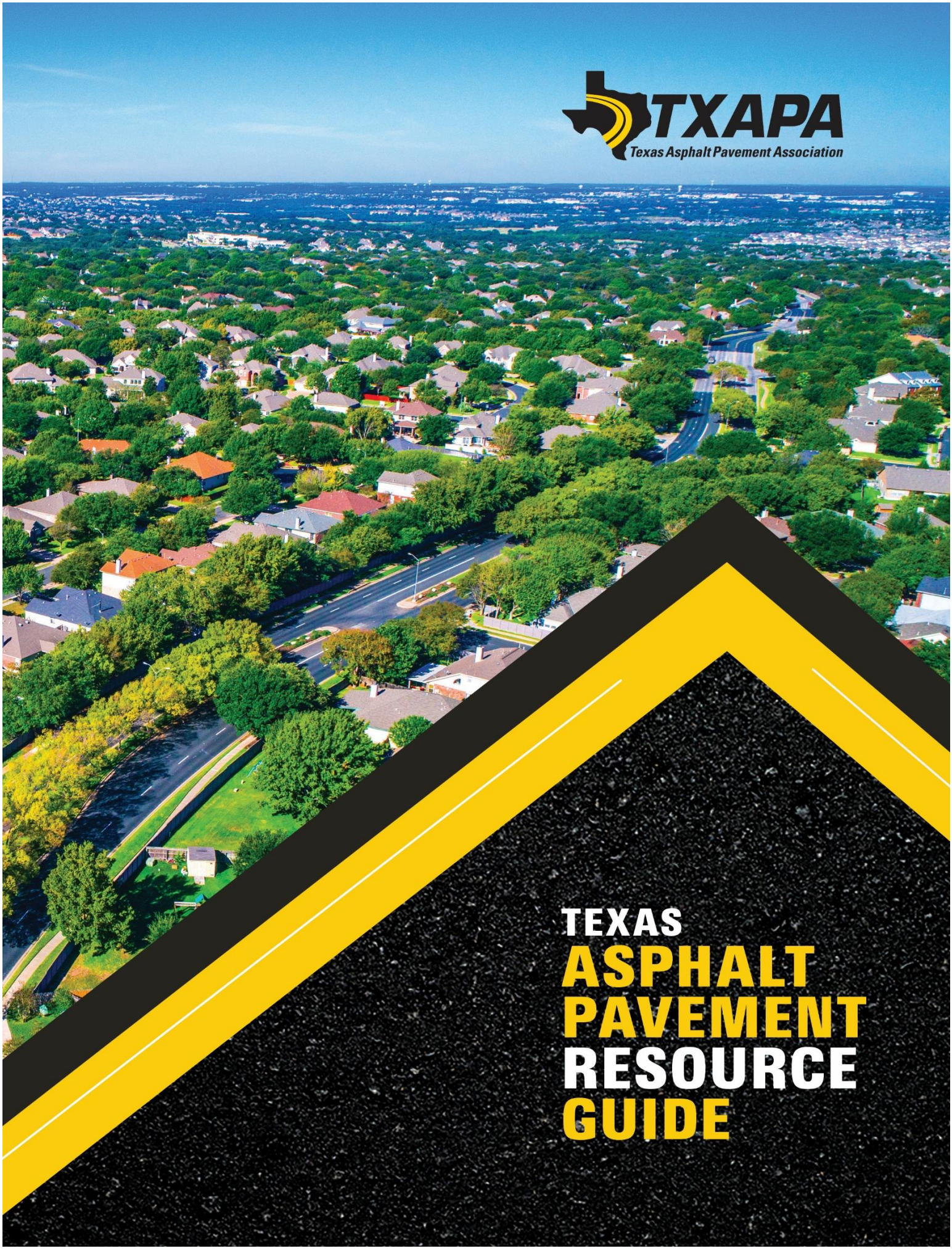
TXAPA
Texas Asphalt Pavement Association
TEXAS
ASPHALT
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RESOURCE
GUIDE

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Executive Summary

This expanded version of the **Texas Asphalt Pavement Design and Construction Guide** provides **up-to-date information** on asphalt pavement materials, engineering, construction, and maintenance. It is organized to guide readers through an in-depth exploration of each aspect, including the benefits, design principles, and applications of asphalt pavements.

Overview of Topics Covered

The guide covers topics systematically, allowing the reader to understand:

- **Advantages of Asphalt Pavements**: Chapter 1 discusses the numerous benefits asphalt pavements provide, from economic to environmental aspects.
- **Materials for Asphalt Pavements**: Chapter 2 introduces the materials that form the foundation of asphalt pavement and details the role of each component.
- **Asphalt Mixture Design Mechanics**: Chapter 3 explores the mechanics of designing asphalt mixtures, highlighting the engineering principles that ensure durability and performance.
- **Flexible Pavement Design**: Chapter 4 explains the methodologies for designing flexible pavements to withstand diverse load conditions.
- **Mix Type Selection**: Chapter 5 guides the selection process for different mix types, ensuring they match the requirements of specific applications.
- **Asphalt Mixture Specifications**: Chapter 6 provides information on specifications to align with performance standards.
- **Special Asphalt Pavement Applications**: Chapter 7 outlines unique uses for asphalt beyond traditional roads and airfields.
- **Pavement System Management**: Chapter 8 addresses the importance of managing pavement systems effectively to prolong service life.
- **Maintenance and Rehabilitation Decision-Making**: Chapter 9 helps with strategic decisions on maintaining and rehabilitating pavements based on their conditions.

Materials and Production of Asphalt Mixtures

The guide also introduces the **process of manufacturing materials** for asphalt mixtures, covering how the materials progress from **refinery and quarry to pavement**. This section familiarizes readers with aggregate mining and crude oil refining steps to obtain **liquid** and **rock asphalt** found naturally in Texas. The basics of asphalt mixture production and paving are also discussed, providing a comprehensive overview of the journey of the material to the completed pavement.

Design Considerations for Asphalt Mixtures

Asphalt mixtures must address **safety**, **performance**, and **economy** during service. Key considerations include:

- **Material and Mixture Selection**: Choosing materials and mixture design suited to the intended use of the mix.
- **Binder Selection**: Selecting the asphalt binder to suit climatic and traffic conditions.
- **Aggregate Selection and Blending**: Choosing and blending aggregates to achieve desired gradation and quality.
- **Weight-Volume Relationships**: Understanding these relationships between binder, aggregate, and mixture, as they are essential to good design.
- **Performance Testing**: Conducting tests for **cracking** and **rutting potential** in mixtures used in critical locations to ensure longevity and reliability.

Structural Design of Asphalt Pavements

The **structural design** of asphalt pavements must consider **traffic loads**, **materials**, **soils**, and **climate**. Key elements in this section include:

- **Traffic Load Considerations**: As traffic loads increase, pavement damage rises exponentially, requiring durable design.
- **Soil Stability**: Weak soils, such as expansive clays, may require stabilization with lime, especially in Texas.
- **Constructability and Layer Thickness**: Constructability is ensured by choosing the right asphalt mixture and lift thickness; usually, lift thickness should be 3 to 5 times the nominal maximum aggregate size.
- **Design Methods**: Various methods allow for streamlined design processes, including PAVExpress (based on the 1993 AASHTO approach) for online design and PerRoadXPress for perpetual pavements.

Mix Type Selection

Choosing the correct **mix type** is integral to pavement design and involves matching **traffic volume**, **loads**, and **safety** considerations to the kind of mixture. The guide provides recommendations for different scenarios:

- **Dense-Graded Mixtures**: Suitable for private, commercial, and local roads.
- **Porous Friction Course**: Ideal for high-speed, high-volume roadways.
- **Stone Matrix Asphalt (SMA)**: Best used in areas with significant heavy commercial truck traffic.
- **Thin Overlay Mixes**: Recommended for pavement preservation to extend pavement life when existing distress is minimal.

Specifications and Contractor Obligations

Specifications are critical to the **contract documents** and describe the contractor and owner's obligations. The guide emphasizes that specifications should:

- Present a **coherent and consistent expectation** for materials and construction.
- Typically include **performance-related specifications** to ensure quality.
- Offer TXAPA's specification **341M** (based on **TxDOT Item 341**), handy for small to medium projects (see **Appendix A**).

Special Applications for Asphalt Pavements

Beyond conventional applications, **asphalt pavements** can be used in various other contexts:

- **Porous Pavements**: Useful for stormwater runoff mitigation.
- **Bike Paths, Sidewalks, and Sports Courts** include outdoor tennis and basketball courts.
- **Running Tracks, Hydraulic Structures, Landfill Caps, and Railroad Track Beds**: Each application requires specific binders, aggregates, and mix design considerations.

Pavement Management Systems

Pavement management is essential in planning, budgeting, and executing treatments from **preservation to rehabilitation**. Effective management involves:

- Addressing pavements at both a **network and project level**.

- Regularly collecting **pavement condition data** through visual surveys.
- Designating preservation, maintenance, or rehabilitation projects based on condition and budget.
- Employing various **pavement management systems**, although the final responsibility for management rests with the overseeing agency.

Maintenance and Rehabilitation of Pavements

Pavements deteriorate over time and require **maintenance and rehabilitation** to sustain their serviceability. The guide identifies key factors in deterioration, such as **traffic volumes and loads**, **material durability**, **mix and structural design**, **construction practices**, and **climatic conditions** (including the presence of water). Maintenance and rehabilitation strategies include:

- **Thin asphalt overlay:** This is used as a preservation treatment to delay the need for more extensive repairs.
- **Maintenance and Rehabilitation Options**: These are chosen based on the severity and extent of distress and fiscal constraints.
- **Temporary vs. Long-Term Fixes**: While temporary solutions may seem cost-effective, addressing issues properly can prevent higher costs later.

Chapter 1 Asphalt Pavement is the Green, Economical, and Durable Choice

Asphalt pavements comprise 94% of the U.S.'s 2.8 million paved roadway miles (NAPA 2020). This chapter identifies and discusses many benefits of asphalt pavement. Asphalt pavements should always be considered when designing and constructing roadways, driveways, parking lots, sidewalks, bike paths, and hiking trails. We have all heard the term "the seven wonders of the world." Below is a list of the "seven wonders of asphalt pavement." These "wonders" or benefits are as follows.

The Top Seven Benefits of Asphalt Pavement

One: Asphalt is the most recycled material in the U.S.

Asphalt is the most recycled material in the U.S. It has been common practice to incorporate recycled materials into asphalt mixtures since the late 1970s. Reusing the asphalt binder in Recycled Asphalt Pavement (RAP) saves energy by consuming less virgin binder, which conserves petroleum and promotes the reuse of aggregate, which conserves natural resources. There are about 18 billion tons of asphalt mixtures in U.S. roadways. Virtually all this material is available for future generations to use. Using RAP instead of discarding it into landfills saves about 90 million cubic yards of landfill space, enough to fill more than 24 Dallas Cowboys Stadiums (the largest covered stadium in the NFL). Furthermore, other waste materials from other industries, such as Recycled Asphalt Shingles (RAS), can be beneficially incorporated into asphalt mixtures. Asphalt can use waste from shingle manufacturers' production and tear-offs from damaged or old roofs that need replacement. By recycling these shingles, it will keep thousands and thousands of tons from being dumped into landfills. Over 90 percent of the removed asphalt pavement is recycled back into pavement. This amounts to about 97 million tons of material annually that is saved from landfills. Recycling preserves resources in terms of virgin asphalt and aggregate, resulting in simultaneous savings in energy and cost. The "mill and fill" operation, frequently used in the surface renewal process, allows properly sized RAP to be taken from the roadway and placed in a stockpile ready for use.

Two: Producing asphalt using Warm Mix Asphalt technology is another way to go green.

WMA is a collection of technologies that allow asphalt mix to be produced and placed at 25 to 50°F lower temperatures than HMA. This process uses less energy to produce and place the asphalt at a much lower temperature. Since 2007, the asphalt paving industry in the U.S. has increasingly moved toward Warm Mix Asphalt (WMA) when placing flexible

pavement. The reasons for this movement are 1) reduced air pollution, 2) reduced fuel consumption by asphalt plants, 3) better workability and compaction of asphalt mixtures, and 4) improved ability to pave in cooler weather. Recent data from the National Asphalt Pavement Association shows that the use of WMA increased from 5 percent of the total tonnage of asphalt mix in 2009 to over 38 percent in 2019. Texas has been a leader in the use of WMA since the beginning. Over the six years covered in the NAPA survey, Texas has remained at a stable value of about 30 percent of the mix tonnage using WMA technology (Hansen and Copeland, 2015). Hassan (undated) has calculated that using WMA provides an overall 15% reduction in environmental impacts compared to HMA, which is about the same as Frank (2012) reported.

Emissions from asphalt mix plants have improved dramatically over the years, declining by 97 percent between 1970 and 2005, while the production of asphalt mixtures increased by 250 percent. ***The emissions improved to the point that the Environmental Protection Agency removed asphalt plants from the list of major sources of hazardous air pollution.*** As mentioned above, warm-mix asphalt technologies can reduce the temperatures required to produce and place the material, reducing fuel consumption and emissions.

Three: Asphalt is flexible and durable and can be used on most sub-surfaces.
Engineering design and construction design must consider the subsurface properties required to provide a solid foundation to lay the final asphalt product. Asphalt pavements have been successfully employed over any soil on which a pavement may be constructed, from gravel to peat. The type of soil will dictate what type of treatment might be employed to obtain the desired performance regardless of what type of pavement is to be built. In Texas, lime treatment of expansive clays is often used to minimize the volume change. Asphalt is flexible enough to withstand a certain amount of settlement or displacement in the underlying soil without significantly losing serviceability.

To highlight the performance of correctly designed asphalt pavements, the Asphalt Pavement Alliance has presented the Perpetual Pavement Award to agencies with pavements meeting the following criteria: The pavement must be at least 35 years old with intervals between overlays of no less than 13 years on average. Over 150 highway and airfield pavements have received this award (APA, 2022). The ability to provide long service life while avoiding the need for costly and time-consuming maintenance or reconstruction is the hallmark of a Perpetual Pavement.

Four: Asphalt is quiet and smooth, essential for residential areas, fuel consumption, and ride enjoyment.

In 1995, the National Quality Initiative Steering Committee commissioned a survey funded by the Federal Highway Administration to determine the general public's satisfaction with the nation's highway system and to identify the public's priorities for highway improvement. Coopers and Lybrand were retained to conduct this survey. Figure 1 shows that the highway characteristic most important to drivers is Pavement Condition (smooth and quiet).

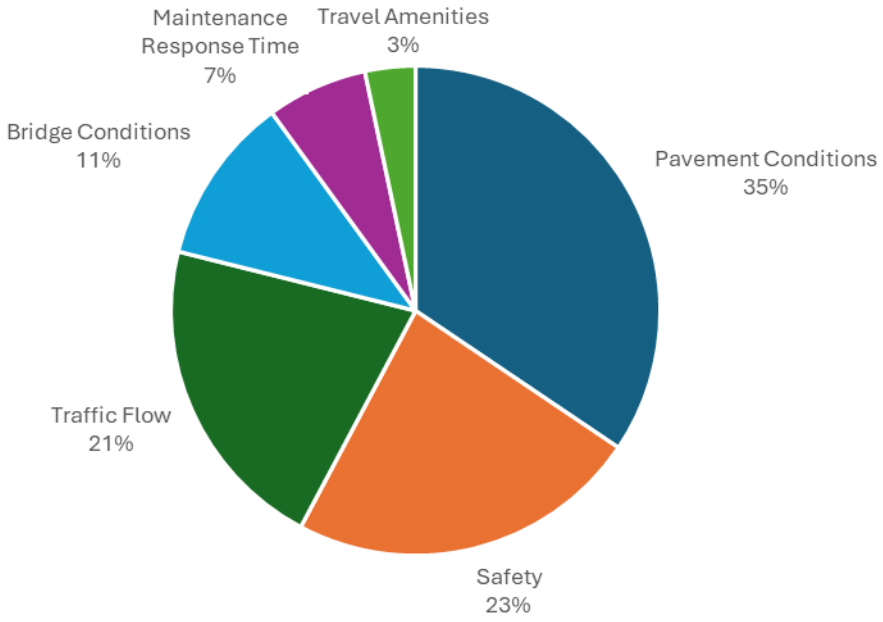


FIGURE 1-1. DRIVER SATISFACTION SURVEY

SOURCE: DRIVER SURVEY RESULTS (NQI-COOPERS AND LYBRAND)

Smooth

Pavement smoothness is a comfort issue for drivers, but which tends to be smoother, asphalt or concrete? One indication comes from state DOT standards, which have smoothness specifications for new roadways. If the road does not meet the smoothness standard, the contractor's pay is reduced, or corrective work, including diamond grinding, is required to improve the ride quality. Some states have different standards for asphalt and concrete, and in every state where this is the case, the requirements for asphalt roads are more stringent than for concrete roads. Texas is one state that recognizes these differences with more stringent requirements for asphalt roads than concrete roads (TxDOT 2021).

Smoother pavements last longer because tires roll more efficiently instead of bouncing on bumps. This bouncing accelerates road deterioration. Studies show that improving pavement smoothness by 25 percent results in almost a 10 percent increase in pavement life (APA 2022). However, smooth roads save taxpayers money by lasting longer and conserving precious natural resources by increasing fuel economy (MoDOT 2006, FHWA 2000).

Quiet

Road noise is a common type of environmental pollution. Studies have shown that hot mix asphalt pavements are generally quieter than concrete pavements (Smith 2016); however, the difference can be narrowed with new types of concrete surface textures (Asphalt Institute 2022).

Five: Asphalt Pavement can be completed quickly and driven on within hours of construction.

This eases road congestion during construction and decreases delays for the traveling public. Asphalt pavements allow flexibility in construction, both in the ability to stage the construction sequence and in the ability to minimize user costs. Stage construction is often advantageous when funding or weather does not allow a facility to be completed in a year. Building a substantial portion of the pavement structure and finishing it later helps agencies stretch budgets to take care of more priorities in tight times. For example, if construction starts late in the year, and finishing it would push the schedule into cold weather, then letting traffic use the road over the winter and completing the next season allows maximum use of the facility.

Since asphalt can be constructed during off-peak traffic, the construction stages can be accomplished with minimal traffic disruption. When comparing the impact of off-peak traffic construction to a 24-hour lane shutdown, the user-delay costs can be as much as three times lower with the off-peak hour option than the full-day option.

Six: Asphalt can handle light and heavy traffic seamlessly.

Asphalt pavements have demonstrated performance across the spectrum of traffic loadings and conditions. Asphalt is the most popular pavement material for low- and medium-traffic roadways and has proven to perform well under heavy truck traffic in urban and rural settings. Asphalt pavements have provided excellent service even under heavy, static, and channelized loadings, such as those at port facilities and commercial airports. Many technological improvements in asphalt pavements have been directed at handling increased loads. These improvements include perpetual pavement design, the

introduction of polymer-modified binders, the development of Superpave binders and mix design, and the introduction of Stone Matrix Asphalt (SMA) as a premium surface material.

Seven: Asphalt is safe and quiet, especially on heavily traveled roads.

Porous Friction Courses (PFCs) are asphalt mixtures that allow water to flow through the top surface of the road and out to the shoulders, keeping your tires on the road and keeping you safe. The main advantage of PFCs is the ability to drain water from the road surface, increasing the skid resistance and reducing splash and spray. Table 1-1 shows accident and rainfall data collected by the Texas Department of Transportation (TxDOT) for Ranch to Market (RM) Road 1431 from 2001 through 2007. Initially, it had a dense surface and a poor accident record in wet weather. A PFC was placed on the roadway in February 2004, and the reduction in wet weather accidents, fatalities, and injuries is remarkable. This surface type should be considered an elective, life-saving safety feature that should be used when feasible on high-speed roadways.

Table 1-1. TxDOT Accident Data on RM 1431 (2001–2007)

YEAR	AVERAGE 2001-03	AVERAGE 2004-07	% CHANGE
TOTAL ACCIDENTS	36.3	16.5	-54.6
DRY WEATHER ACCIDENTS	15.0	15.0	0.0
WET WEATHER ACCIDENTS	21.3	1.5	-93.0
FATALITIES	2.0	0.5	-75.0
TOTAL INJURIES	20.7	7.5	-63.7
INCAPACITATING INJURIES	4.3	0.5	-88.5
NON-INCAPACITATING INJURIES	16.3	4.0	-75.5
ANNUAL RAINFALL, IN.	33.4	39.0	16.7
TOTAL RAIN DAYS (>0.1 IN.)	50.0	57.5	15.0

SOURCE: RAND, 201 SOURCE: RAND, 20111

Each time a new HMA surface is applied to an existing pavement, an opportunity presents to renew the roadway's friction and water-draining characteristics. The use of hard, durable aggregates combined with technology designed to reduce rutting and, consequently, reduce hydroplaning will enhance the skid resistance of the pavement. When a PFC is applied to the surface, the skid and rutting resistance is improved, and the amount of splash and spray during rainstorms is reduced, improving driver visibility (see I-

35 in San Antonio in Figure 1-3). The darker color of asphalt pavements enhances the delineation of lanes and pavement markings.

Noise generation has become an essential consideration on high-speed roadways. At speeds over 50 mph, most traffic noise comes from tire-pavement interaction. Using a low-noise surface reduces traffic noise at the source. Studies have shown that dense-graded asphalt mixtures can reduce the noise level by 2 to 3 dBA compared to a typical textured pavement. A noise reduction of up to 5 dBA can be obtained using a SMA surface, and a PFC can reduce noise by up to 9 dBA (Wayson, 1998). Reducing 3 dBA from 76 to 73 has the same effect as reducing the traffic by half or doubling the distance from the noise source.



FIGURE 1-2. PFC (LEFT SIDE) REDUCES SPLASH AND SPRAY IN WET WEATHER.

SOURCE: RAND, 2011

Chapter 2 Introduction to Asphalt Materials and Construction

Introduction

Asphalt pavements are composed of about 95 percent aggregate and 5 percent asphalt cement by the weight of the mix. By volume, a typical dense-graded mixture comprises about 81 percent aggregate, 12 percent asphalt, and 7 percent air voids. The relationships between the volume and weight of asphalt mixture components will be described in Chapter 3. Recycled asphalt materials are commonplace and a part of almost every modern-day mixture. Certain additives may be used to enhance the performance of the asphalt mixtures, including polymers, anti-stripping agents, rejuvenators, mineral fillers, and fibers. The aggregates must be of the right blend of sizes (gradation) and withstand the environment and traffic they will experience in service. The components of an asphalt mixture must be selected with economy, quality, and desired performance as all considerations. The mix is then designed so that the proportions of the ingredients will satisfy the pavement's requirements to achieve the desired performance and economy.

Once the mixture is designed, the proportions are used to produce the paving mixture in an asphalt plant. After initial adjustments are made to ensure the quality of the plant-produced asphalt mixture, production begins on a large scale, typically between 100 to 300 tons per hour. As the mix is produced, it is sampled and tested for quality to ensure that the ingredients meet the desired properties and specifications. The mixture is transported to the job site via trucks, and there, it is fed through a paving machine, which places the material to its desired width, thickness, and texture. Next, the placed material is compacted by rollers. After compaction, the material is sampled and tested again to ensure it meets specifications. Figure 2-1 shows a flow chart of how asphalt pavements are manufactured.

This chapter discusses the basics of asphalt mixture materials, primarily asphalt binder, aggregates, and recycled materials, as well as the basics of mixture production and placement on pavements. Chapter 3 covers the design of asphalt mixtures, and Chapter 4 covers pavement thickness design.

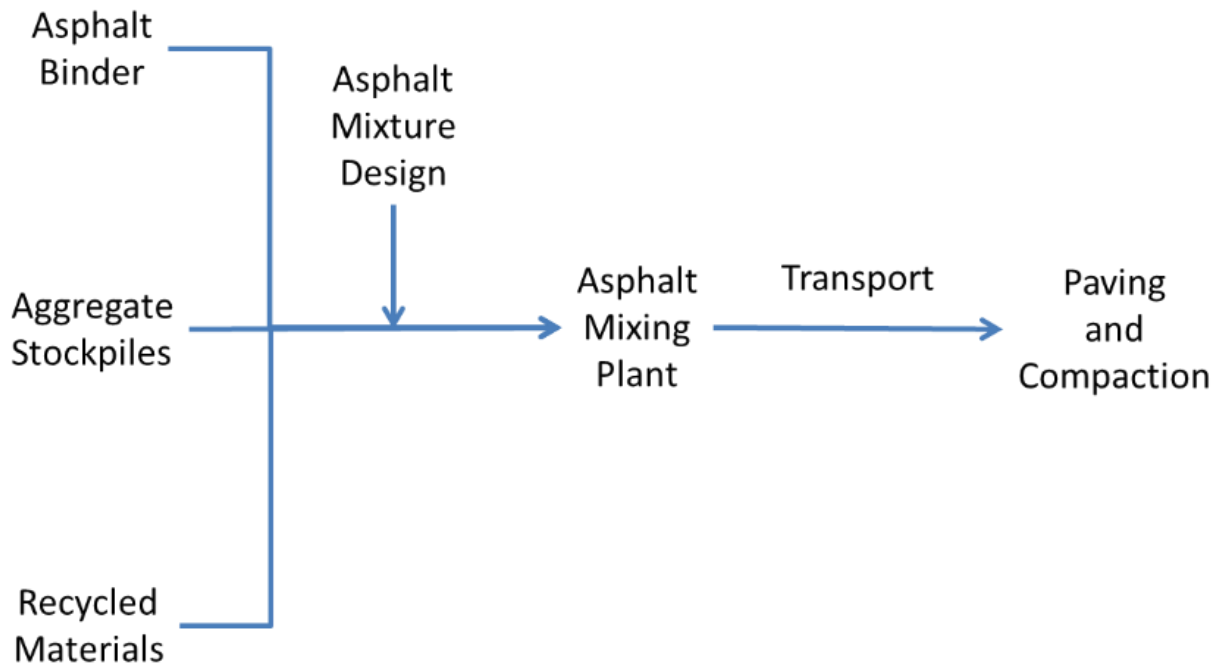


Figure 2-1. Asphalt Mixture Production and Placement.

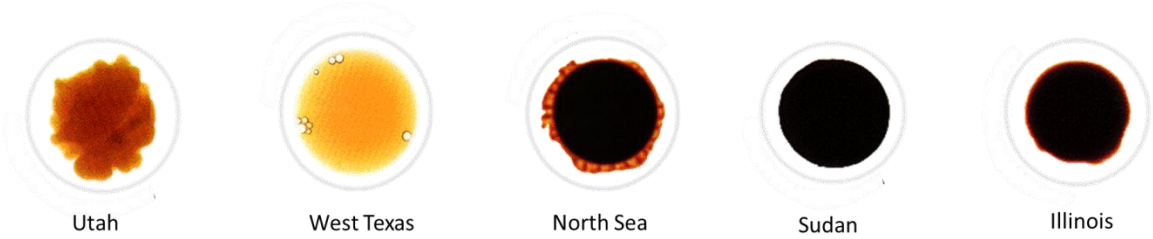
Asphalt Binder

Asphalt binder is the “black glue” that binds the aggregate in the mixture together. In addition to providing this essential cohesion, the binder is responsible for giving the mix lubrication at high temperatures so that it can be mixed, paved, and compacted during construction; filling voids in the mix to decrease permeability to air and water; and coating the aggregate to prevent degradation under traffic and weather. The asphalt binder also provides flexibility so the mix can withstand minor movement without cracking.

Today’s asphalt binders are almost all manufactured materials resulting from petroleum refining. There are a few sources of natural asphalt, such as Trinidad Lake in the Caribbean and the La Brea Tar Pits in California. In Texas, naturally occurring rock asphalt comes from limestone quarries in Uvalde County. Manufactured binders are produced in petroleum refineries or at blending plants. They may include additives that improve the asphalt’s characteristics at low or high temperatures or improve the asphalt mixtures' resistance to moisture sensitivity.

Refinery-Produced Asphalt Binder

Asphalt Binder comes from crude oil, and crude sources are scattered worldwide. While crude oil is often discussed as a uniform material, it varies significantly from source to source. Figure 2-2 shows how crude oils from different locations vary in appearance. The darker the crude oil, the heavier it is, and the more likely it is suitable for asphalt production. Heavy crudes generally have a higher metal content, are more viscous, and are less expensive than lighter crude oil.



SOURCE: MAHONEY AND MUENCH (2012). WWW.PAVEMENTINTERACTIVE.COM

FIGURE 2-2. APPEARANCES OF CRUDE OILS FROM DIFFERENT SOURCES.

The processing of crude oil in a refinery produces many products, including gas, gasoline, chemical feedstocks, kerosene, fuel oils, lubricating oils, and asphalt binder. In the past, the typical refinery used distillation towers to separate the products by heating the crude oil and then applying a vacuum to remove them fractionally (Figure 2-3). The material that remained after separation was called the "bottoms," it was used to produce asphalt binders and its associated products, asphalt emulsions, and asphalt cutbacks. Asphalt emulsions are made by shearing the asphalt into water with an emulsifier, and asphalt cutbacks are produced by combining lighter petroleum products with asphalt. Emulsions and cutbacks are used for cold applications of asphalt binders, such as the placement of seal coats or patching materials. Currently, most refineries go beyond vacuum distillation—techniques to further refine crude oil bottoms, including solvent deasphalting and solvent extraction. Solvent deasphalting involves using propane or butane (the solvent) to strip oils out of the vacuum tower bottoms, and solvent extraction results in a solvent stripping out the asphaltenes (solidified material), resins, and oils. In solvent deasphalting and solvent extraction, the residual materials are combined with lighter flux oils to create asphalt binders with the desired properties.

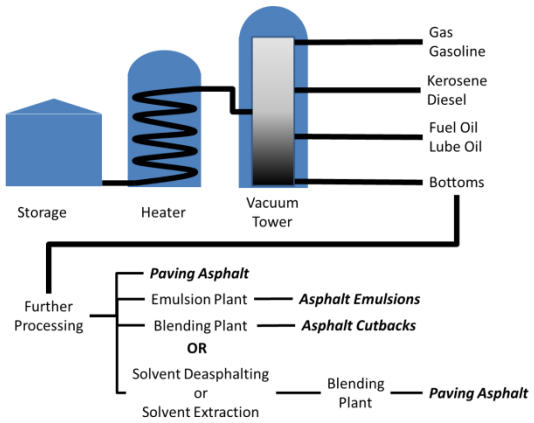


FIGURE 2-3. REFINING AND ASPHALT PRODUCTION SCHEMATIC.

The reconstitution of the heavy components can often occur at a separate blending terminal where the heavy materials, either asphalt or asphaltenes, are taken from a refinery and blended with flux oils and other additives to meet specifications. Additives could include heavy oils, anti-stripping additives, anti-foaming agents, and other additives. The blending terminal must balance the components to meet the specifications of the binder and ensure that the resulting binder provides the desired long-term performance properties and agency specifications.

Asphalt specifications in the U.S. are based upon the Superpave Performance Grading (PG) system. PG binder classification system is explained in more detail in Chapter 3. Still, it focuses on the high-temperature properties of the original and short-term aged asphalt and the low-temperature properties of the long-term aged binder. The PG system intends to avoid problems with rutting and cracking early in the pavement's life and age-related cracking in later stages. The additives mentioned above achieve specific objectives in meeting asphalt specifications. For instance, if asphalt cannot provide adequate stiffness at high temperatures, it may be modified with a polymer additive such as styrene-butadiene-styrene (SBS) or with the addition of PPA. Low-temperature properties may be handled using a softer base asphalt binder with the desired low-temperature behavior and a polymer or PPA to achieve the needed high-temperature properties. An anti-stripping agent may be added to the asphalt to help the binder better adhere to specific aggregates. Additionally, some warm mix asphalt (WMA) additives may be blended into the asphalt to enable a contractor to produce and place the asphalt mixture at lower temperatures.

Asphalt binders may be shipped by trucks, rail, or barge (Walker and Davis, 2016). Rail and barges are usually reserved for shipping asphalt from the refinery to blending terminals, but barges may also be used for transport to large asphalt mix producers. Most asphalt mix

producers receive shipments of binder by trucks with heated tank trailers with capacities of up to 6,000 gallons. Once the tanker truck arrives at the asphalt mix plant, the shipment is loaded into vertical or horizontal heated storage tanks ranging from about 10,000 to 35,000 gallons.

Limestone Rock Asphalt (LRA)

As stated earlier, there are natural sources of asphalt, although they comprise a minimal portion of the overall market in the U.S. Texas is home to Limestone Rock Asphalt (LRA) (Figure 2-4), which is a natural asphalt material that has been mined from two quarries near Uvalde since 1885, and it continues to be an essential part of asphalt pavements in Texas. The typical annual LRA production in the 1980s was about one million tons (TSHA, 2016). The limestone in these formations is impregnated with liquid asphalt. The faces of the quarries are blasted, and the asphalt content may range from one to 20 percent. The material is blended to achieve the desired asphalt content and may have a flux that may be added to increase its workability and storage life for cold applications. It is typically used as either a cold mix surface or cold mix base material or as a patching material.



COURTESY OF ERVIN DUKATZ

FIGURE 2-4. LIMESTONE ROCK ASPHALT.

Aggregate

Types of Aggregate Common to Texas

Aggregates used in Texas include sand gravel and crushed stone. Sands and gravels are water-deposited materials commonly found in current or old riverbeds. These materials are taken from pits in these formations (Figure 2-5). These aggregates are typically composed mainly of silica but may come from several origins. Because the tumbling effect of water gives gravel a rounded shape, it must be crushed to impart angularity to resist rutting before it can be used for highway or airfield pavements. Most sand and gravel

operations are in the Panhandle and the Rio Grande Valley (TxDOT, 2012). Although it used to be common to use sand and gravel in Texas asphalt pavements, environmental regulations and the cost of crushing and processing have reduced usage in favor of crushed stone.



FIGURE 2-5. SAND AND GRAVEL DEPOSIT.

Texas leads the U.S. in the production of crushed stone, and of the ten largest quarries in the U.S., four are in Texas (USGS, 2008). Crushed stone is produced by removing overburden (vegetation, soil, and weathered rock) from the top of the rock formation, blasting the faces of the excavated quarry (Figure 2-6), and crushing and sizing the material. Most crushed stone sources in Texas are limestone, dolomitic limestone, or dolomite. However, there are a few deposits of igneous rock in Southwest and West Texas (TxDOT, 2012) and a sandstone quarry near Marble Falls. The limestone and dolomite sources are primarily located in Central and Northeast Texas. East Texas has few aggregate sources, so aggregates must be imported from other parts of the state or out of state, usually by rail.



FIGURE 2-6. LIMESTONE QUARRY.

Aggregate Quality

Aggregates may vary in their quality characteristics according to the requirements of the material and the structure in which they will be used. Factors such as gradation, shape, texture, cleanliness, skid resistance, and durability are all important to asphalt mixtures, depending on where the mixture will be used in the pavement structure. For example, skid resistance is more critical on the pavement's surface than in the lower base layer. An angular shape and a rough surface texture are desirable characteristics that provide an interlocking of the aggregate particles that are desirable for resisting rutting and providing skid resistance. Flat and elongated aggregates may orient themselves horizontally under compaction and result in a weak mixture. Cleanliness and durability are essential in all mixtures. Cleanliness is related to the amount of dust coating the aggregate particles, which can inhibit the bond between the aggregate and asphalt, which can lead to stripping (loss of adhesion in the presence of moisture) and disintegration of the mix. Durability is the term used to describe an aggregate's ability to resist disintegration from loading and weathering. The gradation describes how the material size is distributed from coarse particles to fine, and the intended use of the asphalt mixture dictates it. The requirements for aggregates in asphalt mixtures are discussed in detail in Chapter 3.

Aggregates Delivery to Asphalt Mix Plant

Some asphalt plants are in quarries, and once the aggregate has been properly crushed and sized, it can then be stockpiled via conveyors or dump trucks operating within the quarries. In most instances, aggregates are barged, railed, or trucked from the quarry to the asphalt plant site. Many contractors in Texas have rail off-loading facilities on their grounds to receive the aggregates more efficiently.

Recycled Products

Using reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) in asphalt mixtures has been widespread since the mid-1980s. Using these in mixtures is essential for economics, the environment, and pavement performance. The environmental benefits were highlighted in Chapter 1. The asphalt contained in these products can be reused in asphalt mixtures as a blending goes on between the recycled and virgin asphalt binders. Thus, using less virgin asphalt in the resulting asphalt mixtures is possible, which saves money and conserves petroleum resources. Sometimes, the blending between the binders may be aided by recycling agents, especially if a high RAP content is desired. Since RAP contains aggregate, the asphalt mixture will also reduce the amount of new aggregate. This reduction in new materials means that asphalt mixtures containing RAP and RAS are less expensive than those containing all virgin materials. In addition to conserving the number of new materials required, asphalt mixtures made with RAP and RAS can usually resist rutting better as they are generally stiffer mixtures.

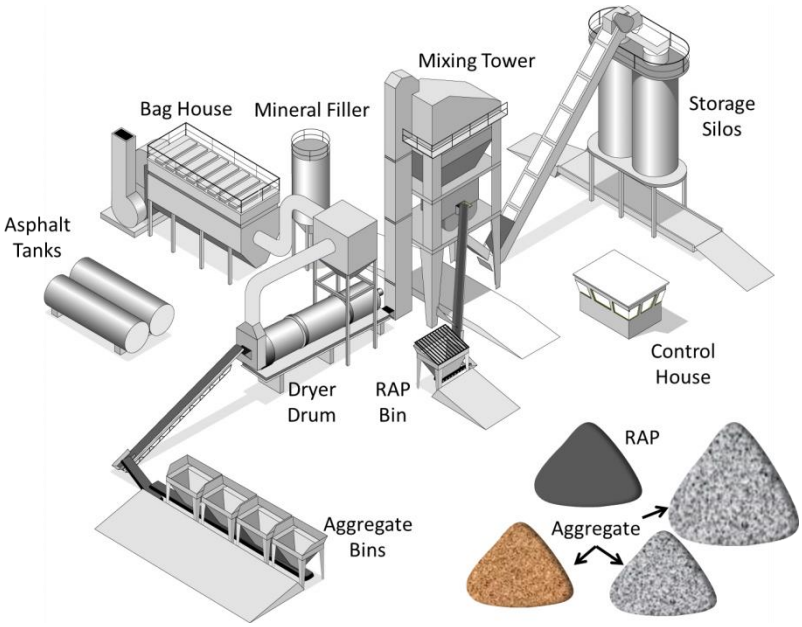
RAP is primarily generated from milling off surfaces of pavements that need overlays. The milling machine takes up the old surface and deposits the material into a dump truck for transport back to the plant. At the plant, the RAP is typically re-sized and further processed for various mixtures, after which it is stockpiled until it is used. TxDOT specifications limit the amount of RAP in surface mixes once the RAP has been fractionated (separated) to control the gradation. Specifications allow more fractionated RAP in intermediate and base layers.

RAS may be from either manufactured waste asphalt shingles (MWAS) from a factory or tear-off asphalt shingles (TOAS) from residential roofs that have been replaced. MWAS must be ground and sized to about 3/8 inches before use. TOAS requires processing and grinding to remove deleterious materials such as gypsum board, wood, and nails and sizing the material to 3/8 inches. After the RAS has been ground and processed, it is usually stored in stockpiles for incorporation into mixtures. In Texas, a maximum of 3 percent RAS may be used in intermediate and base layers, while no RAS is allowed in surface mixtures.

Asphalt Mixture Production

Asphalt mixture production aims to combine aggregates, asphalt binder, and recycled materials in the desired proportions to make an economical material that can be placed and compacted for performance in service. The typical layout of an asphalt mixture plant site is shown in Figure 2-7. Aggregates are stored in stockpiles that are sorted according to

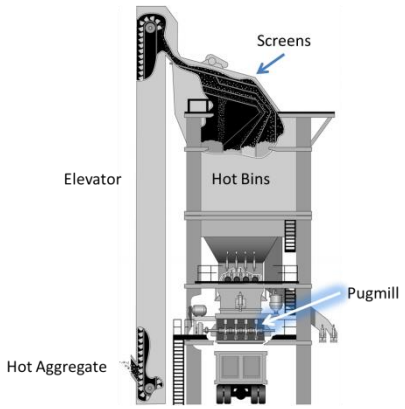
size. RAP stockpiles are also sorted according to size. Typically, the number of stockpiles is dictated by the space available at the plant. Depending on the individual plant design, the asphalt binder is stored in vertical or horizontal tanks. The aggregates and RAP are taken from their stockpiles and placed into bins before mixing. As discussed below, the mixtures may be produced in either a batch or continuous drum plant. A recent research report has shown no differences in mixtures produced in either type of plant (Newcomb et al., 2015). Currently, most asphalt plants in Texas are continuous drum plants.



SOURCE: USACE, 2000

FIGURE 2-7. TYPICAL BATCH PLANT LAYOUT.

In a batch plant (Figure 2-7), the aggregates are taken from stockpiles and placed into bins. The individual aggregate materials are proportioned to a conveyor. The combined aggregate blend enters and travels through a dryer drum to dry and heat the aggregate. It then travels up an elevator to a tower before being re-screened for size and loaded into hot bins. (Figure 2-8). Each hot bin contains a particular size of aggregate. The bins have gates with openings that can be controlled to allow a specific amount of material to flow out when creating a batch of asphalt mix. Gates on the bins are opened, allowing the proper proportion of aggregates to be weighed before dropping into the pugmill. The pugmill is a container with paddles that mix the aggregate and asphalt binder. After the aggregates are placed in the pugmill, they are dry mixed for a short period, after which the asphalt binder is fed into the pugmill through a weigh bucket. The aggregate and binder are then wet mixed to form a uniform product, then discharged from the pugmill into either a waiting truck or onto a slat conveyor for loading into a storage silo. Batch plants are suitable for any production but preferred for operations where the mix types or aggregate proportions may change frequently.

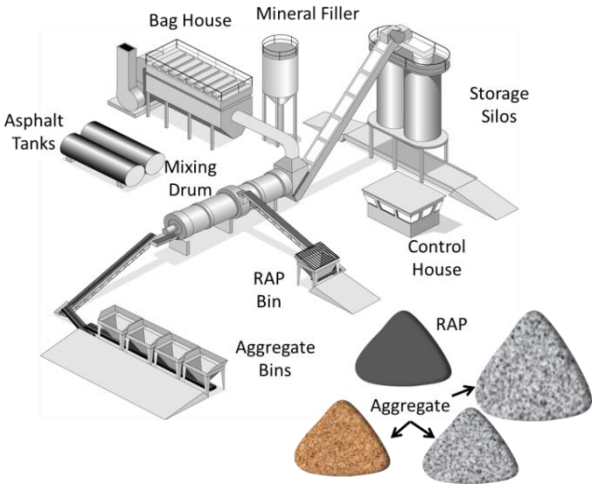


SOURCE: USACE, 2000

FIGURE 2-8. DETAILS OF BATCH PLANT MIXING TOWER.

Beginning in the 1970s, there was an increase in the number of continuous drum mix plants (Figure 2-9) that replaced batch mixing plants. Generally, a continuous plant differs from a batch plant in that cold aggregates are fed onto a conveyor in the proper proportions before entering the drum's elevated end for drying. Advances in aggregate production quality control and plant control technology have improved the uniformity of the aggregate blend, eliminating the need for the aggregate to be re-screened. The aggregates are dried and heated as they tumble through the drum toward the lower end, where they are mixed with binder. Once mixed, the asphalt mix is discharged to a slat conveyor for loading into a silo, where the mix is kept until it is deposited into a truck for

transport to a paving site. The drum may either have the burner directed in parallel with the downward flow of the aggregate or counterflow with the burner directed upward against the aggregate flow. These designs are called parallel flow drum and counter flow drum, respectively. Few parallel flow plants are in service today as they have problems related to aggregate heating, asphalt aging, and emissions control. There are two other variations for continuous plants. One is a dryer mixing drum in which the aggregate is dried in a drum before it is loaded into a continuous pugmill at the end of the drum for mixing with asphalt. The other exception is the unitized drum mixer design, a variation of the counter-flow drum in which the aggregate is dried as it goes through an inner drum. At the end of the inner drum, the material flow is reversed, feeding the aggregate into an outer drum, where it is mixed with asphalt before being discharged. Continuous drum plants offer greater efficiency for high-production operations because the material flow is constant and not dependent upon mixing individual batches.



SOURCE: USACE, 2000

FIGURE 2-9. SCHEMATIC OF DRUM MIX PLANT.

Asphalt mixture production in permanent plant sites usually occurs before paving. For that reason, the mixture is stored in silos until the paving operation is ready to receive it. The storage silo is an insulated container that may hold up to 200 to 300 tons of asphalt mixture. Most plants have multiple silos to allow for flexibility and high demand. The material may usually be held for 2 to 8 hours—however, some conditions require holding the material overnight before transporting it to the paving site. The temperature of the mix should be checked before it leaves the plant or immediately upon arrival at the paving site to ensure that it can be placed and compacted. In portable plants, the mix is usually

loaded into dump trucks or belly dump trucks almost as soon as it is made. It is best practice for the truck to be loaded in several drops alternating from front to back and center to provide better mix uniformity.

Quality control tests are usually performed by contractor personnel at the plant during the production of the mix. Samples of the mixture are typically taken from the trucks at the plant and transported back to the contractor's laboratory. The sample is split into small portions to test the binder content, gradation, and volumetric properties. One portion of the sample is compacted using a laboratory mix compactor and tested to determine if the volume characteristics of the produced mixture are within the specified limits. The agency will take or witness the sampling of quality assurance samples to establish if the results they obtain are consistent with the contractor's results. These samples are often taken and tested later in an agency or consultant laboratory, which requires reheating the material before molding and testing. Care must be taken if the aggregate in the mixture has a relatively high water-absorption capacity, as the transporting and reheating may cause differences in the test results between the quality control and quality assurance samples. Cores may also be taken from the roadway and tested to determine the material's in-place density (or air voids). A density that is too high may indicate that the material could bleed or rut under traffic, while a density that is too low may mean that the material might be weak in service and easily crack or rut.

Asphalt Pavement Construction

The asphalt mixture's transport, delivery, placement, and compaction are crucial to its performance in service. Transportation of the mix from the plant to the paving site may be accomplished by using end-dump trucks, belly-dump trucks, or live-bottom dump trucks. The trucks should have waterproof tarps for long hauls or cooler weather to keep the mix from cooling excessively. End-dump trucks (Figure 2-10) have a hydraulic ram that raises the front of the bed, causing material to flow out the gate at the truck's rear. A live-bottom dump truck has a conveyor at the bottom of the bed, which moves the material toward the back of the trailer and through a gate. End-dump and live-bottom dump trucks are suitable for discharging the asphalt mix directly into the paver hopper (Figure 2-10) or a material transfer device (MTD) (Figure 2-11). Belly dump trucks deposit the asphalt mix directly onto the roadway in a windrow. Material placed into a windrow can be transferred into the paver hopper employing a pick-up machine that feeds the mix into the paver hopper.

