design, traffic analyses, etc. In some cases, locations of or links to various pertinent documents are found within this handbook, including the list of references at the end.

The Pavement Design Unit (PDU) is responsible for creating and updating the content of this handbook. Requests for additional information, questions about pavement structure design or comments about this handbook should be directed to

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To carry the projected traffic loads throughout the expected life of a project, a properly designed and constructed pavement must provide adequate strength, acceptable ride quality, and lasting durability. To ensure this occurs, pavement structures should be engineered using the standards and guidance described in this handbook. For the cases of new construction, reconstruction, widening, structural overlays or rehabilitation, the final pavement structure for each project should be based on a thorough investigation of specific project conditions such as subgrade soils properties, environmental conditions, projected traffic, cost effectiveness, as well as the performance of other pavements in the same area or under similar climatic and traffic conditions. Although somewhat less critical, to ensure cost effectiveness, pavement functional overlays (used for resurfacing (with or without milling)) and other pavement preservation activities should also be based upon the latest available proven state of the practice methodology, as provided and/or referenced in this handbook.

1.2 General Guidelines and Policies

1.2.1 *Pavement Design Goal*

CTDOT's goal is to provide pavement design procedures that result in cost-effective pavement structures, that optimize road service life and provide maximum utility to road users.

1.2.2 *Pavement Design Procedures*

CTDOT currently uses the **1993 AASHTO Guide for Design of Pavement Structures (1993 AASHTO Guide)**. CTDOT plans to begin the transition to the Mechanistic-Empirical Pavement Design Guide (M-EPDG) **AASHTOWare Pavement ME Design™** in future years. There are many reasons for the slow adoption of the M-EPDG including the need for extensive pavement performance datasets and need to calibrate the M-EPDG using local observations.

1.2.3 *Pavement Design Process*

To select an appropriate pavement type and/or treatment, and to properly design a pavement structure, a designer should follow general prescribed procedures and obtain specific information from the CTDOT Pavement Design Unit (PDU) and other sources identified below. Sound engineering judgment must also be applied by the designer. In general, the design process includes many of the following activities:

- Review and Confirmation
    - Review Pavement Management Data to ascertain the appropriate scope of work and treatment type (i.e. new pavement construction, widening, reconstruction, rehabilitation, resurfacing, preservation, or other);
    - Evaluate the existing pavement to confirm the scope of work and determine the preliminary design and appropriate strategy;

- Background and History
    - Research roadway history and traffic data;
    - Verify existing pavement materials and structure;
    - Investigate subbase and subgrade for drainage characteristics and bearing capacity;
    - Perform field trips to make site inspections (as needed);
    - Communicate with engineering and maintenance forces (as needed) for history of roadway performance, groundwater problems and other background information;

- Pavement Evaluation and Design
    - Perform field investigation, including borings, core, GPR, FWD, as required for the particular field investigation;
    - Perform structural calculations. The traffic, soils, and existing pavement data and information must be used to calculate specific pavement layer requirements;

- Develop alternative design solutions including any life-cycle cost analyses;
- Select the best design solution;
- Develop a pavement design report;
- Create plans and specifications: The pavement materials, construction methods, and finished project requirements must be both practical to attain and clearly defined. The designer must ensure that the plans, specifications, and estimates clearly and unambiguously define the requirements

2 Pavement Design – Administrative Process

2.1 Introduction

Design responsibility for pavements on the state roadway network generally depends on the size and complexity of the project. The responsibility falls either on the PDU or on the consulting engineering firm selected and agreed upon to design the project. The determination of who will design the pavement happens during the project scoping phase and is a case-by-case consideration based on current workload of the PDU and the type of project.

All pavement designs prepared by a Consulting Engineering Firm must be prepared and signed by a Professional Engineer licensed in Connecticut. Regardless of who performs a pavement design (in-house staff or consultants), all pavement designs must be submitted to the PDU for review and approval. Those designs so designated for submittal will be reviewed by the PDU, approved, archived, and in some cases reviewed for pavement type selection (if required). When requested by CTDOT, documentation and justification supporting the selection of a specific pavement type (Asphalt vs. PCC) is to be included in the submittal to the PDU. All designs that are reviewed are done so to ensure they meet minimum requirements as identified in this handbook and other pertinent sources. If required information is found to be missing during the review the design may be rejected. Items missing will be noted and the design returned to the consultant for revision. See 2.2.1 for description of content requirements. Designs rejected due to insufficient content must be completed and resubmitted to PDU within 15 calendar days.

Pavement structures are expected to remain structurally sound for a given design life. Although a roadway section may become operationally obsolete or the pavement distressed and in need of restoration or rehabilitation, it has not reached the end of its design life but rather the end of a condition defined as service life. Not until complete replacement [reconstruction] is a pavement considered to have reached the end of its design life.

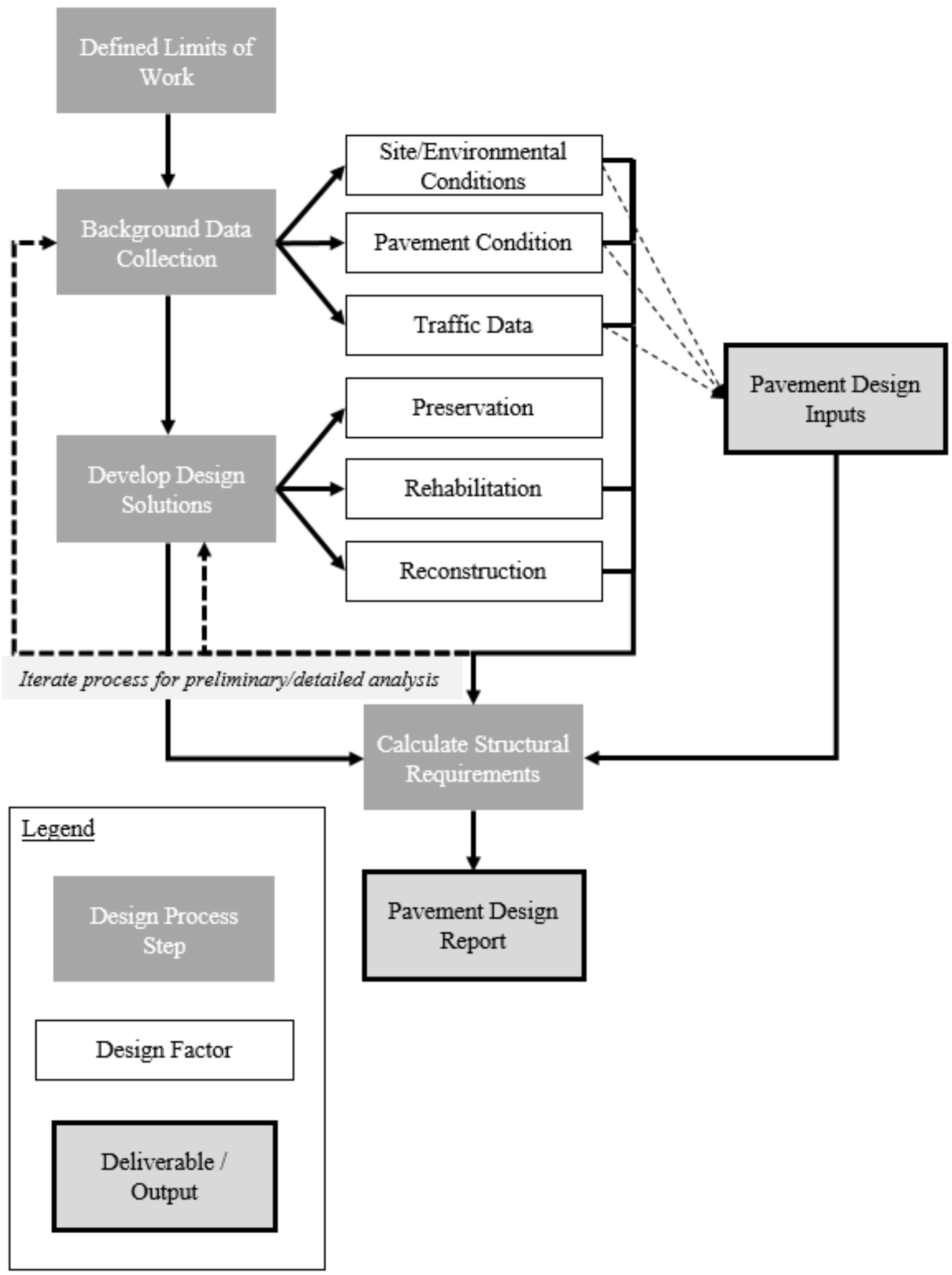

Figure 1 Design Process Flowchart

2.2 Design Submittals

2.2.1 *Pavement Design Report Contents*

Pavement designs will be submitted to the PDU in the Division of Highway Design, Engineering Services. A coversheet memorandum (see example design approval in Appendix A) shall be included that contains the project description and a summary of the pavement type selection (where appropriate). Generally, all the following items, as a minimum, should be included for a pavement design (for additional information and more detailed guidance, see also 2.2.3 "Design Support Documentation" section of this handbook below):

1. Design Executive Summary Paragraph
2. Historical Data and Record Plan Review
3. Type Selection Justification (if appropriate)
4. Geotechnical Information *
5. Traffic Information **
6. Pavement Design
7. Typical Sections and Details
8. Special Notes and Provisions
9. Other Documentation, as deemed appropriate

An example of the pavement design submittal coversheet memorandum, and submittal project information are presented in Appendix A.

**existing soils information for a particular location can be obtained by checking legacy plans on ProjectWise in the project area and seeing if boring logs are available or contacting the CTDOT Soils and Foundation unit directly to see if borings are available.*

*** traffic information can be obtained through Miovision or another method via a request to the CTDOT Traffic Monitoring Unit, Bureau of Policy and Planning.*

2.2.2 *Pavement Design Request Procedures*

Pavement designs are initiated within the CT DOT for several different reasons including:

- Within PDU for maintenance or preservation
- For new constructions or system enhancement projects
- Major Traffic Generator (MTG) projects

For any project requiring a formal pavement design report, the project initiation/design request form should be completed and submitted to PDU. An example of the project initiation form is found in Appendix B. If the user has access to ProjectWise^{TM}, this form can be found here:

4.00 – Engineering Libraries\Engineering Templates\Highway Design folder

2.2.3 *Design Support Documentation (primarily for CTDOT internal submittals)*

The following is a preliminary list of supporting documents for CTDOT to include in a design folder anytime a pavement design is performed. This generally applies to an internal (PDU) project. However, the listed information should also be of informational value for designs prepared by consulting engineers.

<u>Project Info</u> (Word Document)

Provide a word document that briefly includes and/or summarizes the following:

- Background of project/assumptions/thought process
- Scope of request
- Pavement type (flexible, composite, surface treated etc.)
- Bridge No.(s)
- Route(s)
- Town names
- Mile points
- Inventory of pavement sections being improved (for interstate include list of ramps)
- A copy of any pavement testing documents
- Conditions (distress type, severity, and extent present for rehab.; if reconstructing, not necessary)
- Drainage trenching work? Cutting through concrete?
- As built project plan numbers
- Information gathered from Photolog Digital Hiway (reflective cracking from concrete, concrete observed on *wayback image*, drainage problem observed, etc.)
- ADT with year; ADT with year for construction completion year (project with 2% growth)
- Roadway functional classification
- Number of lanes in each direction
- Design speed/posted speed
- Subgrade soil type
- Anticipated construction completion year (year for this current project)
- Current pavement surface age (digital highway 'wayback' feature is useful)
- Availability of adequate funds
- Other considerations or details gathered from meetings, emails etc.
    - traffic disruptions and user delay costs
- Construction feasibility with consideration of:
    - traffic control
    - materials and equipment availability
    - construction issues such as
        - noise
        - pollution
        - subsurface utilities
        - overhead bridge clearances
        - shoulder thickness
    - right-of-way limitations

Traffic Subfolder

All resources should be checked, and the best available data should be used. Traffic data should be projected to the year of construction completion using a two (2) percent growth rate unless a more accurate projection is available.

- PDF of ADT Map: Either ADT – Towns or ADT - Expressways map for project location
  - Available on the CTDOT Maps Page
- PDF of functional classification map for project location
  - Available on the CTDOT Maps Page
- Turning movements or volume counts available from Highways or Traffic Unit
  - Ask whether this information is available
- Check traffic count data webpage (Traffic Monitoring Volume Information)
  - http://www.ct.gov/dot/cwp/view.asp?a=3532&q=330402

For designs on Interstates, or for rehabilitation projects, request classification counts from the Bureau of Policy and Planning, Traffic Monitoring Unit. Actual classification counts are highly recommended as opposed to using the default classification for the functional class in the ESALs calculator (see later section titled "Pavement Design Spreadsheets"). For the PDU this request should be directed through a program called Miovision, which would come to the attention of the Traffic Monitoring Unit. The Traffic unit would then determine whether to have the Miovision vendor perform the counts or do the counts internally. A full week count for interstates is desirable.

Soils Subfolder

Provide brief justification in a word document for chosen subgrade modulus

- Check soils drive to see if soils information is available for project
  - Z:\PM_WD\Projects [Consultants shall coordinate this search with their respective DOT liaison]
  - Check ArcGIS boring base map
- Check plan sheets to see if borings were included
- Check surficial soils maps to determine native soils
  - Also available in ArcGIS boring base map
- Another resource is the USDA web soil survey
  - http://websoilsurvey.nrcs.usda.gov/app/

As-built Subfolder:

- Cross sections - check ProjectWise™. Use the geospatial feature to find projects in vicinity
- Pavement composition:
  (e.g., bituminous concrete on bituminous concrete base on crushed stone subbase, etc.)

- See also Appendix C of this handbook for various sample pavement structures.
- Project rehab/preservation history -

Special Provisions/ Items Subfolder:

- List of Specifications and Items -

Design Subfolder:

Superpave Level**:**

- Check Superpave design level map (preliminary check)
  - Available on the CTDOT Maps Page https://www.ct.gov/dot/lib/dot/documents/dpavement/Superpave_Levels.pdf
- Superpave level should be based on ESALs and on guidance in Section M.04, "Bituminous Concrete Materials" in FORM 817 found at http://www.ct.gov/dot/cwp/view.asp?A=3517&Q=417868

Traffic Volume [ESALs]

- ESALs can be interpreted from Average Daily Traffic maps, available here:
  - https://portal.ct.gov/DOT/PP_SysInfo/2007-2014-ADT-Maps
- Include ESAL CALC spreadsheet (see later section titled, "Pavement Design Spreadsheets")

Pavement Core Info**:**

- Photo documentation of pavement cores
- Summary of coring information
- Indicate depth of bad layers
- Indicate, max., min., average, for different directions, if pertinent, or various sections

Design:

- Flexible Pavement Design Tool (see 2.3 section titled, "Pavement Design Spreadsheets"):
  - Include separate sheets for various alternatives considered
- Composite Design Overlay Tool (See Section 14.4.1 for more information)**:**
- Overlay thickness needed
- Estimated Quantity Calculations (if applicable):
- Provide an MS Excel sheet with quantity estimates for items needed (Partial Depth Patch (PDP), Full Depth Patch (FDP), Crack Seal (CS) etc.)

Field Notes and Photos:

- Field Notes indicating conditions and characteristics of site

- Photos of site features and overall layout
    - Photo Location Plan may be a useful record

2.3 Pavement Design Spreadsheets

A Pavement Design Spreadsheet titled "**Flexible Pavement Design Tool**" is available in Microsoft Excel format on the CTDOT Pavement Design Guidance webpage at http://www.ct.gov/dot/cwp/view.asp?a=1400&q=534372 . The most current version of the spreadsheet will be maintained on this webpage for use on all pavement designs.

There is also a helpful tool at this same webpage titled "**Pavement Management ESAL Calculations**," which can be used for determining design traffic loads for any specific roadway project.

3 Pavement Structure Layer Definitions and Descriptions

3.1 Typical Pavement Cross Sections

Illustrations of typical pavement structure cross sections are shown below in Figure 2.

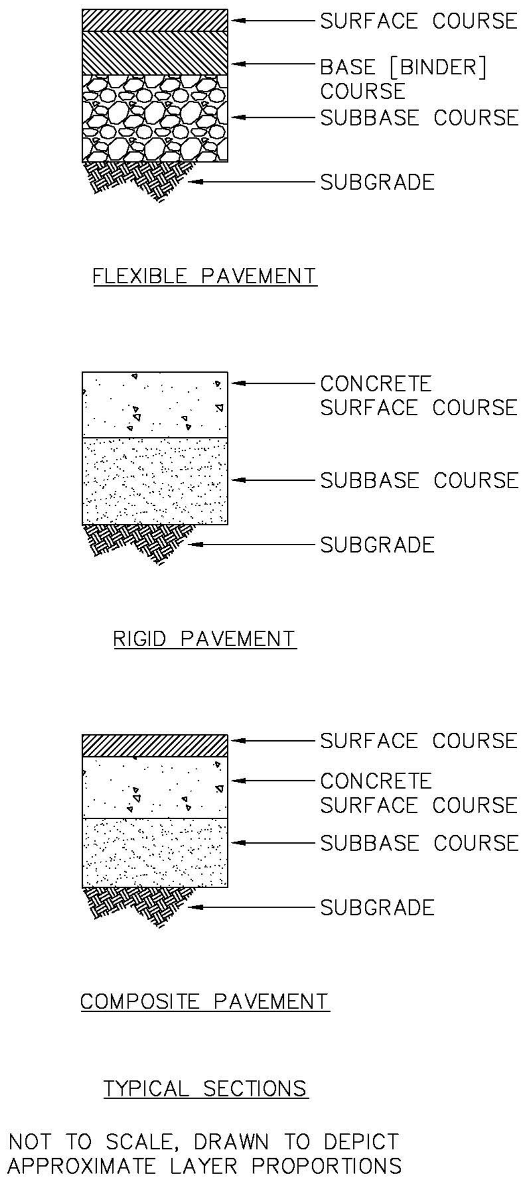

Figure 2 Typical Pavement Structures of CT

3.2 General Pavement Structure Definitions

The following terminology is provided for user reference when reading this document, a more comprehensive glossary may be found in Chapter 18.

Flexible Pavements (FHWA, (8))

"Flexible pavements …have an asphaltic surface layer, with no underlying Portland cement slabs. The asphaltic surface layer may consist of high quality, hot mix asphalt concrete, or it may be some type of lower strength and stiffness asphaltic surface treatment. In either case, flexible pavements rely heavily on the strength and stiffness of the underlying unbound layers to supplement the load carrying capacity of the asphaltic surface layer."

Surface Course (CTDOT)

Sometimes also referred to as the surface layer, the surface course may be composed of a single layer, constructed in one or more lifts of the same material, or multiple layers of different materials. The surface course might also be termed as being composed of a binder course or an intermediate layer such as a leveling course and a surface layer. The surface course is engineered to accommodate and distribute traffic loads, provide skid resistance, minimize detrimental effects of climate, minimize tire/pavement noise, improve surface drainage, and minimize infiltration of surface water into the underlying base, subbase and subgrade.

Surface Course (FHWA, (8))

"..the **surface course** is one or more layers of a pavement structure designed to accommodate the traffic load, the top layer of which resists skidding, traffic abrasion, and the disintegrating effects of climate. The surface layer may consist of asphalt (also called bituminous) concrete, resulting in "flexible" pavement, or Portland cement concrete (PCC), resulting in "rigid" pavement. The top layer of flexible pavements is sometimes called the "wearing" course. The surface course is usually constructed on top of a base layer of unbound coarse aggregate, but often is placed directly on the prepared subgrade for low-volume roads. In addition to providing a significant fraction of the overall structural capacity of the pavement, the surface layer must minimize the infiltration of surface water, provide a smooth, uniform, and skid-resistant riding surface, and offer durability against traffic abrasion and the climate.

Base [Binder] Course (FHWA (8) (CTDOT)

Binder course (also called the asphalt base course): The hot mix asphalt layer immediately below the surface course. The base course generally has a coarser aggregate gradation and often a lower asphalt content than the surface course. A binder course may be used as part of a thick asphalt layer either for economy (the lower quality asphalt concrete in the binder course has a lower material cost than the higher-asphalt content concrete in the surface course) or if the overall thickness of the surface layer is too great to be paved in one lift.

Stabilized Base (CTDOT) (FHWA)

Aggregate Base layer that has had its engineering properties improved through the addition of a stabilizing product such as Portland cement, fly-ash, calcium chloride, lime, asphalt emulsion, foamed asphalt, and/or other products. The stabilizers typically used in Connecticut are asphalt emulsion, foamed asphalt, and calcium chloride. For a full discussion on the use of different stabilizing products the user is referred to the following FHWA publication.

https://www.fhwa.dot.gov/pavement/pubs/013711.pdf

Subbase (FHWA, (8))

The subbase is a layer or layers of specified or selected materials of designed thickness placed on a subgrade to support a base course. The subbase layer is usually of somewhat lower quality than the base layer. In some cases, the subbase may be treated with Portland cement, asphalt, lime, flyash, or combinations of these admixtures to increase its strength and stiffness. A subbase layer is not always included, especially with rigid pavements. A subbase layer is typically included when the subgrade soils are of very poor quality and/or suitable material for the base layer is not available locally, and is, therefore, expensive. Inclusion of a subbase layer is primarily an economic issue, and alternative pavement sections with and without a subbase layer should be evaluated during the design process.

Subbase Course (Aggregate Base Course) (CTDOT, (21))

The subbase consists of compacted granular material, which primarily functions *as structural support. It can also minimize the intrusion of fines from the subgrade into the pavement structure, improve drainage, and minimize frost action damage.* The composition of subbase consists of a clean soil-aggregate mixture of bank or crushed gravel, crusher run stone, reclaimed miscellaneous aggregate containing no more than 2 percent by weight of asphalt cement or any combinations thereof.

Subgrade (FHWA (8))

The subgrade is the top surface of a roadbed upon which the pavement structure and shoulders are constructed. The purpose of the subgrade is to provide a platform for construction of the pavement and to support the pavement without undue deflection that would impact the pavement's performance. For pavements constructed on-grade or in cuts, the subgrade is the natural in-situ soil at the site. The upper layer of this natural soil may be compacted or stabilized to increase its strength, stiffness, and/or stability.

Subgrade (CTDOT, (20))

The area upon which the pavement structure and paved shoulders are placed, including the shoulder base courses and subbase shall be known as the subgrade. This is the plane coincident with the bottom of the subbase and the edge of pavement, as shown on the plans and cross-sections or as ordered by the Engineer. The work of formation of subgrade shall be performed at this plane.

Rigid Pavements (FHWA (8))

Rigid pavements in simplest terms are those with a surface course of Portland cement concrete (PCC). The Portland cement concrete slabs constitute the dominant load-carrying component in a rigid pavement system.

