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GUIDELINES FOR LIMITING DAMAGE TO FLEXIBLE AND COMPOSITE PAVEMENTS DUE TO THE PRESENCE OF WATER

PHASE I TECHNICAL REPORT

Prepared For:
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies

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Prepared By:

L. M. Pierce, N. Kebede, and S. Seeds
Applied Pavement Technology, Inc.
Urbana, Illinois

and

G. White
Pavia Systems, Inc.
Seattle, WA

March 2015

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CHAPTER 1. INTRODUCTION

Background and Problem Statement

There are a number of ways in which the presence of water contributes to damage in asphalt and composite pavements. Understanding these mechanisms begins with an understanding of the sources of water in these pavement structures. Starting with the surface layer, for example, water can enter the pavement structure through cracks, poorly constructed longitudinal joints, open-graded mixtures, and/or poorly consolidated asphalt layers. Water from the surface or outside the pavement structure (e.g., from shoulders or beneath the pavement structure) can saturate and weaken aggregate base and subgrade soils. Pavement structures that restrict the positive flow of water away from the pavement section (e.g., improper cross-slope, edge build-up, bathtub pavement sections) can weaken the pavement layers and accelerate pavement damage and reduce pavement life. Not adequately accounting for existing environmental conditions can also adversely affect pavement performance due to the presence of moisture. Examples include insufficient structural depth to account for freeze-thaw conditions, high water tables, perched water tables, or water trapped between poorly bonded or non-bonded layers.

The resulting pavement damage can include increased susceptibility of the pavement materials to the presence of moisture and reduced strength of certain pavement materials when wet or saturated. In a study conducted by Lu, Harvey, and Monismith (2007), a statistical analysis of condition surveys and field sampling results indicated that air void content, pavement structure, cumulative rainfall, asphalt mix type (dense-graded versus gap-graded rubber modified), anti-strip additive (lime or liquid), and pavement age are variables that have a significant effect on the amount of pavement damage caused by water. Lu, Harvey, and Monismith (2007) also concluded that high air-void asphalt mixtures not only allowed more water intrusion, they also resulted in significantly reduced fatigue life in wet conditions; less than optimum asphalt binder content resulted in lower moisture resistance under repeated loading.

Other studies have reported that the presence of water in pavement layers adversely impacts the bearing capacity and service life of both asphalt and concrete pavements (Ceylan et al. 2013, Grover and Veeraragavan 2010). In addition, in cold climates, the presence of water in pavement layers is further magnified due to potential damage from freeze-thaw effects.

The number of references related to asphalt mix design, the use of asphalt binders, drainage systems, practices for mitigating freeze-thaw damage, and so on, is extensive; however, there is no single document addressing issues and techniques for limiting pavement damage caused by water. Therefore, there is a need to develop a concise practical guide, training course materials, and technical tools to facilitate effective strategies in limiting damage due to the presence of water in asphalt and composite pavements.

Research Objective

The objective of this research is to develop (1) guidelines for limiting damage to flexible and composite pavements due to the presence of water, (2) a stand-alone web-based application that provides ready access to the guidelines (3) a syllabus and materials for a 1-day training course on the use of the guidelines by practicing engineers, and (4) a NCHRP webinar. The guidelines will target practitioners in the pavement and materials engineering community. At a minimum, the guidelines will address the effects of:

- Pavement structure (e.g., drainage layers, "bath tubs," pavement widening, and shoulders).
- Roadway geometry (e.g., cross slope, sag, and ditch lines).
- Regional climate (e.g., wet-freeze).
- Materials (e.g., anti-strip agents and aggregates).
- Construction practices (e.g., longitudinal joint construction and underdrain location).
- Maintenance practices (e.g., crack filling and outlet cleaning).

The guidelines will be supported by technical commentary necessary to enhance their understanding and application by the practicing engineer.

Research Scope and Approach

To accomplish the stated objectives, the project is divided into two phases of work consisting of the following tasks:

<u>Phase I</u>
Task 1. Perform literature search and review.
Task 2. Conduct agency and industry survey.
Task 3. Conduct site visits of agency and industry representatives.
Task 4. Prepare an outline for the guide document.
Task 5. Prepare and submit a Phase I technical report.

<u>Phase II</u>
Task 6. Develop guide document and stand-alone web-based application.
Task 7. Develop NCHRP webinar.
Task 8. Develop training materials.
Task 9. Prepare and submit draft and final report.

A key component of Phase I was gathering information on the practices and experiences of state highway agencies (SHAs) and industry on methods for mitigating damage in asphalt and composite pavements due to the presence of water. This information was accomplished by conducting a detailed literature search/review and through an online survey (including follow-up questions, as needed) with SHAs and industry personnel.

The literature search/review focused on recent or on-going studies examining:

- Material selection and testing (e.g., asphalt additives, asphalt mix design, aggregate base, treated base, and subgrade soils).
- Pavement drainage (e.g., design process, drainage systems).
- Pavement structure (e.g., pavement type selection, thickness design).
- Climate impacts (e.g., freeze-thaw, seasonal variation of in situ materials).
- Pavement performance (e.g., modeling, non-destructive testing, field testing).

- Construction specifications (subgrade soils, pavement structure, shoulder, and drainage systems).
- Preservation and rehabilitation (drainage systems and pavement structure).

The SHA and industry surveys consisted of a series of questions in relation to agency experience and practice for mitigating damage due to the presence of water. The survey was categorized according to experience in mitigating damage, roadway geometry requirements, drainage design details, pavement structural design requirements, material selection, pavement condition assessment, construction practices, drainage and pavement preservation and rehabilitation treatments, and an overall assessment of key activities for mitigating damage in asphalt and composite pavements due to the presence of water.

Results of the literature review and surveys were used to develop the draft outline of the guide document, as well as an outline of a proposed AASHTO standard practice.

Overview of Report

Including this introductory chapter, this report is presented in six chapters. Chapter 2 describes the literature search and review activities and presents a summary of the findings of those activities. Chapter 3 discusses the online surveys performed with SHAs and industry personnel and presents the corresponding results. Chapter 4 discusses the evaluation of agency and industry survey responses for identifying potential site visits. Chapter 5 presents the draft outline of the guide document and proposed AASHTO standard practice. Chapter 6 presents the work plan for the development of the stand-alone web-based application.

CHAPTER 2. SUMMARY OF LITERATURE

Literature Search

A comprehensive literature search was conducted at the outset of the study. This search focused on (1) moisture damage in pavements, (2) methods for mitigating pavement damage due to water, (3) pavement subsurface drainage, and (4) preservation and rehabilitation of drainage systems. The search was largely limited to studies undertaken in the last 10 years and was performed primarily via the Internet and through manual searches of the libraries, files, and other resource materials of the individual research team members.

The following key sources were used in the literature search:

- NCHRP and the Transportation Research Board (TRB).
- American Association of State Highway and Transportation Officials (AASHTO).
- Federal Highway Administration (FHWA) and National Highway Institute (NHI).
- State Departments of Transportation (DOT) pavement drainage manuals, guides, specifications, and plans.
- National pavement research programs and centers (e.g., Innovative Pavement Research Foundation [IPRF], National Center for Asphalt Technology [NCAT], National Concrete Pavement Technology Center [CP Tech Center]).
- Pavement preservation organizations (e.g., Foundation for Pavement Preservation [FP^2], National Center for Pavement Preservation [NCPP]).
- Industry Associations (e.g., National Asphalt Pavement Association [NAPA], American Concrete Pavement Association [ACPA]).

Over 150 documents were identified and obtained (either in electronic or hardcopy form) for possible use in this study. Each of the collected documents was catalogued and reviewed in greater detail. A bibliography of identified document is provided in Appendix A.

Literature Review

This section briefly summarizes some of the identified practices and procedures for limiting damage due to the presence of water in asphalt and composite pavements from published literature. It is not, by any means, an inclusive list of all practices or all aspects of the proposed guide, but provides examples of the type of information that is readily available for use during development of the guideline during Phase II.

Purpose of Subsurface Drainage

The primary purposes of subsurface drainage is to minimize the presence of water within the pavement structure. The presence of water can lead to the softening or weakening of pavement layers and subgrade soils, the degradation of the material quality, and the loss of bond between bound layers.

Sources of Water

It has long been recognized that saturated subgrade soils, regardless of pavement thickness, can results in rapid pavement deterioration, especially when combined with heavy truck traffic and moisture-susceptible materials. The primary sources of water intrusion in a pavement structure include water seeping upward from a high ground water table due to capillary action or vapor movements, flowing laterally from the pavement edge and side ditches, seeping from higher ground, and rain and meltwater infiltrating through joints and cracks (Figure 1).

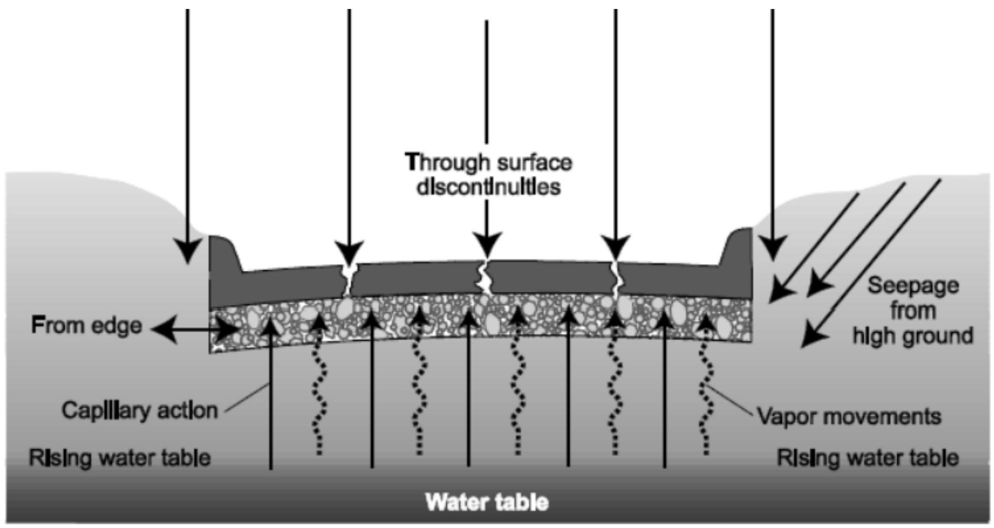


Figure 1. Sources of water (adapted after Ceylan et al. 2013).

Causes of Moisture-Related Distress

The presence and prolonged effect of water in the pavement structure can lead to premature material failure and accelerated distress. Table 1 summarizes sources of moisture-related distresses in asphalt pavements.

Moisture-related issues specific to the asphalt mixture may be due to the use of moisture sensitive aggregates, asphalt binder sensitivity, material production, and construction issues. Each of these are described as follows (TRB 2003):

- Aggregates—aggregate surface chemistry and the amount of clay fines can affect adhesion with the asphalt binder. Methods for addressing aggregate-related moisture issues include using anti-strip agents, limiting the percent of fine material, and quality control through processing.
- Asphalt binder—moisture affects the ability of the asphalt binder to promote adhesion to the aggregate and overall cohesion of the mastic.
- Material production—during mixture production, several issues can impact the moisture-susceptibility of the mixture, including the method used to refine the binder; cleanliness, moisture content and hardness during aggregate production; and mix handling and storage.

- Construction—key issues that can impact moisture-susceptibly of the asphalt mixture during placement include weather conditions that may cool the mix resulting in potential compaction issues, trap water between layers and within the mix, improper mix handling that can result in segregation, thereby increasing the mixture's permeability, and insufficient control of mixture additives.

Table 1. Moisture-related distress in asphalt pavements (adapted after Christopher, Schwartz, and Boudreau 2006).

Distress Type	Moisture Problem	Climate Problem	Materials Problem	Load Associated	Defect Location		
					Asphalt	**Base**	**Subgrade**
Bump or Distortion	Excess moisture	Frost heave	Volume increase	No	No	No	Yes
Corrugation or Rippling	Slight	Moisture, temperature	Unstable mix	Yes	Yes	Yes	No
Stripping	Yes	Moisture	Loss of bond	No	Yes	No	No
Rutting	Excess in granular layers or subgrade	Moisture	Plastic deformation, stripping	Yes	Yes	Yes	Yes
Depression	Excess moisture	Suction, materials	Settlement, fill material	No	No	No	Yes
Potholes	Excess moisture	Moisture, temperature	< strength, > moisture	Yes	Yes and between layers	Yes	Yes
Longitudinal Cracking	No, but is accelerated	No	Construction	No	Poor construction	No	No
Alligator Cracking	No, but is accelerated	Spring-thaw, strength loss	Thickness	Yes	Yes, mix	Yes	No
Transverse Cracking	No, but is accelerated	Low temperature, freeze-thaw cycles	Thermal properties	No	Yes, temperature susceptible	No	No
Slippage Cracking	Yes	No	Loss of bond	Yes	Yes, bond and between layers	No	No

For existing asphalt and composite pavements, it may be difficult to determine if surface distress is due to asphalt mixture moisture-related or construction-related problems. Distresses related to stripping, such as rutting, bleeding, fatigue cracking, potholes, and raveling, can also be associated with too much or too little asphalt binder, poor quality control on aggregate gradation, and insufficient field compaction (TRB 2003). Figure 2 illustrates an example flowchart that may be used to identify stripping versus construction-related distress.

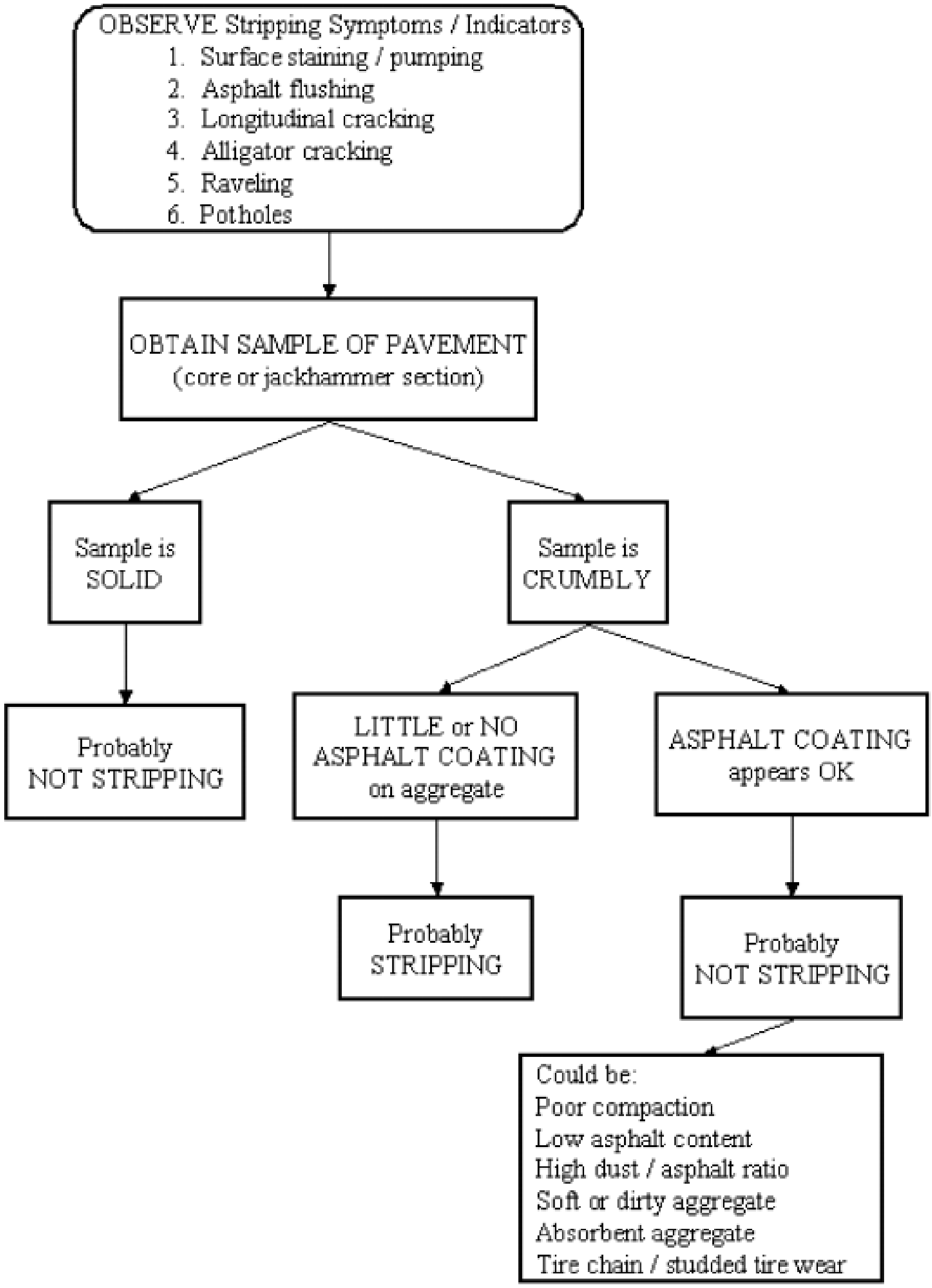


Figure 2. Example flowchart for defining moisture-related distress (TRB 2000).

Design Features

The following provides a brief summary of design features related to roadway geometrics, materials and mix design, and subsurface drainage.

Geometric Design

In order to facilitate the flow of water from the pavement surface, roadways should be built and maintained with a proper cross-slope (or crown). The AASHTO *Green Book* (AASHTO 2011) provides appropriate cross-slope and grade requirements for pavements.

Materials

The importance of selecting and designing each aspect of the pavement structure and drainage system is key to both constructability and long-term performance. The following briefly describes some of the pavement and drainage system materials.

Permeable Base

Permeable bases consist of durable, crushed, and angular aggregate. The permeable base must also be designed for stability to ensure constructability and long-term performance. Recommended properties for treated permeable bases are shown in Table 2.

Table 2. Recommended properties for treated permeable base (adapted after Christopher, Schwartz, and Boudreau 2006).

Specification	**Asphalt-Treated**		**Cement-Treated**	
	Requirement	**Test Method**	**Requirement**	**Test Method**
Aggregate	• Hard, durable, at least two fractured faces; preferably 98% crushed stone • LA Abrasion < 45% • Soundness loss < 12% (sodium sulfate) or < 18% (magnesium sulfate)	• Visual classification • AASHTO T 96 • AASHTO T 104	• Hard, durable, at least two fractured faces; preferably 98% crushed stone • LA Abrasion < 45% • Soundness loss < 12% (sodium sulfate) or < 18% (magnesium sulfate) • Use only clean aggregates	• Visual classification • AASHTO T 96 • AASHTO T 104
Binder	• Binder content to provide well-coated aggregate; minimum binder content between 2.5-3% by weight, based on mix design • Stiff asphalt grade (typically 1 grade stiffer than surface course)	• ASTM D2489 • AASHTO T 283	• Cement content to provide well-coated aggregate; 220 to 285 lb/yd^3 • Water-to-cement ratio range of 0.3 to 0.5 • Slump of 1 to 3 inch	• AASHTO M 85
Permeability	• > 1000 ft/day	• ASTM D3637	• > 1000 ft/day	• ASTM D3637

Geotextiles

Geotextiles are typically used to prevent intermixing between drainable layers and the subgrade and in edgedrain systems. Geotextile selection is based on filtration criteria and survivability and endurance criteria to withstand construction traffic. As an edgedrain filter, the geotextile should provide unimpeded water flow over the life of the system. Geotextile selection is determined using the following steps:

1. Determine D_{85}, D_{15}, and percent finer than the No. 200 sieve for the material to be separated or filtered.
2. Determine the permeability of the base or subbase material that will be placed adjacent to the geotextile.
3. Determine apparent open size, permeability, and permittivity as outlined in Holtz, Christopher, and Berg (1998).
4. Ensure geotextile meets the installation requirements (see Table 3). Class 1 geotextiles are recommended for use with California bearing ratio (CBR) values less than 3 and when heavy construction equipment is expected. Class 2 geotextiles are recommended for CBR > 3, base/subbase layers greater than 6 inch, normal weight construction equipment, and for filters on edgedrains.

Table 3. Geotextile survivability requirements (AASHTO M 288-96).

Test	ASTM Test Method	Units	Geotextile Class[1]			
			Class 1		Class 2	
			< 50 %	≥ 50%	< 50 %	≥ 50%
Grab Strength	D4632	N	1400	900	1100	700
Seam Strength	D4632	N	1200	810	990	630
Tear Strength	D4533	N	500	350	400	250
Puncture Strength	D4833	N	500	350	400	250
Burst Strength	D3786	kPa	3500	1700	2700	1300

[1] Elongation measured in accordance with ASTM D4632 with < 50% typical of woven geotextiles and ≥ 50% typical of nonwoven geotextiles.

Asphalt Mixtures

When exposed to water, some asphalt mixtures lose adhesion between the aggregate particles and the asphalt binder. This is predominantly attributed to the aggregate material properties, although some asphalt binders can be susceptible to stripping. Asphalt mixtures that are moisture-susceptible can lead to oxidation, water damage, raveling, and cracking (Roberts et al. 1996, Brown et al. 2004). Antistripping agents can be added to the asphalt mixture to minimize its susceptibility to stripping.

Evaluation of asphalt mixture susceptibility to moisture is conducted through laboratory testing; primarily to evaluate the effectiveness of antistrip treatments. Laboratory testing can be conducted on loose mixtures, representative mixtures, and compacted mixtures.

- Loose mixture testing includes the Texas DOT boiling test and ASTM D3625. These tests include soaking and boiling (time and temperature varies by test method) the loose mixture and evaluating the degree of bond loss.
- Representative mixture testing includes evaluating a portion of the fine, one-sized aggregate coated with asphalt, compacted, placed on a pedestal, and subject to freeze-thaw cycles until fracture.'
- Compacted mixture testing includes AASHTO T 283, ASTM D1075, and ASTM D467. These test methods evaluate the compacted mixture based on mix designs for paving projects. Samples are subjected to water saturation, with or without freeze-thaw cycles, conditioned and unconditioned, and tested for measures of stiffness-strength (e.g., resilient modulus, tensile strength). Wheel-tracking tests, such as the Hamburg and the Asphalt Pavement Analyzer, evaluate the mixture's resistance to moisture by subjecting the compacted mixture samples to repeated wheel loading in the presence of water.

Asphalt mixtures can be treated with hydrated lime, portland cement, fly ash, flue dust, and polymers in an effort to reduce the mixture's level of moisture-susceptibility. However, predominate treatments include hydrated lime and liquid antistrip (see agency survey results in Chapter 2).

Subsurface Drainage

The design of a reliable and adequate subsurface drainage system should begin with an assessment of the need for subsurface drainage. Table 4 provides general guidelines based on climate condition, number of heavy trucks, and subgrade permeability rates.