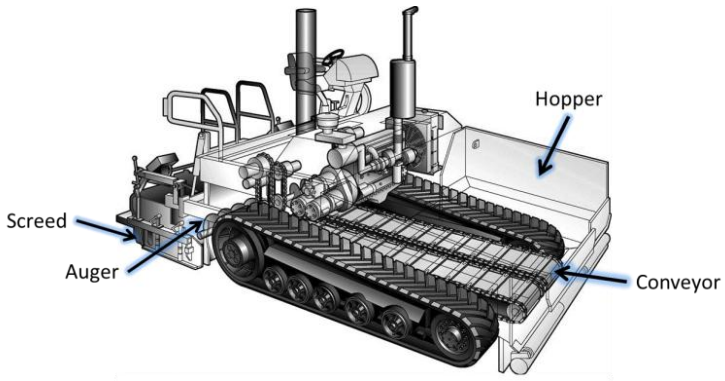


FIGURE 2-10. END DUMP TRUCK DISCHARGING MIX INTO PAVER.



FIGURE 2-11. EXAMPLE OF MATERIAL TRANSFER DEVICE.

A schematic of a paving machine is shown in Figure 2-12. Material enters the paver through the hopper on the front. From the hopper, the mixture travels on a conveyor through tunnels to the back of the paving machine. Augers move the material from the conveyors evenly across the width of the paver. Next, the screed passes over the material to provide a level or properly sloped surface for surface drainage. At this point, the uncompacted asphalt mat is about 2010 to 25 percent thicker than shown on the plans, depending upon the mat thickness and the mixture characteristics. After the mat has been placed, the compaction of the material begins.



SOURCE: USACE, 2000

FIGURE 2-12. SCHEMATIC OF PAVING MACHINE.

Compaction is critically vital to pavement performance. The compaction process increases the density, lowers the permeability, and increases the strength of the material. Three types of compactors or rollers are used in this process: vibratory, pneumatic, and static. Vibratory compactors turn into static rollers by simply turning off the vibrator. Breakdown rolling is where the initial compaction of the asphalt mat occurs, generally accomplished with a vibrating roller (Figure 2-13). The vibration helps re-orient the aggregate particles in the mix to pack tightly and increase density. Next comes the intermediate compaction, usually done with a vibratory or pneumatic roller (Figure 2-14). The pneumatic roller has smooth tires that knead the mixture with front and back tires that overlap to provide complete pavement coverage. Finally, the finish compaction completes the process with a static roller that removes any marks on the surface and provides the remaining slight increase in mat density. The choice of the combination of rollers and the number of passes each of them makes is established when the roller patterns are set at the beginning of the job. Roller patterns are set by monitoring the density gain with different combinations of rollers and passes and can change slightly based on environmental conditions. The pattern providing the most significant density increase with the least effort is used for the remainder of the job.

It is typical to measure density as compaction occurs, which is most often done with a nuclear or non-nuclear density gauge. By constantly monitoring the pavement density, the paving crew can see any potential changes in the pavement that may require extra attention. Variations in mix, base, air temperature, wind speed, and other factors would signal that the roller pattern must be adjusted. It is also common for an agency to take roadway cores to monitor the in-place density to determine that the final product meets specifications. Usually, these cores are taken randomly during the construction.



FIGURE 2-13. VIBRATORY ASPHALT COMPACTOR.



FIGURE 2-14. PNEUMATIC COMPACTOR.

Summary

This chapter provides a brief overview of manufacturing the materials for asphalt mixtures, the production of asphalt mixtures, and the placement of the asphalt mix on the pavement. The remainder of this guide is focused on designing asphalt mixtures, pavement structures, specifications, specialty asphalt mixtures, managing pavement systems, and choosing pavement maintenance and rehabilitation methods.

Chapter 3 Mix Design

Introduction

Asphalt mixtures may be designed to perform various functions, including providing durable, economic base layers; strong, rut-resistant base mixtures; smooth, safe, and durable surfaces; and permeable, high friction, low splash, and spray surfaces. One of the most important keys to a successful pavement structure is to select and properly design mixtures to perform their intended function within the pavement structure. This chapter will focus on the characteristics and properties of asphalt binders, aggregates, RAP, and RAS and how to properly proportion these ingredients in mixtures. The contractor develops the mixture design using materials they can access for the project. Their job is to develop a mixture design that meets the agency's specifications. The following chapter, Pavement Design, will discuss thickness design and the proper selection of mixtures to create an optimum pavement section.

In this Texas Asphalt Pavement User Guide, many TxDOT specifications will be discussed or used as examples. TxDOT updates their standard specification book once every ten years and makes changes in the interim using Special Provisions and Special Specifications. The last specification book was published in 2014. The asphalt and hot mix asphalt specifications were replaced by Special Specifications in 2021 and now the new 2024 TxDOT Specification book will be implemented in the fall of 2024. Item numbers revert to the 300 series. It is important to understand that there are various versions of these specifications in the marketplace and it’s always prudent to verify which specification version is being used on a project to avoid confusion.

Table 3-1. TxDOT Standard Specification and Special Specifications.

Specification Title	TxDOT Standard Specification Number (2014, September 2024 Spec Book)	TxDOT Special Specification Number (2021-August 2024)
Asphalts, Oils, and Emulsions	300	3096
Dense-Grade Hot Mix Asphalt	340, 341	3076
Permeable Friction Course	342	3079
Superpave Mixtures	344	3077
Stone-Matrix Asphalt	346	3080
Thin Overlay Mixtures	347	3081
Thin Bonded Friction Course	348	3082

In this chapter, the Superpave™ system will be discussed, as this is the current method used by the Texas DOT under 2024 Item 344. Superpave™ is a mix design system that was developed in the first Strategic Highway Research Program (SHRP), and it is an acronym that stands for Superior Performing Asphalt Pavements. The result was a system of specifying asphalt binders, aggregate gradation, aggregate quality, a new laboratory method of mix compaction, and a volumetric procedure for defining the optimum asphalt content for mixtures. Since its implementation in 1993, it has undergone numerous refinements to adjust to the reality of materials supply and performance.

The design and testing of asphalt mixtures in Texas should always be done by technicians certified by the Texas HMAC Training Center in Buda, Texas.

Binders

General Characteristics of Asphalt Binders

Asphalt binders must have a liquid consistency during the production and placement of mixtures, solid to semi-solid during the pavement's service life, and provide some resistance to embrittlement due to low roadway temperatures and aging. The Superpave™ binder specification requires that testing encompass these conditions to be used. Suppose the material is too viscous during production and construction. In that case, it is likely that the aggregate will not be sufficiently coated during mixing and that the compaction during paving operations will be difficult, which could lead to premature

failures. The mixture may rut if the binder stiffness is inadequate at high in-service pavement temperatures. If the in-service low-temperature stiffness of the binder is too much, then premature cold-temperature cracking could result. The grading nomenclature describes the pavement temperature extremes where the binder should perform. For instance, PG 64-22 should resist rutting to 64C high pavement temperatures and resist cracking to -22C low pavement temperatures. This temperature span is called the Useful Temperature Interval. In the case of PG 64-22, the UTI is 86.

The aging of an asphalt binder begins at construction and continues through its service life. Aging is the process of binder hardening through oxidation and the combining of large molecules in the material. The binder is subjected to high temperatures and oxygen during production and construction in the mixing and transport phases. This short-term hardening is appreciable and usually results in a pavement that can be used as soon as it cools. However, if mixing temperatures are higher than they should be, it may result in embrittlement, possibly leading to cracking. The asphalt binder will continue hardening in service at a slower rate over decades, and this long-term aging may eventually result in surface cracking. Usually, long-term aging occurs faster in climates with higher temperatures and more solar exposure. Long-term aging can also vary with the asphalt source and can be impacted by the initial degree of short-term aging.

Modifiers are sometimes used to enhance the qualities of asphalt binders. Polymer modifiers are the most common, usually in the form of either a block co-polymer of styrene-butadiene-styrene (SBS) or styrene-butadiene rubber (SBR or latex). Polymer modifiers are usually added to broaden the high-temperature and low-temperature range over which the asphalt binder may be specified (the UTI). The rule of thumb is that the asphalt binder is typically modified when the UTI is 92 or larger. Chemical modifiers are used to produce warm mix asphalt, which improves the coating of aggregate and compaction at lower-than-normal temperatures. Sometimes rejuvenators and recycling agents revitalize aged RAP and RAS binders in high recycled content mixtures. Liquid anti-stripping agents may be blended with the binder to improve the adhesion between the asphalt and aggregate in the mixture.

The characteristics discussed in this section provide a background for the types of tests performed to determine their physical properties, which are used for specification and mix design purposes.

Properties of Asphalt Binders

The consistency of binders at various times during construction and service are determined by viscosity and stiffness measurements at the appropriate levels of aging. The physical testing of the asphalt binder includes the flash point, rotational viscometer, dynamic shear rheometer (DSR), elastic recovery, and the bending beam rheometer (BBR). In some instances, a direct tension test at cold temperature may be required. These tests are performed on the original, unaged binder; after conditioning in the rolling thin-film oven (RTFO); and after conditioning in the pressure aging vessel (PAV). The RTFO (Figure 3-1) is used to simulate the material aged through a hot mix plant at the time of construction, and the PAV (Figure 3-2) aging represents material which has been in service for several years. While it is important to understand the properties of binders and the test methods by which they are determined, the binder supplier most often performs the testing. It is documented in a certificate of compliance that acts as quality control. A third-party testing laboratory may do quality assurance testing, and technicians should be appropriately trained and certified.



FIGURE 3-1. ROLLING THIN-FILM OVEN.



FIGURE 3-2. PAVEMENT AGING VESSEL.

The Performance Grade (PG) specifications for Superpave binders used in TxDOT Item 300 (TxDOT 2024) are presented in Table 3-2. The Performance Grading system is based on a high- and low-temperature grade. For instance, a PG 64-22 means that the binder would be suitable for a region where the average 7-day maximum pavement temperature would be no more than 64°C (147°F) and a minimum pavement temperature of −22°C (−8°F). The PG 64-22 will illustrate the Superpave specifications for asphalt binders. Five high-temperature PG grades are in the TxDOT specification, ranging from PG 58 to PG 82, and four low-temperature grades varying from −16 to −34.

Table 3-2. Superpave Requirements in TxDOT Item 300 (2024 Specification)

Table 18
Performance-Graded Binders

Property and Test Method	Performance Grade																		
	PG 58			PG 64				PG 70				PG 76				PG 82			
	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28
Average 7-day max pavement design temperature, °C[1]	58			64				70				76				82			
Min pavement design temperature, °C[1]	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28	-34	-16	-22	-28
Original Binder																			
Flash point, T 48, Min, °C	230																		
Viscosity, T 316[2, 3]: Max, 3.0 Pa.s, test temperature, °C	135																		
Dynamic shear, T 315[4]: G*/sin(δ), Min, 1.00 kPa, Max, 2.00 kPa[5], Test temperature @ 10 rad/sec., °C	58			64				70				76				82			
Elastic recovery, D6084, 50°F, % Min[6]	–	–	30	–	–	30	50	–	30	50	60	30	50	60	70	50	60	70	
Rolling Thin-Film Oven (RTFO) (T 240)																			
Mass change, T 240, Max, %	1.0																		
Dynamic shear, T 315: G*/sin(δ), Min, 2.20 kPa, Max, 5.00 kPa[5], Test temperature @ 10 rad/sec., °C	58			64				70				76				82			
MSCR, T350, Recovery, 0.1 kPa, High Temperature, % Min[6]	–	–	20	–	–	20	30	–	20	30	40	20	30	40	50	30	40	50	
Pressure Aging Vessel (PAV) Residue (R 28)																			
PAV aging temperature, °C	100																		
Dynamic shear, T 315 G*sin(δ), Max, 5,000 kPa (Max, 6,000 kPa for δ ≥42°) Test temperature @ 10 rad/sec., °C	25	22	19	28	25	22	19	28	25	22	19	28	25	22	19	28	25	22	
Creep stiffness, T 313[7, 8]: S, max, 300 MPa, m-value, Min, 0.300 Test temperature @ 60 sec., °C	-12	-18	-24	-6	-12	-18	-24	-6	-12	-18	-24	-6	-12	-18	-24	-6	-12	-18	
Direct tension, T 314[8] Failure strain, Min, 1.0% Test temperature @ 1.0 mm/min., °C	-12	-18	-24	-6	-12	-18	-24	-6	-12	-18	-24	-6	-12	-18	-24	-6	-12	-18	

1. Pavement temperatures are estimated from air temperatures and using an algorithm contained in a Department-supplied computer program, may be provided by the Department, or may be obtained following the procedures outlined in AASHTO MP 323 and R 25.
2. This requirement may be waived at the Department's discretion if the supplier warrants that the asphalt binder can be adequately pumped, mixed, and compacted at temperatures that meet all applicable safety, environmental, and constructability requirements. At test temperatures where the binder is a Newtonian fluid, any suitable standard means of viscosity measurement may be used, including capillary (T 201 or T 202) or rotational viscometry (T 316).
3. Viscosity at 135°C is an indicator of mixing and compaction temperatures that can be expected in the lab and field. High values may indicate high mixing and compaction temperatures. Additionally, significant variation can occur from batch to batch. Contractors should be aware that variation could significantly impact their mixing and compaction operations. Contractors are therefore responsible for addressing any constructability issues that may arise.
4. For quality control of unmodified asphalt binder production, measurement of the viscosity of the original asphalt binder may be substituted for dynamic shear measurements of G*/sin(δ) at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary (T 201 or T 202) or rotational viscometry (T 316).
5. Max values for unaged and RTFO-aged dynamic shear apply only to materials used as substitute binders, as described in Item 341, "Dense-Graded Hot-Mix Asphalt," and Item 344, "Superpave Mixtures."
6. Elastic recovery (D6084) is not required unless MSCR (T 350) is less than the Min % recovery. Elastic recovery will be used for the acceptance criteria in this instance.
7. Silicone beam molds, as described in AASHTO TP 1-93, are acceptable for use.
8. If creep stiffness is below 300 MPa, direct tension test is not required. If creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used instead of the creep stiffness requirement. The m value requirement must be satisfied in both cases.

SOURCE: TXDOT, 2024

The Brookfield rotational viscometer (Figure 3-3) (AASHTO T 316) consists of a spindle suspended in the liquid binder inside a heating chamber. The torque required to keep the spindle rotating at a constant speed is measured, and a viscosity is computed from this. The rotational viscosity is measured on unaged material to ensure that it can be pumped at the plant, mixed uniformly with aggregate, and provide the ability to compact the mix at the construction site. The specification for all grades of asphalt is to have a viscosity of less than or equal to 3 Pa· s measured at 275°F (135°C) regardless of PG grade, as shown in Table 3-2.



SOURCE: MAHONEY AND MUENCH (2012). WWW.PAVEMENTINTERACTIVE.ORG

FIGURE 3-3. BROOKFIELD VISCOMETER.

Another universal requirement of all Superpave binders is that the unaged binder's flash point (AASHTO T 48) be equal to or higher than 445°F (230°C) to minimize the plant's fire risk. The flash point is the temperature at which volatiles will ignite, but a flame will not be sustained.

The DSR (AASHTO T 315) is shown in Figure 3-4, and instead of spinning, it uses torque to oscillate a sample between two plates. The amount of torque used to twist the sample through an angle and these measurements, along with the sample geometry, are used to calculate stiffness in the form of shear modulus, G*. Since the strain is delayed from when the stress is applied, a phase shift or phase angle (δ) occurs, which is also recorded. Two parameters are calculated from G* and δ: the rutting parameter (G*/sinδ) and the cracking parameter (G*sinδ).

The Dynamic Shear Rheometer (DSR) tests the unaged binder for purchasing compliance, the RTFO-aged material to ensure that it will not rut prematurely, and the PAV-aged material to ensure cracking resistance. Table 3-2 shows that the unaged binder must meet a G*/sinδ value between 1.00 and 2.00 kPa at the specified high PG grade temperature (64°C (147°F) for PG 64-22). For RTFO-aged material, the G*/sinδ value should be between 2.20 kPa and 5.00 kPa (Note 1). The PAV-aged binder is tested in the DSR to ascertain its resistance to cracking over the long term. In this case, the cracking parameter G*sinδ is

used, and the specifications require a maximum value of 5000 kPa at the intermediate test temperature (25°C (77°F) for PG 64-22).

Note: The maximum DSR G*/sinδ value only applies when the PG binder is substituted for a higher grade according to the mixture specifications. For all other situations, there is not a maximum G*/sinδ.

The binder's mass loss during RTFO aging is specified at a maximum of 1 percent. This is to ensure that volatiles do not evaporate excessively during the production and placement of the asphalt mixture.



SOURCE: MAHONEY AND MUENCH (2012). WWW.PAVEMENTINTERACTIVE.ORG

FIGURE 3-4. DYNAMIC SHEAR RHEOMETER.



SOURCE: MAHONEY AND MUENCH (2012). WWW.PAVEMENTINTERACTIVE.ORG

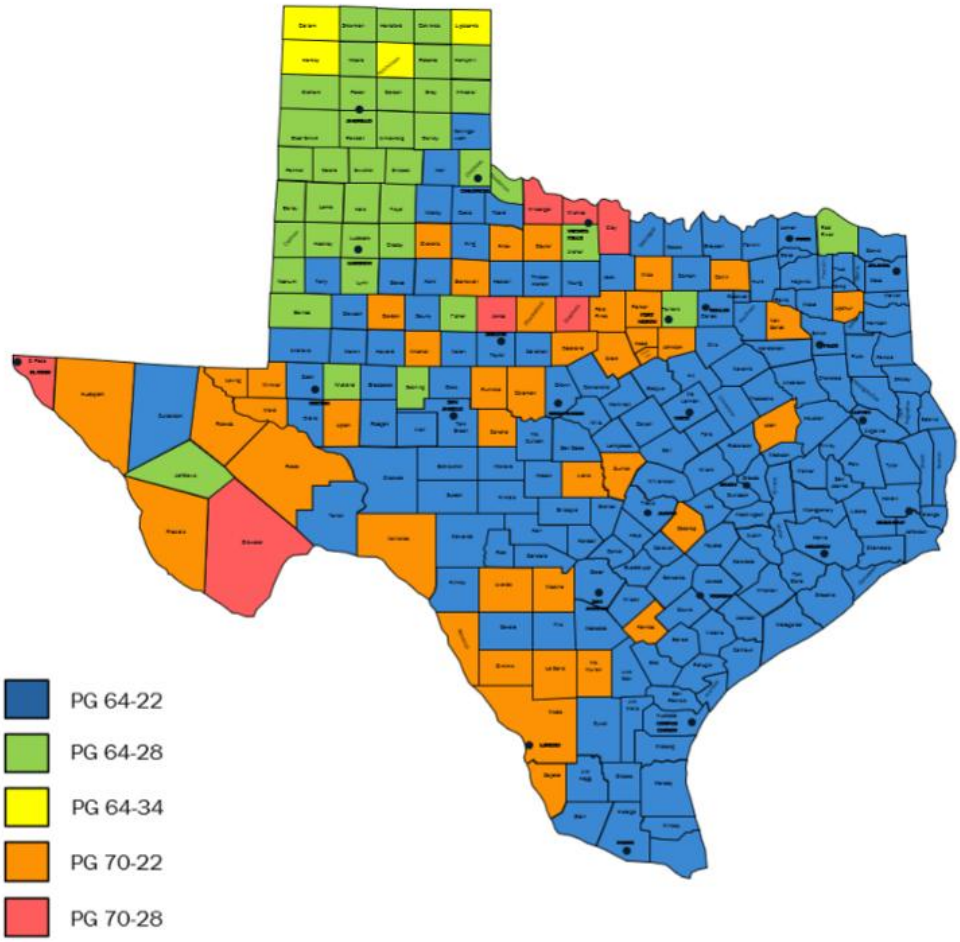
FIGURE 3-5. BENDING BEAM RHEOMETER.

The BBR (Figure 3-5) (AASHTO T313) is used to test the material at very low temperatures (-12°C (10°F) for PG 64-22) and on PAV-aged material where some DSR equipment cannot be used. A beam of asphalt is molded and conditioned to the test temperature. The sample is subjected to simple center-point loading at a prolonged rate in a temperature-controlled bath. The creep stiffness of the binder is calculated at intervals during the testing as a function of the load, sample geometry, and deflection of the beam. The slope of the stiffness versus time curve is the m-value. Low-temperature cracking may occur due to higher thermal stress if the stiffness is too much (over 300 MPa). Likewise, if the m-value is too low (less than 0.300), the material may not relax at low temperatures. In cases where the BBR creep stiffness is above the specified values, a direct tension test (AASHTO T 314) may be performed at the same temperature to ascertain the material's ductility.

The elastic recovery test tests the ability of an asphalt binder to return to its original state after it has been stretched. The test uses a ductility test at ten °C (50°F). The material is stretched and then cut. The percentage that the material rebounds to its unloaded length is calculated and reported as the elastic recovery. This type of testing is usually reserved for asphalt grades that are likely to contain some polymer modification. Note that PG 64-22 has no specified value for elastic recovery.

Binder Grade Selection

The binder grade selected for use in a particular project should be based primarily on climate and the criticality of the roadway. Unique features of traffic loads, economy, and availability should also be considered. Figure 3-6 shows a map with a 95 percent confidence level for the counties in Texas. For most paving applications in Texas, a PG 64-22 binder will meet project requirements (counties that are yellow, green, and purple). A few areas in South and West Texas call for a high-temperature grade of PG 70. Some areas in the Panhandle show low-temperature grades of −28 and −34. For most of these areas, a PG 64-22 will still be acceptable for lower-traffic volume facilities.



SOURCE: HTTPS://FTP.TXDOT.GOV/PUB/TXDOT/MTD/CROSSROADS/MATERIAL-SELECTION-GUIDE.PDF

FIGURE 3-6. COUNTY LEVEL MAP OF TEXAS FOR PERFORMANCE GRADE ASPHALT.

Using a higher-grade, high-temperature binder is usually only justified where critical roadways are present, such as high-volume traffic (e.g., interstate highways) or slow-moving, heavy loads, such as commercial airports or freight transfer yards.

Stiff binders with high-temperature grades above those shown in Figure 3-6 **SHOULD NOT BE USED** for pavements having thin asphalt structures less than 4 inches thick. Using these binders for thin pavements may result in cracking under heavy traffic loads.

Aggregates

General Characteristics

Aggregates provide the structure of the asphalt mixture and play critical roles in its strength and durability. They must withstand the production and construction processes without degradation and provide long-term resistance to environmental influences such as water exposure, freezing, and thawing.

Aggregates comprise about 95 percent of an asphalt mixture by weight and about 85 percent by volume. The selection of aggregate is as essential, if not more important, to the mixture's performance than the binder selection. The aggregate will provide the structure for supporting loads and largely dictate the mixture's durability. Aggregate testing includes sieve analysis, cleanliness and dust content, durability, particle shape, and wear resistance.

Aggregate Requirements

Gradation and Blending

Aggregates for asphalt mixtures should provide the necessary gradation for an adequate structure depending upon the intended use of the mixture. Different aggregate gradations for different purposes are generally classified as 1) open-graded, 2) dense-graded, coarse, 3) dense-graded fine, and 4) gap-graded. These are illustrated in Figure 3-7. Open-graded aggregates have essentially one size (Curve A), and they are used in porous friction courses or open-graded friction courses where it is desirable to provide drainage in surfaces to reduce splash and spray and improve skid resistance in wet weather. Curve B is an illustration of a dense-graded coarse aggregate. It is considered coarse due to the material retained (not passing) in the larger sieve sizes. A dense-graded fine aggregate is shown in Curve C, where the more material passes, the larger the sieves. Curve D represents a gap-graded aggregate typically used in Stone Matrix Asphalt. Gap-graded aggregates have specific aggregate sizes missing to create a strong stone skeleton and allow room for more

asphalt and fine material. Superpave mixtures generally fall within the definition of dense-graded aggregates.

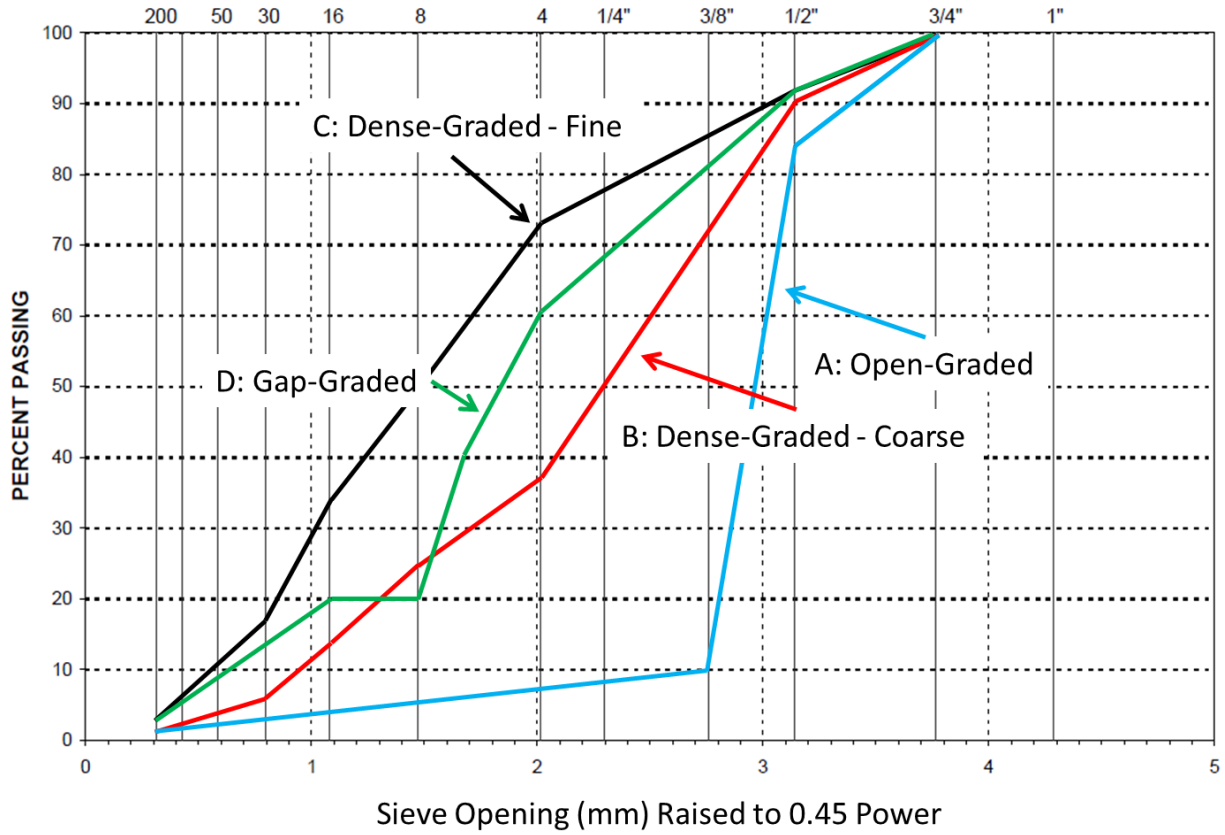


FIGURE 3-7. VARIOUS AGGREGATE GRADATIONS USED IN FLEXIBLE PAVEMENTS.

The aggregate gradations and voids in mineral aggregate (VMA) for Superpave mixtures specified by TxDOT are given in Table 3-2. The selection of gradation and VMA are based on nominal maximum aggregate size (NMAS), which depends on the intended purpose of the mix. The VMA is the space volume between the mix's aggregate particles. The definition and role of VMA in mix design will be discussed later. The NMAS is defined as one sieve size larger than the first sieve to retain more than 10 percent of the material. In Table 3-3, SP-B mixtures may be used in intermediate or base layers, and SP-C mixtures may be used for surface or intermediate layers. SP-D mixtures have the finest gradation with an NMAS of 3/8 inch, and these are also suitable surface mixtures. The selection of the aggregate gradation should be based on the expected performance of the mixture, availability of aggregate, and economic considerations. Mixtures with a greater NMAS are cheaper than those with smaller aggregates.

It is frequently the case that aggregates from one stockpile will not meet the requirements of the entire gradation. It is common for up to five or six stockpiles to be used in the

blending process. Combining aggregate stockpiles to meet the overall gradation requires evaluating the gradation of the aggregate in each stockpile (including the aggregate in the RAP stockpile). For the RAP stockpile, the asphalt is removed from the RAP by burning it off in an ignition oven (Tex-236-F) before grading the aggregate.

Table 3-3. TxDOT Gradation VMA Requirements for Superpave Mixtures.

Sieve Size	SP-B Intermediate	SP-C Surface	SP-D Fine Mixture
2"	–	–	–
1-1/2"	100.0[1]	–	–
1"	98.0–100.0	100.0[1]	–
3/4"	90.0–100.0	98.0–100.0	100.0[1]
1/2"	Note[2]	90.0–100.0	98.0–100.0
3/8"	–	Note[2]	90.0–100.0
#4	23.0–90.0	28.0–90.0	32.0–90.0
#8	23.0–34.6	28.0–37.0	32.0–40.0
#16	2.0–28.3	2.0–31.6	2.0–37.6
#30	2.0–20.7	2.0–23.1	2.0–27.5
#50	2.0–13.7	2.0–15.5	2.0–18.7
#200	2.0–8.0	2.0–10.0	2.0–10.0
Design VMA, % Minimum.			
–	14.0	15.0	16.0
Production (Plant-Produced) VMA, % Minimum.			
–	13.5	14.5	15.5

Defined as maximum sieve size. No tolerance allowed.
Must retain at least 10% cumulative.

SOURCE: TXDOT, 2024

Below in Table 3-4 is an example of 3 aggregate stockpiles and one RAP stockpile for blending. Stockpile 1 is relatively coarse, Stockpile 2 has intermediate-sized material, Stockpile 3 has fine material, and the RAP stockpile is dense-graded. A total of 20 percent of RAP material will be used in the final mix. The target gradation will be an SP-C, as shown in Table 3-3 notes. The blending process is trial-and-error and begins with an initial guess of what percentage will be needed from each stockpile to meet the combined gradation requirements.

Table 3-4. Example of Combining Stockpile Aggregates to Meet Gradation Requirements.

Sieve Size	Stockpile 1	Stockpile 2	Stockpile 3	RAP Aggregate	Combined Gradation	SP-C Surface
Stockpile %	*20*	*40*	*20*	*20*		–
1"	100.0	100.0	100.0	100.0	100.0	100.0[1]
3/4"	96.3	100.0	100.0	100.0	99.3	98.0–100.0
1/2"	85.7	92.4	100.0	96.7	93.4	90.0–100.0
3/8"	40.3	65.3	93.6	85.4	70.0	-
#4	17.4	44.7	85.4	72.2	52.9	28.0–90.0
#8	8.5	16.5	63.9	54.3	31.9	28.0–37.0
#16	4.8	9.3	49.1	38.5	22.2	2.0—31.6
#30	2.3	5.6	28.6	15.3	11.5	2.0–23.1
#50	0.5	2.4	17.5	9.5	6.5	2.0–15.5
#200	0.2	1.3	10.6	7.4	4.2	2.0–10.0

One should choose an aggregate size near the middle of the gradation; in this case, the gradation band for the No. 4 sieve will be used. Thus, a percentage for each stockpile will be chosen so that the combined gradation will fall between 28.0 and 90.0 percent (the requirement for an SP-C mix). The goal is to get the combined gradation to fall well within the middle of the required gradation band. This is because if the gradation falls too close to the limits, then there is a possibility that the gradation in production will fall outside of the gradation band. If this happens, production must stop to change the gradation being used. As a starting point, a combination of 20 percent of Stockpile 1, 40 percent of Stockpile 2, 20 percent of Stockpile 3, and 20 percent of the RAP aggregate will be tried. The equation to find the amount of material passing the No. 4 sieve of the combined stockpiles at these percentages is:

$$Combined\ \%\ No.4\ = (0.20\ X\ 17.4) + (0.40\ X\ 44.7) + (0.20\ X\ 85.4) + (0.20\ X\ 72.2)$$

(Eq. 3-1)

$$Combined\ \% = 52.9\%$$

In this case, the combined percentage resulted in 52.9 percent of the material passing the No. 4 sieve, and that falls between the limits of 28.0 and 90.0 percent. The next step is to validate the results on all the other sieve sizes, as shown in Table 3-3, and graph the results against the specification band, as shown in Figure 3-8. If the gradation falls outside or very close to the limit, then the process begins again with different stockpile percentages.

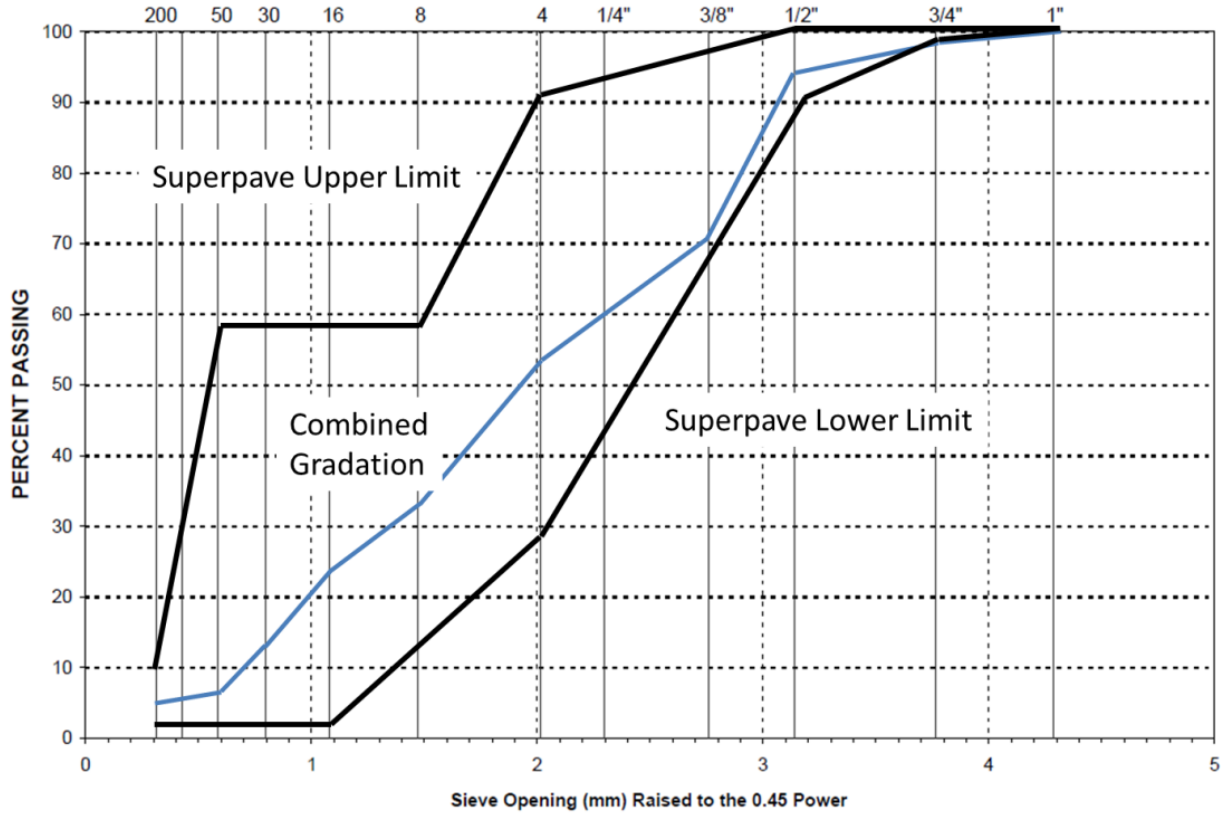
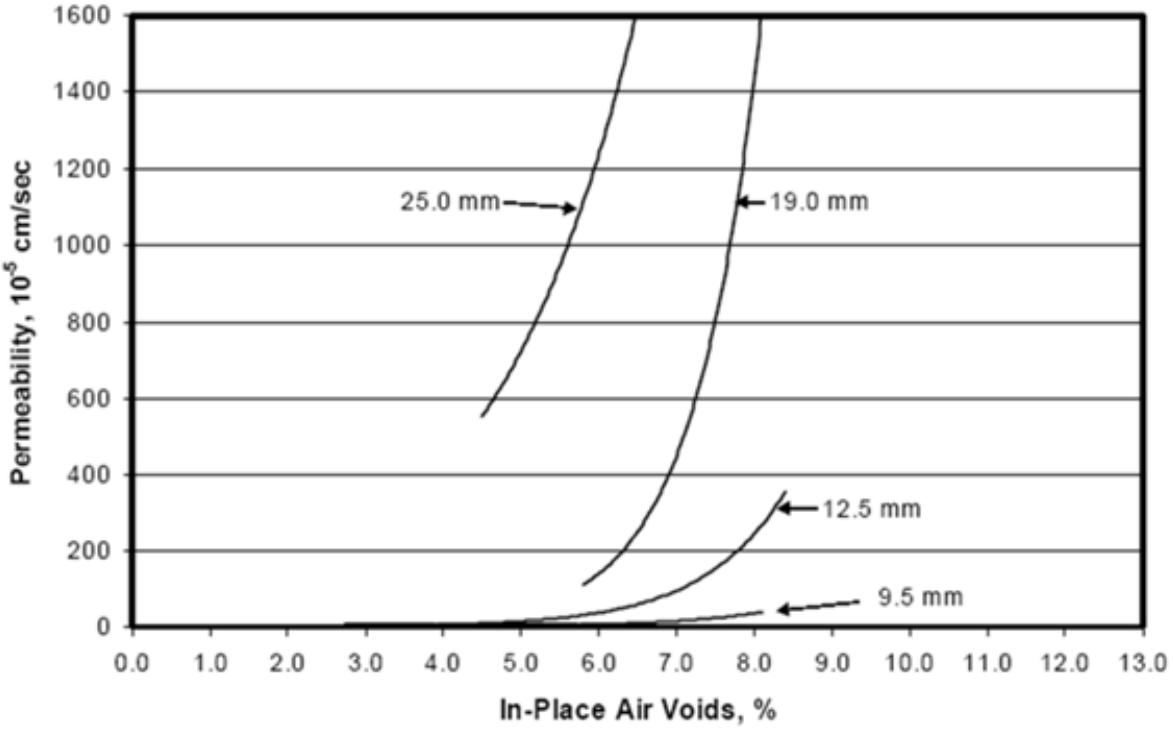


FIGURE 3-8. COMBINED GRADATION OF AGGREGATE STOCKPILES IN TABLE 3-3 AND SP-C GRADATION LIMITS.

The selection of the size and gradation of the aggregate is crucial to the performance of the pavement. Using a large NMAS aggregate with a coarse gradation (Figure 3-7) will likely result in problems due to the permeability of the mix. A National Center for Asphalt Technology (NCAT) study has shown that for the same volume of air voids, the permeability can increase dramatically for more significant NMAS mixtures (Figure 3-9). Likewise, mixtures with a coarser gradation will tend to be “boney” mixes as they will not have

enough fines to fill the space between the aggregates adequately. This will lead to low in-place density, high permeability, difficult workability, and poor performance.



SOURCE: BROWN ET AL., 2004

FIGURE 3-9. RELATIONSHIP BETWEEN AIR VOIDS AND PERMEABILITY FOR VARIOUS NMAS MIXTURES.

Aggregate Classification

Aggregates should be hard, durable, clean, and have a surface texture and particle shape suitable for their pavement function. In Texas, a Surface Aggregate Classification (SAC) designates aggregates with specific durability and shape characteristics. SAC A is considered the highest quality, and aside from the requirements for Magnesium Sulfate Soundness and crushed face count in Table 3-4, must have an Acid Insoluble Residue minimum of 55 percent. SAC B and SAC C aggregates have no requirements for Acid Insoluble Residue, higher limits on Magnesium Sulfate Soundness, and the same crushed faces count as SAC A. The general requirements for Superpave aggregates in Texas are given in Table 3-5. It should be noted that aggregates contained in RAP are not subject to these requirements. SAC A aggregates are usually required for surface mixtures on high-volume, high-speed roads. SAC B and C aggregates are warranted for lower pavement lifts, lower-volume roadways, and pavement features such as parking lots.

Table 1
Aggregate Quality Requirements

Property	Test Method	Requirement
Coarse Aggregate		
SAC	Tex-499-A (AQMP)	As shown on the plans
Deleterious material, %, Max	Tex-217-F, Part I	1.0
Decantation, %, Max	Tex-217-F, Part II	1.5
Micro-Deval abrasion, %	Tex-461-A	Note [1]
Los Angeles abrasion, %, Max	Tex-410-A	35[2]
Magnesium sulfate soundness, 5 cycles, %, Max	Tex-411-A	25[3]
Crushed face count,[4] %, Min	Tex-460-A, Part I	85
Flat and elongated particles @ 5:1, %, Max	Tex-280-F	10
Fine Aggregate		
Linear shrinkage, %, Max	Tex-107-E	3
Sand equivalent, %, Min	Tex-203-F	45[5]
Organic impurities	Tex-408-A	Note [6]

1. Used to estimate the magnesium sulfate soundness loss in accordance with Section 344.2.1.1.2., "Micro-Deval Abrasion."
2. For base mixtures defined in Section 344.2.7., "Recycled Materials," the Los Angeles abrasion may be increased to a Max of 40%.
3. For base mixtures defined in Section 344.2.7., "Recycled Materials," the magnesium sulfate soundness, 5 cycles, may be increased to a Max of 30%.
4. Only applies to crushed gravel.
5. The Department may perform Tex-252-F on fine aggregates not meeting this Min requirement. Fine aggregates with a methylene blue value of 10.0 mg/g or less may be used.
6. Optional test.

SOURCE: TXDOT, 2024

Cleanliness and Presence of Dust

The cleanliness of the coarse aggregate is determined by the maximum percent of deleterious materials (Tex-217-F, Part I) and the maximum percent decantation (Tex-217-F, Part II). Deleterious materials include any foreign matter in the aggregate, such as organic materials, clay balls, trash, or any other substance that is not a mineral aggregate. This is determined by visually inspecting the material retained on a No. 4 or 8 sieve. The weight percent of material that is not mineral aggregate is considered deleterious. The decantation test quantifies the dust or clay coating on the coarse aggregate, which may interfere with the asphalt's adhesion to the aggregate. In the decantation test, coarse aggregate is weighed and soaked overnight. The material is then agitated in the water and poured over a No. 200 sieve repeatedly until the water is clear. All the material retained on the No. 200 sieve is dried and weighed, and the percentage loss is calculated. A further check on the quantity of clay-like particles is performed on the fine aggregate in the Sand Equivalent test (Tex-203-F). The Sand Equivalent test measures the aggregate volume in a graduated glass cylinder, suspends the clay particles in a calcium chloride solution, and

the remaining aggregate volume is not suspended in the solution. Expressed as a percent of the original material volume, the remaining aggregate volume is the Sand Equivalent.

Wear Resistance and Durability

The Los Angeles Abrasion test (Tex-410-A) determines the coarse aggregate's wear resistance. This test loads a portion of coarse aggregate into a 27-inch diameter drum with 6 to 12 steel balls. The drum has a ledge that forces the material and ball to fall within it. The weight of material retained on the No. 4 sieve is measured before and after running the drum through 500 revolutions. The difference in the amount of material retained on the No. 4 sieve, in percent, is the LA Abrasion value.

The durability of the coarse aggregate is measured by the Magnesium Sulfate Soundness (Tex-411-A) and Micro-Deval (Tex-461-A) tests. The Magnesium Sulfate Soundness test is performed on specific sieve-sized material. The material is subjected to five cycles of immersion in magnesium sulfate and drying. The material is sieved after five cycles, and the amount lost on the sieve is expressed as the percent loss during the test. The magnesium sulfate forms crystals in the pores of the aggregate, and the expansion may cause the aggregate to degrade. This degradation is measured and reported as the percent loss.

The Micro-Deval test introduces a coarse aggregate sample into a steel jar with water and steel balls. The aggregate, water, and balls are rotated at 100 rpm for approximately 100 minutes, depending on the aggregate size. The weight of the sample retained on the No. 4 sieve both before and after the test is recorded. The weight loss during the Micro-Deval test is used when the Sodium Magnesium Sulfate test results indicate a loss of greater than 15 percent as an additional check for durability.

Aggregate Weight and Volume Measurements

The weight and volume characteristics of aggregates are essential to properly proportioning asphalt mixtures. The specific gravity of the aggregates (density of the aggregate/density of water) is used to express these characteristics. The general equation for the specific gravity of any material is:

$$Specific\ Gravity = \frac{Mass\ (g)}{\frac{Volume\ (ml)}{Density\ of\ Water\ (\frac{g}{ml})}}$$

(Eq. 3-2)

Water's density is assumed to be 1.000, so it is frequently omitted from calculating specific gravity.

Three measures of specific gravity for the aggregate are of concern in asphalt mix design. These are the bulk specific gravity (G_{sb}), the effective specific gravity (G_{se}), and the apparent specific gravity (G_{sa}). The bulk specific gravity is the weight of the aggregate divided by the volume of the total aggregate particle, including all voids, as shown in Figure 3-10(a). The apparent specific gravity is the aggregate's weight divided by the aggregate's volume, excluding the voids permeable to water (Figure 3-10(c)). Figure 3-10(b) shows that the effective specific gravity is the aggregate's weight divided by the aggregate's volume, excluding the voids permeable to asphalt, and this value lies between the apparent and bulk-specific gravities. For mix design purposes, only the aggregate bulk specific gravity and the effective specific gravity are used in calculations. The effective specific gravity will be addressed in the Superpave mix design process section.

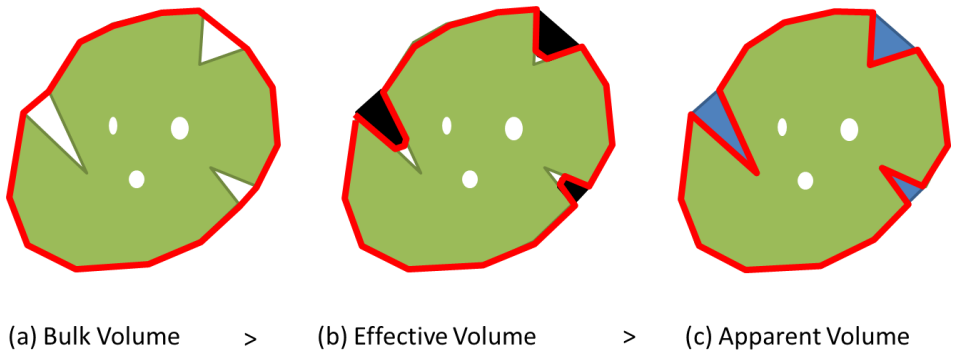


FIGURE 3-10. VOLUME DEFINITIONS (WITHIN RED OUTLINE) FOR AGGREGATE SPECIFIC GRAVITY.