Jointed Plain Concrete Pavement (JPCP) (FHWA, (8))

These unreinforced slabs require a moderately close spacing of longitudinal and transverse joints to maintain thermal stresses within acceptable limits. Longitudinal joint spacing typically conforms to the lane width, around 12 ft, and transverse joint spacing typically ranges between 15 and 30 ft. Aggregate interlock, often supplemented by steel dowels or other load transfer devices, provides load transfer across the joints.

Jointed Reinforced Concrete Pavement (JRCP) (FHWA, (8))

The light wire mesh or rebar reinforcement in these slabs is not designed to increase the load capacity of the pavement, but rather to resist cracking under thermal stresses and, thereby, permit longer spacings between the transverse joints within slabs. Transverse spacing typically ranges between 30 and 100 ft. Dowel bars or other similar devices are required to ensure adequate load transfer across the joints.

Continuously Reinforced Concrete Pavement (CRCP) (FHWA, (8))

Transverse joints are not required in CRCP pavements. Instead, the pavement is designed so that transverse thermal cracks develop at very close spacings, with typical spacings on the order of a few feet. The continuous conventional reinforcement bars are designed to hold these transverse thermal cracks tightly together and to supplement the aggregate interlock at the cracks, to provide excellent load transfer across the cracks. In addition to the benefit of no transverse joints, CRCP pavement designs are typically 1 - 2 in. thinner than conventional JPCP or JRCP systems.

Pavement Slab

The smallest division of a concrete pavement structure. This is controlled by the type (jointed vs. continuously reinforced), roadway geometry, layer thickness, and base/subbase type.

Composite Pavements (FHWA, (8))

Composite pavements combine elements of both flexible and rigid pavement systems, usually consisting of an asphaltic concrete surface placed over PCC or bound base.

4 Design Parameters

4.1.1 *Traffic volume and vehicle class*

The traffic volume on a facility is a major factor in determining the required strength of the pavement structure. Pavement strength requirements for traffic are primarily influenced by projected truck traffic loads over the pavement design life. Passenger cars and pickup trucks are considered to have negligible effect when determining traffic loads. In the design process, traffic data are reduced into "equivalent" axle loads, axle configuration, and number of applications of these loads. For the design calculations, traffic data are converted into 18-kip [80 kN] equivalent single axle loads or ESAL's."

To determine expected traffic loads on a pavement, it is first necessary to determine projected traffic volumes during the design life for the facility. Traffic volume or loading on State highways can come from vehicle counts and classification, weigh-in-motion (WIM) stations, or the Truck Traffic (Annual Average Daily Truck Traffic) this data is readily available in maps by town on the CT DOT Maps website, linked in section 2.2.3 of this report. Current and projected traffic volume by vehicle classification must be obtained for each design. The pavement design should be coordinated early in the project development process with the required traffic projections. If traffic projections are not available for the project right-of-way, the design shall use a growth rate of 2% in accordance with the 1993 AASHTO Guide.

4.1.2 *Subgrade soil*

Pavement structures rest on a graded and compacted subgrade. This prepared subgrade can be either of suitable natural material or on specified imported material. The strength of a subgrade is defined as resilient modulus (M_R) and is a measure of the elastic property of soil (reported in *psi* or *kPa)*. The resilient modulus is used directly for designing flexible pavements but must be converted to a modulus of subgrade reaction (k-value) for the design of rigid pavements or composite pavements (Reported in *pci* or kg/m^3).

4.1.3 *Materials of construction*

1. Wet clays – Clay is material with particles finer than 0.075 mm and is generally not desirable as a subgrade or subbase material.
2. Cohesionless sandy soil – Cohesionless sandy soil is material that is primarily composed of either well graded or poorly graded sand size particles (0.075 mm – 4.75 mm) and may or may not contain significant amounts of silt. This is generally not desirable as a subbase material on its own.
3. Gravel and aggregates – Gravel and aggregates refer to a generally well graded product consisting of both sand size (0.075 mm – 4.75 mm) and gravel size (> 4.75 mm) particles that (together when compacted sufficiently) will give the best options for subgrade and subbase materials.
4. Flexible or rigid paving materials (see later sections)

4.1.4 *Climate (and variations)*

The effects that climate will have on pavement must also be considered as part of the pavement design process. Temperature changes create pressures that can cause pavements to expand and buckle or shrink and crack. Asphalt binders in flexible pavements become softer at higher temperatures and brittle at colder temperatures. Precipitation can increase the potential for water to infiltrate the base and subbase layers, increasing the structure's susceptibility to erosion, and weakening the pavement strength. During freeze/thaw cycles, the expansion and contraction of water, plus the use of studded tires, and snowplows, create additional stresses on pavements. Solar radiation can also cause pavements to oxidize.

Connecticut's climate is rated as zone 1A, which is wet-freeze, based on the Thornthwaite Potential Evaporation and Moisture Index. This rating means that much of Connecticut is susceptible to high potential for moisture presence in the entire pavement structure throughout the year. There is also high potential for frost penetration to appreciable depths into the subgrade.

Depth of frost varies across the state from roughly 38 inches in coastal areas to up to 65 inches at the northern border of the state. A useful reference in confirming frost depth is the Unified Facilities Criteria tool from the US Department of Defense. A link to their design parameter resource is below:

https://www.wbdg.org/additional-resources/tools/ufcsldt

Due to the fact that Connecticut is a relatively small state geographically, the variability in climate across the state is small enough to have a single design input for environmental factors for the entire state.

4.1.5 *Subsurface Drainage*

As part of the pavement design considerations, the engineer shall consider either the effectiveness of existing drainage infrastructure (including geometric/surface drainage such as cross slope and profile vs. drainage components such as storm sewer/catch basins, swales, and underdrains). Poorly draining pavements are susceptible to premature failure when water infiltrates the various layers. Note any site constraints in need of mitigation and identify such in the pavement design submission.

Preference is to include edge drain. Detrimental moisture conditions can develop externally by climatic conditions and internally by certain properties of the materials which comprise the pavement structure. It is noted in the 1993 AASHTO Guide that pavement distress is often either caused or accelerated by the presence of moisture in the pavement structure. When designing pavement rehabilitation, the engineer should investigate the role of drainage improvements in correcting declining pavement performance. The severity of damage caused by excessive moisture will influence the decision on which rehabilitation strategy to select. Since moisture problems can exist in any layer of the pavement structure, more than visual observations may be needed; cores may have to be taken (or test pits/borings in the case of new construction). It is necessary to determine which material is responsible for the moisture-related damage and if an economical rehabilitation to correct the problem can be implemented. Failure to identify and correct the problem could lead to premature degradation of pavement within a given project. A valuable tool in this evaluation is the as-built plans.

Standard Details for subsurface drainage can be found in the CT DOT Highway Standard Drawings HW-751_01 downloadable as a. dgn or .pdf file here:

https://portal.ct.gov/DOT/Highway-Standard-Drawings/Highway-Standard-Details.

4.2 Field Inspection

4.2.1 *Pavement Condition Analyses*

CTDOT's PMU utilizes automated survey equipment and software to collect and summarize surface conditions of all state roads. The Pavement Management system classifies each roadway segment by identifying the amount and types of observable surface cracking, as formulated from pavement images using Wisecrax software or from surface scanning with lasers. These data are summarized and combined with other automated condition data, namely roughness in IRI (m/km and/or in/mile) and rut depths (mm and/or in.) and converted to indices. The indices translate into CTDOT's traditional Office of Maintenance Pavement Serviceability Rating (PSR) on a scale of 1-9. CTDOT has more recently termed this index the PCI (Note: This is not the metric used in ASTM D6433), which is similar to the CTDOT Office of Maintenance PSR, but also includes drainage, disintegration, cross slope and grade. This information is available from the PMU for every route segment. An annual network-level pavement condition report is published by the PMU.

Another important function in pavement management is a project-level analysis of existing roadway sections. Project level analysis is the inspection of pavements to determine the causes of deterioration. Pavement distress can be caused by either traffic loads or non-load factors such as climate, constructability issues, or material durability. Once a project-level analysis has been conducted, then the most reliable pavement design can be performed.

Depending on available historic information, a designer should be prepared to conduct additional pavement evaluations in the form of a windshield survey, site walk, geotechnical investigations, field distress surveys, or automated road survey equipment to ensure an adequate level of relevant and accurate information is being used for a pavement design, for all lanes within the project limits.

4.2.2 *Site Condition Evaluation*

A preliminary field review and evaluation needs to occur before a detailed design has been initiated. This will include an evaluation of both the general and detailed condition of the pavement. This preliminary field review is intended to evaluate the pavement for any additional distress and/or damage that has taken place in addition to what was observed during the previous pavement review. The following list consists of some of the types of distresses and/or conditions for which the pavement should be evaluated.

Flexible (Bituminous Concrete) Pavements can have the following distresses (ASTM D6433):

- alligator cracking
- bleeding
- block cracking
- bumps and sags
- corrugations
- longitudinal and transverse cracking
- patching & utility cuts
- polished aggregate
- potholes
- rutting

- depressions
- edge cracking
- joint reflection cracking
- lane/shoulder drop off
- shoving
- slippage cracking
- swelling
- weathering or raveling

Rigid pavement may have the following distresses (ASTM D6433):

- Blow up/buckling
- Corner breaks
- Divided slab
- Durability cracking
- Faulting
- Joint seal
- Lane/shoulder separation
- Linear cracking
- Patching (large)
- Patching (small)
- Polished aggregate
- Popouts
- Pumping
- Punchouts
- Scaling
- Shrinkage
- Spalling corner
- Spalling joint

These distresses are described (with photos) in detail in FHWA's Distress Identification Manual for LTPP, found at https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03031/03031.pdf

Pavement distresses for both flexible and rigid pavements, and their causes can also be found in the 1993 AASHTO Guide *[AASHTO, (1)]* Tables 3.2 and 3.3 on page III-29.

Definitions of some of these distresses are also found in other sections of this handbook, including the glossary of terms and pavement preservation discussions.

Appendix D of this handbook contains a sample pavement evaluation form that can be used in the field for evaluation of flexible or composite pavements (although it was developed primarily for pavement preservation). The engineer may alternatively use other forms such as those in ASTM D6433 or the above cited FHWA Distress Identification Manual. Regardless of the form used, however, having a standard set of definitions and language to describe distress is strongly suggested for future reference, for ease of communication, and for documentation purposes.

4.3 Subgrade Soil Evaluation (Support Value)

Pavements are engineered to distribute stresses imposed by traffic to the subgrade. For this reason, subgrade condition is a principal factor in selecting the pavement structure. Before a pavement is designed, the structural quality of the subgrade soils must be evaluated to ensure that it has adequate strength to carry the predicted traffic loads during the design life of the pavement.

4.3.1 *Soil Classification*

CT DOT uses Modified Burmeister classification – check the Geotech manual.

See CT DOT Geotech Manual (link below) for Subsurface investigation methods https://portal.ct.gov/-/media/DOT/documents/dpublications/Geotechncial_Engineering_Manual_1-20_revisions.pdf?la=en

5 Pavement Design - Flexible Pavement Structures

5.1 Introduction

New construction is the complete development of a pavement system from a proposed design alignment or to the new part of a widened highway. A *new* pavement typically refers to a structure (bound and unbound layers) built during a single project that is placed on a subgrade.

A reconstructed pavement is a subset of *new* pavements which is in reference to removing an existing pavement bound structure (asphaltic or Portland Cement Concrete layers) and replacing it with a new pavement structure. This type of work may be needed when the existing pavement is in a poor condition that cannot be salvaged. These projects are often needed to update old roadways to new geometric standards. Reconstruction may also be a more cost-effective or time-effective construction alternative to certain repairs/rehabilitations.

CTDOT's flexible pavement design method is based upon the 1993 AASHTO Guide. The information below on the AASHTO 1993 Guide is not comprehensive, and to complete a design, additional resources will require referencing, such as the FHWA Pavements Reference Manual, Appendix C – AASHTO 1993 Design Method, or the AASHTO *Guide for Design of Pavement Structures 1993* itself.

https://www.fhwa.dot.gov/engineering/geotech/pubs/05037/ac.cfm

Furthermore, this chapter pertains only to **flexible pavement designs**. If Portland cement concrete pavement is being considered or if the project entails overlaying concrete pavement (composite pavement), the procedure varies significantly from the one presented below. For those cases, other sections of this handbook should be consulted.

5.2 Structural Number

The structural number (SN) is an abstract number expressing the structural strength of pavement that is required for a given combination of the effective resilient modulus, M_R, of the subgrade soils, the total equivalent 18-kip [80 kN] single-axle loads (ESALs) [Traffic Volume], the design serviceability loss [Limit conditions for service life], and the standard deviation and reliability factors. The AASHTO Guide provides a nomograph for determining this value. The theoretical SN is ultimately converted to an actual thickness of surface, base and subbase required by means of appropriate layer coefficients representing the relative strength of the material used for each layer.

The Flexible pavement design process consists of the following general steps:

- Determine design inputs needed to calculate the structural number ($\mathbf{SN_{Req'd}}$)
- Calculate the $\mathbf{SN_{Req'd}}$
- Design a pavement structure with $\boldsymbol{SN_{des} = SN_f \geq SN_{Req'd}}$
- Specify pavement materials

5.3 Design Period (Performance Period)

The design period is the period of time that a new, reconstructed or rehabilitated structure will theoretically last before reaching its service life, this determines the amount of load experienced by the structure, factors that affect the design load of a pavement include the years of performance period and traffic growth factors to name a few **.** In actual practice the performance of a pavement can be significantly affected by the type and level of maintenance performed on the roadway and initial quality of construction. The longer the design period, the greater lifetime traffic volume will be experienced, resulting in a larger structural requirement. It is recommended to start with relatively standard design periods (See FHWA Pavements Reference Manual Appendix C, table C-1). However, it is worthwhile to test a design's sensitivity to design life, as increasing or decreasing it several years may prove more cost beneficial when considering the lifecycle of the pavement.

It is noteworthy that the analysis period will likely vary from the design period described. A discussion on the differences between these two parameters may be found in the FHWA guidance on Life cycle cost analysis listed as a reference document to this handbook.

5.3.1 *Pavement performance concepts/definitions:*

Serviceability/Service Life of a pavement is a characterization of how well a pavement will serve the user. This metric is primarily how a pavement is perceived (i.e. rideability, slipperiness (friction), and noise). While it is linked to all other factors like structural performance or design life, it differs in that the service life of a pavement may be reached before (unlikely) or after (typical of rural, low-volume roads) a design life is reached.

The Functional Life/Structural Performance of a pavement relates to its physical condition; including the occurrence of cracking, faulting, raveling, or other conditions that would adversely affect the load-carrying capability and traversability of the pavement or would require maintenance.

The Design Life of a structure is the intended duration of in-place performance for a given asset. In many cases, for pavement structures the maintenance and reconstruction cycle short-circuits the original design life through resurfacing or adding structure at the surface to extend the original design life. This parameter is more for design inputs on traffic and climatic loadings applied during analysis.

5.4 Traffic Design Inputs

The design procedures are based on cumulative expected 18-kip equivalent single axle loads (ESALs) during the analysis period. The designer must factor the design traffic by direction, and then by lanes if/when there are more than two (See Table 1). ESAL data should be obtained and calculated as defined in earlier sections of this handbook. Additional traffic factors include growth rate and percent trucks. Table 2 in the next chapter and the ESALCALC.xls spreadsheet developed for use on CTDOT roadways provide further guidance for these parameters.

Table 1 Typical Lane Distribution Factors

Number of Lanes in Each Direction	Percent of 18-kip ESAL in Design Lane
1	100
2	90
3+	70

5.5 Considerations for SN

5.5.1 *New Construction, Reconstruction*

For new construction or reconstruction, only the design Structural Number is required.

$$SN_{des} = SN_f \geq SN_{Req'd}$$

5.5.2 *Rehabilitation*

For rehabilitation, two numbers are needed: the effective existing SN (**SN_{eff}**) and the additional structure (future/design) **SN_f**. The effective existing structure is calculated based on known thicknesses, material types and approximate age (where a modulus range can be assigned based on the condition/age of the various layers)

$$SN_{des} = SN_{eff} + SN_f \geq SN_{Req'd}$$

The effective existing structure may be deducted from the required SN to determine the remaining structural requirement to be added (SN_f).

5.5.3 *Widening*

For widening projects, the widened section needs only a design SN (**SN_f**), but the rest of the pavement structure should be done as a rehabilitation design.

5.5.4 *Preservation*

Preservation projects are not designed to add structure but to extend the life of the pavement. A structural design is not necessary; however, an evaluation of existing condition must be performed to show that the pavement is structurally adequate (For more information see also Chapter 18 – Pavement Preservation Guidelines.

6 Pavement Design Tools and Checklist

6.1 Steps for Pavement Design

Step 1. Obtain the ESALs for the entire design life (see section 4.2 for clarification on this term)

Use the Excel spreadsheet named ESALCALC.xls for the appropriate road functional classification. This can be accessed from the Pavement Design Unit's Website, linked below.

https://www.ct.gov/dot/cwp/view.asp?a=1400&q=534372

If you have more specific site information, you may change the classification percentages for each truck class. For instance, if the percent heavy trucks is significantly different from the defaults, simply adjust the percentages for the ESAL calculations.

ESALCALC is where the traffic growth can be adjusted through the TRAFFIC GROWTH FACTOR (TGF).

Equation 1 is the formula for the TGF (See Reference [AASHTO, (1)] for more information):

Eq. 1

$$\frac{((1+g)^n - 1)}{g} = TGF$$

(Where g is the percent annual growth rate divided by 100 and n is the number of years).

Example, for g = 0.02 and n = 20, the TGF is $((1+0.02)^{20} - 1)/(0.02) = 24.30$

This is automatically calculated in the ESALCALC spreadsheet, you simply have to enter the growth rate in percent, (as in 2 for 2%) and the design life in years.

ESAL factors <u>should not be modified</u> from the defaults.

Step 2. Obtain the required Structural Number for design (SN_f) (future SN)

Guidance is provided in Table 2 below for calculating the structural number of flexible pavements. While the '93 Method can be calculated by hand, there are various web-based tools and the Excel pavement-design files that provide assistance to designers.

Table 2 Suggested Values for Calculating Structural Number (SN) of Flexible Pavements

Input	Description of Value	Tool and/or Default Values
W18 (ESALs)	AADT and % Heavy Trucks (2-axle, 6-tire or greater, including buses)	Use ESALCALC.xls
	Traffic Growth % per year	See Section 4.1.1
	Design Life (Structural)	See Section 4
	Directional distribution	See Section 4.1.1
Roadbed Soil Resilient Modulus (M_R)	Gravels Glacial Till Sands Silts Clays	10,000-12,000 psi 10,000 psi 7,500 – 10,000 psi (Use lower values for “silty” or “clayey” sands) 6,000-7,500 psi* 4,000-6,000 psi* * Consult with Geotechnical Engineer regarding subgrade stabilization requirements.
Overall Standard Deviation	new construction overlays	0.45 0.49
Reliability	Percent reliability of design	90% (95% for Interstates & Expressways)
Design Serviceability Loss (Δ PSI)	Initial Minus Terminal Serviceability	Initial PSI of hot-mix asphalt; 4.2 Terminal PSI (depends on importance of roadway): - higher-functional-class roadways; **Δ=1.7** 2.0 - for secondary roadways; Δ=2.2

Step 3. Calculate the existing effective Structural Number

Calculation of the existing effective structural number **SN_{eff}** is only necessary for rehabilitation (and the existing portion of widening).

SN_{eff} is typically obtained from a pavement condition survey (or remaining service life analysis). This is discussed on Page III-105 of reference [AASHTO, (1)]. The AASHTO suggested layer coefficient ranges are reproduced in Table 3 below. Remaining service life calculation is not recommended unless, per the judgment of the pavement designer, because this analysis discounts “survivor” pavements (those that have outlasted past ESAL accumulated loadings). The methodology is on Page III-107 of reference [AASHTO, (1)].

Any layers to be milled should be removed from the **SN_{eff}** calculation.

Table 3 Suggested Layer Coefficients for Calculating Effective Structural Number (SNeff)

Material	**Surface Condition**	**Coefficient Range**
AC Surface	Little or no alligator cracking and/or only low-severity transverse cracking	0.35 – 0.40 per inch
	< 10% low-severity alligator cracking and/or <5% medium- and high- severity transverse cracking	0.25 – 0.35 per inch
	> 10% low-severity alligator cracking and/or < 10% medium-severity alligator cracking and/or > 5-10% medium- and high- severity transverse cracking	0.20 – 0.30 per inch
	> 10% medium-severity alligator cracking and/or < 10% high-severity alligator cracking and/or > 5-10% medium- and high- severity transverse cracking	0.14 – 0.20 per inch
	10% high-severity alligator cracking and/or > 10% high- severity transverse cracking	0.08 – 0.15 per inch
Stabilized Base (includes Bituminous Concrete)	Little or no alligator cracking and/or only low-severity transverse cracking	0.20 – 0.35 per inch
	< 10% low-severity alligator cracking and/or < 5% medium- and high- severity transverse cracking	0.15 – 0.25 per inch
	> 10% low-severity alligator cracking and/or < 10% medium-severity alligator cracking and/or > 5-10% medium- and high- severity transverse cracking	0.15 – 0.20 per inch
	> 10% medium-severity alligator cracking and/or < 10% high-severity alligator cracking and/or > 5-10% medium- and high- severity transverse cracking	0.10 – 0.20 per inch
	10% high-severity alligator cracking and/or > 10% high- severity transverse cracking	0.08 – 0.15 per inch
Granular Base or Subbase	No evidence of pumping, degradation, or contamination by fines	0.10 – 0.14 per inch

Material	Surface Condition	Coefficient Range
	Some evidence of pumping, degradation, or contamination by fines	0.00 – 0.10 per inch

Step 4. Calculate the SN

The SN for any combination of lifts is determined with a design equation, the layer coefficients and the proposed thickness of each lift. Alternate designs can be prepared by varying the thickness. The computed SN should equal or exceed the required SN determined from the nomographs in the AASHTO Guide.

For new/widened/reconstructed pavements, Use Equation 2 to calculate the SN:

Eq. 2

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \cdots + a_i D_i m_i$$

where the $a's$ are layer coefficients representative of surface, base, and subbase lifts,

D is the actual thicknesses (in inches) of surface, base, and subbase lifts, respectively, and

$m's$ are drainage coefficients for (granular) base and subbase layers, respectively.

(Use m_i = 1 unless you have site-specific information that can be used for Table 2.4 in the 1993 AASHTO guide, page II-25, which is reproduced below as Table 4).