Table 4. Assessing the need for subsurface drainage (adapted after Christopher, Schwartz, and Boudreau 2006).

Climate Condition	> 12 million[1,2]			2.5 to 12 million[1,2]			< 2.5 million[1,2]		
	Subgrade Permeability, $k_{subgrade}$ (m/day)								
	< 3	3 to 30	> 30	< 3	3 to 30	> 30	< 3	3 to 30	> 30
Wet-freeze	R	R	F	R	R	F	F	NR	NR
Wet no-freeze	R	R	F	R	F	F	F	NR	NR
Dry-freeze	F	F	NR	F	F	NR	NR	NR	NR
Dry-no-freeze	F	NR	NR	NR	NR	NR	NR	NR	NR

1 20-year design lane heavy trucks.
2 F: Feasible, the addition of subdrainage should also consider past performance, life-cycle cost, and durability of paving materials.
R: Recommended, some form of subdrainage or other design features are recommended to combat potential moisture problems.
NR: Not required, subsurface drainage is not required.

Once the need for subsurface drainage has been established and it's been determined that adequate capacity can be constructed cost effectively, the following steps can be conducted to determine the drainage system requirements (http://www.vaasphalt.org/asphalt-pavement-drainage/):

- Determine, during the preliminary soil survey, the location of all seepage areas which may cause water to enter the structural elements of the pavement.
- Determine the maximum rate of flow of water which may enter the structural section from any seepage and infiltration areas.
- Locate a source of aggregate suitable for filter material to prevent clogging of drains by water-borne soil.
- Locate a source of aggregate which, if needed, may be used as drain rock to remove the water from beneath the pavement.
- Combine these materials into a design of adequate capacity to meet all requirements for the life of the pavement.

Typically used pavement subsurface drainage systems include daylight bases, edgedrains, and permeable bases, interceptor drains, and underdrains. Each drainage system is briefly described in the following sections.

Daylighted Base

Daylighted bases consist of a dense-graded aggregate base that extends to a roadside ditch or side slope. Water is drained from the pavement section through the base and into the ditch. An example cross-section for a daylighted base is shown in Figure 3.

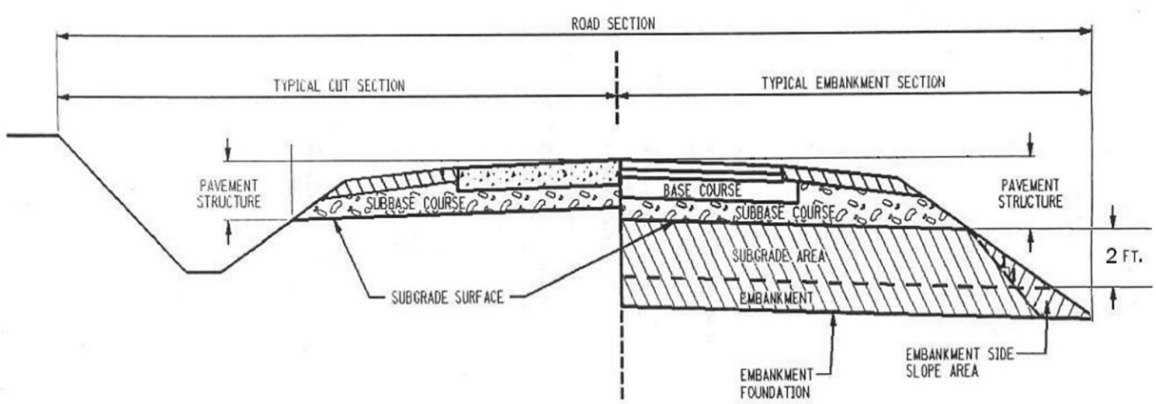


Figure 3. Daylighted base example (NYSDOT 2013).

Edgedrains

Edgedrains are used to remove water that enters the edge of the pavement structure through the use of longitudinal drains running parallel to the edge of the pavement. Edgedrains include slotted pipes placed in aggregate filled trenches, pipes with porous concrete filled trenches, prefabricated geocomposite drains in a sand backfilled trench, and aggregate trench drains (French drain). Edgedrain systems also include outlet pipes, used to drain water from the edgedrain to the roadside ditch, and headwalls, which protect the outlet end from maintenance activities. Figure 4 illustrates the typical components of an edgedrain system and Figure 5 illustrates edgedrain examples.

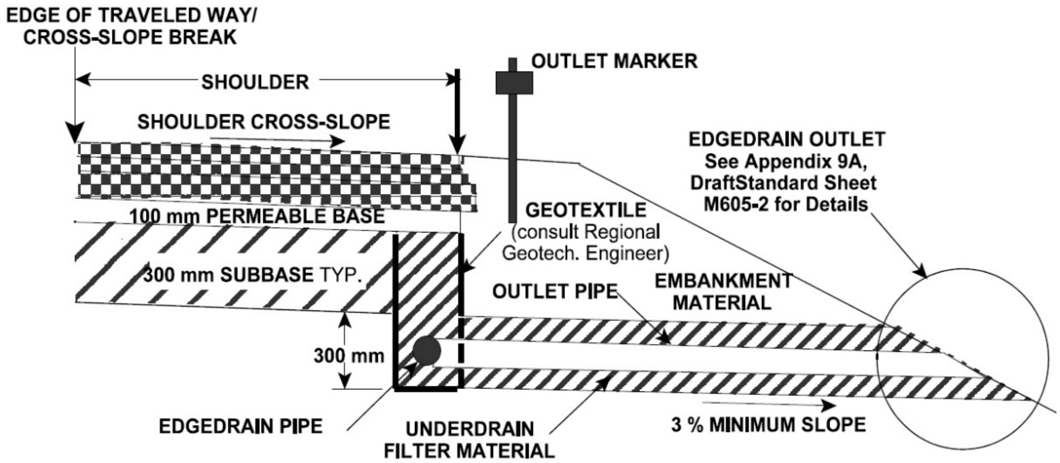
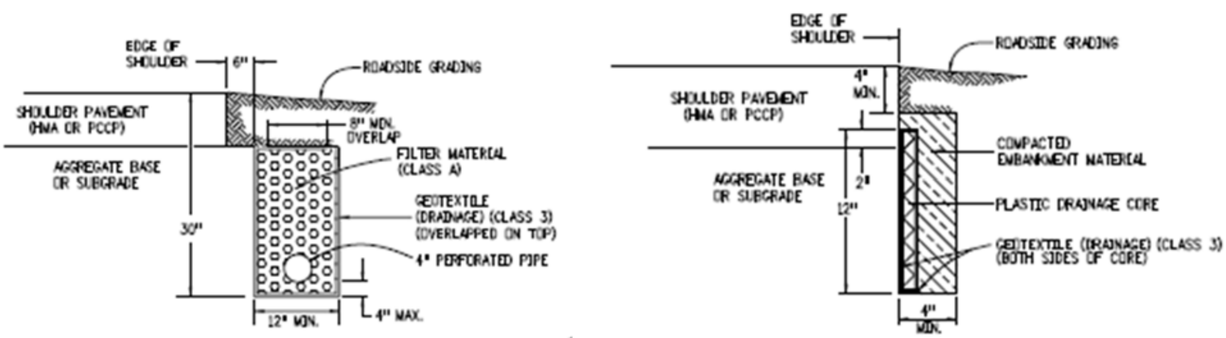


Figure 4. Edgedrain components (adapted after NYSDOT 2002).



a. Pipe edgedrain b. Geocomposite edgedrain

Figure 5. Edgedrain examples (CODOT 2012).

Permeable Bases

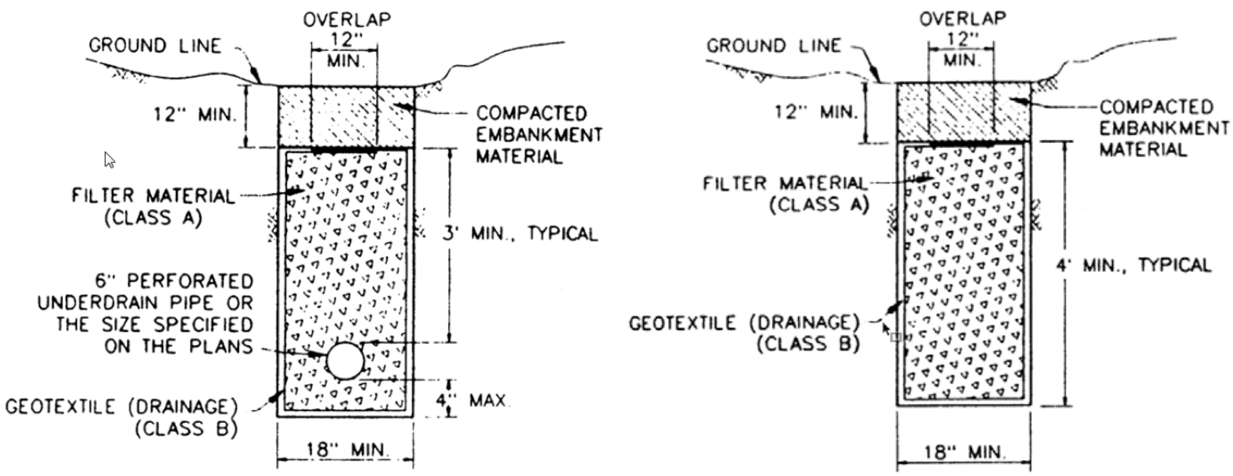
Permeable bases are designed to contain no fine material, have permeability values in excess of 1000 feet/day, and a layer thickness of at least 4 inch. Permeable bases may consist of aggregate, asphalt-treated, or cement-treated materials. A key component of a permeable base is the rate at which moisture flows through it; however, layer stability is also important during construction and in order to obtain long-term pavement performance. A separator layer is often used in conjunction with permeable bases. Separator layers typically consist of dense-graded aggregate or geotextile layers.

Interceptor Drains

Interceptor drains are constructed primarily to control groundwater. Drains are usually placed outside the pavement section to intercept the lateral movement of water.

Underdrains

Underdrains are constructed primarily to control groundwater and to lower the groundwater level. Deep underdrains may exceed a depth of 3 feet. Examples of underdrains are shown in Figure 6.



a. Underdrain. b. French drain.

Figure 6. Examples of underdrains (CODOT 2004).

Frost-Susceptible Soils

If not properly addressed, freeze-thaw conditions can result in drainage issues, weakening of the unbound aggregate and soil resulting in increased pavement surface roughness, rutting, and cracking (Figure 7).

Figure 7. Example of pavement damage due to freeze-thaw (photo courtesy of WSDOT).

In order for frost action to occur the following conditions need to exist: presence of frost-susceptible soils (typically when more than 15 percent is passing the No. 200 sieve), subfreezing temperatures, and a source of water (generally a water table within 10 feet of the pavement surface). Treatments for minimizing the damaging effects of frost action include (Christopher, Schwartz, and Boudreau 2006):

- Remove and replace frost-susceptible soils with non-frost susceptible materials.
- Place non-frost susceptible materials to a sufficient thickness to prevent subgrade freezing.
- Stabilize the frost-susceptible soils through chemical-stabilization (e.g., cement, lime, or lime-flyash), by reducing the amount of water that enters the pavement zone (e.g., install deep drains and/or a capillary barrier), or by altering the freezing point of the soil moisture.
- Increase the pavement structure to compensate for subgrade weakening during spring-thaw.

Construction

A properly designed pavement and drainage system can achieve the anticipated performance by adhering to established material production, delivery, and placement procedures. The following provides a brief summary of construction considerations for subgrade preparation, edgedrains, permeable bases, and asphalt mixtures.

Subgrade Preparation

Subgrade preparation should be conducted to meet elevation requirements through grubbing and grading, remove unsuitable materials, and establish the proper grade. Depending on agency requirements, unsuitable subgrade soils may be removed and replaced with higher quality material or be chemically stabilized. A summary of the more common subgrade stabilization methods are provide in Table 5. In addition, guidance for admixture type based on percent passing the No. 200 sieve and plasticity index is summarized in Table 6.

Edgedrains

Edgedrain construction should include proper pipe grade control, outlet placement, trench placement and depth, and ditch lines to ensure the effective movement of water. Drain lines should also be carefully marked to minimize crushing of the pipe from construction equipment. Prior to final acceptance, the edge drain system's functionality should be verified. Verification may include flushing the system (comparing inflow and outflow rates), pushing a flexible rod from the outlet to the edgedrain to verify continuity, or through the use of video equipment.

Permeable Bases

Permeable base materials should be protected from contamination by minimizing construction traffic and adjacent backfilling operations.

Table 5. Common subgrade stabilization methods (adapted after Rollings and Rollings 1996).

Stabilization Method	**Soil Type**	**Improvement/Comment**
Mechanical		
Additional gravel	• Silts and clays	• Reduces dynamic stress level
Blending	• Moderately plastic • Other	• Difficult to mix • Improve gradation, reduce plasticity, reduce breakage
Geosynthetics	• Silts and clays	• Strength gain through minimum disturbance and consolidation, fast placement, provides long-term separation
Lightweight fill	• Very weak silts, clays, peats	• Fast placement, reduces dynamic stress level • Thermal barrier for frost protection
Admixture		
Portland cement	• Plastic • Coarse	• Less pronounced hydration of cement • Hydration of cement
Lime	• Plastic • Coarse with fines • Non-plastic	• Drying, strength gain, reduce plasticity, coarsen texture, long-term pozzolanic cementing • Same as plastic, and dependent on quality of plastic fines • No reactive material
Lime-flyash	• Same as lime	• Same as lime
Lime-cement-flyash	• Same as lime	• Same as lime
Bituminous (liquid asphalt)	• Coarse • Some fines • Fines	• Strengthen, bind and waterproof • Same as coarse • Difficult or unable to mix
Pozzolanic and slags	• Silts and coarse	• Acts as a filler, cementing of grains, and dense and strong
Chemicals	• Plastic	• Strength increase and volume stability, vendor specific, can be difficult to mix
Water proofers		
Asphalt	• Plastic and collapsible	• Reduce change in moisture, long-term moisture mitigation problem
Geomembranes	• Plastic and collapsible	• Reduce change in moisture, long-term moisture mitigation problem

Table 6. Guide for selecting admixtures (adapted after Austroads 1998).

Form of Stabilization	**> 25% Passing No. 200 Sieve**			**< 25% Passing No. 200 Sieve**		
	PI ≤ 10	**10 < PI < 20**	**PI ≥ 20**	**PI ≤ 6[1]**	**PI ≤ 10**	**PI ≥ 20**
Cementitious	✓	?	X	✓	✓	✓
Lime	?	✓	✓	X	?	✓
Bituminous	?	?	X	✓	✓	?
Bituminous/cement blends	✓	?	X	✓	✓	?
Granular	✓	X	X	✓	✓	?
Miscellaneous chemicals	X	✓	✓	X	?	✓

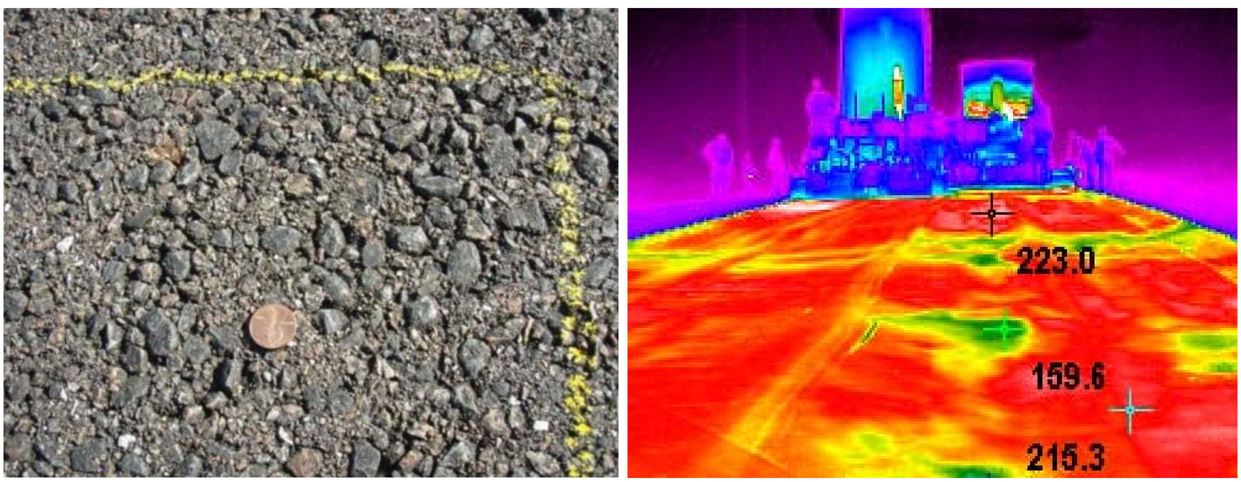
✓ – usually suitable; ? – doubtful; X – usually not suitable.

[1] In addition, PI of the percent passing the No. 200 sieve ≤ 60.

Asphalt Mixtures

Obtaining sufficient compaction of dense-graded asphalt mixtures is important for ensuring long-term performance. To minimize rutting, bleeding, and shoving the initial in-place air voids of dense-graded mixes should be no less than 3 percent and no more than 8 percent to limit the mixtures exposure to air and water (Brown et al. 2004). Linden, Mahoney, and Jackson (1989) determined that a 10 percent reduction in pavement life occurs for each 1 percent increase in air voids above 7 percent.

During production, delivery, and placement special care should be taken to minimize the potential of aggregate segregation and construction-related temperature-differentials (Figure 8). Aggregate segregation may occur anytime between stockpiling and laydown, and construction-related temperature-differentials are typically associated with haul time and placement. However, both aggregate segregation and construction-related temperature differentials can result in higher air void mixtures that are susceptible to water damage. Aggregate segregation can be eliminated through proper mix design, and proper maintenance and operation of plants, trucks, and paving equipment (AASHTO 1997). Temperature differentials are typically addressed by minimizing mixture heat loss during transport, on-site remixing with material transfer vehicles/devices, and good construction practices.



a. Aggregate segregation (Chun et al. 2013).

b. Construction-related temperature differentials (image courtesy of WSDOT)

Figure 8. Examples of aggregate segregation and construction-related temperature differentials.

Proper construction of the longitudinal joint will also minimize the amount of water that can enter the pavement structure. An improperly constructed longitudinal joint can result in low density (high permeability), raveling, and cracking. Low density and surface irregularity can be avoided at the longitudinal joint by using proper equipment and construction techniques. Several NCAT studies have been conducted and summarize issues related to longitudinal joint construction, density and surface irregularities, and construction solutions (Kandhal and Mallick 1996 and 1997, and Kandhal, Ramirez, and Ingram 2002). The following is a summary of recommended best practices for longitudinal joint construction (Kandhal, Ramierz, and Ingram 2002):

- Use a rubberized joint adhesive material or a notched wedge joint.
- Require the first pass of the roller to be on the hot side, 6 inches away from the longitudinal joint.
- Require a minimum density at the longitudinal joint of approximately 2 percent less than that specified for the mat.
- Do not allow the use of the cutting wheel and edge restraining device techniques.
- Use cores for determining longitudinal joint densities.

Maintenance and Preservation Strategies

Maintenance and preservation strategies for limiting water intrusion into the pavement structure and ensuring water flow through the drainage system are essential to long-term performance (Christopher and McGuffey 1997). Routine pavement maintenance and preservation strategies for limiting infiltration of water may include (singularly or in combination) crack sealing, thin surfacing (e.g., chip seals, microsurfacing), and thin asphalt overlays. For drainage systems, strategies include inspection and monitoring, cleaning catch basins, pipes, outlets (screens and headwalls), and ditches, verifying and re-establishing ditch grade, system flushing, and repairing damaged components.

Potential References

This sections provides a summary of potential references to be used in Phase II during the development of the guide document. Several relevant FHWA, NCHRP, TRB, industry, and SHA documents were identified as potential sources of information related to the project topic areas (see proposed guide document outline in Chapter 5). A summary of relevant references is shown in Table 7. It is anticipated that as the guide document development progresses, additional sources of information may be discovered and incorporated into the process. While the documents listed in Table 7 are the result of the research team's literature search, it is not uncommon for additional sources of information to become available or located during guide document development.

Table 7. Summary of references and relevance to guidelines.