The G_{sb} is determined using the TxDOT Test Method Tex-201-F for coarse and fine materials. The material retained on the No. 4 sieve is separated from the finer material. For the coarse material, the aggregate is soaked in water for 24 hours. Afterward, the aggregate is towel-dried to a saturated-surface-dry (SSD) condition, filling the pores with water while the aggregate surface is dry. The sample is then placed in a pycnometer and weighed, after which water is added to the calibration level, and the pycnometer is weighed again. The sample is then placed into a tared pan and dried in an oven. After drying, the dry weight of the sample is recorded. Figure 3-11 shows the relationships to calculate the aggregate bulk specific gravity.

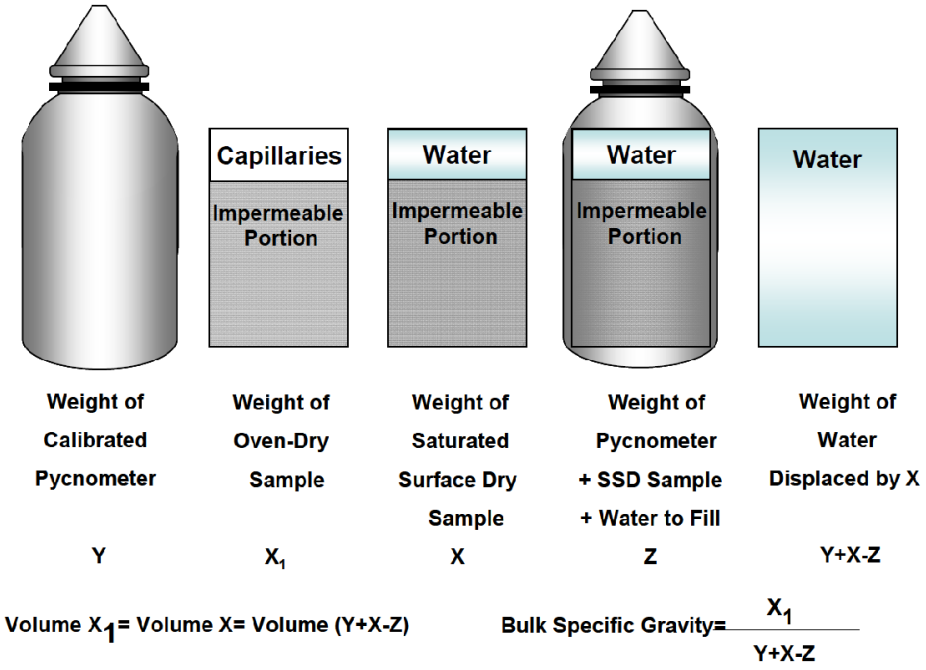


FIGURE 3-11. ILLUSTRATION OF AGGREGATE BULK SPECIFIC GRAVITY DETERMINATION (TEX-201-F).

For fine aggregate, the SSD condition is determined by examining the flow characteristics of aggregate as the surface changes from wet to dry. When the wetted aggregate shows that the flow characteristics are consistent between wet and dry conditions, the aggregate is in the SSD state. The same basic process applies to the fine aggregate as to the coarse aggregate in terms of weight and volume measurements once the SSD weight has been established. Once the specific gravity for both procedures has been determined, the combined bulk specific gravity for the coarse and fine aggregate is calculated as shown in Equation 3-3.

$$G_{sb} = \frac{100}{\frac{W_{CA}}{G_{CA}} + \frac{W_{FA}}{G_{FA}}}$$

(Eq. 3-3)

Where: G_{sb} = bulk specific gravity of combined aggregate.
W_{CA} = weight percentage of coarse aggregate.
G_{CA} = bulk specific gravity of coarse aggregate.
W_{FA} = weight percentage of fine aggregate.
G_{FA} = bulk specific gravity of fine aggregate.

Another important volume quantity used in evaluating aggregate is the amount of moisture absorbed. This parameter is related to the amount of asphalt that may be absorbed into the aggregate pores, although it is not an exact indicator. The absorption is simply the SSD weight minus the oven-dry weight divided by the oven-dry weight. Absorption values for typical aggregates vary from 0.2 percent to 3.5 percent.

The aggregate's apparent specific gravity is the aggregate's weight divided by the volume of the aggregate particle and all voids impermeable to water. Using the nomenclature identified in Figure 3-4, it is calculated as:

$$G_{sa} = \frac{X_1}{Y + X_1 - Z}$$

(Eq. 3-4)

The combined apparent specific gravity is determined similarly to the combined bulk-specific gravity in Equation 3-3.

Ranges of specific gravity for different types of rock aggregates used in construction are shown in Table 3-6 (Nemati, 2015). Manufactured lightweight materials such as expanded clay or shale may have specific gravities in the range of 1.4 to 2.0 (Hemmings et al., 2009), and heavier-weight materials such as steel slag may have bulk-specific gravities up to 3.6 (Chesner et al., 1998). Lightweight aggregates are not commonly used in asphalt mixtures but are occasionally employed in seal coat applications. Heavier weight materials such as slag are used in areas where steel or other metal manufacturing is common.

Table 3-6. Typical Ranges of Natural Aggregate Specific Gravity.

Rock Type	Average Specific Gravity	Range of Specific Gravity
Basalt	2.80	2.6-3.0
Flint	2.54	2.4-2.6
Granite	2.69	2.6-3.0
Gritstone	2.69	2.6-2.9
Hornfels	2.82	2.7-3.0
Limestone	2.66	2.5-2.8
Porphyry	2.73	2.6-2.9
Quartzite	2.62	2.6-2.7

SOURCE: NEMATI, 2015

Reclaimed Asphalt Pavement (RAP) and Recycled Asphalt Shingles (RAS)

The beginning of widespread asphalt recycling occurred because of the Arab Oil Embargo of the 1970s, and the cost benefits have encouraged its continued use. Equipment for removing pavement surfaces, sizing the material, and introducing it into asphalt plants developed rapidly with the desire to make greater use of RAP. Very high RAP contents in the 1970s resulted in emissions problems that could only be addressed with the day's technology by reducing the amount of RAP in the mixes. Investigations into using RAS began in the 1980s and continued into the 1990s. It was shown that RAS could be successfully incorporated into asphalt mixtures, and permissive specifications were subsequently developed. Renewed interest in maximizing the amount of RAP and RAS occurred in the latter half of the first decade of the 21st Century as crude oil prices once again climbed very steeply. The industry was much better prepared at this time to deliver high-quality mixes containing higher amounts of recycled materials that could be produced without emissions problems.

RAP is an asphalt mixture that is taken up from an existing pavement, processed, crushed to an appropriate gradation, stockpiled, and reused into a new asphalt mix for use in the construction or rehabilitation of pavements. It has been a common practice since the 1970s to introduce RAP into asphalt mixtures to conserve asphalt, conserved aggregate, reduce landfill volume, improve air quality, and provide better economy for agencies and road users. According to the National Asphalt Pavement Association (NAPA), more than 97.5% of RAP and RAS collected for use was reused in pavement structures (HMA, base materials, or patching mixes), showing that RAP is considered a critical resource by the

industry. The amount of RAP used in mixes increased from 56 million tons in 2009 to over 90 million tons in 2019. (NAPA, 2020) The use of RAP has become an institution within the asphalt paving industry and is critical to the sustainability and economy of pavements.

The RAP aggregate's gradation and the RAP mix's asphalt content need to be accounted for in the mix design process. RAP is usually taken up from pavement by a milling machine as a densely graded material or in slabs, which are then crushed at an asphalt plant. The RAP is usually screened to remove oversized materials and may be separated into fractions of different sizes (fractionation) before reintroducing the material into a new mix. Usually, RAP from different sources is co-mingled into the same stockpiles, so it is important to sample the as-processed material used in the pavement. The specific gravity of the RAP aggregate is not generally determined as the RAP aggregate is assumed to have the same specific gravity as the combined virgin aggregate used in the mix.

The asphalt content of the RAP can be determined through either an ignition oven procedure (Tex-236-F) or a solvent extraction process (Tex-210-F). If used, the ignition oven needs to be calibrated for locally used aggregates. Some carbonate aggregates may show a higher asphalt content due to some minerals burning off during the ignition process. Solvent extraction is usually not preferred due to the amount of solvent waste that must be disposed of as a hazardous substance.

The asphalt binder in RAP has been aged through oxidation during construction and its time in service in the pavement. Usually, for RAP contents that are relatively low (i.e., less than 25 percent), this does not pose a problem, and no adjustment to the binder grade of the virgin asphalt needs to be made. However, a lower high-temperature grade may be needed for mixes containing higher amounts of RAP (up to 40 percent). For instance, if a PG 70-22 was planned, a PG 64-22 might be warranted.

Recycled asphalt shingles used in asphalt mixtures may come from the waste generated during the manufacturing of roofing shingles, such as cut-out tabs or off-color shingles, or they may be generated from tear-off waste generated during the reroofing of buildings. However, RAS does not include waste from membrane roofing such as built-up, thermosets, or thermoplastic materials. Manufactured asphalt shingle waste should be ground to a set size (typically less than 3/8 inch) before use. Tear-off shingles must be processed to remove all foreign materials, such as wood, nails, and other construction debris, before grinding to size.

Mix Design Process (Superpave) (Tex-204-F)

Objectives of Mix Design

The ultimate objective of asphalt mixture design is to determine a combination of asphalt binder, aggregate, and air voids that will provide the desired performance characteristics to support the anticipated traffic and ensure the durability of the pavement while being reasonably economical. The desired performance characteristics are functions of the role that the mix plays within the structure, the type and volume of traffic anticipated, and the climate. The role of the mixture in the pavement is discussed in Chapter 4, Pavement Design, under Mix Type Selection. Mix type selection is a crucial link between the material and structural design of the pavement section. Durability is the resistance of the material to loading and the environment. The aggregate structure and asphalt content dictates the ability to carry loads without cracking or rutting. The goal is to have the asphalt content sufficiently high to avoid premature cracking while not posing a risk for rutting. The mix should also be designed to resist moisture damage due to stripping. Thus, once the asphalt binder and aggregate have been selected, the mix design process finds the best combination to provide the needed performance.

The fundamental relationships between the weight and volume of binder, aggregate, and air in an asphalt mix are shown in the phase diagram in Figure 3-12. The total weight of the mix is composed of the aggregate and asphalt, while the total volume is composed of the aggregate, the asphalt not absorbed by the aggregate, and the air voids. The volume of asphalt not absorbed by the aggregate is referred to as effective asphalt since this is the portion that coats and binds the aggregate together. Understanding these relationships is fundamental to understanding the Superpave mix design process.

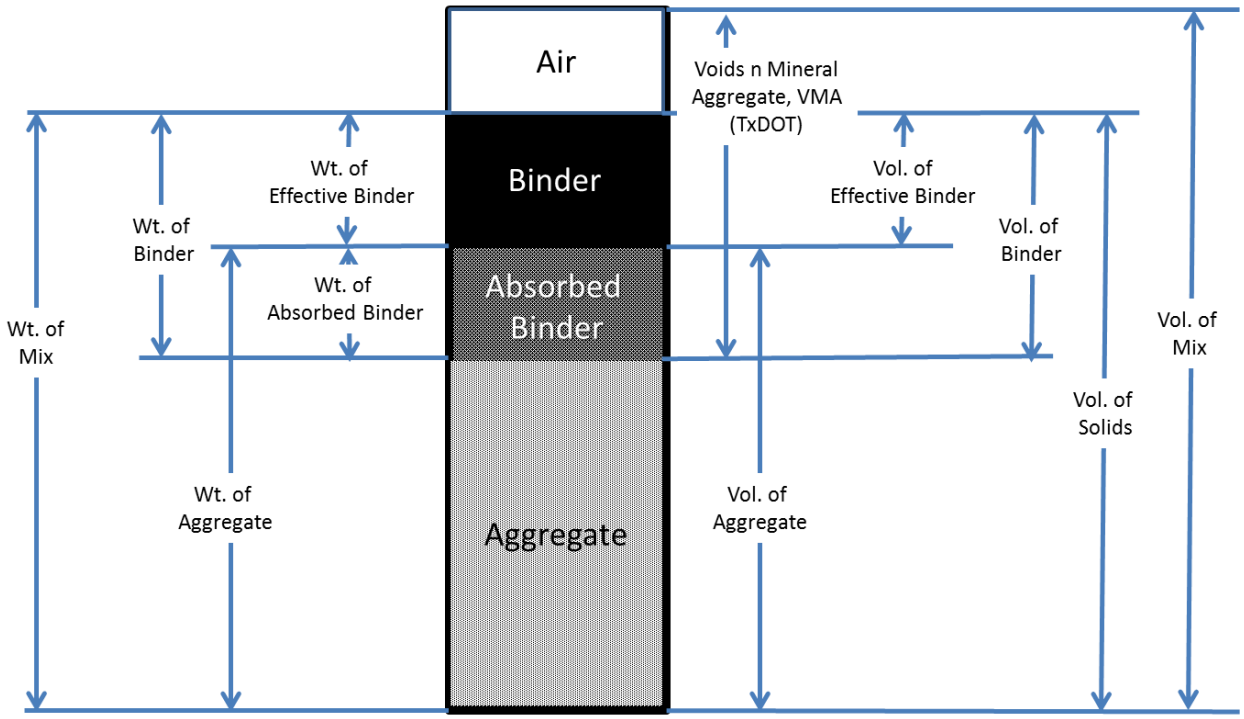


FIGURE 3-12. WEIGHT-VOLUME PHASE DIAGRAM OF ASPHALT MIXTURE.

Preparation of Mix Design Samples

Suppose the materials are familiar to the mix designer. In that case, the initial asphalt content range for mix design is usually set as the anticipated optimum asphalt content (OAC) ±0.5 or 1.0 percent on either side of the OAC. If the materials are unfamiliar, four or five asphalt contents may be used to bracket the OAC. Extra iterations may be needed if the asphalt contents do not produce the desired mix characteristics. Another approach is to adjust the aggregate gradation by varying the percentage of selected stockpiles to provide a different level of aggregate packing.

In preparing the materials, the virgin aggregates and RAP are combined according to the desired gradation and weighed to provide mixture weights of 2000 g for one sample and two samples of 4600 g at each asphalt content. The 2000 g sample determines the mix's maximum theoretical specific gravity (Gmm). The two 4600 g samples are for bulk specific gravity (G_{mb}) measurements and performance testing. The virgin aggregate, RAP and binder are heated to the appropriate mixing temperature described in Table 3-8. Care must be taken not to overheat the RAP material.

Table 3-8. Mixing Temperatures for Asphalt Mix Design.

Asphalt Grade[1]	Mixing Temperature[2], oF (oC)
PG 70-28, PG 76-22	325 (163)
PG 64-28, PG 70-22	300 (149)
PG 64-22, PG 64-16	290 (143)

1. If RAP or RAS and a substitute binder are used, use the original PG grade for mixing temperature.
2. When using RAP or RAS, the mixing temperature may be increased to 325oF to provide an adequate coating.

SOURCE: TXDOT, TEST METHOD TEX-205-F, 2016

The heated aggregates and RAP are placed into a heated mixing bowl, followed by adding the appropriate amount of binder. The mixing bowl is placed into the mixer, and the materials are combined until the virgin aggregate is thoroughly coated with binder. The loose samples are then placed in an oven at the appropriate compaction temperature for 2 hr.

The 2000-g sample is removed from the oven and spread out on a pan to cool at room temperature. The 4600-g samples are loaded into a compaction mold and compacted to 50 gyrations in a Superpave gyratory compactor (SGC) (Figure 3-13). The height of the compacted specimen should be 115 ± 5mm. If the specimen height falls outside the tolerance range, the following sample's weight should be adjusted accordingly.



SOURCE: FHWA, 2004.

FIGURE 3-13. SUPERPAVE GYRATORY COMPACTOR.

Volumetric Testing and Calculations

Two volumetric measurements are made on the prepared asphalt mix samples. The first is the maximum specific gravity of the mix (G_{mm}) (Tex-227-F) measured on the loose mix

sample, and the other is the bulk specific gravity of the mix (G_{mb}) (Tex-207-F) from the compacted samples.

The maximum specific gravity of the mix is the specific gravity with the air voids removed. Referring to Figure 3-12, the weight of the mix is divided by the volume of solids. This is performed on the loose mix sample spread out on the flat pan and left to cool. The weight of the loose mix sample in the air is determined first. The sample is then placed into a pycnometer and covered with water. A vacuum is applied to the pycnometer, and the sample is agitated to remove the air from the mix. The pycnometer is then filled with water to its calibration mark and weighed. The maximum theoretical specific gravity may be calculated by:

$$G_{mm} = \frac{A}{D + A - E}$$

(Eq. 3-6)

Where: A = Wt. of dry sample in air
D = Wt. of calibrated pycnometer filled with water.
E = Wt. of pycnometer containing the sample and filled with water to calibration mark.

The bulk specific gravity is the total weight of the mix divided by the total volume, as shown in Figure 3-12. It is measured on the compacted specimen by weighing the compacted specimen in air (dry), then weighing it submerged in water, and finally weighing it in a surface saturated-dry (SSD) condition. The bulk specific gravity is calculated as follows:

$$G_{mb} = \frac{A}{B - C}$$

(Eq. 3-7)

Where: A = Wt. of sample in air.
B = Wt. of SSD sample.
C = Wt. of sample in water.

These two measurements of specific gravity can then be used to calculate important volumetric parameters for the asphalt mix. The first of these is the volume of air voids in the mixture (voids in the total mix (VTM)), which is simply one minus the volume of solids (G_{mb}/G_{mm}). It is calculated as a percentage by:

$$VTM = \left(1 - \frac{G_{mb}}{G_{mm}}\right) 100 \quad \text{(Eq. 3-8)}$$

The effective specific gravity (G_{se}) of the aggregate is the weight of the aggregate relative to the volume of the aggregate in which asphalt is not absorbed (Figure 3-12) and should be between the bulk specific gravity and the apparent specific gravity. It can be determined by:

$$G_{se} = \frac{1 - P_b}{\frac{1}{G_{mm}} - \frac{P_b}{G_b}} \quad \text{(Eq. 3-9)}$$

Where: P_b = Percent binder in the mix (as a volume fraction).
G_b = Specific gravity of binder (usually provided by asphalt supplier).

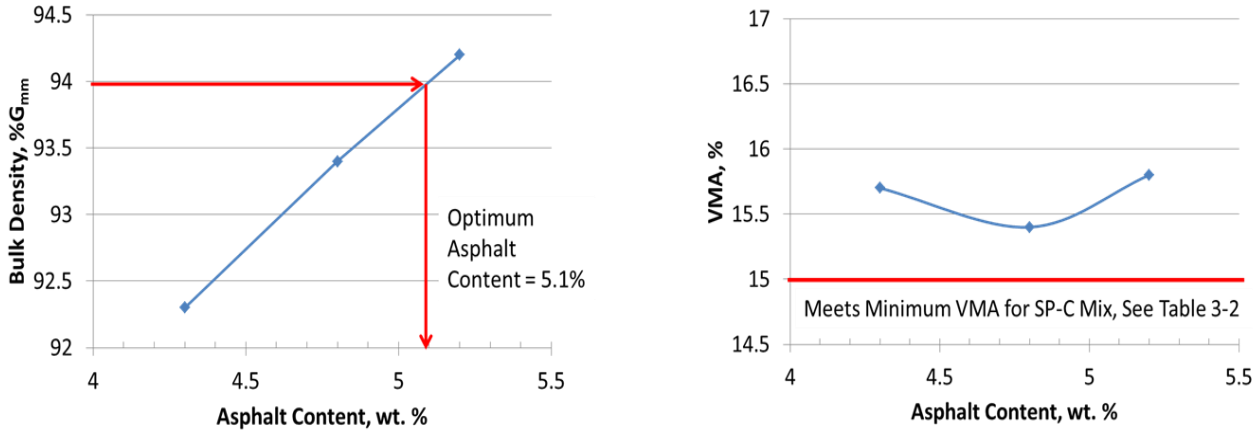
The voids in mineral aggregate (VMA) are the amount of space between aggregate particles, and they are used as a measure of the room available for asphalt and air voids in the mix. In most references, the VMA is calculated as a function of aggregate bulk specific gravity, but the Texas DOT uses the effective specific gravity of the aggregate (Figure 3-12). This will lead to a higher VMA value than using the aggregate bulk-specific gravity. VMA is calculated as per TxDOT as:

$$VMA = 100\left(1 - \frac{G_{mb}(1 - P_b)}{G_{se}}\right) \quad \text{(Eq. 3-10)}$$

Determining the Optimum Asphalt Content

The optimum asphalt content is defined as the amount of asphalt needed to produce a G_{mb} of 96 percent of G_{mm} (or 4 percent air voids) in a mix compacted to the design number of gyrations (N_{design}) while meeting the VMA criteria. The G_{mb} and G_{mm} are measured for the samples prepared at each of the trial asphalt contents. Going back to the stockpile example for a SP-C (Surface Mix) in Table 3-3, the G_{mb} is plotted against the asphalt content as shown in Figure 3-14(a). In this example the OAC is found by interpolating between the results for 4.8 and 5.3 percent asphalt resulting in an OAC of 5.1 percent binder. The VMA is then found for the resulting OAC (Figure 3-14(b)), and in this case the VMA is 15.4 percent and meets the minimum requirement for a SP-C as shown in Table 3-2. If either the density falls outside the range of asphalt contents used in the mix design or if the mix does

not meet the VMA requirements, then a new mix design should be done with a new aggregate gradation and/or a new aggregate source.



(a) Optimum Asphalt Content (b) VMA Requirement

FIGURE 3-14. EXAMPLES: PLOTS OF ASPHALT CONTENT VERSUS GMM AND VMA FOR MIX DESIGN.

Determining the optimum asphalt content at mix design is considered an initial step. As will be discussed later, further refinement of the mix design is needed through plant verification.

Mechanical Testing and Criteria for Asphalt Mixtures

As shown in Tables 3-9 and 3-10, there are requirements for both volumetric and mechanical testing including tensile strength and rutting/stripping behavior. The bulk density of the sample was established as 96 percent of G_{mm} at the N_{design} level of 50 gyrations established during the mix design. Another volumetric parameter used for mix design is the dust-to-asphalt ratio, defined as the amount of material passing the No. 200 sieve in the aggregate gradation divided by the asphalt content. Values from 0.6 to 1.4 are the lower and upper limits for the dust-to-asphalt ratio. Values lower than this may indicate the mix is over-asphalted and prone to bleeding. Higher values may indicate a mix that might be dry and susceptible to cracking.

The indirect tensile strength of the mix is determined according to Tex-226-F, which requires that a cylindrical sample be loaded across its diameter at a rate of 2 in/min at 77oF, as shown in Figure 3-15. An average of 4 samples is used for the specification. Tensile strengths are required to be in the range of 85 to 200 psi unless allowed by the agency engineer. Values lower than 85 psi may indicate a weak mix susceptible to cracking, while values higher than 200 psi may indicate a brittle mixture.



SOURCE: MAHONEY AND MUENCH (2012). WWW.PAVEMENTINTERACTIVE.ORG

FIGURE 3-15. INDIRECT TENSILE STRENGTH TEST SET-UP.

The Texas Boil Test (Tex-530-C) is used to judge an asphalt mixture's moisture susceptibility. In this test, a sample of the mix is boiled in water for 10 minutes. At the end of that time, the water is decanted off, the mix is spread on a paper towel, and the percentage of stripping is estimated. This value is used for comparison against the plant-produced mixture to ensure resistance to moisture damage. The agency engineer may waive this test.

Table 3-9. TxDOT Requirements for Superpave Mixtures.

Mixture Property	Test Method	Requirement
Target laboratory-molded density, %	Tex-207-F	96.0
Design gyrations (Ndesign)	Tex-241-F	50[1]
Indirect tensile strength (dry), psi	Tex-226-F	85–200[2]
Dust/asphalt binder ratio[3]	–	0.6–1.4
Boil test[4]	Tex-530-C	–

1. Adjust within a range of 35–100 gyrations when shown on the plans or specification or mutually agreed between the Engineer and Contractor.
2. The Engineer may allow the IDT strength to exceed 200 psi if the corresponding Hamburg Wheel rut depth is greater than 2.5 mm and less than 12.5 mm.
3. Defined as % passing #200 sieve divided by asphalt binder content.
4. Used to establish a baseline for comparison to production results. May be waived when approved.

SOURCE: TXDOT, S344, 2024

The Hamburg Wheel Tracking Test (HWTT) (Tex-242-F) is the last mechanical test. In this test, laboratory or core samples are subjected to passes from a loaded wheel, as shown in Figure 3-16. The test is performed in a water bath heated to 122°F (50°C). The loaded wheels are run back and forth across the samples until a rut depth of 0.5 inches (12.5 mm)

is reached or the required number of passes has been achieved without failing. The required number of passes depends upon the PG grade of the asphalt as shown in Table 3-9.

Table 3-10. TxDOT Hamburg Wheel Tracking Test Requirements for Superpave Mixtures.

High-Temperature Binder Grade	Test Method	Minimum # of Passes @ 12.5 mm[1] Rut Depth, Tested @ 50°C
PG 64 or lower	Tex-242-F	10,000[2]
PG 70		15,000[3]
PG 76 or higher		20,000

1. The Hamburg wheel test will have a minimum Rut Depth of 2.5 mm.
2. May be decreased to at least 5,000 passes when shown on the plans.
3. May be decreased to at least 10,000 passes when shown on the plans.

SOURCE: TXDOT, 344, 2024



SOURCE: FHWA, 2004.

FIGURE 3-16. HAMBURG WHEEL TRACKING TEST.

Field Verification

As stated earlier, determining the optimum asphalt content during mixture design is an initial target for asphalt plant production. The mix design should be verified within the first lot of material, ideally within the first 200 tons. After loading, the mix should be sampled from a truck and taken to the plant laboratory. The sample should be quartered, and enough material should be prepared to conduct volumetric testing for G_{mm}, Gmb, and HWTT testing.

The asphalt content of the plant-produced mixture should be tested according to Tex-236-F. This check will validate the operation of the asphalt production process and ensure that the aggregate feeds in the plant are in proper order. The asphalt content oven results must be corrected according to previously defined calibration factors for the aggregate.

The VMA should meet the requirements for plant-produced mix as shown in Table 3-2. It should be noted that the VMA requirements are 0.5 percent lower than the mix design requirements. This is because aggregates change due to handling during plant production. Aggregate shape can change due to rounding of particles during loading and drying. Also, there may be a slight increase in the amount of material passing the No. 200 sieve. If the VMA requirements are not met at this point, adjustments to aggregate gradation should be made before proceeding.

The Hamburg Wheel Tracking Test is performed on the plant produced mix to ensure that the mix being placed has the desired rutting and stripping resistance. Failing results in the HWTT at this point may require the addition of an antistripping agent or a change to a higher PG asphalt. Lowering the asphalt content to gain better rutting resistance is not recommended.

Summary

Asphalt mixtures need to address safety, performance, and economy during their service lives. The selection of materials and mixture design should reflect the intended use of the mixture. The asphalt binder should suit the climatic and traffic conditions. The aggregates need to be selected and blended to achieve the desired gradation and quality characteristics. Care should be taken to ensure that the gradation does not run too close to the allowable gradation band as this periodically may cause out-of-specification materials. It is important to understand the weight-volume relationships between the asphalt binder, the aggregate, and the mixture as these are keys to good design. The mixture needs to be subjected to performance testing for cracking and rutting potential.

Chapter 4 Pavement Design

Introduction

The structural design of pavements determines the combination of materials and their thicknesses needed to support traffic, considering vehicle numbers and weights, climate, and soil conditions. Prior to designing a pavement, the engineer should have access to recent traffic studies, realistic projections for traffic growth, soil conditions at the site, including any changes that may exist along the planned length of the pavement, characteristics of any existing materials in the pavement, and weather data including temperature and precipitation. A general flow chart of the pavement design process is shown in Figure 4-1. Every effort should be made to ensure that the latest available information is used, and where information is not available sampling, testing and data collection should be done. It is also important to be aware of possible future changes in traffic patterns that could affect the pavement. For instance, if a subdivision is being constructed in phases, then it would be important to note that once the initial phase is constructed, the subsequent phases will require the delivery of concrete, bricks, wood, etc. all of which would need to be supported on the designed pavement.

In this chapter, the general considerations, typical design methods used in Texas and nationally, **PAVExpress** and **PerRoadXPress** approaches to pavement design, and special considerations for pavement design will be discussed. Examples of designs using PAVExpress will be presented. All pavements need to be designed for their intended purpose and not be merely “typical sections” that are applied from previous projects. Careful consideration of site conditions, materials, materials selection and traffic will be the best way to avoid either under-designing or over-designing the pavement structure, and therefore providing the most economical pavement over its intended life. Pavement design methods have evolved over time from simplistic empirical approaches where observations of pavement performance in a limited number of situations lead to the development of a design procedure to more mechanistic-empirical (M-E) methods which use relationships between stresses and strains and the development of distresses in the pavement to predict pavement performance.

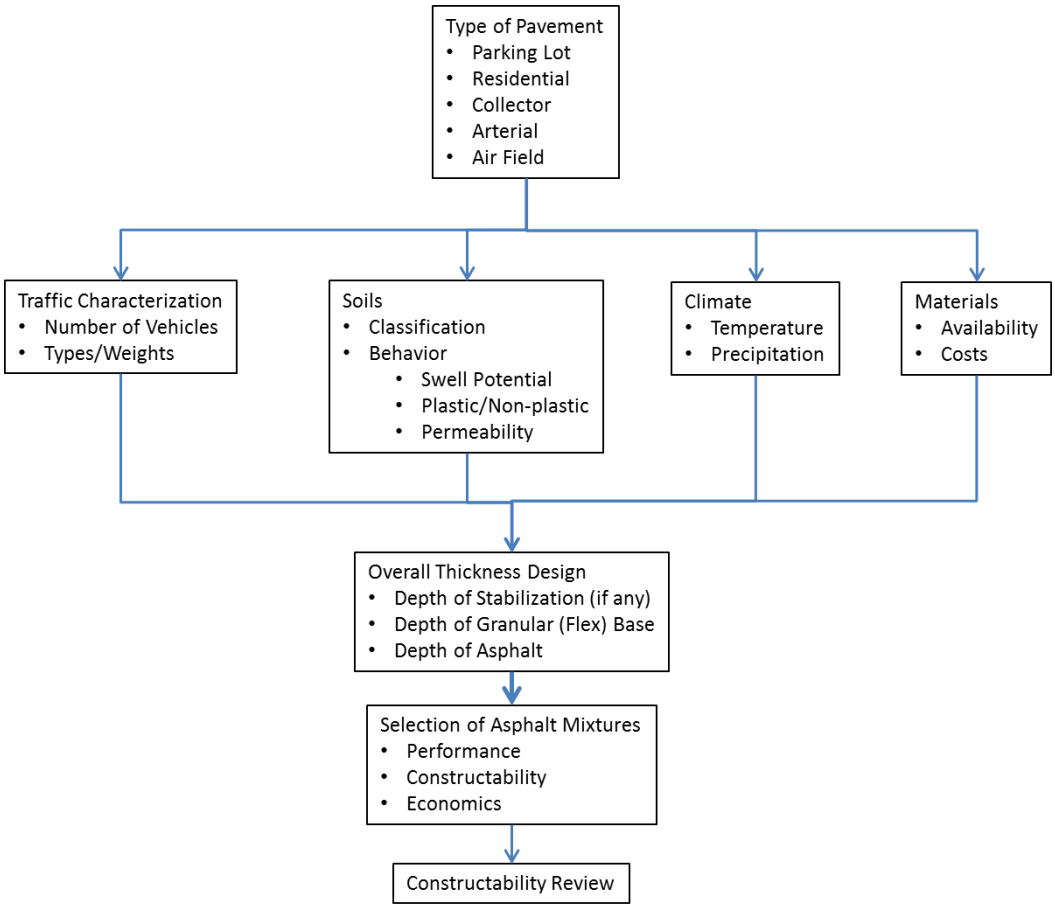


FIGURE 4-1. PAVEMENT DESIGN PROCESS.

A further development that will make asphalt pavements an even more economical choice over the long term is Perpetual Pavements (Newcomb et al., 2010). This long-life pavement approach ensures that the asphalt pavement structure is designed for the heaviest loads in the traffic mix. This eliminates the need for precise traffic forecasts and prevents an unnecessary over-design of the pavement section. The only future work needed on a Perpetual Pavement will be whatever preservation or maintenance strategies are needed to avoid or correct defects at the pavement surface, a much cheaper alternative to partial or complete reconstruction.

While flexible pavements are most frequently associated with roadways, a great deal of asphalt mix is used in the construction of parking lots. Just as the economy of the pavement is an important consideration in parking lots, it is also critical to design the pavement for the loads that will be applied such as passenger vehicles, delivery trucks, garbage trucks, etc. In other words, part of the parking lot may have relatively thin areas where passenger vehicles park, and thicker pavements on routes that delivery trucks would take. Since parking lots tend to cover a wide area, drainage must be incorporated

into the design to avoid ponding and the collection of water in lower pavement layers that can weaken as they get wet. One method to address drainage, in areas where it is feasible, is the use of Porous Pavements. These pavements allow water to permeate the structure of the parking lot into a stone reservoir layer where it can then infiltrate the soil and recharge the water table (Hanson, 2008).

General Considerations

Before beginning the design of a pavement structure, the engineer should take an inventory of the information in-hand. For instance, the type and amount of traffic needs to be estimated as accurately as possible. Just the number of vehicles will not be sufficient as the weight becomes exponentially more important as it increases. Damage on a pavement increases at a rate of approximately the fourth power as weight increases. Thus, one school bus in a driveway can do hundreds of times more damage than a typical automobile. The effects of weather on a pavement include creating a seasonality in the material properties, the long-term aging of the asphalt, and permanent roughness due to the expansion or contraction of underlying soils (subgrade). Materials availability in each area needs to be recognized by the pavement designer. For instance, aggregates must be transported into areas along the coastal region and in east Texas where they are scarce. Thus, it may be considerably cheaper to build a thicker asphalt section and use less unbound base (flex base). In addition to the typical pavement design considerations, the designer needs to be cognizant of the proper types of asphalt mixtures to apply at different levels in the pavement structure and design considerations that will lead to optimal construction conditions. Choosing the right material for the right application will result in better pavement performance and optimize the long-term economics.

Traffic Loading (Weights and Numbers)

Traffic loads need to be considered in terms of both the weight and numbers of vehicles expected on a given pavement. As previously mentioned, the amount of pavement damage increases exponentially with vehicle weight. Figure 4-2 illustrates what is commonly known as the 4th power law of damage. Thus, a 2000-lb wheel load is 16 times more damaging than a 1000-lb wheel load, and a 5000-lb wheel load is over 600 times more damaging. A typical tractor-trailer is many thousand times more damaging than a passenger vehicle. It should be noted that damage does not always increase to the fourth power. It does increase exponentially, but it depends on the pavement structure.

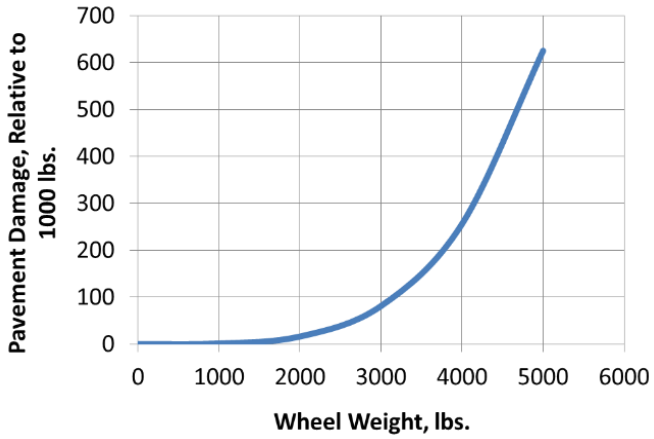


FIGURE 4-2. ILLUSTRATION OF 4TH POWER LAW.

Normally, traffic loads are considered in terms of 18,000-lb equivalent single axle loads (ESAL). This concept was introduced during the American Association of State Highway Officials (AASHO) Road Test of the late 1950s and early 1960s (AASHTO, 1993). The damage caused by truck loadings on the pavement sections at the Road Test was expressed in terms of ESAL, and that measure continues to be used in most pavement design procedures used by State DOTs. A legal but heavily loaded truck would be about 2.2 ESAL, so one lane on a freeway that is a busy shipping corridor could accumulate as many as 30,000 ESAL in just one day. Low volume, rural roads have 20-year traffic design values that may be in the range of 50,000 to 300,000 ESAL. A busy urban collector may have a 20-year traffic level of 1,000,000 to 10,000,000 ESAL. Some extremely busy interstate highways, such as those in southern California, can reach 20-year design levels of 200,000,000 ESAL or more. There is not a linear relationship between the number of ESALs and pavement thickness. Rather, exponentially more traffic can be supported for small increases in asphalt thickness, and there comes a point at which the pavement will support a very large number of the heaviest loads and additional thickness is unnecessary. These are Perpetual Pavements, and they offer many economic and operational benefits as will be discussed later. Asphalt pavements can be economically designed for a broad range of traffic levels.

Traffic on roads is held to strict loading standards through enforcement of load limits. The maximum legal, non-permitted load for highways is 80,000 lb. gross weight with tandem axles limited to 34,000 lb. and single axles limited to 20,000 lb. However, there are certain facilities where the loading conditions require special attention. For instance, freight transfer yards or port container yards use special vehicles to move containers from ships or trains to trucks and vice versa. These vehicles can place very high shear stresses on the

pavement when they are fully loaded which is different from highway loading. In such instances, a mechanistic analysis of the stresses in the pavement and the use of shear-resistant, large stone asphalt mixes are likely to be warranted.

Climate

Due to its size, Texas has several climates ranging from hot, wet environments in east Texas along the coastal plain to cold, dry winters in the Texas panhandle. The primary climate concerns in terms of pavement performance in Texas are wet conditions leading to soft subgrade, rutting due to hot weather, and cracking due to cold temperatures. Moisture can also infiltrate low-density asphalt mixes and result in damage to the asphalt mix.

In areas that are moist for large parts of the year, providing adequate drainage is a high priority. If a new road is being constructed, it is important to design the side ditches to a sufficient depth and slope them toward a drainage basin such as a detention pond or a natural creek. For roads with curbs and gutters, the road should be sloped toward a storm sewer inlet. If culverts are used to run the water from one side of the road to the other, it is important that they have adequate cover to prevent damage from heavy vehicles. In all cases, follow the directions from the appropriate permitting authorities. Many pavement performance problems can be directly tied to poor drainage of pavements.

Materials

Pavement materials are classified according to their strength or stiffness. Figure 4-3 shows a typical pavement section and how the stiffness increases from the subgrade or natural soil to unbound crushed rock (flexible base or flex base) to the asphalt mixtures in the upper portion of the pavement. In this guide, two types of indexes or properties will be used to describe the structural characteristics of pavements, the AASHTO Structural Coefficient and Modulus. A brief description of each of these is given below.

The 1993 AASHTO Guide for the Design of Pavement Structures, the concept of a Structural Number (SN) is used to assign an overall level of strength to a pavement. The structural number is derived by multiplying the structural coefficient (a_i) for each pavement layer by its thickness (D_i) and summing the results for all the pavement layers:

$$SN = a_1D_1 + a_2D_2 + \ldots + a_nD_n \qquad \text{(Eq. 4-1)}$$

The structural coefficient for each layer is a value that was originally determined at the AASHO Road Test of the late 1950s and early 1960s. It is an indicator of the contribution of

the material to the overall performance of the pavement. Some commonly used values for structural coefficients are given in Table 4-1.

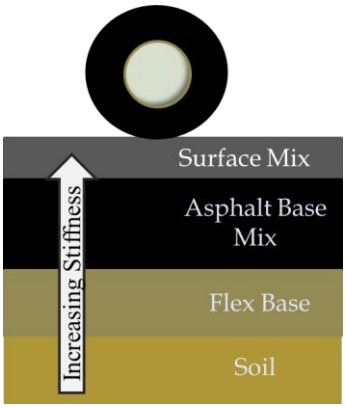


FIGURE 4-3. RELATIVE STIFFNESS OF PAVEMENT LAYERS.

The upper end of the structural coefficient values for asphalt mix was determined by research at the National Center for Asphalt Technology for the Alabama Department of Transportation (ALDOT) and recognizes the improvements made in asphalt mixtures over a period of five decades. The higher end of this range for asphalt mixtures has been adopted by ALDOT and the Washington State Department of Transportation (WSDOT). It is recommended here that asphalt mixtures be assigned a structural coefficient of 0.54. The flexible base range of structural coefficients covers a CBR range of from 20 to 100 or a Texas Triaxial Classification of 3.7 to 2.0. The range of values for cement-treated base roughly correlates to an unconfined compressive strength of 100 to 1500 psi, and the structural coefficient range for asphalt-treated base covers a range of modulus values of 100,000 to 350,000 psi.

Table 4-1. Typical AASHTO Structural Coefficients (ai) for Various Materials.

Material	Typical Structural Coef. (ai)	Range of ai
Asphalt Mix	0.54	0.35 – 0.54
Flex Base	0.11	0.07 – 0.14
Cement Treated Base	0.20	0.10 – 0.28
Asphalt Treated Base	0.20	0.12 – 0.30

The modulus of a material is an indication of its stiffness. The modulus values used for roadway materials are frequently termed “resilient modulus” or “dynamic modulus,” and while they are not the same, they are relatively close. The resilient modulus (Figure 4-4) is

measured in the laboratory by subjecting a material to a 0.1-second load followed by a 0.9-second rest period, and the modulus is calculated by dividing the stress by the recoverable strain. The dynamic modulus is determined by applying a sine wave loading and measuring the recoverable strain, and the modulus is the stress divided by the recoverable strain. There is also an approach to inferring the modulus of materials by loading the pavement with a Falling Weight (FWD), which measures pavement deflection from an impact weight applied to the pavement surface (Figure 4-5) and measuring the deflections at distances from zero to six feet out from the center of the loading plate. The technique for estimating the modulus values of different pavement layers is called back calculation, and it involves matching the combination of layer moduli with the measured pavement deflection.

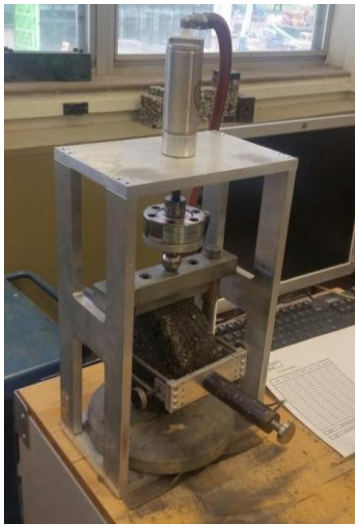


FIGURE 4-4. RESILIENT MODULUS TEST FOR ASPHALT MIX.
SOURCE: FHWA



FIGURE 4-5. FALLING WEIGHT DEFLECTOMETER.

For asphalt, the temperature and time of loading affect the modulus values. For typical applications, it is more important to account for temperature effects than loading time. As shown in Figures 4-6, the modulus of asphalt at cold temperatures can be very high, while at hot temperatures, it is relatively low. This change in material behavior is used in more complicated mechanistic-empirical (ME) approaches to pavement design, where seasonal, monthly, or even daily changes are used to better reflect actual pavement conditions.

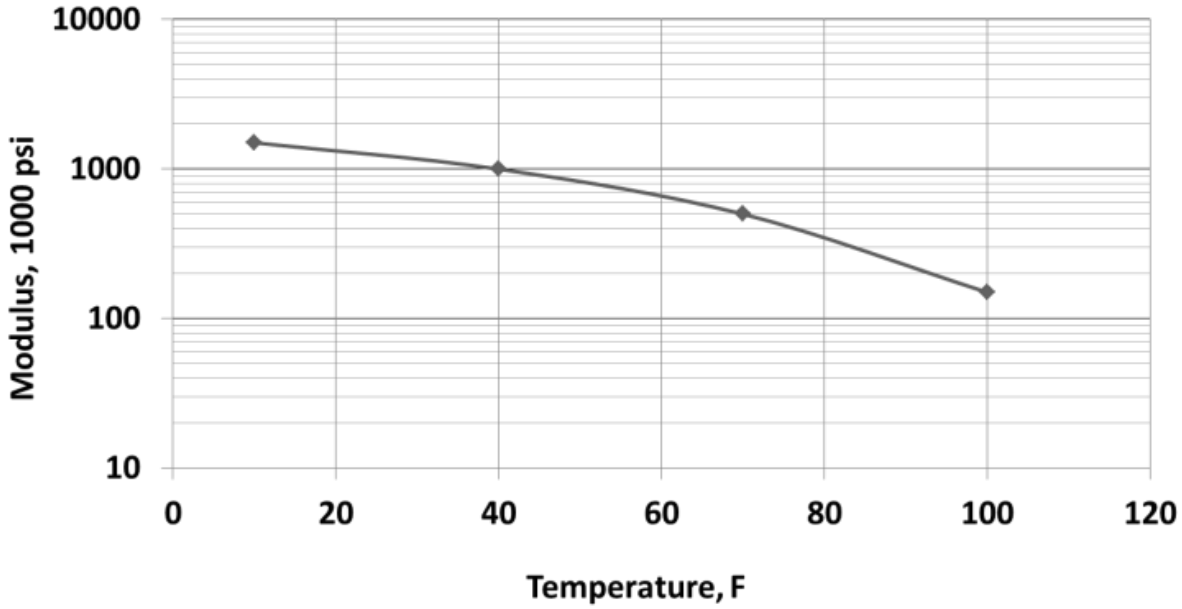


FIGURE 4-6. EXAMPLE OF HOW TEMPERATURE AFFECTS MODULUS (STIFFNESS) OF ASPHALT MIX.

Flex-base materials are most affected by the presence of water. As moisture increases, the material becomes softer and weaker, as Figure 4-7 shows. Base course moisture content fluctuations depend on the climate and seasonal rainfall. For instance, in West Texas, the material will likely be dry for much of the year, and there is little risk of having prolonged periods of weakness. In southeast Texas, rainfall can occur in any season, which could cause the flex base to become soft and less able to support traffic loading. Although it may be tempting to try to counter the effects of moisture by using a greater thickness of flex base, it is probably best to use a thicker layer of asphalt mix.