The layer coefficient expresses the empirical relationship between the SN and the thickness of a given material, which allows each layer to be summed into a single, homogeneous layer for the calculation of the SN. To determine the thickness required for a flexible pavement, the total structural number (SN) for a given roadbed soil condition is computed. Then, the structural numbers for the subbase and the base layers are determined. Using the differences between these values, the maximum thickness of any layer can be computed. This is often an iterative process when performed manually.

Layer coefficients per 1 in. [25 mm] of material have been established for various types and classes of flexible pavement, base course, and subbase. The suggested layer coefficients (‘a’ in equation 2) for new materials used in Connecticut are given in Table 4.

Table 4 Suggested Layer Coefficients (a_i) for New Structures

Material Type	Layer Coefficient (per inch)
Bituminous Top Course (First 3 to 4 inches)	0.44
Bituminous Base Course (remainder of bound pavement layer)	0.34
Processed Aggregate Base	0.14
Subbase	0.11
Subgrade	Not Applicable

Do not assign layer coefficients to existing subgrade.

For rehabilitation designs Use Equation 3 to calculate the SN:

Eq. 3

$$SN_{des} = SN_{eff} + SN_{ol} \geq SN_{Req'd}$$

Where:

SN_f = The structural number required for future traffic loading

SN_{eff} = Existing pavement structural number.

SN_{ol} = The structural number necessary to be gained by overlay "ol." This is the difference between the existing pavement and that structural needs of the future pavement design. This is the amount of pavement structure that needs to be added with an overlay.

The SN_{ol} is determined by summing the combination of layer coefficients (a's) and thicknesses (D's) of the proposed overlay, in a similar fashion to the new/widened/reconstructed pavement calculation.

6.2 Other structural design considerations

6.2.1 *Drainage*

In areas of rock cut water must travel a longer path to leave the engineered pavement structure. CTDOT typically increases the depth of granular subbase (Subbase or Processed Aggregate Base) by a minimum of 8 inches (providing at least 18"), and often recommends underdrains.

6.2.2 *Frost protection*

The total depth of the pavement structure (including hot-mix-asphalt and granular layers, including subbase) used for CT DOT-Maintained roads is a minimum of 19 in., which is roughly 50%

protection (this strikes a balance between cost-effectiveness and durability). The designer should consider subsurface information and historical pavement performance in accordance with section 4.1.4 of this manual.

Reflective Cracking

When considering rehabilitation, some pavements may be structurally adequate ($\mathbf{SN_{ol}} \leq 0$) but require repair of cracks; some measures include milling, cold-in-place recycling, and hot-in-place recycling. Reflection cracking in AC overlays of AC/JRCP or AC/CRCP are usually the result of strain concentration in the overlay due to movement in the vicinity of joints or cracks. This situation may require pre-overlay repairs, including full-depth repairs, partial-depth repairs, sublayer crack repair, and/or the use of an increased overlay thickness. The subsequent chapter covers this in greater detail.

6.2.3 *Shoulder Design*

The inclusion of a shoulder adjacent to the main pavement structure improves pavement performance. The 1993 AASHTO guide does not provide a design method for determining the shoulder section. However, the shoulder should be compatible with the proposed mainline pavement section, have good constructability and be shown to have performed well in the past as well as the ability to sustain [prolonged] temporary traffic loads during construction. For rehabilitation, if the initial shoulder pavement design was not compatible with the mainline pavement structure, it may be a major contributor to its failure. Two of the most common problems which occur are lane/shoulder joint separation which allows water into the subbase, and blockage of water draining out of the mainline subbase which is usually more granular and of higher quality. The material used in shoulder construction also may be of a different thickness. CTDOT has used a rule of thumb for many existing shoulder pavements of a 6 in. minimum bituminous thickness, in good condition, to support short term traffic loading. An optional strategy to consider is to cross check the 6 in. minimum thickness with a shoulder designed to carry 10 percent of the projected Average Daily Traffic (ADT).

7 Minor and Major Rehabilitation for Flexible Pavements

7.1 Introduction

Much of the pavement improvement activity that occurs within Connecticut involves pavement overlays. Overlaying [Resurfacing] can be implemented to correct many minor distresses and provide additional strength to an existing pavement structure. In many cases, this treatment will involve pavement removal by milling. Guidelines on best practices for milling and resurfacing of bituminous-concrete pavements are presented below. It is noteworthy that any increase in the overall pavement thickness constitutes a structural overlay and has implications regarding roadway geometry (profile, grade, height of curbs, traffic signs, guardrail, etc.) that must be vetted beyond the pavement structural performance.

According to the 1993 AASHTO Guide, overlay designs require consideration of items such as pre-overlay repairs, control of reflection cracks, traffic loadings, subdrainage, milling needs, recycling of existing materials, structural adequacy, presence and severity of rutting in existing structure, and possibly other considerations depending upon the specific project.

Note that the design of flexible pavements in this section of the handbook only considers the use of dense-graded bituminous concrete in the Superpave mix-design system. Specialized mixes such as Stone Matrix Asphalts (SMAs), Open-Graded Friction Courses (OGFC), and ultra-thin hot mix wearing course mixes, as well as other preservation treatments are covered elsewhere and would require alternative/customized layer coefficients that are often research-grade and require validation from CTDOT personnel.

7.2 Structural Overlays

If it has been determined that a pavement is failing structurally, this means that the deterioration from accumulated traffic loadings is the main contributor to the poor condition of the pavement. If feasible the overlay applicable to a rehabilitation would then be classified as a "structural overlay." The milling-depth and overlay-thickness determination should follow a pavement evaluation and design process found elsewhere in this handbook. In many cases, if a pavement is already exhibiting structural cracking, an overlay would only be considered a stop-gap measure until full-depth repair could be carried out. This is due to the fact that load-related distresses manifest from the bottom of a layer, and therefore can only truly be repaired if the entire cracked portion of pavement is removed/replaced. Alternatively, before a pavement exhibits structural distresses, revisions to traffic forecasts or changes in AADT may serve as justifications for structural overlays. The previous chapter outlines the procedure for calculating the difference in thickness for an existing structure compared to the required thickness

7.3 Functional Pavement Overlays

In many cases, structural capacity of the existing pavement is not the cause of the distresses, and the overall thickness of the structure has been determined to be adequate, but the pavement surface has failed in its "functionality," leading to unsatisfactory serviceability. This is typically referred to as a functional failure. *Functionality* relates to the performance of the surface layer itself and includes resistance to top-course rutting (by using the Superpave design method), surface texture and skid resistance (through mix selection).

7.4 Rationale for Milling a Pavement

Milling is usually performed because the existing bituminous concrete on a roadway is deemed to be deficient in some way. Other deficiencies that could be mitigated via milling include improving roadway smoothness, improving skid resistance, and preserving existing roadway curbside elevations (when combined with an overlay).

The depth of milling is determined based on the scope of work and the composition of the existing pavement layers but under normal circumstances, ranges from 0.5" to 3.0". If the scope of work is to rehabilitate the existing roadway pavement because it has deteriorated to an overall poor condition, the depth will be dependent on condition at depth, i.e. distressed interlayers will adversely impact the life of any new material placed above. If the principal mode of failure is thermal cracking (surface-originated cracking), the depth of milling to be performed is dependent on how wide the cracks are and how deep they extend down into the pavement layers. If pavement friction is the mode of failure, but there are no other problems with the surface course, then micro-milling with no overlay (or an ultra-thin overlay) could be determined as an appropriate fix. In this case, the depth of milling could be as shallow as ½ inch. In summary, the milling determination and the milling-depth determination should be the outcome of an evaluation of existing pavement and site conditions. When funding and site conditions permit, milling should be employed due to the increased interlayer bond strength created by a milled interface. Additional potential benefits of a milled surface include the elimination of existing lane striping and/or roadway contaminants, and the increased macro-texture available for interlayer bonding of the new surface treatment.

Milling machines are destructive and can do a lot of damage if not maintained or used properly; consequently, good milling specifications are critical. Specifying proper surface texture, surface tolerances, and slope and grade controls are among the more important aspects of a sound specification.

7.5 Types of Milling

There are three categories of milling commonly available for use in CTDOT projects discussed in the table below. However, for best results, the vast majority of mill-and-functional overlay applications should strive to use fine milling.

Table 5 Types of Milling used on CTDOT Projects

Milling Type	Depth (inches)	Uses	Comments
Milling	3-8	Structural overlays, deep rehabilitation	This may also be referred to as "general milling"; if milling depth is three (3) inches or less, fine milling is preferable although general milling can be done at lower depths in certain circumstances.
Fine Milling	0.5-3	Functional and structural overlays	Typical fine-milling depth is 1 to 3 inches; it can be used down to 0.5 inches for specific locations within a project where fine milling is the main milling technique used and it would be more costly or inconvenient to specify micro milling; in these cases the maximum milling speed may have to be limited on critical applications (such as on certain bridge decks) – a separate specification (project-specific special provision, or note on the plans) may be required to accomplish this. If a fine milled surface is desired for construction staging, but the project requires milling in excess of 3 inches, fine milling can still be used but must be estimated in two passes which may be costly.
Micro-milling	0-1	Preparing for ultra-thin surfacing; Minor cross slope adjustments or improvements prior placement of an overlay; Short-term (temporary) improvement of friction; Milling	Typical use is 5/8 in. micro milling; achieving more than 1.0 in. of depth typically requires two passes (this depth should only be used for bridges or specific locations within a project where micro milling is the major milling technique specified and including a second (fine milling) would be more costly because of the limited quantity of milling > 1.0 in. required)
Diamond Grinding (PCC Only)	0-0.5	Highly Specialized Applications. Re-profiling for short-term improvement in smoothness and/or friction	Should only be used when project-specific conditions warrant its use based on engineering analysis. Diamond grinding is typically used for rigid concrete pavements to improve ride.

7.6 Other Milling Considerations

Cleanliness and proper tack coating of the surface (milled or otherwise), prior to resurfacing, are key factors for producing a quality resurfacing project. If the milled surface is dirty and/or tacked improperly, the bond between the overlay and the milled surface will be less than optimal, and a reduction in pavement surface life can be expected. To minimize strain in the independent pavement layers, it is critical that they be properly adhered together to resist traffic loading.

Requirements for sweeping can be found in the current milling specification. Tack coat requirements can be found in the Department's Standard Specifications for Roads and Bridges.

Please note that the presence of underlying Portland-cement concrete (PCC) does not preclude the use of functional overlays; for existing composite pavements the milling takes place in the existing bituminous concrete layers only and the paving is with bituminous concrete.

Pavement surface courses that have deteriorated to a poor condition should be completely removed. Significant amounts of cracking, raveling, and potholing are indications of this. These failures indicate that the existing pavement surface has lost its ability to withstand environmental- (rain, snow, freeze/thaw) or traffic-applied loads. Rapid degradation is often imminent. Should this layer remain in place and be overlaid, it would cripple the performance of the overall structure. The thickness of this deteriorated layer of pavement must be determined so that it can be completely removed. Failure to remove the entire surface layer may result in "scabbing" of the milled surface in which portions of the poor surface layer remain adhered to the underlying pavement layer in "raised patches." The poor-quality material left behind on the milled surface is likely to cause an inadequate bond of the newly placed pavement surface to the existing milled surface upon which it is placed. The irregular surface resulting from scabbing will also result in a highly variable overlay thickness, negatively affecting compaction and ultimately the life cycle of the new surface. For these reasons, scabbing should be avoided. Increasing the milling depth slightly can help eliminate it.

Any irregular or deteriorated surface on which an overlay is placed will detract from the smoothness and longevity of the overlay. If it is suspected that pavement layers below the surface are in poor condition such that it will result in a poor milled surface on which the overlay will be placed, methods such as reviewing old highway photolog images, pavement coring, or test milling can be employed to gather information for determining whether to increase the depth of milling to include removal of additional pavement structure layers.

Pavement condition is what typically controls the depth of milling. When considering the depth of milling, designers must also balance the thickness of the overlay. Experience has shown that many pavements require only 1.5 to 2.0 inches of milling. For an 'inlay' scenario in which the mill depth matches the overlay depth, this would warrant a single-lift overlay. When placing single-lift overlays on a milled surface, it is important to use the proper bituminous-concrete mix at the proper thickness.

Roadway type, or classification, can also influence milling depth. On high-speed roadways, smoothness is one of the most important characteristics. In order to achieve optimum smoothness, an overlay consisting of two lifts of hot mix asphalt should be used. In such cases, the milling depth may be to accommodate the combined thickness of a two-lift overlay. Overlays consisting of two lifts should also be used on lower- volume/speed roadways where the resulting milled surface is in a poorer condition. When placing functional two-lift overlays, the first lift is commonly referred to as a leveling course. Leveling courses are intended to fill irregularities, improve profile and increase the smoothness of roadways.

Table 1 Examples of Functional One-Lift Overlays with Milling

Mix	Milling and Paving Depth (inches)**	Type of Milling	Comments
HMA or PMA S0.25	1.0 to < 1.25	Fine milling	Not for roadways with skid-resistance issues due to geometry or roadways with posted speed limits > 45 mph
HMA or PMA S0.375	1.25 to < 2	Fine milling	Higher-speed roadways (>45 mph) may require "coarse" 0.375 mixes (a subset of 0.375-inch mixes that are difficult to specify)
HMA or PMA S0.5	2 – 2.5	Fine milling	Most applications of single-lift functional overlays with milling will use this combination; This mix may be necessary at less than 2 inches (1.5 inch minimum) on bridges with significant grades or horizontal curves, or on high-speed pavements (50-mph posted speed limit or higher)

Fine milling can be used for specific locations if the main milling item being used for other purposes is Fine Milling.

*** Milling depth could be lower (as little as 0.5 inches or less in project-specific applications) depending on function of milling for the project. Lifts greater than 2.0 inches would not be typically specified for milling depths that are lower than the paving lift (i.e. there is no need to pave thicker than the recommended lift thickness for S0.5, which is 2.0 inches, unless it is necessary to regain the surface elevation of the existing pavement.)*

7.7 Compacted Lift Thickness

The recommended lift thicknesses listed in this document refer to the thickness of the mix after placement and compaction. This is the value used by designers and pavement engineers to specify pavement layer thickness and for Construction engineers to measure as-built thickness. Mixes with finer gradations are ideal for placement on a milled surface for leveling, specifically HMA (or PMA) S0.25 and HMA (or PMA) S0.375 (see section 7.5). Their smaller maximum aggregate size permits greater interlock with increased interlayer surface area, filling the textured surface more effectively than a coarser mix. Furthermore, the higher asphalt contents associated with finer mixes likely contribute to their bond to a milled surface more effectively and make them generally less susceptible to water infiltration. These mixes can also be placed in thinner lifts, which is desirable when placing functional overlays. Minimum lift thicknesses should be at least three times the nominal maximum aggregate size of the mix. Placing a two-lift overlay with coarser mixes requires thicker lifts; for functional overlays, the same degree of smoothness and durability can be achieved for less money by utilizing a finer mix placed in a thinner lift as a leveling course.

8 Asphalt Concrete Pavement Mix Selection Guidelines

8.1 Introduction

Asphalt [Bituminous] Concrete Pavement (ACP) (often referred to as Hot-Mix Asphalt, or Bituminous Concrete) consists of a mixture of performance graded (PG) asphalt binder and aggregates with gradations ranging from coarse to very fine particles. The aggregate may be treated, (for example to prevent stripping) and the binder may be modified (for example with polymers to improve performance across a variety of temperatures). ACP can also be manufactured from new or recycled (or a combination of both) materials.

8.2 Asphalt Binder Selection

Asphalt Concrete Pavement is comprised primarily of stone and sand, the binding agent, however, is Liquid petroleum asphalt, a natural derivative of crude oil. Asphalt binder chemically consists of long hydrocarbon chains (Asphaltenes, Oils, and Resins), and these constituent chemicals vary by crude oil source and distillation type, resulting in variable material characteristics. The material itself is described as *viscoelastic*, meaning it can behave as a fluid through to an elastic solid across a temperature range. As practitioners prescribing this material, it is important to understand how an asphalt is 'graded' [characterized] to ensure the construction material is suitable for the given traffic and environmental loading parameters. Asphalt binders are thus characterized by their physical properties across a temperature spectrum with a variety of mechanical load/response instruments. Binder tests and specifications have been developed to accurately characterize temperature extremes that pavements in the field are expected to withstand. These tests and specifications (AASHTO M320 and M332) are specifically designed to address three specific pavement distress modes: permanent deformation (rutting), fatigue cracking, and low temperature cracking.

Asphalt Binder can be delivered to a mix producer as an unmodified (a.k.a virgin or neat) or modified. Unmodified binders are straight-run liquids from a petroleum refiner and have a smaller user temperature band as compared to a modified liquid. Several modifiers and their purpose are identified in the table below. Each modifier has cost and production implications that should be weighed by the designer prior to implementation.

Table 2 Typical Asphalt Binder Modifiers

Modifier Family	Examples of Material	Purpose
Mineral	Hydrated Lime	Anti-Strip
Liquid Mineral	Polyphosphoric Acid[1.]	Low-Temperature strength, anti-strip
Polymer	Styrene-Butadiene-Styrene Styrene-Butadiene Rubber[1.] Elvaloy RET[1.]	High-Temperature Performance High/Low Temp. Performance High-Temperature Performance
Liquid Anti-Strip		Anti-Strip
Warm Mix	See Associated Chapter	
Crumb Rubber	High-Temperature Strength	

1. *Not permitted for use in accordance with CT DOT M.04.01 specifications*

Performance Graded (PG) asphalt binders meet expected physical test thresholds for a given climatic condition. The PG system uses a common set of tests to quantify physical properties of the binder. AASHTO M332 is the accepted standard for characterization by CT DOT. It outlines how an asphalt binder achieves a temperature rating.

The first value in a PG binder rating is the high-temperature grade. This is reference to the average 7-day maximum pavement temperature ¾ of an inch below the surface. Separately, the last value refers to the low temperature limit of the binder. This refers to a single-day pavement temperature minimum also ¾ of an inch below the surface. Both values are in degrees Celsius. Finally, the letter identifier in the middle of the grade refers to a binder's elasticity– or the ability to return to its original state after a shear load is applied at high-end temperatures. The alphabetic designator and its corresponding traffic equivalency is given in Table 8.

Table 3 Alphabetic Designators for Creep Compliance (AASHTO M332)

Designator	Traffic Loading Category	kPa^{-1}[AASHTO T350]
S	Standard	≤ 4.5
H	Heavy*	≤ 2.0
V	Very Heavy*	≤ 1.0
E	Extremely Heavy	≤ 0.5

**Not typically used by CT DOT*

The actual creep recovery test (AASHTO T350) repeatedly applies a fixed stress to a sample in a dynamic shear rheometer for 1 second followed by a 9-second recovery period. This is repeated 10 times at two different applied stress levels. For each cycle, the strain of the sample is measured before and after the stress/recovery period; the change in strain is the non-recoverable creep.

Within Connecticut, a PG 64-22 is used for all state flexible pavements, with the associated letter (S, or E) depending on traffic levels and application (e.g. 64E-22). For many years, conventional/neat (unmodified) binder had been predominant for most applications in Connecticut. Modified binder can provide improved performance and durability for sensitive climate conditions. For example, improved resistance to rutting, thermal cracking, fatigue damage, stripping, and temperature susceptibility have led polymer modified binders to be substituted for conventional asphalt in many paving and maintenance applications.

8.3 Polymer Modified Asphalt – PMA

Polymer is a technical word for plastic. Polymers are homogeneous chemicals with uniform strength and stiffness characteristics throughout a variety of temperature ranges (i.e. formulated to improve rutting resistance/high-temperature versus cracking resistance/low-temperature). When the right polymer, at the right amount, is added to an asphalt binder, it can greatly enhance the properties of the asphalt binder without any detrimental effect to any other performance characteristic. NCHRP Report 459, "Characterization of Modified Asphalt Binders in Superpave Mix Design," provides further detail on the types of polymer modification and the various effects they have on asphalt binder.

Higher volume roadways need to accommodate more trucks and other heavy vehicles and could be susceptible to rutting during the hot summer months. Asphalt softens with increases in temperature. It is when temperatures are hottest and traffic is the heaviest that asphalt pavements are most vulnerable to deformation – (flushing, bleeding, rutting, and shoving). There are two ways to stiffen bituminous concrete – make the aggregate interlock stronger and/or stiffen the binder properties at higher temperatures.

CT DOT has adopted the use of PMA for all interstate roadway resurfacing, as well as for any rut prone section of the roadway. For such roadway sections, specifying Traffic Level 3 Superpave Polymer Modified Asphalt (64E-22) provides the greatest level of rut resistance. Beginning in 2019, CTDOT simplified the asphalt concrete pavement mixes in use to those displayed in Table 9.

Table 9. CTDOT Superpave Mixes and Traffic Levels

Traffic Level	Design ESALs (millions)
1*	< 0.3
2	0.3 to < 3.0
3	≥ 3.0

*NOTE: Level 1 for use by Towns and Municipalities only

All Level 3 mixes that are used in Connecticut contain polymer.

Adding polymer can increase the overall durability of any bituminous concrete and can help resist cracking and raveling/disintegration of any type of Superpave bituminous concrete. Using polymer modification for enhanced durability and cracking resistance should be evaluated on a case by case (project by project) basis. Note that polymer can make the mix sticky and cause hand placement to be difficult. It is not appropriate for pothole patching or most trenches for this reason. Due to the increased stiffness of polymer mixes, the CTDOT material specification currently requires the addition of a warm-mix additive to any polymer-modified asphalt concrete pavements.

If polymer modification of asphalt concrete pavement is determined to be appropriate for a particular project, it should be specified, measured, and paid for under the appropriate "PMA" item. All PMA specification requirements can be found in the most recent version of the CTDOT Standard Section 4.06 - Bituminous Concrete.

8.4 Warm Mix Asphalt

Warm mix asphalt, also known as WMA, is a term/title describing a technology used to reduce the production and placement temperatures of bituminous concrete. This is generally accomplished with one of three different families of products: organic (waxes), chemical, or water-based foaming products ([25] NCHRP Research Report 843). Warm mix modification aims at changing the viscosity characteristics of the binder or acts as a lubricant only in the production and placement range of temperatures, while not affecting the final ambient temperature performance characteristics of the in-place asphalt mixture. Currently, the Northeast Asphalt User-Producer Group maintains a list of qualified modifiers. This list can be accessed at the NEAUPG website:

https://neaupg.engr.uconn.edu/welcome-to-the-neaupg-website/warm-mix-asphalt-wma-information/

Current warm mix technologies typically reduce the production and placement temperatures of bituminous concrete by 40-85° F. In general, Superpave mixes are produced in the 300 - 325° F range with compaction primarily achieved in the 300 - 250° F range. Warm mix technology offers the ability to shift these ranges to 250 - 275° F and 250 - 200° F, respectively.