Reference	Relevance to Guidelines
AASHTO T 283, *Standard Method of Test for Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage*	• Measurement of strength change from the effects of water saturation, accelerated water conditioning, and freeze-thaw cycles
AASHTO T 324, *Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)*	• Measures potential for moisture damage effects

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
AASHTO HDG-4, *Highway Drainage Guidelines, 4th Edition*	• Hydraulic considerations • Hydraulic design • Hydraulic aspects in restoration and upgrading of highways • Culvert inspection, material selection, and rehabilitation • Stormwater management
ASTM D4867, *Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures*	• Test potential for moisture damage • Determine effectiveness of anti-stripping additive • Determine anti-stripping additive dosage
Aggregate Tests for Hot-Mix Asphalt Mixtures Used in Pavements (NCHRP Report 557)	• Interpretation, appraisal, and application of moisture-susceptible mixtures
Best Practices for Crack Treatments for Asphalt Pavements (NCHRP Report 784)	• Project selection • Materials • Construction • Performance
Calibration and Validation of the Enhanced Integrated Climatic Model for Pavement Design (NCHRP Report 602)	• Description of EICM model • Impact on pavement design • Used for summary description only
Colorado DOT Drainage Design Manual, Chapter 18 Groundwater and Seepage	• Sources of groundwater • Impact on highway projects • Underdrains • Drainable pavement systems • Construction considerations • Maintenance and inspection
Construction of Pavement Subsurface Drainage Systems (Reference Manual)	• Permeable bases • Aggregate separator layer • Edgedrains • Video inspection • Maintenance
Designing Pavement Drainage Systems: The MnDRAIN Software (Final Report 2003-17)	• MnDRAIN user guide
Development of Guidelines for the Design of Subsurface Drainage Systems for Highway Pavement Structural Sections (Report No. FHWA-RD-72-30)	• Need for subsurface drainage • Subsurface drainage criteria • Subsurface drainage systems

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
Drainable Pavement Systems (Instructor's Guide) (Report No. FHWA-SA-94-062)	• Sources of water • Pavement distress due to water • Roadway geometry • Pavement water infiltration • Drainage design (e.g., porosity, time to drain) • Base types and design considerations (aggregate, asphalt- and cement-treated) • Use of geosynthetics • Edgedrains, outlet pipes, headwalls • Construction details • Drainage maintenance activities
Drainage of Highway Pavements (FHWA HEC 12)	• Roadway geometry • Highway pavement drainage • Drainage design for storm water removal
DRIP Version 2 Drainage Requirements in Pavements User's Guide	• DRIP software user guide • Design concepts • Design components (permeable base, separator layer, edgedrains, retrofit edgedrains, outlet drain, fin drain) • Design examples • Sensitivity analysis
Effects of Subsurface Drainage on Pavement Performance, Analysis of the SPS-1 and SPS-2 Field Sections (NCHRP Report 583)	• Field testing of drainage systems • Evaluation of roughness and distress in asphalt and concrete pavements • Permeable base drainage systems
Effects of Subsurface Drainage on Performance of Asphalt and Concrete Pavements (NCHRP Report 499)	• Field inspection observations and results • Effect of drainage on asphalt pavement performance • Effect of drainage on concrete pavement performance
Enhancing the Durability of Asphalt Pavements (Transportation Research Circular E-C186)	• Impact of mix design on asphalt pavement durability • Optimization of tack coat for hot-mix asphalt placement • Implementation of performance-based mixture designs to enhance durability of asphalt pavements in New Jersey
Evaluating Roadway Subsurface Drainage Practices (IHRB Project TR-643)	• Component description • Forensic testing and evaluation program • Field investigations • Performance analysis
Evaluation of the Moisture Susceptibility of WMA Technologies (NCHRP Report 763)	• Moisture susceptibility of asphalt mixtures • Field results and laboratory testing • Effects of anti-stripping agents • Mixture performance evaluation

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
Geosynthetic Materials Association, *Handbook of Geosynthetics*	• Introduction to geosynthetics • Separation, subgrade stabilization, and installation • Subsurface drainage and installation • Generic material specifications
Geotechnical Aspects of Pavements (FHWA NHI-05-037)	• Case histories of drainage failure and soils collapse • Incorporating geotechnical issues in pavement design • Geotechnical exploration and testing • Subgrade characterization • Drainage and pavement design • Subsurface water and drainage requirements • Subgrade conditions requiring special design consideration • Subgrade improvement and stabilization • Drainage construction techniques and inspection
Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures	• Mechanistic-empirical design principles • Subgrade and foundation • Material characterization • Environmental effects • Drainage • Shoulders
Guide for the Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures, Appendix TT: Drainage Requirement in Pavements (DRIP) Microcomputer Program User's Guide	• Software capabilities • New features • User guide
Improved Conditioning and Testing Procedures for HMA Moisture Susceptibility (NCHRP Report 589)	• Mix design verification • ASTM D4867 results • Hamburg wheel tracking test • Dynamic modulus testing
Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content (NCHRP Report 752)	• Moisture susceptibility of asphalt mixtures
Improved Surface Drainage of Pavements (NCHRP Web Document 16)	• Methods for controlling water film thickness • Design guidelines for improving pavement drainage • PAVDRN software

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
Indiana DOT Design Manual, Chapter 52, Pavement and Underdrain Design Elements	• Pavement types (aggregate base, open-graded drainage layer) • Pavement design guidelines • Video-inspection construction quantities • Underdrains (and retrofit underdrain) • Pavement preventive maintenance
Investigation of Conditions for Moisture Damage in Asphalt Concrete and Appropriate Laboratory Test Methods: Summary Report (Report No. UCPRC-SR-2005-01)	• Field studies to evaluate moisture damage • Laboratory testing and results (aggregates, asphalt, anti-strip treatments, and specimen preparation) • Performance-based test procedures • Evaluation of long-term effect of additives
Journal of Indian Roads Congress, *Quantification of Benefits of Improved Pavement Performance Due to Good Drainage*	• Quantifying benefits of drainage to pavement performance
LTPP Data Analysis: Daily and Seasonal Variations in In situ Material Properties (NCHRP Web Document 60)	• Freeze/thaw effects • Moisture-related effects in the absence of freezing
LTPP Data Analysis: Influence of Design and Construction Features on the Response and Performance of New Flexible and Rigid Pavements (NCHRP Web Document 74)	• Effect of construction on drainage • Effect of drainage features on performance • Effect of environmental factors on performance
Maintenance of Highway Edgedrains (NCHRP Synthesis 285)	• Maintenance and highway drainage performance • Drainage maintenance practices • Design and construction • Effective practices • Minimizing maintenance requirements
Maryland SHA Pavement & Geotechnical Design Guide	• Pavement materials and design properties • Pavement preservation, rehabilitation, and design • Geotechnical design (subgrades, subsurface drainage—underdrain and trench drain, drainage blanket, subgrade drain, spring control, other alternatives to subsurface drainage)
Minimizing Moisture Damage in Asphalt Pavements (Pavement Technical Update, Vol. 2, No. 2)	• Factors affecting moisture damage • Moisture sensitivity of asphalt pavements • Mechanisms of moisture damage • Tests to predict moisture sensitivity • Treatment methods

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
Minnesota DOT Pavement Manual, Drainage	• Surface drainage systems • Ditches, curb and gutter, and culverts • Subsurface drainage types and design guidelines (sub cut drains, edgedrains, permeable aggregate base, discharge pipe and headwall, ditch depth, interceptor drains, horizontal drains, special drains • Sources of moisture • Moisture accelerated damage • Approaches to address moisture in pavements • Subsurface drain materials • Subsurface drain maintenance
Moisture Damage in Asphalt Mixtures – A State-of-the-Art Report (FHWA-RD-90-019)	• Cause of moisture damage (mixture design and construction, environment, traffic, anti-strip additive properties) • Methods for controlling damage in asphalt mixtures • Asphalt mixture moisture damage tests (aggregate, additives, and mixtures)
Moisture Sensitivity of Asphalt Pavements, A National Seminar	• Chemical and mechanical processes of moisture damage in asphalt mixtures • Test methods to predict moisture sensitivity in asphalt pavements • Material treatments (aggregate and binder) • Material production, mixture design, and pavement design effects on moisture damage • Production and construction issues for moisture sensitivity of asphalt pavements • Field experience • Specifications for controlling moisture sensitivity problems in asphalt pavements • Implementation and strategic plan
New York State DOT Comprehensive Pavement Design Manual, Chapter 9, Subsurface Pavement Drainage	• Basic pavement drainage guidelines • Edgedrains and retrofit edgedrains • Cross drains • Outlet details
New York State DOT Geotechnical Design Manual, Chapter 7, Engineered Granular Mixes	• Subbase course (frost susceptibility, open-graded) • Underdrain filter material • Material acceptance
Nondestructive Testing to Identify Delaminations between HMA Layers (SHRP Report S2-R06D-RR-1)	• Use of testing equipment to identify the presence of asphalt layer delamination

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
Ohio DOT Location and Design Manual, Volume Two, Drainage Design	• Types of subsurface drainage (underdrains, edgedrains) • Drainage design procedures • Construction • Drainage cross-sections
Pavement Drainage (www.vaasphalt.org)	• Drainage plans • Drainage types • Subsurface drainage design
Pavement Drainage and Pavement Shoulder Joint Evaluation, Numerical Modeling of Infiltration and Drainage in Pavements (Report No. FHWA/JHRP/IN 93/2-1)	• Hydraulic characteristics • Modeling • Model validation and applications (including examples) • PURDRAIN User guide
Pavement Subsurface Drainage Systems (NCHRP Synthesis 239)	• Drainage design issues and approaches • Construction issues • Maintenance • Performance evaluation • Example guidelines for permeable aggregate base • Example guidelines for construction and maintenance inspection forms
Performance of Pavement Subsurface Drainage (NCHRP Digest 268)	• Effects of subsurface drainage features on asphalt and concrete pavement performance
Rehabilitation Strategies for Highway Pavements (NCHRP Web Document 35)	• Guidelines for drainage inspection • Guidelines for drainage evaluation • Guidelines for rehabilitation based on drainage evaluation
Rehabilitation Techniques for Stripped Asphalt Pavements (FHWA/MT-002-003/8123)	• Pavement rehabilitation techniques specific to stripped asphalt pavements.
Subsurface Drainage Manual for Pavements in Minnesota (Report No. MN/RC 2009-17)	• Purpose, effects, source of moisture, and system types • Pavement and drainage requirements • Selection criteria • Design • Construction • Maintenance • Economic analysis • Recommended flowchart for design, construction, and maintenance • Plans, charts, and tables • Examples

Table 7. Summary of references and relevance to guidelines (continued).

Reference	Relevance to Guidelines
Wisconsin DOT Facilities Development Manual, Chapter 13, Section 40 Subgrade Drainage	• Underdrains • Outlets • Design criteria • Material considerations • Construction • Subdrains details, and placement depth and spacing

CHAPTER 3. AGENCY AND INDUSTRY SURVEYS

Introduction

The research team developed and conducted an online survey of highway agencies and pavement industry personnel to identify successful practices for limiting damage of asphalt and composite pavements due to the presence of water. The agency survey was sent to all US highway agencies and Canadian Provincial Governments (total of sixty-three agencies). The industry survey was sent to the state asphalt and concrete associations, the American Concrete Pavement Association, the Asphalt Emulsion Manufactures Association, the Asphalt Interlayer Association, the Asphalt Recycling and Reclaiming Association, the FP^2 for Pavement Preservation, the Geosynthetics Material Association, the International Slurry Surfacing Association, the National Asphalt Pavement Association, and the National Center for Pavement Preservation (total of seventy-three industry personnel). Agency survey questions are shown in Appendix B and industry survey questions are shown in Appendix C.

Agency Survey Results

A total of thirty-nine highway agencies (response rate of 62 percent), including five Canadian Provinces and thirty-four SHAs, responded to the agency survey. The research team made multiple attempts to increase the agency response rate by email notifications and personal outreach, with the above results.

The survey requested agency personnel to respond to a variety of questions related to their experience with water-related damage issues, geometrics, pavement design, drainage design, construction, preservation, and rehabilitation. The following provides a summary of key survey findings (a complete list of survey responses is provided in Appendix D).

General Information

Agencies were asked to provide their assessment of which distress/condition types tend to indicate damage due to the presence of water. A number of agencies also indicated that while damage may not be initially caused by water, distress tends to become more severe in the presence of water. A summary of agency-identified asphalt and composite pavement distresses due to the presence of water is provided in Figures 9 and 10, respectively. The majority of respondents indicated that pumping, stripping, and potholes were the primary distress types that indicate damage due to water in new construction, rehabilitation, and preservation of asphalt pavements (Figure 9). Alligator cracking, heaving, raveling, and delamination were also identified as distress types that tend to indicate damage in asphalt pavements due to the presence of water.

Similarly, for composite pavements, the majority of respondents indicated that pumping, stripping, and potholes indicated damage in composite pavements due to the presence of water (Figure 10). A number of respondents also indicated that delamination, patching, and raveling were indicators of water-related damage in composite pavements.

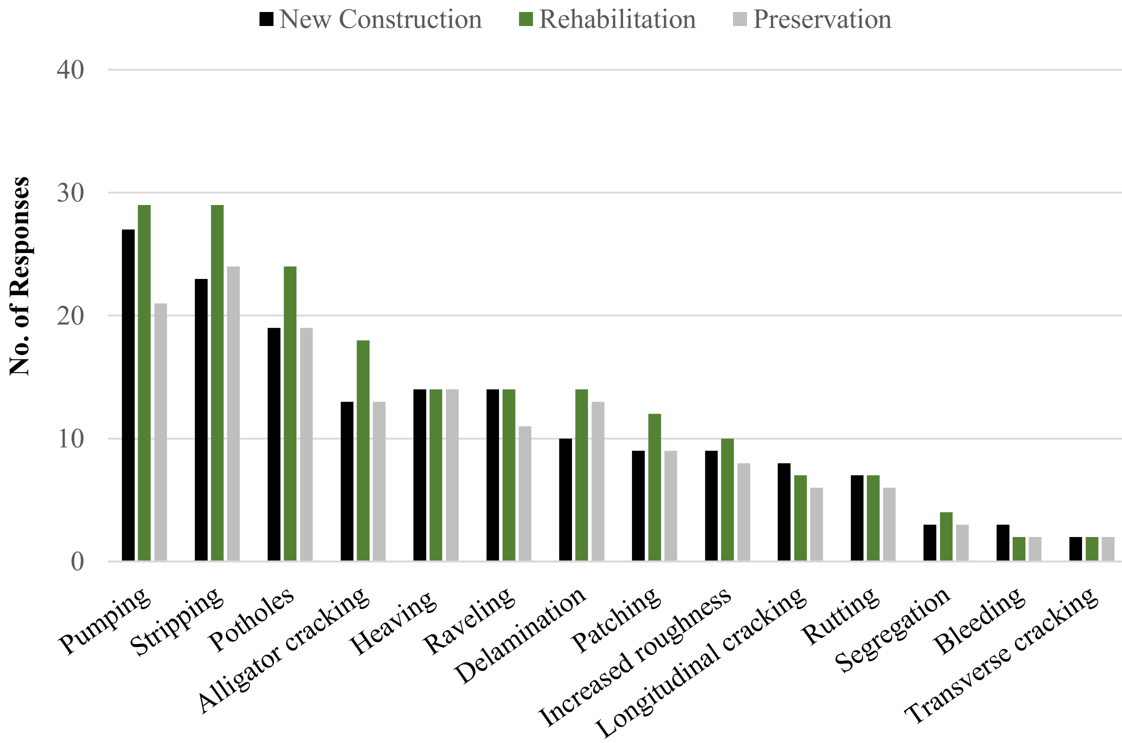


Figure 9. Asphalt pavement distress due to the presence of water.

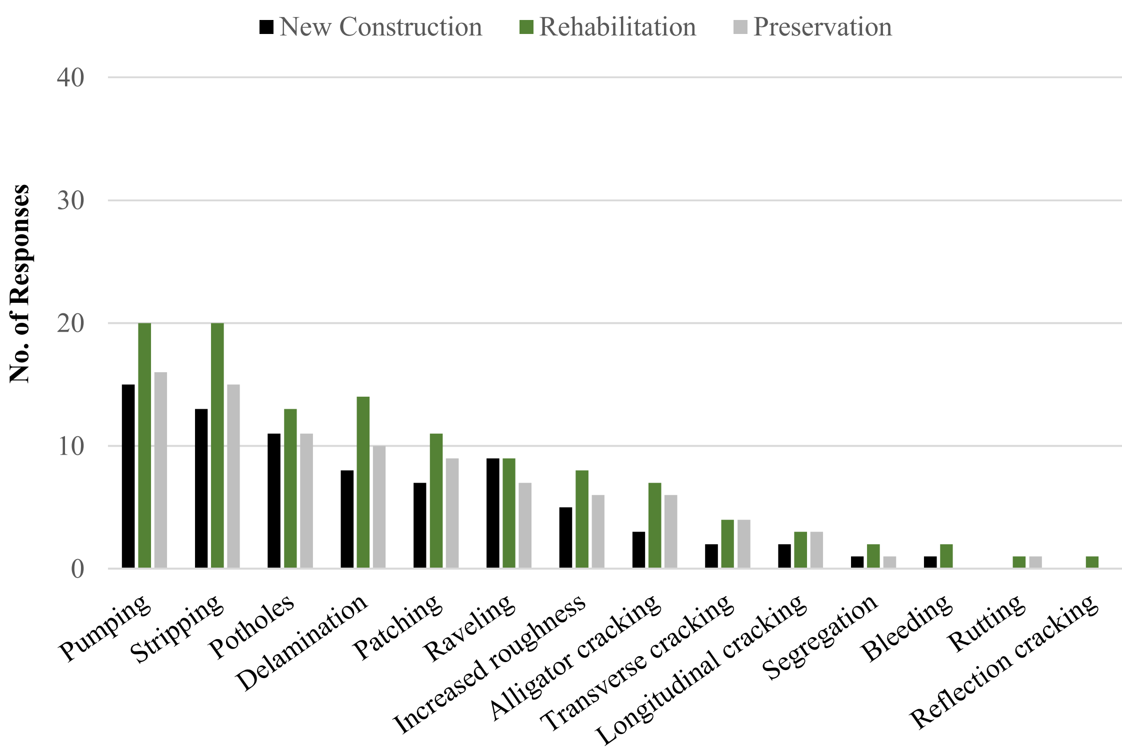


Figure 10. Composite pavement distress due to the presence of water.

Agencies were asked to identify the methods used for assessing pavement damage due to the presence of water. Figure 11 illustrates the identified water-related pavement damage assessment methods. The majority of agencies (twenty-eight) indicated that damage assessment is predominantly conducted through pavement coring, asphalt laboratory testing (seventeen responses), notification by agency personnel (fourteen responses), and pavement condition assessment (fourteen responses).

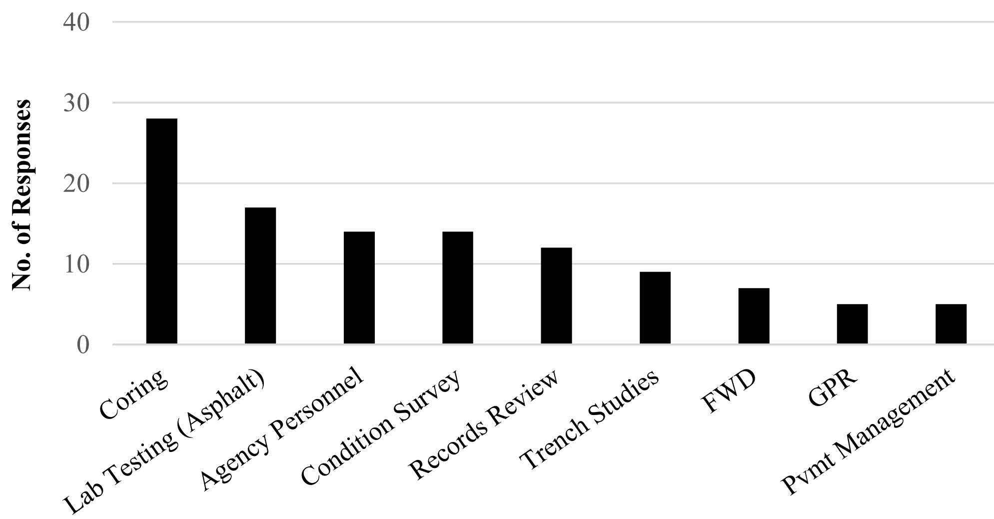


Figure 11. Methods for assessing pavement damage due to the presence of water.

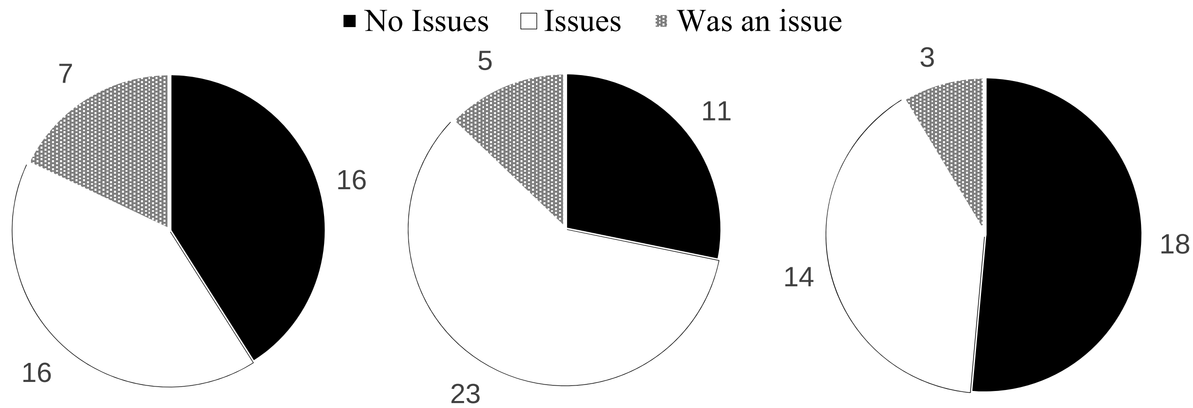
In order to determine the extent of pavement damage due to the presence of water, agencies were asked to indicate whether water-related pavement damage was (1) not an issue, (2) an issue, or (3) an issue in the past, but current agency specifications and practices have minimized the damage. Table 8 provides a summary of agency responses in relation to premature failure or accelerated distress in new construction, rehabilitation (rehab), and preservation (pres) of asphalt and composite pavements due to the presence of water.

Of the responding agencies, sixteen indicated premature failure or accelerated distress due to the presence of water in new asphalt pavements, while only one agency indicated an issue with new composite pavement construction (only fourteen agencies indicated construction of new composite pavements). Twenty-three agencies indicated issues in asphalt pavement rehabilitation treatments and fourteen agencies indicated issues in composite pavement rehabilitation treatments. Finally, fourteen agencies indicated issues in asphalt pavement preservation treatments and eight agencies indicated issues in composite pavement preservation treatments. Nine agencies indicated that water-related premature failure or accelerated distress had been an issue in the past; however, these issues have been minimized due to specification or process changes. These responses are further illustrated in Figures 12 and 13 for asphalt pavements and composite pavements, respectively (note: values shown indicate the number of responding agencies).

Table 8. Agencies' experience with damage due to water in asphalt and composite pavements.