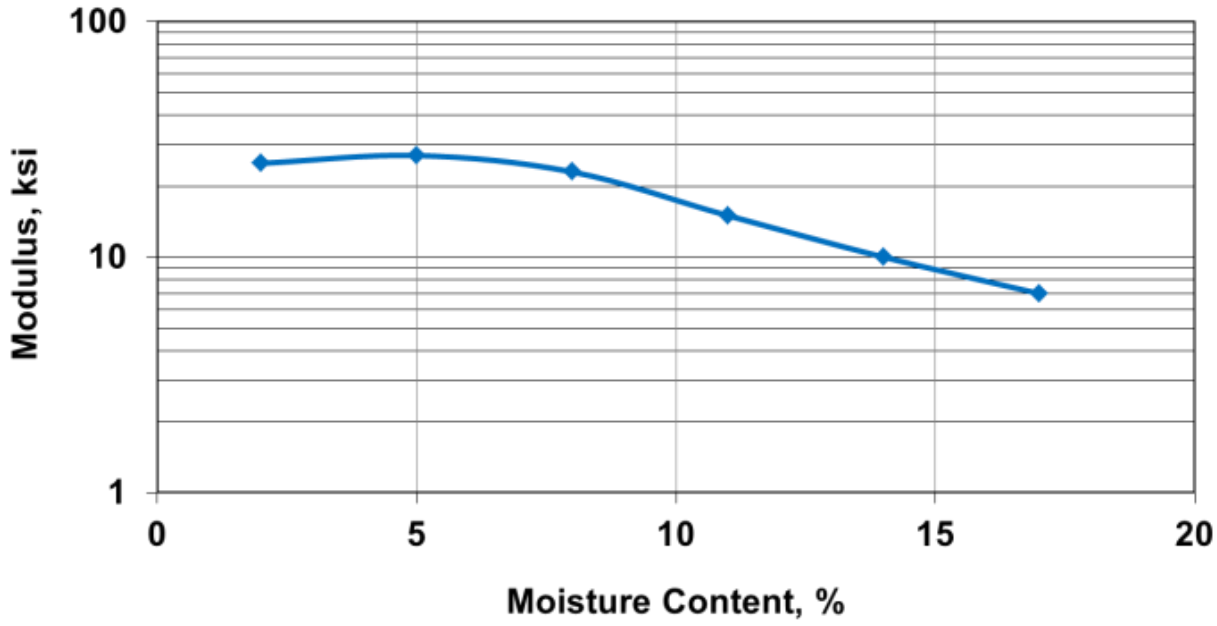


FIGURE 4-7. EXAMPLE OF HOW MOISTURE CONTENT AFFECTS MODULUS (STIFFNESS) OF BASE.

Soils, even more than flex base materials, are affected by the presence of water. The degree to which the modulus decreases in the presence of water is dependent upon the soil type. Fine-grained materials such as clays and silts weaken a great deal when they are wet. Sandy-clays and clay-sands do not weaken as much, and sands, sandy-gravels, and gravels weaken to an even lesser degree. Many of the clay soils in Texas are known as expansive clays, and they undergo severe volume change as their moisture content changes from high to low. Unless these soils are stabilized, they will swell when they are wet causing humps in the pavement, and they will shrink when they are dry causing cracking on the pavement surface. The most effective approach to dealing with swelling soils is to stabilize them with the application of lime to a depth of between six and twelve inches. Typical modulus values and ranges for asphalt pavement materials are presented in Table 4-2.

Table 4-2. Typical Modulus Values and Ranges for Asphalt Pavement Materials.

Material	Typical Modulus, psi	Modulus Range, psi
Asphalt Mix	500,000	100,000 to 2,000,000
Asphalt Stabilized Base	200,000	100,000 to 350,000
Cement Stabilized Base	200,000	50,000 to 500,000
Granular Base	20,000	15,000 to 50,000
Gravel Subgrade	20,000	15,000 to 30,000
Sandy Subgrade	15,000	12,000 to 20,000
Silt Subgrade	12,000	8,000 to 15,000
Clay Subgrade	9,000	7,000 to 15,000

Constructability Review and Mix Type Selection

An important component of preparing any set of plans and specifications is the constructability review, where an engineer experienced in construction checks the details to see if any unnecessary impediments are inadvertently included. For instance, the thickness of each lift of asphalt shown in the plans should be checked against the nominal maximum aggregate size for the specified mix. The ratio of lift thickness to NMAS should be 3:1 to 5:1. This will help ensure the mixture can be placed and adequately compacted. Another example would be to check the stiffness of the mix against the anticipated amount of hand work. A highly polymerized binder or the use of a coarse aggregate gradation can make the mix very difficult to manipulate with hand tools, and this can cause problems for mix to be placed in tight corners, around drainage inlets, or hard-to-reach locations. This can result in low in-place density and a segregated mix. The consequences of not conducting a constructability review of plans and specifications include contradictory or ambiguous plans and specifications, unrealistic expectations during construction, confusion during construction concerning the intent of specifications or plans, and poor pavement performance, among other issues.

While the structural design is concerned with providing the right overall combination of materials and layer thicknesses to meet the requirements of traffic, climate and soil, selecting the proper asphalt mixture for a particular application within the pavement structure is critical to good pavement performance. Recommendations for mix type selection are found in the National Asphalt Pavement Association's (NAPA) publication IS-128, *HMA Pavement Mix Type Selection Guide* (Garcia and Hansen, 2001). The lift thickness should be between 3 and 5 times the nominal maximum aggregate size (NMAS).

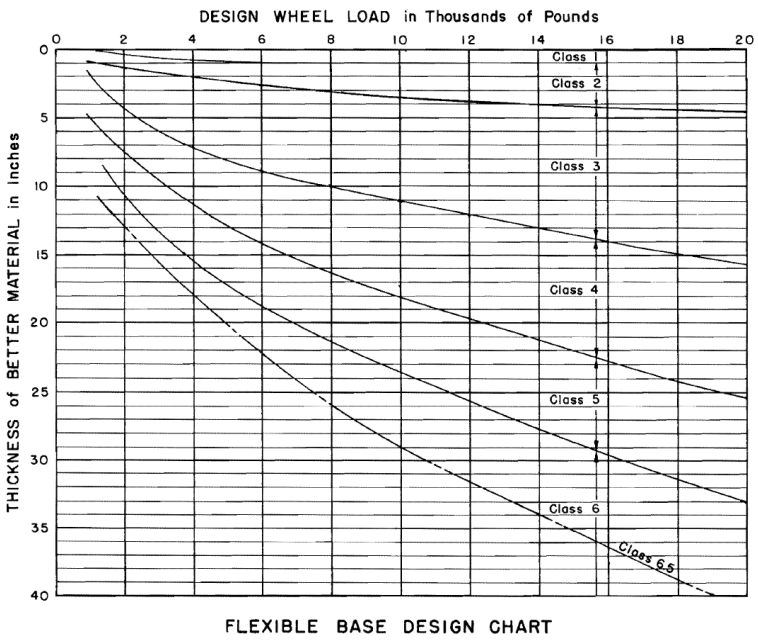
This will provide the necessary thickness of mix to allow for the best compaction. Mix type selection for asphalt pavements will be discussed in more detail in Chapter 5.

In the design process, it is important to remember that the thickness of any given lift of material is limited to a tolerance of about 0.25 in. during construction. So, it is best during design to round the thickness of the total pavement section up to the nearest 0.25 in. This will ensure that the pavement thickness will be adequate.

Design Methods

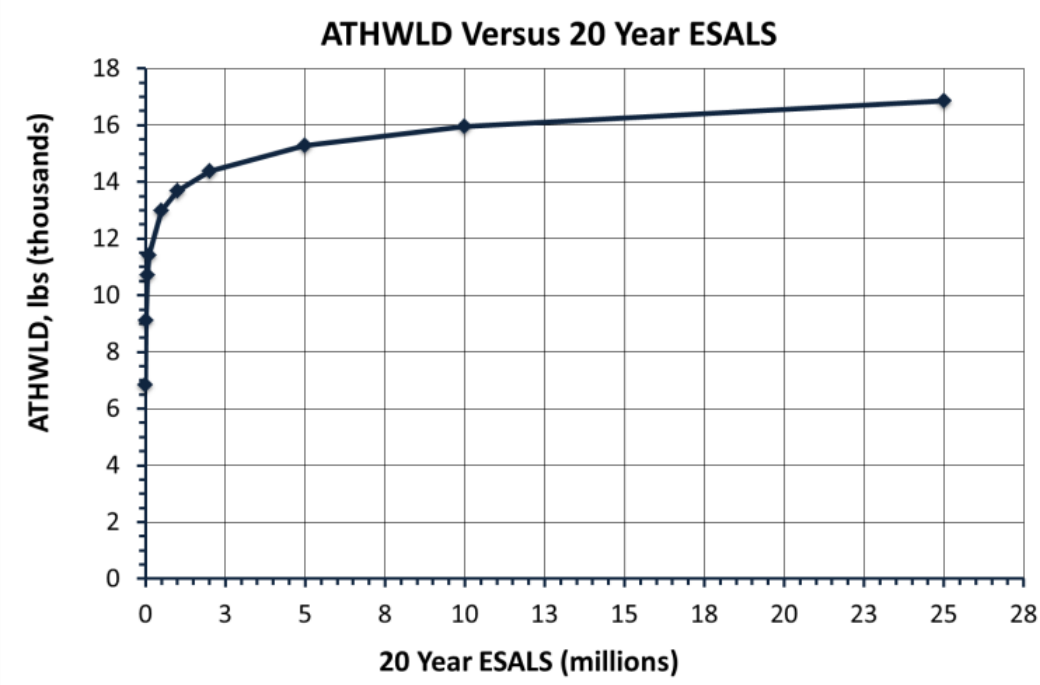
Design procedures for asphalt pavement structures fall into two very broad categories. The first is empirical methods which were developed by relating pavement thicknesses and material characteristics to observed performance under closely monitored conditions. Examples of this type of design procedure include the 1993 AASHTO Pavement Design, the California Bearing Ratio approach previously used by the U.S. Army Corps of Engineers, and the Texas Triaxial Classification method. While these approaches are rational, they are generally limited to the conditions under which they were developed including the range of loading, the climate, and the pavement structures tested. The other category is known as mechanistic-empirical (ME), and these differ from purely empirical methods in that stresses and strains in the pavement are related to the observed performance of roadway sections. While ME methods also have their limitations, changes in loadings, materials, and pavement structure can be accommodated by changing the inputs to the program that computes the stresses and strains. ME pavement design offers more flexibility to evaluate the effects of new types of loads, new materials, etc. Examples of ME design methods include Texas FPS-21, the new AASHTO Pavement ME, and the perpetual pavement design method PerRoadXPress.

The Modified Texas Triaxial Design Method (Smith and Dyer, 1973) was originally devised in the 1940s and 1950s as a means of providing enough pavement structure and thickness to avoid shear failure in the subgrade. Pavement materials are classified according to their shear strength from Class 1 (strongest) to Class 6 (weakest). Figure 4-8 shows the thickness of flex base required above various classes of materials for different levels of design wheel load. The design wheel load is the daily average of the ten heaviest wheel loads anticipated for the roadway. The relationship between the Average Ten Heaviest Wheel Loads Daily (ATHWLD) and ESALs is shown in Figure 4-9. Currently, the Texas Triaxial Design Method is used primarily as a check to ensure that low-volume roads have an adequate thickness to avoid catastrophic failure by a few heavy loads.



SOURCE: SMITH AND DYER, 1973

FIGURE 4-8. DESIGN CHART FOR TEXAS TRIAXIAL CLASSIFICATION DESIGN METHOD.



SOURCE: SMITH AND DYER, 1973

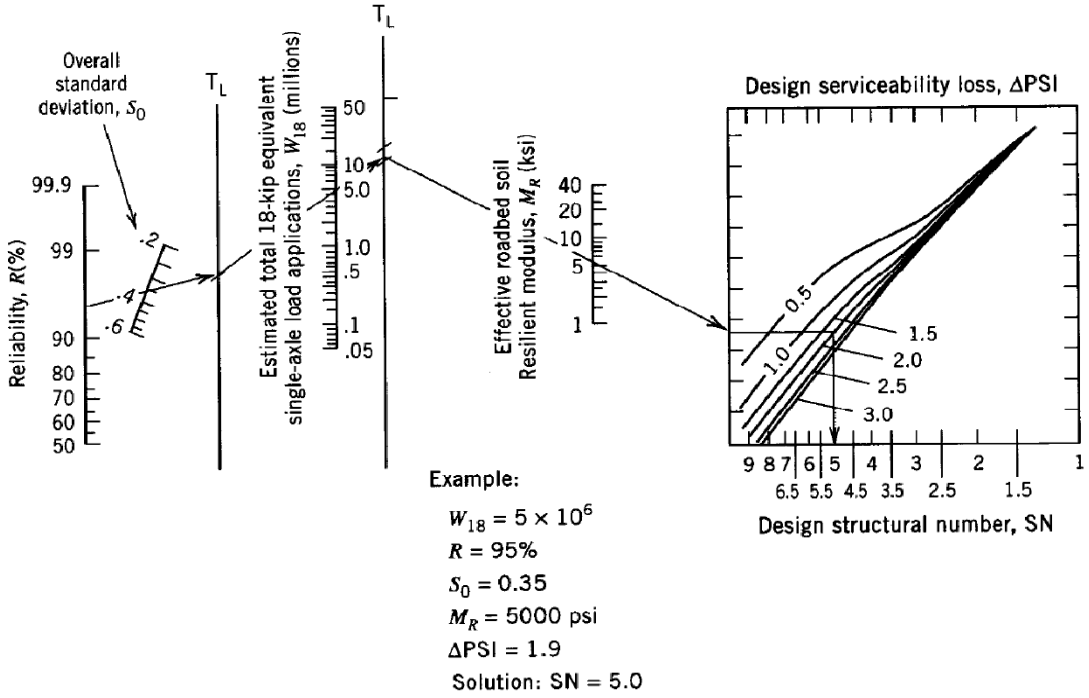
FIGURE 4-9. RELATIONSHIP BETWEEN ESAL AND ATHWLD FOR TEXAS TRIAXIAL CLASSIFICATION DESIGN.

The Texas Flexible Pavement System (FPS) for the design of asphalt roads was first developed in the 1970s and has evolved to its current version, FPS-23 (Liu and Scullion, 2011). This is a mechanistic-empirical approach to pavement design using a layered elastic analysis and empirical performance equations developed in Texas. The analysis uses the stresses and strains calculated within the pavement model under an 18,000-lb single axle load (in other words, one ESAL) and the number of ESALs over the design life along with the performance models to estimate the rutting and fatigue cracking performance. Modulus values for the materials may be either laboratory-determined, back-calculated from FWD data, or obtained from a list of default values on TxDOT's online pavement design guide. Up to six separate pavement layers may be specified in FPS-21. This is useful in analyzing asphalt mixture layers with different modulus values, such as those sometimes found in Perpetual Pavement design. The program also provides a check on shear failure in the subgrade and base using the Modified Texas Triaxial criteria discussed above. FPS-21 and its manual may be downloaded at http://pavementdesign.tamu.edu/fps21.htm.

The AASHTO 1993 Guide for the Design of Pavement Structures is based on the original AASHO Road Test performance equation (AASHTO, 1993). The 1993 guide differed from earlier versions only in how the subgrade characteristics were handled and the addition of reliability and variability to the required inputs. Figure 4-10 shows the design nomograph for determining the SN of the pavement section. This process starts by entering the desired level of reliability on the right side of the nomograph and drawing a straight line through the overall standard deviation of expected performance. The level of reliability is dependent upon the expected level of traffic with higher reliability (say 95%) being assigned to a busy freeway and lower reliability (say 85%) being used for a low-volume road. The level of reliability acts as a multiplier of traffic and increasing the value from 95 to 99% has a profound effect on pavement thickness. The overall standard deviation is a measure of consistency of the performance of pavements, and it is usually set at 0.35 as it is very difficult to determine for any given area or agency. The ESALs are the next input, and it is simply based on the weight distribution and numbers of trucks as discussed earlier in this chapter. The effective roadbed soil resilient modulus is a weighted average of the expected road damage for the resilient modulus for each month of the year (i.e., higher damage for lower modulus). Finally, the loss of serviceability index over the expected design life is entered. The serviceability index of a new pavement is commonly considered to be 4.5 (out of a 5-point scale) and the terminal serviceability is 2.0 for higher functional classification roads and 1.5 for lower volume roads. Once the structural number is determined, the thicknesses of the layers are determined according to Equation 4.1. The 1993 AASHTO

design method may be easily done by using PAVExpress software available on-line at http://www.pavexpressdesign.com/. A design example using PAVExpress will be presented later in this chapter.

PerRoadXPress is a software package developed for the design of Perpetual Pavement, a way of building an economical, sustainable pavement that will only need periodic maintenance and occasional resurfacing. As discussed earlier, this is a term for long-life asphalt pavements, and it works by designing the pavement section to withstand the heaviest of the expected axle loadings, and keeping the pavement from experiencing the fatigue cracking and rutting distresses that originate deep in the pavement structure. This ensures that any distresses that do develop are confined to the surface of the pavement.



SOURCE: AASHTO, 1993

FIGURE 4-10. DESIGN NOMOGRAPH FOR 1993 AASHTO DESIGN METHOD.

This concept is illustrated in Figure 4-11. The key to designing a Perpetual Pavement is to keep the bending strain at the bottom of the asphalt layer, where fatigue cracking starts, below what is known as the fatigue endurance limit (FEL), also sometimes referred to as the limiting strain. This strain value depends upon the type of mix, the type of binder in the mix, and the aggregate gradation. For most dense-graded mixtures with unmodified asphalt, a FEL of 125 macrostrain (με) is appropriate while 250 με has been suggested for

mixtures with polymer modified asphalt. A simplified Perpetual Pavement design procedure called PerRoadXPress will be used in an example later in this chapter. Both the PerRoadXPress and PerRoadXPress software may be downloaded from the Asphalt Pavement Alliance at http://www.asphaltroads.org/why-asphalt/engineering/perpetual-pavement/.

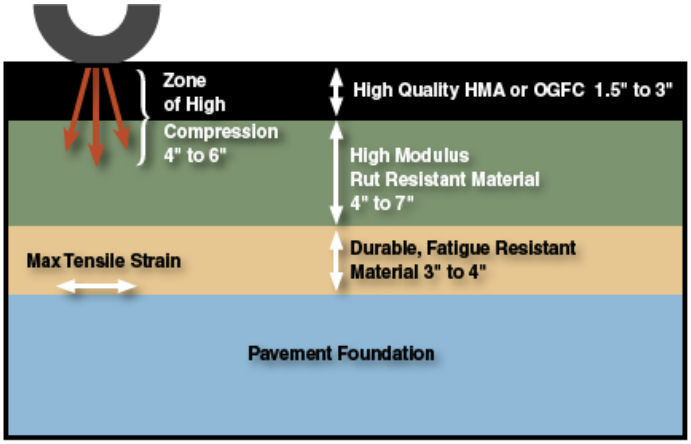


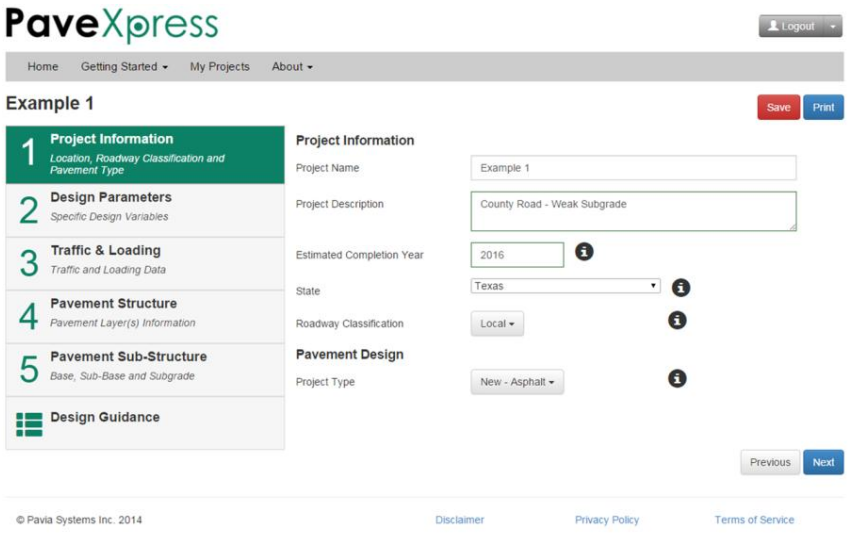
FIGURE 4-11. PERPETUAL PAVEMENT CONCEPT.

AASHTO encourages its member states and territories to adopt its Pavement M-E software to design pavement structures (AASHTO, 2020). This newer approach differs considerably from the 1993 AASHTO design guide. Instead of using the ESAL to measure traffic intensity, the Pavement M-E uses the spectrum of axle types and loads in a layered elastic analysis. Materials are considered in terms of modulus values, and these are changed according to an embedded climatic model that relies on data from weather stations near the pavement site. The climatic model considers changes in both temperature and precipitation in one-hour increments throughout the entire analysis period. The performance of pavement sections is predicted for rutting, thermal cracking, bottom-up fatigue cracking, top-down fatigue cracking and roughness. The goal is to design a pavement section which will not exceed a certain level of distress for each of these. Reliability is considered in terms of the probability of early failures. For instance, a 95% reliability level would mean that the pavement would be designed so that no more than 5% of the pavements would experience a given level of distress. While Pavement M-E represents an advancement in pavement design, it requires that the models used in predicting the performance of pavements be calibrated to local conditions. It should also be noted that according to its developers, it is not an appropriate design procedure for low-volume roads.

Pavement Thickness Design Example (PAVExpress)

PAVExpress is an on-line tool that is available for free to design pavements according to the 1993 AASHTO design procedure. The latest version includes the online pavement design software with additional PerRoadXPress and Life Cycle Cost Analysis modules. In addition, the program has a Pave Instruct module for online training of its many functions).

As you enter the site it will allow you to establish a username (e-mail address) and a password to save your information for later use. Next, a folder can be established for a given type of project and a file can be started for a project. In this case, the project name is Example 1 as shown in Figure 4-12 which is the "Project Information" screen. For Example, 1, a pavement for a county road with a weak subgrade will be designed to be constructed in 2016. The roadway classification selected is "Local" and it will be a new asphalt pavement. The program also allows the design of concrete, asphalt overlay of asphalt, and asphalt overlay of concrete or composite pavement.

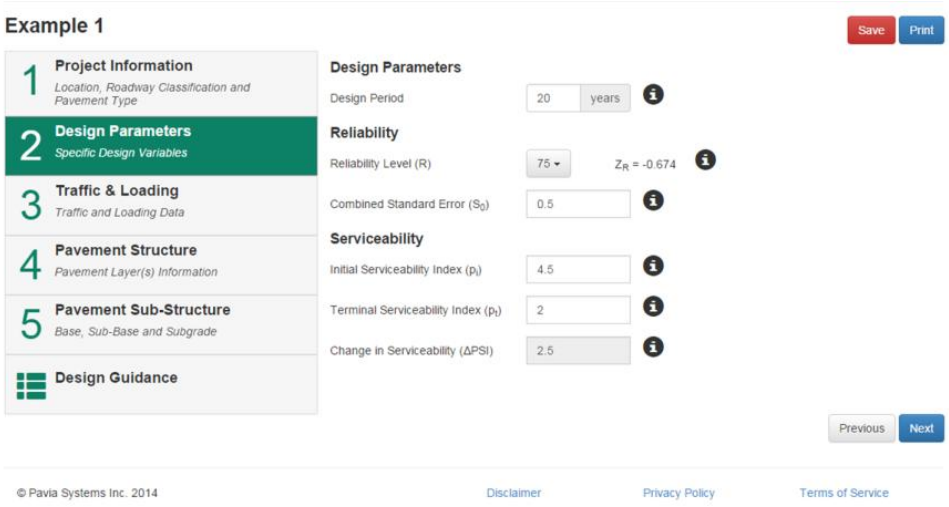


Source: Pavia Systems, 2014

FIGURE 4-12. PAVEXPRESS PROJECT INFORMATION SCREEN.

Figure 4-13 shows the next screen in PAVExpress which is for the design parameters. In this case, a design period of 20 years was selected. This is the period over which the ride quality of the pavement is expected to decrease from an assumed initial serviceability index (p_0) of 4.5 to a terminal serviceability index (p_t) of 2.0 creating a change in serviceability (ΔPSI) of 2.5. The reliability level selected for this low volume road pavement is 75% which means that there is a 75% probability that major rehabilitation of the road will not be needed before 20 years. The designer needs to choose the reliability level carefully as higher levels (say 90% or more) which may be appropriate for high volume roads will

lead to gross overdesign for low volume roads. Table 4-3 presents recommended levels of reliability for different classes of roadways. The combined standard error (S_o) is a way to account for the overall variability in roadway performance. In other words, identical pavements do not all perform the same even though they are designed at the same level of reliability for the same design period for a variety of reasons and this can be accounted for in the design procedure. AASHTO recommends that asphalt pavements have a range of S_o from 0.4 to 0.5.



SOURCE: PAVIA SYSTEMS, 2014

FIGURE 4-13. PAVEXPRESS DESIGN PARAMETERS SCREEN.

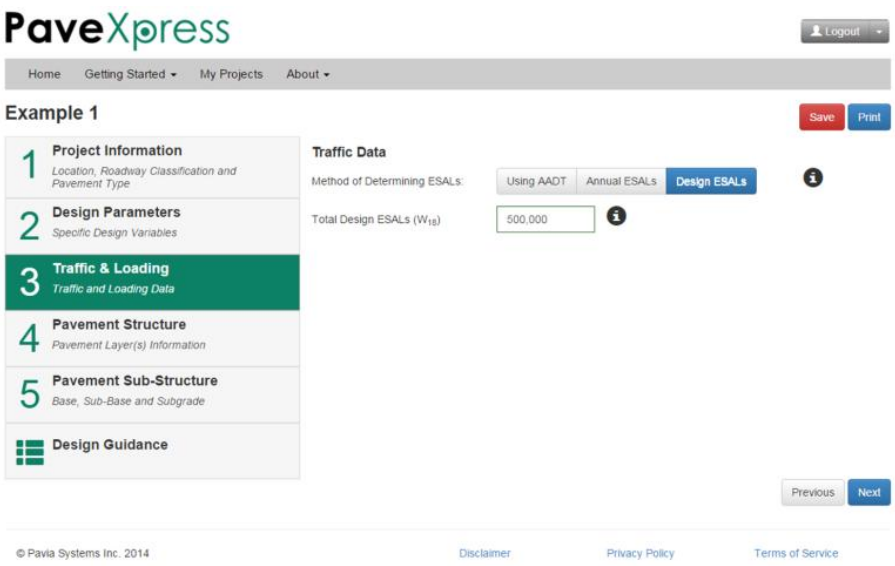
TABLE 4-3. AASHTO RECOMMENDED RELIABILITY LEVELS.

Functional Classification	Recommended Reliability Level	
	Urban	Rural
Interstates/Other Freeways	85 – 99.9	80 – 99.9
Principal Arterials	80 – 99.9	75 – 95
Collectors	80 – 95	75 – 95
Local	50 – 80	50 – 80

Traffic and loading calculations are done on the third input screen (Figure 4-14). This screen allows for the calculation of ESALs over the design life of the pavement. This may be done in three different ways by clicking one of the three tabs: 1) Using the current annual average daily traffic (AADT) (one-direction count), 2) Entering an estimate of the current annual ESALs, and 3) Inputting the design ESALs for the full design period. The program

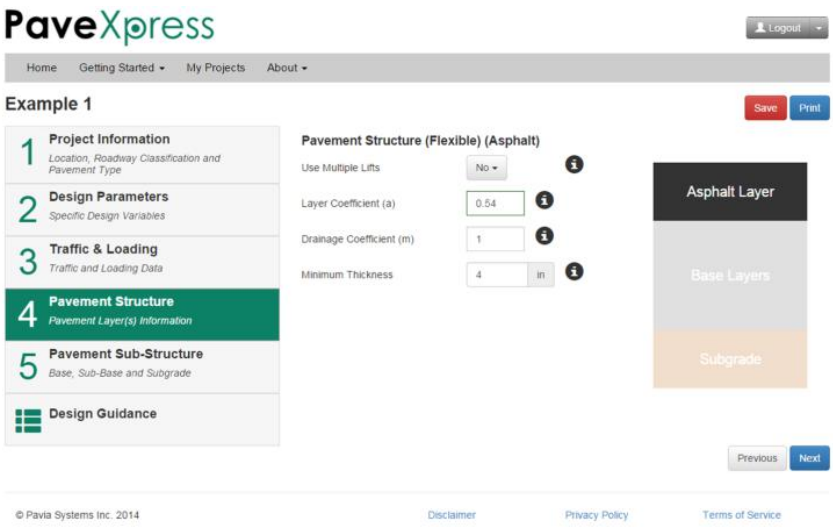
provides step-by-step instructions for estimating ESALs from AADT or from the current annual ESALs. However, it should be noted that the growth rate is a compounding process, and small changes can make a substantial change in the design ESALs. For instance, a 4% annual growth rate is essentially the same as doubling the traffic every 10 years. For this example, we will assume a 20-year design ESAL level of 500,000.

Information concerning the structure of the asphalt layers is entered on the Pavement Structure screen (Figure 4-15). Here you can insert information for up to three separate asphalt mixture types to be used in the upper portion of the pavement. In this case we will use only one layer with a layer coefficient (a_1) of 0.54. The default value of 0.44 is what many DOTs have been using since the early 1960s. The 0.54 structural coefficient is an updated value recently recommended by NCAT based on results from their test track. A minimum asphalt thickness of 4 inches is used in this example. A thickness of less than 4 inches should only be used where no heavy traffic is expected, including bus and garbage trucks due to the potential for fatigue cracking.



SOURCE: PAVIA SYSTEMS, 2014

FIGURE 4-14. PAVEXPRESS TRAFFIC AND LOADING SCREEN.

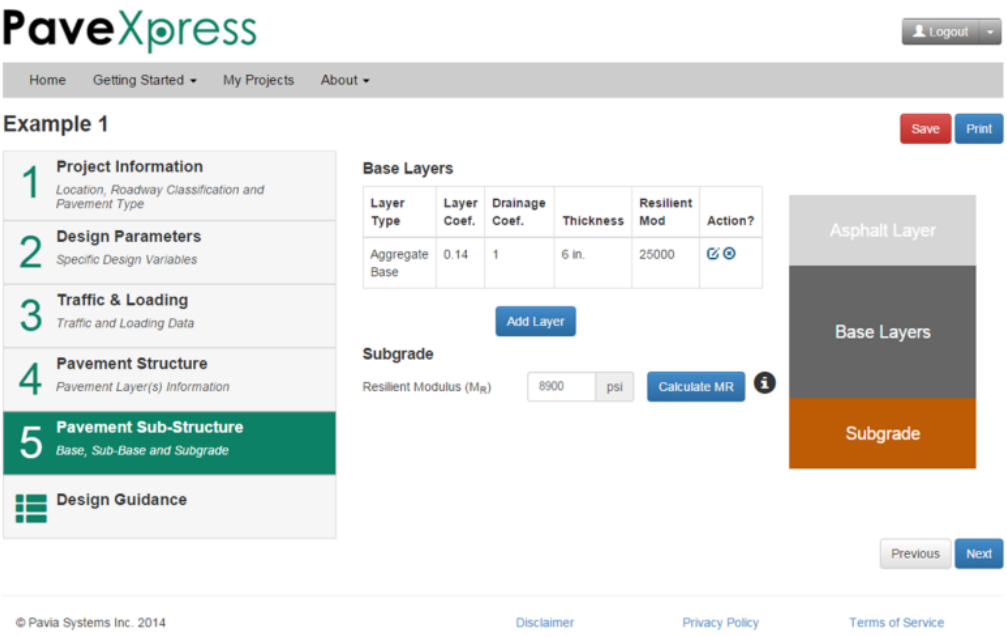


SOURCE: PAVIA SYSTEMS, 2014

FIGURE 4-15. ASPHALT LAYER STRUCTURAL INFORMATION SCREEN.

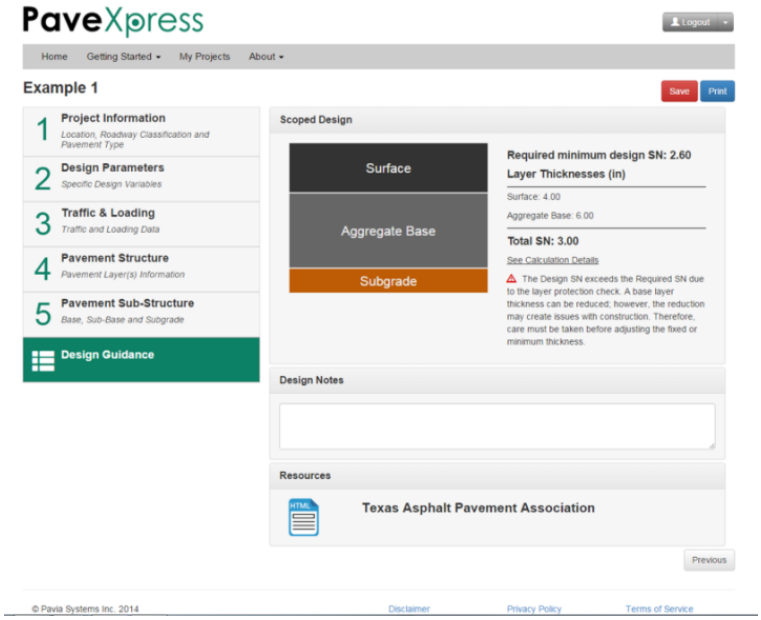
The Pavement Substructure screen (Figure 4-16) is used to input the information concerning the soils and any unbound base (flex base) materials used in the pavement section. In this example, a flex base six inches thick will be used with a modulus of 25,000 psi that is typical of many granular base materials. The value of six inches was fixed in the design as thinner base courses can be problematic in terms of placement and compaction, especially on roadways. This information is entered when the user clicks on the “Add Layer” button. The subgrade modulus of 8900 psi is representative of a relatively weak soil as might be found in South Texas (CBR ≈ 7). The modulus or the CBR may be input after the “Calculate MR” button is clicked.

The final output of the program is shown in Figure 4-17. In the case of this example, the minimum asphalt depth of 4 inches and minimum flex base thickness of 6 inches provides for a Structural Number of 3.00 which exceeds the required Structural Number of 2.60. Using a thinner pavement on a weak subgrade could lead to problems in terms of supporting loads, especially during wet periods. The slight overdesign of the pavement should provide a readily constructed pavement that will withstand the loads on this county road. The final cross-section of the pavement is shown in Figure 4-18.



SOURCE: PAVIA SYSTEMS, 2014

FIGURE 4-16. BASE AND SUBGRADE INFORMATION SCREEN.



SOURCE: PAVIA SYSTEMS, 2014

FIGURE 4-17. DESIGN GUIDANCE SCREEN FOR PAVEXPRESS.

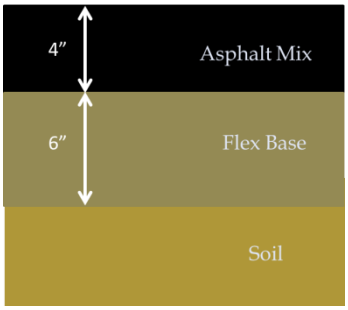


FIGURE 4-18. FINAL CROSS SECTION DESIGN FOR PAVEXPRESS EXAMPLE.

Pavement Thickness Design Example (PerRoadXPress)

PerRoadXPress is now incorporated into the PAVExpress program. As discussed earlier, a Perpetual Pavement is a long-life asphalt pavement designed and constructed to provide a pavement thickness such that any distress is confined to the surface. This ensures that deep structural problems such as bottom-up fatigue cracking or rutting in the base course or subgrade, both of which could trigger very expensive rehabilitation or reconstruction activities, do not occur. So, while the resulting pavement structure may be thicker than a normal design, the anticipated performance of the pavement should be much better.

Special Considerations for Parking Lots

Parking lots may be designed structurally using either PAVExpress or PerRoadXPress. However, they have features and considerations that need attention, especially in terms of traffic, drainage, and layout.

For instance, the type of traffic needs to be considered in terms of the type of facility being served, types of service vehicles, paths for delivery trucks, and the types of transient traffic. Also, if the facility is being constructed in phases or is subject to frequent modifications it may be important to consider future construction traffic. Truck terminals and warehouses need to be designed for the average number of trucks entering and exiting the facility each day. Loading areas should be designed for the total of deliveries and loadouts. If separate roadways are provided in and out of the facility, then design the structure for the number of one-way trucks only. For big stores, it is desirable to keep the truck traffic out of the parking areas for customers. A designated delivery route will facilitate this along with curbs that direct truck flow around the parking area. Delivery routes need to be designed for fully loaded trucks as they often do not leave empty. Ramp areas are subject to slow-moving loads, and it may be warranted to use a polymer modified binder for the pavement. The parking area for passenger vehicles can be designed for light traffic unless there is transient heavy traffic using the parking area at night (recreational vehicles, commercial trucks, etc.).

Drainage is also important for parking lots to avoid the presence of “birdbaths” which can result in annoying puddles, icy areas, or damage to the pavement structure. It is best to design the drainage sloping away from structures and into an outlet which feeds into either an existing storm sewer or a detention basin, depending upon local building codes. An alternative to traditional approaches to drainage design is the use of porous asphalt pavement which allows water to drain through the pavement structure and into an open-graded granular base with about 40% voids where it can then percolate into the soil. For more information concerning the design of porous asphalt pavements, consult the National Asphalt Pavement Association’s guidelines in publication IS-131E (Hansen, 2008).

Summary

The design of asphalt pavements requires consideration of the traffic loads, materials, soils, and climate. As traffic loads increase, the damage they cause to pavements increases exponentially. Weak soils may be especially problematic from bearing capacity and volume change considerations. In Texas, it may be of benefit to stabilize expansive clays with lime prior to pavement construction. The constructability of a pavement must be ensured by choosing the proper type of asphalt mixture for the application in a pavement structure. The compatibility of mixtures usually dictates that lift thickness is 3 to 5 times the nominal maximum aggregate size. There are several empirical and mechanistic methods for designing pavements. PAVExpress is a method based upon the 1993 AASHTO design approach that can be done online with little effort. Perpetual pavements may be designed using PerRoadXPress, allowing the user to complete the design process on one screen.

Chapter 5 Mix Type Selection

Introduction

Recommendations for mix type selection can be found in the TxDOT Material Selection Guide at https://ftp.txdot.gov/pub/txdot/mtd/crossroads/material-selection-guide.pdf. Mix type selection is as important to performance as mix design and structural design. Choosing the right combination of mixes for the pavement structure, climate, traffic, and economy can ensure excellent roadway performance. This guide presents the methodology and mix types for use in Texas for various conditions and applications.

Factors in Mix Type Selection

Traffic

Traffic conditions come down to three primary concerns:

- Volume of traffic (numbers of vehicles).
- Weight of vehicles (passenger versus heavy trucks).
- Speed of traffic (high versus moderate or low speed).

The volume of traffic is important for considering user costs and pavement economy. The City of Lenexa, Kansas, guidelines (Lenexa, undated) for vehicles per day and NAPA guidelines (Garcia and Hansen, 2001) in terms of equivalent single axle loads (ESAL) (Chapter 4) over the pavement life for designating traffic volumes are presented in Table 5-1.

TABLE 5-1. GUIDELINES FOR TRAFFIC LEVELS.

Traffic Level	Vehicles/Day	ESAL
Low	< 10,000	< 300,000
Moderate	10,000 – 25,000	300,000 – 10,000,000
High	> 25,000	> 10,000,000

If the pavement is located on a high-volume road such as a freeway or urban state highway, the appearance of work zones becomes an inconvenience to road users as congestion builds. Selecting a pavement surface such as a stone matrix asphalt (SMA) that is expected to have a relatively long life will help ensure that work zones will be minimized over the life of the pavement. However, an SMA that is likely to have a long life will also be

considerably more expensive than economical mixtures such as dense-graded asphalt (DGA) and Superpave Mixes (SP). DGA mixtures will suffice for lower volume pavements such as most commercial, private, or local roads since the first cost is lower. Superpave mixes are a step up from Dense Graded mixes in terms of strength and performance.

The weight of vehicles is important in several scenarios that are not necessarily considered high volume. For instance, oil field traffic may be most of the traffic on a low-volume county or farm-to-market road, but the loads imposed on the pavement may dictate that a thicker than normal pavement structure with a stronger pavement surface such as SP or SMA be used. This may also be true for industrial parks and commercial freight transfer facilities where heavy loads congregate. In most applications where the number of passenger vehicles is far greater than the heavy trucks, less expensive dense-graded mixtures will suffice for all the pavement layers.

Crashes in wet weather are more likely on high-speed freeways and highways, and it is important to provide as much visibility and safety as possible. For these roads, the use of a porous friction course (PFC) or thin bonded friction course (TBFC) will increase the wet-weather skid resistance and reduce the amount of splash or spray that inhibits driver visibility. However, if these mixtures are used on roads with speeds lower than 45 mph, they quickly can become clogged with dust and dirt, losing their effectiveness. The designer should be cautioned when using Porous Friction Courses in intersections, crossovers, and turn lanes as the shearing action due to steering/turning can cause raveling in the mix. PFC is more suited to high-speed, full-width lanes.

Climate

Climate in mix type selection becomes important for selecting materials which will perform well for the temperature regime as well as for skid resistance and splash and spray. A pavement in a hot climate subjected to a high number of heavy loads would be well served by a rut resistant SMA. As shown in the example above, a road in an area with a high number of rain events and high-speed traffic may be a good candidate for PFC or TBFC. Roads where the surface has become polished over time could benefit from the application of a thin overlay mix (TOM) to improve skid resistance in wet weather.

Pavement Structure

Each layer of the asphalt pavement structure (base, intermediate, and surface) requires a different consideration for mix type selection. For instance, the base layer is best served by the application of a DGA mixture for both economy and durability. Referring to Chapter 3, the DGA mixtures which would work best would be either a Type B or Type C. Due to the

dense gradation these mixtures will be strong enough to provide a cost-effective foundation layer and provide a good platform for the compaction of the overlying layers. For an intermediate layer for low to moderate traffic levels, a DGA or SP mix of either Type C or Type D would be a good choice, and for high volume, high truck traffic roads a SMA would provide some insurance of good performance. Surface mixtures would depend upon the traffic volume, traffic weight, traffic speed and weather as discussed above.

If the road under consideration needs a new surfacing, then the condition of the roadway in addition to the other issues already presented need to be considered. If a road needs a pavement preservation treatment to extend its life, improve skid resistance, and treat minor pavement distresses then a TOM mix should be selected. If a structural overlay is needed, then a DGA, SP, or SMA should be considered based upon the traffic volume and loadings.

Construction

Pavement performance is greatly affected by the nominal maximum aggregate size (NMAS) (Chapter 3) and the thickness of the lift being paved and compacted. If the lift is too thin for the NMAS it becomes very difficult to achieve the desired density and early failure of the pavement becomes more probable. For DGA and SMA mixtures, the suggested guidelines are for the paving lift to be a minimum of 3 to 4 times the NMAS of the mixture (Tran et al., 2016). If the aggregate gradation is on the lower side gradation band, then a minimum of 4 times the NMAS is recommended. If the gradation is on the upper side of the band, then a minimum of 3 times the NMAS should be used. In general, coarse gradations should be used with caution as they tend to be somewhat more permeable than fine gradations and more prone to aggregate segregation during production and construction. Permeability can lead to moisture intrusion and premature cracking while segregation can lead to non-uniformity and premature rutting or cracking. This guideline does not apply to PFC, TOM or TBPFC mixtures. For DGA mixtures the guidelines for lift thickness are given in Table 5-2.

Table 5-2. Lift Thickness for TxDOT 341 Mixtures.

Compacted Lift Thickness and Required Core Height			
Mixture Type	Compacted Lift Thickness Guidelines		Min Untrimmed Core Height Eligible for Testing (in.)
	Min (in.)	Max (in.)	
DG-B	2.50	5.00	1.75
DG-C	2.00	4.00	1.50
DG-D	1.50	3.00	1.25
DG-F	1.25	2.50	1.25

Types of Mixes Used in Texas

Dense-Graded Asphalt (DGA)

The specification for DGA mixtures in Texas may be found in Item 341 (TxDOT 2024) Dense gradations were covered in Chapter 3, and it means that the gradation changes gradually from coarse to fine aggregate. Dense-graded mixtures Figure (5-1) are often referred to as the workhorse mixture in the asphalt industry and may be used in a variety of applications ranging from high-volume to low-volume roadways with the appropriate binder grade and aggregate properties. They have been used in road and airfield construction since the 1910s. They are commonly used in all pavement layers whether base, intermediate, or surface layers. The advantage of DGA mixtures is that they can provide a sound pavement structure at a low cost. They are often the best surface and intermediate layer choice for commercial applications, city streets, county roads, and state highways subjected to low or moderate truck traffic. They are appropriate for a base layer for any traffic level. A DGA mixture is designed using the Superpave Gyratory mix design method, unless the Texas Gyratory mix design method is shown on the plans. (TxDOT is transitioning away from the Texas Gyratory to the Superpave Gyratory in most applications.) Usually, a mix for a high-volume road will have a polymer modified binder in the surface and, possibly, in the intermediate course. Any reputable contractor will be familiar with the production and placement of dense-graded mixtures. SS 3076 is a quality control/quality acceptance (QC/QA) specification requiring both contractor testing and TxDOT testing for acceptance, but some uses (low production or low-tonnage projects [less than 5000 tons] can allow the engineer to waive production and placement testing by the contractor in favor of all TxDOT testing with pay factors set to 1.00 (no penalties or bonuses).

Superpave Mixes

Mixes designed using the Superpave system are designated as Item 344 (TxDOT 2024) and were discussed exclusively in Chapter 3, Asphalt Mixture Design. The Superpave system provides a different aggregate gradation, volumetric requirements, and method of compaction than the original 341 Dense Graded Asphalt (but has since changed). The aggregate gradation bands are larger for Item 344, allowing the mix designer greater latitude to select an economical combination of aggregates that will satisfy performance requirements. The VMA requirements are one percent higher for Superpave mixtures for various type mixes than they are for an item 341, which means that more asphalt will be required for the same gradation. The Superpave Gyratory Compactor is also not as aggressive as the Texas Gyratory Compactor which means that it will be less likely to fracture aggregate and allow for a higher asphalt content in the finished mix design. Superpave mixes have all the advantages of Dense-Graded mixes with added benefits for greater durability.



FIGURE 5-1. DENSE-GRADED ASPHALT.

Permeable Friction Course (PFC)

As the name suggests a permeable friction course (Figure 5-2) is a mixture for use in surface courses only, and the specification for PFC is found in TxDOT Item 342 (TxDOT 2024). Their primary purpose is to provide enhanced safety in wet weather by significantly reducing splash and spray and increasing skid resistance. These mixtures are open-graded meaning that they have essentially one-sized aggregate to create voids in the mixture which will allow water to drain through the surface during rainstorms. Because of the aggregate interlock, they are very resistant to rutting. They are recommended for roads with a posted speed limit of 45 mph or higher. The PFC mixture is normally composed of open-graded aggregate, a highly modified asphalt binder (PG76-22), and fibers to prevent the asphalt from draining down through the mixture during construction. An asphalt-rubber binder is sometimes used when the PFC is placed over a jointed or cracked concrete pavement or a highly cracked asphalt pavement to delay reflection cracking. Because they are normally placed in a thin layer of less than one inch, PFCs are a safety feature and their presence in an asphalt pavement structure is not considered as a part of the total

pavement thickness. Research is currently being done at TTI to assess the structural contribution of PFC. An additional advantage of this mix is that research on the evaluation of stormwater runoff from roadways has shown that the water quality is better when a PFC is used (Barrett, 2008). PFCs have a relatively high initial cost per ton, but they are used in a thin layer which minimizes the impact on the overall cost.