A 40-85° F reduction in temperature for both the production and placement phases can have several positive effects on the entire bituminous concrete operation. Some of the benefits include: lower production costs; possible increase in the ability to achieve compaction; reduction in environmental impacts; and increased worker safety. Because of these positive impacts, an increase in the use of WMA has been experienced both in Connecticut and nationally in the last decade. The user should consult Table M.04.03-4 in CTDOT Form 817 for mixture production temperature requirements for use with WMA.

The use of WMA additives is an option for all Superpave mixtures. Both HMA and PMA can utilize a WMA additive. Currently, the decision to use WMA additives is made by the Contractor at his discretion unless PMA is being utilized at which point a WMA technology is required. There will be no separate item or payment made for the use of WMA. The cost (or savings) shall be included in the general cost of the HMA or PMA item. If a WMA additive is used with HMA or PMA it shall be included in the submissions required for the "Job Mix Formula" (JMF) and

"Contractor Quality Control (QC) Requirements for Placement," and subject to the same approvals from CTDOT Division of Materials as conventional HMA.

8.5 Superpave Asphalt Concrete Mix Selection

The Superpave mix design method was an outcome of the Strategic Highway Research Program (SHRP) study performed during the 1990's. Older design methodologies such as Hveem and Marshall Methods are no longer supported by CTDOT. The Superpave system ties asphalt binder and aggregate selection into the mix design process, and considers traffic and climate, as well. The resultant dense graded Superpave mixes contain a uniform distribution of aggregate sizes along the maximum density line. These mixes can be "fine" or "coarse" graded depending on whether the aggregate gradations are above or below the maximum density line. Superpave mixes are identified (named) using the Nominal Maximum Aggregate Size (NMAS). The NMAS is defined as one sieve size larger than the first sieve to retain more than 10% of the particles in a given blend. Typical uses of Connecticut's various mixes are described below.

8.5.1 *HMA S0.25 (1/4-inch Superpave mix)*

Ideal for leveling of deteriorated and raveled surfaces, milled surfaces, or repaired concrete surfaces prior to overlay. It should not be used as a surface course on wet weather/skid sensitive roadways. This mix is also good for a first lift overlay of many bridge membrane systems, and is the surface course of choice for walkways, bikeways, and sport courts.

8.5.2 *HMA S0.375 (3/8-inch Superpave mix)*

This mix can be used for leveling of deteriorated and raveled surfaces, milled surfaces, or repaired concrete surfaces. It is ideal as a surface course for most local roads and many secondary roadways with speed limits less than 50 mph. It is the preferred mix for patching small areas that require a lot of handwork. It is also good for short-term or temporary thin lift maintenance overlays of any roadway. HMA S0.375 may be acceptable for some limited access highways and interstates depending on surface texture and wet weather/skid sensitive pavement needs. This is the mix of choice for driveways and parking lots and is the most versatile mix for wedge course applications.

8.5.3 *HMA S0.5 – (1/2-inch Superpave mix)*

HMA S0.5 is the most versatile and widely used bituminous concrete mix. It is ideal as a surface course and intermediate course for all types of roadways. This mix is the primary surface for most interstates, limited access, and other higher volume roadways, and can also be used for some wedge course applications.

8.5.4 *HMA S1 – (1- inch Superpave mix)*

This mix is used as the primary base/binder course mix. It may not be suitable as a riding surface due to its larger aggregate size, and therefore may be required to be covered with a Superpave mix of smaller maximum aggregate size, typically one or two lifts/courses of

HMA S0.375 or HMA S0.5 mixes. This mix is usually placed on bank run or crushed subbase/base and can be used in thicker filling/wedging applications.

8.6 Polymer Modified Asphalt Concrete Mixes

In general, polymer modified asphalt (PMA) mixes follow all of the same usage guidelines as their HMA Superpave counterparts. However, because they're modified with polymer, they provide increased durability and rut resistance. There are two main reasons to specify a PMA mix instead of the standard HMA mix item: 1) to increase mix stability and resistance to rutting: 2) to increase the overall durability (resistance to raveling and cracking.) Adding polymer increases the bituminous concrete's stiffness at elevated temperatures and may increase its elasticity at lower temperatures. Polymer modification generally increases the cost of the mix, but it can also increase the lifespan.

8.6.1 *PMA S0.25 – (1/4-inch polymer modified mix)*

This mix may be used as a binder course on rut sensitive roadways to support a thin or ultra-thin surface treatment.

8.6.2 *PMA S0.375 – (3/8-inch polymer modified mix)*

This mix can be used as a surface lift for secondary and local roadways where increased durability or strength, and resistance to rutting or cracking are warranted. It may be used as a binder course on high volume or rut sensitive roadways to support the placement of a thin or ultra-thin surface treatment.

8.6.3 *PMA S0.5 – (1/2-inch polymer modified mix)*

PMA S0.5 is a mix primarily used for the surface lift of high volume limited-access roadways where increased durability and longer surface life is desired. The mix can also be used as a surface for roadways subjected to heavy loads (trucks, buses, or specialized vehicles) where increased mix stiffness to guard against rutting is warranted. It can also be used anywhere an increase in strength, durability, and resistance to cracking is needed. It may be used as a binder course on high volume or rut sensitive roadways to support a thin or ultra-thin surface treatment.

8.6.4 *PMA S1.0 – (1-inch polymer modified mix)*

This mix may be used as a high strength/high resiliency base course for high volume or heavily loaded roadways.

NOTE: LEVEL 3 Mixes **shall be** polymer modified.

9 Guidelines for Superpave Bituminous Concrete Mixes

9.1 Superpave Traffic Level Rationale

For each nominal maximum aggregate size, the Superpave design method contemplates four traffic design levels, which are based on the accumulated traffic to which they will be subjected over their in-service life. The accumulated traffic in the Superpave design method is characterized by standardizing the axle loads into an equivalent number of repetitions of a single, 18-kip reference axle.

(Note: The state of the art in traffic characterization for pavement design is to consider "load spectra" instead of ESALs to measure the cumulative effect of traffic loadings on a pavement structure. This is currently only used with the AASHTO Mechanistic Empirical Pavement Design Guide (M-EPDG). Should this level of traffic loading be provided, it can be converted to ESALs.)

CTDOT has reduced the number of Superpave traffic levels needed for the state roadway system to two – Traffic Level 2 and Traffic Level 3. Traffic Level 4 mix design requirements were eliminated due to low demand for these mixes on the state roadway system (See State Specification Section M.04.2). There may be certain applications where it may be beneficial to use polymer modification for Levels 1 and 2, but it is required for all Level 3 mixes. When a polymer is added, the bituminous concrete shall be designated as Polymer Modified Asphalt (PMA) and should be specified, measured, and paid for under the appropriate PMA item.

The Traffic Level 1 Superpave mix is not used on roadways maintained by CTDOT. This traffic level is maintained in DOT specifications for use on municipal roadways only.

9.2 Thickness Guidelines for Superpave Bituminous Concrete Mixes

Below are recommended compacted lift thicknesses for Superpave bituminous concrete mixes. These recommended lift thicknesses apply to both unmodified Hot Mix Asphalt (HMA)] and modified [Polymer Modified Asphalt (PMA)] Superpave bituminous concrete mixes.

Table 10 Typical Compacted Lift Thicknesses for Superpave Bituminous Concrete Mixes

Traffic Level **(See Notes 1, 2, 3, 4, 5)**	**Minimum Lift Thickness (inches)**	**Maximum Lift Thickness (inches)**	**Typical Lift Thickness (inches)**
HMA and PMA S0.25*			
Level 2	0.75	1.25	1.0
Level 3*	0.75	1.25	1.0
HMA and PMA S0.375**			
Level 2	1.25	2.0	1.5
Level 3	1.25	2.0	1.5
HMA and PMA S0.5***			
Level 2	2.0	3.0	2.0
Level 3	2.0	3.0	2.0
HMA and PMA S1****			
Level 2	3.0	5.0	3.0 to 4.0
Level 3	3.0	5.0	3.0 to 4.0

**HMA/PMA S0.25, Level 3 should only be specified when approved for use by the Pavement Design Unit. Use "Level 2" in all cases unless otherwise specified.*

*** Surface lift minimum lift thickness on bridges for HMA/PMA S0.375 = 1.5 inches*

**** Surface lift maximum lift thickness on bridges for HMA/PMA S0.5= 2.5 inches; top lift of 1.5 inches for HMA/PMA S0.5 may be considered in certain extenuating circumstances (for friction- or texture-sensitive areas, i.e. steep grade, curve, posted speed limit >= 50 mph)*

***** HMA/PMA S1 is not to be used for the surface lift.*

Note 1: Mix designations are composed of three elements: the mix design method, the nominal maximum aggregate size in the mixture, and the design level based on the accumulated traffic loading to which the material will be subjected. Example: "HMA S1.0 – Traffic Level 3" represents a hot mix asphalt mix designed in the Superpave system (S), with a nominal maximum aggregate size of 1.0 inch, designed for Level 3 traffic.

Note 2: If a design level is not shown in Table 10 above, it is generally not approved for use on state roadways and facilities.

Note 3: Lower design level mixes can be used on higher level roadways as long as the mix is not being used as a permanent surface course. For example, an HMA S0.25– Design Level 2 could be used on a Level 3 roadway as a thin lift maintenance overlay or as a leveling course that would be covered with a Level 3 permanent surface course.

Note 4: Placement of lifts outside these guidelines incurs a significantly greater risk of early in-service failure and is therefore not recommended. Lift thicknesses above and below the recommended ranges present compaction, workmanship, durability, and rideability challenges that may result in roughness, raveling, rutting, or delamination failures. These failures could occur within a short period of time. Surface or wearing courses should never be placed outside of the recommended thickness tolerances above.

Note 5: For shim or wedge courses, e.g. to develop the proper cross-slope and grade, lift thicknesses may be allowed to fall outside of the tolerances recommended above. Recommendations for such placement can be found below in Guidelines for [Shim] Wedge Courses.

10 Guidelines for [Shim] Wedge Courses

10.1 Introduction

Shim/Wedge courses are defined as those that have a cross-section approximating a triangle (or have a distinct elevation difference from one side of the cross-section to the other, with a "trapezoidal" cross-section), with one end approaching zero inches and the other end being placed as thick as the particular mix allows, in order to develop an elevation difference in the cross-section. The table below presents wedging lift-thickness practical limits.

Table 11 Wedging Lift thickness Practical Limits

Mix Designation (See Note 1)	Maximum Lift Thickness in Wedging (inches)	Minimum Lift Thickness in Wedging (inches)
HMA/PMA S0.25	1.5	0.0
HMA/PMA S0.375	2.5	0.5
HMA/PMA S0.5	3.5	1.0
HMA/PMA S1	6.0	2.0

Note 1: End wedge at a minimum distance of:

One (1) foot from the minimum-thickness edge (or thin edge of following wedging lift) for HMA S0.25 and HMA S0.375 wedges

Two (2) feet from minimum-thickness edge (or thin edge of following wedging lift) for HMA S0.5 wedges, and

Three (3) feet from minimum-thickness edge (or thin edge of following wedging lift) for HMA S1 wedges.

Note 2: Wedge courses should be covered by a uniform 2-inch pavement thickness from curb-to-curb without exception.

10.2 Compacted Lift Thickness

As noted previously, the lift thicknesses described throughout this document refer to the thickness of the mix after placement and compaction. This is the value used by designers and pavement engineers to specify pavement lift thickness and for Construction engineers to measure as-built thicknesses. (Individuals who have to address the actual placement of the mix may make use of the "rule of thumb" that uncompacted mix placed by a paver is generally ¼ inch higher per inch of compacted thickness desired. For example, to achieve a 2-inch compacted lift thickness, the uncompacted thickness should be approximately 2-1/2 inches.)

11 Considerations for Construction of Bituminous Concrete Overlays for Bridge Decks -- Background

11.1 Introduction

The CTDOT has a standard practice to protect the condition of its bridge decks with one of several waterproofing membrane systems, and to place a bituminous concrete riding surface over the membrane. The current standard practice is to place a 3-inch bituminous concrete overlay atop the waterproofing membrane. This standard practice should be followed unless there are extenuating circumstances as discussed in the remainder of this section.

11.2 General Considerations

The general design considerations and constraints for placing a bridge deck overlay can be categorized into major topics according to the purpose and the constructability of the proposed bituminous concrete pavement structure, which are as follows:

11.2.1 *Protecting the waterproofing membrane over the bridge deck*

Use the smallest aggregate size mix and minimum lift thickness to pave the first lift of bituminous concrete over the waterproofing membrane. Accordingly, CTDOT's standard practice is to use a 1-inch HMA S0.25 lift over the waterproofing membrane on bridge deck overlays.

The 1-inch lift thickness reduces the heat transfer to the underlying membrane and the chance of re-liquefying or re-melting the membrane, thus creating a slippage plane for the initial lift of the overlay. This concern primarily applies to bridges that utilize a woven glass fabric waterproofing membrane. Recently, the CTDOT has moved to using mostly spray-applied cold liquid elastomeric waterproofing membranes to protect bridge decks, which are not at risk of re-melting during paving. Bridge designers are responsible for which type of waterproofing membrane system to incorporate.

In order to satisfy other design constraints, it may not be feasible or necessary to place the recommended 1-inch HMA S0.25 as the bottom lift of the overlay in every situation. If the selected membrane type is not susceptible to the issues outlined above, the following alternatives are acceptable:

- The lift thickness of HMA S0.25 may be altered to a minimum of 0.75 inches or a maximum of 1.25 inches.
- The mix can be changed to HMA/PMA S0.375 with a recommended lift thickness of 1.5 inches (minimum of 1.25 inches, maximum of 2.0 inches).

Additional concerns have been raised with using coarse-graded mixes, S0.5 and S1, directly on top of either waterproofing membrane system and should not be used. The maximum aggregate size is such that these mixes may tear or puncture the membrane during paving and risk exposure to the bridge deck itself and costly repairs. For these reasons, it is recommended to avoid using these mix types for the bottom lift of the overlay.

11.2.2 *Providing a durable riding surface that can be subsequently maintained or replaced without disturbing underlying materials*

The selected lift thickness should provide the best chance to achieve proper compaction of the surface lift, thus maximizing density and durability. In addition, maintaining a constant thickness for the surface lift helps minimize disruption of the underlying materials during future resurfacing.

This is the aim of the standard practice of placing a lift of 2-inch HMA/PMA S0.5 for the riding surface, which is the generally recommended placement thickness for the S0.5 mix type on roadway sections. The top lift thickness should also be uniform through the project limits to promote placement of the approach pavement in conjunction with the bridge overlay.

11.2.3 *Minimizing permeability of the bituminous concrete layers*

Protection of the bridge deck from water intrusion is a primary purpose of the membrane. Utilizing a finer mix typically reduces the probability of having interconnected air voids thus minimizing permeability of the bituminous concrete overlay. HMA S0.25 has the smallest aggregate size of all the CTDOT's standard mix types.

When faced with a choice of lifts and maximum aggregate sizes, select the mix type with the smaller aggregate size to minimize permeability (e.g. HMA S0.25 is likely less permeable than HMA S0.375, and HMA S0.375 less permeable than HMA S0.5 – the same applies for the PMA equivalents). Mixes with smaller aggregate sizes are also more workable in tight areas or constrained edges where handwork would be necessary.

Using the recommended lift thickness for the selected mixture can help achieve the highest density for a given compactive effort, which is related to decreased permeability. This also reduces the chances of "dragging" of the mix at lower thicknesses, or instability at higher thicknesses.

Although thicker total overlays assist in increasing the path for moisture and chlorides down into the membrane of the bridge, there are practical and economic considerations that limit the maximum thickness of an overlay on a bridge deck. The 3-inch overlay standard practice balances these considerations.

11.2.4 *Achieving proper compaction and quality placement of bituminous concrete lifts*

This is best done by adhering to the CTDOT's published recommendations for placing Superpave bituminous concrete mixes. These recommendations include lift thickness guidelines for each standard mix type, covering lifts of uniform thickness as well as lifts of varying thickness used in wedge course applications, for which there is a different set of limits.

11.2.5 *Maximizing constructability of the project by minimizing the different mix types where possible*

Wherever possible, when faced with two feasible choices that achieve the remaining desired design features for the bituminous concrete overlay, select a combination that minimizes the number of mixes. Where limitations exist due to other considerations, attempt to strike a balance between minimizing different mix types and design needs. In most cases, two mix types can achieve the majority of the required design features of the bridge deck overlay.

11.3 Recommendations

As previously noted, the standard total overlay thickness that has been adopted by the CTDOT is three (3) inches. This is typically made up of two lifts consisting of the following:

11.3.1 *OPTION A1*

- 2 in. HMA/PMA S0.5 Traffic Level 2/3, on,
- 1 in. HMA S0.25 Traffic Level 2

11.3.2 *OPTION A2*

- 2 in. HMA/PMA S0.375 Traffic Level 2/3, on,
- 1 in. HMA S0.25 Traffic Level 2

In cases where the existing bridge is only designed to support a total overlay thickness of 2.5 inches, and the project scope does not include adequate strengthening improvements to the structural capacity of the bridge, the recommended pavement structure is as follows:

11.3.3 *OPTION B1*

- 1.5 in. HMA/PMA S0.375 Traffic Level 2/3, on,
- 1 in. HMA S0.25 Traffic Level 2

11.3.4 *OPTION B2*

- 1.75 in. HMA S0.5 Traffic Level 2, on,
- 0.75 in. HMA S0.25 Traffic Level 2

11.4 Notes

1. The decision to use HMA or PMA and Traffic Level 2 or 3 for the top surface lift will be made at the project level on a case-by-case basis. In general, PMA and Traffic Level 3 mixes should be used on high-volume roadways such as interstates and other expressways. The designer should consult with PDU if unsure of what type of mix to use and a recommendation has not been previously provided.

2. Concerns have been raised from bituminous concrete producers about the ability to make a PMA S0.25 Traffic Level 3 mix. For this reason, HMA S0.25 Traffic Level 2 mixes are exclusively recommended as the first lift of the overlay as a standard practice.

3. PMA substitution is not allowed for the 1.75” HMA S0.5 lift (Option B2), as it is difficult to achieve the required density for the mix at this lift thickness on a bridge structure where vibration is not permitted as a compaction method.

4. Use of the S0.375 mix as a riding surface should be avoided for roadway sections that have a high pavement friction demand, such as sharp horizontal curves, steep grades, and/or areas with frequent braking and maneuvering. The options that utilize HMA/PMA S0.375 (Option A2 and B1) as the surface lift generally should only be considered for traffic speeds under 50 mph and for sections that do not have high pavement friction demand. A certain amount of engineering judgement is needed for these determinations.

5. When the cross slope of the bridge deck is different from the required cross slope of the riding surface, bituminous concrete wedge courses are often used in conjunction with the standard overlay design. Any variable depth wedge lifts should be meet the minimum and maximum lift thickness guidelines for each mix type and be placed between the surface and bottom lifts of the overlay, which are to remain as uniform thickness lifts.

6. Other combinations of mixes and lift thicknesses may be considered for extenuating circumstances but should follow the guidance provided in this document. Please consult with PDU before incorporating alternatives.

11.5 Special Surface Mixes

There are cases where superior skid resistance is required on a bridge deck. In these cases, the wearing surface available at this time is "Ultra-Thin Bonded PMA Pavement (Type B)", which is placed at a thickness of 5/8 inches (0.625 in.). This can be best achieved by modifying the conventional 2 in. HMA/PMA S0.5 surface lift to 1.375 in. HMA/PMA S0.375. Additionally, other potential alternatives for the Ultra-Thin Bonded PMA are listed below in the case that the total overlay thickness is constrained to less than 3 inches.

11.5.1 *OPTION C1*

- 0.625 in. Ultra-Thin Bonded PMA Pavement (Type B), on,
- 1.375 in. HMA/PMA S0.375 Traffic Level 2/3, on,
- 1 in. HMA S0.25 Traffic Level 2

11.5.2 *OPTION C2*

- 0.625 in. Ultra-Thin Bonded PMA Pavement (Type B), on,
- 0.875 in. HMA S0.25 Traffic Level 2, on,
- 1 in. HMA S0.25 Traffic Level 2

11.5.3 *OPTION C3*

- 0.625 in. Ultra-Thin Bonded PMA Pavement (Type B), on,
- 1.5 to 2 in. HMA/PMA S0.375 Traffic Level 2/3 (on cold applied membrane only)

11.6 Culverts

On culverts, where there is no true abutment or bridge deck, keep the same pavement structure as the adjacent roadway throughout the section. After designing the pavement structure to meet the needs of the roadway conditions, verify that sufficient depth between the bottom of the asphalt layers and top of the culvert exists to place a minimum of 6 inches of subbase/processed aggregate base (for the purpose of facilitating drainage). If insufficient depth exists between the pavement structure and top of culvert, it is recommended to remove the granular layer entirely and instead fill the remainder of the area with additional bituminous concrete pavement to the top of the culvert.

12 Structural Overlays

For information on design of structural overlays, the reader is referred to the section in this handbook on see Chapter 7.2.

13 Pavement Widening Designs

13.1 State of Connecticut Major Traffic Generator (MTG) Pavement Design Catalog

The PDU has developed a Pavement Design Catalog for Major Traffic Generators (MTG) projects. MTGs are typically the result of a private developer wishing to expand or create a new property/facility in which a significant amount of new traffic will be generated. The existing traffic facilities and routes in the vicinity of the proposed development are then evaluated for potential impact by the increase in traffic generated. In some cases, expansion of existing roadways is warranted.

The Pavement Design Catalog (which can be found in its entirety at http://www.ct.gov/dot/cwp/view.asp?a=1400&q=467546) provides Engineers and Planners with pavement designs and guidance for MTG and other encroachment-permit projects in which State routes will either be newly constructed, reconstructed, or widened. Also included are a few explanatory documents related to bituminous concrete specifications. These pavement designs are based on the traffic volume (Average Daily Traffic (ADT), from the Traffic Log) and classification (percent of cars, trucks, and/or buses). The subgrade soil characteristics are assumed to be acceptable unless a field review indicates there may be a subgrade soils issue, or it is brought to the attention of PDU by others. In such rare cases, additional subgrade soil considerations may be warranted.

Several other considerations have been built into the Catalog that result in Pavement Structure or Superpave Level variations along route segments. These include an attempt to make long, homogeneous segments wherever possible, the presence of underlying concrete on a segment of highway, and strict correspondence with the information provided in the statewide Superpave Design Levels map.