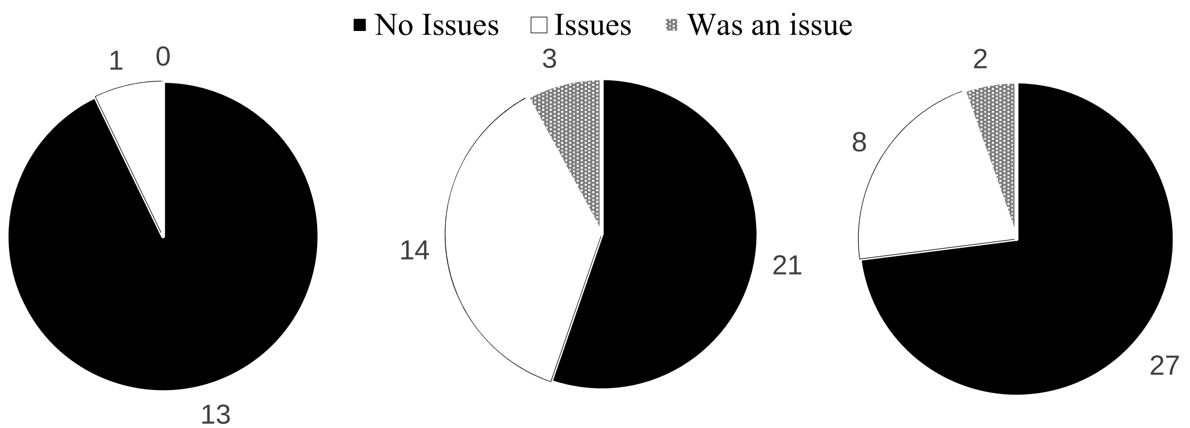
Agency	Asphalt Pavements			Composite Pavements		
	New	Rehab	Pres	New	Rehab	Pres
Alabama DOT	○	○	○	✖	○	○
Alaska DOT&PF	●	●	●	✖	●	●
Alberta Transportation	●	○	—	●	●	—
Arizona DOT	●	○	●	●	●	●
California DOT	●	○	○	●	○	●
Colorado DOT	○	○	○	✖	○	○
Connecticut DOT	○	○	●	✖	○	○
Florida DOT	●	●	●	✖	●	●
Hawaii DOT	●	●	●	●	●	●
Idaho TD	◉	◉	◉	✖	●	●
Indiana DOT	○	○	◉	✖	○	◉
Kansas DOT	●	○	○	✖	○	○
Kentucky TC	○	○	○	✖	○	●
Maine DOT	○	○	○	✖	○	○
Manitoba I&T	●	●	●	✖	○	●
Maryland SHA	◉	●	●	✖	●	●
Michigan DOT	○	○	—	—	—	—
Minnesota DOT	◉	●	●	●	●	●
Mississippi DOT	◉	◉	●	●	●	●
Missouri DOT	○	○	○	✖	●	○
Nebraska DOR	○	●	●	●	●	●
Nevada DOT	◉	◉	○	●	●	●
New Brunswick DOTI	○	○	○	✖	●	●
New Jersey DOT	○	○	○	◉	○	○
New York State DOT	○	○	—	✖	○	●
Ohio DOT	○	●	●	✖	●	●
Oklahoma DOT	◉	◉	●	✖	◉	●
Ontario MOT	●	●	●	✖	●	●
Oregon DOT	●	○	○	●	○	●
Pennsylvania DOT	◉	◉	◉	✖	◉	◉
Saskatchewan MHI	●	○	○	✖	●	●
South Carolina DOT	○	○	●	●	◉	●
South Dakota DOT	●	●	●	✖	○	●
Tennessee DOT	○	○	●	✖	●	●
Texas DOT	○	○	○	●	●	●
Virginia DOT	●	○	●	●	●	●
Washington State DOT	●	●	●	●	●	●
West Virginia DOH	○	○	—	✖	●	●
Wisconsin DOT	○	○	○	✖	○	○

● = Water-related damage not an issue—no premature failures or accelerated distress.
○ = Water-related damage an issue—premature failures or accelerated distress.
◉ = Water-related damage a past issue, now minimized by current practice.
✖ = new composite pavements are not constructed.
— = no response.



a. New Construction. b. Rehabilitation. c. Preservation.

Figure 12. Number of agencies experiencing distress in asphalt pavements due to water.



a. New Construction. b. Rehabilitation. c. Preservation.

Figure 13. Number of agencies experiencing distress in composite pavements due to water.

The nine agencies that indicated water-related damage had been minimized due to current practice include Idaho, Indiana, Minnesota, Mississippi, Nevada, New Jersey, Oklahoma, Pennsylvania, and South Carolina. The current practices and procedures for these nine agencies (and others who indicated no issues with damage due to the presence of water) will be considered for use as case studies or agency examples in the guidelines.

Agency practices that have helped to minimize premature failure or accelerated distress are summarized in Tables 9 and 10 for asphalt and composite pavements, respectively.

Table 9. Summary of agency practices for mitigating pavement damage due to moisture.

New Construction	Rehabilitation	Preservation
Geometrics		
• Correct cross-slope.	• Re-establish cross slopes. • Rebuild cross-slope.	• No practices provided.
Pavement Structure		
• Total pavement depth at least 30 inch thick. • Use drainable pavement layers. • Address drainage during the design phase. • New construction, design a "rich bottom" asphalt layer.	• Proper drainage in pavement design.	• Identify saturated pavements. • Do not apply treatments that provide a seal. • Crack seal. • Apply seal coats (e.g., microsurfacing).
Materials		
• Require > 0.5 percent liquid anti-strip. • Add 1 percent hydrated lime to the asphalt mixtures. • Use a 0.375-inch asphalt surface mixture.	• Require > 0.5 percent liquid anti-strip. • Add 1 percent hydrated lime to the asphalt mixes. • Use lime marination in the asphalt surface mix.	• Require > 0.5 percent liquid anti-strip in all asphalt mixes.
Drainage		
• Place edgedrains for new construction or widening. • Place transverse trench drains. • Install base drains. • Design hydraulic system for greater year extreme storms.	• Improve drainage design. • Pipe replacement.	• No practices provided.
Construction		
• Limit the amount of fine aggregate. • Use lime marination for asphalt surface mixture. • Remove weak soils, place geotextile, drain rock, and suitable material. • Edge drain—drain rock, geosynthetic, and aggregate base.	• Pavements that are widened are “keyed-in.” • Construct paved V-ditch. • Use geosynthetic.	• Specifications to suspend work if rain is eminent or pavement is wet. • Tighter requirements on bituminous material. • Cleanness value of screening.

Table 10. Summary of agency practices for mitigating damage in composite pavements due to the presence of moisture.

New Construction	Rehabilitation	Preservation
• No specific agency practices were provided.	• Proper drainage in pavement design. • Rebuild cross-slope. • Increase resistance to stripping in asphalt mixes. • Saw-cut and seal joints.	• Identify saturated pavements. • Do not apply treatments that provide a seal. • Crack seal. • Apply surface treatment, such as microsurfacing.

Table 11 summarizes agency responses to the types of drainage features used by roadway functional classification. As expected, the predominant drainage features used by the majority of agencies are roadside ditches, followed by curb and gutter, underdrains, and daylighted bases. The less common drainage design features from the responding agencies include the use of fin drains, permeable friction courses, and cement-treated permeable bases.

Table 11. Agency drainage feature utilization by functional classification.

Drainage Feature	Interstate		Principal Arterial		Minor Arterial		Collector	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Ditches	21	30	21	30	20	28	18	24
Curb and gutter	21	6	31	12	29	13	24	9
Underdrain	18	16	17	16	11	10	8	8
Daylighted base	10	18	9	17	10	17	9	13
Edgedrains	17	16	14	14	9	9	8	8
Aggregate permeable base	10	11	10	11	10	11	9	9
Geosynthetic separator layer	12	13	10	11	9	10	6	6
French drains	9	11	9	11	7	8	7	6
Asphalt-treated permeable base	11	11	8	8	4	4	4	4
Retrofit edgedrains	9	8	5	8	2	3	1	2
Open-graded friction course	8	8	7	6	2	2	2	2
Cement-treated permeable base	6	5	4	3	2	2	1	1
Permeable friction course	6	6	4	4	2	2	0	0
Fin drains	2	2	2	3	0	1	0	0

Note: values shown represent number of responding agencies.

Agencies were asked to indicate if a drainage design checklist was used to assist the designer in determining if and when special designs are warranted for mitigating existing water or potential water problems. Three agencies, the Florida DOT, the Maryland SHA, and the New Jersey DOT indicated that a checklist was used (see Appendix E).

Practices for Addressing Freeze-Thaw Conditions

Figure 14 illustrates agency responses to practices for addressing freeze-thaw conditions. Of the agencies that indicated freeze-thaw conditions exist, the primary practices include increasing the aggregate base layer thickness (seventeen agencies), placement of a non-frost susceptible material over the existing subgrade (fourteen responses), minimizing the percent passing the No. 200 sieve in the aggregate base course (thirteen responses), and imposing spring load restrictions (eleven responses). Additional agency practices include adding a Styrofoam layer (Colorado DOT), stabilizing the subgrade (Nebraska DOR and Ohio DOT), including drainage (New York State DOT), and applying a seasonal factor to the subgrade resilient modulus value in the pavement design process (Pennsylvania DOT). It should be noted that many agencies employ multiple methods to mitigate pavement damage due to freeze/thaw conditions. For example, Washington State DOT indicated the use of all six methods, while Idaho TD, Maine DOT, Indiana DOT, and Manitoba I&T indicated using five of the six methods to mitigate freeze-thaw damage.

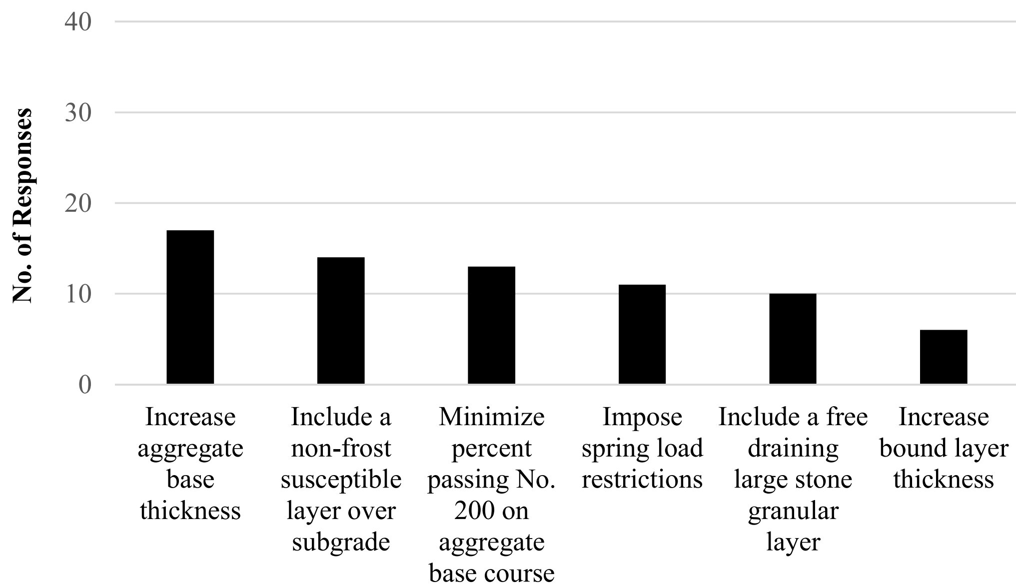


Figure 14. Agency practices for mitigating damage due to freeze-thaw conditions.

Practices for Addressing Weak Soils

Figure 15 provides a summary of agency practices for addressing weak soil conditions. The primary practices include removing and replacing weak soil with higher quality material (twenty-eight responses), placing a geosynthetic between the subgrade soil and the base layer (twenty-four responses), increasing the aggregate base layer thickness (twenty-four responses), and stabilizing the subgrade layer (twenty-two responses). As with freeze-thaw mitigation, agencies may include multiple methods for minimizing damage due to weak soils.

Practices for Addressing High or Perched Water Tables

Twenty-three agencies indicated having practices for addressing high or perched water tables, which include installing edgedrains, increasing the depth of roadside ditches, and installing culverts (Figure 16). Nine agencies indicated that high or perched water tables are typically not a concern.

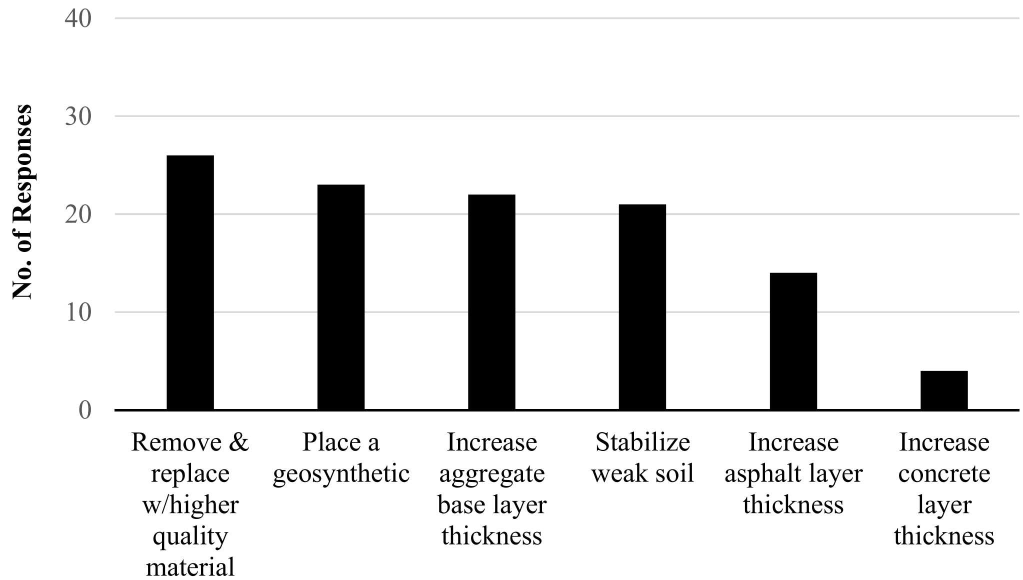


Figure 15. Agency practices for mitigating damage due to weak soils.

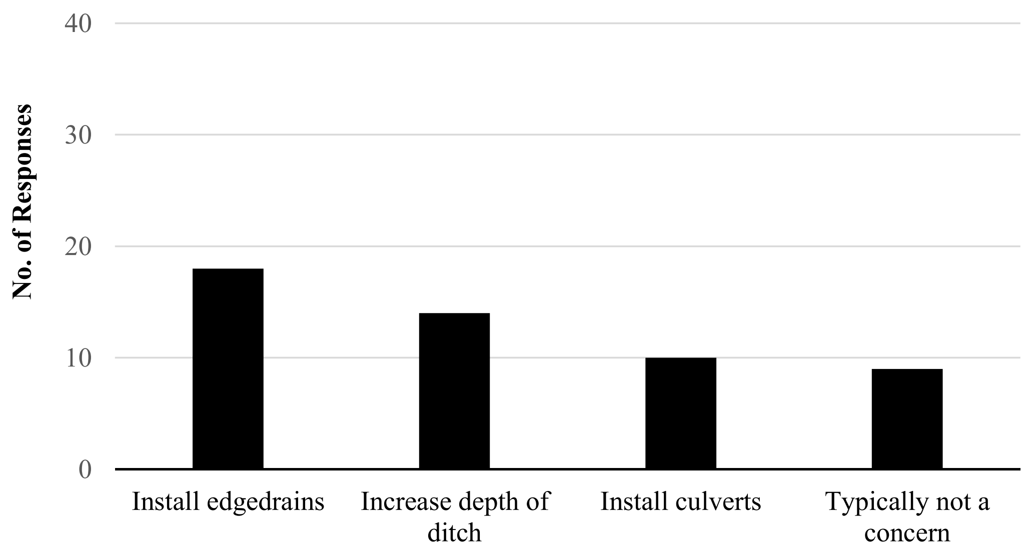


Figure 16. Practices for mitigating damage due to high or perched water tables.

Agencies provided several additional practices, including adding subdrains or underdrains (six agencies), asphalt base (one agency), dry wells (one agency), French drains (one agency), drain rock (one agency), and increasing the pavement structural thickness (one agency).

Materials

Agencies responded to a number of questions related to material properties for aggregate base, asphalt- and cement-treated permeable base, geosynthetics, and asphalt materials. Table 12 provides a summary of agency responses related to base materials; additional details (e.g., property values) are provided in Appendix D. Of the responding agencies, a majority (twenty-one agencies) indicated the use of permeable aggregate base or a separator layer, fifteen agencies indicated the use of asphalt-treated permeable base, and nine indicated the use of cement-treated permeable base. For all base types, predominate material specifications include L.A. Abrasion, non-plastic materials, and sodium sulfate soundness. For asphalt- and cement-treated permeable bases, the majority of agencies also indicated the use of maximum aggregate size and percent asphalt/cement.

Table 12. Agency permeable base material specifications.

Material Property	Aggregate Base or Separator Layer	Asphalt-Treated	Cement-Treated
L.A. Abrasion	15	11	8
Non-plastic	11	8	3
Sodium Sulfate Soundness	7	6	5
No. of fractured faces	6	6	2
Angularity	3	4	NA
Coefficient of Permeability	3	NA	NA
Lime or liquid anti-strip	NA	7	NA
Maximum aggregate size	NA	10	7
Percent binder/cement	NA	11	7

Note: values shown represent number of responding agencies.

Agencies indicated a variety of uses for geosynthetic materials. As shown in Figure 17, these include subgrade separation (twenty-one agencies), subgrade stabilization (sixteen agencies), base reinforcement (fourteen agencies), drainage systems (twelve agencies), and overlay stress absorption and reinforcement (seven agencies).

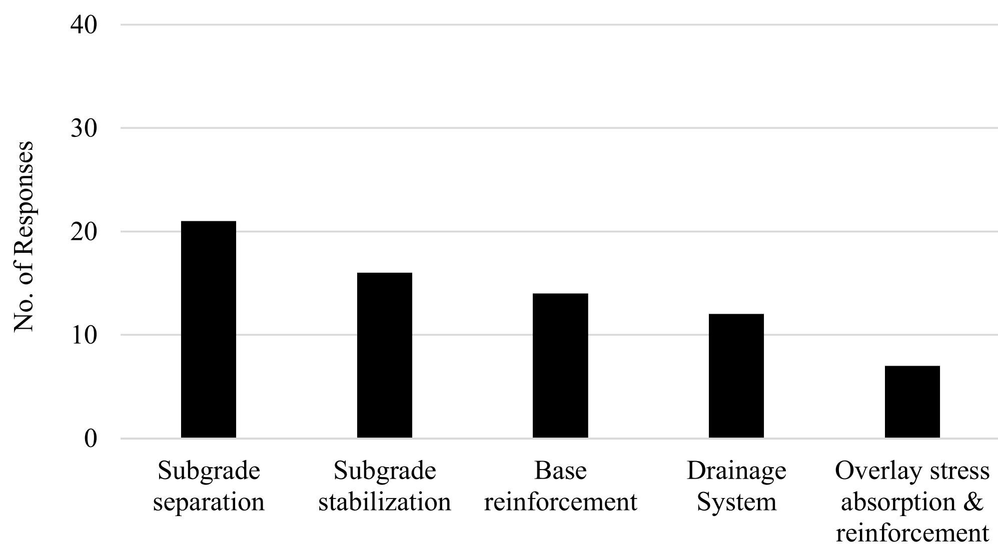


Figure 17. Agency uses of geosynthetic materials.

In relation to asphalt materials, agencies were asked to provide information related to predominant asphalt surface material type, test type for quantifying material moisture susceptibility, and the type of additive used to mitigate moisture-related damage. The following summarizes the responses.

- Predominate asphalt mixture type used by responding agencies include (see Figure 18):
  - Dense-graded (thirty-two responses).
  - Open-graded (nine responses).
  - Gap-graded (six responses).
- Tests for moisture susceptibility used by the responding agencies include (see Figure 19):
  - AASHTO T 283 (thirty-three responses).
  - ASTM D4867 (six responses).
  - AASHTO T 324 (five responses).
  - AASHTO T 340 (one response).
- Asphalt mixture additives used by the responding agencies include (see Figure 20):
  - Liquid anti-strip (thirty-five responses).
  - Dry or hydrated lime (twenty-six responses).
  - Lime slurry (four responses).
  - Lime slurry and marination (four responses).

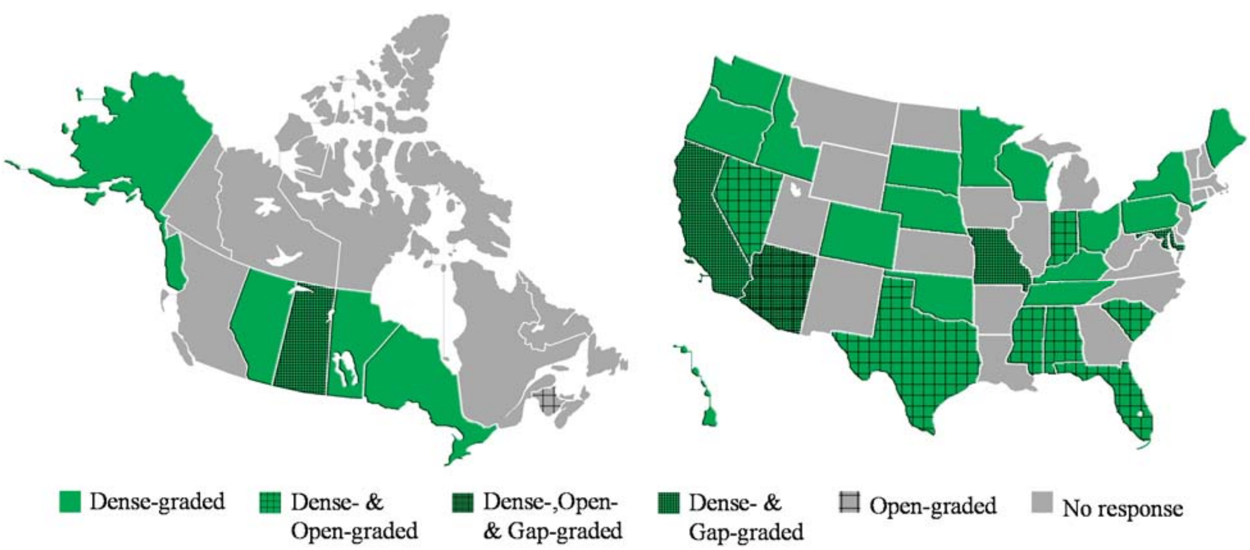


Figure 18. Agency predominant asphalt mixture type.

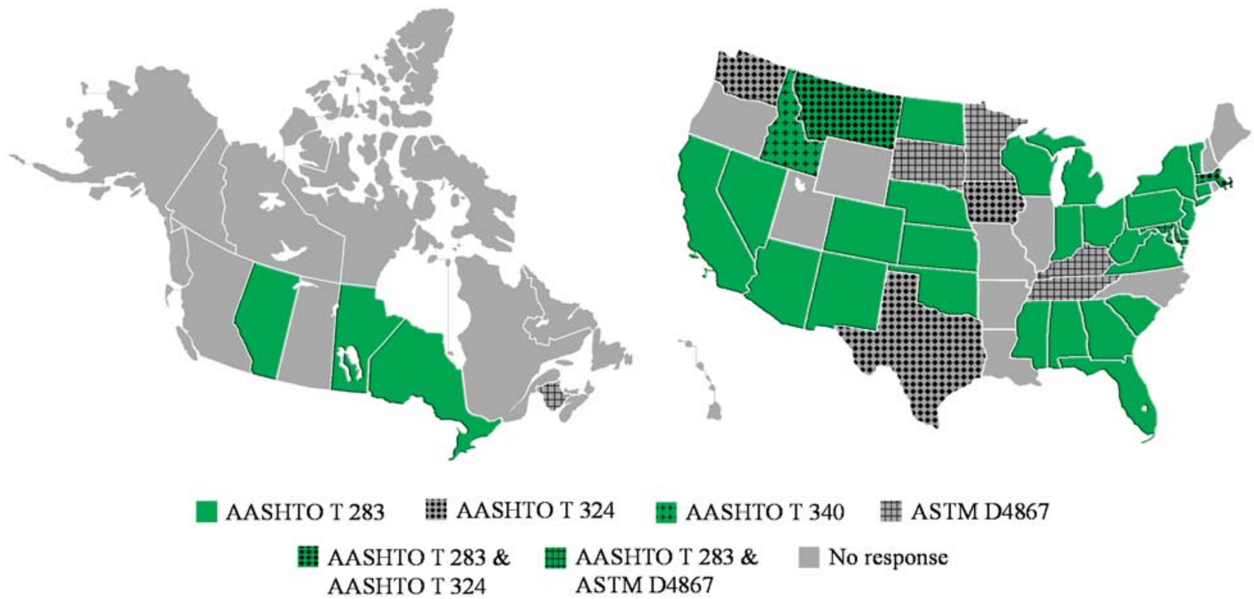


Figure 19. Agency test procedures for asphalt mixture moisture susceptibility.