FIGURE 5-2. PERMEABLE FRICTION COURSE.

Stone Matrix Asphalt (SMA)

SMA mixtures (Figure 5-3) are used as surface or intermediate layers in asphalt pavement structures subject to high traffic volumes and high truck loadings. The specification for these mixtures may be found in TxDOT ITEM 346 (TxDOT 2024). They are composed of a gap-graded aggregate-on-aggregate structure that creates room for a rich, strong mastic composed of a polymer modified asphalt (normally PG 76-22), fibers, and mineral fillers. There are also asphalt rubber versions. The minimum asphalt content for this mixture is 6 percent (7% for asphalt rubber) which helps to minimize the permeability of the mix to air and water which in turn reduces the aging of the mix. The combination of a strong aggregate structure and the mastic provides a mixture that is both crack resistant and rut resistant. This high level of performance is important to busy roadways as it will lower the frequency of maintenance and rehabilitation which will minimize road user delays. The surface texture of SMA provides good traction in wet weather. While SMA is usually used as an intermediate layer under a PFC on many high-speed roadways, it can also be used as a high-quality surface on roads with heavy truck loadings such as arterials in industrial areas. SMA mixtures require a lot of attention to detail and high-quality ingredients making them relatively expensive in terms of first cost but reduced requirements for maintenance and rehabilitation may mean a reduce life cycle cost.



FIGURE 5-3. STONE MATRIX ASPHALT.

Thin Overlay Mix (TOM)

TOMs (Figure 5-4) are excellent pavement preservation treatments that are between ½ inch and 1 ¼ inches thick which are to be used in extending pavement life, and they are specified according to TxDOT Item 347 (TxDOT 2024). Pavement preservation treatments should be used on existing pavements before appreciable distresses have accumulated, especially fatigue cracking and rutting originating deep in the pavement. While TOMs are crack resistant, they will neither fix the underlying pavement layers nor substantially increase the load carrying capacity of the pavement. In those cases, rehabilitation will be needed. TOMs can be used on all types of roads from high volume to low volume to improve ride quality, reduce tire-pavement noise, and dramatically improve skid resistance. Depending upon the aggregate size and gradation, TOMs can have an asphalt content of up to 7 percent with a polymer modified binder (PG 76-22). The aggregate should come from a quarry known to produce hard, low polish value rock. TOMs must meet minimum requirements for the overlay tester (cracking resistance) and Hamburg wheel tracking test (rutting resistance).



FIGURE 5-4. THIN OVERLAY MIX.

Thin Bonded Friction Course (TBFC)

A TBFC mixture (Figure 5-5) is a pavement preservation treatment used to improve the skid resistance and ride quality of high-speed roads, and the specification may be found in TxDOT Item 348 (TxDOT 2024). This surface layer is generally paved at ¾ inch to 1 ½ inches thick and includes the application of a polymer modified asphalt emulsion membrane ahead of the placement of the TBPFC. The placement is normally accomplished with a spray paver that applies the asphalt emulsion membrane and deposits the mix in one step. This avoids having construction traffic run over the tack coat prior to placing the TBFC. The TBFC is preferred to a PFC as an overlay on jointed or cracked concrete pavement or on an existing asphalt pavement that has more than a moderate amount of cracking. A TBFC mixture has a higher initial cost than other surface mixtures, and the spray paver necessary to place may not be available.



FIGURE 5-5. THIN BONDED FRICTION COURSE.

Example of Mix Type Selection in Pavement Design

For this example, we will use the results of the PerRoadXPress example from Chapter 4 which is repeated in Figure 5-6. The asphalt portion of the pavement cross section is 6 inches thick. Since the road is low volume (1000 vehicles/day) all the lifts will be DGA. Since it is desirable to have an impermeable surface, a Type C mix (minimum lift thickness 2.0 inches) could be specified at 2.0 inches thick, and a Type B mix (minimum lift thickness 3.0 inches) could be specified at 4.0 inches thick. Alternatively, two 3.0-inch lifts of Type C mix could be specified to reduce possible costs associated with changing mix types during production.

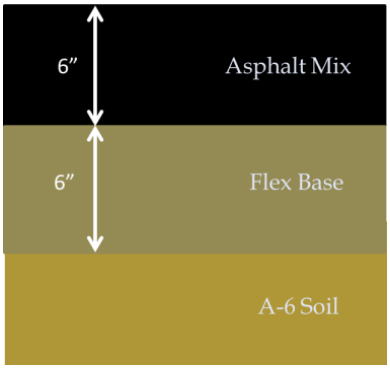


FIGURE 5-6. PAVEMENT CROSS SECTION FROM PERROADXPRESS EXAMPLE IN CHAPTER 4.

Table 3.3
Summary of Mixture Types, Sizes, and Typical Use

HMA Mixture Type		Nominal Maximum Aggregate Size	Minimum Lift Thickness (inches)	Maximum Lift Thickness (inches)	Typical Location of Pavement Layer
Dense-Graded (Item 341)	TY-B	1"	2-1/2"	5"	Base/Intermediate
	TY-C	3/4"	2"	4"	Intermediate/Surface
	TY-D	1/2"	1-1/2"	3"	Surface/Level-Up
	TY-F	3/8"	1-1/4"	2-1/2"	Surface/Level-Up
PFC (Item 342)	PFC-F PG 76	1/2"	3/4"	1-1/2"	Surface
	PFC-C PG 76	3/4"	1"	2"	Surface
Superpave Mixtures (Item 344)	SP-B	3/4"	2-1/2"	4"	Base/Intermediate
	SP-C	1/2"	2"	3"	Intermediate/Surface
	SP-D	3/8"	1-1/4"	2-1/2"	Surface/Level-Up
SMA (Item 346)	SMA-C	3/4"	2-1/4"	4"	Surface
	SMA-D	1/2"	1-1/2"	3"	Surface
	SMA-F	3/8"	1-1/4"	2"	Surface
	SMAR-F	3/8"	1-1/2"	3"	Surface
CAM (SS 3000)	CAM	3/8"	1"	2"	Base/Intermediate
Thin Overlay Mixtures (Item 347)	TOM-F TOM-C	1/2" 1/2"	1/2" 3/4"	1" 1-1/4"	Surface Surface
Thin Bonded Friction Courses (Item 348)	TBPFC-F PG 76	1/2"	3/4"	1-1/2"	Surface
	TBPFC-C PG 76	3/4"	1"	2"	Surface
	TBWC TY-A	3/8"	1/2"	3/4"	Surface
	TBWC TY-B	1/2"	5/8"	1"	Surface
	TBWC TY-C	3/4"	3/4"	1-1/4"	Surface

SOURCE: HTTPS://FTP.TXDOT.GOV/PUB/TXDOT/MTD/CROSSROADS/MATERIAL-SELECTION-GUIDE.PDF

FIGURE 5-7 FROM TXDOT MATERIALS SELECTION GUIDE.

Figure 5-7 above is taken from TxDOT's Materials Selection Guide and lists typical lift thicknesses and applications by mix types.

Summary

Mix type selection is an integral part of pavement design, and it requires the designer to match traffic volume, loads, and safety to the asphalt mixture that will offer an economical and functional base, intermediate, and surface course within the pavement structure. For most private, commercial, and local roads, dense-graded mixtures will provide the best solution. High-volume, high-speed roadways may be best served by a porous friction course or thin bonded porous friction course. SMAs are most useful where a significant amount of heavy commercial truck traffic is expected. Thin overlay mixes are a good choice for pavement preservation applications to extend a pavement life provided that the distress in the existing pavement is minimal.

Chapter 6 Asphalt Mixture Specifications

Introduction

Procedures for acceptance of paving materials and mixtures are a part of the construction contract document which is an agreement between the owner or buyer (public agency or private party) and the seller (contractor or materials supplier). These procedures are part of the legal documents that describe the obligations of the buyer and seller for the performance of the work described. Material specifications are part of these documents and define the materials and mixtures; construction operation; sampling, testing, inspection procedures, and methods for acceptance and payment (TRB, 2013).

Specifications describe the work to be performed and typically consist of standard specifications, supplemental specifications and other special provisions. Uniform standard specifications are not used in the United States by all public agencies. Specifications and test methods published by the American Society for Testing and Materials (ASTM International), American Association of State Highway and Transportation Officials (AASHTO) and various federal agencies including the Federal Highway Administration (FHWA) and Federal Aviation Administration (FAA) are most frequently referenced. ASTM standards are developed by users and producers (buyers and sellers) as well as general interest (research) personnel. AASHTO standards are developed by representatives from state Departments of Transportation (DOTs). Representatives from the various federal agencies including the Federal Highway Administration and Federal Aviation Administration develop their own specifications.

Every State Department of Transportation (DOT) has standard specifications which they have developed. TxDOT's specifications can be found here. https://www.txdot.gov/business/resources/txdot-specifications.html Some states routinely obtain input from materials suppliers and contractors to develop these specifications. For most states, the typical practices used for the construction of asphalt mixtures are in the state DOT specifications. As metropolitan areas grow in the United States, additional sets of specifications have been developed by various councils of government, counties, and cities. These specifications attempt to address the special needs for materials and construction in particular areas.

Private construction projects requirements for asphalt mixtures often follow state DOT specifications or regional specifications. Consulting engineers also develop specifications for use on individual local government and private projects.

In each market area, multiple specifications for asphalt paving mixture may be found. In these areas, federal, state, regional and consultant developed specifications are in use for essentially the same asphalt paving mixtures. The use of multiple specifications in a particular area can add costs to a project as the materials suppliers and contractors must have the capability to supply a wide range of products for the same purposes.

This chapter defines the purpose, types and key elements of specifications for asphalt paving mixtures, Specifications used by TxDOT for asphalt mixtures are summarized. Steps to develop specifications are briefly described as well as a specification developed by the Texas Asphalt Pavement Association for small and mid-size paving projects based upon the TxDOT specifications.

Purpose of Specifications

Specifications for asphalt mixtures serve several purposes including the following:

1. Defining the quality of materials and construction needed to achieve the project objectives.
2. Defining the method of acceptance for the materials and construction operations.
3. Serving as a guide to the contractor to bid and build the project.
4. Forming a part of the contract between the buyer and seller.

Several types of specifications have been used in the United States as briefly summarized below.

Types of Specifications

Five types of specifications are in part used for asphalt mixtures. These types include proprietary products, materials and methods, result, quality assurance and performance. Statistics are part of many of these types of specifications and warranties are sometime utilized as part of the specifications. Each of these types of specifications is briefly described below.

Proprietary Product

The proprietary product specification names a given brand or manufacturer or equal product and relies on the past performance and integrity of the producer to supply the desired product. Prolonged use of this type of specification for asphalt mixtures is difficult as most users and governmental agencies require material specifications that will provide for competitive bidding.

Materials and Methods

This type of specification is also referred to as method, materials and workmanship, recipe, descriptive, prescriptive or procedural. The specification requires the contractor to use specified materials in defined proportions and specific types of equipment and methods to produce and place the asphalt mixture. The specifying agency or owner directs each step of the process and as a result is largely responsible for the performance of the product.

End-Result

The specifying agency or owner establishes minimum requirements for the in-place material. The contractor or seller assumes the responsibility of supplying the asphalt materials that meet the end-result specification. Some end-result specifications do not specify material requirements and construction requirements. Thus, the contractor has a great deal of flexibility in the selection of materials and construction operations.

The agency's responsibility with this type of specification is to accept or reject the final product or to apply a pay adjustment commensurate with the degree of compliance with the specification.

Quality Assurance

This type of specification requires the contractor to perform **quality control** testing, and the agency performs acceptance activities (**quality assurance**) during production and placement of the asphalt mixture. The contractor may also perform some level of **process control** testing. Acceptance by the agency is usually based on statistical sampling and performance of tests for key quality characteristics such as asphalt binder content, aggregate gradation, in-place air voids, etc. Random sampling is typically performed, and contractor quality control test results may or may not be used for acceptance by the agency or owner.

Three distinct and separate sampling and testing activities are performed with quality assurance types of specification. Quality control testing by the contractor, quality assurance testing by the owner or agency and independent assurance testing by a third party. Many states utilize their central or state testing laboratory for independent assurance testing while others use a third-party laboratory. Independent assurance is an unbiased evaluation of all sampling and testing (or inspection) procedures used in the quality assurance program. Independent assurance provides an independent verification of the reliability of the acceptance data obtained by the agency and the data obtained by

the contractor. The results from independent assurance testing or inspection are not used as a basis of acceptance.

Performance

Performance specifications describe how the material should perform over time. The performance of an asphalt mixture is typically described in terms of changes in the physical condition of the surface of a pavement with respect to traffic and environmental loads. Specifications containing warranty/guarantee clauses are a form of performance specification. Warranty/guarantee types of specifications are typically defined as one of two types: materials and workmanship or performance. Other than warranty/guarantee types of specification used in a few states, performance specifications have not been used extensively at the national, state, and local level. Advances in technology will likely be needed to develop usable performance specifications.

Two types of performance specifications have been conceptually defined: performance-based and performance-related:

- **Performance-based** specifications describe the desired levels of fundamental engineering properties (resilient modulus, fatigue, permanent deformation, aging, etc.) that are predictors of performance (rutting, fatigue cracking, transverse cracking, etc.) and appear in primary prediction relationships or models that predict stress, strain, deformation, etc.
- **Performance-related** specifications describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance. These characteristics may include asphalt binder content, aggregate gradation, in-place air voids, etc. that are routinely determined during quality control and acceptance testing at the time of construction. Performance related specifications describe the desired levels of quality characteristics as well as the relationships between these parameters and pavement performance. This provides a rational basis for acceptance/pay adjustment decisions.

Statistics

Statistics play a very important role in establishing specifications for asphalt mixtures. Those responsible for developing specifications should consult with a statistician during the development of specifications to ensure that:

- Sound statistical principles are used to develop specifications.
- Statistical principles used in specifications are simple, straight forward and easily understood.

- Realistic acceptable and rejectable quality targets and limits for quality attributes based on past construction experience are developed.
- Buyer (agency) and seller (contractor) risks are defined.
- Sample size or number is based on a balance of buyer and seller risks as well as testing workload.
- Reasonable lot sizes are used.
- A reasonable number of samples are obtained for each lot.
- Random sampling is used.
- Location and method of sampling and testing is well defined.
- Within lab and between lab precision and bias is defined for test methods.
- The number of samples are based on precision and bias associated with test methods.
- Action taken for noncompliance is defined.
- Dispute resolution or referee testing is based on sound statistical principles.

AASHTO Recommended Practice R9, " Acceptance sampling Plans for Highway Construction, " and other publications provide a detailed discussion of the use of statistics in specification development.

Those individuals responsible for enforcing and working with most forms of specifications and, specifically with quality assurance type specifications, should have a fundamental working knowledge of statistics including the following:

- An understanding and ability to calculate common statistical terms of mean, standard deviation, variance, coefficient of variations and standard normal and student “t” distributions for a group of test results.
- Precision and bias statements for test methods.
- Typical materials testing variability (sampling, testing and production/construction) for quality attributes commonly measured by quality control and quality assurance tests.
- Quality Index (QI) including percent within limits (PWL) and percent defective (PD).
- “F” and “t” test to compare sample means and variances between two data sets.

Certification and Accreditation

Many asphalt paving specifications require the use of certified technicians and accredited laboratories. Certified technicians are required to sample and test materials, while the laboratories in which the testing is performed are accredited.

Certification

A technician is typically certified by some agency or organization to ensure proficiency in performing certain duties associated with sampling and testing. These certification bodies may or may not include training in their programs. Certification bodies typically include

written examinations and requirements for the individual to demonstrate competency in individual test methods. Certification programs may or may not include regular proficiency testing in the certified person's laboratory.

National and state organizations are available to certify individuals. Several state DOTs use state asphalt paving association facilities and operational capabilities to manage their technician certification programs. The content of these programs is typically jointly established by the DOT and the material suppliers and contractors that are members of the state association. TXAPA performs this function for TxDOT.

Some organizations do not certify a technician but qualify a technician to sample and perform tests associated with specifications. A certified technician is qualified. A qualified technician may or may not be certified.

Accreditation

Laboratories are recognized by a formal accrediting body as meeting quality system requirements including demonstrated competence to perform standard test procedures. These requirements include calibration and condition of test equipment, regular training and/or certification of technicians and the use of procedures to ensure that a quality system is in place and operating. The AASHTO Accreditation Program (AAP) administered by the AASHTO resource is used in Texas for the accreditation of non-TxDOT laboratories. TxDOT's central or state laboratory is AASHTO Accredited, and the district and project laboratories are accredited by a group responsible for these activities within TxDOT. A proficiency testing program is also administered by TxDOT for their laboratories.

Contracting Methods

Specifications are common to all forms of contracting. Specifications will often contain different elements when used in various types of contracting methods. Five different contracting methods are currently used in the United States (TRB, 2013), and there are hybrids of these methods.

Design-Bid-Build (DBB)

This is a project delivery system in which the **design** is completed either by in-house professional engineering staff or a design consultant before the construction contract is advertised. The contractor then bids on the project and, if selected, builds it. This is the traditional form of contracting in Texas and the United States.

Design-Build (DB)

In this form of project delivery both the design and construction (build) of the project are performed simultaneously and awarded to a single entity. Design-build forms of contracts have been used on a limited basis in Texas.

Design-Build-Finance-Operate-Maintain (DBFOM)

This is a project delivery system in which the design, construction, financing, operations and maintenance of the project are awarded to a single entity. This is a type of public-private partnership (P3) concession.

Construction Manager at Risk (CMR)

This form of contracting is also called **construction manager-general contractor (CMGC)** and entails a commitment by the construction manager to deliver a project within a guaranteed maximum price (GMP). The construction manager acts as a consultant to the owner in the development and design phases and as the equivalent of a general contractor during the construction phase.

Public-Private Partnership (P3)

A public-private partnership is a government or private business venture funded and operated through a partnership of government and one or more private-sector companies. A P3 concession is an alternative way for a public agency to deliver a public-purpose project. The P3 concession has three primary elements: a concession goal, a compensation structure, and a term or length of time. The public agency establishes each of these elements.

Acceptance of Materials

The specifications identified above (proprietary product, materials and method, result, quality assurance, and performance) have all been used to specify asphalt mixtures. These specifications are often included in a more comprehensive plan for materials acceptance. With reasonable risks, these material acceptance plans ensure that the materials meet the specifications. Guidelines for acceptance plans typically recognize two broad categories of materials: manufactured products and project-produced materials. Manufactured products are produced under controlled conditions and generally have little potential variation as they are incorporated into the project. These materials include asphalt cement, cutback asphalts, emulsified asphalt, and chemical modifiers of asphalt binders. Properties of the project-produced materials are soils, aggregates, and asphalt mixtures.

Manufactured Materials

Acceptance plans for manufactured materials typically consist of the following:

- Development of an approved product list.
- Testing of material lots by manufacturers to ensure control of the operation.
- Receiving a materials certification from the manufacturer.
- Visual inspection of the material at the job site.
- Performance of verification/check tests as required.
- Provisions for removal of defective materials.
- Testing plan for materials not on approved product list.

Project Produced Materials

Two types of specifications are typically used for acceptance of project produced materials: **pass/fail** and **statistically based specifications**.

In the **pass/fail** acceptance type of specifications, a specific limit is established and the material either passes or fails. AASHTO R9 identifies this as "acceptance by attribute." This type of specification does not necessarily recognize the inherent variability in sampling, testing and materials.

Statistically based specifications recognize the risks in sampling, testing and materials and the probability of failing test results. AASHTO R9 identifies this type of specification as "acceptance by variables."

Contractor Process/Quality Control Plan

Process control sampling and testing are performed to provide information for the contractor to control his or her operation. In the past, most, if not all, of the process control sampling was performed by the public agency. With recent reductions in public agency staffing, increases in production capabilities and the need for more frequent control tests, many public agencies now require a formal quality control testing program developed and administered by the contractor and approved by the public agency. The quality control plan is a formal document submitted by the contractor and followed during the production of the material. This is typically referred to as quality control sampling and testing. Although these specified tests are used to control the contractor's operations additional tests also may be used by the contractor to control his or her process. These are referred to as process control tests and are not required to be reported as part of the more formal quality control plan. The non-specified process control tests can be beneficial to control the various production operations.

Key elements of the contractor's quality control plan include the following:

- Calibration of plant and construction equipment.
- Certification of scales.
- Designation of a person responsible for process/quality control.
- Demonstration that technicians are certified, and laboratories are accredited.
- Process control sampling and testing including test method, point of sampling, test methods and frequency of tests.
- Process control limits.
- Process control mechanisms including corrective actions.
- Documentation and reporting of process control activities.

Agency Acceptance Sampling and Testing Plan

This sampling and testing program is typically included as part of the specification and defines the methodology which provides assurance that the materials and workmanship used on the project are in reasonably close conformity with the requirements of the plans and specifications. The sampling and testing program typically identifies:

- Properties upon which acceptance is based.
- Acceptance limits including pay adjustment factors.
- Sampling and testing methods.
- Point of sampling or sampling location.
- Frequency of sampling and testing.
- Acceptance criteria.
- Provisions for retesting.
- Provisions for corrective actions.

Acceptance testing is normally performed by the owner or public agency representative.

Basis of Acceptance

As identified previously, a key element of the acceptance sampling and testing plan is the identification of the test parameters/properties or quality attributes upon which acceptance is based. For asphalt mixtures the properties of the asphalt binder, aggregate and asphalt mixture are of importance. It is not unusual for agencies to use both pass/fail or "acceptance" type specifications and statistically based or "acceptance by variables" types of specification to define these requirements. The "pass/fail" type of requirement is often used for asphalt cement and some aggregate properties while statistically based specification is used for aggregate gradation and asphalt mixture properties.

Typical requirements for asphalt binder properties and aggregate characteristics are contained in TxDOT specifications and are discussed in Chapter 3. Typical requirements

for aggregate gradation and asphalt mixture properties are also contained in TxDOT specification. The point or location of sampling these materials is of importance as well as typical variations associated with commonly used acceptance parameters.

Point of Sampling

Asphalt binders are typically sampled at one or more of the following locations:

- Manufacturer's tank.
- Terminal tank.
- Loadout point in manufacturer's terminal (transfer from tank storage to truck transport).
- Transport truck discharges from truck to contractor's storage tank.
- Contractor's storage tank.
- Feed line from contractor's storage tank to hot mix asphalt mixing chamber.

Manufacturer tanks, terminal tanks and loading points from these tanks to truck transports are common locations of sampling for the **asphalt binder manufacturer**. The manufacturers use these samples and their testing programs to certify asphalt binders as well as for process or quality control.

Contractors typically sample from truck transports during discharge from the truck to their storage tanks, from their storage tanks or from the feed line between the storage tank and the hot mix asphalt mixing chamber. Contractors typically do not test these binder samples but hold them in the event of a dispute with the asphalt binder manufacturer and/or agencies.

Agency sampling is typically performed at the feed line between the contractor's storage tank and the hot mix asphalt mixing chamber. These samples are tested for compliance. An alternate method gaining popularity is the use of asphalt binder manufacturer's certificate of compliance based on an approved manufacturer quality management program.

Aggregates are typically sampled at one or more of the following locations:

- Flowing aggregate streams at manufacturer's production facility (bin or belt discharge points or conveyor belt)
- Stockpiles at aggregate manufacturing production facility
- Transport vehicles
- Stockpiles at hot mix asphalt plant
- Collector belt at contractor's continuous hot mix asphalt plant
- Hot bin discharge points at contractor's batch hot mix asphalt plant

- Asphalt mix transport vehicles (after it is coated with asphalt binder)
- Behind the asphalt mix paver (after it is coated with asphalt binder)

Aggregate manufacturers typically sample from flowing aggregate streams, stockpiles and transport vehicles to maintain quality requirements and to provide information for process control. **Asphalt mix suppliers** typically sample from stockpiles at either the aggregate manufacturer's production facility or stockpiles at their plant locations for mixture design purposes. For process control and quality control purposes the aggregates are sampled from collector belts, hot bin discharge points and asphalt mix transport vehicles at the hot mix asphalt plant. Sampling behind the asphalt mix paver is also a common location for sampling for quality control and quality assurance testing. **Agency** sampling is typically performed from haul trucks or from behind the paver.

Asphalt mixtures are typically sampled from haul trucks or from behind the asphalt mix paver. **Asphalt mix producers, contractors and agencies** typically use one of these two sampling locations. Aggregate gradations are determined after the asphalt binder has been removed from the aggregate either by ignition or by solvents.

Typical Variability

The most used properties or attributes of asphalt mixtures used for acceptance are as follow:

- Asphalt binder content.
- Aggregate gradation.
- Air voids (density) of laboratory compacted field produced mixtures.
- Air voids (density) of in-place asphalt mixture (field cores).
- Mixing temperature.
- Thickness or yield.
- Smoothness.

Variability associated with the measurement of these parameters is of interest since specification tolerances must consider the capability of the technicians to sample and test materials and the contractor to consistently produce materials. Unrealistic specification acceptance ranges should not be used.

Variability associated with either quality control or quality assurance testing is due to the sampling, testing and construction (materials and construction) variability. Typical variability expressed as the standard deviation is shown in Table 6-1 for selected acceptance parameters. ASTM and AASHTO test methods provide test method variability.

State proficiency test programs (depending on how they are conducted) can also define test method variability.

Table 6-1. Typical Quality Control/Quality Assurance Allowed Variability Using Standard Deviation.

Measured Property or Attribute	Typical Standard Deviation Range	Representative Value
Asphalt binder content	0.20-0.30	0.23
Aggregate Gradation **Plus No. 8** **No. 16 to No. 50** **No. 100 to No. 200**	 2.5-4.5 1.0-2.5 0.5-1.5	 3.0 1.7 1.0
In-place density/air voids	1.0-3.0	2.0

Typical quality control or quality assurance data sets reflect all sources of variability: sampling, testing and construction. The method of test and the point of sampling should be known when considering variability from data sets and the use of this information in specifications.

Asphalt binder content variability expressed as standard deviation for quality control or quality assurance data sets is typically in the range 0.20 to 0.30 with 0.23 as a representative value (Table 6-1). It is interesting to note that typically results from ignition tests have lower variability as measured by standard deviation but have a larger bias for some mix types as compared to solvent extraction methods. The industry has rapidly moved to the use of ignition tests for determining asphalt binder content.

Aggregate gradation variability depends on the sieve size as the data are often presented in terms of accumulated percent passing a given sieve. Table 6-1 shows typical and representative values for standard deviation for various sieve sizes. Recognize that these values depend upon several factors including the nominal maximum size of the aggregate, the characteristics of the deposits, characteristics of manufacturing equipment as well as sampling and testing variability.

Field Air Voids or Density standard deviation is typically in the range of 1.0 to 3.0 with 2.0 a representative value (Table 6-1). Laboratory compacted air voids determined from plant produced asphalt mixtures typically have a standard deviation near 0.9.

These values may be useful to determine if a construction operation is in good control or is out of control and needs to be improved as well as for specification development.

Asphalt Mixture Specifications in Texas

This section will briefly review TxDOT specifications for hot and warm mixes and will briefly present a specification developed by TXAPA for use on smaller tonnage projects. The TXAPA specification for smaller projects is provided in Appendix A.

Key Elements of Specifications

Most specifications contain the same set of key sections, articles or elements. The key sections typically used in TxDOT specifications are shown below:

- Description.
- Materials.
- Equipment.
- Construction.
- Measurement.
- Payment.

Other key sections of specifications include mixture design, quality control and acceptance as well as referee testing for dispute resolution. TxDOT specifications contain these sections of the specification under the “Construction” articles.

TxDOT Specifications

TxDOT (2024) has seven specifications for hot or warm mix asphalt materials. These specifications define 21 different mixtures. The specification number, title and brief comments are shown on Table 6-2.

Table 6-2. TxDOT Specification for Asphalt Mixtures.

Special Specification No.	2024 Standard Item No.	Title	Description
3076	341	Dense Graded Hot Mix Asphalt	Dense-graded mixture designed with Superpave Gyratory Compactor. For small quantities (low production and/or projects less than 5,000 tons) the QC/QA requirements can be waived.
3079	342	Permeable Friction Course	Open-graded mixture used to provide friction, reduce noise and splash and spray. Designed with Superpave Gyratory Compactor. Typically applied in relatively thin lifts.
3077	344	Superpave Mixtures	Superpave Dense-graded mixture designed with Superpave Gyratory Compactor
3080	346	Stone Matrix Asphalt	Gap-graded mixture with high asphalt binder content, improved durability and friction. Designed with Superpave Gyratory Compactor.
3081	347	Thin Overlay Mixtures	Open-graded mixture with small maximum size aggregate and typically used in lifts ¾ inch or less. Designed with Superpave Gyratory Compactor.
3082	348	Thin Bonded Friction Courses	Open-graded mixture immediately placed over a spray applied polymer modified asphalt emulsion membrane. Designed with Superpave Gyratory Compactor.

SOURCE: TXDOT, 2022

TxDOT has two specifications for dense-graded hot and warm mix asphalt. Dense Graded Hot Mix Asphalt (2024 Item 341 - old Special Specification 3076) covers dense-graded mixtures designed with the Superpave Gyratory compactor. Superpave Asphalt Mixes (2024 Item 344 - old item Special Specification 3077) covers Superpave dense-graded mixtures designed with the Superpave Gyratory compactor. Gradations for the mixtures identified in these specifications were given in Chapter 3 and their typical applications were explained.

Superpave Dense-graded mixtures designed with the Superpave compactor in 2024 Item 344/old SS3077 are designated as Type SP-B, SP-C and SP-D (Chapter 3). Mixtures that conform to the B gradations are typically used for non-surface mixtures while both SP-C and SP-D are used for surface courses. 2024 Item 344/old SS3077 is a type of quality assurance specification.

TXAPA Specification

The TXAPA specification 341M (TXAPA, 2024) was developed for use on local government or private projects and is found in Appendix A. The source of the specification is the TxDOT 2024 341 Dense Graded Hot Mix Asphalt Specification, with much of the TxDOT specific Quality Assurance criteria deleted as well as the incentive/disincentive specification. Since most municipalities lack the staffing and resources to provide much of the project oversight and testing in 341, this specification 341M relies on the Contractor's quality control testing (conducted by certified technicians) being made available to the agency as

well as establishing reasonable lot sizes typically used in municipal works. This is not a TxDOT specification but allows for substituting current TxDOT 341 and 344 specifications. This specification can be found at https://texasasphalt.org/pavement-design/#341M

Developing Specifications

When possible, standard state DOT or regional specifications should be used. The development of good specifications is time consuming and requires a substantial amount of knowledge and historic data from construction projects. Experienced personnel from agencies (owners) and materials suppliers and contractors should be used to form a specification development team. Knowledgeable/experienced facilitators should be employed to guide the discussion of the specification development team. The facilitators should be responsible for developing the required drafts of the specification.

Trial implementation of the specification is necessary. Before formal adoption of the specification, implementation of trial projects without the use of pay factors followed by implementation on trial projects with the use of pay factors is recommended. The ultimate decision as to the specification's content should be the responsibility of the agency or owner, with input from the materials suppliers and contractors being seriously considered before the final specification is adopted.

Inspection

Inspection guidelines are available from the Federal Highway Administration, asphalt paving associations, and some state agencies. These guidelines identify the inspector's responsibilities and provide guidelines for the inspection process. Some agencies supply inspector checklists that are very useful to ensure the completeness of inspection tasks.

Contractor quality control plans often include inspector guidelines to ensure that the contractor takes responsibility for his or her operations.

Summary

The specification is a key component of the contract documents that describe the obligations of the contractor and owner. It is important that specifications present a coherent and consistent expectation for the contractor and the materials. There are several contracting methods which are available, but design-bid-build is the most widely used. Likewise, there are several ways of specifying materials with performance-related specifications being the most typical. It is important for a specifier to keep in mind the size of the project, sampling points and sample sizes for the materials, the types and number of

tests to be performed, the method of analysis, the target and limits for acceptance. TXAPA has a specification based on TxDOT 2024 Standard Specification Item 341 (referred to as 341M), which can be used on small to medium projects. This specification may be found in https://texasasphalt.org/pavement-design/#341M or in Appendix A.

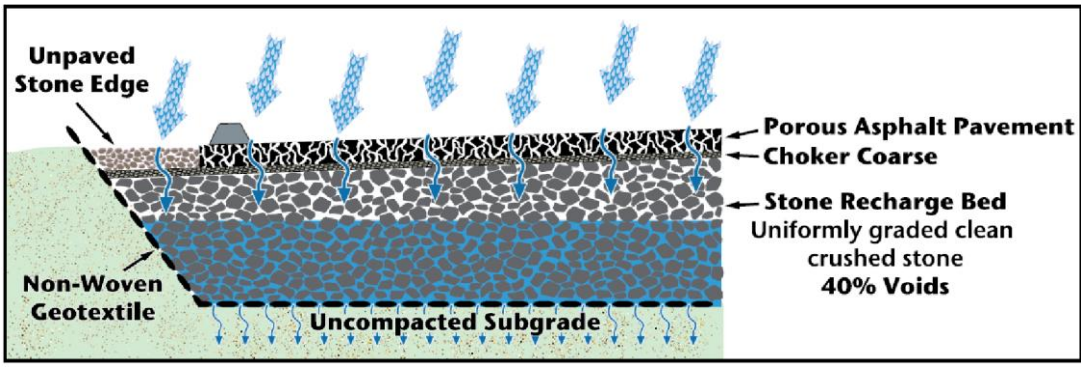
Chapter 7 Specialty Uses

Introduction

Asphalt is commonly thought of as a structural material for roads, airfields and parking lots, but its durability, smoothness, and flexibility make it suitable for other applications as well. In many areas around the world and across the U.S. asphalt pavements are successfully used for stormwater mitigation, sidewalks, bicycle paths, tennis courts, running tracks, pond liners, and railroad track beds. These specialty uses of asphalt mixtures are the subject of this chapter.

Porous Pavement

Certain areas are susceptible to stormwater runoff issues such as flooding, environmentally fragile ecosystems, stream bed erosion, groundwater recharge, and surface water pollution. In these locations, a viable option may be using porous pavements. Porous pavements allow water to pass through the pavement surface into an open stone reservoir with about 40 percent voids where the water can be stored until it infiltrates the soil beneath it (Figure 7-1). A cross-section of a porous pavement used for a subdivision street in Oregon is shown in Figure 7-2. The National Asphalt Pavement Association has excellent guidelines for site selection, design, and construction of porous pavements in their publication IS-131 *Porous Asphalt Pavements for Stormwater Management*.



SOURCE: NAPA, 2008

FIGURE 7-1. TYPICAL POROUS PAVEMENT DESIGN.



COURTESY OF JIM HUDDLESTON

FIGURE 7-2. CROSS-SECTION OF POROUS PAVEMENT FOR OREGON SUBDIVISION STREET.

One of the most famous porous pavements was constructed at Henry Thoreau's Walden Pond in Massachusetts in 1977 (Figure 7-3). This pavement served over thirty years before it needed to be resurfaced. Another early porous pavement was constructed in 1975 under an Environmental Protection Agency (EPA) grant in the Woodlands, north of Houston, where a great deal of data on runoff and pollution was gathered. Since that time, porous pavements have become an accepted practice in mitigating stormwater runoff issues, especially in the heavily developed northeastern U.S.



COURTESY OF KENT HANSEN

FIGURE 7-3. POROUS PAVEMENT SIGN AT WALDEN POND.

Porous pavements are frequently used for purposes such as paths, parking lots or driveways in areas subject to coastal flooding, adjacent to streams where excessive bank erosion may occur, and where detention ponds are impractical due to land area constraints. Before deciding to use a porous pavement, it is recommended that site planners carefully review the guidance in the NAPA (2008) document. **Due to the wetting**

and drying cycle of the subgrade underneath the pavement, it is recommended that designers avoid using porous pavements in areas with highly expansive clays.

Pedestrian and Recreational Uses

Bicycle Paths and Sidewalks

The National Asphalt Pavement Association (NAPA) has also developed guidelines for the design and construction of asphalt trails and paths (NAPA, 2002). Pavement design, mix design, construction and inspection guidelines, and maintenance of asphalt paths are all included in this document. Because asphalt does not require joints, it may be built smoothly, which appeals to bicycle riders, skateboarders, rollerbladers, and joggers. Asphalt paths such as the one shown in Figure 7-4 can also be built to follow gently undulating terrain and to withstand small settlements and movements with time.



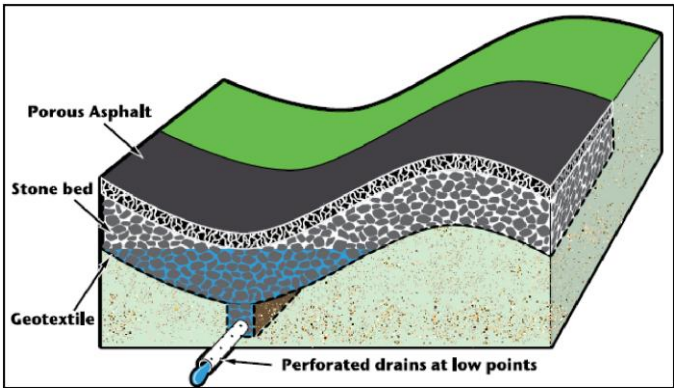
COURTESY OF KENT HANSEN

FIGURE 7-4. ASPHALT BIKE PATH.

Design standards for asphalt paths suggest a minimum width of 8 feet, as this is the minimum width of many asphalt paving machines (NAPA, 2002). Also, longitudinal grades of 5 percent or more should be avoided to comply with AASHTO standards on paths (1999). NAPA provides guidance for pavement thickness design for full-depth asphalt sections ranging from 2.5 inches for light traffic on high-quality soil to 6.5 inches for heavy traffic on poor-quality soil. For poor-quality soils, a granular base course may be used to provide a stable construction platform for the asphalt mix. Each additional 2 inches of granular base course may replace one inch of asphalt mixture to a minimum of 3 inches for heavy traffic and 2 inches for light or medium traffic. In areas where swelling clays are prevalent, the typical soil stabilization or remediation practices apply (NAPA, 2002).

Asphalt mixtures for paths should be designed primarily for durability. A small nominal maximum size aggregate of no greater than 12.5 mm should be used with a high asphalt content and a low air void content of 3 to 3.5%. The small aggregate will make for a smoother riding surface, and the low air voids will help resist cracking due to subsurface movements (NAPA, 2002).

Where stormwater runoff is a concern, asphalt paths can be constructed as porous pavements. It is necessary to pay attention to areas where a high groundwater table may be present, and flooding of the path could take place. Figure 7-5 shows how the bottom of the open-graded granular layer may be used to direct water away from the path.



SOURCE: NAPA, 2008

FIGURE 7-5. POROUS PAVEMENT OPTION FOR ASPHALT PATH.

Outdoor Tennis Courts and Basketball Courts

Outdoor courts for tennis and basketball (Figure 7-6) are recreational fixtures in the U.S. Many of these facilities are constructed with asphalt pavement surfaces, and it is considered the more affordable option with relatively easy installation (Westhead, 2014). An added advantage is that an asphalt court does not require expansion joints which could affect play with either sport. The International Tennis Federation provides guidelines on the construction of outdoor tennis courts (ITF, 2016) primarily associated with the type of surface and requirements for levelness.



COURTESY OF KENT HANSEN

FIGURE 7-6. ASPHALT BASKETBALL COURT.

Both tennis and basketball courts have been constructed using dense-graded asphalt surfaces. In many instances, the paved surface is used as the playing surface with line markings painted in white, but a polyurethane or acrylic surface may also be applied to provide color and contrast for line markings. Porous asphalt is also an option for either type of court to provide drainage through the surface and to reduce stormwater runoff. For porous surfaces, it is important to follow the guidelines of providing drainable substrates with successively smaller aggregate toward the top of the base directly below the surface to allow water to flow all the way through the pavement structure.

Running Tracks

Most running tracks in the U.S. have either polyurethane or latex surfaces over an asphalt base or an asphalt surface. The synthetic surfaces are generally about 3/8 to 1/2 inch thick and may have a variety of rubber particle types and colors. The American Sports Builders Association (ASBA) provides detailed guidelines on the construction of asphalt surfaces for athletic purposes including selecting qualified producers and contractors, materials, mix design, testing and construction procedures. A small maximum aggregate size (<1/2 inch), crushed aggregate that is non-rusting, a fine gradation, and low target air voids (3.5 percent) are considered desirable. The ASBA also specifies the elimination of cold joints in the paving process and using a minimum specified in-place density of 94.0 percent (ASBA, 2021). Further requirements contained in the ASBA guidelines pertain to the geometry of tracks and provisions for surface drainage.

Other Uses

Environmental Liners

Asphalt mixtures are ideal as capping material for certain types of landfills. They are used to prevent water from entering the landfill and leaching pollutants into ground water sources (EPA, 2016). Landfill caps are intended to isolate materials which may be hazardous to the environment. A cap is used to: 1) prevent precipitation from leaking into contaminated material and carrying the contaminants to the groundwater, 2) keep stormwater from running over the material and carrying pollutants into lakes and streams, 3) keep the wind from picking up and depositing the contaminated soil, 4) control the release of gas from wastes, and 5) keep animals and people from coming into contact with hazardous materials (EPA, 2012). Asphalt caps are generally placed on top of a granular base material which overlies the contaminated soil. An asphalt mixture placed as a capping material should be designed to be as impermeable as possible by having a high asphalt content (6.5 to 10 percent by weight), a low air void content (less than 3 percent) (EAPA, 2015), and a fine-graded aggregate structure. Because the mix is flexible an asphalt cap is usually able to tolerate slight shifting in the soil mass without excessive cracking. The asphalt cap could also serve as a parking lot. Because of the impermeable nature of asphalt capping material, surface runoff may need to be handled with an adjacent porous pavement to prevent excessive erosion (NJDEOP, 2014).

Asphalt mix caps for hazardous waste sites are reported to have a very low permeability of less than 10^{-8} cm/s (for 4 inches of thickness) to 10^{-11} cm/s (with a liquid asphalt seal on top) (Anthony et al., 1993; Bowders et al, 2000). In fact, Bowders and his co-authors (2000) stated that asphalt mix caps topped with a liquid seal on a fabric layer may have the service life of 1000 years required by the Department of Energy for hydraulic layers over radioactive and mixed waste sites.

Hydraulic Structures

Impermeable asphalt mixtures may also be used to capture water for use by consumers. The California Department of Water Resources constructed the Devil Canyon Afterbay in San Bernadino County using an asphalt mixture for the lining of the 31-million-gallon facility (Humer, 1993). The liner was required to be impervious, durable, erosion-resistant and flexible to handle small settlements. A combination of asphalt treated permeable base mixture overlaid with a covering of impermeable asphalt mix and a seal coat were used to construct the basin. The impermeable mixture was compacted to a density of 96 percent

on the slopes and 98 percent on the bottom of the reservoir. Asphalt pond liners are also very effective containment structures for agricultural purposes (University of Idaho, 2016).

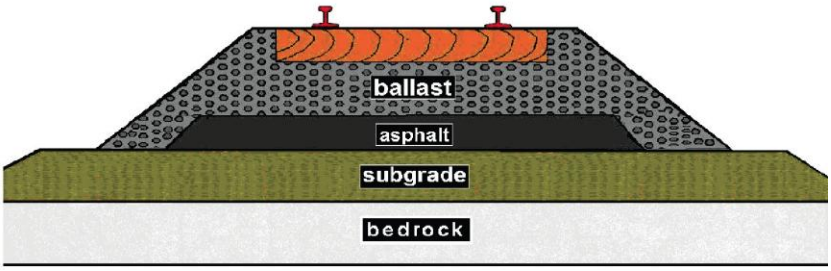
The Asphalt Institute's manual MS-12 (Asphalt in Hydraulics) provides guidance on the design of asphalt mixtures for both permeable and impermeable mixtures.

Agricultural Applications

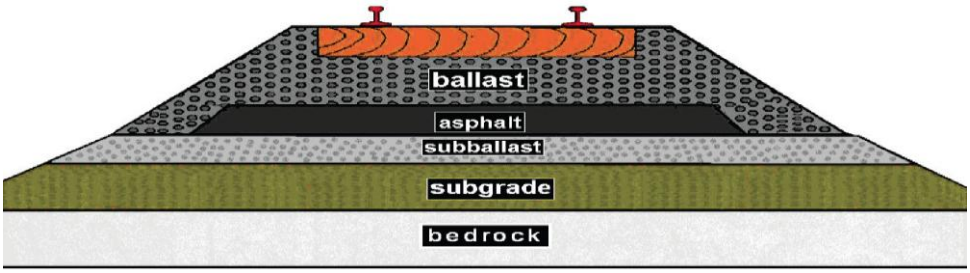
Asphalt mixes have been used to pave cattle pens, feed lots, silage platforms, bunker silos and stack silos. Paving around these areas can help keep both cattle and equipment cleaner. Cleaner cattle will improve hygiene and help reduce disease, and cleaner equipment will reduce maintenance costs. Additionally, asphalt mixtures have been used to pave the floors of horse barns to improve health and ease the cleaning of stalls. Depending upon the soil conditions and the application, the agricultural uses for asphalt mixes usually have about 4 to 6 inches of granular base under 2 to 4 inches of a dense-graded asphalt mixture.

Railroad Track Beds

Asphalt has been used in railroad applications in two ways: as a sub-ballast and as a ballast-less track bed. In the sub-ballast role, the asphalt mixture provides a firm foundation above a highly compacted embankment material. The ballast (rock) material that forms the bed for the tracks is placed over the top of the asphalt sub-ballast layer. The asphalt layer is a foundation to prevent the railroad bed from settling underneath the tracks. This avoids the need to maintain the track as frequently as it would without the sub-ballast. Additionally, the sub-ballast acts as a construction platform for many activities that follow its placement prevents the contamination of the ballast by fines in the embankment, reduces vibrations from trains, and reduces the pressure on the embankment (EAPA, 2015). This approach to railroad construction has been used in the U.S. in two different configurations. In the case of high-quality soil, the asphalt can be placed directly on top of the compacted subgrade (Figure 7-7(a)). For poor-quality soil, a sub-ballast granular material is placed and compacted ahead of the asphalt layer over which the ballast layer is placed (Figure 7-7(b)) (Rose et al., 2010).



(a) Asphalt sub ballast on Subgrade.



(b) Asphalt Sub ballast on Granular subballast.

Source: Rose et al., 2010

FIGURE 7-7. TWO U.S. METHODS FOR USING ASPHALT SUBBALLAST.

In the ballastless approach, the asphalt layer supports the "sleepers" or ties that directly support the railroad track. This is especially attractive for high-speed rail applications as there are very strict tolerances on the level of the track (±2 mm) and modern asphalt paving equipment can maintain this tolerance. This greatly reduces the profile of the track, reduces the maintenance associated with traditional ballast, and reduces the clearance height for tunnels and bridges. Furthermore, contraction joints are not needed in the asphalt mat, and there are no concerns about slab curling or warping. It also speeds up the construction of the track as there are fewer operations involved.