The Connecticut DOT document titled "Picking a Pavement Structure for an MTG" is included below to show the general process involved.

Picking a Pavement Structure for an MTG

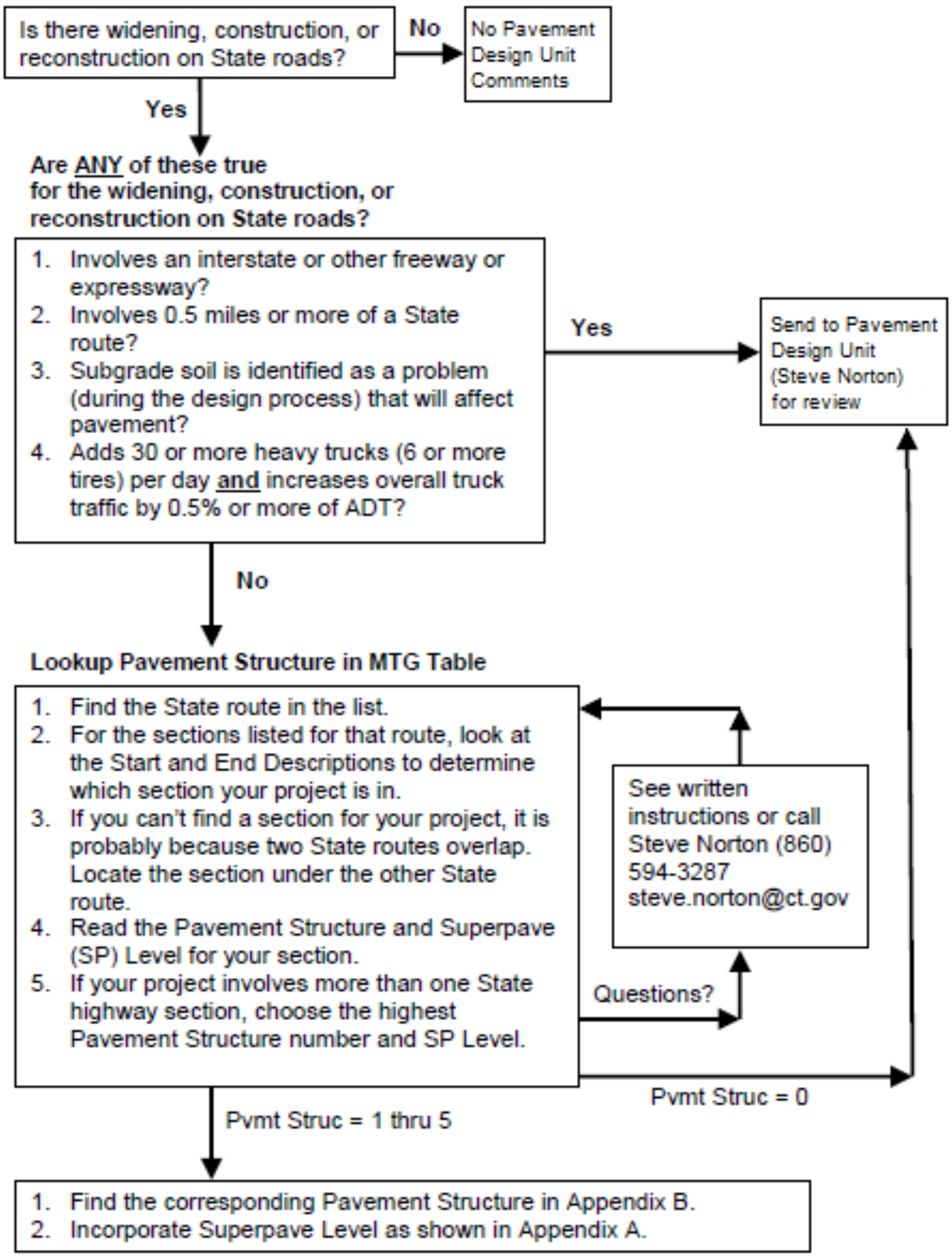

Figure 3 Picking a Pavement Structure for an MTG

14 Pavement Design -- Rigid Pavement Structure

14.1 New and Reconstructed Rigid Pavement Designs

Rigid pavements consist of a Portland cement concrete slab on a subbase course. The design procedure consists of developing an effective modulus of subgrade reaction based on subbase treatment and thickness, determining the slab thickness, considerations for any staged construction, adjusting for adverse environmental conditions, determining type and dimensions of joints, joint sealant, load transfer device size and spacing, and any required reinforcement.

14.2 Concrete Pavement Design Details

CTDOT uses the 1993 AASHTO method for PCC Pavement design. The AASHTO Guide provides a nomograph on page II-45, which outputs the slab thickness based on the user-specified k-value, the estimated future traffic, the reliability factor to be achieved, the standard deviation, the design serviceability loss, the concrete elastic modulus, the mean concrete modulus of rupture, the load transfer coefficient, and the drainage coefficient.

Concrete pavements inherently crack. Historically, designers would call for steel mesh reinforcement within the top of the pavement slab. The purpose of this mesh reinforcement is not to prevent cracking (as structural reinforcement may at the base of the PCC structure) but to control the crack width post-fracture. Excessive cracking and crack widths allows for moisture intrusion into the pavement subgrade, which is the leading cause for distress in the slab. The AASHTO Guide provides methods for designing the necessary reinforcement for jointed reinforced concrete pavement. In some cases, mesh reinforcement is called for in the case of odd-shaped panels where stress concentrations will exist, or slabs considered *slender*, where the length-to-width ratio exceeds 1.25.

Guidance is provided in Table 12 below for calculating the structural thickness required for rigid pavements. While the 1993 AASHTO Guide allows for calculation by hand, there are various web-based tools available.

There is also the Excel pavement-design spreadsheet tool that provides assistance to designers on the CTDOT PDU website. Furthermore, CTDOT Standard Form Sections 4.01 and M.03 provide greater details on construction materials and methods for Portland Cement Concrete Pavement.

Table 4 Design Parameter for Rigid Pavements

Design Input	CT DOT Range of Values	Notes
Typical Thickness	8 to 12 inches	To be verified by designer
Flexural Strength	600 to 750 psi	
Joint Spacing	15 ft and lane width	
Transverse Load Transfer Device	1 in. dia. by 18 in. length	See M.03.08 for additional details
Dowel Spacing	12 in. on-center (o.c.)	
Dowel offset from edges	12 in.	
Longitudinal Tie Bars	30 in. long, spaced 30 in. o.c.	Epoxy Coated Meeting AASHTO M 284

Standard details for both expansion and contraction joints are found in Appendix E along with standard drawings for concrete pavement replacement.

14.3 Typical CT DOT Rigid Design Parameters

For any new rigid pavement construction, most common applications within Connecticut will dictate Jointed Plain Concrete Pavement (JPCP). This rigid pavement structure is comprised of a base (bound or unbound) on subgrade topped by a section of Portland Cement Concrete (typically 8 to 12 inches thick). The concrete is constructed with formed or cut joints to control shrinkage cracking during curing and from thermal warping, however load transfer is re-established at these joints by the use of dowels. The following sections outline the methodology to confirm the thickness.

14.3.1 *Contraction Joints*

Contraction joints are either formed [sometimes called construction joints] or cut into green concrete shortly after placement to control the location of cracking as the concrete cures. These joints are doweled (this is the approach for CTDOT transverse joints), keyed, or connected with deformed bars (the case for longitudinal joints).

14.3.2 *Expansion Joints*

Expansion joints are transversely-doweled joints with mechanisms in place to permit expansion and contraction of adjacent pavement section. This is often accomplished with end caps on the dowels and a layer for compression board at the joint. Specialty expansion joints often occur a bridge interfaces and are often used periodically when constructing Continually Reinforced Concrete Pavement (CRCP). If expansion joints are to be called for, it is important for designers to understand this creates a condition where all contraction joints may spread apart as the structure's expansion joint permits gradual separation of these joints.

14.3.3 *Isolation Joints*

Similar to an expansion joint in construction but different in application, an isolation joint is used to separate portions of a pavement structure or separate structures to prevent sympathetic cracking, heaving, or blowups as pavements of differing materials, sizes, or joint patterns expand and contract separately. Isolation Joints can be doweled but are often implemented as thickened edges with compressible material in the joint to permit movement of the adjacent structures independent of each other. Designers should consider the conditions on both sides of an isolation joint to ensure the load transfer is not differential (varied deflections could cause premature spalling across the joint as the pavements deflect to different depths.

All three of the jointing conditions described above are explained in greater detail including typical construction drawings in the FHWA *T 5040.30 Technical Advisory on Concrete Pavement Joints* and the *Unified Facilities Criteria, Pavement Design for Roads and Parking Areas UFC-3-250-01* developed by the Army Corps of Engineers for the Department of Defense, and of course the AASHTO *Guide for Design of Pavement Structures 1993 i*tself.

14.3.4 *Thickness Design*

The AASHTO 1993 Pavement Design methodology for rigid pavements is similar to the flexible methodology from a framework standpoint, but has differing design inputs and ultimately the equation is different as well, the largest difference is that there is no *Structural Number* parameter in the equation, and the formula leads directly to a required slab thickness for PCC.

Environmental factors for PCC are equally important as compared to flexible design, due to the fact that a weak subgrade during frost could cause a slab to fracture under load, or a slab too thin may not be able to handle curling/warping stresses due to local temperature differentials. Design inputs to calculate the required slab thickness include

- Estimated future traffic W_{18}
- Reliability R
- Overall Standard Deviation S_o
- Design Serviceability Loss ΔPSI (similar to flexible design)
- Concrete Elastic Modulus E_c
- Concrete modulus of Rupture S'_c
- Load Transfer Coefficient J, and
- Drainage Coefficient C_d

14.4 Composite pavement

Two thirds of the state's existing centerline miles are composite pavement. These were almost all constructed as rigid pavements and overlaid with flexible pavement as a means of preservation and in some cases to accommodate increased traffic load. Certain situations will dictate the need to construct a composite pavement to match existing roadway, but in most situations, designers encounter composite pavement as rehabilitation or preservation projects.

14.4.1 *Structural Considerations*

The minimum Asphalt Pavement overlay thickness for the underlying concrete slab is 5 inches. This is to ensure sufficient thickness of the asphalt layer to minimize excess strain at the interface with the underlying concrete slab and to prevent debonding of the flexible overlay. The CTDOT Pavement Design unit provides designers with a composite overlay design tool (spreadsheet) to guide the designer through the requisite parameters of the structural evaluation. The tool walks a designer through evaluating the existing thickness of the PCC slab and ACP overlay compared to the ultimate traffic and serviceability needs of the pavement, resulting in a recommended overlay thickness (added thickness to existing structure).

14.4.2 *Preparation of the Underlying Material*

Patch underlying PCC (Partial-Depth spall repair and Full-Depth repairs (partial-slab replacement). Replacement materials may only be approved cementitious products. For full-depth repairs, see the CT DOT standard details for guidance on saw cutting, removal, and tie-in. For partial-depth repairs, the Engineer shall mark out limits of replacement (minimum dimensions of 12-inch length by 4 inch width). Existing deleterious materials shall be removed via approved methods to a minimum depth of 2 inches taking care to avoid any embedded steel. If spalled material is present at depths greater than 1/3 of the total slab thickness, the repair approach becomes a full-depth replacement. Follow manufacturer's recommendations for applying the approved cementitious repair product such as the use of a bonding agent, curing, and finishing. Additional design and construction guidance from the FHWA can be found here.

15 Pavement Type Selection

15.1 Introduction

The general types of pavement to be considered for new construction and rehabilitation in Connecticut are rigid, flexible and composite. When viable, rigid pavement may be considered as a potential alternative on Interstate and other high traffic volume roadways. Flexible pavement should be considered as the preferred alternative for most other State highway facilities. With few exceptions composite pavements have only resulted from structural enhancement by overlay or rehabilitation of rigid pavements on State highways.

15.2 Pavement Type Selection Factors

If a pavement type selection determination is required during or prior to the design process, then the following information should be considered. The selection of pavement type where required, is a major decision, particularly for reconstruction and new construction and must be performed prior to proceeding with the full design. A type-selection evaluation should be based on good engineering judgment utilizing the best information available. The process for pavement type selection can be complex and must be tailored to the specific project. Factors to be considered in pavement type selection vary from empirical to subjective and may include any number of the following:

- Pavement design life
- Cost comparisons (initial and life cycle)
- Lane closure requirements, traffic delays and safety
- Soils (subgrade) characteristics
- Climatic and environmental considerations
- Existing and adjacent pavement type and condition
- Availability of materials
- Recycling considerations
- Maintainability:
  - Ability to be restored in a timely and cost-effective way with minimal traffic exposure to the workers and minimal traffic delays to the traveling public
  - Projected future traffic control and other costs to perform maintenance, restoration or rehabilitation
- Constructability:
  - Construction sequencing as it relates to serving commercial areas
  - Construction sequencing as it relates to maintaining quality control of pavement construction
  - Availability of work areas for the paving equipment
  - Windows when the project must be completed
- Size and complexity of the project
- Stage construction
- Available project funding

- Historical Performance of similar pavements under similar soil conditions and traffic loadings
- Conservation of Materials and Energy
- Recognition of local industries
- Contractor capabilities
- Stimulation of competition

NOTE: Pavement type selection guidelines can also be found in Appendix B of the 1993 AASHTO Guide. Also, for guidance in making the pavement type selection for Federal-aid projects on the National Highway System (NHS), FHWA Technical Advisory – "Use of Alternate Bidding for Pavement type Selection" can be found at **http://www.fhwa.dot.gov/pavement/t504039.cfm**

16 Life-cycle costs

For Life-cycle cost analysis the user is referred to the following FHWA resource page. This web resource contains technical bulletins, fact sheets, case studies and software tools.

https://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm

17 Pavement Preservation Guidelines

As described earlier, pavement preservation is performed to simply preserve or repair and maintain a roadway in good condition. Table 13 contains a list of preservation treatments that have been used at CTDOT. The list is not all-encompassing (the main treatments missing are the traditional chip seal, and cold-in-place recycling or full-depth reclamation, which have not been implemented in the state on a dedicated-fund basis).

Table 5 CTDOT Preservation Treatments

Treatment	Description	Expected Service Life (in preservation) (years)
Crack Sealing	Using hot-poured rubberized asphalt sealant to fill working cracks.	6-8
Crack Filling	Filling non-working cracks (those that have little movement) with a high PG graded (PG76-22) asphalt with polyester fibers or some other filler material designed to fill those voids.	4-10
Rubberized Chip Seal	A layer of single-sized, cubical, pre-coated aggregate spread over a hot liquid asphalt to which 10% or 20% crumb rubber has been incorporated.	6-8
Microsurfacing	A truck-mixed polymerized slurry of emulsion, polymer, and aggregate (and maybe an additive) laid down typically in two lifts, one of which may be for rut-filling.	6-9
Ultra-thin Bonded Hot Mix Asphalt	Gap-graded, high-durability Hot-Mix-Asphalt placed immediately after a heavy polymerized tack coat placed with a spray paver, ranging from ½ to ¾ inches thick.	9-12
Thin Overlays	Hot-mix asphalt (gap- or dense- graded), from ¾ to 1 inch in thickness, used as a surface treatment and to correct minor imperfections.	9-11
Functional Overlays	Hot-mix asphalt overlays (typically dense-graded) without milling (may be preceded by leveling course or surface (micro) milling (to correct, say, minor rutting), typically ranging from 1.25 to 2 inches in thickness depending on mix maximum aggregate size.	10-14
Milling and Filling	Functional Overlays as defined above but with milling to the same depth as the overlay.	10-14

17.1 Crack Sealing and/or Crack Filling Project Selection Guide

17.1.1 *General Definitions*

Crack Sealing

ASTM 6690 Type II (AASHTO M 324 Type II) rubber-asphalt hot-poured material with sufficient elasticity to withstand horizontal crack movements. Sealing is best for placement in working cracks, with the optimum crack width range: ⅛ to ¾ inches in width.

Crack Filling

Asphalt binder (PG 76-22) with polyester fibers, with a high temperature performance grade (76ºC) to prevent tracking under Connecticut pavement surface temperatures on the hottest days. Filling should be used in non-working cracks or joints (such as open paving joints, longitudinal cracks due to aging of the surface). This material is non-proprietary and can be prepackaged/ produced using standard methods.

17.1.2 *Crack Sealing vs. Filling*

Crack sealant would be the material of choice for:

- Working cracks in flexible pavement (those cracks that show horizontal movement, mostly in the transverse direction but some longitudinal wheelpath cracks can be treated as long as alligator cracking has not started – vertical movement is indicative of structural failure and there are no known sealing materials that can take that kind of repetitive movement (one cycle per axle load of a heavy vehicle)).
- cracks and transverse joint-reflection cracks in composite (bituminous overlays over concrete) pavement when enough working cracks reflect through to make it worthwhile to seal an entire road segment.
- sealing rigid pavement joints and cracks (where the Portland-cement concrete – PCC – is exposed at the surface).

Crack filling would be the material of choice for:

- Non-working cracks such as longitudinal paving joints that are opening up, or longitudinal reflection joints in composite (bituminous concrete over PCC) pavement, or non-wheelpath longitudinal cracks that show little horizontal movement.
- treating cracks prior to placement of a bituminous concrete overlay (1 inch or thicker). In this case the asphalt without rubber has less expansion with change in temperature and can reduce the formation of slippage bumps or cracks on the overlay mat itself, as long as no excessive filler is used (this is an issue especially in the transverse direction). Crack filling prior to an overlay provides some support for the paving and can reduce the width of the reflective crack once it forms. Success of crack filling prior to a bituminous concrete overlay is dependent on the care taken not to overfill underlying cracks; typically this is done by specifying a “flush fill” with no overband, by filling only cracks wider than ½

inches, and by using a sand-asphalt mixture instead for transverse cracks wider than 1.25 inches).

Sealing and/or Filling Cracks in Composite Pavement:

The main difference in Composite Pavement is the presence of joint-reflection cracks.

Table 6 Applicability of Crack Sealing and Crack Filling for Various Crack-type Distresses

Distress	Severity	Crack Seal	Crack Fill
Thermal Cracking	L	E	X
	M	E	X
	H	X	X
Block Cracking	L	E	E
	M	E	E
	H	X	X
Longit. Paving Joint	L	E	E
	M	X	E
	H(1)	X	X
Non-wheelpath Cracking	L	E	E
	M	E	M
	H	X	X
Fatigue Cracking	L	M	X
	M	M	X
	H	X	X
Edge Cracking	L	M	X
	M	M	X
	H	N	X
Transverse Joint Reflect. Cracking	L	E	X
	M	E	X
	H	X	X
Longit. Joint Reflect. Cracking	L	M	E
	M	X	E
	H	X	X

(1): High-severity paving joint can be locally repaired (20" min. mill and patch centered around joint, then considered as a Low Severity condition), or milled-and-filled joint and mat

E = effective, M = marginally effective, X = counterproductive/not recommended.

17.1.3 *Preservation crack sealing/filling:*
Optimal time window: 3-6 years after bituminous concrete surface has been placed for overlays, 5-8 years after reconstruction if cracks or open joints are present.

Expected service life: 5-8 years.

Expected pavement life extension due to sealant presence: 3 years.

17.1.4 *Types of Cracking*
See the glossary for definitions of distress types which may influence project selection (decisions) about whether to crack seal, fill, both, or neither as a stand-alone project.

17.1.5 *Measuring Cracks*

Transverse Cracks

Transverse cracks may or may not cross the road entirely. In order to quantify them in a uniform manner, the "full-width equivalent" (FWEQ) transverse cracks are used. You get an equivalent FWEQ transverse crack when the length of transverse cracking equals the width of the roadway. Transverse cracks are also measured by severity (width and whether they are spalled or deteriorated).

You can count FWEQ by lane instead of road width if there are many lanes, in which case the spacing for the entire roadway would be the same; however, if cracking amounts vary significantly among lanes then please note that fact and use the most representative lane.

Things Not to Count as Transverse Cracks:

- Cracks forming roughly square blocks (or almost forming these blocks), where the blocks are 5 ft. x 5 ft. or less in size on average.
- Hairline cracks that are also forming square blocks and are not specifically in the wheelpath (these cracks would go in every direction and typically form when the mix is too dry or drying out).

Figure 4 Example of 1 FWEQ (full-width equivalent) crack (add up crack length to approximately one lane)

Road width

Cracking Extent

Using the FWEQ concept, estimate the spacing between cracks, in feet, i.e. “one transverse crack every 50 feet on average”. If there are partial cracks, say each 10 ft long on average and the road is 30 feet wide, then you’d have to see three of these to get one crack; if one of these 10-ft cracks is present every 50 feet, the FWEQ spacing would be 150 feet, i.e. “one full-width equivalent crack every 150 feet on average.”

Longitudinal Cracks

Longitudinal cracks may or may not extend all the way through a section. In order to quantify them in a uniform manner, the “full-length equivalent” (FLEQ) longitudinal cracks are used. You get an equivalent FLEQ longitudinal crack when the total length of longitudinal cracking equals the length of the section of roadway. Longitudinal cracks are also measured by severity (width and whether they are spalled or deteriorated). Longitudinal cracks that take place mostly in the wheelpath are an indication of structural failure (same as alligator, but typically on thicker pavements) and it should be indicated whether the longitudinal cracks are mostly in the wheelpath or outside the wheelpath.

Figure 5. Example of 2 FLEQ cracks (about 1/2 in lane to the left (down arrow), 1-1/2 in lane to the right), or 1 FLEQ per lane.

Cracking Severity

Estimate the typical crack width of transverse cracks as observed at the pavement surface. Try to give a range of typical widths, i.e. ¼ to ½ inch.

Estimate the maximum crack width (if there are some exceptionally wider cracks than the rest).

Use “HL” for hairline.

Count FLEQs by lane instead of entire road width if there are many lanes, in which case the FLEQs for the entire roadway would be multiplied by the number of lanes (i.e. 1 FLEQ per lane in a 4 lane road would be 4 FLEQs), or the FLEQs for each lane would be the number observed over the entire pavement width and divided by the number of lanes; however, if cracking amounts vary significantly among lanes then please note that fact and use the most representative lane.

Alligator Cracking

Estimate the percentage of the section area that has alligator cracking if generalized, or the total square yards (to the nearest 100 sy if greater than 300 sy) if only present in a couple of spots (isolated) or is intermittent and small in quantity.

Block Cracking

Estimate the typical block size (maximum 5 ft. x 5 ft., otherwise call it transverse and longitudinal cracking) and the percent of the total segment pavement area that has block cracking, or the total square yards (to the nearest 100 sy if greater than 300 sy) if only present in a couple of spots (isolated) or if small quantity is present only.