Note: Responses have been supplemented with the results from a survey conducted in December 2014 by the AASHTO Subcommittee on Materials.

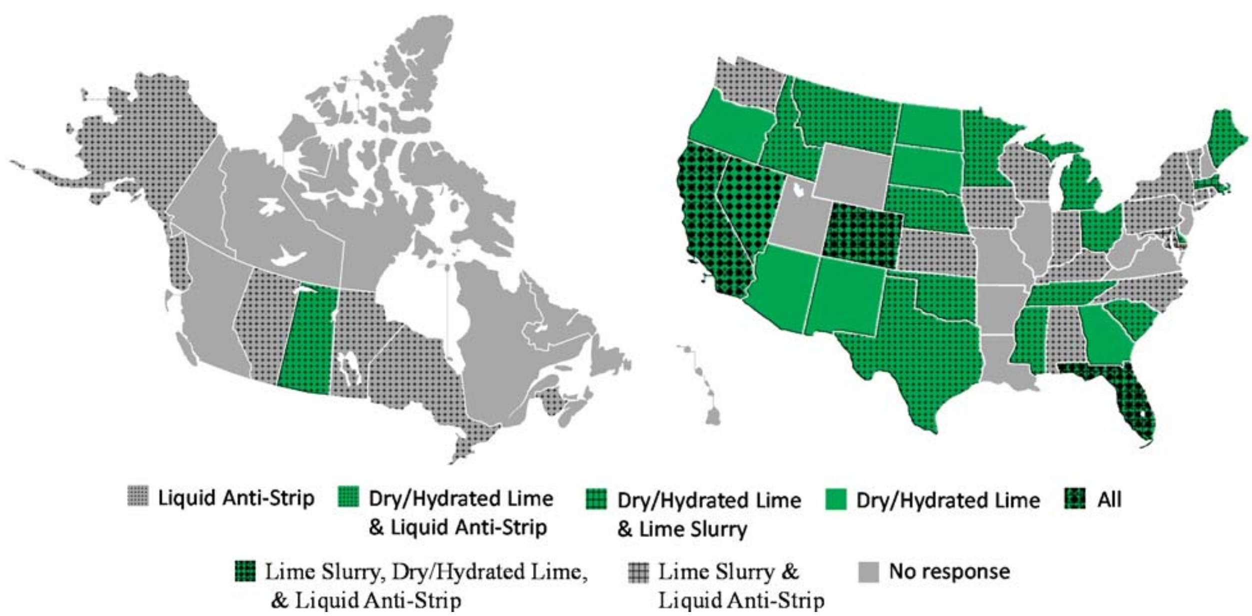


Figure 20. Agency approved asphalt mixture additives.

Note: Responses have been supplemented with the results from a survey conducted in December 2014 by the AASHTO Subcommittee on Materials.

Construction

Table 13 summarizes responses on methods for accepting subgrade preparation, drainage, permeable aggregate base/separator layer, asphalt- and cement-treated permeable base, and asphalt mixtures.

Table 13. Agency construction-related requirements.

Feature	No. of Responses
Measuring Subgrade Compaction	
In-place density	30
Proof rolling	16
Moisture content	13
Number of passes	4
Timing of Drainage Construction	
Construct prior to pavement (placed at pavement/shoulder edge)	21
After pavement (retrofitted)	1
After pavement (placed at edge of outside shoulder)	1
Verifying Drain Functionality	
Agency specification for inspection and repair	16
Contractor option	5
Permeable Aggregate Base/Separator Layer	
Aggregate gradation	18
Layer thickness	17
In-place density	14
Number of passes	4
Asphalt-Treated Permeable Base	
Layer thickness	12
Binder content	9
Aggregate gradation	8
In-place density	7
Placement temperature	6
Number of passes	6
Compaction temperature	4
Permeability/drainability	1
Asphalt Mixture Placement Density	
Cores	28
Nuclear density gauge	24
Non-nuclear density gauge	6
Cement-Treated Permeable Base	
Layer thickness	9
Aggregate gradation	6
Curing method	6
Cement content	5
In-place density	4

Maintenance and Preservation

Figures 21 through 23 illustrate the agency responses for maintaining drainage features and preserving asphalt and composite pavements to minimize damage due to the presence of water. In total, thirty-one responses were received in regards to maintaining drainage features and preserving pavements to minimize damage due to the presence of water.

Figure 21 illustrates that the majority of agencies maintain drainage features through cleaning ditches and removing culvert debris (twenty-four responses each), mowing and cleaning ditches (twenty-one responses), and repairing or replacing defective components (twenty responses). A number of respondents also indicated pipe inspection (sixteen responses), mowing around outlet pipes (sixteen responses), and unplugging outlets, filters and drains (fifteen responses) as drainage maintenance activities. The fewest responses included deepening ditches (ten responses), drainage system video inspection (six responses), and flushing edgedrains (six responses).

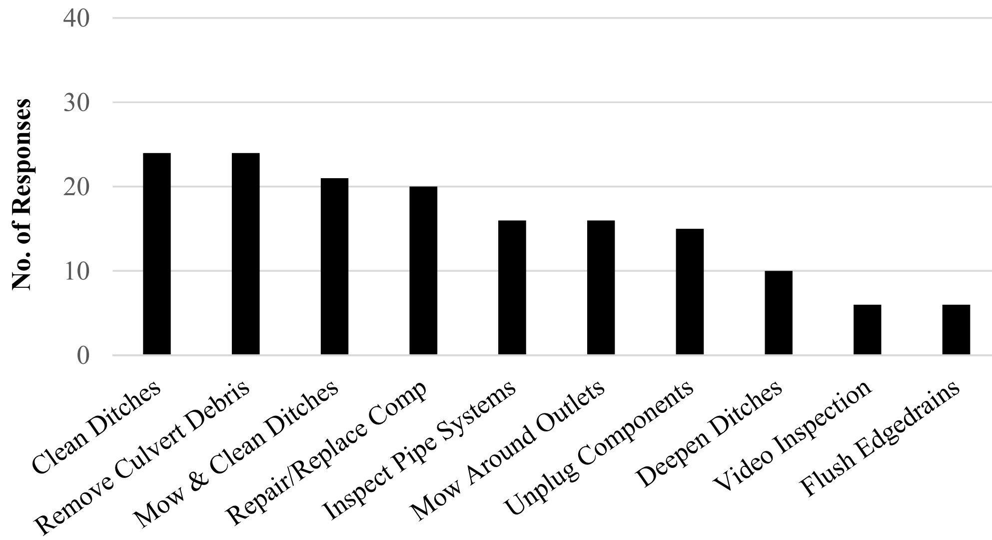


Figure 21. Agency drainage maintenance activities.

For asphalt pavement preservation activities, the majority of responses indicated the use of crack sealing (twenty-nine responses), chip sealing (twenty-two responses), and thin asphalt overlays (twenty responses) (Figure 22). A number of responses included the use of microsurfacing (seventeen responses) and surface seals (fourteen responses). For the purpose of this survey, surface seals were defined as fog seals, sand seals, and scrub seals.

Although the response rate is slightly lower, the pavement preservation activities for composite pavements are ranked in the same order as the asphalt pavement preservation activities (Figure 23). Agencies indicated that crack sealing is one of the more prevalent preservation activities on composite pavements (twenty-four responses). Chip seal, thin asphalt overlay, and microsurfacing applications on composite pavements are conducted by half of the responding agencies, and ten agencies indicated the use of surface seals.

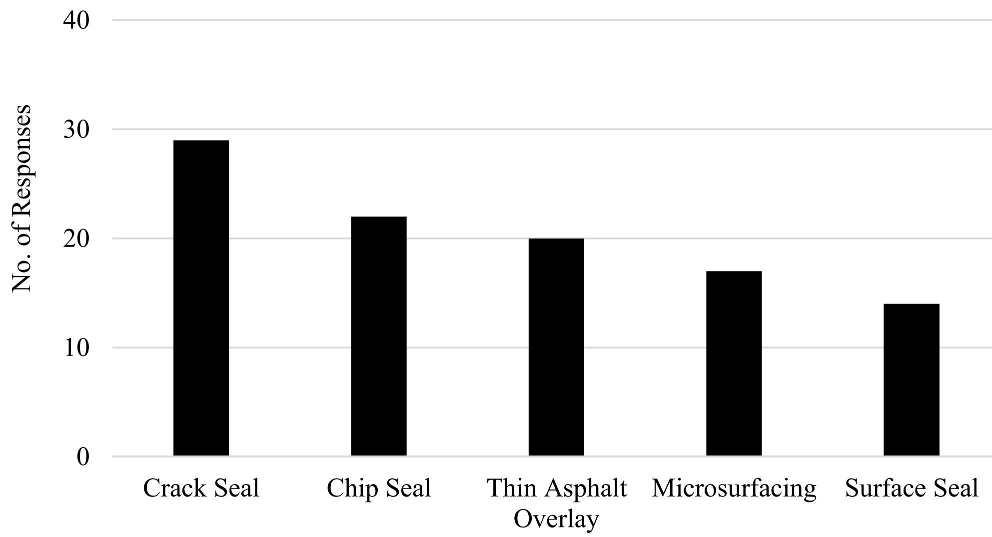


Figure 22. Agency asphalt pavement preservation activities.

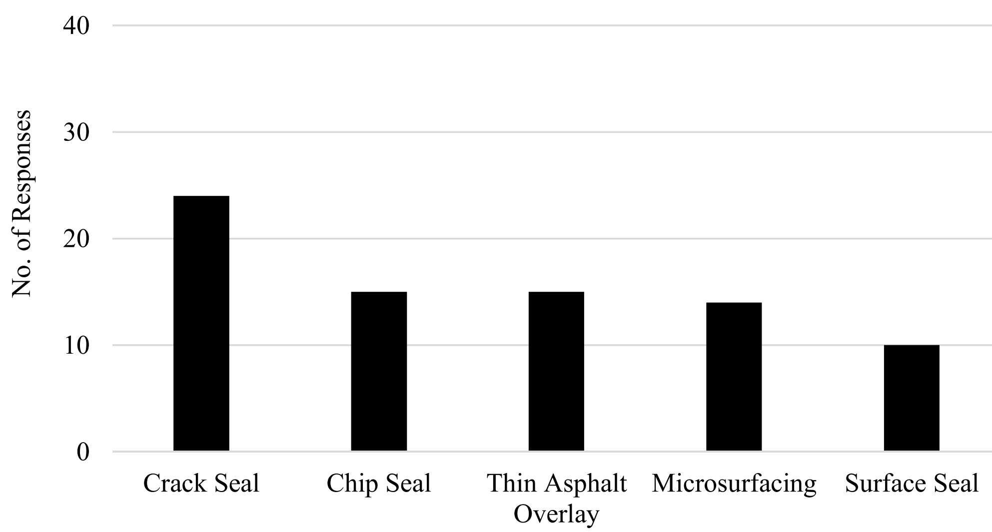


Figure 23. Agency composite pavement preservation activities.

Rehabilitation

A summary of agency responses for asphalt pavement rehabilitation treatments for mitigating damage due to the presence of water is shown in Figure 24. Of the thirty agencies responding to this survey question, the predominant responses included milling followed by an asphalt overlay (twenty-eight responses), pavement reconstruction (twenty-three responses), and an asphalt overlay (sixteen responses). Seven agencies indicated the use of cold in-place recycling and retrofit edgedrains, two agencies indicated the use of an unbonded concrete overlay, two agencies indicated the use of milling, asphalt overlay, and sawing and sealing, and only one agency indicated using an asphalt overlay and sawing and sealing.

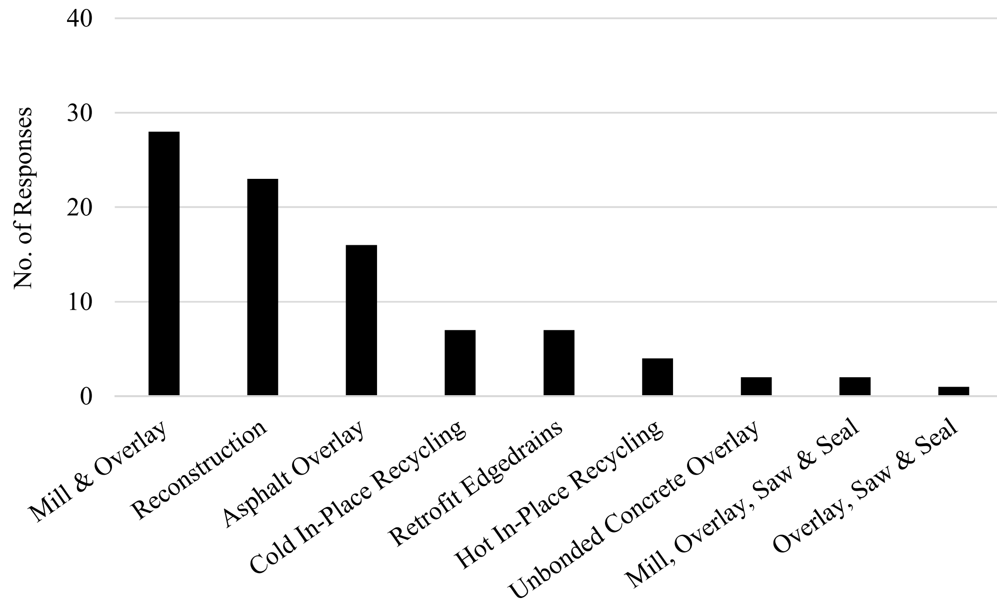


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Figure 24. Agency asphalt pavement rehabilitation treatments.

The majority of agencies (twenty responses) indicated milling followed by an asphalt overlay as an effective treatment for mitigating damage to composite pavements due to the presence of water (Figure 25). Reconstruction, retrofitting edgedrains, and asphalt overlays received nine to eleven responses, and the remaining treatments had less than three responses each.

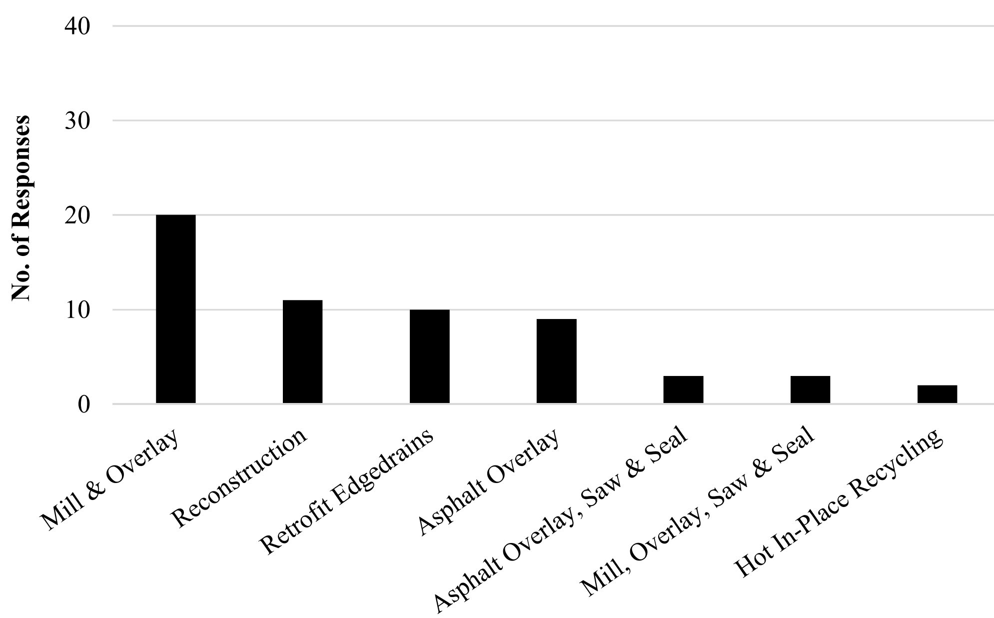

Figure 25. Agency composite pavement rehabilitation treatments.

The final survey question asked respondents to identify which pavement and drainage features they considered to be the most effective in mitigating pavement damage due to the presence of water. Feature effectiveness was based on a scale of 1 to 5, with 5 being effective and 1 being ineffective in limiting pavement damage. A summary of agency responses on pavement and drainage feature effectiveness is provided in Table 14. Agencies indicated that the most effective (based on the sum of responses indicating an effectiveness ranking of 4 and 5) pavement and drainage features for mitigating damage due to the presence of water include asphalt mixture additives, asphalt mixture aggregate quality, pavement drainage design, and asphalt mixture air voids/in-place density.

Table 14. Agency assessment of drainage and pavement feature effectiveness.

Feature/Condition	**Effectiveness[1]**				
	1	**2**	**3**	**4**	**5**
Asphalt mixture additives	1	2	7	9	12
Asphalt mixture aggregate quality	1	3	6	12	8
Asphalt mixture air voids/in-place density	1	2	4	10	10
Pavement drainage design	0	3	5	5	14
Asphalt mixture binder content	1	2	10	12	4
Asphalt mixture type	1	3	8	6	8
Environmental conditions	1	2	12	6	4
Traffic level considerations	3	1	11	8	0
Base type	1	4	12	2	5
Pavement age consideration	2	2	14	3	0

Note: values shown represent number of responding agencies.
[1] Rated on a scale of 1 (ineffective) to 5 (effective).

Industry Survey Results

A total of twelve industry members (out of seventy-three, for a response rate of sixteen percent) responded to the industry survey. Responses were received from nine asphalt industry members and three concrete industry members. As with the agency survey, the research team made several attempts to increase the survey response rate through email notifications. Unfortunately, no additional responses were received. A summary of industry survey results is provided in the following discussion (a complete list of survey responses is provided in Appendix F).

Drainage and Pavement Feature Effectiveness

Industry members were asked to identify the effectiveness of various drainage and pavement features in minimizing the presence of water in asphalt and composite pavements. Feature effectiveness was based on a scale of 1 to 5, with 5 being effective and 1 being ineffective in limiting pavement damage. Figure 26 presents the industry responses that have a feature effectiveness ranking of 4 or 5. Industry members indicated that asphalt permeable base (nine responses) was an effective feature, followed by aggregate permeable base, ditches, and open-graded friction courses (six responses each), and curb and gutter and edgedrains (five responses each). Industry members also identified cement-treated permeable base as the least effective feature.

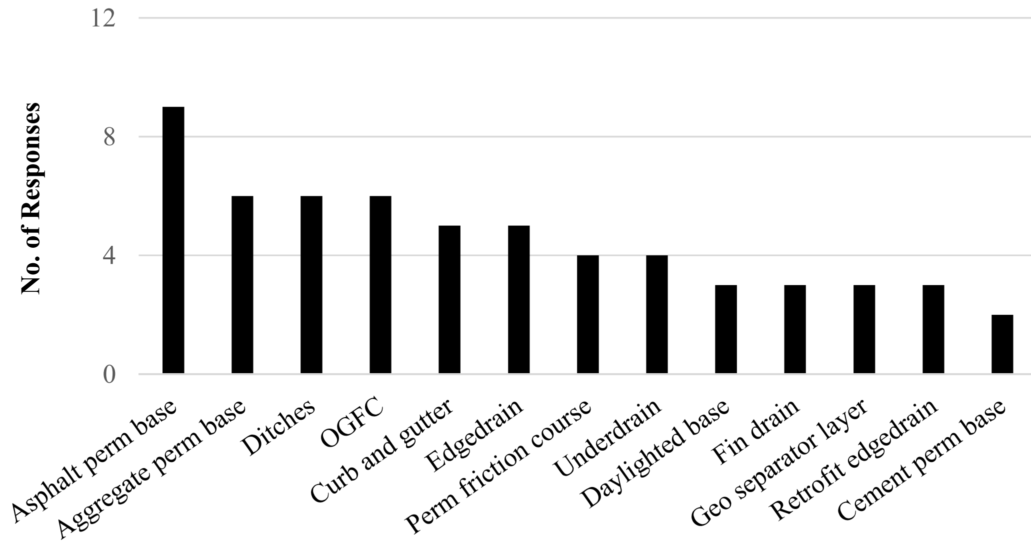

Figure 26. Industry assessment of drainage and pavement feature effectiveness.

Effectiveness of Drainage Systems

Next, industry members were asked to rate the effectiveness (on a scale of 1 to 5) of drainage systems in removing water from the roadway. Specifically, industry members were asked to rank the effectiveness of aggregate trenches, edgedrains, underdrains, and fin drains. Figure 27 illustrates industry responses on drainage systems' effectiveness. As in Figure 26, the number of responses illustrated in Figure 27 indicate the sum of responses received with a ranking of 4 and 5. While the results of the industry survey indicated that edgedrains and underdrains were more effective than fin drains and aggregate trenches in removing water from the pavement structure, very few of the industry responses indicated that these drainage systems were effective in removing water from the pavement structure.

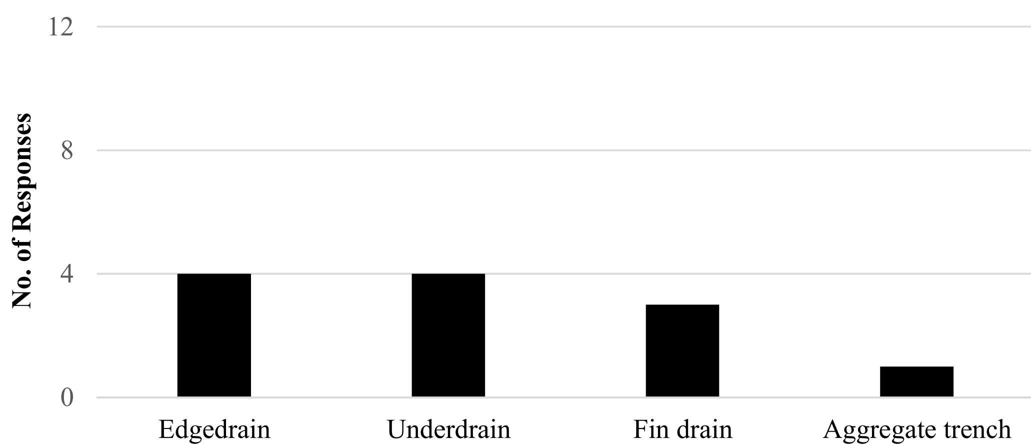

Figure 27. Industry assessment of drainage system effectiveness.