As high-speed rail comes to the U.S., asphalt sub-ballast layers and direct placement of ties on asphalt layers should be considered to ease construction, reduce vibrations, reduce maintenance, and maintain the level and profile of railroad tracks.

Chapter 8 Managing Asphalt Pavements

(This chapter borrows heavily from *Pavement and Road Surfaces Management for Local Agencies* by Tom Freeman and Roger Smith, Texas A&M Transportation Institute, 1994.)

Overview of Pavement Management

Purpose

Managing the condition of pavements and pavement systems is a means to providing cost-effective treatments at the pavement project level as well as lowering the overall cost of the pavement network with better budget forecasting. The concept of "pay me now or pay me later" is as true for pavements as it is in any other aspect of ownership of an asset such as a house or a car. Applying the right type of "fix" at the right time can save considerable money and effort later. Figure 8-1 illustrates that spending a little money on pavement preservation is much cheaper than trying to play "catch up" with reactive maintenance and very much cheaper than either rehabilitation or reconstruction. If a pavement is structurally adequate, then the continued application of pavement preservation would allow the pavement to remain in good condition over several cycles as shown in Figure 8-2. It is not always possible to avoid the more expensive treatments due to issues such as loads that exceed the intended design or subgrade swelling and shrinking, but through proper management techniques it is usually possible to delay the necessity of these treatments so that expenditures are spread over time in a more predictable way. Many local agencies also have a backlog of maintenance and rehabilitation needs that must be corrected before they can fully adopt a preventive maintenance approach.

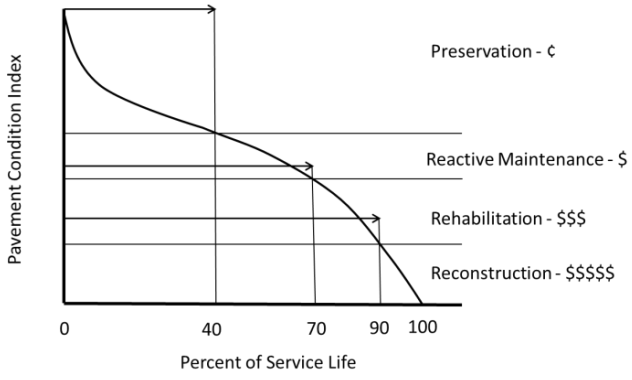


FIGURE 8-1. EFFECT OF TREATMENT TIMING ON REPAIR COSTS.

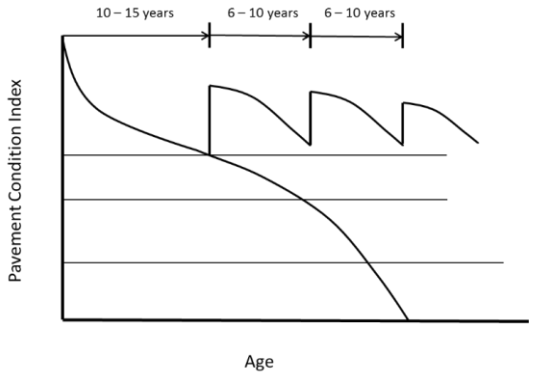


FIGURE 8-2. ILLUSTRATION OF KEEPING A "GOOD" PAVEMENT GOOD THROUGH PAVEMENT PRESERVATION.

General Description

Pavement management practices are based on finding a cost-effective combination of treatments to apply at any given time to provide the desired level of service. Pavement management systems (PMS) can evaluate various strategies, use the expected impact of maintenance and rehabilitation treatments on the future performance of the road surface, identify those that need treatment, and identify the mixture of pavement preservation, maintenance, and rehabilitation that will provide the desired overall condition within imposed financial constraints.

Pavement management systems have been developed to address maintenance, rehabilitation, reconstruction, and, sometimes, new design. They are generally restricted to looking at the maintenance and rehabilitation (M&R) needs of the existing pavement system and very seldom consider the need for additional pavement area to address increased traffic capacity.

Pavement Management Systems

A pavement management system (PMS) is a decision support tool designed to be used in helping to make cost-effective decisions concerning the maintenance and rehabilitation of pavements and road surfaces (AASHTO, 1990; Peterson, 1987; FHWA, 1991; OECD, 1987). Many people refer to software programs as pavement management, but the software does not manage or make decisions. The responsible personnel manage pavements and make decisions; the software only assists in information management and decision support. Pavement management systems provide a means to organize the data that develops with a road and street network.

Pavement management is generally divided into two levels, network- and project-level (AASHTO, 1990; Peterson, 1987; Haas et al., 1994). The differences between network level and project level extend beyond the level for which the decisions are being made to include differences in the amount and type of data required. Data collection is expensive, and it is often unknown exactly what type and how much data will be required until some of the data has been collected and analyzed. Excessive data collection has created problems in the implementation and continued use of PMS in the past (Wells et al., 1985). To avoid this problem, the absolute minimum data is normally collected at the network level. This allows the PMS to be implemented with less initial investment in data collection; however, the data collected at the network-level may not be adequate for making most project-level decisions. More complete data must be collected on individual management sections of pavement identified as being primary candidates for maintenance or rehabilitation by the

network-level analysis. Minimizing data collection costs is a fundamental reason for separating pavement management elements into network and project-level elements.

A generalized distinction between project-level and network-level activities in relation to the PMS elements is shown in Figure 8-3. The inventory of road sections is used to define the system of roads in the network and to define individual sections of contiguous construction, age, traffic, etc. Routine monitoring is used to generate distress surveys for roadway segments and leads to the determination of pavement conditions. The scores from distress surveys and other measurements, such as ride quality, are used to determine the maintenance and rehabilitation needs of project-level sections and are used in the aggregate to determine the network's overall health. The system needs are defined in terms of the percentage of the system needing preservation, maintenance, and rehabilitation. The needs of the system are considered considering the available funding, and work to improve the system can be prioritized for individual projects. At this point, the backlog of work can be quantified along with the projection of future network conditions based on the improvement made under the current budget. As a last step, the pavement models used to predict project and network conditions should be reviewed and updated as per the most recent data collection. This will help better define future conditions.

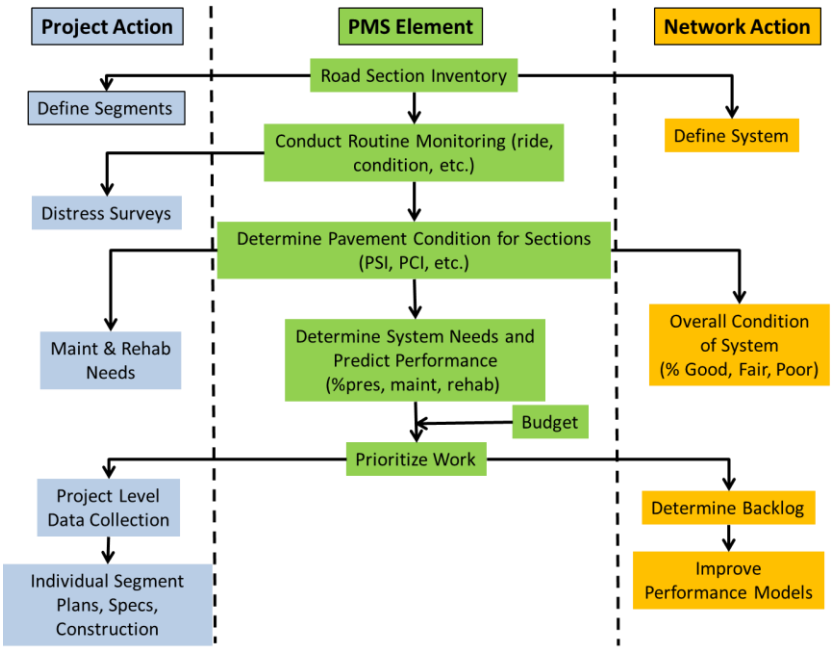


FIGURE 8-3. RELATIONSHIP BETWEEN PROJECT- AND NETWORK-LEVEL ACTIVITIES AND PMS ELEMENTS.

Network Level

The purpose of the network-level management process is related to the budget process of identifying pavement maintenance and rehabilitation needs, selecting sections to be funded, and determining the impact of various funding options on the health of the pavement system (Haas et al., 1994). The portion that deals with selecting sections to be funded may also be described as project selection and programming; in some agencies this has been called project-level management. However, it is an element of the network-level management process. The primary results of network-level analysis include maintenance and rehabilitation needs, funding needs, prioritized listings of candidate projects needing repair, and forecasted future conditions for various funding options. Also, the impact of repair strategies can be evaluated and updated within the management system to improve performance predictions in the future.

As an example of examining funding impacts on a road network consider Figures 8-4 and 8-5. These are just illustrations, and not applicable to any given road system. The scenario in Figure 8-4 is that at the current 2015 level of funding, 8 percent of the road network is in poor condition. Future projections include cases of 1) maintaining the current funding level, 2) decreasing the future funding by 10 percent, 3) increasing funding by 10 percent over the current level, and 4) increasing the funding by 20 percent. Looking ahead five years, if the current level of funding remains constant, the percentage of networks in poor condition will increase to 15 percent. Decreasing funding by 10 percent will increase the percentage of networks in poor condition to 17 percent. Even increasing funding by 10 percent will result in a network that has increased poor conditions. With a 20 percent increase in funding, the percentage of those in poor condition drops to 5 percent. Figure 8-5 shows an example of an analysis on the amount of work backlogged in the network for various funding scenarios. These types of analysis help improve communications with political decision-makers concerning the allocation of funding for pavements.

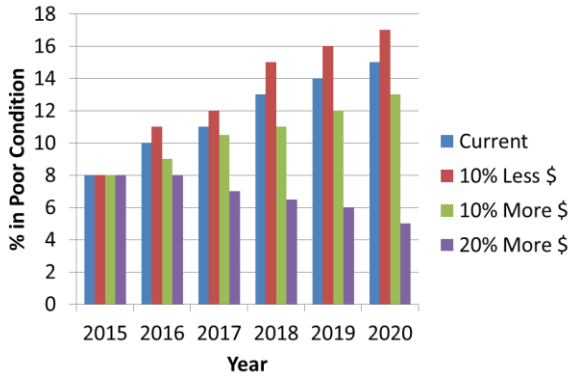


FIGURE 8-4. EXAMPLE OF ANALYSIS OF FUNDING IMPACTS ON ROAD CONDITIONS.

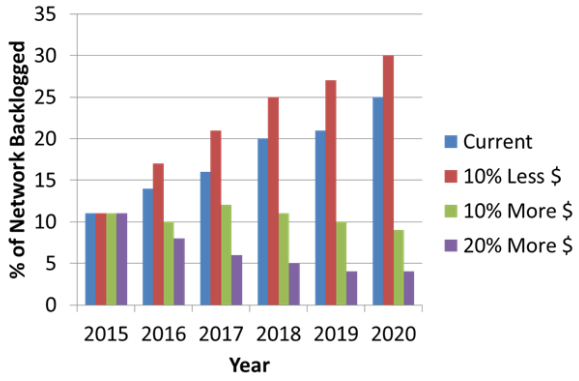


FIGURE 8-5. EXAMPLE OF ANALYSIS OF FUNDING IMPACTS ON BACKLOGGED WORK.

Project Level

Establishing the network inventory will result in identifying roadway segments to be monitored. These can have designations as simple as street or route names, street names with delineators such as reference markers or GPS coordinates, or a numbering system to avoid confusion if any streets become renamed. These segments should remain constant from year to year to track their performances. The change in roadway segment performance will trigger what actions (no action, pavement preservation, maintenance, rehabilitation, or reconstruction) are to be taken. The performance deterioration should allow for a projection of what action should be taken ahead of when it will be needed. This will permit the planning, design, and estimating to be completed and put the project into a queue for funding.

At the project level, the purpose of a PMS is to provide the most cost-effective original design, maintenance, rehabilitation, or reconstruction strategy possible for a selected section of pavement for the available funds (Haas et al., 1994). The primary results of the project-level PMS include an assessment of the cause of deterioration, identifying possible design, maintenance, rehabilitation, and reconstruction strategies, and selecting the most cost-effective strategy within imposed constraints. This requires considerable detailed data. However, much detailed information can be collected once the distress has been analyzed and the repair is identified as either a structural (pavement strengthening) or functional (ride quality, friction, etc.) fix. The pavement rating process provides this distinction.

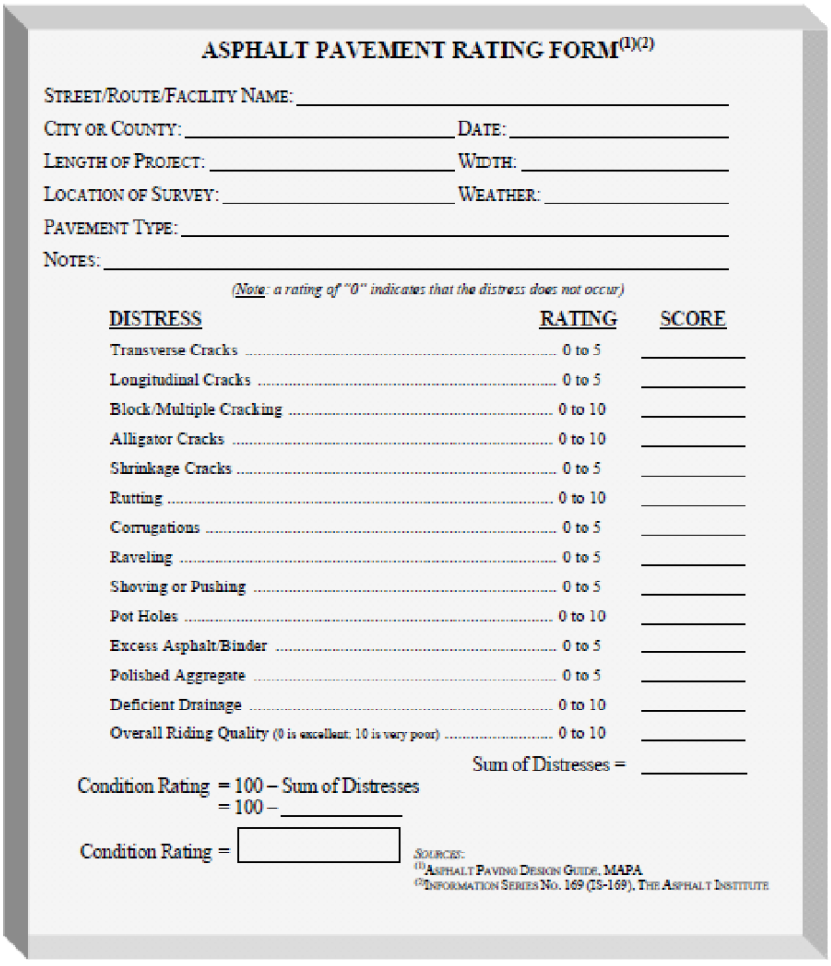
Rating Pavements

Pavement condition assessment begins with collecting data to determine the type, amount, and severity of surface distress, structural integrity, ride quality, and the pavement's skid resistance. Pavement condition data is necessary for pavement evaluation and determination of maintenance and rehabilitation needs. They are also used to project pavement performance, establish maintenance and rehabilitation strategies, and help optimize maintenance and rehabilitation funds. Pavement conditions at a local government level are typically first monitored through surface distresses. If the distresses indicate that rehabilitation may be warranted, a structural evaluation may be conducted to determine the extent of damage and practical approaches to repair the pavement segment (e.g., thin overlay, mill and overlay, base repair and overlay) A decision tree for determining the best approach for pavement maintenance or rehabilitation is presented in Chapter 9.

Surface distress is damage visible on the pavement surface. Visual surveys are performed to determine the type, severity, and quantity of surface distress. This information is often used to determine a condition rating, which is used to compute a rate of deterioration, and is often used to project future conditions. Surface distress and the current or anticipated future condition rating values are often used to help identify the timing of maintenance and rehabilitation as well as the funding needs in the PMS process. Distress is the measure most used by maintenance personnel to determine the type and timing of needed maintenance.

An example of a simple pavement rating form for visual surveys used by the Minnesota Asphalt Pavement Association and the Asphalt Institute is shown in Figure 8-6. On this form, the segment is identified at the top along with the date that the survey was conducted, the dimensions of the project, location at which the survey was conducted, weather and pavement type. Here distresses are rated on a scale of either 0 to 5 or 0 to 10, depending upon the impact of the distress type. For instance, alligator cracking which is an indication of a structural problem has a scale of 0 to 10 while transverse cracks which usually indicate a problem only in the surface are rated from 0 to 5. In this rating scheme, a score of 0 for a particular distress means that it is not evident while a score of 10 indicates that the problem is widespread and severe. Ride quality is also rated in this approach in a qualitative manner from smooth to very rough. This parameter should consider inherent roughness due to manholes, intersections, driveways, etc. Once the distresses have all been rated, they are summed and subtracted from 100 to determine the condition rating on the pavement segment. Appendix B gives examples of the distresses in Figure 8-6 along with their levels of severity.

Certain types of pavement distress such as alligator cracking or rutting can be indicators of structural failure and should be investigated more thoroughly before deciding upon rehabilitation options. The structural capacity is the maximum load and number of repetitions a pavement can carry. Structural analysis is normally conducted at project-level to determine the pavement load-carrying capacity and to determine the capacity needed to accommodate projected traffic. Non-destructive deflection testing of the pavement is a simple and reliable method to assist in making this evaluation; however, coring and component analysis techniques may be used as well. In certain instances, a ground penetrating radar survey can help establish the variability in pavement thickness and detect locations where water is present. Pavement structural evaluation is important in the selection of treatments at the project level. Structural repairs are often the most expensive to make, and if intervention can occur soon after the distress appears, it could save a significant amount of money.



ASPHALT PAVEMENT RATING FORM[1][2]

STREET/ROUTE/FACILITY NAME: _____

CITY OR COUNTY: _____ DATE: _____

LENGTH OF PROJECT: _____ WIDTH: _____

LOCATION OF SURVEY: _____ WEATHER: _____

PAVEMENT TYPE: _____

NOTES: _____

(Note: a rating of "0" indicates that the distress does not occur)

DISTRESS	RATING	SCORE
Transverse Cracks	0 to 5	
Longitudinal Cracks	0 to 5	
Block/Multiple Cracking	0 to 10	
Alligator Cracks	0 to 10	
Shrinkage Cracks	0 to 5	
Rutting	0 to 10	
Corrugations	0 to 5	
Raveling	0 to 5	
Shoving or Pushing	0 to 5	
Pot Holes	0 to 10	
Excess Asphalt/Binder	0 to 5	
Polished Aggregate	0 to 5	
Deficient Drainage	0 to 10	
Overall Riding Quality (0 is excellent; 10 is very poor)	0 to 10	
	Sum of Distresses =	

Condition Rating = 100 – Sum of Distresses
= 100 – _____

Condition Rating = [ ]

SOURCES:
[1] ASPHALT PAVING DESIGN GUIDE. MAPA
[2] INFORMATION SERIES NO. 169 (IS-169). THE ASPHALT INSTITUTE

SOURCE: AI, UNDATED; MAPA, 2014

FIGURE 8-6. PAVEMENT RATING FORM.

Roughness is a measure of pavement surface distortion or an estimate of the ability of the pavement to provide a comfortable ride to the users. Roughness is often converted into an index such as the Present Serviceability Index (PSI) or the International Roughness Index (IRI). Pavement roughness is considered most important by the public, and it is especially important on pavements with speed limits above 45 miles per hour. It is considered very important by state highway agencies but generally of less importance to cities because of the difference in speed limits as well as the causes of roughness. For instance, the presence of manholes in the roadway and at-grade crossings will affect the ride quality on local streets. These features are integral to the pavement. Roughness can sometimes be indicative of structural issues, but often it just reflects a surface condition. It is best to ascertain whether the problems are functional or structural prior to deciding upon a repair approach.

Skid resistance is the ability of the pavement surface to provide sufficient friction to avoid skid related safety problems. Skid resistance is of most importance to pavements with higher speeds. This type of survey may be done on a network basis or on an as-needed basis depending upon whether the network contains many high-speed roadways. It is generally considered a separate measure of the condition of the pavement surface and often can be used to determine the need for remedial maintenance such as an overlay or seal coat by itself. A lack of skid resistance by itself is clearly a functional issue and should be addressed with some type of surface remedy such as the application of thin overlay.

The pavement condition factors discussed above can be used to determine the overall pavement condition and to identify the most cost-effective and optimum maintenance and rehabilitation treatment. These factors vary in their degree of importance in terms of pavement performance and maintenance and rehabilitation needs. It is obvious that any treatment recommended to correct the structural capacity of the pavement can take care of all other deficiencies that might be present, including roughness. Also, any treatment selected to correct pavement roughness can also be used to improve the surface skid resistance and correct any surface distresses as well.

Several methods can be used to collect each of the four measures discussed above (Hicks and Mahoney, 1981; Epps and Monismith, 1986). Each method has advantages and disadvantages. In general, those procedures which require the least effort and cost the least are also the least accurate. Those which are most accurate are also the most expensive and time-consuming. The agency must carefully consider the type and level of

decisions being made along with the resources available to determine the best method and correct measures for their system. In most state agencies, at least distress and roughness are collected at network-level. In local agencies, distress is the most often used measure. In general, most agencies use less accurate methods for network-level analysis and more detailed measures for project-level analysis. Data is normally collected to define the condition of each individual management section identified in the inventory. Pavement ratings normally can be integrated in City/county government GIS data. Over time, these ratings can help manage street/road conditions and track improvements in pavement performance.

Summary

This chapter has presented a brief overview of pavement management and its importance in planning, budgeting, and executing pavement treatments from preservation to rehabilitation. The best approach to pavement management is to collect pavement condition information such as visual surveys regularly to track the performance of segments of road networks. As pavement conditions warrant, individual projects can be designated for preservation, maintenance, or rehabilitation. Those exhibiting distresses consistent with structural weakening can be identified for further testing and investigation. Pavement scores may be analyzed to provide information concerning the status of the network such as the percent of the network in poor, good, and excellent condition; the projected funding needs; and the work backlog. There are numerous pavement management systems available for local implementation. It must be remembered that these systems are useful for organizing and presenting data, but the final management of the system must be done by the agency.

Chapter 9 Asphalt Pavement Maintenance and Rehabilitation

Introduction

Pavements deteriorate with time and require maintenance and rehabilitation to maintain their serviceability. The causes associated with pavement deterioration include traffic volumes and loads, durability of materials, mix design, structural design, construction, and climate, including water in pavement layers and the subgrade. Pavement management systems (Chapter 8) define several types of distress used to measure deterioration according to the extent and severity. Types of flexible pavement distress include rutting, raveling, bleeding, shoving/corrugations, transverse cracking, longitudinal cracking, alligator cracking, and patching. Types of rigid pavement distress include surface deterioration, spalling, faulting, slab cracking, punch-outs, and joint condition. Types of distress, severity, and extent are recorded in periodic visual surveys and used to track pavement deterioration.

As stated in Chapter 8, visual condition surveys and other measurements such as ride quality and skid resistance are inputs to most pavement management systems. Ride quality is the most important factor for most users. Friction is a general indicator of safety for pavement and is particularly important on high-speed roads. Depending upon the type of distress, some measures of pavement load carrying capacity is also included in some pavement management project level systems.

This chapter will discuss Pavement Maintenance and Pavement Rehabilitation Methods. The alternatives that provide long term pavement repairs are emphasized as short-term repairs should be replaced within one to two years to mitigate further pavement damage. Definitions for Pavement Maintenance and Rehabilitation are also provided to provide a structure for the discussion that follows.

Definitions

Definitions for pavement maintenance and rehabilitation have changed over the years as new techniques are developed and federal and state funding categories change. The Federal Highway Administration (FHWA) provides definitions for Routine and Preventive Maintenance and Pavement Preservation in 2016 (FHWA, 2016). Texas Department of Transportation (TxDOT) has definitions for Routine Maintenance, Major Maintenance and Preventive Maintenance (TxDOT, 2014; Sims, undated; TxDOT, 2021; TxDOT, 2020). The

definitions used by FHWA and TxDOT are used as guides for funding categories. The National Center for Pavement Preservation (NCPP) (NCPP, 2016) has a definition for Pavement Preservation. The definition of Pavement Rehabilitation varies considerably among public agencies. Definitions for pavement preservation, maintenance, and rehabilitation are summarized below. Note that different agencies use different definitions. As stated above, most states' funding categories are based on these definitions. A list of definitions used by various agencies is included in Appendix C. The definitions of maintenance levels presented below are from TxDOT:

- **Maintenance:** Pavement-related work to include restoration of pavement serviceability, including patching, reconditioning, rebuilding, level-up, and overlay. This would include, but not be limited to, pavement repair, crack seal, bituminous level-ups with light overlays to restore rideability (overlays not to exceed total average depth of 2 inches), additional base to restore rideability and seal coats (TxDOT, 2020)
- **Major Maintenance:** Pavement related work to strengthen the pavement structure for the current and projected future traffic usage. Work should include restoration of pavement serviceability or roadway. This would include but not be limited to recondition and stabilizing base and subgrade, add base, level-up, overlays and seal coats. Pavement widening can be considered major maintenance if done to correct a maintenance problem (TxDOT, 2020).
- **Preventive Maintenance:** Pavement related work performed to prevent major deterioration of the pavement. Work would normally include, but not limited to milling or bituminous level-ups to restore rideability, light overlays (overlays not to exceed total average depth of 2 inches), seal coats, crack sealing and micro-surfacing. Preparatory work such as milling, repairs or level-up may also be performed (TxDOT, 2020). Some public agencies perform some of the preventive maintenance activities with in-house personnel.
- **Preservation:** Pavement preservation is the extension of the life of good pavements via the application of timely preventive maintenance treatments, performed at the optimal time to preserve pavement condition throughout its service life or to extend the life of the pavement and to reduce the amount of water infiltrating the pavement structure, protecting the pavement system, slowing the rate of deterioration and correcting surface deficiencies. Routine maintenance generally includes activities performed daily by public agencies. Preventive and preservation activities are typically performed by contractors (TxDOT, 2020).
- **Rehabilitation:** Pavement rehabilitation includes procedures that add structural load-carrying ability to a pavement. This includes, but is not limited to, overlays over 2 inches thick, removal and replacement of some or all of the pavement surface, and full-depth reclamation of the surface and base with an asphalt overlay.

Selection of Maintenance and Rehabilitation Alternatives

Decision Process

The selection of an appropriate maintenance or rehabilitation alternative for a given pavement is dependent on the factors outlined below. Typically, information on the existing facility is gathered and based on this information and engineering judgment, a maintenance or rehabilitation procedure is selected. Figure 9-1 illustrates typical steps used in this process (Epps and Newcomb, 2014). These include:

- Gathering of roadway geometric information
- Determining the condition of the existing pavement
- Estimating traffic volumes and weights
- Pavement thickness design
- Identification of constraints
- Identification of maintenance (major, preventative and preservation) and rehabilitation alternatives
- Selecting alternatives
- Performing life cycle cost determinations
- Performing life cycle assessment determinations

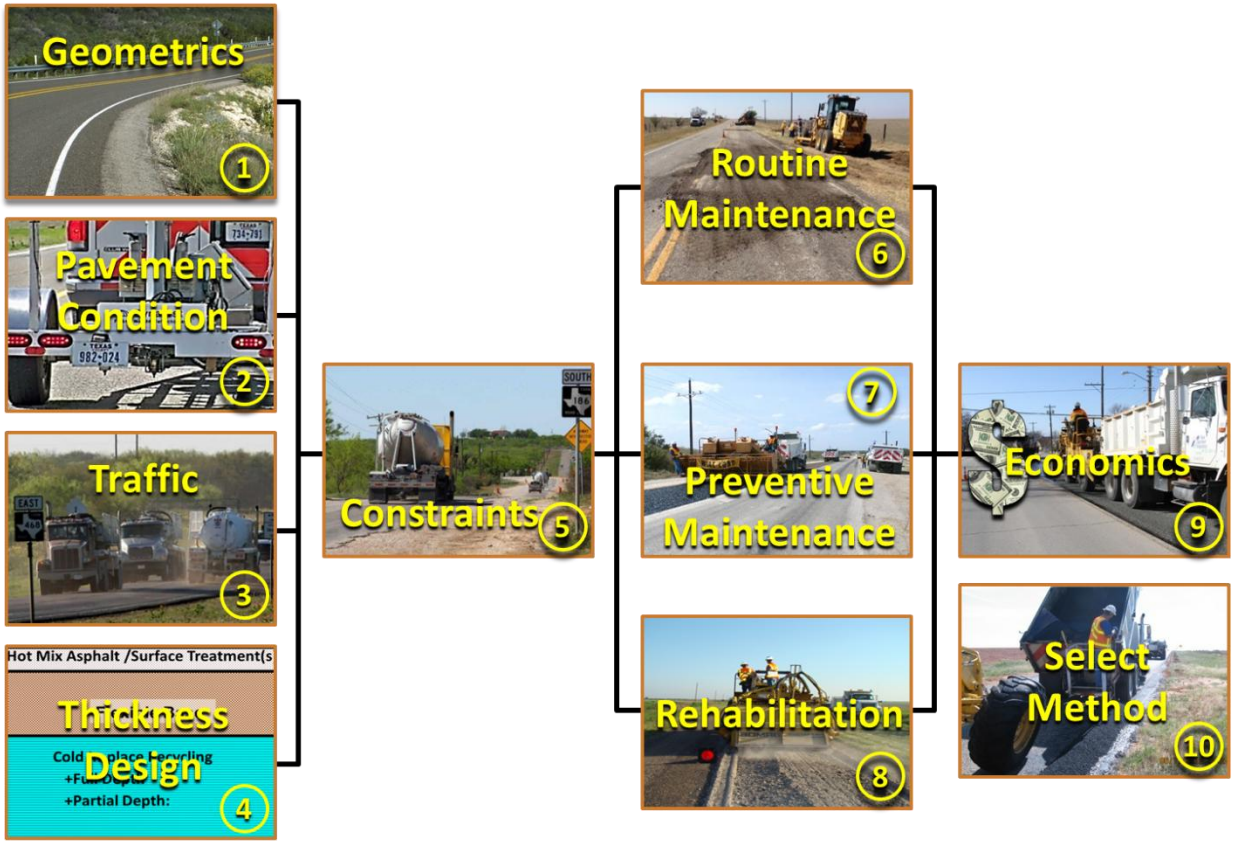


FIGURE 9-1. STEPS ASSOCIATED WITH THE SELECTION OF MAINTENANCE AND REHABILITATION ALTERNATIVES.

The term “decision tree” is used in pavement management systems to identify the process for selecting the type of pavement maintenance or rehabilitation operation to use on a specific pavement according to the distress and traffic volumes/weights. Typically, several alternatives are technically and economically (first and life cycle cost) viable for a given project. The alternative selected by the public agency or owner for a specific project is often based on experience and availability of materials, equipment, and a trained workforce. New maintenance and rehabilitation materials and techniques are being developed and should be considered as they are proven and have become available.

The amount of time and expense of determining maintenance and rehabilitation alternatives for a given project can be large. In general, the amount of time and expense associated with information gathering should be established based on the amount of money available for the project and the risk of not utilizing the available funding for the greatest benefit of the roadway system. In other words, the money spent gathering Information on a project level should be proportional to the type and amount of distress, traffic, and the needs of other road segments. Data gathering can range from a project site “drive-through” to detailed information gathering, non-destructive pavement testing, sampling and laboratory testing, pavement thickness design and first cost life cycle cost and environmental assessments. For larger, more expensive projects, detailed information gathering, and analysis is recommended.

A detailed discussion of the various components of a decision tree can be obtained in Epps and Newcomb (2014). A detailed state DOT decision tree is available in Caltrans (2008; 2008b). As stated previously, a summary of a procedure that may be used to select maintenance and rehabilitation alternatives, is shown on Figure 9-1. Decision trees are an important tool in this process. The steps in the process are discussed below.

Pavement Geometrics

As-built plans and site visits should be used to define the project geometrics. Items of interest include the following:

- Right of way widths.
- Lane widths.
- Shoulder widths.
- Drainage (cross drainage and ditches).
- Horizontal and vertical curves.
- Intersections, driveways.
- Curbs, gutters.
- Adjacent businesses.

These geometric features will impact the maintenance/rehabilitation alternative selection process.

Pavement Condition

The condition of the existing pavement and shoulders needs to be defined. The extent of the effort expended to determine the pavement condition depends on the project's expected funding and workforce requirements. If a pavement is severely distressed and sufficient funds are available for rehabilitation, a high level of effort is justified to define the pavement and shoulder condition.

Three levels of effort to determine pavement condition are defined below. The length of the project, pavement condition, and the funding available to the project for maintenance or rehabilitation should be used to determine the level of effort and cost expended to gather pavement condition information. Note that “Level Two” efforts include all Level One and Two activities. “Level Three” activities include all activities associated with Levels One, Two, and Three activities.

Level One

Historical Records. As built plans and maintenance records should be reviewed to determine the uniformity of the project. These records will help define the width of the travel lanes and the shoulders as well as the thickness of the materials. The maintenance history will help define the types of treatments that have been placed on the roadway section and to identify the location of pavement problems along the section. Large maintenance expenditures associated with one or more sections of the project likely will indicate subgrade, base or surfacing problems. Identifying past maintenance activities performed on the roadway and tying that to pavement distresses from the visual survey will help determine where the performance problems (subgrade, base, surface, shoulders) originate. Maintenance Management records will be very helpful at this stage.

Visual Condition Survey. The current condition of the pavement needs to be evaluated to help determine the causes of pavement distresses within the project. As a starting point the agency’s Pavement Management System’s (PMS) data over the last several years should be reviewed. Simple graphs of Pavement Condition Index or the extent of distresses with time help to identify sections for different levels of preservation, maintenance, or rehabilitation. A visual condition survey by one or more experienced individuals should be conducted. The PMS visual evaluation form shown in Chapter 8 and Appendix B can be used. As a minimum it is important to define the type, extent, and severity of the distress

types listed below for flexible pavements. Visual condition survey methods are also available for rigid pavements.

- Rutting or permanent deformation
- Raveling
- Bleeding
- Shoving/corrugations
- Alligator or fatigue cracking
- Transverse or thermal cracking
- Longitudinal cracking-wheel path or fatigue cracking
- Longitudinal cracking-near edge of pavement (moisture change in clay soils)
- Potholes or localized failures
- Edge drop-off/disintegration

A brief description of the types of distress and their association with different causes of pavement performance problems is provided in Appendix B. Knowledge of the potential causes of the pavement distress (structural design, materials selection, materials design, construction, etc.) will help identify appropriate maintenance and rehabilitation strategies.

After performing the visual condition survey of the project pavement, it is often helpful for the person or persons performing the survey to list potential maintenance and rehabilitation alternatives. These recommendations should be accompanied by photographs or videos of the roadway and a summary of distress type, extent, and severity information.

Ground Penetrating Radar. Ground penetrating radar (GPR) has proven to be a valuable tool for determining the thickness of the various pavement layers along a section of highway and locating areas of the pavement that may be wet. This device can be operated at highway speeds, the data reduction is fast, and the GPR output is relatively easy to interpret. The GPR can be used to verify the historic records indicating the types and depths of the various layers of the pavement along a project. It is not unusual to identify discrepancies associated with historic records with this device. The types of materials and their thicknesses are important inputs for determining maintenance and rehabilitation alternatives.

Level Two

Level Two activities involve the use of a Falling Weight Deflectometer (FWD) and Dynamic Cone Penetrometer (DCP). This information is vital to help determine the load carrying ability of the existing pavement structural section as well as the individual materials that comprise the structural section. Both devices require traffic control for data collection.

The FWD must stop for a short period of time at a particular location and the DCP requires a work crew for up to an hour at a fixed location.

FWD. The result from this testing provides information on the overall load carrying ability of the pavement structural section as well as an indication of the load carrying ability of each pavement layer. Stiffness or resilient modulus values for the various materials comprising the structural layer can be estimated by computer back calculation methods.

DCP. The results from the DCP will help determine the load carrying ability of the base, subbase and subgrade materials. Correlations are available to allow for the determination of stiffness or resilient modulus values for the different pavement materials.

Level Three

Level Three activities include field sampling and laboratory testing of the existing pavement materials. Samples of the subgrade, subbase, base, and surfacing materials are obtained, and laboratory tests are performed to determine their load-carrying ability. Additional laboratory tests can also be conducted to determine appropriate stabilizers (Portland cement, emulsified asphalt, foamed asphalt, fly ash, lime-fly ash, etc.) and stabilizer contents to use with the existing pavement materials.

Recommended Levels of Investigation

Three levels of data gathering are described above. The level of activity and the cost of each level of investigation differ from one to another. Recommended levels of investigation associated with anticipated maintenance/rehabilitation activities are provided below (Table 9-1).

TABLE 9-1. RECOMMENDED LEVEL OF INVESTIGATION TO DETERMINE MAINTENANCE AND REHABILITATION ALTERNATIVES.

Anticipated Maintenance/Rehabilitation	Pavement Condition Investigation	
	Level	Activities
Routine Maintenance	1	Historic records/visual condition and perhaps GPR
Preventive Maintenance	1 & 2	GPR/FWD and perhaps DCP
Rehabilitation	1, 2 &3	Field sampling and laboratory testing

Traffic Levels

Traffic information should include present and future annual average daily traffic as well as the number and axle weights of trucks that use and will use the roadway. The number of trucks and their axle weight distribution is used to calculate the design or number of Equivalent Single Axle Loads (ESALs) expected on the roadway for the design period (typically 20 years). Methods for calculating ESALs are available from most state DOTs. TxDOT has designed ESALs for all state routes. The development of ESALs for roadways in

local government entities is performed in several different ways including assigned values for different classes of roadways and performing traffic counts with load distributions for typical trucks.

Regardless of the methodology used it is difficult to forecast traffic into the future. Good estimates of present traffic together with land use planning are typically used by local governments to estimate future traffic.

Constraints

Selection of maintenance and rehabilitation alternatives is based on several engineering related factors as well as a wide variety of others including financial constraints, workforce availability, equipment availability, materials availability, weather conditions, scheduling, and traffic control. A more detailed discussion of these constraints is available in Epps and Newcomb (2014).

If only limited funding is available for a project, the selected alternative will be to prevent further severe deterioration of the roadway until more substantial funding is available. Workforce availability and skill sets as well as equipment can be an issue with certain maintenance and rehabilitation alternatives. Materials availability is typically not a problem. Weather and scheduling issues should be considered when selecting an alternative. Certain maintenance and rehabilitation alternatives are not suitable for late season or winter use. Traffic control and disruption to the traveling public are important considerations. Alternatives should generally be selected that minimize disruption to traffic.

Typical Maintenance Activities

The maintenance definitions shown above and a review of common practices in Texas and other states provide the background for the listing of typical maintenance activities associated with the various definitions shown on Table 9-2 for flexible pavements. FHWA's National Highway Institute (NHI) training programs for pavement maintenance and rehabilitation gives guidance on several maintenance activities.

Table 9-2. Typical Maintenance Activities Associated with Routine and Preventive Maintenance.

Type of Maintenance	Maintenance Activity	Reference
Routine	Crack sealing	FHWA, 1999; 2002
	Shallow patch	FHWA, 1999b; Epps et al, 2016
	Deep patch	FHWA, 1999b; Epps et al, 2016
	Level-up	Epps et al, 2016
	Localized pavement strengthening	Epps et al, 2016
	Localized sealing (fog, chip)	Epps et al, 2016
Preventive	Thin overlay	Newcomb, 2009; FHWA, 2002b
	Chip seal	TxDOT, 2010; FHWA 2002c
	Slurry seal	FHWA, 2006
	Micro-seal	FHWA, 2003
	Fog Seal	FHWA, 2003b

Additional information is provided below for selected maintenance alternatives.

Asphalt Maintenance Materials and Activities

Asphalt Binders

A wide variety of patching materials are used in maintenance activities. Materials for routine maintenance operations include emulsions, cutbacks, and paving grade asphalt binders specified in the TxDOT Special Specification 3077, Asphalt, Oils and Emulsions (TxDOT, 2021). These materials will not be discussed at length in this document. Table 18 of this specification contains a list of materials that are typically used for various maintenance and construction operations.

Asphalt Mixtures

A wide variety of asphalt bound patching materials may be used including cold mixed-cold laid, hot mixed-cold laid and hot mixed-hot laid materials. Hot mixed-hot laid materials provide a patch with a long life provided the patched area is prepared properly and the materials are placed hot and compacted to the desired density. Cold mix-cold laid and hot mixed-cold laid are often used for winter patching needs as hot mixed-hot laid materials are not conveniently available. Replacement of these patches with hot mixed-hot laid materials is often necessary as they become available during the spring.

As discussed in Chapter 3, the grade of asphalt binders is determined by the climate in which the materials are to be used according to the PG binder specification selection procedure. This binder is for the hot mix asphalt paving mixtures used in that region and for hot-mixed-hot laid maintenance materials.

The hot mix patching materials and thin overlay materials should be selected for the depth of application. The nominal maximum size of the aggregate (larger aggregate sizes) should be 1/3 to 1/4 the thickness of patch or overlay. Since relatively small quantities of hot mix asphalt are used in maintenance operations, Special Specification Item 340 for small

projects is typically the specification used, and Type D (Fine Surface (3/8 inch)) and Type F (Fine Mixture (No. 4 sieve)) are called for.

The Texas Asphalt Pavement Association (TXAPA) has developed a specification for hot mixed asphalt for use by local governments that is suitable for patching purposes. This specification is found in Appendix A.

Table 9-3 provides a summary of the types of mixtures that are used for patching and thin overlays.

Table 9-3. Dense-Graded Mixtures for Patching and Overlays.

Specification Item	Mixture Designation	Description	Use		Comments
			Patching	Thin Overlay	
Special Specification 3076, with a small quantity exemption	Type D & F	Dense graded mixture - small projects –	X	X	Commonly used hot mix asphalt patching material
TXAPA	Type D & F	Conventional dense graded mixture for local government projects	X	X	Used for patching and thin overlay applications

Crack Sealing

Several techniques are used for crack sealing. Preparation of the crack to receive the asphalt sealing material is critical to the performance of the sealed crack. Crack preparation techniques include cleaning the crack with compressed air and routing. Routing can take several geometric shapes. Typically, in Texas routing is not performed. Cleaning the crack prior to pour or placing the crack sealing materials is preferred to ensure the performance of the seal.

Common crack sealing materials used in Texas include SS-1P (polymer modified slow setting emulsion containing an elastomeric polymer), polymer modified AE (asphalt emulsion) crack sealant and rubber asphalt crack sealers (Class A and Class B) as defined in Special Specification 3077 (TxDOT, 2021).

Shallow and Deep Patches

The area to be repaired should be large enough to include all the observed distress plus an additional area surrounding the distress. The area to be patched is a judgment made by the maintenance crew, an engineer, or inspector. Good practice suggests that the repaired area should extend 12 inches or more beyond the observed distressed area.

As a rule, the thickness of the patch or repaired area should be twice the thickness of the existing thickness of the asphalt bound materials. Many pavement areas needing thin or thick patches are structurally distressed or have experienced de-bonding between pavement layers. For both causes of pavement distress, a greater thickness precludes future distress of a similar type. The minimum thickness of hot mix asphalt patch should be 4 inches (Figure 9-2).



Figure 9-2. Deep Patch.

The distressed material in the area to be patched should be removed to the suggested depth. The materials in the bottom of the patch should be compacted as necessary and primed or tacked. The sides of the patch should be at right angles and longitudinal to the direction of traffic. If possible, avoid placing a longitudinal joint between the patch and the surrounding pavement in the wheel patch. The sides of the patch should be tacked prior to placing the hot mixed-hot laid material. It is a good practice to make the width of the patch wide enough for a small roller to be able to “get-in” to the patched area to allow for compaction of one or more lifts prior to placement of the surface course material. The life of the patch is very dependent on the density of the material placed in the patch.

Level-up

Localized pavement roughness and/or wheel path rutting is typically treated with a level-up patch. Both cold laid and hot laid materials can be used. Hot mixed-hot laid materials typically perform better.

Cold milling (Figure 9-3) of the rough area prior to placing a thin overlay is recommended. Placement of a thin lift of asphalt bound materials over the milled area with a paving machine will provide substantial improvement in the ride quality (Figure 9-4). In addition, the milling operation can be used to remove the ruts in the wheel path avoiding a problem with differential density and further rutting under traffic after placement of the overlay.

Milling ahead of the placement of a thin, limited length overlay can result in more ride quality improvements than simply overlaying the rough pavement. If rutting is present, differential compaction of the overlay material in the ruts will result in lower density and may result in further rutting as indicated above. Steel wheel rollers will bridge over the overlay material placed in the ruts and poor density (high air voids) will result. This can also cause premature raveling.



FIGURE 9-3. COLD MILLING.



FIGURE 9-4. LEVEL-UP PATCH.

Preservation and Maintenance Overlays

Asphalt overlays (Figure 9-5) may be used for pavement preservation, maintenance or rehabilitation depending upon the extent of the work and the thickness of overlay. When used for pavement preservation, thin overlays or thinlays are applied to the pavement surface to extend pavement life while improving ride quality and skid resistance. Overlays less than 2 inches thick are employed as maintenance treatments to restore ride quality and address surface defects.

Thin asphalt overlays for pavement preservation and maintenance overlays provide several benefits as compared to other preservation and maintenance alternatives (FHWA, 1999). These benefits are identified below.

- Long service life.
- Low life cycle costs.
- Ability to withstand heavy traffic.
- Smooth surface.
- Quick opening to traffic.
- Low tire noise.
- High friction with proper selection of aggregates.
- Ability to be recycled.
- Uniform appearance.



FIGURE 9-5. HOT MIX ASPHALT OVERLAY.

Thin and maintenance overlays are commonly used to repair various types of pavement distress. Thin overlays only marginally increase the roadway's load-carrying capability and should not be used to repair pavements damaged by traffic loads.

Table 9-4 has been developed to provide an indication of the type of overlay (thin and thick, with and without cold milling) that is suitable for repair of different types of pavement distress. Cold milling operations can be used in combination overlays to repair pavements. Cold milling operations allow the distressed area to be removed as well as to provide an improved opportunity to provide pavement ride quality or smoothness. Several factors including type, severity and extent of distress; traffic, pavement geometrics and structural load carrying ability of the existing pavement need to be considered prior to the selection of a maintenance or rehabilitation alternative. Table 9-4 is a simplified approach for selection of overlay type. Thick asphalt overlays are discussed in more detail later under Asphalt Pavement Rehabilitation.

Table 9-4. General Guide for the Use of Asphalt Overlays.

Type of Distress	Thin Overlay	Cold Mill & Thin Overlay	Thick Overlay	Cold Mill & Thick Overlay	Comments
Rutting		X		X	Depends on severity of corrugations
Raveling	X				
Bleeding	X				
Shoving/Corrugations		X		X	Depends on severity of corrugations
Transverse Cracking	X		X		Cracks will reflect through overlays after a few years
Longitudinal Cracking	X		X		Cracks will reflect through overlays after a few years
Alligator Cracking			X	X	Use overlay thickness design method to determine thickness. Patched alligator cracked areas prior to overlay if thin overlay is to be used.
Patching	X				Assumes that the patching has solved structural deficiencies
Roughness	X	X		X	Depends on level of roughness
Friction	X				Select aggregates with high friction
Appearance	X				

Materials and Mix Design

The mixture types suitable for preservation and maintenance overlays are presented in Table 3-1. The materials and mixture design methods for hot-mix asphalt were discussed in Chapter 3.