Longitudinal Paving Joint

Classify as “N” (not visible), “V” (visible but not open), “O” (open, indicate typical width at the pavement surface), or “R” (raveled or potholed more than 2 inches in width).

Raveling

Indicate whether “in spots” or “generalized”, and severity (low, medium, high (with potholes or patches)).

Rutting

Indicate whether “in spots” or “generalized” and estimate rut depth in inches or fractions of an inch. Indicate whether “mix instability” or “base” as probable cause based on rutting shape.

Bleeding or flushing

Indicate whether “in spots” or “generalized” and estimate severity (low, medium, high).

Transverse Joint Reflection Cracks

The typical spacing of the transverse joint-reflection cracks that are visible should be noted (every slab, every other slab, every third slab, every 500 feet, etc.).

The number of bad transverse joints (patched, potholed, multiple-cracked, or very bumpy) in the section should be noted.

The typical (predominant) severity level ("Low" (single transverse crack), "Medium" (double cracks more than single cracks, maybe some spalling), or "high" (the typical joint is bad)) should be indicated.

Longitudinal Joint Reflection cracks

The typical (predominant) severity level ("Low" (single transverse crack), "Medium" (double cracks more than single cracks, maybe some spalling), or "high" (the typical joint is bad)) should be indicated. In addition, estimate how many feet of longitudinal joint-reflection crack should be repaired beyond sealing (patched, etc.).

Alligator Cracking in Composite Pavement

NOTE: Alligator cracking in composite pavement typically takes place outside of the concrete slab, in particular if the outermost longitudinal joint-reflection crack is within the mainline and there is some pavement in the lane that is not concrete. Evaluate as for flexible pavement.

17.2 Project Selection

17.2.1 *Criteria for Filtering Segments*

Prior to field reviews, etc. look at age of pavement surface to focus in on good preservation segments. The "sweet spot" is typically:

- Flexible or composite pavements 3-6 years old.

But there may be specific instances where there is additional information about a specific project that may merit consideration, for instance:

- A segment where enough underlying cracks have come through early on to seal as a project (could be one winter, but mostly two (for 2 inches thick pavement).
- Older, sound pavements with little structural distress, where the distress is mostly only cracking and typical transverse cracks are no more than ¾ inch wide and longitudinal paving joints less than 2 in. open (1.5 in. or less is better).

Typically, preservation crack treatments will take place when cracking extent is low or medium, and severity is not high.

The first thing to do is note what distress form is driving the deterioration of the pavement.

The following "deterioration drivers" (where they occur over the majority of the pavement surface) will typically **exclude** stand-alone crack-treatment projects.

- Raveling of the pavement surface
- Flushing, bleeding, pushing, shoving
- Rutting, heaves, depressions
- Structural failure (alligator cracking, wheelpath cracking)

17.3 Procedure for Selecting a Pavement Segment for Preservation Crack Filling or Sealing (or Both)

The following procedure provides a way of documenting observations about pavement condition and would constitute an adequate pavement evaluation for crack-sealing project selection purposes. Use Table 15, below, with the following instructions:

1. Find all deterioration drivers. Circle all X's that apply.
2. Look at "Exclude" Column. If any X's are circled, reject the project.
3. Look at all other Columns.
4. If No X's are checked, reject the project.
5. Go to bottom of table 15 and write the number of x's in every column in the "project" row.

Table 7 Segment Selection for Preservation Crack Filling or Sealing (or Both)

PROJECT: Route ______, MP _____ to ______, Direction ___ (if divided; log or reverse)

Distress Form	**Quantity Unit (circle unit used)**	**Quantity**	**Severity. Unit**	**Severity**	**Deterioration Driver (“X” or leave blank)**
Alligator Cracking	[%] [S.Y.]		L,M,H		
Block Cracking	[%] [S.Y.]		L,M,H		
	Typ. Size (ft x ft)		n/a		
Transverse Cracking	FWEQ spacing, ft		n/a		
	Typical width, in.		n/a		
	Max. width, in.		n/a		
Longitudinal Cracking	FLEQs per lane		n/a		
	Typical width, in.		n/a		
	Max. width, in.		n/a		
	% LC in wheelpaths		n/a		
Raveling	[General, %] [Spots, SY]		L,M,H		
Segregation	[General, %] [Spots, SY]		L,M,H		
Patching/ Deterioration	[% , #] [S.Y. , #]		n/a		
Trans. Joint - Refl Cracks			L,M,H		
Long. Joint - Refl cracks			L,M,H		
Longitudinal Paving Joint			[N]one [V]isible [O]pen [R]aveling		

Distress Form	Quantity Unit (circle unit used)	Quantity	Severity. Unit	Severity	Deterioration Driver (“X” or leave blank)
Rutting	[General, typ & max depth, in.] [Spots, max depth, in.]		n/a		
Bleeding, Push/shov, flushing	[General, %] [Spots, SY]		L,M,H		
Other (specify)			n/a		

Table 16 Project Selection Matrix for Crack Sealing/Filling

PROJECT: Route ______, MP _____ to ______, Direction ___ (if divided; log or reverse)

Deterioration Driver	(sub-category)	Crack Seal	Crack Fill	Call for subsequent surface treatment (same project or following season)	Exclude	
Alligator Cracking (except if only isolated in a couple of locations)					X	
Block Cracking < 10% of area	Block Size < 3x3 ft.			X		
	Block Size 3x3 ft. to 5x5 ft.		X			
Block Cracking >= 10% area	Block Size < 3x3 ft.				X	
	Block Size 3x3 ft. to 5x5 ft.			X		
Transverse Cracking	Spacing < 15 feet Per FWEQ				X	
	Spacing 15-500 feet					

Deterioration Driver	**(sub-category)**	**Crack Seal**	**Crack Fill**	**Call for subsequent surface treatment (same project or following season)**	**Exclude**	
		X				
	Spacing >500 feet					
Longitudinal Cracking	Majority Non-fatigue, > 2 FLEQ per lane (4 FLEQs for 2-lane roadway)				X	
	Majority Non-fatigue, 0.25 – 2 FLEQ per lane (4 FLEQs per 2-lane roadway)		X			Can seal if combined with transverse cracking
	Majority Non-Fatigue < 0.25 FLEQ per lane (0.5 FLEQs per 2-lane roadway)					Can seal if combined with transverse cracking
Raveling	Low or medium severity			X		
	High				X	(requires milling)
Segregation				X		
Patching/ Deterioration	Generalized				X	
Transverse Joint-Reflection Cracks	Typically, low or medium severity, no high severity (or one or two high-severity max)					

Deterioration Driver	**(sub-category)**	**Crack Seal**	**Crack Fill**	**Call for subsequent surface treatment (same project or following season)**	**Exclude**	
		X				
	Typically high severity, or medium with significant no. of high severity joints (more than 3 per mile per lane)				X	
Longitudinal Joint-Reflection cracks	Low or medium severity, little or no high-severity		X			
	High severity more than 5% of length or 1000 feet, whichever is lower				X	
Longitudinal Paving Joint	None					
	Visible		X			
	Open (< 2 inches for at least ¾ of length)		X	X		
	Raveling/Potholing (more than 5% of length)					If bad enough, exclude segment

Deterioration Driver	**(sub-category)**	**Crack Seal**	**Crack Fill**	**Call for subsequent surface treatment (same project or following season)**	**Exclude**	
					X	(requires milling)
PROJECT		[ ]	[ ]	[ ]		

NOTE: Some distress quantities do not have any X's. This means they don't impact project selection (you would not do anything) but they don't kick it out.

You may use only one treatment if one (crack seal vs. fill) is highly predominant vs. the other.

For pavement preservation activities listed in the table other than crack sealing and crack filling, please refer to the web application that can be found at: https/www/ct.gov or the actual pavement preservation manual developed by the CTDOT PDU [CTDOT-2, (22)].

18 Glossary of Terms

Alligator Cracking [FHWA, (27)]

Fatigue cracking: A series of small, jagged, interconnecting cracks caused by failure of the AC surface under repeated traffic loading (also called "alligator cracking").

Alligator Cracking: [CTDOT, (23)]

Fatigue cracking (alligator cracking in thinner pavements, longitudinal wheelpath cracks in thicker pavements). Note: edge cracking is technically fatigue cracking in form, but if confined to the pavement edge well outside the travelway or in areas subjected to traffic (such as driveways, mailboxes, etc.) it may be possible to address it, depending on the treatment, as long as it is not pervasive or severe.

Analysis Period [FHWA, (5)]

Transportation assets are constructed to provide service for generations. Competing design alternatives may each have a different service life, which is the time period that the asset will remain open for public use. Life-cycle cost analysis (LCCA), however, uses a common period of time to assess cost differences between these alternatives so that the results can be fairly compared. This time period is termed the "analysis period".

Asphalt Tack Coat: [FHWA (28)]

Sprayed application of asphalt binder upon an existing asphalt or Portland cement concrete pavement surface prior to an overlay, or between layers of new asphalt concrete.

Base Course: [FHWA, (8)]

Binder course (also called the asphalt base course): The hot mix asphalt layer immediately below the surface course. The base course generally has a coarser aggregate gradation and often a lower asphalt content than the surface course. A binder course may be used as part of a thick asphalt layer either for economy (the lower quality asphalt concrete in the binder course has a lower material cost than the higher-asphalt content concrete in the surface course) or if the overall thickness of the surface layer is too great to be paved in one lift.

Binder: [Asphalt Institute, (29)]

A dark brown to black cementitious material in which the predominating constituents are bitumen which occur in nature or are obtained in petroleum processing. Asphalt is a constituent in varying proportions of most crude petroleum.

Binder Course:

See: *Base Course*

Bituminous Concrete: [CTDOT, (21)]

A concrete material that uses a bituminous material (typically asphalt) as the binding agent and stone and sand as the principal aggregate components. Bituminous concrete may also contain any of a number of additives engineered to modify specific properties and/or behavior of the concrete material.

Block Cracking: [FHWA, (27)]

A pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 1 to 108 sf.

Block Cracking: [CTDOT (23)]

Transverse and longitudinal cracking that connects at roughly 90% angles to form blocks of pavement surrounded by cracks. Although blocks formed by this cracking can be large, for purposes of evaluation the maximum block size is 5 ft x 5 ft (a little bit smaller than ½ of the lane width). Note: After blocks form, the wheelpath areas are somewhat weaker to resist vehicle axle loads, so often block cracking contains fatigue cracking (longitudinal wheelpath cracking or alligator cracking) within the block-cracked area. When block and fatigue cracking are combined, first count the fatigue cracking and then subtract that area from the total block-cracked area. Fatigue cracking is an indicator of structural deficiency and is therefore more critical in pavement-preservation decisions.)

California Bearing Ratio (CBR): [FHWA (8)]

The California Bearing Ratio or CBR test is an indirect measure of soil strength based on resistance to penetration by a standardized piston moving at a standardized rate for a prescribed penetration distance. CBR values are commonly used for highway, airport, parking lot, and other pavement designs based on empirical local or agency specific methods (*i.e.*, FHWA, FAA, AASHTO). CBR has also been correlated empirically with resilient modulus and a variety of other engineering soil properties.

CBR is not a fundamental material property and thus is unsuitable for direct use in mechanistic and mechanistic-empirical design procedures. However, it is a relatively easy and inexpensive test to perform, it has a long history in pavement design, and it is reasonably well correlated with more fundamental properties like resilient modulus. Consequently, it continues to be used in practice.

Chip Seal: [FHWA, (30)]

Chip seals or seal coats are a common bituminous pavement preservation treatment used to seal fine cracks in the pavement surface and prevent water intrusion into the underlying pavement structure, while sustaining or improving pavement friction. Chip seals are constructed by first applying a bituminous membrane onto the existing pavement followed by a layer of aggregate or "chips," which are dropped onto the surface then rolled to embed them in the binder. The bituminous membrane is typically a polymer-modified asphalt emulsion but can also be a liquid asphalt material (asphalt cement or cutback), including rubberized asphalt.

Composite Modulus of Subgrade Reaction (Kc): [AASHTO, (1)]

A design input for rigid pavement design which takes into account several characteristics of the subgrade besides the resilient modulus.

Composite Pavement: [FHWA, (8)]

Composite pavements consist of asphaltic concrete surface course over PCC or treated bases.

Composite Pavement: [CTDOT, (23)]

HMA overlays of Portland-cement concrete (PCC).

Construction Joint: [FHWA, (27)]

The point at which work is concluded and reinitiated when building a pavement.

Contraction Joint: [CTDOT, (21)]

Transverse contraction joints shall consist of planes of weakness created by forming or cutting grooves in the surface of the pavement and, when shown on the plans, shall include transfer assemblies.

Depressions: [DelDOT, (6)]

Depressions are localized pavement surface areas that are slightly lower than the surrounding pavement. Depressions are most noticeable during and after a rain. If deep and large enough, depressions may cause hydroplaning or an unpleasant ride. Depressions may be initially built into the pavement by the paving operation or as a result of settling of the surface support structure.

Design Life (Performance Period): [AASHTO, (1)]

The design period is the period of time that a new, reconstructed or rehabilitated structure will last before reaching its terminal serviceability **(P_T)**.

Design Serviceability Loss (ΔPSI): [AASHTO, (1)]

The change in the serviceability index of a pavement from the time it is constructed to the end of its design period. The numerical difference between the initial serviceability (P_0) and the terminal serviceability (P_t). Whereby $\Delta PSI = P_o - P_t$

Diamond Grinding: [GeorgiaDOT, (15)]

A process that uses a series of diamond-tipped saw blades mounted on a shaft or arbor to shave the upper surface of a pavement to remove bumps, restore pavement rideability, and/or improve surface friction.

Distress: [NYSDOT, (3)]

Any indication of poor or unfavorable pavement performance or signs of impending failure; any unsatisfactory performance of a pavement short of failure.

Drainage Coefficient (m): [OhioDOT, (12)]

A factor used to modify structural layer coefficients in flexible pavements or stresses in rigid pavements as a function of how well the pavement structure can handle the effect of water infiltration.

Effective Modulus of Subgrade Reaction (K): [AASHTO, (1)]

The composite modulus of subgrade reaction modified by loss of support.

Equivalent Single Axle Load (ESAL): [Asphalt Institute, (29)]

The effect on pavement performance of any combination of axle loads of varying magnitude equated to the number of 80-kN (18,000-lb.) single-axle loads that are required to produce an equivalent effect.

Fatigue Cracking: See Alligator Cracking.

Flexible Pavement: [FHWA, (8)]

Flexible pavements contain an asphaltic surface layer, with no underlying Portland cement slabs. The asphaltic surface layer may consist of high quality, hot mix asphalt concrete, or it may be some type of lower strength and stiffness asphaltic surface treatment. In either case, flexible pavements rely heavily on the strength and stiffness of the underlying unbound layers to supplement the load carrying capacity of the asphaltic surface layer.

Full Depth Reclamation: [FHWA, (31)]

Full depth reclamation is a rehabilitation technique in which all of the asphalt pavement section and a predetermined amount of underlying materials are treated to produce a stabilized base course. The procedure consists of five steps:

1. pulverization of existing material,
2. introduction of additive,
3. shaping of the mixed material,
4. compaction, and
5. application of wearing course.

Functional (Performance) Characteristics: [OhioDOT, (12)]

Those characteristics that affect the highway user but have little effect on the load carrying capacity of the pavement. Ride quality is the predominant functional characteristic. Others include skid resistance and surface oxidation.

Functional Classification: [HPMS, (32)]

Functional classification is the process by which streets and highways are grouped into classes, or systems according to several factors that contribute to the overall importance of a given roadway to a region or area. All streets and highways are grouped into one of seven classes, depending on the character of the roadway and the degree of land access that they allow.

Grooving: [FHWA, (30)]

Grooving is a treatment in which narrow grooves are sawcut into the pavement surface, typically in the direction of traffic, and typically 0.75-inches apart. The grooves increase pavement macrotexture, providing a path for bulk water drainage. Grooving is a surface treatment that can be used when it is undesirable to apply any topical treatment to the pavement surface (e.g., bituminous surface treatments) or to remove any of the pavement surface (e.g., milling or diamond grinding)

Hot-Mix Asphalt (HMA): see Bituminous Concrete.

Initial Serviceability (P_o): [AASHTO, (1)]

The Initial Serviceability (P_o) is the condition of a newly constructed roadway, often designated as 4.2 for flexible pavements and 4.5 for rigid (on the scale of 0 to 5, based on the original AASHO Road test)

International Roughness Index (IRI): [FHWA, (33)]

Since its development in the 1980s, the IRI has become the standard for expressing pavement smoothness. AASHTO standard R 43M/R 43-07, Standard Practice for Quantifying Roughness of Pavements and the ASTM standard E1926, Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements provide standardized methods to compute the IRI. The IRI is computed using a mathematical model known as the "quarter-car model," which represents the way a single tire system (a quarter of a car) is affected by the profile of the pavement.

Jointed Plain Concrete Pavement (JPCP): [FHWA, (8)]

These unreinforced slabs require a moderately close spacing of longitudinal and transverse joints to maintain thermal stresses within acceptable limits. Longitudinal joint spacing typically conforms to the lane width (around 12 ft), and transverse joint spacing typically ranges between 15 - 30 ft. Aggregate interlock, often supplemented by steel dowels or other load transfer devices, provides load transfer across the joints.

Jointed Reinforced Concrete Pavement (JRCP): [FHWA, (8)]

The light wire mesh or rebar reinforcement in these slabs is not designed to increase the load capacity of the pavement, but rather to resist cracking under thermal stresses and, thereby, permit longer spacings between the transverse joints between slabs. Transverse spacing typically ranges between 30 - 100 ft in JRCP pavements. Dowel bars or other similar devices are required to ensure adequate load transfer across the joints.

Layer coefficient: [AASHTO, (1)]

An assigned value of the relative ability of a unit thickness of a given material to function as a structural component of the pavement. The layer coefficient is a multiplier for the thickness of the layer(s) required to carry the expected load. The stiffer the supporting layer, the higher the layer coefficient will be.

Life-cycle cost analysis (LCCA): [MAP 21 23 U.S.C. 101(a)(2), MAP-21 § 1103]

A process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment

Longitudinal Crack: [FHWA, (27)]

Cracks predominantly parallel to pavement centerline. Location within the lane (wheel path versus non-wheel path) is significant.

Longitudinal Joint:

A sawed or formed joint, in the direction of traffic flow, used to control longitudinal cracking on a rigid pavement or the seam formed between adjacent passes of a paver on a flexible pavement.

Major Rehabilitation: [FHWA, (34)]

consists of non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develop in flexible pavements due to environmental exposure. Because of the non-structural nature of minor rehabilitation techniques, these types of rehabilitation techniques are placed in the category of pavement preservation.

Micro-Surfacing: [CTDOT, (23)]

A truck-mixed polymerized slurry of emulsion, polymer, and aggregate (and maybe an additive) laid down typically in two lifts, one of which may be for rut-filling.

Minor Rehabilitation: [FHWA, (34)]

"Consists of structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability." Source: AASHTO Highway Subcommittee on Maintenance Definition

Nomograph: [Dictionary.com]

A graph, usually containing three parallel scales graduated for different variables so that when a straight line connects values of any two, the related value may be read directly from the third at the point intersected by the line.

Standard Deviation: [AASHTO, (1)]

S_o, variable in the AASHTO design method to account for chance variation in traffic prediction and inherent variation in pavement performance.

Pavement Preservation Program (Plan): [FHWA, (35)]

A program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations.

(Pavement) Reconstruction: [FHWA, (34)]

The replacement of the entire existing pavement structure by the placement of the equivalent or increased pavement structure. Reconstruction usually requires the complete removal and replacement of the existing pavement structure. Reconstruction may utilize either new or recycled materials incorporated into the materials used for the reconstruction of the complete pavement section. Reconstruction is required when a pavement has either failed or has become functionally obsolete.

(Pavement) Rehabilitation: [FHWA, (34)]

consists of "structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays." Source: AASHTO Highway Subcommittee on Maintenance

Rehabilitation projects extend the life of existing pavement structures either by restoring existing structural capacity through the elimination of age-related, environmental cracking of embrittled pavement surface or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions. Two sub-categories result from these distinctions, which are directly related to the restoration or increase of structural capacity.

Pavement Structure:

The pavement structure is a combination of subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.

Present Serviceability Index (PSI): [AASHTO, (1)]

The Present Serviceability Index (PSI) represents the ability of a roadway to serve the traffic which uses the facility. The index is on a scale of 0 to 5. A PSI of 5 indicates an exceptionally smooth pavement. As road condition decreases due to deterioration, the PSI decreases.

Preventive (Preventative) Maintenance: [FHWA, (34)]

is "a planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system (without significantly increasing the structural capacity)." Source: AASHTO Standing Committee on Highways, 1997

Pumping: [FHWA, (27)]

Seeping or ejection of water from beneath the pavement through cracks. In some cases, it is detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface.

Reflection Cracking:

Cracks in AC overlay surfaces that occur over joints in concrete pavements, previously existing cracks in underlying asphalt layers or unrepaired cracks in underlying PCC pavements.

Reliability (R): [AASHTO, (1)]

A means of incorporating some degree of certainty into the design process to ensure various design alternatives will last for the prescribed analysis period.

Rigid Pavements [FHWA (8)]

Rigid pavements in simplest terms are those with a surface course of Portland cement concrete (PCC). The Portland cement concrete slabs constitute the dominant load-carrying component in a rigid pavement system.

Rutting: [FHWA, (27)]

A longitudinal surface depression in the wheel path. It may have associated transverse displacement.

Friction Treatments

<u>High Friction Surface Treatment (CTDOT)</u>

A High Friction Surface Treatment (HFST) applies a highly durable aggregate to the pavement using a strong polymer binder to restore or maintain pavement friction. The textured aggregate provides a riding surface with superior pavement friction to keep vehicles on the roadway during times of high friction demand, such as through a deficient geometric design like a sharp curve with inadequate superelevation (i.e., banking of the curve) or on the approach to a high-speed intersection. High Friction Surface Treatment

(HFST) is used where friction demand is high. HFST consists of a highly durable, polish-resistant aggregate (typically calcined bauxite) surface that is bound to the pavement with a polymer resin binder (generally epoxy).

<u>Micro-milled Surface</u>

See Chapter Minor and Major Rehabilitation for Flexible Pavements7

<u>Ultra-thin Bonded Wearing Surface (CTDOT)</u>

Ultra-thin Bonded wearing surface is a thin applied, gap graded surface application. The spray paver applies a polymer-modified asphalt emulsion membrane to the roadway. The same machine then immediately applies the polymer modified gap graded mixture over the membrane.