Practices for Addressing Weak Soils

Industry members were asked to identify methods that are effective in reducing the impact of weak soils on pavement performance. A summary of responses is shown in Figure 28. All industry members indicated that removing and replacing weak soils with higher quality material or stabilizing weak soils (twelve responses each) are effective measures in reducing pavement damage due to weak soil conditions. In addition, increasing the aggregate base thickness (nine responses) and placing a geosynthetic between the weak soil and the base layer (eight responses) were also effective methods for addressing weak soils. Only three industry members indicated increasing the asphalt layer thickness and only two industry members indicated increased the concrete layer thickness (for composite pavements) as effective methods for minimizing damage due to weak soil conditions.

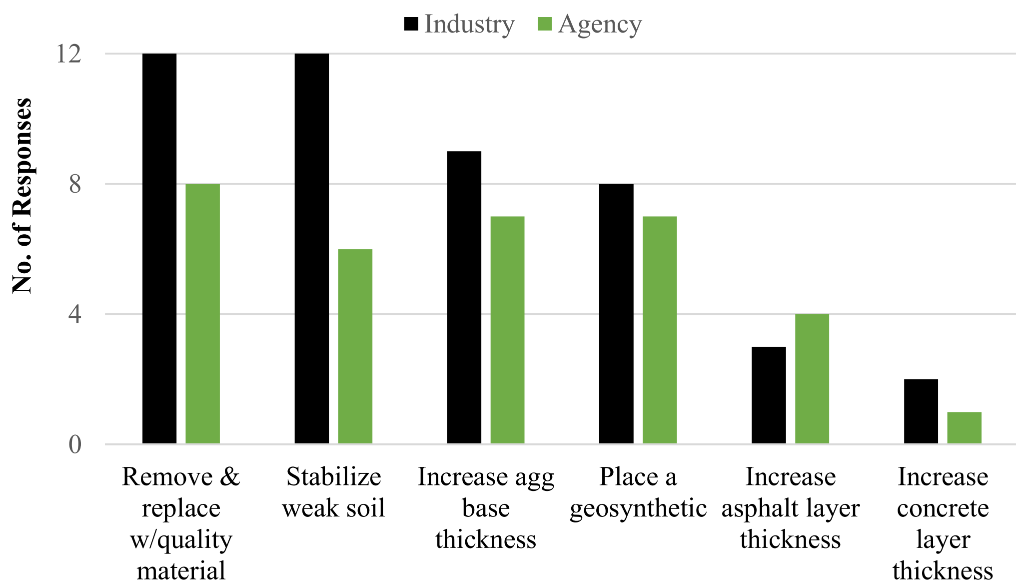

Figure 28. Industry assessment of effective methods for addressing weak soils.

Figure 28 also includes the results of the agency responses on methods of addressing weak soil conditions (for all comparison plots, agency responses have been normalized to the number of industry responses for comparison purposes). As shown, there is a strong agreement between agency and industry responses on the top four methods; however, the order of method ranking is slightly different between the two survey results. Agencies and industry ranked remove and replace with high quality materials and increase the aggregate base thickness in the same order, but industry ranked stabilizing the weak soil higher than placing a geosynthetic, which was opposite of the agency ranking. Both surveys were in agreement on the rank order for increasing the asphalt or concrete layer thicknesses.

Practices for Addressing High or Perched Water Tables

The assessment of the effective methods for addressing high or perched water tables by the responding industry members indicated that installing edgedrains (seven responses) and deepening roadside ditches (six responses) were slightly more effective than installing culverts (five responses) (Figure 29). Three of the industry members indicated that high or perched water tables were typically not a concern. Additional comments included adding course aggregate drains and adjusting roadway profiles (during the design phase) to account for high or perched water tables. As shown in Figure 29, the industry rank order of effective methods for addressing high or perched water tables is the same as the agency responses.

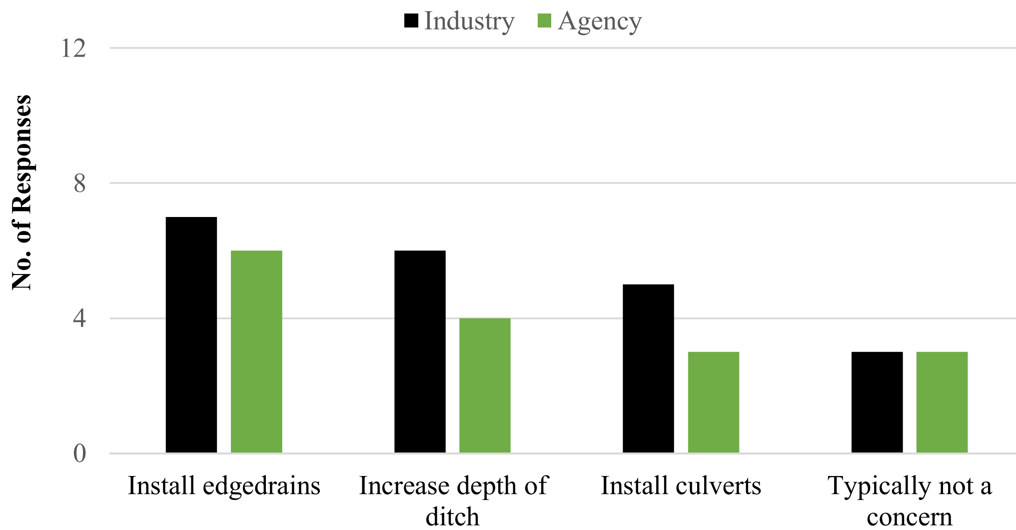

Figure 29. Industry assessment of methods for addressing high or perched water tables.

Effective Use of Geosynthetics

Figure 30 summarizes the industry ranking of effective uses for geosynthetic materials. Industry members indicated that geosynthetics were effective in drainage systems (eight responses), separating subgrade soil from the base layer (seven responses), and subgrade stabilization (seven responses). Industry members ranked the use of geosynthetics as base reinforcement (two responses) and as an overlay stress absorption/reinforcement layer (one response) considerably lower than the other three uses. In comparison, agencies indicated a slightly different rank order for geosynthetic uses, ranking drainage systems lower than that of the industry members.

Construction

Similar to the agency construction-related questions, industry members were asked to respond to a series of questions related to construction of drainage systems, and subgrade, base, and asphalt layer placement. The following provides a summary of industry construction-related responses:

- The appropriate timing for drainage system installation is prior to pavement construction (eight responses). However, three responses indicated that placement should be at the edge of the outside shoulder, while five responses indicated that placement should be at the pavement/shoulder edge. The majority of responding agencies (twenty-one responses) indicated that the preferred location is at the pavement/shoulder edge.
- The drainage system installation should be verified by flushing the system (two responses), conducting a video survey (two responses), conducting a visual survey or

taking cores (one response), ensuring good inspection during installation (one response), and verification is not required (one response).

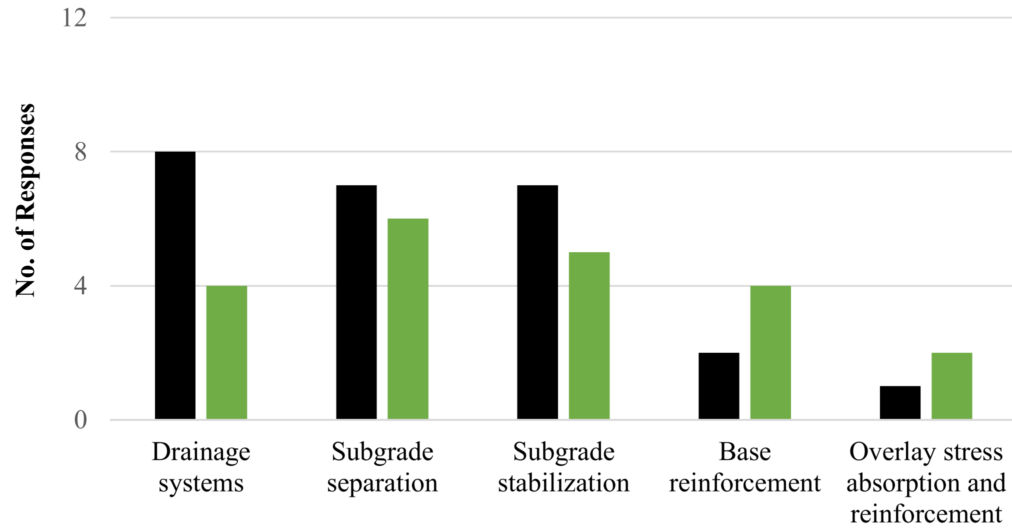

Figure 30. Industry assessment of effective uses of geosynthetic materials.

- The effective methods for measuring subgrade compaction requirements are shown in Figure 31. The majority of the industry responses included monitoring subgrade compaction through in-place density (ten responses), proof rolling (eight responses), and monitoring moisture content (five responses). None of the industry members indicated the number of passes as an effective measure for monitoring subgrade compaction. The agency ranking of the effective methods for measuring subgrade compaction is similar to those of the industry responses.

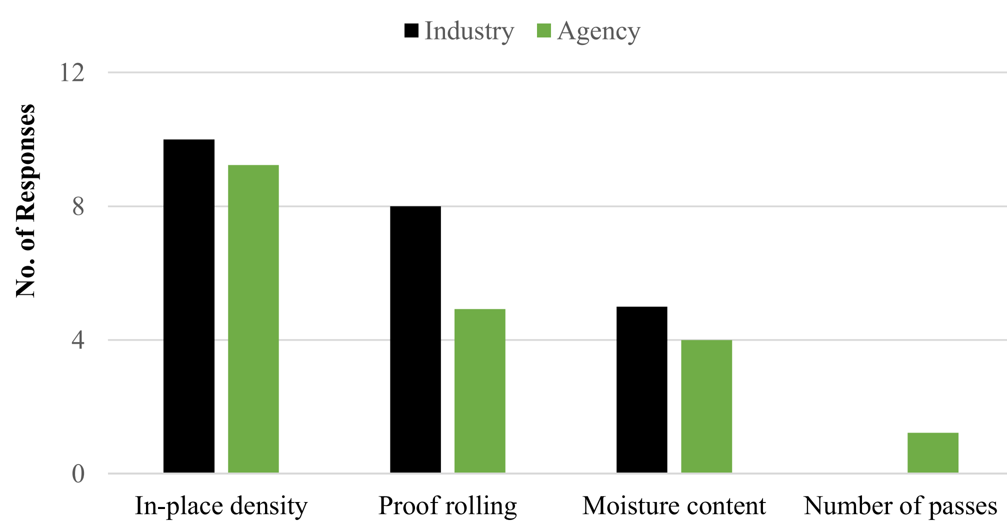

Figure 31. Industry assessment of effective methods for measuring subgrade compaction.

- The industry's assessment of effective methods for controlling placement of aggregate base/separator layers is shown in Figure 32. The ranking includes aggregate gradation (nine responses), layer thickness (eight responses), permeability/drainability (six responses), in-place density (four responses), and number of passes (one response). The rank order of agency responses was similar to that of the industry, except agencies did not identify permeability/drainability as an effective measure for monitoring aggregate base/separator layer placement.

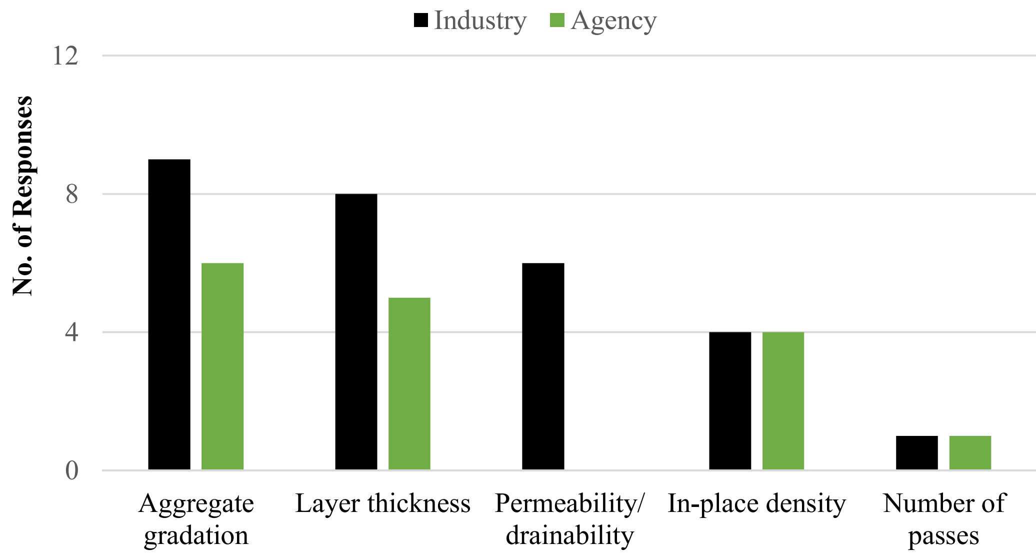

Figure 32. Industry assessment of effective methods for controlling placement of aggregate base/separator layers.

- The industry responses for effective methods for controlling placement of asphalt-treated permeable base, as well as comparison to agency responses, are provided in Figure 33. Aggregate gradation (nine response) had the highest number of responses followed by layer thickness (eight responses), binder content (seven responses), permeability/ drainability (six responses), compaction temperature (five responses), and in-place density (four responses). Placement temperature and number of passes had two and one responses, respectively. Interestingly, the rank order identified by the industry is different than the agency responses. The highest ranking methods according to agency responses were layer thickness, binder content, in-place density, placement temperature, and number of passes.

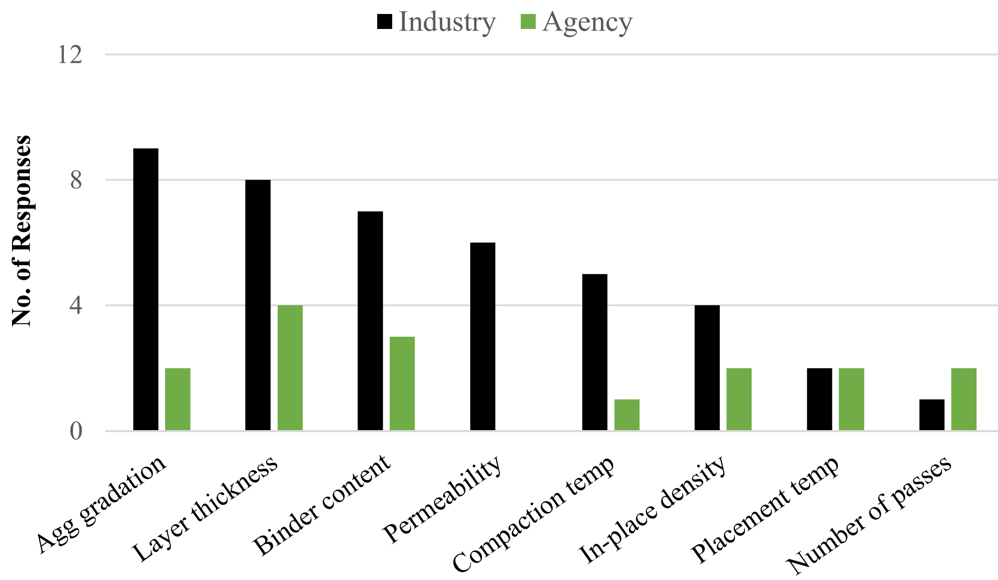

Figure 33. Industry assessment of effective methods for controlling placement of asphalt-treated permeable base.

- The industry responses for the methods for controlling placement of cement-treated permeable base are shown in Figure 34. The highest number of responses include aggregate gradation (six responses), layer thickness, cement content, and permeability/drainability (five responses), and curing method (four responses). In-place density and number of passes had two and one response, respectively. The highest ranked agency responses included layer thickness, aggregate gradation, and curing method.

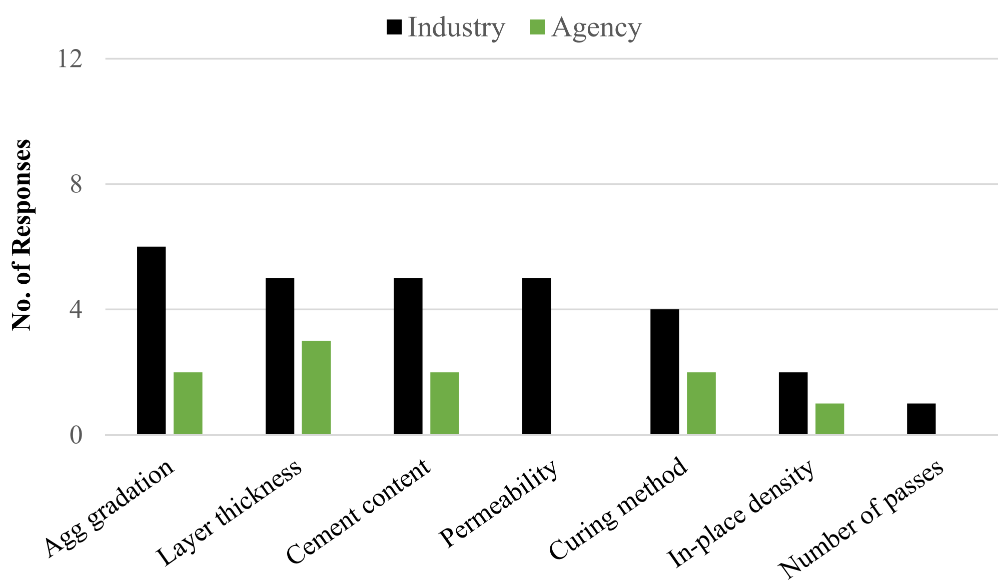

Figure 34. Industry assessment of effective methods for controlling placement of cement-treated permeable base.

- Figure 35 summarizes industry responses for methods to control placement density of asphalt mixtures. The highest ranked method identified by the industry responses included the nuclear density gauge, followed by cores and non-nuclear density gauges. Agency responses indicated a somewhat different result in that coring was rated as more effective than nuclear density gauge testing for controlling asphalt mixture placement.

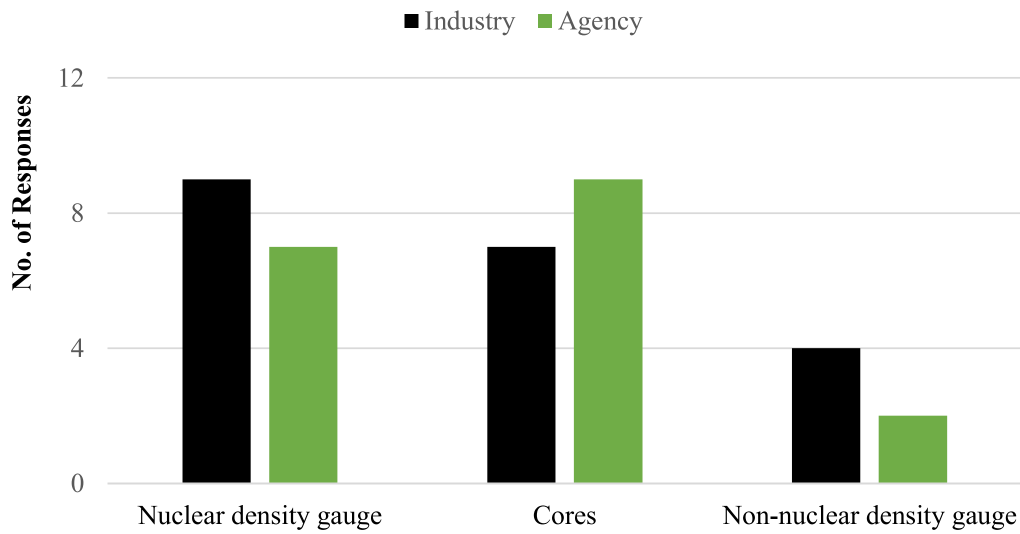

Figure 35. Industry assessment of effective methods for controlling placement of asphalt mixtures.

CHAPTER 4. AGENCY AND INDUSTRY SITE VISITS

Introduction

The intent of the task 3 site visits was to identify those agencies who have taken positive steps to minimize pavement damage due to water, but whose practices have not been well documented in the literature. However, based on the results of the literature search, agency and industry survey, and survey follow-up questions, the research team believes that sufficient information is available to develop best practice guidelines without having to perform site visits. As was discussed in Chapter 2 and 3, the literature search identified a wealth of information that can be used in the development of the guidelines and the results of the agency survey provided a number of opportunities to showcase agency practices.

Summary of Agency Practices

The information contained in Tables 15 through 17 summarizes agency practices that may be used during guideline development to showcase a variety of drainage and pavement features. Table 15 provides a summary of agency base material types, Table 16 provides a summary of drainage features, and Table 17 provides a summary of other features.

As shown in Table 15, the majority of agencies responding to the survey indicated the use of aggregate permeable and daylighted bases. In addition, a number of agencies indicated the use of asphalt- and cement-treated permeable base layers. The majority of agency Standard Specifications and Standard Plans/Drawings are also readily available online.

Table 15. Potential agencies for case studies and examples—base materials.

Agency	Aggregate Permeable Base	Asphalt-Treated Permeable Base	Cement-Treated Permeable Base	Daylighted Base
California DOT	✓	✓	✓	✓
Florida DOT	✓	—	—	—
Idaho TD	✓	✓	—	✓
Indiana DOT	✓	✓	—	✓
Kentucky TC	—	✓	✓	✓
Maryland SHA	✓	—	—	✓
Minnesota DOT	✓	—	—	✓
Mississippi DOT	—	✓	—	—
Missouri DOT	✓	✓	✓	✓
New Jersey DOT	—	✓	—	—
Oklahoma DOT	✓	✓	✓	✓
Ontario MOT	✓	✓	✓	—
Pennsylvania DOT	✓	—	—	✓
South Carolina DOT	✓	✓	✓	—
Tennessee DOT	—	✓	—	✓

Agencies also indicated the use of a broad range of drainage features, which are summarized in Table 16. Drainage features include the use of drain outlets, edge drains, retrofit edge drains, fin drains, French drains, and under drains. There are a number of potential agency examples for drain outlet spacing, edge drain, and under drain details. There are also four to five examples of French drain and retrofit edge drain details. As reflected in the agency survey results, very few agencies use fin drains; however, at least one example of agency practice was identified.

Table 16. Potential agencies for case studies and examples—drainage features.