Construction Guidelines

Construction guidelines are available in TxDOT standard specifications (TxDOT, 2014) as well as from National Asphalt Pavement Association (Newcomb, 2009) and the Federal Highway Administration (2002b). The National Asphalt Pavement Association has developed suggestions for methods to utilize prior to placement of thin overlays. These suggestions are summarized in Table 9-5 (Newcomb, 2009).

Table 9-5. Suggested Surface Preparation Prior to Placement of Thin Overlays.

Distress Type	Extent of Distress	Surface Preparation
Raveling	Up to 100 percent of surface	Clean and tack
Longitudinal Cracking (non-wheel path)	Crack depth in surface layer only	Mill to crack depth, clean and tack
Longitudinal Cracking (wheel path)	Crack depth in surface layer only	Mill to crack depth, clean and tack
Transverse Cracking	Crack depth in upper layers only	Mill surface, clean, fill exposed cracks and tack
Alligator or Fatigue Cracking	Crack depth in surface layer only	Mill to crack depth, clean and tack
Rutting or Shoving	Rutting in surface layer only	Mill to depth of surface layer, clean and tack

SOURCE: NEWCOMB, 2009

Quality control and quality assurance guidelines used by TxDOT and contained in the standard specifications, or the specification contained in the appendix as developed by TXAPA can be used to ensure the manufacture and placement of a high-quality asphalt mixture.

Chip Seal or Seal Coats

Chip seal or seal coats are defined as spray applications of an asphalt binder immediately followed by an open-graded aggregate (see Chapter 3) (Figure 9-6). Pneumatic tire rolling is used to "set" the chip or compact the surface. TxDOT Item 316 (Surface Treatments) provides a specification for this operation while the TxDOT "Seal Coat and Surface Treatment Manual" provides design and construction guidelines (TxDOT, 2017).



FIGURE 9-6. CHIP SEAL.

Chip seals are used for several reasons in pavement maintenance, including:

- Seal the existing asphalt surface against the intrusion of air and water.
- Enrich an existing dry or raveled surface.
- Provide a skid-resistant surface.
- Provide surface or macro texture to reduce hydroplaning.
- Provide a color and/or noise demarcation between lanes and shoulders.
- Provide a uniform surface.

The seal coat itself has little or no structural strength, but by keeping water out of the structure, it preserves the inherent strength of the pavement and the subgrade.

If a pavement shows evidence of load associated distress (alligator cracking, longitudinal cracking in the wheel paths) a seal coat is only a temporary solution. Seal coats placed on top of corrugated or rutted pavement offer little or no benefit. Seal coats applied to pavements showing signs of non-traffic load associated with longitudinal and transverse cracks are somewhat effective. However, cracks will eventually propagate through the seal coat.

Ride quality cannot be improved significantly by the application of a seal coat. Pavements demonstrating flushing or bleeding are difficult to repair with seal coats. Seal coats with large aggregate sizes are suggested for use if they are to be used over bleeding pavements.

Seal coats have been used successfully on both low and high traffic volume roadways. The best performance is obtained on lower traffic volume highways. Bleeding and rock loss can be problems on the higher traffic volume roadways and especially roadways with high truck traffic. The use of seal coats in urban areas where accelerating/decelerating traffic and turning movements frequently occur should be approached with caution as bleeding and rock loss are common problems.

Materials Selection

Currently, TxDOT uses a tiered approach based on traffic volumes for the selection of seal coat binders (Table 9-6) (TxDOT, 2013b). The selection process was implemented in 2010. However, it is undergoing change, and implementation is proceeding with an asphalt binder system based on a performance grading system.

Table 9-6. Seal Coat Materials Selection Guidelines.

Traffic Level	Asphalt Emulsion	Asphalt Cement	Asphalt Rubber
Light	CRS-2, CRS-2H HFRS-2	AC-5 AC-10	
Moderate	CHFRS-2P HFRS-2P CRS-2P	AC-5 w/2% SBR AC-10 w/2% SRB AC-15P AC-20XP AC-10-2TR	
Heavy		AC-15P AC-20XP AC-20-5TR	A-R Type II A-R Type III

SOURCE: TXDOT, 2013B

Three types of seal coat binders are identified in the TxDOT specification (Table 9-6) (TxDOT, 2013b). Asphalt emulsion, asphalt cement and asphalt rubber binders. Typically asphalt emulsions are used for lower traffic volumes (light and moderate traffic) while polymer modified asphalts are used for higher traffic volumes (moderate and heavy) and asphalt rubber binders are used only on heavy traffic volume facilities. Asphalt cement is used on all levels of traffic. Item 300 (TxDOT 2024) contains the requirements for these materials. If public agencies place seal coats, emulsions are typically used as they are easier to handle and require less equipment.

Aggregate selections are also based on traffic volumes as well as other considerations. For high traffic volume roadways larger maximum size aggregates should be used (TxDOT Grade 3 rather than Grade 5) (TxDOT, 2014). Lower traffic volume facilities can use all three grades (Grades 3, 4 and 5). Grade 3 chips have a larger maximum size and require a higher asphalt binder shot quantity than the smaller Grade 5 chips. Bleeding is more likely with Grade 5 aggregate as compared to Grade 3. Raveling is somewhat more likely with Grade 3 chips as compared with Grade 5. Note that raveling or chip loss is possible with all grades. The Grade 4 aggregate gradations are used most often.

Design Considerations

TxDOT uses the Modified Kearby Design Method to establish asphalt binder application rates and aggregate distribution rates. The TxDOT (2017) *Seal Coat and Surface Treatment Manual* should be consulted for details associated with the design method. Best practice suggests that a design should be performed for each project and aggregate source and size. Note that design quantities should be adjusted for traffic volumes, condition of the old surface, temperature of application and the type of binder (emulsion or asphalt cement). Higher asphalt binder shot quantities should be used on dry surfaces with

surface texture and low volume traffic roadways. Typical asphalt binder shot rates and aggregate distribution rates for the various sizes of aggregates are shown on Table 9-7. Note that the asphalt binder application rates are based on residual asphalt binder content. Asphalt emulsion shot rates should be adjusted as shown in the seal coat design manual (TxDOT, 2017).

Table 9-7. Typical Asphalt Binder Shot Rates and Aggregate Application Rates.

Aggregate Gradation	Asphalt Binder Shot Rate, Gallons per square yard	Aggregate Distribution Rate, Square yards per cubic yard
2	0.45 to 0.50	70 to 80
3	0.40 to 0.45	95 to 105
4	0.35 to 0.40	110 to 120
5	0.30 to 0.35	140 to 160

Construction Guidelines

Construction guidelines are available in the FHWA (2002c; 2006) checklists for chip seals and slurry seals. Construction should be performed in warm to hot weather and without rainfall at the time of construction and ideally for 48 hours afterwards. Uniform application of asphalt binder and aggregate are critical to the success of a project. Aggregate or chip application rates should be within the design tolerances. Excessive aggregate will crush and potential cause bleeding and fling stones when trafficked. Low chip distribution rates will cause construction problems as the rubber-tired construction equipment will pick up the asphalt binder. Pneumatic tire rollers should be used to seat the chips. A minimum of four rollers are suggested. Sweeping off loose rock after construction is a necessary step associated with the construction project. Traffic should be allowed on the project only after the surface has been swept and a pilot car has trafficked the surface at elevated speed without causing flying stones. Be aware of loose aggregate, because Grade 3 aggregate can break windshields and can be a source of many public complaints.

An important part of the construction operation is the inspection of all construction equipment. All equipment must be in good operating condition and the asphalt distributor and aggregate distributor should be calibrated so that the proper quantities of materials can be uniformly distributed across the pavement. Note that on projects with bleeding wheel paths it may be desirable to reduce asphalt binder shot quantities in the wheel paths. This can be accomplished by changing spray nozzles or using a new generation of distributors that allow individual nozzles to be adjusted for spray rates.

Rehabilitation of Flexible Pavements

Several methods are available for the rehabilitation of flexible pavements. These include the use of hot mix asphalt overlays to improve the structural capacity of the pavement as well as cold milling and overlaying with hot asphalt materials. A variety of cold in-place recycling options in combination with hot mix asphalt materials are sometimes used to strengthen roadways. This discussion will be limited to the use of hot mix asphalt materials.

Rehabilitation of flexible pavements should consider the use of milling prior to overlay operations if the following conditions are present in the roadway. Table 9-4 can be used as a general guide for milling. Considerations for asphalt overlays include:

- Vertical control problems with bridge clearances, roadside safety hardware (barriers, guard rails, etc.)
- Vertical control problems with drainage structures (bridges, curbs, gutters, etc.)
- Raveling
- Bleeding
- Cracking (longitudinal or transverse) of limited depth in the pavement
- Rutting in the wheel paths
- Corrugations or shoving
- Rough pavement

Vertical height controls due to clearances and roadside appurtenances must be identified before developing plans. It may be necessary to remove and replace a greater depth of material in these locations or use a thinner section that will need to be repaired sooner. Pavement distresses and roughness should be addressed by milling to remove any existing surface defects to provide a longer performance for the overlay.

Thickness design tools for asphalt overlay design are available from TxDOT in the form of the Texas Flexible Pavement Design method (FPS-21) (Liu and Scullion, 2011). This computer program is used to establish overlay thickness for specific projects. As discussed in Chapter 4, an easy-to-use overlay design procedure is PAVExpress (NAPA, 2015) which is based on the 1993 AASHTO Guide for the Design of Pavement Structures. Key inputs to these programs include traffic volume and weights, type and thickness of existing pavement layers, condition of existing pavement, climate, and design life. The thickness of the asphalt overlay should be determined based on a pavement investigation to determine the composition and strength of the existing pavement.

Rehabilitation of Rigid Pavements

Several methods are available for the rehabilitation of rigid pavements as well. Some of these include the use of hot mix asphalt overlays of sufficient thickness to improve roughness, slow joint reflection cracking and improve the load carrying ability of the pavement.

Crack and seat and rubblization of the old concrete pavements can be performed prior to overlaying with hot mix asphalt. These treatments are used to prevent the problem of reflection cracking at the joints by effectively reducing the slab expansion and contraction as well as seating the broken pieces of concrete to prevent slab rocking. Temperature and/or reinforcing steel, if present in the rigid pavement is generally fully de-bonded from the concrete by rubblization. Some projects have used cold milling of the concrete prior to overlaying with hot asphalt materials. However, while this approach makes a smooth surface to pave on, it does not prevent the expansion and contraction or possible slab rocking. A variety of other techniques have been used to repair old rigid pavements including concrete pavement restoration techniques (CPR) and reconstruction. Below, the use of hot mix asphalt materials in combination with crack and seat or rubblization operations will be discussed.

Rubblization and crack and seat operations for the rehabilitation have been used in several states (FAA, 2004; Decker, 2006; NAPA, 1991; Ceylan, 2015; TxDOT, 2015) to help mitigate reflection cracking from the old rigid pavement roadway through the asphalt overlay. The best way to control reflection cracking in a hot mix asphalt overlay over a rigid pavement is to fracture the slabs prior to placement of the overlay. “Slab fracturing” techniques are discussed in detail in a NAPA publication (1991) titled “Guidelines for the Use of HMA Overlays to Rehabilitate PCC Pavements.” Slab fracturing can be accomplished by crack and seat, break and seat or rubblization.

Project evaluation tools, hot mix asphalt thickness design methods, a description of the construction equipment and construction operations used to place the hot mix asphalt overlay are contained in Decker (2006) and NAPA (1991). Performance information is also available in these reports.

Life Cycle Costing

First cost and life cycle cost analysis should be performed on several maintenance and rehabilitation alternatives selected for a given project. Budget, work force availability, equipment availability, materials availability, traffic control, weather or scheduling may

eliminate some of the maintenance or rehabilitation alternatives under consideration. The Federal Highway Administration has a procedure available for conducting life cycle costs (FHWA, 1998). This procedure can consider both agency and user costs. A life-cycle cost analysis will help the engineer decide on viable alternatives with the lowest long-term cost.

Life Cycle Assessment

Life cycle assessment is a process to calculate the sustainability of a selected maintenance and/or rehabilitation alternative. An easy-to-use process is currently not currently available, but Van Dam, et al (2015) and Robinette and Epps (2000) provide information and examples of life cycle assessments for maintenance and rehabilitation alternatives. Sustainability or being “Green” should be considered in the selection process.

Typical Maintenance and Rehabilitation Alternatives

Tables 9-8 guide selecting typical maintenance and rehabilitation alternatives associated with various types of flexible pavement distress. This table is intended to be a general guide only if the extent and severity of the distress are not identified. Note that public agencies use a variety of alternatives depending on the availability of financial resources, equipment, materials, and workforce capability.

Selection of a maintenance or rehabilitation alternative is often tricky as several types of distress are commonly present on a roadway at any given time. If the pavement distress is localized, it should be treated with localized repair techniques such as patching. If the distress is more extensive, a more general maintenance or rehabilitation alternative, such as a thin overlay, should be considered.

Table 9-8. Maintenance and Rehabilitation Alternatives for Specific Types of Distress.

Type of Distress	Maintenance/Rehabilitation Alternatives	Comments
Rutting	• Mill and Overlay • Overlay	• Need for milling and thickness of overlay depends on the cause of rutting and depth of rutting
Raveling	• Chip Seal • Thin Overlay	• Depends on extent and severity • Severe and extensive raveling will require a thin overlay
Bleeding	• Thin Overlay • Mill and Overlay	• Depends on extent and severity • Severe and extensive bleeding will require mill and thin overlay
Shoving/Corrugations	• Remove and patch	• Typically, a localized form of distress that should be removed and replaced with hot mix asphalt
Alligator Cracking	• Remove and Place Thick Patch • Thick Overlay	• If localized alligator cracking, remove and place a thick patch prior to structurally designed overlay
Transverse Cracking	• Seal Cracks • Thin Overlay • Chip Seal	• Seal crack prior to overlay or chip seal • Cracks will reflect
Longitudinal Cracking-wheel path	• Seal Cracks • Thick Overlay	• If “top-down” cracking removes cracked layer and place structurally designed overlay • If not “top-down” cracking place a structurally designed overlay
Longitudinal Cracking-edge	• Seal Cracks • Seal Coat • Thin Overlay	• Reflection cracking will occur • Amount of cracking will primarily be dependent on soil and climatic conditions
Patching	• Remove and Replace Patch	• Increase thickness of patch and replace with hot mix asphalt patching material
Edge Drop Off	• Extend Width of Pavement • Patch	• If edge drop off is severe and extensive extend the width of pavement by removal and replacement with structurally design pavement section

References

American Association of State Highway and Transportation Officials (AASHTO) (1993) *Guide for the Design of Pavement Structures*. Washington, DC.

American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, 3rd Edition, 2020

American Association of State Highway and Transportation Officials (AASHTO) (2012). *Guide for the Development of Bicycle Facilities*. Washington, DC.

American Association of State Highway and Transportation Officials (AASHTO) (1990). *Guidelines for Pavement Management Systems*. Washington, DC.

American Sports Builders Association Asphalt Guidelines, Asphalt for Athletic Use. https://sportsbuilders.org/page/asphalt_guidelines. (Nov. 2021) Accessed May 12, 2022

Anthony, J.W., G. Shepherd, R.J. Sterrett (1993). Performance Evaluation of a Hydraulic Asphalt Concrete Pavement Capping a Hazardous Waste Site. Proceedings. 3rd International Conf. on Case Histories in Geotechnical Engineering. St. Louis. pp. 1235-1244.

Asphalt Pavement Alliance. Asphalt Performs – Smoothness, Quite Pavement https://www.driveasphalt.org/why-asphalt/asphalt-performs. Accessed May 16, 2022.

Asphalt Institute. Asphalt-The Magazine of the Asphalt Institute. http://asphaltmagazine.com/noise-reducing-pavements-get-loud-acclaim-in-us-and-europe-understanding-the-issue/. Accessed May 16, 2022.

Asphalt Pavement Alliance. Perpetual By Performance Awards. https://www.driveasphalt.org/awards/perpetual-by-performance. Accessed May 13, 2022.

Asphalt Institute (AI) (undated). A Pavement Rating System for Low-Volume Roads. IS-169. Lexington, KY.

Barrett, M. (2008). Effects of a Permeable Friction Course on Highway Runoff. *Jn. of Irrigation and Drainage Engineering*. Vol. 135, No. 5. Am. Soc. of Civil Engineers. Reston, VA. pp. 646-651.

Bowders, J.J., J.E. Loehr, D.T. Mooney, and A. Bouazza (2000). Asphalt Barriers for Waste Isolation. Proceedings. International Soc. For Rock Mechanics. Melbourne. Australia.

Brown, E.R., L.A. Cooley Jr, D. Hanson, C. Lynn, B. Powell, B.D. Prowell, and D. Watson (2002). *NCAT Test Track Design, Construction, and Performance*. NCAT Report No. 2002-12. National Center for Asphalt Technology. Auburn, AL.

Brown, E.R., M.R. Hainin, A. Cooley, and G. Hurley (2004) Relationships of HMA In-Place Air Voids, Lift Thickness, and Permeability. NCHRP Report 531. National Cooperative Highway Research Program. Transportation Research Board. Washington, DC.

California Department of Transportation (Caltrans) (2008). Maintenance Technical Advisory Guide-Volume I-Flexible Pavement Preservation. Second Edition. Sacramento. http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/Reference%20Documents/Operations%20and%20Maintenance/Maintenance%20Technical%20Advisory%20Guide%20-%20Volume%20I%20-%20Flexible%20Pavement%20Preservation.pdf

California Department of Transportation (Caltrans) (2008b). Maintenance Technical Advisory Guide-Vol II Rigid Pavement Preservation. Second Edition. Sacramento. http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/Reference%20Documents/Operations%20and%20Maintenance/Maintenance%20Technical%20Advisory%20Guide%20-%20Volume%20II%20-%20Rigid%20Pavement%20Preservation.pdf

Caterpillar (2016). CB64. http://www.cat.com/en_US/products/new/equipment/compactors/tandem-vibratory-rollers/18243890.html. Accessed May 27, 2016.

Ceylan, H., et al. (2015). Rehabilitation of Concrete Pavements Utilizing Rubblization and Crack and Seat Methods. Report No. IHRB Project TR-473. Iowa State University Ames. http://www.intrans.iastate.edu/reports/rubblization.pdf

Chesner, W.H., R.J. Collins, and M.H. McKay. (1998). User Guidelines for Waste and By-Product Materials in Pavement Construction. Report No. FHWA-RD-97-148. Federal Highway Administration. Washington, DC.

Chevron (2002). http://www.chevron.com. Accessed 2002.

City of Lenexa (undated). Road Classification System. http://lenexa.com/Assets/departments/commdev/pdfs/road_classifications.pdf. Accessed Nov. 9, 2016.

Coopers and Lybrand, LLP Opinion Research Corporation, National Highway User Survey, 1995

Decker, D. (2006). Design and Construction Guidelines on Rubblizing and Overlaying PCC Pavements with Hot-Mix Asphalt. Information Series 132. National Asphalt Pavement Association. Lanham, MD. http://driveasphalt.org/assets/content/resources/IS-132_Rubblization.pdf

Environmental Protection Agency (2021). A Citizen's Guide to Capping. EPA 542-F-12-005. https://semspub.epa.gov/work/HQ/401585.pdf. Accessed May 12, 2022

Environmental Protection Agency (EPA) (1980). Porous Pavement: Phase I Design and Operational Criteria. No. EPA-600/2-80-135. Cincinnati.

Environmental Protection Agency (EPA) (2020). Remediation Technologies Screening Matrix and Reference Guide, Version 4. Federal Remediation Technologies Roundtable. https://frtr.gov/matrix2/section4/4-27.html. Accessed May 12, 2022.

Epps, J., and D. Newcomb (2014). Maintenance and Rehabilitation Strategies for Repair of Road Damage associated with Energy Development and Production. Research Report No. 409186-03. Texas A&M Transportation Institute. College Station.

Epps, J., Newcomb, D. and Gurganus, C. (2016). Current TxDOT Practices for Repair of Road Damage Associated with Energy Development and Production. Implementation Report 409186-0-1, Texas Department of Transportation. Austin.

Epps, J.A., and C.L. Monismith (1986). Equipment for Obtaining Pavement Condition and Traffic Loading Data. NCHRP Synthesis 116. Transportation Research Board. Washington DC.

European Asphalt Pavement Association (EAPA) (2014). Asphalt in Railway Tracks. Brussels. http://www.eapa.org/userfiles/2/Publications/EAPA%20paper%20-%20Asphalt%20in%20Railway%20Tracks%20-%20version%202014.pdf . Accessed June 1, 2016.

European Asphalt Pavement Association (EAPA) (2015). Driving Ahead with Sustainable Asphalt Roads. Brussels. http://www.eapa.org/promo.php?c=176. Accessed June 1, 2016.

Federal Aviation Administration (FAA) (2004). Rubblized Portland Cement Concrete Base Course. Engineering Brief No. 66. Washington, DC. https://www.faa.gov/airports/engineering/engineering_briefs/media/EB-66.pdf

Federal Highway Administration (2000). *WesTrack Track Roughness, Fuel Consumption, and Maintenance Cost*. Tech Brief No. FHWA-RD-00-052, Federal Highway Administration, Washington, DC, 2000.

Federal Highway Administration (FHWA) (1991). An Advanced Course in Pavement Management Systems. Washington, DC.

Federal Highway Administration (FHWA) (1998). Life Cycle Cost Analysis in Pavement Design. Publication No. FHWA-SA-98-079. Washington, DC https://www.fhwa.dot.gov/infrastructure/asstmgmt/013017.pdf

Federal Highway Administration (FHWA) (1999). Materials and Procedures for Sealing and Filling Cracks in asphalt Surfaced Pavements-Manual of Practice. Report No. FHWA-RD-99-147. Washington, DC. http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/99147/99147a.pdf

Federal Highway Administration (FHWA) (1999b). Materials and Procedures for Repair of Potholes in Asphalt-Surfaced Pavements - Manual of Practice. Report No. FHWA-RD-99-168. Washington, DC. http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/99168/99168.pdf

Federal Highway Administration (FHWA) (2002). Construction Inspection Checklist Series No. 1-Crack Seal Application. Report No. FHWA-IF-02-005-2002. Washington, DC. http://www.fhwa.dot.gov/pavement/preservation/ppcl01.pdf

Federal Highway Administration (FHWA) (2002). *Pavement Smoothness Index Relationships, Final Report.* Publication No. FHWA-RD-02-057. Federal Highway Administration. Office of Research, Development, and Technology. McLean, Virginia.

Federal Highway Administration (FHWA) (2002b). Construction Inspection Checklist. Pavement Preservation Checklist Series-03. Report No. FHWA-IF-02-049. Washington, DC. http://www.fhwa.dot.gov/pavement/preservation/ppcl03.pdf

Federal Highway Administration (FHWA) (2002c). Construction Inspection Checklist, Pavement Preservation Checklist Series-02. Report No. FHWA-IF-02-046. Washington, DC. http://www.fhwa.dot.gov/pavement/preservation/ppcl02.pdf

Federal Highway Administration (FHWA) (2003). Pavement Preservation Checklist Series No. 5. Report No. FHWA-IF-03-002. Washington, DC. http://www.fhwa.dot.gov/pavement/preservation/ppcl05.pdf

Federal Highway Administration (FHWA) (2003b). Pavement Preservation Checklist Series No. 4. Report No. FHWA-IF-03-001. Washington, DC. http://ww.fhwa.dot.gov/pavement/preservation/ppcl04.pdf

Federal Highway Administration (FHWA) (2006). Construction Inspection Checklist Series No. 13. Report No. FHWA-IF-06-014. Washington, DC. http://www.fhwa.dot.gov/pavement/preservation/ppcl13.pdf

Federal Highway Administration (FHWA) (2016). Guidance on Highway Preservation and Maintenance. Memorandum from W.C. Waidelich, W.C. to Directors of Field Services, Federal Lands Highway Division Engineers and Division Administrators. Federal Highway Administration. Washington, DC. https://www.fhwa.dot.gov/preservation/memos/160225.cfm

Federal Highway Administration (FHWA) (undated). Course Catalog for Pavement Maintenance. National Highway Institute. Washington, DC. http://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=paveemnt+maintenance&res=1

Frank, B. (2012). Recent Advances in Production Facilities. *Asphalt Technology*. vol. 81. Association of Asphalt Paving Technologists. Lino Lakes, MN. pp. 751-754.

FUROCK.com (December 7, 2010). Texas Rock Quarry Blast. Video. YouTube. https://www.youtube.com/watch?v=0npec5h_DPg. Accessed May 20, 2016.

Garcia, J., and K. Hansen (2001) *Mix Type Selection for Asphalt Pavements*. Publication IS-128. National Asphalt Pavement Assn. Lanham, MD.

Haas, R., W. R. Hudson, and J. Zaniewski (1994). *Modern Pavement Management*. Krieger Publishing Co. Malablar, FL.

Hansen, K. (2008) *Porous Asphalt Pavements for Stormwater Management*. Publication IS-131E. National Asphalt Pavement Assn. Lanham, MD.

Hansen, K. (2008). Porous Asphalt Pavement for Stormwater Management. IS-131. National Asphalt Pavement Association. Lanham, MD.

Hansen, K.R., and A. Copeland (2014) Annual Asphalt Pavement Industry Survey on Recycled Materials and Warm-Mix Asphalt Usage: 2009-2013. Report No. IS-138. National Asphalt Pavement Association. Lanham, MD.

Hansen, K.R., and A. Copeland (2015). Asphalt Pavement Industry Survey on Recycled Materials and Warm Mix Asphalt Usage: 2014. Report No. IS-138. National Asphalt Pavement Association. Lanham, MD.

Hardsurfacecleaning (undated). Asphalt Tennis Court After Cleaning. http://www.hardsurfacecleaning.co.uk/asphalt_surfaces. May 31, 2016.

Hassan, M. (undated). Life-Cycle Assessment of Warm-Mix Asphalt: An Environmental and Economic Perspective. Louisiana State University. http://www.ltrc.lsu.edu/ltc_09/pdf/Hassan,%20Marwa.pdf. Accessed May 15, 2016.

Hemmings, R.T., B.J. Cornelius, P. Yuran and M. Wu (2009). Comparative Study of Lightweight Aggregates. 2009 World of Coal Ash Conference. Lexington, KY.

Hicks, R.G., and J.P. Mahoney (1981). Collection and Use of Pavement Condition Data. NCHRP Synthesis 76. Transportation Research Board. Washington, D.C.

http://store.asphaltpavement.org/index.php?productID=748

http://www.asphaltpavement.org/images/stories/is-135.pdf

http://www.nhi.fhwa.dot.gov/training/course_search.aspx?tab=0&key=concrete+maintenance&res=1

Humer, B. (1993). Asphalt Reservoir Liner Allows for State-of-the-Art Seepage Monitoring System. *Asphalt*. Vol. 9, No. 2. The Asphalt Institute. Lexington, KY.

International Tennis Federation (ITF) (2019). Building an Asphalt Court. https://www.itftennis.com/media/2233/courts-building-an-asphalt-court.pdf. Accessed May 24, 2022.

L.L. Pelling, Inc. (2016). http://www.llpelling.com/projects/recreationother/. Accessed May 31, 2016.

Liu, W., and Scullion, T. (2011). *Flexible Pavement Design System FPS-21: User's Manual*. Texas A&M Transportation Institute. College Station. http://pavementdesign.tamu.edu/manuals/FPS21.pdf

Mahoney, J.P., C.L. Monismith, J. Coplantz, J. Harvey, V. Kannekanti, L. Pierce, J. Uhlmeyer, N. Sivaneswaran, and T. Hoover. (2007). Pavement Lessons Learned from the 50-Year-Old Interstate Highway System: California, Oregon, and Washington. *E-Circular No. 118*. Transportation Research Board. Washington, DC. pp. 88-103.

Mahoney, J.P. and S. Muench. Materials. *Pavement Interactive.* Pavia. www.pavementinteractive.com. 2012.

Marks, Howard, PhD. (2009). Smoothness Matters: The Influence of Pavement on Fuel Consumption. *Hot Mix Asphalt Technology* Vol. 14, No. 6, pp. 18-29, available

Martin-Marietta (2016). Limestone Rock Asphalt (LRA). http://www.martinmarietta.com/Safety-Data-Sheets/. Accessed May 20, 2016).

Minnesota Asphalt Pavement Association (MAPA) (2014). Asphalt Paving Design Guide. New Brighton, MN.

Missouri Department of Transportation. Pavement Smoothness and Fuel Efficiency: An Analysis of the Economic Dimensions of the Missouri Smooth Roads Initiative. November 2006.

National Asphalt Pavement Association (2002). A Guideline for the Design and Construction of Hot Mix Asphalt Pavements for Trails and Paths. IS 129. Lanham, MD.

National Asphalt Pavement Association (NAPA) (1991). Guidelines for Use of HMA Overlays to Rehabilitate PCC Pavements. Information Series 117. Lanham, MD.

National Asphalt Pavement Association (NAPA) (2015). PAVExpress Adds Asphalt Overlay Design Feature. Lanham, MD. http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=1064

National Asphalt Pavement Association (NAPA) (undated). Schematic of Paving Machine.

National Asphalt Pavement Association (NAPA). (2016). Engineering Overview. http://www.asphaltpavement.org/index.php?option=com_content&view=article&id=14&Itemid=33. Accessed May 15, 2016.

National Asphalt Pavement Association. Lanham, MD. http://www.asphaltpavement.org/images/stories/is-135.pdf

National Center for Pavement Preservation (NCPP) (2016). Preservation Definitions. Michigan State University. Lansing. https://www.pavementpreservation.org

Nemati, K.M. (2015) Course Notes for CM425. Concrete Technology. University of Washington.

New Jersey Department of Environmental Protection (NJDOEP) (2014). Technical Guidance on the Capping of Sites Undergoing Remediation, Version 1. Site Remediation Program. http://www.nj.gov/dep/srp/guidance/srra/capping_remediation_sites.pdf. Accessed May 30, 2016.

Newcomb, D. (2009). Thin Asphalt Overlays for Pavement Preservation. Information Series 135. National Asphalt Pavement Association. Lanham, MD.

Newcomb, D.E., D. Timm, and R. Willis (2010) *Perpetual Pavements – A Synthesis*. Report No. APA 101, Asphalt Pavement Alliance, Lexington, KY.

Newcomb, D.E., J.A. Epps and F. Zhou. (2016). Use of RAP & RAS in High Binder Replacement Asphalt Mixtures: A Synthesis. Special Report 213. National Asphalt Pavement Association. Lanham, MD.

Newcomb, D.E., M. Stroup-Gardiner, B. Weikle, and A. Drescher. 1993. *Influence of Roofing Shingles on Asphalt Concrete Mixture Properties*. Report MN/RC-93/09. Minnesota Department of Transportation. St. Paul, MN.

Organization for Economic Co-operation and Development (OECD) (1987). Pavement Management Systems. Paris.

Pavia Systems (2012) Pavement Interactive. www.pavementinteractive.com. Seattle.

Pavia Systems (2014) PAVExpress. Online Software. Seattle.

Perera, R.W., C. Byrum, and S.D. Kohn (1997). *Roughness Trends of Flexible Pavements*. Report No. FHWA-RD-97-147. Federal Highway Administration, Washington, DC.

Peterson, D.E. Pavement Management Practices (1987). NCHRP Synthesis 135, Transportation Research Board. Washington, DC.

Pro Dunk Hoops (2016). Pro Dunk Platinum on Half-court in MA. http://www.produnkhoops.com/photos/albums/michael-36x36-pro-dunk-platinum-basketball-system-124/. Accessed May 31, 2016.

Public Works Journal Corp. (2002). Asphalt Reconstruction of the Atlanta Beltway. *Public Works*. vol. 133. No. 1. Ridgewood, NJ. pp. 24-26.

Raleigh Paving Co (2016). Specialty Sport Surfaces. http://www.raleighpaving.com/specialty/sport-surfaces/. Accessed June 1, 2016.

Rand, D. (2011). Update on Permeable Friction Courses (PFC) in Texas. Slide Presentation. Louisiana Transportation Conference. Baton Rouge. https://www.ltrc.lsu.edu/ltc_11/pdf/Update%20on%20Permeable%20Friction%20Courses%20(PFC)%20in%20Texas.pdf. Accessed May 15, 2016.

Robinette, C., and Epps, J. (2000). Energy, Emissions, Materials Conservation and Prices Associated with Construction, Rehabilitation and Materials Alternatives for Flexible Pavement. TRB Compendium of Papers. Transportation Research Board. Washington, DC.

Robinette, C., and J.A. Epps. (2010). Energy, Emissions, Materials Conservation, and Prices Associated with Construction, Rehabilitation, and Material Alternatives for Flexible Pavement. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2179*. Transportation Research Board of the National Academies. Washington, DC. pp. 10–22.

Rose, J.G., P.F. Teixeira, and N.E. Ridgway (2010). Utilization of Asphalt/Bituminous Layers and Coatings in Railway Trackbeds – A Compendium of International Applications. *Proceedings*. 2010 Joint Rail Conference. Urbana, IL.

Sims, T.B. (2014). Texas Pavement Preservation Program. http://www.utexas.edu/research/tppc/pubs/sims.pdf

Smit, Andre de Fortier, et. al. Selection and Design of Quiet Pavement Surfaces. Texas Department of Transportation. (2016)

Smith, A.W., and K.A. Dyer (1973) *Triaxial Classification of the Surface Soils of Texas as Grouped by Soil Conservation Service Series*. Report No. 3-05-71-035. Texas Highway Department. Austin.

Texas Asphalt Pavement Association (TXAPA) (2016). Asphalt Mixture Specifications for Local Governments. Buda, TX.

Texas Asphalt Pavement Association (TXAPA) (2018). Asphalt Pavement Mix Types. Buda, TX.

Texas Department of Transportation (TxDOT) (2015). Concrete Repair Manual. Austin. http://onlinemanuals.txdot.gov/txdotmanuals/crm/index.htm

Texas Department of Transportation (TxDOT) (2021). Maintenance Operations Manual, Section 2: Routine Pavement Maintenance. Austin http://onlinemanuals.txdot.gov/txdotmanuals/ope/ope.pdf

Texas Department of Transportation (TxDOT) (2017). Seal Coat and Surface Treatment Manual. Austin. http://onlinemanuals.txdot.gov/txdotmanuals/scm/index.htm

Texas Department of Transportation (TxDOT) (2013b). Seal Coat Material Selection Table. Form 2388 Rev. 09/13. Austin.

http://www.txdot.gov/txdoteforms/GetForm?formName=/2388.xdp&appID=/CST&status=/reportError.jsp&configFile=WFServletConfig.xml

Texas Department of Transportation (TxDOT) (2014). Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges. Austin.

Texas Department of Transportation (TxDOT) (2021). Special Specification 3077, Asphalts, Oils, and Emulsions.

Texas Department of Transportation (TxDOT) (2019). Special Specification 3096, Superpave Mixtures.

Texas Department of Transportation (TxDOT) (2016). Test Method Tex-205-F, Laboratory Method of Mixing Bituminous Mixtures.

Texas Department of Transportation (TxDOT) (2020). Maintenance Management Manual. Austin http://onlinemanuals.txdot.gov/txdotmanuals/mmt/index.htm

Texas Department of Transportation (TxDOT) (2021). Pavement Manual. http://onlinemanuals.txdot.gov/txdotmanuals/pdm/manual_notice.htm

Texas State Historical Association (TSHA) (2016). Uvalde County Limestone Rock Asphalt. *The Handbook of Texas*. https://tshaonline.org/handbook/online/articles/gpu01. Accessed May 19, 2016.

Timm, D.H. (2008) PerRoadXpress. On-line Software. Auburn, AL.

Tran, N., P. Turner, and J. Shambley (2016). Enhanced Compaction to Improve Durability and Extend Pavement Service Life: A Literature Review. Report No. 16-02R. National Center for Asphalt Technology. Auburn, AL.

Transportation Research Board (TRB) (2013). Glossary of Transportation Construction Quality Assurance Terms. E-Circular 173. Washington DC.

United States Army Corps of Engineers (USACE) (2000). *Hot-Mix Asphalt Paving Handbook*.

United States Geological Survey (USGS) (2008). Mineral Industry Surveys. Reston, VA.

University of Idaho. (2016). Waste Facility Construction Requirements. University of Idaho. Idaho One Plan. http://www.oneplan.org/Stock/wasteFac/manual3.asp. Accessed May 30, 2016.

Van Dam, T., Harvey, J., Muench, S., Smith, K., Snyder, M., Al-Qadi, I., Meijer, O., Ram, P., Roesler, J. and Kendall, A. (2015). Towards Sustainable Pavement Systems: A Reference Document. FHWA-HIF-15-002. Federal Highway Administration. Washington, DC.

Volvo (2016). PT240R Pneumatic Tire Compactor. www.volvo.com. Accessed May 27, 2016.

Walker, D., and J. Davis (2016). Current Practices for Transporting Asphalt Binders. *Asphalt.* online magazine. Asphalt Institute. Lexington, KY. http://asphaltmagazine.com/current-practices-for-transporting-asphalt-binder/. Accessed May 19, 2016.

Waste Management World. Landfill. https://waste-management-world.com. Accessed June 1, 2016.

Wayson, Roger L. (1998). *Relationship between Pavement Surface Texture and Highway Traffic Noise.* NCHRP Synthesis 268. Transportation Research Board, Washington, DC.

Weiler, Inc. E2850 Remixing Transfer Vehicle. http://www.weilerproducts.com/equipment/remixing-transfer-vehicles/e2850-remixing-transfer-vehicle-2/. Accessed May 27, 2016.

Wells, W., M. Y. Shahin, R. E. Smith, and M. I. Darter (1985). Implementing Pavement Management Systems, Do's and Don'ts at the City/County Level. Proceedings, North American Pavement Management Conference, Ontario Ministry of Transportation and Communication, Toronto.

Westhead, M. (2014). Basketball Court Costs. Blog. http://basketballhoopsblog.com/2014/02/03/basketball-court-costs/. Accessed May 31, 2016.

York Building Products. Sand and Gravel. www.yorkbuilding.com. Accessed May 27, 2016.

Item 341M Municipal Dense-Graded Hot-Mix Asphalt

1. DESCRIPTION

Construct a hot-mix asphalt (HMA) pavement layer composed of a compacted, dense-graded mixture of aggregate, asphalt binder, and additives mixed hot in a mixing plant.

Furnish uncontaminated materials of uniform quality that meet the requirements of the plans and specifications.

2. MATERIALS

Notify the Engineer of all material sources and before changing any material source or formulation. The Engineer will verify that the specification requirements are met and document all material source changes when the Contractor makes a source or formulation change. The Engineer may sample and test project materials anytime during the project to verify specification compliance.

Substitution: An TxDOT approved existing dense graded (341/3076) or Superpave (344/3077) mix design is considered an equal or better substitution and may be substituted for this item.

2.1 **Aggregate**. Furnish aggregates from sources that conform to the requirements shown in Table 1 and this Section. Aggregate requirements in this Section, including those shown in Table 1, may be modified or eliminated when shown on the plans. Additional aggregate requirements may be specified when shown on the plans. Provide aggregate stockpiles that meet the definitions in this Section for coarse, intermediate, or fine aggregate. Aggregate from reclaimed asphalt pavement (RAP) is not required to meet Table 1 requirements unless otherwise shown on the plans. Supply aggregates that meet the definitions in Tex-100-E for crushed gravel or crushed stone. The Engineer will designate the plant or the quarry as the sampling location. Provide samples from materials produced for the project. The Engineer will establish the Surface Aggregate Classification (SAC) and perform Los Angeles abrasion, magnesium sulfate soundness, and Micro-Deval tests. Perform all other aggregate quality tests shown in Table 1. Document all test results in the mixture design report. The Engineer may perform tests on independent or split samples to verify Contractor test results. Stockpile aggregates for each source and type separately. Determine aggregate gradations for mixture design and production testing based on the washed sieve analysis in accordance with Tex-200-F, Part II.

2.1.0. **Coarse Aggregate**. Coarse aggregate stockpiles must have no more than 20% material passing the No. 8 sieve. Aggregates from sources listed in the TxDOT's Department's *Bituminous Rated Source Quality Catalog* (BRSQC) are preapproved for use. Use only the rated values for HMA listed in the BRSQC. Rated values for surface treatment (ST) do not apply to coarse aggregate sources used in HMA.

For sources not listed in the TxDOT's BRSQC:

- build an individual stockpile for each material;
- test the stockpile for specification compliance;
- use only when tested and approved; and
- once approved, do not add additional material to the stockpile unless otherwise allowed by the Engineer.

Provide coarse aggregate with at least the minimum SAC shown on the plans. SAC requirements apply only to aggregates used on the surface of travel lanes, unless otherwise shown on the plans. The SAC for sources in the TxDOT's *Aggregate Quality Monitoring Program* (AQMP) (Tex-499-A) is listed in the BRSQC.

2.1.0.1. **Blending Class A and Class B Aggregates**. Class B aggregate meeting all other requirements shown in Table 1 may be blended with a Class A aggregate to meet requirements for Class A materials, unless otherwise shown on the plans. When blending Class A and Class B aggregates to meet a Class A requirement, ensure that at least 50% by weight, or volume if required, of the material retained on the No. 4 sieve comes from the Class A aggregate source, unless otherwise shown on the plans. Blend by volume if the bulk specific gravities of the Class A and Class B aggregates differ by more than 0.300. Coarse aggregate from RAP will be considered as Class B aggregate for blending purposes.

The Engineer may perform tests anytime during production, when the Contractor blends Class A and Class B aggregates to meet a Class A requirement. The Engineer will use TxDOT's mix design template, when electing to verify conformance, to calculate the percent of Class A aggregate retained on the No. 4 sieve by inputting the bin percentages shown from readouts in the control room at the time of production and stockpile gradations measured at the time of production. The Engineer may determine the gradations based on either washed or dry sieve analysis from samples obtained from individual aggregate cold feed bins or aggregate stockpiles. The Engineer may perform spot checks to verify the percent of Class A aggregate retained on the No. 4 sieve. The Engineer will use the gradations supplied by the Contractor in the mixture design report as an input for the template. A failing spot check will require confirmation with a stockpile gradation determined by the Engineer.

2.1.0.2. **Micro-Deval Abrasion**. The Engineer may perform at least one Micro-Deval abrasion test in accordance with Tex-461-A for each coarse aggregate source used in the mixture design that has a rated source soundness magnesium (RSSM) loss value greater than 15 as listed in the BRSQC. The Engineer may perform testing before the start of production and may perform additional testing anytime during production. The Engineer may obtain the coarse aggregate samples from each coarse aggregate source or may require the Contractor to obtain the samples. The Engineer may waive all Micro-Deval testing based on a satisfactory test history of the same aggregate source.

The Engineer will estimate the magnesium sulfate soundness loss for each coarse aggregate source, when tested, using the following formula:

$$Mg_{est.} = (RSSM)(MD_{act.}/RSMD)$$

where:
$Mg_{est.}$ = magnesium sulfate soundness loss
$RSSM$ = rated source soundness magnesium
$MD_{act.}$ = actual Micro-Deval percent loss
$RSMD$ = rated source Micro-Deval

When the estimated magnesium sulfate soundness loss is greater than the maximum magnesium sulfate soundness loss specified, the coarse aggregate source will not be allowed for use unless otherwise approved.

2.1.1. **Intermediate Aggregate**. Aggregates not meeting the definition of coarse or fine aggregate will be defined as intermediate aggregate. Supply intermediate aggregates, when used, that are free of organic impurities. Supply intermediate aggregate from coarse aggregate sources, when used, that meet the requirements shown in Table 1, unless otherwise approved.

Test the stockpile if 10% or more of the stockpile is retained on the No. 4 sieve, and verify that it meets the requirements in Table 1 for crushed face count (Tex-460-A) and flat and elongated particles (Tex-280-F).

2.1.2. **Fine Aggregate**. Fine aggregates consist of manufactured sands, screenings, and field sands. Fine aggregate stockpiles must meet the fine aggregate properties in accordance with Table 1 and the gradation requirements in accordance with Table 2. Supply fine aggregates that are free of organic impurities. The Engineer may test the fine aggregate in accordance with Tex-408-A to verify the material is free of organic

impurities. Unless otherwise shown on the plans, at most 10% of the total aggregate may be field sand or other uncrushed fine aggregate. Use fine aggregate, except field sand, from coarse aggregate sources that meet the requirements shown in Table 1, unless otherwise approved.

Test the stockpile if 10% or more of the stockpile is retained on the No. 4 sieve and verify that it meets the requirements in Table 1 for crushed face count (Tex-460-A) and flat and elongated particles (Tex-280-F).

Table 1
Aggregate Quality Requirements

1. Property	2. Test Method	3. Requirement
4. Coarse Aggregate		
Surface Aggregate Classification SAC	6. Tex-499-A (AQMP)	7. As shown on the plans
Deleterious material, %, Max	9. Tex-217-F, Part I	10. 1.5
Decantation, %, Max	12. Tex-217-F, Part II	13. 1.5
Micro-Deval abrasion, %	15. Tex-461-A	16. Note [1]
Los Angeles abrasion, %, Max	18. Tex-410-A	19. 40
Magnesium sulfate soundness, 5 cycles, %, Max	21. Tex-411-A	22. 30
Crushed face count,[2] %, Min	24. Tex-460-A, Part I	25. 85
Flat and elongated particles @ 5:1, %, Max	27. Tex-280-F	28. 10
29. Fine Aggregate		
Linear shrinkage, %, Max	31. Tex-107-E	32. 3
Sand equivalent, %, Min	34. Tex-203-F	35. 45[3]
Organic impurities	37. Tex-408-A	38. Note [4]

1. Used to estimate the magnesium sulfate soundness loss in accordance with Section 341.2.1.1.2., "Micro-Deval Abrasion."
2. Only applies to crushed gravel.
3. The Engineer may perform Tex-252-F on fine aggregates not meeting this minimum requirement. Fine aggregates with a methylene blue value of 10.0 mg/g or less may be used.
4. Optional test.

Table 2
Gradation Requirements for Fine Aggregate

Sieve Size	% Passing by Wt. Or Volume
3/8"	100
#8	70–100
#200	0–30

2.2. **Mineral Filler**. Mineral filler consists of finely divided mineral matter such as agricultural lime, crusher fines, hydrated lime, or fly ash. Mineral filler is allowed unless otherwise shown on the plans. Use no more than 2% hydrated lime or fly ash, unless otherwise shown on the plans. Use no more than 1% hydrated lime if a substitute binder is used, unless otherwise shown on the plans or allowed. Test all mineral fillers except hydrated lime and fly ash in accordance with Tex-107-E to ensure specification compliance. The plans may require or disallow specific mineral fillers. Provide mineral filler, when used, that:

- is dry enough, free-flowing, and free of clumps and foreign matter as determined by the Engineer;
- does not exceed 3% linear shrinkage when tested in accordance with Tex-107-E; and
- meets the gradation requirements shown in Table 3, unless otherwise shown on the plans.