<u>Thin Friction Wearing Course</u>

Thin Friction Wearing Course (TFWC) is a paver placed, thin (usually 1.0 ± 0.25 inches) application of polymer modified gap graded bituminous concrete. The emphasis of this mix is taking advantage of the highly durable, low-polish coarse aggregates available in Connecticut and using them to create a high texture wearing surface.

Serviceability: [AASHTO, (1)]

A pavement's ability to accommodate the type of traffic which use the facility. This is based on a scale of 0 to 5, wherein users have indicated a "like-new" pavement is around 4.2 - 4.5 and a "failed" pavement is 2.5-2.0.

Shoulder: [FHWA, (36)]

A portion of the roadway contiguous with the traveled way that accommodates pedestrians, bicycles, stopped vehicles, and emergency use, as well as for lateral support of the subbase, base, and surface courses.

Skid Resistance: [Asphalt Institute, (29)]

The ability of an asphalt paving surface, particularly when wet, to offer resistance to slipping or skidding. The factors for obtaining high skid resistance are generally the same as those for obtaining high stability. Proper asphalt content and aggregate with a rough surface texture are the greatest contributors. The aggregate must not only have a rough surface texture, but also resist polishing.

Slab Length [AASHTO, (1)]

The joint spacing or distance between free (i.e. untied) transverse joints.

Spalling of Joints: [FHWA, (27)]

Cracking, breaking, chipping, or fraying of slab edge within 1 ft from the face of the joint.

Stone Matrix (Mastic) Asphalt (SMA): [FHWA, (37)]

SMA is a gap-graded HMA that maximizes rutting resistance and durability with a stable stone-on-stone skeleton held together by a rich mixture of AC, filler, and stabilizing agents such as fibers and/or asphalt modifiers. SMA was developed in Europe to resist rutting (permanent deformation) and studded tire wear.

Structural Coefficient: See layer coefficient.

Structural Number (SN): [AASHTO 93)]

A theoretical 'normalized' strength value for a flexible pavement which expresses the cumulative relationship of each layers' coefficient, and the thickness. Where layer coefficient is an empirical characterization of a material's ability to function as a structural component of a pavement.

Subbase: [FHWA, (8)]

The subbase is a layer or layers of specified or selected materials of designed thickness placed on a subgrade to support a base course. The subbase layer is usually of somewhat lower quality than the base layer. In some cases, the subbase may be treated with Portland cement, asphalt, lime, flyash, or combinations of these admixtures to increase its strength and stiffness. A subbase layer is not always included, especially with rigid pavements. A subbase layer is typically included when the subgrade soils are of very poor quality and/or suitable material for the base layer is not available locally, and is, therefore, expensive. Inclusion of a subbase layer is primarily an economic issue, and alternative pavement sections with and without a subbase layer should be evaluated during the design process

Subbase: [CTDOT, (21)]

The subbase shall consist of a clean soil-aggregate mixture of bank or crushed gravel, crusher run stone, reclaimed miscellaneous aggregate containing no more than 2% by weight of asphalt cement or any combinations thereof.

Subgrade: [FHWA, (8)]

The subgrade is the top surface of a roadbed upon which the pavement structure and shoulders are constructed. The purpose of the subgrade is to provide a platform for construction of the pavement and to support the pavement without undue deflection that would impact the pavement's performance. For pavements constructed on-grade or in cuts, the subgrade is the natural in-situ soil at the site. The upper layer of this natural soil may be compacted or stabilized to increase its strength, stiffness, and/or stability.

Subgrade: [CTDOT, (21)]

Subgrade is the area upon which the pavement structure and paved shoulders are placed, including the shoulder base courses and subbase. This is the plane coincident with the bottom of the subbase and the edge of pavement, as shown on the plans and cross-sections.

Subgrade (Soil) Resilient Modulus (M_R): [AASHTO, (1)]

A measurement of a pavement's stress-strain behavior under normal pavement loading conditions. This is primarily a function of soil type however, other factors like moisture and in-place density also can impact the M_R.

Surface Course (HMA): [CTDOT, (21)]

A surface course is defined as the total thickness of the same bituminous concrete mix that extends up to and includes the final wearing surface whether it is placed in a single or multiple lifts, and regardless of any time delays between lifts.

Surface Treatment: [OhioDOT, (12)]

Work performed on a structurally sound pavement intended to preserve the pavement, retard future deterioration, and maintain or improve the functional characteristics without substantially increasing the structural capacity. Surface treatments include such things as chip seals, microsurfacing, thin overlays and diamond grinding. Surface treatments are typically less than 1 in. thick.

Terminal Serviceability Index (P_t): [AASHTO, (1)]

The lowest present serviceability index used in the design equations (2.5 for CTDOT); The Terminal Serviceability (P_t) is the numerical transcription of the condition a road that reaches a point where some type of rehabilitation or reconstruction is warranted.

Transverse Crack:

Cracks that are predominantly perpendicular to pavement centerline [FHWA, (8)].

Cracking the endpoints of which, when connected, form a line that is oriented across the roadway more than along the direction of travel [CTDOT, (23)].

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2001.

20 Appendices

Appendix A. Design Submittal Example

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

memorandum

subject **Pavement Design**
Project No. [redacted]
F.A.P. No. [redacted]
Interchange [redacted]
Town of Orange

date December 30, 2019

to [redacted]
Transportation Supervising Engineer
Bureau of Engineering and Construction

from [redacted]
Transportation Principal Engineer
Bureau of Engineering and Construction

As requested by your memorandum dated October 29, 2019, engineers from the Pavement Design Unit have reviewed the subject project and offer the following recommendations:

<u>Project Description:</u>

The project area evaluated is located on Route 15 (Wilbur Cross Parkway) at the Exit 57 Interchange with Route 34 (Derby Turnpike) in the Town of Orange. The project limits on Route 15 SB begin at Bridge No. 00766 (MP 42.80) and extend southerly approximately 2500 feet (MP 42.33). The limits include a portion of the on-ramp from Route 34 EB to Route 15 SB (15S106) as well as the entirety of each of the four inner loop/cloverleaf ramps within the interchange (15N107, 15S108, 15N109, 15S110).

The purpose of this project is to reduce the occurrence of rear-end crashes and congestion at the on-ramp from Route 34 EB to Route 15 SB. This will be done by removing the stop control at the present ramp limit and providing an acceleration lane for vehicles to merge with the Route 15 mainline traffic. In addition, none of the existing inner loop ramps conform to current geometric design standards due to short radii with restricted sight lines and substandard cross section widths. While not on the High Frequency Crash Location List, this location has historically been included on the SLOSSS. To address this issue, it has been proposed that high friction pavement be placed on these ramps.

Based on existing records, Route 15 is a composite pavement structure consisting of approximately 4"-5" of bituminous concrete pavement on 8" of reinforced concrete pavement on various amounts of granular subbase material within the travel lanes and left/inner shoulder. The right/outer shoulder is a flexible structure and consists of 6"-7" of bituminous concrete pavement on 6" gravel base on various amounts of granular subbase.

A review of as-built plans revealed that the roadway section was originally constructed between 1940-1941 under Project Nos. 0185-0034 and 0185-0062. The concrete pavement was placed approximately 21 feet wide (10-foot outer lane, 11-foot inner lane), with an attached section of dowelled concrete park curbing for the inner shoulders immediately adjacent to the grass median. The shoulder concrete section that the curbing sits on is an additional 2'-8" in total width (the curbing itself is 7" wide).

A subsequent resurfacing project was completed in 1957 under Project No. 0106-0050. This project placed a 2.5" bituminous concrete overlay curb-to-curb over the existing concrete pavement. Several other resurfacing projects were performed under the Department's VIP paving program after this. These include Project No. 0083-0195 in 1987 and Project No. 0173-0334 in 2001. Both projects were done at a 2" depth, but it is anticipated that the 1987 project was placed as a straight overlay without milling, which further increased the roadway elevation and pavement section thickness. Finally, Route 15 within the project limits was last resurfaced recently in 2017 under the Department's pavement preservation program. The scope for this project was a 2.5" mill and overlay with crack filling and patching.

Photolog images from 2019 show an overall good pavement condition on the mainline with little to no surface distresses. Prior to the 2017 resurfacing, predominant distresses were mostly functional and included reflective cracking from the underlying concrete pavement, block cracking, moderate severity deterioration of and along cracks and joints, and general raveling of the mix.

A field visit was made by this unit in February of 2019 to review the pavement condition of the loop ramps for consideration of a High Friction Surface Treatment (HFST). It was found that the loop ramps were all still in good condition from the previous resurfacing efforts, similar to the mainline pavement. The observed distresses were all low in severity and included edge cracking with loss of backing material for lateral support, only a few instances of transverse cracking, light raveling of the longitudinal paving joints (15S110), some isolated gouges and surface defects (15N109), and possible mix segregation.

Recommendations:

Full depth reconstruction will be required for widening of Route 15 to provide an acceleration lane for Route 34 EB traffic entering Route 15 SB mainline. The median area will also be reconstructed to provide the required roadway width, install concrete median barrier, and modify pavement markings. In addition, each of the four loop ramps will be milled and paved with a surface material that can provide improved friction to traditional HMA/PMA mixes.

Reconstruction/Widening

The following full depth pavement structure is recommended for widening of Route 15 SB as well as reconstruction of the on-ramp from Route 34 EB within the project limits:

- 2.5" PMA S0.5 Traffic Level 2, on
- 2" PMA S0.5 Traffic Level 2, on
- 8" HMA S1 Traffic Level 2 (placed in two equal lifts), on
- 10" Subbase

Ramp Resurfacing

Two options were considered for a resurfacing treatment of the loop ramps with high friction pavement within the project limits. Coordination between Highway Design and Pavement Design is likely required to determine which option will be incorporated.

The first option is a higher cost option, which would be to mill and overlay the existing bituminous concrete and then place a High Friction Surface Treatment (HFST) onto the new pavement. For the HFST to perform as intended, the treatment requires the existing pavement to have little to no distresses and is best placed on a new surface. The unit cost for this entire treatment could be roughly $40-$50/s.y. If this option is pursued, the following treatment would be recommended for all loop ramps:

- 1.5" Fine Milling of Bituminous Concrete
- PMA S0.375 Traffic Level 2 wedge course (each lift varying between 0.5" – 2.5", as needed)
- 1.5" PMA S0.375 Traffic Level 2
- High Friction Surface Treatment

Please note that for application on new asphalt pavements, a mandatory 30-day period must elapse prior to the installation of the HFST per the latest special provision.

As previously mentioned, these ramps were resurfaced in 2017 and have begun to show minor distresses. By the time of construction (assumed 2022), distress are expected to progress and it is likely that the condition will be not good enough to place the HFST directly on the existing surface. But at the same time, it will still be early to remove the surface lift that was only placed 5 years prior. Assuming the pavement will still be performing relatively well as expected at this age, the cost of removing and replacing the asphalt surface in order to place the HFST may be unreasonably high.

An alternative, less expensive option would be to mill a lesser depth and then place an Ultra-Thin Bonded PMA Pavement treatment, which also has been shown through testing to have very good frictional characteristics compared to our standard mix types due to the texture that the gap graded aggregate structure provides. This treatment has also been used previously on various ramps and curves to improve areas of reduced skid resistance. The unit cost for this entire treatment could be roughly $15-$20/s.y. If this option is pursued, the following treatment would be recommended for all loop ramps:

- 5/8" (0.625") Fine Milling of Bituminous Concrete
- Ultra-Thin Bonded PMA Pavement

Additional verification can be done as the design process progresses to monitor the condition of these ramps and help guide a reasonable decision.

Items:

The following pavement-related items should be included with this project:

- **0202000 – EARTH EXCAVATION**
- **0202501 – CUT CONCRETE PAVEMENT**
- **0202502 – REMOVAL OF CONCRETE PAVEMENT**
- **0202529 – CUT BITUMINOUS CONCRETE PAVEMENT**
- **0209001 – FORMATION OF SUBGRADE**
- **0212000 – SUBBASE**
- **0305001 – PROCESSED AGGREGATE**
  - This item should be included for backing of bituminous concrete overlays where vertical drop offs occur at the edge of road. It should also be used as the base material to support guiderail.
- **0406158 – PMA S0.375**
- **0406159 – PMA S0.5**
- **0406163A – HIGH FRICTION SURFACE TREATMENT**
- **0406170 – HMA S1**
- **0406192A – POLYMER MODIFIED ASPHALT EMULSION (TYPE 1)**
- **0406193A – ULTRA-THIN BONDED PMA PAVEMENT (TYPE B)**
- **0406236 – MATERIAL FOR TACK COAT**
  - A uniform application of tack coat is required between all pavement lifts unless placed in the same work shift per special provision "Section 4.06 – Bituminous Concrete". Tack coat shall also be placed on the exposed surface of a wedge joint without exception. Please include an estimated quantity in gallons for this item in accordance with these requirements.

- **0406275A – FINE MILLING OF BITUMINOUS CONCRETE (0 TO 4 INCHES)**
  - This item is the Department's standard milling item, which utilizes maximum 5/16 inch tooth spacing. This item should be used for all resurfacing up to 3 inches deep. If there is a desire to provide a fine milled surface for staging or for deeper milling this item can be used beyond the recommended 3 inch depth; however, the estimate should reflect the number of passes needed to accomplish the milling.
- **0406600A – MATERIAL TRANSFER VEHICLE**
  - To promote a uniform mix, the use of a Material Transfer Vehicle (MTV) is required when placing a bituminous concrete surface course per special provision "Section 4.06 – Bituminous Concrete". The use of this equipment is not required if areas of paving are limited to less than 500 feet in length for a single paver pass (ECB-2018-7). Please include an estimated quantity in tons for this item in accordance with these requirements.
- **0406999A – ASPHALT ADJUSTMENT COST**
  - Any bituminous concrete pavement designated as HMA or PMA with an estimated quantity over 1000 tons (or for a project duration greater than 6 months) will require a cost adjustment specified under the Asphalt Adjustment Cost special provision item.

Special Provisions:

The following pavement-related special provisions should be included with this project. The latest version of each specification can be found on ProjectWise at the link below or will be provided by the Pavement Design Unit:

pw:\\ctdot.projectwiseonline.com:CTDOT\Documents\04.00 - Engineering Libraries\Owned Special Provisions\

- **SECTION 4.06 – BITUMINOUS CONCRETE**
- **SECTION M.04 – BITUMINOUS CONCRETE MATERIALS**
- **0406163A – HIGH FRICTION SURFACE TREATMENT**
- **0406192A - POLYMER MODIFIED EMULSION (TYPE 1)**
- **0406193A – ULTRA-THIN BONDED PMA PAVEMENT (TYPE B)**
- **0406275A – FINE MILLING OF BITUMINOUS CONCRETE (0 TO 4 INCHES)**
- **0406600A – MATERIAL TRANSFER VEHICLE**
  - Please note that this item is typically not used as a special provision, but the work has been modified slightly for inclusion in the 0406192A and 0406193A special provision for the ultra-thin treatment.
- **0406999A – ASPHALT ADJUSTMENT COST**

Please contact Joseph Locore at 860-594-3066 or at Joseph.Locore@ct.gov if you have any questions.

Attachments

Appendix B – **Project Initiation/Design Request Form**

STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

memorandum

subject: **Pavement Design Request**

Project No.:
FAP No.:
Title
Town(s)/City

date:

to: Leo L. Fontaine
Transportation Principal Engineer
Bureau of Engineering and Construction

from: Insert Name
Transportation Principal Engineer
Bureau of Engineering and Construction

Attention: Steven Norton

Please provide a pavement design for this project by **Xxxxxxx YY, 20ZZ**.

Attached for your information and use are the following:

- Project Description
- Location Plan
- Soils Investigation Report if available
- Description of additional attachments

Please contact Xxxxx Yyyyyy, Project Engineer, at (860) 594-ZZZZ, should you have any questions or require additional information.

Please address your response to the attention of: Xxxxx Yyyyyy, Project Manager – Xxxxx Yyyyyy, Project Engineer.

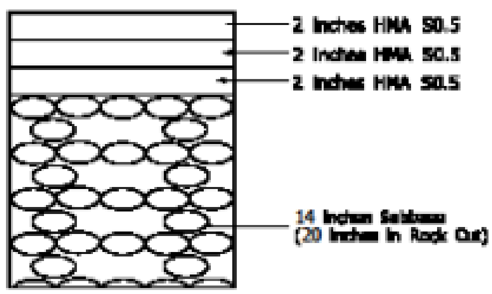
Attachments

Author/Initials
cc: Principal Engineer – Supervising Engineer

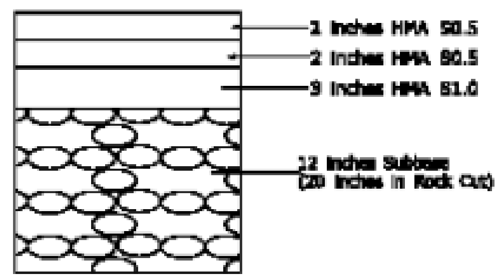
H-50_Pavement Design Request Revised: 1/3/20

Appendix C – Sample Project Design –Flexible Pavement Structures

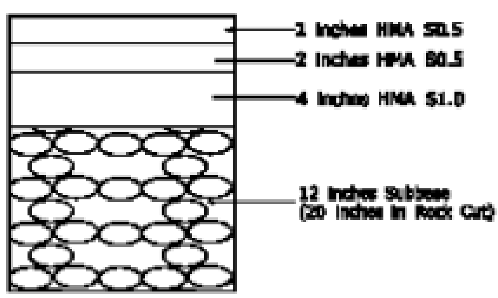
Pavement Structure 1



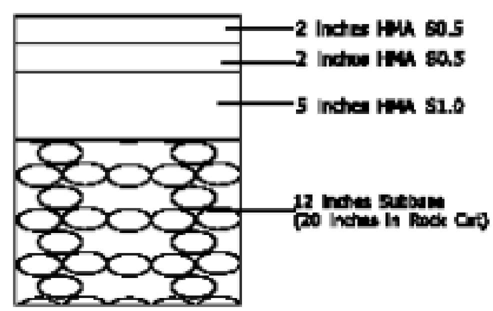
Pavement Structure 2



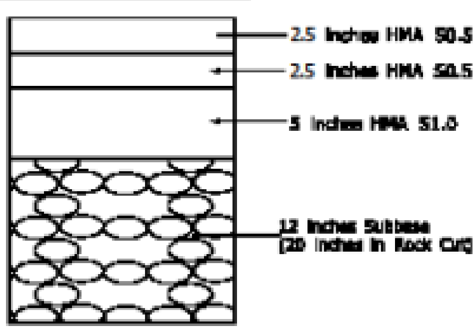
Pavement Structure 3



Pavement Structure 4



Pavement Structure 5



Appendix D – Sample Pavement Evaluation Form for Determining Preservation Needs

Form instructions:

The form is divided into five (5) sections, plus a heading to identify the location of the route segment being evaluated.

Section I. Deterioration drivers

This is an overall assessment of what distress is driving deterioration of the pavement in this section of roadway. Distress forms are the same as the individual distress forms. Up to three main distress forms are listed. If you identify a fourth main distress form, you'll have to write it in. Although it would be unusual to have more than three predominant distress forms driving deterioration, this may be the case on badly deteriorated roadways.

Section II. Cracking

Cracking is one of the most common pavement distress forms. The crack patterns visible at the surface often help explain what the cause of the distress is, in particular whether the cracking is structural in nature or not. Cracking can be confined to the surface (this may be the case for longitudinal paving joints, or low-severity block cracking, slippage cracking, "Spiderweb" cracking that is from an under-asphalted mix, roller cuts of the paving mat, sometimes longitudinal cracking in very thick pavements (top-down cracking that is fatigue related but can be corrected through milling and filling – this could only happen if the pavement structure is very strong and the truck wheel loads are very heavy, otherwise the fatigue cracking would extend through the pavement structure resulting in a full-depth longitudinal wheelpath crack and/or alligator cracking)).

Transverse cracking is cracking the endpoints of which, when connected, form a line that is oriented across the roadway more than along the direction of travel.

Longitudinal cracking is cracking the endpoints of which, when connected, form a line that is oriented along the direction of travel more than across the roadway.

Block cracking is transverse and longitudinal cracking that connects at roughly 90% angles to form blocks of pavement surrounded by cracks. Although blocks formed by this cracking can be large, for purposes of evaluation the maximum block size is 5 ft x 5 ft (a little bit smaller than ½ of the lane width). Note: After blocks form, the wheelpath areas are somewhat weaker to resist vehicle axle loads, so often block cracking contains fatigue cracking (longitudinal wheelpath cracking or alligator cracking) within the block-cracked area. When block and fatigue cracking are combined, first count the fatigue cracking and then subtract that area from the total block-cracked area. Fatigue cracking is an indicator of structural deficiency and is therefore more critical in pavement-preservation decisions.)

The form is available in an Excel format along with a scoping form so it can be filled out in the field on paper. Use the LTPP Distress Identification Manual to learn distress definitions.

Section III. Surface Distress Forms

Surface Distress Forms include raveling, segregation, bleeding/flushing, rutting, and more severe structural failure such as depressions or full-depth potholes and patches.

Section IV. Reflected Joint Condition

In Connecticut there are many composite pavements (Bituminous concrete overlays of Portland-cement concrete (PCC)). The deterioration in these pavements tends to follow that of the underlying concrete slabs, so there are specific distress forms that are related to the joint. There is more relative movement at the transverse joints – horizontal movement from thermal gradients and vertical movement when the load transfer is inadequate and/or there is loss of support.

When old concrete pavements are widened without concrete, there is a differential response from the two pavement structures, often resulting in crack formation and subsequent deterioration. In these situations, it is not uncommon to see fatigue (alligator) cracking on the pavement section outside the concrete. Vertical movements generally cannot be addressed by preservation. The usual strategy is to seal the reflected joints before additional distress forms and the joints require patching.

Section V. Other Distress

There may be distress specific to your jurisdiction or to the project that is not listed in the form.

This area can be used to describe and measure it.