Agency	Drain Outlet Spacing	Edge Drains	Fin Drains	French Drain	Retrofit Edge Drains	Under Drain
California DOT	✓	✓	—	—	✓	✓
Florida DOT	—	✓	—	✓	—	✓
Idaho TD	✓	✓	—	—	—	✓
Indiana DOT	✓	✓	—	✓	✓	✓
Kentucky TC	✓	✓	—	✓	✓	✓
Maryland SHA	✓	✓	—	—	—	—
Minnesota DOT	✓	✓	—	—	—	✓
Mississippi DOT	✓	✓	—	✓	—	✓
Missouri DOT	✓	✓	✓	✓	✓	✓
Nevada DOT	—	—	—	✓	—	✓
New Jersey DOT	—	—	—	—	—	✓
Oklahoma DOT	—	✓	—	—	—	✓
Ontario MOT	—	✓	—	—	—	—
Pennsylvania DOT	✓	✓	—	—	—	✓
South Carolina DOT	✓	✓	—	—	—	✓
Tennessee DOT	✓	—	—	✓	✓	✓

Table 17 summaries a variety of agency practices for addressing potential water issues in pavement structures. These include freeze/thaw, high or perched water tables, weak soil conditions, and permeable wearing courses. All but one agency has developed practices for addressing weak soil conditions, and seven to eight agencies have practices for addressing freeze/thaw conditions and high or perched water tables. In addition, several agencies utilize open-graded and/or permeable friction courses for moving water from the pavement surface.

As discussed, the research team believes there to be sufficient and readily available material and information to capture agency best practices for mitigating damage due to water in asphalt and composite pavements. However, if additional good practices are identified during guideline development and are not readily available, the research team will contact the identified agency (or industry) and make every effort to obtain the needed information, including site visits, if warranted.

Table 17. Potential agencies for case studies and examples—other.

Agency	Freeze/ Thaw Criteria	High or Perched Water Table Criteria	Weak Soils Criteria	Open-Graded Friction Course	Permeable Friction Course
California DOT	—	—	—	—	✓
Florida DOT	—	✓	✓	✓	—
Idaho TD	✓	✓	✓	—	—
Indiana DOT	✓	✓	✓	✓	—
Kentucky TC	—	—	✓	—	—
Maryland SHA	✓	✓	✓	—	—
Minnesota DOT	✓	✓	✓	—	—
Mississippi DOT	—	✓	✓	✓	—
Missouri DOT	—	—	✓	—	✓
Nevada DOT	✓	✓	✓	✓	✓
New Jersey DOT	—	—	—	✓	—
Oklahoma DOT	—	✓	✓	✓	✓
Ontario MOT	✓	—	✓	—	—
Pennsylvania DOT	✓	—	✓	—	—
South Carolina DOT	—	✓	✓	✓	—
Tennessee DOT	✓	✓	✓	✓	—

Note: Porous friction courses typically have high air voids and asphalt binder contents and are designed so that they are less likely to trap water. Open-graded friction courses typically have high air voids and asphalt binder contents, single-size coarse aggregate, and are designed to drain water through the open-graded layer.

CHAPTER 5. OUTLINE OF BEST PRACTICES GUIDELINES

Introduction

The guide document will be developed based on the information obtained from the literature search and the agency and industry surveys. The guide document will include best practices for limiting damage due to water in asphalt and composite pavements arranged according to design features (e.g., geometrics, drainage, and pavement structure), materials (e.g., material properties, mixture design, binder selection), construction (e.g., subgrade treatment, compaction requirements, testing, treatment to minimize reflective cracking), preservation (e.g., activity or treatment type and timing), and rehabilitation (e.g., maintain conditions, upgrade or address existing conditions, reflective cracking treatments), with accompanying appendices. This chapter presents the proposed outline of the guide document and the proposed AASHTO Standard Practice.

Proposed Guide Outline

The proposed outline for the guide document is provided in Table 18. The guide document will consist of an executive summary, nine technical chapters, and supporting appendices.

Table 18. Proposed outline of the guide document.

Chapter	Content
Executive Summary	• Introduction – purpose, background and scope • Approach –research approach • Findings – primary findings • Summary – guide document and stand-alone application summary • Recommendations for implementation – checklist, plans, and practices
1. Introduction	• Purpose – provide guidelines, practices, plans, and specifications for limiting damage to asphalt and composite pavements due to water • Background – factors contributing to distress, impact on pavement performance, readily available information; however, no currently available guide document • Scope – contents of guide document, case studies, design procedures, specifications, construction practices • Audience – design, construction, and maintenance engineers and technicians at state highway and local transportation agencies • Document organization – chapter number, title, and description • How to use this guide and stand-alone application – summary of guide content and summary of functionality of stand-alone application
2. Sources of Water	• Description of water sources - Surface infiltration - Capillary action and vapor movements - Changes in depth to water table - Seepage from high ground - Pavement edge

Table 18. Proposed outline of the guide document (continued).

Chapter	Content
3. Damage Mechanisms	• Description of damage caused by water - Asphalt layer(s) and between layers - Base layer(s) - Subgrade - Moisture-related distress types in asphalt and composite pavements
4. Design Features	• Roadway geometric design - Cross-slope - Longitudinal slope - Length of drain path - Curb and gutter, shoulders • Subsurface drainage - Need for subsurface drainage (e.g., collect and drain water from the surface, remove subsurface water, minimize erosion, intercept water, impact of climate zone, traffic, and subgrade permeability) - Summary of drainage design procedures (e.g., rational method, DRIP, PAVDRN, PURDRAIN) - Design considerations (e.g., pavement type, infiltration rate, time to drain, grades, rain/storm events, subgrade conditions) - Subsurface drainage considerations (e.g., drainable base, edgedrains, underdrains, ditches, daylighted base) • Pavement design - Summary of pavement design procedures (new and rehabilitation) - Subgrade treatments (e.g., cement-treated, lime-treated) - Base type selection (e.g., aggregate, asphalt- and cement-treated) - Asphalt- and composite pavement-specific design considerations (e.g., reflective cracking mitigation) - Surface type considerations (e.g., dense-, open-, gap-graded) - Shoulder design considerations • Freeze-thaw considerations - Freeze-thaw mechanism (subfreezing temperatures, presence of moisture, and frost susceptible soils) - Heaving potential (uniform versus differential) - Methods for mitigating (e.g., increase depth, remove and replace with suitable materials, capillary break, load restrictions) • Design interactions - Interaction of features (e.g., drainable base, no need for edgedrains)
5. Material Type and Selection	• Pavement layers - Base material types and properties (e.g., lean concrete, cement-treated, asphalt-treated, granular base) - Asphalt binder grade and binder additives - Asphalt mixture properties and design - Laboratory testing procedures and recommended criteria • Drainage systems - Backfill material, geosynthetics, pipe, outlets, and so on - Laboratory testing procedures and recommended criteria

Table 18. Proposed outline of the guide document (continued).

Chapter	Content
6. New Construction	• Pavement layers - Subgrade treatment requirements (based on material properties) - Base placement and compaction - Asphalt placement and compaction requirements (e.g., tack coat, longitudinal joint compaction, construction joints) - Concrete construction requirements (e.g., joint details) - Construction quality control and acceptance testing requirements and monitoring procedures • Drainage systems - Excavation, placement, compaction, and so on - Drainage system inspection - Construction quality control and acceptance testing requirements and monitoring procedures • Roadway widening - Maintaining drainage between existing and new construction - Addressing permeability differences
7. Maintenance and Preservation Strategies	• Pavement - Treatment type and timing including an assessment of effectiveness in mitigating water intrusion - Pretreatment application requirements - Techniques to address reflective cracking - Construction requirements • Drainage - Inspection - Cleaning outlets - Clean or replacing rodent screens - Flushing or replacing outlet pipes - Deepening ditches
8. Rehabilitation Treatments	• Pavement - Treatment type and timing (including assessment of effectiveness in mitigating water intrusion) - Pretreatment application requirements (e.g., tack coat, crack sealing) - Techniques for mitigating/addressing reflective cracking in composite pavements and asphalt overlays - Construction requirements • Drainage - Retrofit edgedrains - Shoulder reconstruction (better-draining material) - Installation of new or replacement system - Construction requirements
9. Benefits and Barriers	• Summary of recommended practices • Benefits of implementation • Potential barriers of practices and features

Table 18. Proposed outline of the guide document (continued).

Chapter	Content
Appendix A. Standard Plans	• Drainage details • Pavement cross-sections
Appendix B. Standard Specifications	• Materials specifications • Testing and evaluation requirements • Construction specifications
Appendix C. Agency Fact Sheets	Agency fact sheets to describe: • Description of practice • Where and when to use • Limitations • Expected costs and benefits

Proposed Outline of AASHTO Standard Practice

A proposed AASHTO standard practice will be developed from the guide document and will target practitioners in the pavement and materials engineering community. The AASHTO standard practice format includes defining the scope, reference documents, terminology, and significance and use of the developed guidelines. This information will be followed by successful practices for geometric, drainage, and pavement design, materials selection, construction practices, maintenance and preservation, and rehabilitation considerations. The outline of the proposed AASHTO standard of practice includes (shown in Standard Practice format):

Standard Practice for

Limiting Damage to Flexible and Composite Pavements Due to the Presence of Water

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AASHTO Designation: ______

1. SCOPE

1.1 This Standard Covers The Design, Materials Selection, Construction, Maintenance, And Rehabilitation Practices For Limiting Damage Due To The Presence Of Water In Asphalt And Composite Pavements.

1.2 *This Standard Does Not Purport To Address All Of The Safety Problems Associated With Its Use. It Is The Responsibility Of The User Of This Standard To Establish Appropriate Safety And Health Practices And Determine The Applicability Of Regulatory Limitations Prior To Use.*

2. REFERENCED DOCUMENTS

2.1 *AASHTO Standards:*

- List of applicable AASHTO Standards

2.2 *ASTM Standards:*

- List of applicable ASTM Standards

2.3 *Other Standards:*

- List of other applicable Standards

2.4 *Research Reports:*

- List of applicable research reports

3. TERMINOLOGY

3.1. *Definitions:*

- List of definitions used in this Standard, for example:

3.2. *Acronyms:*

- List of acronyms used in this Standard, for example:

4. SUMMARY OF PRACTICE

Provide a brief description of the practices that can be used to limit damage to asphalt and composite pavements due to the presence of moisture, such as material specifications, drainage considerations, addressing spring thaw, and so on.

5. SIGNIFICANCE OF USE

Include purpose and how to use the document. For example, the procedures described in this practice can be used to limit damage in asphalt and composite pavements through the selection of materials, conducting appropriate mix design and pavement design practices, ensuring proper construction techniques, and through effective preservation and rehabilitation treatments that minimize the infiltration of water into the pavement structure.

6. SOURCES OF WATER

6.1. *Surface Infiltration*

6.2. *Capillary Action and Vapor Movement*

6.3. *Changes in Depth to Water Table*

6.4. *Seepage from High Ground*

6.5. *Pavement Edge*

7. DAMAGE MECHANISMS

7.1. *Susceptibility of Materials to Moisture*

7.1.1. *Lubricating/Softening Effect*

7.1.2. *Stripping Effect*

7.1.3. *Layer Debonding Effect*

7.1.4. *Pumping/Erosion of Fines Effect*

7.2. *Prolonged Exposure to Moisture*

7.3. *Interaction with Wheel Loading*

8. DESIGN CONSIDERATIONS

8.1. *Roadway Geometric Design*

- Goal is to convey surface moisture away from the traffic lanes.
- Design factors include cross slope, length of drainage path, and presence of curb and gutter or shoulders.

8.2. *Subsurface Drainage*

- Goal is to removing moisture that infiltrates the underlying base, subbase, and subgrade soil materials.
- Design factors include consideration of drainable bases and edgedrains.

8.3. *Pavement Structural Design*

- Goal is to design a structure that can withstand the effects of moisture exposure.
- Design factors include layer thicknesses, layer material types, and anticipated exposure times.

8.4. *Freeze-Thaw Considerations*

- Goal is to prevent frost from penetrating into the subgrade soils that have the capacity to develop ice lenses in winter and become saturated during spring thaw.
- The primary design factors are the material types, layer thicknesses, depth of ditches, and drainage systems.

9. MATERIAL TYPE AND SELECTION

9.1. *Base Layers*

- Base type can be selected to provide for subsurface drainage, add structural capacity, or protect the subgrade soil from frost penetration.
- Drainable base – select an aggregate type and gradation that can meet the minimum flow requirements and provide satisfactory support to the upper layers.
- Structural layer – select an aggregate type and gradation (and possibly a binder type and content) that can increase overall structural capacity of the pavement to compensate for any loss in strength that will occur as a result of prolonged exposure to moisture.
- Insulation layer – if the frost insulation provided by the pavement layers is insufficient to protect the subgrade soil from freezing, select an aggregate type and gradation that will be structurally sound and increase the level of insulation.

9.2. *Asphalt Mixture*

- In general, the design for asphalt mixtures only considers the impact of moisture exposure if the aggregates and/or binders used have a history of problems with stripping. Ideally, aggregates and binders that have a propensity to strip should be avoided. However, if these materials must be used, there are materials and processes available that can help mitigate the problem.
- Warm mix asphalt.
- Asphalt mixtures with high reclaimed asphalt pavement content.
- Primary test method for moisture susceptibility of the asphalt mixture is AASHTO T 283. Goal is to maintain a minimum tensile strength ratio (TSR) of 70 percent between moisture conditioned and non-moisture conditioned asphalt mix specimens.
- Hydrated lime or liquid anti-strip additives are typically used to reduce the asphalt mixture's moisture susceptibility.
- Conventional dense-graded mixes typically have very few interconnected air voids, and therefore are more impermeable and less susceptible to stripping. Because they have such high air voids, open-graded and gap-graded mixes are more susceptible to stripping. The mix design for these should focus on the use of aggregates with low stripping potential.

9.3. *Drainage Systems*

- Geosynthetics
- Pipe
- Aggregate For Backfill

10. CONSTRUCTION CONSIDERATIONS

10.1. *Subgrade Treatment*

- Chemical (lime or cement) stabilization
- Geosynthetic moisture barriers and reinforcing layers

10.2. *Drainable Base*

- Aggregate
- Asphalt-treated
- Cement-treated

10.3. *Drainage System*

- New installation
- Retrofit

10.4. *Prime Coat*

- Application of a cutback or emulsion to base course to help protect base from moisture exposure and improve adhesion between base and asphalt pavement layer.

10.5. *Tack Coat*

- Application of a dilute, slow-setting emulsion between asphalt pavement layers to provide for better adhesion (and prevent debonding).

10.6. *Compaction and Placement Requirements*

- Subgrade soil
- Base layer(s)

- Asphalt pavement layer(s)
- Concrete pavement layer

10.7. *Testing and Monitoring*
- Gradation
- Mix design
- Density
- Drainage system inspection

11. PAVEMENT PRESERVATION AND REHABILITATION TREATMENTS

11.1. *Preservation*
- Crack sealing
- Patching
- Surface seals (fog seal, sand seal, scrub seal, and slurry seals)
- Microsurfacing
- Chip seals
- Cape seals
- Thin overlays
- Ultra-thin bonded wearing course

11.2. *Rehabilitation*
- Localized removal and replacement
- Structural overlay
- Mill and overlay
- Retrofit edgedrains
- Shoulder improvements

12. DRAINAGE PRESERVATION AND REHABILITATION TREATMENTS

12.1. *Preservation*
- Inspection
- Cleaning outlets
- Clean or replacing rodent screens
- Flushing or replacing outlet pipes
- Deepening ditches

12.2. *Rehabilitation*
- Retrofit edgedrains
- Shoulder reconstruction
- Installation of new or replacement system

13. BENEFITS AND BARRIERS

13.1. *Benefits of Implementation*
- Less pavement damage due to water
- Longer service life and improved performance
- Less likelihood of moisture-related deterioration
- Lower life-cycle cost

13.2. *Potential Barriers of Practices and Features*

- Overcome familiarity with past practices and procedures
- Need for sampling and testing
- Need for adopting improved practices
- Reallocation of funds

14. KEYWORDS

- List of key words used in this standard

CHAPTER 6. WORK PLAN FOR DEVELOPMENT OF STAND-ALONE WEB-BASED APPLICATION

Introduction

Based on the research team's experience in designing and developing stand-alone web-based applications, it will apply a formal software development process aimed at developing a web application to facilitate broad use of the guide document. A key aspect of development will include incorporating logic to help direct the user to the appropriate pavement and drainage guidelines based on project conditions.

This approach will require incorporating a flexible web delivery framework which will provide common user interfaces and registration mechanisms for the subsequent work flows and guidance developed in this project. The research team applied a process similar to the one proposed herein on the Strategic Highway Research Program 2 (SHRP2) Project R23, *Using Existing Pavement in Place and Achieving Long Life*, to develop the *Pavement Renewal Solutions* tool. Figure 36 illustrates the launch screen that was developed for the SHRP2 Project R23 tool.

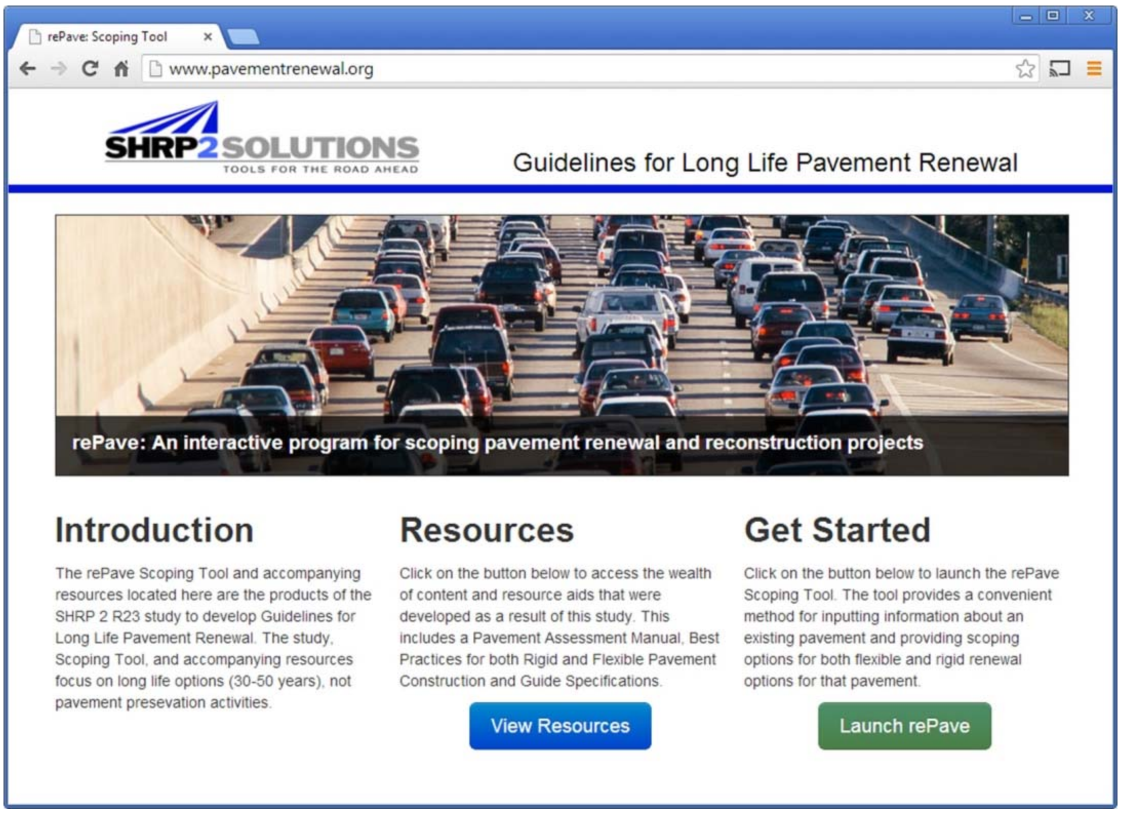


Figure 36. Example screenshot of the tool launch page.

There are a number of benefits with the development of the proposed responsive web approach, including:

- **Significantly reduced development cost**. In developing one platform that can be accessible by all devices, the up front development costs are significantly reduced.
- **Greater accessibility to all devices and operating systems**. The web-based approach will improve accessibility by making the tool useable on any web-enabled device and platform (phone, tablet, laptop, etc.). No user will be outside of the reach of the tool.
- **Enhanced user experience**. Rather than re-running scenarios and conditions from one laptop to the next or passing files in between devices, users will be allowed to access their project treatment recommendations from any device seamlessly over the web simply by using a consistent login and password.
- **Improved platform for marketing and outreach**. In utilizing a web-based approach, NCHRP can leverage the users for communications and outreach on a variety of topics that may be relevant to the user.
- **Greater visibility for tool**. The web tool and help interfaces are populated in an indexable and searchable web-based format to provide maximum search engine traffic for organic searches (distinguishes "real" results from ads) leading to enhanced opportunities to connect the requested information to the target audience.
- **Significantly reduced maintenance and support cost**. A centralized web-based approach removes the third party software maintenance requirements and allows application and documentation updates to occur instantly without additional compilation, testing, or release steps for each platform (i.e., Windows, Android, iOS).

One consideration with this approach is that to deliver a responsive web application requires that the end-user has an internet connection. Based on the team's experience developing web applications for a similar target audience, the team strongly believes this consideration to be a non-issue in meeting the project objectives. In addition, with a web approach, NCHRP will have direct feedback on usage statistics and devices used to access the stand-alone application to plan for future development and enhancements.

Application Development Approach

The research team will develop a responsive web-based stand-alone application that can be expanded on in the future as new guidance or revisions become available. Responsive web design (RWD) is a web design approach that provides easy reading and navigation with a minimum of resizing, panning, and scrolling—across a wide range of devices (from desktop computer monitors to mobile phones). The research team's approach for the formal software development process is outlined in Figure 37 and further described in the following subtasks.