Pavement Evaluation Form

PAVEMENT EVALUATION FORM

	From MP__0.89________		To MP___1.62________	
Route:	From Description: ____			
166	To Description: ____			
	DIRECTION: [ ] Log/Frwrd only [ ] Reverse only [ ] Both [X] Undivided (Both)			

DISTRESS EVALUATION

I. Deterioration Mechanism(s) driving overall condition

1	Block cracking	(predominant)
2	Transverse cracking	
3	Longitudinal cracking (non-wheelpath)	

II. Cracking

Y	Transverse Cracking	80	Avg. Spacing FWEQ* (ft)	0.25	Typical ck. width (in.)	0.25	Max. ck. width (in.)
Y	Longitudinal Cracking	1.5	# FLEQ** (typ. Per lane)	0.125	Typical ck. width (in.)	0.25	Max. ck. width (in.)
			Check if Fatigue Long. Ckg (WP) is present		Check if Non-fatigue Long. Ckg (NWP) is present		
Y	Block Cracking	10	% project area **OR**		Typical Block Size (Max 5 x 5 ft)	5 x 5	ft
			area (square yards)				
Y	Alligator Cracking		% project area **OR**	20	area (square yards)	L	Severity (L,M,H)
Y	Longitudinal Paving Joint	Y	Spots	V	Condition (**V**isible, **O**pen, **R**aveling)		length in feet
			General		Condition (**V**isible, **O**pen, **R**aveling)		% length affected

III. Surface Distress Forms

	Raveling		Extent (**S**pots, **G**eneralized)		Severity (L,M,H)		
			Check if mostly related to longitudinal paving joint				
	Segregation		Extent (**S**pots, **G**eneralized)		Severity (L,M,H)		
			Type (**L**oad to Load, Lon**g**itudinal, **R**andom)				
	Bleeding, Flushing		Extent (**S**pots, **G**eneralized)		Severity (L,M,H)		
	Pushing, Shoving		Extent (**S**pots, **G**eneralized)		Severity (L,M,H)		
	Rutting		Extent (**S**pots, **G**eneralized)		Typical depth (in.)		Cause: Soft mix
					Max. depth (in.)		Cause: Base
Y	Struc. Failure	S	Extent (**S**pots, **G**eneralized)		% project area **OR**		
	(Full-depth patch req'd)	2	number	20	cum. area (s.y.)		
	Surface Failures		Extent (**S**pots, **G**eneralized)		% project area **OR**		
	(Surface potholes/ptch req'd)		number		cum. area (s.y.)		

IV. Reflected Joint Condition (Composite Pavt Only - Hot-mix asphalt overlays of underlying concrete pavement

	Transverse Joint Reflection Cracks		General Severity*** (**N**one, **L**ow, **M**oderate, **H**igh)
			% of transverse joint reflection cracks requiring full-depth repair, **OR**
			Number of transverse joint reflection cracks requiring full-depth repair
	Longitudinal Joint Reflection Cracks		General Severity*** (**N**one, **L**ow, **M**oderate, **H**igh)
			% of length of joint reflection crack requiring full-depth repair, **OR**
			Length in feet requiring full-depth repair
			Check if long. Jt. Refl. Crack distress is mostly at edge of concrete with hot-mix-asphalt shoulder (where fatigue distress may appear)

V. Other Distress Forms (List, Specify Extent (with units) and Severity)

1	________________	Extent______________	Severity_____________
2	________________	Extent______________	Severity_____________
3	________________	Extent______________	Severity_____________

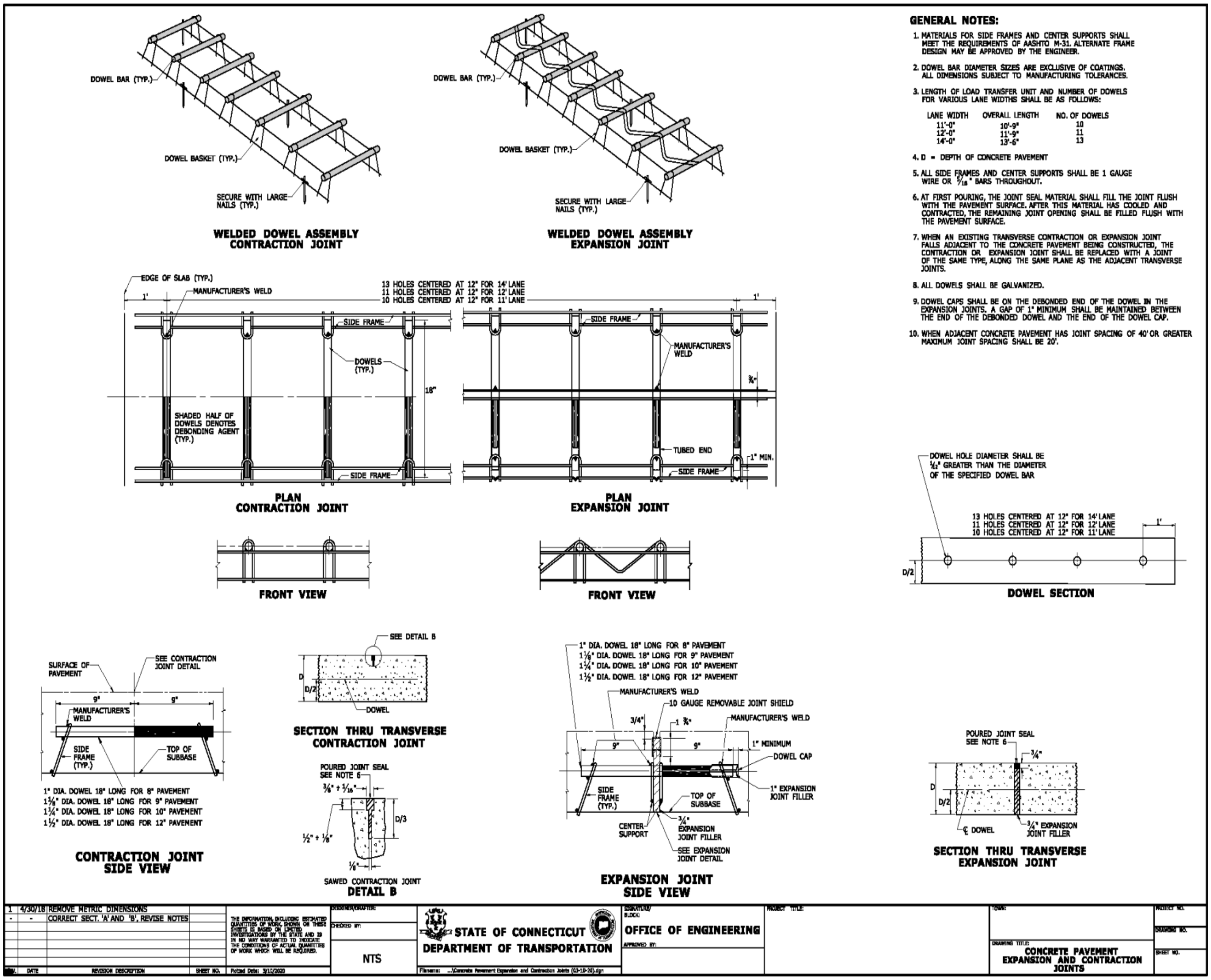
Notes:

*FWEQ = Full-width Equivalent for lane being surveyed (if many lanes, use % of the total width or use a representative lane)

**FLEQ = Full-length Equivalent for lane being surveyed (if many lanes, use total observed for road and divide by # of lanes)

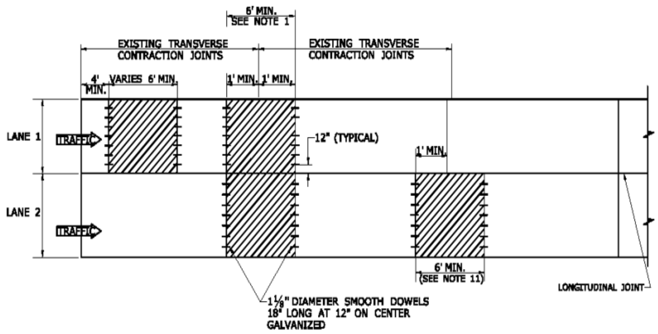
***Severity of Joint Reflection Cracks: in composite pavement	**N**one = no joint reflection crack is visible
	Low = single joint reflection crack with little or no spalling
	Moderate = multiple joint-reflection cracks
	High = Joint reflection crack is open more than 2", potholed/patched, or bumpy

Appendix E. Expansion and Contraction Joints and Standard Drawings for Concrete Pavement Replacement

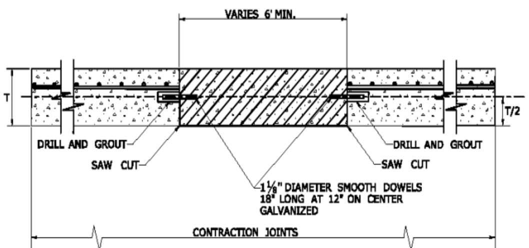


GENERAL NOTES:

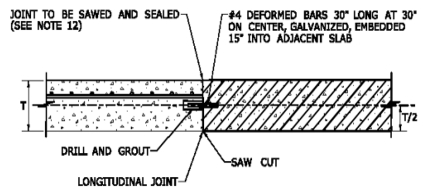
1. THE MINIMUM LENGTH OF ANY REPAIR IN THE LONGITUDINAL DIRECTION SHALL BE SIX (6) FEET. THE WIDTH SHALL BE THE FULL LANE WIDTH OR THE FULL SLAB WIDTH, WHICHEVER IS GREATER.
2. SLAB REPAIRS, 12 FEET OR GREATER IN LENGTH, MAY ESTABLISH A "DUMMY JOINT" (TO CONTROL SHRINKAGE CRACKING) IN THE MIDDLE OF THE PATCH CONSISTING OF A TOOLED OR SAWCUT TRANSVERSE JOINT, OF THE SAME DIMENSIONS AS SHOWN IN THE TRANSVERSE JOINT DETAILED DRAWINGS. MORE THAN ONE DUMMY JOINT MAY BE ESTABLISHED AS LONG AS IT IS A MINIMUM OF 6 FEET FROM ANY OTHER TRANSVERSE JOINT OR DUMMY JOINT. THE CONTRACTOR SHALL DETERMINE THE USE OF DUMMY JOINTS.
3. WHEN DRILLING THE DOWEL BAR HOLES, THE FIRST HOLE SHALL BE DRILLED 1 FOOT FROM THE EDGE OF THE SLAB AND THEN DRILLED EVERY FOOT. FOR EXAMPLE, A 12 FOOT SLAB WILL REQUIRE 11 DRILLED HOLES WITH THE HOLES ON THE ENDS DRILLLED 1 FOOT FROM THE EDGE OF THE SLAB.
4. WHERE CONCRETE PAVEMENT DISTRESS IN ADJACENT LANES IS SIMILAR, AND WHEN APPROVED BY THE ENGINEER, THE PATCH BOUNDARY (S) SHALL BE EXTENDED TO AVOID SMALL OFFSETS BETWEEN PATCHES IN ADJACENT LANES.
5. FOR FULL SLAB REPLACEMENTS (INCLUDES SLAB LENGTHS OF 25 FEET OR GREATER) AN ADDITIONAL TRANSVERSE JOINT SHALL BE ESTABLISHED IN THE MIDDLE OF THE FULL-DEPTH PATCH. THIS TRANSVERSE JOINT SHALL BE A CONTRACTION JOINT UTILIZING A FULL DOWEL BAR BASKET ASSEMBLY, AS SPECIFIED, TO BE PREPARED AND PLACED AT THE CENTER OF THE SLAB TO FORM A NEW CONTRACTION JOINT.
6. FOR DOWEL BAR ASSEMBLIES, ALL SIDE FRAMES SHALL BE 1 GAUGE WIRE MEETING THE REQUIREMENTS OF AASHTO M-31.
7. FOR REPAIRS LESS THAN A FULL SLAB LENGTH, NO TIE BARS SHALL BE RE-INSTALLED. FOR FULL SLAB LENGTH REPAIRS, #4 TIE BARS SHALL BE DRILLED AND SET EVERY 30 INCHES, OR AS SPECIFIED, ALONG THE LONGITUDINAL JOINT OF THE EXISTING ADJACENT CONCRETE SLAB(S).
8. WHEN A FULL-DEPTH SLAB REPAIR IS PERFORMED ON A COMPOSITE PAVEMENT (ASPHALT PAVEMENT OVER CONCRETE PAVEMENT), THE SAWCUTTING SHALL INCLUDE ANY OVERLYING BITUMINOUS LAYERS AS WELL AS THE FULL DEPTH OF THE CONCRETE SLAB. WHEN PLACING AND FINISHING THE CONCRETE, UNLESS OTHERWISE SPECIFIED, IT SHALL BE STRUCK OFF AND FINISHED EVEN WITH THE EXISTING SURROUNDING BITUMINOUS SURFACE. ALL CONCRETE PATCHES SHALL NOT DEVIATE MORE THAN $\frac{1}{4}$ INCHES IN ANY DIRECTION WHEN TESTED WITH A 10 FOOT STRAIGHTEDGE.
9. ANY PATCHES WITH EXPANSION JOINTS INSTALLED IN A COMPOSITE PAVEMENT SHALL BRING THE TYPE 2, EXPANSION JOINT MATERIAL, UP TO THE SURFACE OF THE EXISTING COMPOSITE PAVEMENT PRIOR TO PLACING AND FINISHING THE PATCH.
10. ANY UNCONTROLLED SHRINKAGE CRACKS THAT FORM IN THE SLAB REPAIR, OUTSIDE OF THE TRANSVERSE OR DUMMY JOINTS, ARE SUBJECT TO REMOVAL, REPLACEMENT OR REPAIR, AS DETERMINED BY THE ENGINEER, AT NO ADDITIONAL COST TO THE DEPARTMENT.
11. WHENEVER A REPAIR IN ONE LOCATION IS CONSTRUCTED IN TWO OR MORE SEGMENTS BECAUSE OF TRAFFIC RESTRICTIONS OR STAGING, EACH SEGMENT SHALL BE CONSIDERED A SEPARATE PATCH MEETING THE 6 FEET MINIMUM DIMENSION.
12. ONLY NEWLY FORMED TRANSVERSE AND LONGITUDINAL JOINTS NOT COVERED WITH NEW HMA WILL BE SAWED AND SEALED WITH JOINT SEALANT. ANY SEALING OF JOINTS WILL BE PERFORMED AND PAID FOR UNDER SEPARATE ITEMS OF WORK.



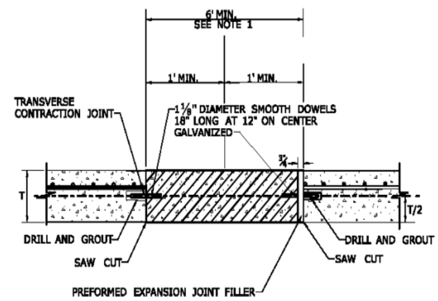
CONCRETE PAVEMENT FULL DEPTH REPAIR
TYPICAL ROADWAY PLAN



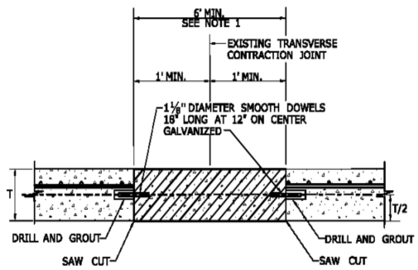
REPAIR FULL DEPTH ONE LANE



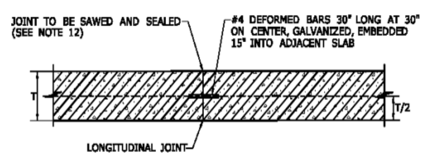
REPAIR ALONG LONGITUDINAL JOINT



REPAIR AT EXPANSION JOINT



REPAIR AT CONTRACTION JOINT



REPAIR THROUGH LONGITUDINAL JOINT

LEGEND

- EXISTING WELDED WIRE FABRIC (10" PAVEMENT ONLY)
- EXISTING PAVEMENT
- PROPOSED CONCRETE PAVEMENT REPAIR - FULL DEPTH
- CONCRETE PAVEMENT THICKNESS: T

REV. | DATE | REVISION DESCRIPTION | SHEET NO. | Plotted Date: 2/21/2020

THE INFORMATION, INCLUDING ESTIMATED QUANTITIES OF WORK, SHOWN ON THESE SHEETS IS BASED ON LIMITED INVESTIGATIONS BY THE STATE AND IS IN NO WAY WARRANTED TO INDICATE THE CONDITIONS OF ACTUAL QUANTITIES OF WORK WHICH WILL BE REQUIRED.

DESIGNER/DRAFTER: MS/EL
CHECKED BY: DD

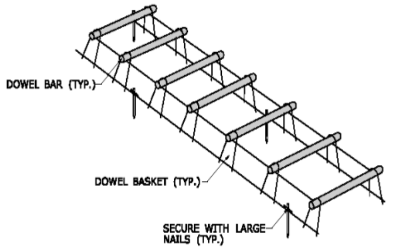
STATE OF CONNECTICUT
DEPARTMENT OF TRANSPORTATION

SIGNATURE/BLOCK: OFFICE OF ENGINEERING
APPROVED BY:

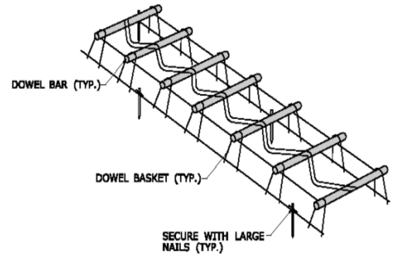
PROJECT TITLE: CONCRETE PAVEMENT REPLACEMENT FOR ROADWAY (FULL DEPTH)

TOWN:
DRAWING TITLE:
PROJECT NO.
DRAWING NO.
SHEET NO. 1 OF 2

Filename: ...\Concrete Pavement Replacement for Roadway (Full Depth) Sheet 1 of 2 (02-21-20).dgn



WELDED DOWEL ASSEMBLY CONTRACTION JOINT



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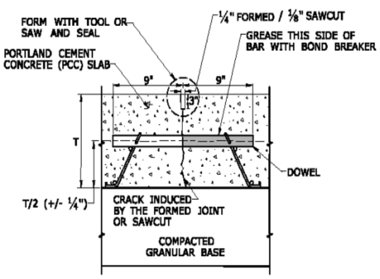
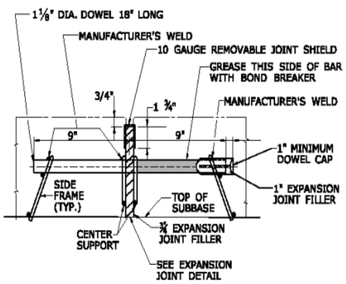
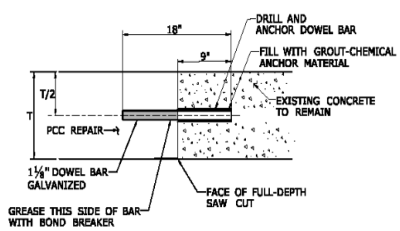


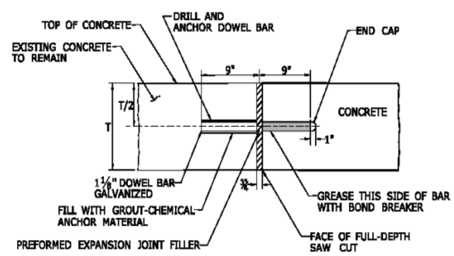
CONTRACTION JOINT WITH DOWEL BASKET ASSEMBLY



EXPANSION JOINT SIDE VIEW



TRANSVERSE CONTRACTION JOINT



SECTION THROUGH EXPANSION JOINT

REV.	DATE	REVISION DESCRIPTION	SHEET NO.	THE INFORMATION, INCLUDING ESTIMATED QUANTITIES OF WORK, SHOWN ON THESE SHEETS IS BASED ON LIMITED INVESTIGATIONS BY THE STATE AND IS IN NO WAY WARRANTED TO INDICATE THE CONDITIONS OF ACTUAL QUANTITIES OF WORK WHICH WILL BE REQUIRED. Plotted Date: 2/21/2020	DESIGNER/DRAFTER: MS/EL CHECKED BY: DD	STATE OF CONNECTICUT DEPARTMENT OF TRANSPORTATION	SIGNATURE/BLOCK: OFFICE OF ENGINEERING APPROVED BY:	PROJECT TITLE: CONCRETE PAVEMENT REPLACEMENT FOR ROADWAY (FULL DEPTH)	TOWN: DRAWING TITLE:	PROJECT NO. DRAWING NO. SHEET NO. 2 OF 2

Filename: ...\Concrete Pavement Replacement for Roadway (Full Depth) Sheet 2 of 2 (02-21-20).dgn

Appendix F. Additional Pavement Design Resources

Additional standards and guidance related to pavement engineering are listed below with appropriate links.

Technical Guidance Publications – The FHWA, AASHTO and other pavement research and highway organizations such as NAPA, NCAT, Connecticut Advanced Pavement Laboratory (CAP Lab) at UConn and the Asphalt Institute provide useful information and guides. Information can be found by 'Googling' most of these organizations. Of particular interest for pavements are:

FHWA – Pavements - https://www.fhwa.dot.gov/pavement/guid.cfm The site provides access to various guides, technical briefs and reports on topics such as recycling, pavement friction, quality assurance and preservation.

AASHTO - Guide for the Design of Pavement Structures (1993 AASHTO Design Method)- This is a primary document used to design new and rehabilitated highway pavements. All versions of the AASHTO Design Guide are empirical design methods based on field performance data measured at the AASHO Road Test in 1958-60. https://bookstore.transportation.org/item_details.aspx?id=374

NAPA - The National Asphalt Pavement Association provides technical, educational, and marketing materials and information to its members, and supplies technical information to users and specifiers of paving materials. http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=130&Itemid=225

NCAT -National Center for Asphalt Technology - Auburn University - NCAT was established in 1986 as a partnership between Auburn University and the National Asphalt Pavement Association (NAPA) Research and Education Foundation. NCAT was created to ensure the asphalt industry's ability to provide durable, sustainable, quiet, safe and economical pavements. http://eng.auburn.edu/research/centers/ncat/

CAP Lab - Connecticut Advanced Pavement Laboratory – University of Connecticut – Connecticut Transportation Institute. The CAP Lab is a key organization for CTDOT's implementation of Superpave, as well as ongoing state-of-the-art pavement-related research. http://www.cti.uconn.edu/caplab/

ACPA – American Concrete Pavement Association - Founded in 1963, The ACPA is the world's largest trade association that exclusively represents the interests of those involved with the design, construction, and preservation of concrete pavements. http://www.acpa.org/advocacy/

NCPTC – National Concrete Pavement Technology Center – Iowa State University – is a national hub for concrete pavement research and technology transfer. The Center was founded in 2000 and has been instrumental in developing and helping to advance the nation's strategic plan for concrete pavement research, The CP Road Map. http://www.cptechcenter.org/

PTC - The Pavement Tools Consortium is a partnership between several state DOTs, the FHWA, and the University of Washington to further develop and use computer-based pavement tools. The Consortium is funded via a Pooled Fund arrangement and managed by the Washington State Department of Transportation and the Maryland State Highway Administration. The consortium website is an information resource for the pavement community. It provides a ready reference on common paving topics, the ability to look up typical methods and practices, and links to additional resources. http://www.pavementinteractive.org/