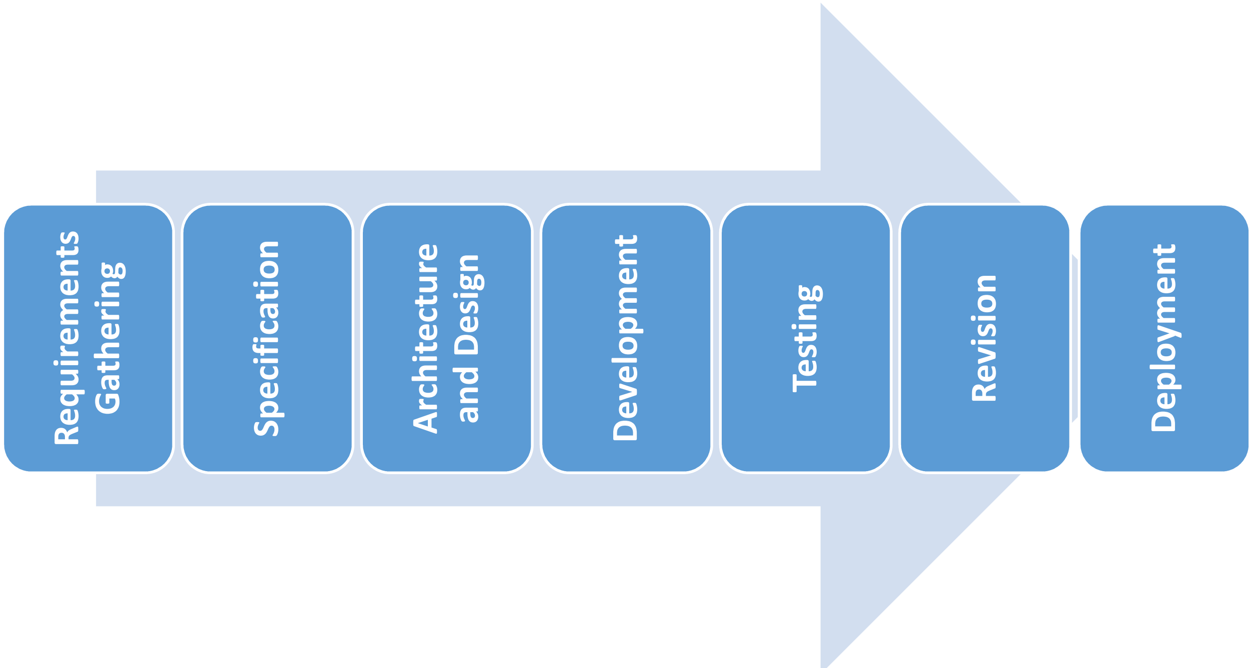


Figure 37. Software development steps and process.

Task 6.1 Requirements Gathering

During this subtask the research team will utilize the developed guidelines and input from NCHRP to transform the findings and user requirements into functional and technical requirements for the stand-alone application. As outlined in Figure 38, the user requirements will be used to establish the functional requirements for the web-based stand-alone application. The functional requirements will then be used to develop the technical requirements that will be the criteria upon which the software tools and hardware configurations will be assessed and selected.

Figure 38. Requirement development flow chart.

The deliverable for this task will be a documented set of functional and non-functional requirements. This subtask will be led by Mr. Katara with support from Mr. White and Mr. Latham.

Task 6.2 Specification

During this subtask the research team will transform the user and functional requirements into a technical specification for the stand-alone application. This includes evaluation and selection of the database and software platforms intended to provide the functional results identified during the requirements gathering subtask. The research team was responsible for developing the SHRP2 Project R23 web tool, *Pavement Renewal Solutions*, and intends to utilize that tool as an example for subsequent design and implementation decisions to maintain consistency.

Software Evaluation

The research team will utilize a weighted comparison matrix to evaluate the various appropriate technology tools before identifying final software selections. The weighting factors of the matrix will align with the project requirements and will identify tools that maximize the following elements:

- **Meets feature requirements**. Ultimately the user requirements will need to be met, such that any technology or tool selected must demonstrate a capability to meet the user and design requirements.
- **Well supported**. Given the anticipated life cycle of technology at 5 to 10 years, it is important to select technologies that are broadly deployed in similar situations and well supported by the user and development communities.
- **Cost**. In evaluating the various commercial off-the-shelf (COTS) and open source technology elements that will be deployed, the research team will consider both up front licensing costs, and longer term maintenance and support costs. The research team has strong experience in providing low total cost of ownership solutions for its customers, and as such will use that strength to identify components that will minimize total costs to ensure a sustainable solution is presented for approval.
- **Administration and security**. The software will be evaluated on its ease of administration and its ability to support the application's broader security scheme. The research team will ensure that recommendations meet NCHRP and AASHTO requirements.
- **Scalability and flexibility**. The research team anticipates that users' demands on the system will increase over time and thus the need for improved and enhanced features and capabilities will be required. In each case, the research team will evaluate the software's ability to be customized and enhanced independent of the tool's update cycle.

Based on work conducted for previous NCHRP and SHRP projects, the research team anticipates that in order to best support the aims of this study and provide a system that can be readily used by a wide range of users across the nation, a single-page web-application using JavaScript and a supporting database application programming interface (API) to collect, manage, analyze and display the data to users. The research team has demonstrated success in delivering these types of products in projects such as the Western Federal Lands Roadprint Calculator, NCHRP Project 1-46, *Handbook for Pavement Design, Construction, and Management*, and the SHRP2 Project R23 web-based tool.

This subtask will be conducted by Mr. White and Mr. Katara and will involve Dr. Pierce's coordination with NCHRP staff to approve the appropriate technology platform that will ensure subsequent implementation of the work products from this study are well supported.

Task 6.3 Architecture and Design

During this subtask the research team will define the structures of the stand-alone application including the data structures, interfaces, and the underlying technical design of the system which conforms to the criteria described in the specification.

Similar to the SHRP2 Project R23, the research team anticipates constructing a self-contained data structure that provides a framework for inserting the developed guidelines. In addition, to aid in the acceptance of the interface, the research team will develop wire frame mockups prior to development to ensure functional requirements are met effectively in the interface. This includes a description of the behaviors and logic that will accompany the interface elements.

The deliverable for this subtask will be a complete design document that includes all specification and design elements, including mockups. This subtask will be conducted by Mr. White and Mr. Katara, with interface design by Mr. Latham.

Task 6.4 Development

The research team has significant experience with state-of-the-art computing technologies that will be needed to successfully deliver the software application. It is anticipated that some of the software technologies that will be used to build the tools will include a web server, database engine, compiled and interpreted programming languages, and graphics packages to build user friendly, scalable web-based tools. However, users of the system will simply need a computer and common web browser (e.g., Internet Explorer, Chrome, Mozilla, or Firefox) to fully access the data and utilize the system. Users will not need any unusual software installations to access and use the tool.

Stand-Alone Application Workflow

To develop the application workflow the research team intends to analyze the various outcomes of the guidelines to establish a common workflow for the stand-alone application. The goal of the workflow within the stand-alone application is to have the user specify as much information as they know about the project in order to have the appropriate guidelines and recommendations appear. A preliminary version of the workflow and input parameters is outlined below.

1. **Specify Project Information**. Users will input general project information and location conditions about the project during this step. This includes where the project is located, the regional climate, and general traffic and loading conditions. In addition, the user will indicate if they are constructing a new pavement or rehabilitating or preserving an existing pavement in order to shape the subsequent inputs appropriately
2. **Specify Pavement and Materials**. Users will enter information on the pavement structure and geometry, base layer types, and relevant materials. In addition, if existing pavement exists, any observations on the existing pavement condition will be captured to help assess the cause of any water-related issues that will need to be corrected.

3. **Specify Drainage Parameters**. Users will input various characteristics of the sources of water on the project, types of flow, rates, subgrade drainage characteristics, and other general differentiating parameters identified during development of the guidelines. This may include flow direction and flow amount. These parameters will be used in the decision matrix to identify applicable drainage strategies.
4. **Select Strategy**. Based on the previous inputs provided by the user, the application will narrow down the applicable guidance categories and present the user with options for addressing drainage and water-related concerns on the project. Each option will be presented with some benefits and considerations to allow users to select which strategy they would like to associate with guidance and recommendations.
5. **Guidance and Recommendations**. Once a drainage category has been selected, the relevant section of the guidelines along with summary guidance will be provided to the user such that they can easily extract the guidance, guide specification, and so on for incorporation into their own project.

Figures 39 and 40 provide example screenshots from the SHRP2 Project R23. These screenshots illustrate several potential steps in the work-flow process envisioned for the NCHRP 1-54 application. For example, Figure 39 illustrates the potential tool layout, as well as the process for user data entry. Figure 40 illustrates an example layout for the tool interface for linking user input, responses, and potential recommendations.

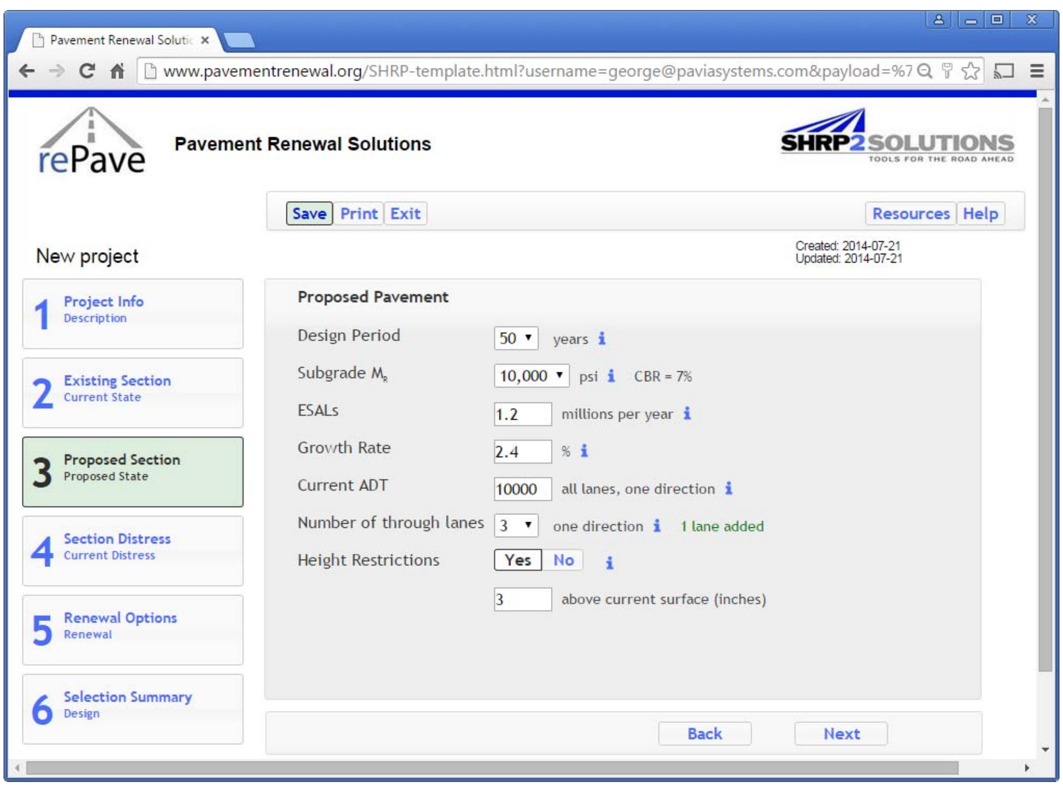


Figure 39. Example interface illustrating the process and inputs.

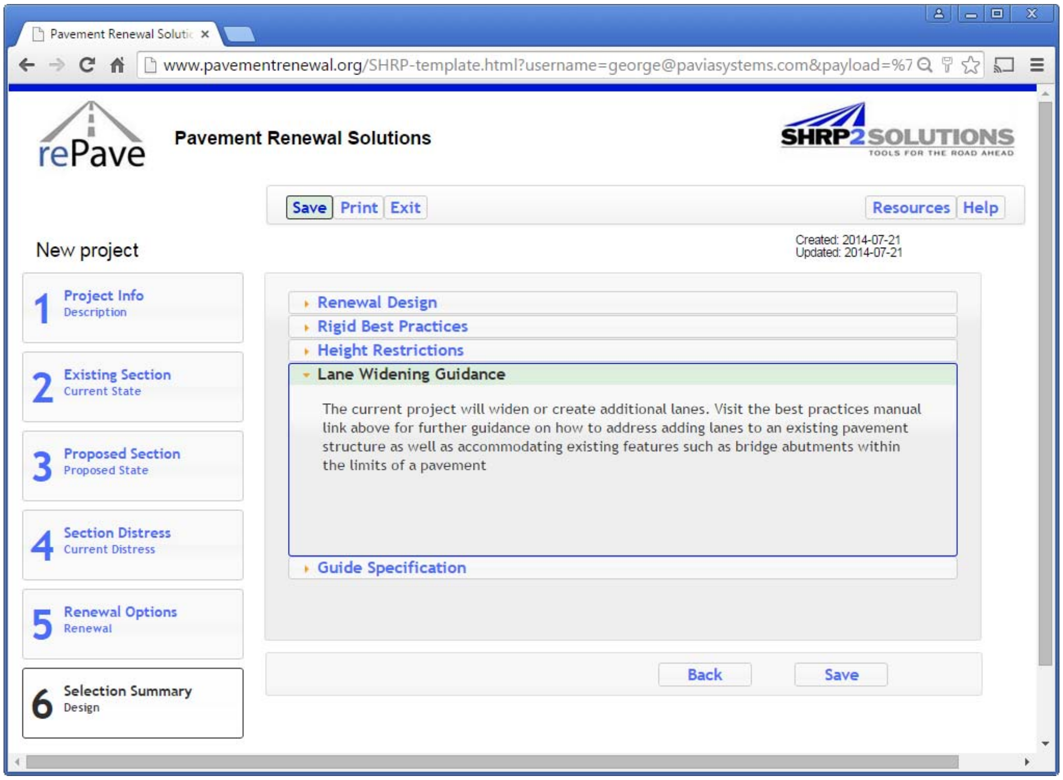


Figure 40. Example interface illustrating linkages and guidance recommendations.

Stand-Alone Application Features

In order to facilitate a broad use of the stand-alone application and to encourage implementation of the tool, several features will also be incorporated into the development process:

1. **Landing Page**. An entry page for application to promote the application, resources, and NCHRP project. It will be the first page accessible to any user coming to the site. It will allow users to access the resources of the developed guidelines and access the tool via a log in schema.
2. **User Accounts**. Provide user registration to reduce login time and allow users to store, save, and manage projects and guidelines. This will simply require the user to provide an email address if they want to save and store their projects securely on the site.
3. **Project Folders**. This feature will allow a registered user to create and organize projects and resources and alternative outcomes within the web interface. In addition, the user can easily compare, edit or share any of the guidelines at the click of a link. The mockup shown in Figure 41, layout purposes only, illustrates how the interface will provide a familiar folder-based navigation.
4. **Comparison Tool.** Provide the ability to compare guidance and drainage options side by side and visually highlight key differences between outcomes.

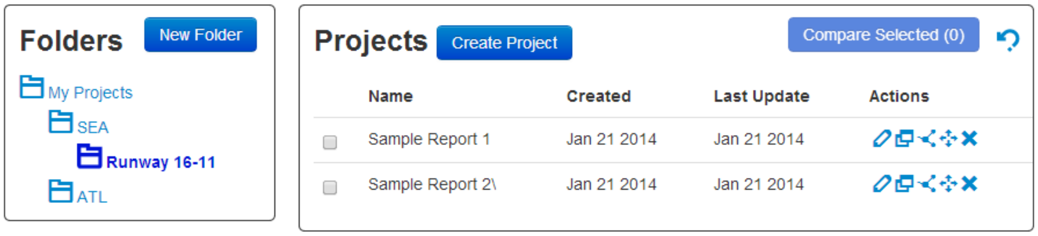


Figure 41. Example illustration of folder structure.

The deliverable for this activity will be a working prototype of the stand-alone application. This prototype will be made available for subsequent review and testing by the research team as well as NCHRP when appropriate. This sub task will be led by Mr. White, with support from Mr. Katara and Mr. Latham.

Task 6.5 Testing

As part of this subtask, the research team will develop and execute a test plan that will outline the approach and activities associated with managing quality on this development effort. The test plan will contain the steps and processes the research team will check during development, including load, performance, security, functionality, interface, and compatibility issues with user environments. To execute the plan, the research team will utilize a two-phase strategy in the testing process; one phase for ensuring quality control, and the other phase for external review and feedback.

Quality Control Processes

To ensure the proper testing regimen during the stand-alone application development process, the research team will use a multi-faceted approach to quality control testing. The testing plan will include standard testing methods for multi-tiered web application development including unit testing, scalability testing, and integration testing. The testing protocol will be automatically run on the application using the test plan requirements during each software building process.

External Testing and Review

A testing guide and checklist document will be developed and provided to NCHRP to outline the tasks or application behaviors that are to be evaluated. The testing guide will provide the review participants with the following information:

- **Goals and objectives**. A number of goals will be outlined to help NCHRP identify the desired outcomes following testing and review.
- **Use scenarios for features to be tested**. A description of use cases for the stand-alone application to evaluate functions and provide feedback on their use.
- **Reporting procedures**. Guidance on how to report issues using the issue tracking system described in the following section.

The web tool and guidelines will be made available to NCHRP for review via a private web-accessible location such that access will only require an internet connection.

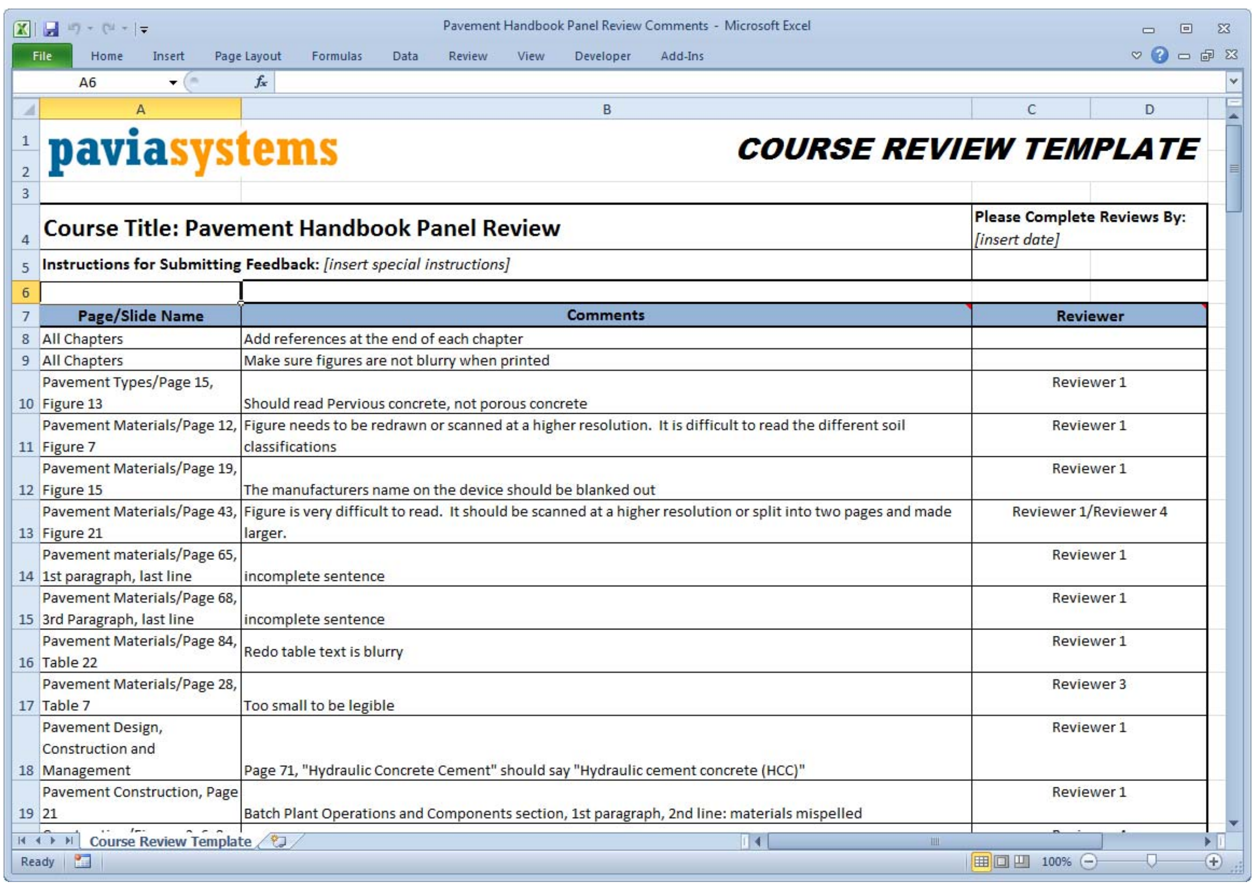
Issue Tracking

The research team will utilize an issue tracking system that provides accountability for each of the issues identified during development. Issues, or tickets, will be submitted electronically by reviewers and catalogued. The research team will then assign a priority to each request and assign an individual to carry out the activity to ensure follow through and issue resolution. All of the tracking will be summarized in a test results section of the draft final report, including issue descriptions, reproduction cases, status, and feature additions for NCHRP review and approval.

The deliverable for this task will be the issue tracking report. This effort will be led by Mr. White and coordinated amongst all research team members for proper feedback and testing. Dr. Pierce will coordinate the review period with NCHRP following internal research team testing and review.

Task 6.6 Revisions

During this subtask modifications will be made to the stand-alone application based on NCHRP feedback. Each comment will be acted upon, and where comments from separate panel members are in conflict, the research team will generate a recommendation for approval by NCHRP prior to performing the update to the tool. An example of the review tracking system from the NCHRP Project 1-46 is shown in Figure 42.



Page/Slide Name	Comments	Reviewer
All Chapters	Add references at the end of each chapter	
All Chapters	Make sure figures are not blurry when printed	
Pavement Types/Page 15, Figure 13	Should read Pervious concrete, not porous concrete	Reviewer 1
Pavement Materials/Page 12, Figure 7	Figure needs to be redrawn or scanned at a higher resolution. It is difficult to read the different soil classifications	Reviewer 1
Pavement Materials/Page 19, Figure 15	The manufacturers name on the device should be blanked out	Reviewer 1
Pavement Materials/Page 43, Figure 21	Figure is very difficult to read. It should be scanned at a higher resolution or split into two pages and made larger.	Reviewer 1/Reviewer 4
Pavement materials/Page 65, 1st paragraph, last line	incomplete sentence	Reviewer 1
Pavement Materials/Page 68, 3rd Paragraph, last line	incomplete sentence	Reviewer 1
Pavement Materials/Page 84, Table 22	Redo table text is blurry	Reviewer 1
Pavement Materials/Page 28, Table 7	Too small to be legible	Reviewer 3
Pavement Design, Construction and Management	Page 71, "Hydraulic Concrete Cement" should say "Hydraulic cement concrete (HCC)"	Reviewer 1
Pavement Construction, Page 21	Batch Plant Operations and Components section, 1st paragraph, 2nd line: materials mispelled	Reviewer 1

Figure 42. Example review tracking and feedback form.

Coordination with NCHRP for review comments will be the responsibility of Dr. Pierce. Mr. White will coordinate technical responses from the research team and Mr. Katara will lead the technical implementation activities. The remainder of the research team will support these activities as required by the feedback received. The deliverable for this task will be a revised stand-alone application that will be available via the web to NCHRP in the subsequent task.

Task 6.7 Deployment

This subtask will coincide with a review period where the application will be made available to NCHRP for review and comment. During this subtask, the research team will be available to support the testing of the stand-alone application and for troubleshooting user issues. The stand-alone application will be made available to NCHRP via a private web-accessible location such that access to the system will only require an internet connection.

This subtask will be coordinated with NCHRP by Dr. Pierce and Mr. White. Any technical needs will be addressed by Mr. Katara and Mr. Latham.

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