Table 3
Gradation Requirements for Mineral Filler

Sieve Size	% Passing by Wt. or Volume
#8	100
#200	55–100

2.3. **Baghouse Fines**. Fines collected by the baghouse or other dust-collecting equipment may be reintroduced into the mixing drum.

2.4. **Asphalt Binder**. Furnish the type and grade of performance-graded (PG) asphalt binder shown on the plans that meets the requirements of Item 300, "Asphalts, Oils, and Emulsions."

2.5. **Tack Coat**. Furnish CSS-1H, SS-1H, EBL, or a PG binder with a minimum high-temperature grade of PG 58 for tack coat binder in accordance with Item 300. Specialized tack coat materials on TxDOT's Material Producer List (MPL) for *Tracking Resistant Asphalt Interlayer* (TRAIL) will be allowed or required when shown on the plans. Do not dilute emulsified asphalt at the terminal, in the field, or at any other location before use, unless required in conformance with the manufacturer's recommendation for approved TRAIL products on the MPL.

2.6. **Additives**. Use the type of additive specified when shown on the plans. Use the rate of additive specified in conformance with the manufacturer's recommendation. Additives that facilitate mixing and compaction, or improve the quality of the mixture are allowed when approved. Provide the Engineer with documentation such as the bill of lading showing the quantity of additives used in the project unless otherwise directed.

2.6.0. **Lime and Liquid Antistripping Agent**. Lime or liquid antistripping agent is required when shown on the plans. When lime or a liquid antistripping agent is used, add in accordance with Item 301, "Asphalt Antistripping Agents." Do not add lime directly into the mixing drum of any plant where lime is removed through the exhaust stream unless the plant has a baghouse or dust collection system that reintroduces the lime into the drum.

2.6.1. **Warm-Mix Asphalt (WMA)**. WMA is defined as HMA that is produced within a target temperature discharge range of 215°F and 275°F using approved WMA additives or processes from the MPL.

WMA is allowed for use on all projects and is required when shown on the plans. When WMA is required, the maximum placement or target discharge temperature for WMA will be set at a value at or below 275°F.

MPL-approved WMA additives or processes may be used to facilitate mixing and compaction of HMA produced at target discharge temperatures above 275°F; however, such mixtures will not be defined as WMA.

2.6.2. **Compaction Aid**. Compaction aid is defined as a MPL-approved chemical warm-mix additive, denoted as "chemical additive" on the MPL, that is used to facilitate mixing and compaction of HMA at a discharge temperature greater than 275°F.

Compaction aid is allowed for use on all projects. Compaction aid is required when shown on the plans or as required in Section 341.4.7.1., "Weather Conditions."

Warm-mix foaming processes, denoted as "foaming process" on the MPL, may be used to facilitate mixing and compaction of HMA at target discharge temperatures greater than 275°F; however, warm-mix foaming processes are not defined as a compaction aid.

2.7. **Recycled Materials**. Use of RAP is permitted unless otherwise shown on the plans. Do not exceed the maximum allowable percentages of RAP in accordance with Table 4. The allowable percentages in accordance with Table 4 may be decreased or increased when shown on the plans. Determine the asphalt binder content and gradation of the RAP stockpiles for mixture design purposes in accordance with

Tex-236-F, Part I. The Engineer may verify the asphalt binder content of the stockpiles anytime during production. Perform other tests on RAP when shown on the plans. Use a separate cold feed bin for each stockpile of RAP during HMA production.

Surface, intermediate, and base mixes referenced in Table 4 and Table 5 are defined as follows, unless otherwise shown on the plans.

- **Surface**. The final HMA lift placed at the top of the pavement structure.
- **Intermediate**. Mixtures placed below an HMA surface mix and less than or equal to 8.0 in. below the riding surface.
- **Base**. Mixtures placed greater than 8.0 in. below the riding surface. Unless otherwise shown on the plans, mixtures used for bond breaker are defined as base mixtures.

2.7.0. **RAP**. RAP is salvaged, milled, pulverized, broken, or crushed asphalt pavement. Fractionated RAP is defined as a stockpile that contains RAP material with at least 95.0% passing the 1/2-in. sieve, before burning in the ignition oven, unless otherwise approved. The Engineer may allow the Contractor to use an alternate to the 1/2-in. screen to fractionate the RAP.

Use of Contractor-owned RAP, including HMA plant waste, is permitted unless otherwise shown on the plans. Perform any necessary tests to ensure RAP is appropriate for use. The Contractor will retain ownership of RAP generated on the project unless otherwise shown on the plans.

Do not use RAP contaminated with dirt or other objectionable materials. Do not use RAP if the decantation value exceeds 5% and the plasticity index is greater than 8. Test the stockpiled RAP for decantation in accordance with Tex-406-A, Part I. Determine the plasticity index in accordance with Tex-106-E if the decantation value exceeds 5%. The decantation and plasticity index requirements do not apply to RAP samples with asphalt removed by extraction or ignition.

Remove unused Contractor-owned RAP material from the project site upon completion of the project.

Table 4
Max Allowable Amounts of Fractionated RAP

39. Max Allowable 40. Fractionated RAP (%)		
1. Surface	Intermediate	43. Base
44. 20.0	45. 30.0	46. 35.0

2.8. **Substitute Binders**. No binder substitution will be allowed when shown on the plans. The Contractor may use a substitute PG binder shown in Table 5 instead of the PG binder originally specified, if using recycled materials, and if the substitute PG binder and mixture made with the substitute PG binder meet the following.

- The substitute binder meets the specification requirements for the substitute binder grade in accordance with Section 300.2.10., "Performance-Graded (PG) Binders."
- The mixture has less than 10.0 mm of rutting on the Hamburg wheel test (Tex-242-F) after the number of passes required for the originally specified binder. Use of substitute PG binders may be allowed only at the discretion of the Engineer if the Hamburg wheel test results are between 10.0 mm and 12.5 mm.

Table 5
Allowable PG Binders

Originally Specified PG Binder	Allowable Substitute PG Binder for Surface Mixes	Allowable Substitute PG Binder for Intermediate and Base Mixes
76-22	70-22	70-22
70-22	N/A	64-22
64-22	N/A	N/A
76-28	70-28	70-28
70-28	N/A	64-28
64-28	N/A	N/A

3. EQUIPMENT

Provide required or necessary equipment in accordance with TxDOT Item 320, "Equipment for Asphalt Concrete Pavement."

4. CONSTRUCTION

Produce, haul, place, and compact the specified paving mixture. In addition to tests required in accordance with the Specification, the Contractor may perform other QC tests as necessary. Anytime during the project, the Engineer may perform production and placement tests as necessary. Schedule and participate in a mandatory pre-paving meeting with the Engineer on or before the first day of paving unless otherwise shown on the plans.

4.1. **Certification**. Personnel certified by the TxDOT-approved HMA certification program (www.TXHMAC.org) must conduct all mixture designs, sampling, and testing in accordance with Table 6. Supply the Engineer with a list of certified personnel and copies of their current certificates before beginning production and when personnel changes are made. Provide a mixture design developed and signed by a Level 2-certified specialist. Provide Level 1A-certified specialists at the plant during production operations. Provide Level 1B-certified specialists to conduct placement tests. Provide Level AGG101-certified specialists for aggregate testing.

Table 6
Test Methods, Test Responsibility, and Min Certification Levels

Test Description	Test Method	Contractor	Engineer	Level[1]
Aggregate and Recycled Material Testing				
Sampling	Tex-221-F	✓	✓	1A/AGG101
Dry sieve	Tex-200-F, Part I	✓	✓	1A/AGG101
Washed sieve	Tex-200-F, Part II	✓	✓	1A/AGG101
Deleterious material	Tex-217-F, Part I and Part III	✓	✓	AGG101
Decantation	Tex-217-F, Part II	✓	✓	AGG101
Los Angeles abrasion	Tex-410-A		✓	Engineer
Magnesium sulfate soundness	Tex-411-A		✓	Engineer
Micro-Deval abrasion	Tex-461-A		✓	AGG101
Crushed face count	Tex-460-A	✓	✓	AGG101
Flat and elongated particles	Tex-280-F	✓	✓	AGG101
Linear shrinkage	Tex-107-E	✓	✓	AGG101
Sand equivalent	Tex-203-F	✓	✓	AGG101
Bulk-specific gravity	Tex-201-F	✓	✓	AGG101

Test Description	Test Method	Contractor	Engineer	Level[1]
Asphalt Binder and Tack Coat Sampling				
Asphalt binder sampling	Tex-500-C, Part II	✓	✓	1A/1B
Tack coat sampling	Tex-500-C, Part III	✓	✓	1A/1B
Mix Design and Verification				
Design and job-mix formula (JMF) changes	Tex-204-F	✓	✓	2
Mixing	Tex-205-F	✓	✓	2
Molding (Superpave gyratory compactor [SGC])	Tex-241-F	✓	✓	1A
Laboratory-molded density	Tex-207-F, Part I and Part VI	✓	✓	1A
Rice gravity	Tex-227-F, Part II	✓	✓	1A
Indirect tensile strength	Tex-226-F	✓	✓	1A
Hamburg wheel test	Tex-242-F	✓	✓	1A
Production Testing				
Selecting production random numbers	Tex-225-F, Part I		✓	1A
Mixture sampling	Tex-222-F	✓	✓	1A/1B
Molding (SGC)	Tex-241-F	✓	✓	1A
Laboratory-molded density	Tex-207-F, Part I and Part VI	✓	✓	1A
Rice gravity	Tex-227-F, Part II	✓	✓	1A
Gradation and asphalt binder content[2]	Tex-236-F, Part I	✓	✓	1A
Control charts	Tex-233-F	✓	✓	1A
Moisture content	Tex-212-F, Part II	✓	✓	1A/AGG101
Hamburg wheel test	Tex-242-F	✓	✓	1A
Micro-Deval abrasion	Tex-461-A		✓	AGG101
Abson recovery	Tex-211-F		✓	Engineer
Placement Testing				
Selecting placement random numbers	Tex-225-F, Part II		✓	1B
Trimming roadway cores	Tex-251-F, Part I and Part II	✓	✓	1A/1B
In-place air voids	Tex-207-F, Part I and Part VI	✓	✓	1A
In-place density (gauge method)	Tex-207-F, Part III	✓		1B
Establish rolling pattern	Tex-207-F, Part IV	✓		1B
Control charts	Tex-233-F	✓	✓	1A
Ride quality measurement	Tex-1001-S	✓	✓	Note[2]

1. Levels 1A, 1B, AGG101, and 2 are certification levels provided by the Hot Mix Asphalt Center certification program. www.TXHMAC.org
2. Profiler and operator are required to be certified at the Texas A&M Transportation Institute facility when surface test Type B is specified.

4.2. **Reporting and Responsibilities**. Use TxDOT-provided or approved templates to record and calculate all test data, including mixture design, production and placement QC and QA, control charts, The Engineer and the Contractor will provide any available test results to the other party when requested. The maximum allowable time for the Contractor and Engineer to exchange test data is as shown in Table 7, unless otherwise approved. The Engineer and the Contractor will immediately report to the other party any test result that requires suspension of production or placement, or that fails to meet the specification requirements. Record and electronically submit all test results and pertinent information on TxDOT-provided templates.

Subsequent sublots placed after test results are available to the Contractor, which require suspension of operations, may be considered unauthorized work. Unauthorized work will be accepted or rejected at the discretion of the Engineer in accordance with Article 5.3., "Conformity with Plans, Specifications, and Special Provisions."

Table 7
Reporting Schedule

Description	Reported By	Reported To	To Be Reported Within
Quality Control			
Gradation Asphalt binder content Laboratory-molded density In-place air voids	Contractor	Engineer	1 working day of completion of the lot
Quality Assurance			
Gradation Asphalt binder content Laboratory-molded density In-place air voids Hamburg wheel test[1]	Engineer	Contractor	1 working day of completion of the lot

1. Optional Test.

Use the procedures described in Tex-233-F to plot the results of all QC and QA testing. Update the control charts as soon as test results for each sublot become available. Make the control charts readily accessible at the field laboratory. The Engineer may suspend production for failure to update control charts.

4.3 Quality Control Plan (QCP). Develop and follow the QCP in detail. Obtain approval for changes to the QCP made during the project. The Engineer may suspend operations if the Contractor fails to comply with the QCP.

Submit a written QCP before the mandatory pre-paving meeting. Receive approval of the QCP before beginning production. Include the following items in the QCP.

4.3.1 Project Personnel. For project personnel, include:

- a list of individuals responsible for QC with authority to take corrective action,
- current contact information for each individual listed, and
- current copies of certification documents for individuals performing specified QC functions.

4.3.2 Material Delivery and Storage. For material delivery and storage, include:

- the sequence of material processing, delivery, and minimum quantities to assure continuous plant operations;
- aggregate stockpiling procedures to avoid contamination and segregation;
- frequency, type, and timing of aggregate stockpile testing to assure conformance with material requirements before mixture production; and
- procedure for monitoring the quality and variability of asphalt binder.

4.3.3 Production. For production, include:

- loader operation procedures to avoid contamination in cold bins;
- procedures for calibrating and controlling cold feeds;
- procedures to eliminate debris or oversized material;

- procedures for adding and verifying rates of each applicable mixture component (e.g., aggregate, asphalt binder, RAP, lime, liquid antistrip, compaction aid, foaming process, and WMA);
- procedures for reporting job control test results; and
- procedures to avoid segregation and drain-down in the silo.

4.3.4 Loading and Transporting. For loading and transporting, include:

- type and application method for release agents, and
- truck-loading procedures to avoid segregation.

4.3.5 Placement and Compaction. For placement and compaction, include:

- proposed agenda for mandatory pre-paving meeting, including date and location;
- proposed paving plan (e.g., production rate, paving widths, joint offsets, and lift thicknesses);
- type and application method for release agents in the paver and on rollers, shovels, lutes, and other utensils;
- procedures for the transfer of mixture into the paver while avoiding segregation and preventing material spillage;
- process to balance production, delivery, paving, and compaction to achieve continuous placement operations and good ride quality;
- paver operations (e.g., speed, operation of wings, and height of mixture in auger chamber) to avoid segregation and other surface irregularities; and
- procedures to construct quality longitudinal and transverse joints.

4.4 Mixture Design.

4.4.1. Design Requirements. Use the dense-graded design procedure provided in Tex-204-F, unless otherwise shown on the plans. Design the mixture to meet the requirements shown in Tables 1, 2, 3, 4, 5, 8, 9, and 10.

Design the mixture using an SGC, and 50 gyrations as the design number of gyrations (Ndesign). Use a target laboratory-molded density of 96.0% to design the mixture; however, adjustments can be made to the Ndesign value as shown in Table 9. The Ndesign level may be reduced to at least 35 gyrations at the Contractor's discretion.

Provide the Engineer with a mixture design report that meets the specifications. Include the following items in the report:

- the combined aggregate gradation, source, specific gravity, and percent of each material used;
- the binder source and optimum design asphalt content;
- asphalt binder content and aggregate gradation of RAP stockpiles;
- the Ndesign level used on the SGC);
- results of all applicable tests;
- the mixing and molding temperatures;
- the signature of the Level 2 person or persons who performed the design;
- the date the mixture design was performed; and
- a unique identification number for the mixture design.

Table 8
Master Gradation Limits (% Passing by Wt. or Volume) and Void in Mineral Aggregate (VMA) Requirements

Sieve Size	DG-B Fine Base	DG-C Coarse Surface	DG-D Fine Surface	DG-F Fine Mixture
2"	–	–	–	–

Sieve Size	DG-B Fine Base	DG-C Coarse Surface	DG-D Fine Surface	DG-F Fine Mixture
1-1/2"	100.0[1]	–	–	–
1"	98.0–100.0	100.0[1]	–	–
3/4"	84.0–98.0	95.0–100.0	100.0[1]	–
1/2"	–	–	98.0–100.0	100.0[1]
3/8"	60.0–80.0	70.0–85.0	85.0–100.0	98.0–100.0
#4	40.0–60.0	43.0–63.0	50.0–70.0	70.0–90.0
#8	29.0–43.0	32.0–44.0	35.0–46.0	38.0–48.0
#30	13.0–28.0	14.0–28.0	15.0–29.0	12.0–27.0
#50	6.0–20.0	7.0–21.0	7.0–20.0	6.0–19.0
#200	2.0–7.0	2.0–7.0	2.0–7.0	2.0–7.0
Design VMA), % Min				
–	13.0	14.0	15.0	16.0
Production (Plant-Produced) VMA), % Min				
–	12.5	13.5	14.5	15.5

1. Defined as Max sieve size. No tolerance allowed.

Table 9
Laboratory Mixture Design Properties

Mixture Property	Test Method	Requirement
Target laboratory-molded density, %	Tex-207-F	96.0
Design gyrations (Ndesign)	Tex-241-F	50[1]
Indirect tensile strength (dry), psi	Tex-226-F	85–200[2]
		–

1. Adjust within a range of 35–100 gyrations when shown on the plans, in accordance with the specification, or when mutually agreed between the Engineer and Contractor.
2. The Engineer may allow the indirect tensile test strength to exceed 200 psi if the corresponding Hamburg wheel rut depth is >2.5 mm and <12.5 mm.

Table 10
Hamburg Wheel Test Requirements

High-Temperature Binder Grade	Test Method	Min # of Passes at 12.5-mm[1,2] Rut Depth, Tested at 50°C
PG 64 or lower	Tex-242-F	5,000
PG 70		10,000
PG 76 or higher		20,000

1. The Hamburg wheel test will have a minimum rut depth of 2.5 mm.
2. The Engineer may elect to use the Contractor's Hamburg Test Results

4.4.2 **Job-Mix Formula Approval**. The JMF is the combined aggregate gradation, Ndesign level, and target asphalt percentage used to establish target values for hot-mix production. JMF1 is the original laboratory mixture design used to produce the trial batch. When WMA is used, JMF1 may be designed and submitted to the Engineer without including the WMA additive, foaming process, or compaction aid. When WMA or a compaction aid is used, document the additive or process used and recommended rate in the JMF1 submittal. The Engineer and the Contractor will verify JMF1 based on plant-produced mixture from the trial batch, unless otherwise approved. The Engineer may accept an existing mixture design previously used on a project and may waive the trial batch to verify JMF1.

4.4.1.1. Contractor's Responsibilities.

4.4.1.1.1. Providing Superpave Gyratory Compactor. Provide an SGC in accordance with Item 504, "Field Office and Laboratory," and make the SGC available to the Engineer for use in molding production samples.

4.4.1.1.2. Gyratory Compactor Correlation Factors. Use Tex-206-F, Part II, to perform a gyratory compactor correlation when the Engineer uses a different SGC. Apply the correlation factor to all subsequent production test results.

4.4.1.1.3. Ignition Oven Correction Factors. Notify the Engineer before performing Tex-236-F, Part II. Allow the Engineer to witness the mixing of ignition oven correction factor sample. Determine the aggregate and asphalt correction factors from the ignition oven in accordance with Tex-236-F, Part II.

Correction factors established from a previously approved mixture design may be used for the current mixture design if the mixture design and ignition oven are the same as previously used, unless otherwise directed. Correction factors must be performed every 12 mo.

4.4.1.1.4. Trial Batch Produce a trial batch (JMF2) as necessary to obtain a mixture that meets the specification requirements. The Engineer may accept test results from recent production of the same mixture instead of a new trial batch.

4.4.1.1.5. Trial Batch/JMF2 Sampling. After the Engineer grants full approval of JMF1, Obtain a representative sample of the trial batch/JMF2 and split it into three equal portions in accordance with Tex-222-F. Label these portions as "Contractor," "Engineer," and "Referee." Deliver samples to the appropriate laboratory as directed. Referee testing process shall be agreed to by Contractor and Engineer. Evaluate the trial batch test results, determine the optimum mixture proportions, and submit as JMF2 Adjust the asphalt binder content or gradation to achieve the specified target laboratory-molded density. The asphalt binder content established for JMF2 is not required to be within any tolerance of the optimum asphalt binder content established for JMF1; however, mixture produced using JMF2 must meet the VMA requirements for production shown in Table 8. If the optimum asphalt binder content for JMF2 is more than 0.5% lower than the optimum asphalt binder content for JMF1, the Engineer may perform or require the Contractor to perform Tex 226 F on Lot 1 production to confirm the indirect tensile strength does not exceed 200 psi. Verify that JMF2 meets the mixture requirements shown in Table 4 and Table 5.

4.4.1.1.6. Development of JMF2.

4.4.1.1.7. Mixture Production. Use JMF2 to produce Lot 1 in accordance with Section 341.4.9.1.3, "Lot 1 Placement," after receiving approval for JMF2 and a passing Hamburg wheel result on the trial batch from a laboratory listed on the MPL. Once JMF2 is approved, and without receiving the results from the Engineer's Hamburg wheel test on the trial batch, the Contractor may proceed to Lot 1 production at their own risk. The Engineer may elect to use the Contractor's Hamburg results.

4.4.1.1.8. Development of JMF3. Evaluate the test results from Lot 1, determine the optimum mixture proportions, and submit as JMF3 for use in Lot 2.

4.4.1.1.9. JMF Adjustments. If JMF adjustments are necessary to achieve the specified requirements, make the adjustments before beginning a new lot. The adjusted JMF must:

- be provided to the Engineer in writing before the start of a new lot,
- be numbered in sequence to the previous JMF,
- meet the mixture requirements in accordance with Table 4 and Table 5,
- meet the master gradation limits in accordance with Table 8, and
- be within the operational tolerances of JMF2 in accordance with Table 11.

4.4.1.1.10. Requesting Referee Testing. Use referee testing, if needed, in accordance with Section 341.4.9.1., "Referee Testing," to resolve testing differences with the Engineer. Referee testing process shall be agreed to by Contractor and Engineer.

Table 11
Operational Tolerances

Description	Test Method	Allowable Difference Between JMF2 and JMF1 Target[1]	Allowable Difference Between Current JMF and JMF2[2]	Allowable Difference Between Contractor and Engineer[3]
Individual % retained on #8 sieve and larger	Tex-200-F or Tex-236-F	Must be Within Master Gradation Limits in Table 8	±5.0[4]	±5.0
Individual % retained on sieves smaller than #8 and larger than #200			±3.0[4]	±3.0
% passing the #200 sieve			±2.0[4]	±1.6
Asphalt binder content, %	Tex-236-F	±0.5	±0.3	±0.3
Laboratory-molded density, %	Tex-207-F	±1.0	±1.0	±1.0
In-place air voids, %		N/A	N/A	±1.0
Laboratory-molded bulk specific gravity		N/A	N/A	±0.020
VMA, %, Min	Tex-204-F	Note 5	Note[5]	N/A
Theoretical maximum specific (Rice) gravity	Tex-227-F	N/A	N/A	±0.020

1. JMF1 is the approved laboratory mixture design used for producing the trial batch. JMF2 is the approved mixture design developed from the trial batch used to produce Lot 1.
2. Current JMF is JMF3 or higher. JMF3 is the approved mixture design used to produce Lot 2.
3. Contractor will take corrective action to bring test results back within tolerances.
4. When within these tolerances, mixture production gradations may fall outside the master gradation limits; however, the % passing the #200 will be considered out of tolerance when outside the master gradation limits.
5. Verify that Table 8 requirements are met for VMA.

4.4.2. Engineer's Responsibilities.

4.4.2.1.1. Superpave Gyratory Compactor. The Engineer will use a SGC, calibrated in accordance with Tex-241-F, to mold samples for laboratory mixture design verification. For molding trial batch and production specimens, the Engineer will use the Contractor-provided SGC at the field laboratory or provide and use a SGC at an alternate location.

4.5. Production Operations. Perform a new trial batch when the plant or plant location is changed. All source changes for asphalt will require a passing Hamburg wheel test result from a laboratory listed on the MPL. The Contractor may proceed at their own risk with Lot 1 production without the results from the Hamburg wheel test on the trial batch. All aggregate source changes will require a new laboratory mixture design and trial batch. Take corrective action and receive approval to proceed after any production suspension for noncompliance with the specification. Submit a new mix design and perform a new trial batch when the asphalt binder content of any RAP stockpile used in the mix is more than 0.5% higher than the value shown in the mixture design report.

4.5.1. Storage and Heating of Materials. Do not heat the asphalt binder above the temperatures specified in Item 300, or outside the manufacturer's recommended values. Provide the Engineer with daily records of asphalt binder and HMA discharge temperatures (in legible and discernible increments) in accordance with Item 320, unless otherwise directed. Do not store mixture for a period long enough to affect the quality of the mixture, nor in any case longer than 12 hr. unless otherwise approved.

4.5.2. Mixing and Discharge of Materials. Notify the Engineer of the target discharge temperature and produce the mixture within 25°F of the target. Monitor the temperature of the material in the truck before shipping to ensure that it does not exceed the maximum production temperatures shown in Table 12. The Engineer will not pay for or allow placement of any mixture produced above the maximum production temperatures shown in Table 12.

Table 12
Max Production Temperature

High-Temperature Binder Grade[1]	Max Production Temperature (°F)
PG 64	325[2]
PG 70	335[2]
PG 76	345[2]

1. The high-temperature binder grade refers to the high-temperature grade of the virgin asphalt binder used to produce the mixture.
2. The Maximum production temperature of WMA is 275°F. The contractor may elect to run the first few loads warmer than the maximum WMA temp to pre-heat construction equipment.

Produce WMA within the target discharge temperature range of 215–275°F when WMA is required. Take corrective action anytime the discharge temperature of the WMA exceeds the target discharge range. As an exception when running Warm Mix, the contractor may run the first 1-4 loads at normal temperatures to allow the mix to preheat the construction equipment. The Engineer may suspend production operations if the Contractor's corrective action is not successful at controlling the production temperature within the target discharge range. Note that when WMA is produced, it may be necessary to adjust burners to ensure complete combustion such that no burner fuel residue remains in the mixture.

Control the mixing time and temperature so that substantially all moisture is removed from the mixture before discharging from the plant. Determine the moisture content, if requested, by oven-drying in accordance with Tex-212-F, Part II, and verify that the mixture contains no more than 0.2% of moisture by weight. Obtain the sample immediately after discharging the mixture into the truck and perform the test promptly.

4.6. Hauling Operations. Use belly dump, live-bottom, or end dump trucks to haul and transfer mixture. Use other hauling equipment only when allowed.

Clean all truck beds before use to ensure that mixture is not contaminated. Use a release agent listed on the TxDOT Materials Producer List MPL to coat the inside bed of the truck when necessary. Do not use diesel or any release agent not listed on the MPL. Use a solid tarp of watertight construction to cover the load.

4.7. Placement Operations. Collect haul tickets from each load of mixture delivered to the project and provide the Agency's copy to the Engineer approximately every hour, or as directed. Use a handheld thermal camera or infrared thermometer, or probe-type thermometer to measure and record the internal temperature of the mixture as discharged from the truck or material transfer device (MTD) before or as the mix enters the paver. To obtain windrow internal temperature, remove surface asphalt to a depth of at least 6 inches. Measure the mixture temperature at a minimum frequency of one per ten trucks, or as approved. Include an approximate station number or Global Positioning System coordinates of the location where the temperature was taken on each ticket. Ensure the mixture meets the temperature requirements shown in Table 12. Calculate the daily yield and cumulative yield for the specified lift and provide to the Engineer at the end of paving operations for each day unless otherwise directed. The Engineer may suspend production if the Contractor fails to produce and provide haul tickets and yield calculations by the end of paving operations for each day.

Prepare the surface by removing raised pavement markers and objectionable material such as moisture, dirt, sand, leaves, and other loose impediments from the surface before placing mixture. Remove vegetation from pavement edges. Place the mixture to meet the typical section requirements and produce a smooth, finished surface with a uniform appearance and texture. Offset longitudinal joints of successive courses of hot mix by at least 6 in. Place mixture so that longitudinal joints on the surface course coincide within 6 in. of lane lines, are not placed in the wheel path, or will not be covered with pavement markings, or as directed. Ensure that all finished surfaces will drain properly. Place the mixture at the rate or thickness shown on the plans. The Engineer will use the guidelines shown in Table 13 to determine the compacted lift thickness of each layer

when multiple lifts are required.

Table 13
Compacted Lift Thickness and Required Core Height

Mixture Type	Compacted Lift Thickness Guidelines		Min Untrimmed Core Height Eligible for Testing (in.)
	Min (in.)	Max (in.)	
DG-B	2.50	5.00	1.75
DG-C	2.00	4.00	1.50
DG-D	1.50	3.00	1.25
DG-F	1.25	2.50	1.25

4.7.1. Weather Conditions.

4.7.1.1. Pavement Surface. Place mixture when the roadway surface is dry and the roadway surface temperature is at or above the temperatures shown in Table 14 unless otherwise approved or as shown on the plans. Place mixtures only when weather conditions and moisture conditions of the roadway surface are suitable as determined by the Engineer. The Contractor may pave at temperatures 10°F lower than these values when a chemical WMA additive is used as a compaction aid in the mixture, when using WMA, or when using a paving process with equipment that eliminates thermal segregation.

Table 14
Minimum Pavement Surface Temperatures

High-Temperature Binder Grade[1]	Min Pavement Surface Temperatures (°F)	
	Subsurface Layers	Surface Layers
PG 64	45	50
PG 70	55	60
PG 76	60	60

1. The high-temperature binder grade refers to the high-temperature grade of the virgin asphalt binder used to produce the mixture.

4.7.2. Tack Coat.

4.7.2.1. Application. Clean the surface before placing the tack coat. The Engineer will set the rate between 0.04 and 0.10 gal. of residual asphalt per square yard of surface area. Apply a uniform tack coat at the specified rate unless otherwise directed. Apply the tack coat in a uniform manner to avoid streaks and other irregular patterns. Apply the tack coat to all surfaces that will come in contact with the subsequent HMA placement, unless otherwise directed. Apply adequate overlap of the tack coat in the longitudinal direction during placement of the mat to ensure bond of adjacent mats, unless otherwise directed. Allow adequate time for emulsion to break completely before placing any material. Prevent splattering of tack coat when placed adjacent to curb, gutter, and structures. Do not dilute emulsified asphalts at the terminal, in the field, or at any other location before use, unless required in conformance with the manufacturer's recommendation for approved TRAIL product use, or when shown on the plans.

4.7.2.2. Sampling. The Engineer may obtain at least one sample of the tack coat binder per project per source in accordance with Tex-500-C, Part III, and test it to verify compliance with Item 300. The Engineer will notify the Contractor when the sampling will occur and will witness the collection of the immediately before use. For emulsions, the Engineer may test as often as necessary to ensure the residual of the emulsion is greater than or equal to the specification requirement in Item 300.

4.7.3. Lay-Down Operations. Use the placement temperatures shown in Table 15 to establish the minimum placement temperature of the mixture delivered to the paving operation.

Table 15
Minimum Mixture Placement Temperature

High-Temperature Binder Grade[1]	Min Placement Temperature[2,3,4] (°F)
PG 64	260
PG 70	270
PG 76	280

1. The high-temperature binder grade refers to the high-temperature grade of the virgin asphalt binder used to produce the mixture.
2. The mixture temperature must be measured using a handheld thermal camera, probe thermometer, or infrared thermometer immediately before entering MTD or paver.
3. Minimum placement temperatures may be reduced 20°F if using a chemical WMA additive as a compaction aid, MTD with remixing capabilities, or paver hopper insert with remixing capabilities.
4. When using WMA, the minimum placement temperature is 215°F.

4.7.3.1. Windrow Operations. Operate windrow pickup equipment so that when hot mix is placed in windrows, substantially all the mixture deposited on the roadbed is picked up and loaded into the paver.

4.7.3.2. Screed Heaters. Turn off screed heaters to prevent overheating of the mat if the paver stops for more than 5 min.

4.8. Compaction. Compact the pavement uniformly to contain between 3.8% and 8.5% in-place air voids. Take immediate corrective action to bring the operation within 3.8% and 8.5% when the in-place air voids exceed the range of these tolerances. If the in-place air voids are less 2.7% or more than 9.9%, the Engineer may suspend operations or require removal and replacement. The Engineer will allow paving to resume when the proposed corrective action is likely to yield between 3.8% and 8.5% in-place air voids.

In lieu of cores, a calibrated and correlated density gauge may be used to measure in place air voids. Take one density core per day to correlate the density gauge reading.

Areas defined in Section 341.4.9.2.3. “Miscellaneous Areas,” are not subject to in-place air void determination.

Furnish the type, size, and number of rollers necessary to ensure desired compaction. Use additional rollers as required to remove any roller marks. Use only water or an approved release agent on rollers, tamps, and other compaction equipment unless otherwise directed.

Use the control strip method shown in Tex-207-F, Part IV, on the first day of production to establish the rolling pattern that will produce the desired in-place air voids, unless otherwise directed.

Use tamps to thoroughly compact the edges of the pavement along curbs, headers, and similar structures and in locations that will not allow thorough compaction using rollers. The Engineer may require rolling using a trench roller on widened areas, in trenches, and in other limited areas.

Complete all compaction operations using breakdown rollers before the pavement temperature drops below 180°F, unless otherwise allowed. Compaction using a pneumatic or light finish roller operated in static mode is allowed for pavement temperatures above 160°F.

Allow the compacted pavement to cool to 160°F or lower before opening to traffic, unless otherwise directed. Sprinkle the finished mat with water or limewater, when directed, to expedite opening the roadway to traffic.

4.9. Acceptance Plan. Payment adjustments for the material will be in accordance with Article 341.6., “Payment.”

Sample and test the hot mix on a lot and sublot basis. Mixture meeting specification requirements will be paid for a pay factor of 1.0.

Referee Testing. The referee testing process shall be agreed to by Contractor and Engineer. The Contractor may request referee testing if a "remove and replace" condition is determined based on the Engineer's test results, or if the differences between Contractor and Engineer test results exceed the maximum allowable difference in accordance with Table 11 and the differences cannot be resolved. The Contractor may also request referee testing if the Engineer's test results require suspension of production and the Contractor's test results are within specification limits. Make the request within 5 working days after receiving test results and cores from the Engineer. Referee tests will be performed only on the sublot in question and only for the tests in question. Allow 10 working days from the time the referee laboratory receives the samples for test results to be reported.

Determine the laboratory-molded density based on the molded specific gravity and the maximum theoretical specific gravity of the referee sample. The in-place air voids will be determined based on the bulk specific gravity of the cores, as determined by the referee laboratory, and the Engineer's average maximum theoretical specific gravity for the lot. Except for "remove and replace" conditions, referee test results are final.

4.9.1. Production Acceptance.

4.9.1.1. Production Lot. A Production Lot is defined as a minimum of one test per 500 tons.

4.9.1.2. Production Sampling.

4.9.1.2.1. Random Sample. Determine random sample locations in accordance with Tex-225-F. Take one sample for each lot at the randomly selected location. The Contractor will perform all sampling and the Engineer may witness the sampling of production lots.

4.9.1.2.2. Mixture Sampling. The Contractor will perform the sampling of production lots from trucks at the plant in accordance with Tex-222-F The sampler will split each sample into three equal portions in accordance with Tex-200-F and label these portions as "Contractor," "Engineer," and "Referee." The Engineer may witness the sample splitting and may take immediate possession of the samples labeled "Engineer" and "Referee."

4.9.1.2.3. Asphalt Binder Sampling. The Engineer may elect to test the sample by a TxDOT qualified binder laboratory to verify compliance with Item 300.

4.9.1.3. Production Testing. The Contractor will perform production tests on each lot as shown in Table 16. Determine compliance with operational tolerances shown in Table 11 for all lots. The Engineer may use the Contractor's test results as acceptance tests, in lieu or performing tests. No testing is required when less than 100 tons per day is produced.

Take immediate corrective action if the Engineer's laboratory-molded density on any sublot is less than 95.0% or greater than 97.0% to bring the mixture within these tolerances. The Engineer may suspend operations if the Contractor's corrective actions do not produce acceptable results. The Engineer will allow production to resume when the proposed corrective action is likely to yield acceptable results.

Table 16
Production and Placement Testing Frequency

Description	Test Method	Min Contractor Testing Frequency	Min Engineer Testing Frequency
Individual % retained on #8 sieve and larger	Tex-200-F or Tex-236-F	1 per lot	1 per day
Individual % retained on sieves smaller than #8 and larger than #200			
% passing #200 sieve			
Laboratory-molded density	Tex-207-F	1 per lot	1 day
Laboratory-molded bulk specific gravity			
In-place air voids[3]			
VMA	Tex-204-F		
Theoretical maximum specific (Rice) gravity	Tex-227-F	1 per lot	1 per day
Asphalt binder content	Tex-236-F	1 per lot	1 per day
Hamburg wheel test	Tex-242-F	–	
Asphalt binder sampling and testing[1,2]	Tex-500-C, Part II	–	
Tack coat sampling and testing	Tex-500-C, Part III	–	

47. Sampling performed by the Contractor. The Engineer will witness sampling and retain the samples for 1 yr.
48. Testing performed by accredited laboratory.
49. Placement Lot is defined in 4.9.2.1.

4.9.1.4. Operational Tolerances. Control the production process within the operational tolerances shown in Table 11. When production is suspended, the Engineer will allow production to resume when test results or other information indicates the next mixture produced will be within the operational tolerances.

4.9.1.4.1. Gradation. Suspend operation and take corrective action if any aggregate is retained on the maximum sieve size shown in Table 8. A sublot is defined as out of tolerance if either the Engineer's or the Contractor's test results are out of operational tolerance. Suspend production when test results for gradation exceed the operational tolerances shown in Table 11 for three consecutive sublots on the same sieve or four consecutive sublots on any sieve, unless otherwise directed. The consecutive sublots may be from more than one lot.

4.9.1.4.2. Asphalt Binder Content. A lot is defined as out of operational tolerance if either the Engineer's or the Contractor's test results exceed the values shown in Table 11. No production or placement payment adjustments greater than 1.000 will be paid for any lot that is out of operational tolerance for asphalt binder content. Suspend production and shipment of the mixture if the Engineer's or the Contractor's asphalt binder content deviates from the current JMF by more than 0.5% for any lot.

4.9.1.4.3. VMA. The Contractor will determine the VMA for every lot. Take immediate corrective action if the VMA value for any sublot is less than the minimum VMA requirement for production shown in Table 8. Suspend production and shipment of the mixture if the Contractor's VMA results on two consecutive lots are below the minimum VMA requirement for production shown in Table 8.

4.9.1.4.4. Hamburg Wheel Test. The Engineer may perform a Hamburg wheel test on plant-produced mixture anytime during production. Suspend production until further Hamburg wheel tests meet the specified values when the production samples fail the Hamburg wheel test criteria shown in Table 10.

4.9.1.5. Individual Loads of Hot Mix. The Engineer may reject individual truckloads of hot mix. When a load of hot mix is rejected for reasons other than temperature, contamination, or excessive uncoated particles, the Contractor may request that the rejected load be tested. Make this request within 4 hr. of rejection. The Engineer will sample and test the mixture. If test results are within the operational tolerances shown in Table 11, payment will be made for the load. If test results are not within operational tolerances, no payment will be made for the load.

4.9.2. Placement Acceptance.

4.9.2.1. Placement Lot. A Placement Lot is defined as a minimum of one density core per 250 tons or as approved by the Engineer. If a density gauge is used for acceptance, a minimum of one density test is required per 500 feet of paving.

4.9.2.2. Shoulders, Ramps, Etc. Shoulders, ramps, intersections, acceleration lanes, deceleration lanes, and turn lanes are subject to in-place air void determination. Intersections may be considered miscellaneous areas when determined by the Engineer.

4.9.2.3. Miscellaneous Areas. Miscellaneous areas include areas that typically involve significant handwork or discontinuous paving operations, such as temporary detours, driveways, mailbox turnouts, crossovers, gores, spot level-up areas, pavement repair sections less than 300 ft., and other similar areas. Temporary detours are subject to in-place air void determination when shown on the plans. Miscellaneous areas also include level-ups and thin overlays when the layer thickness shown on the plans is less than the minimum untrimmed core height eligible for testing in accordance with Table 13. Miscellaneous areas are not eligible for random placement sampling locations. Compact miscellaneous areas in accordance with Section 341.4.8., "Compaction." Miscellaneous areas are not subject to in-place air void determination.

4.9.2.4. Placement Sampling. The Engineer will provide the Contractor with the placement random numbers only immediately after the lot is completed. Mark the roadway location at the completion of each lot and record the station number. Determine one random sample location for each placement lot in accordance with Tex-225-F. Adjust the random sample location by no more than necessary to achieve a 2-ft. clearance if the location is within 2 ft. of a joint or pavement edge.

Shoulders, ramps, intersections, acceleration lanes, deceleration lanes, and turn lanes are always eligible for selection as a random sample location; however, if a random sample location falls on one of these areas and the area is shown on the plans as not subject to in-place air void determination, cores will not be taken for the sublot and a 1.000 pay factor will be assigned to that sublot. In lieu of cores, use of a calibrated and correlated density gauge is acceptable.

Dry the core holes and tack the sides and bottom immediately after obtaining the cores. Fill the hole with the same type of mixture and properly compact the mixture. Repair core holes using other methods when approved.

4.9.2.5. Placement Testing. Perform placement tests in accordance with Table 16. After the Engineer returns the cores, the Contractor may test the cores to verify the Engineer's test results for in-place air voids. The allowable differences between the Contractor's and Engineer's test results are shown in Table 11.

4.9.2.5.1. In-Place Air Voids. The Engineer will measure in-place air voids in accordance with Tex-207-F and Tex-227-F. In lieu of cores, use of a calibrated and correlated density gauge is acceptable. Before drying to a constant weight, cores may be pre-dried using a CoreDry or similar vacuum device to remove excess moisture. The Engineer will average the values obtained for all sublots in the production lot to determine the theoretical maximum specific gravity. The Engineer will use the average air void content for in-place air voids.

4.9.2.5.2. Irregularities. Identify and correct irregularities, including segregation, rutting, raveling, flushing, fat spots, mat slippage, irregular color, irregular texture, roller marks, tears, gouges, streaks, uncoated aggregate particles, or broken aggregate particles. The Engineer may also identify irregularities, and in such cases, the Engineer will promptly notify the Contractor. If the Engineer determines that the irregularity will adversely affect pavement performance, the Engineer may require the Contractor to remove and replace (at the Contractor's expense) areas of the pavement that contain irregularities. The Engineer may also require the Contractor to remove and replace (at the Contractor's expense) areas where the mixture does not bond to the existing pavement.

If irregularities are detected, the Engineer may require the Contractor to immediately suspend operations or may allow the Contractor to continue operations for no more than 1 day while the Contractor is taking appropriate corrective action.

4.9.3. **Ride Quality**. Measure ride quality in accordance with Item 585, "Ride Quality for Pavement Surfaces," unless otherwise shown on the plans.

5. MEASUREMENT

5.1. **Dense-Graded HMA**. Hot mix will be measured by the ton of composite hot mix, which includes asphalt, aggregate, and additives. Measure the weight on scales in accordance with TxDOT Item 520, "Weighing and Measuring Equipment."

5.2. **Tack Coat**.Tack coat will be measured at the applied temperature by strapping the tank before and after road application and determining the net volume in gallons from the calibrated distributor. The Engineer will witness all strapping operations for volume determination. All tack, including emulsions, will be measured by the gallon applied. The Engineer may allow the use of a metering device to determine asphalt volume used and application rate if the device is accurate within 1.5% of the strapped volume.

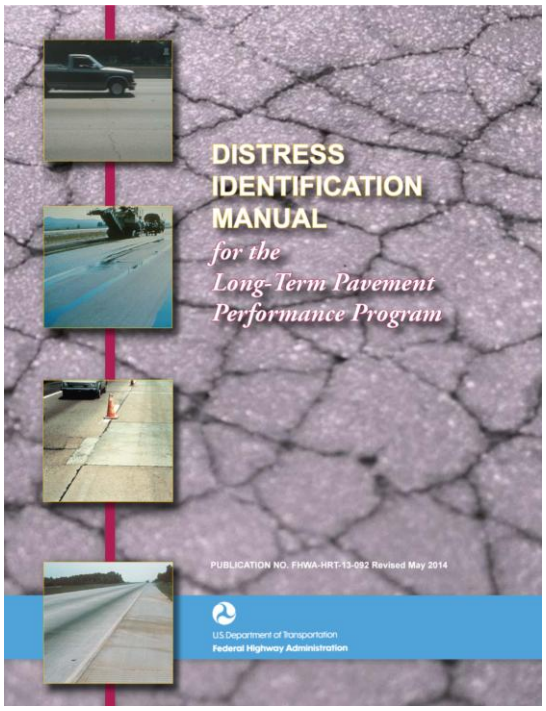
6. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under Section 341.5.1., "Dense-Graded HMA," will be paid for at the unit price bid for "341M Municipal Dense-Graded Hot-Mix Asphalt" of the mixture type, SAC, and binder specified. These prices are full compensation for surface preparation, materials, placement, equipment, labor, tools, and incidentals.

The work performed and materials furnished in accordance with this Item and measured as provided under Section 341.5.2., "Tack Coat," will be paid for at the unit price bid for "Tack Coat" of the tack coat provided. These prices are full compensation for materials, placement, equipment, labor, tools, and incidentals.

Appendix B: Flexible Pavement Distress Identification

Distress Identification Manual for the Long-Term Pavement Performance Program: TXAPA strongly recommends using this manual, which can be downloaded for free at the address listed. For decades, this has been the premiere guidance document for distress identification, with photos showing the severity of different distress types for both flexible and rigid pavement types. Below are generally accepted definitions of distresses in flexible pavements.



HTTPS://HIGHWAYS.DOT.GOV/SITES/FHWA.DOT.GOV/FILES/DOCS/RESEARCH/LONG-TERM-PAVEMENT-PERFORMANCE/PRODUCTS/1401/DISTRESS-IDENTIFICATION-MANUAL-13092.PDF

Rutting: Rutting or permanent deformation is a depression in the cross-section of the pavement in the wheel path and can be caused by poor quality hot mix asphalt or base course as well as inadequate structural capacity, which can cause rutting due to subgrade permanent deformation. In general, the greater the width of the rut, the deeper the source

of the problem in the pavement section. A wide rut depth indicates a subgrade or perhaps base course issue. A very narrow rut is associated with the permanent deformation of hot mix asphalt.

Raveling: Raveling is a loss of fine and/or coarse aggregate from the surface of the pavement. Raveling is a term usually associated with hot mix asphalt pavement. Aggregate loss for seal coats can also be defined as raveling or shelling.

Raveling may be an indicator of water sensitivity (stripping), low asphalt content, changes in aggregate gradation (especially the finer fractions of the aggregate), inadequate compaction or high air voids and/or asphalt binder hardening in hot mix asphalt pavements.

Loss of chips or stones from seal coats or chip seals can be caused by low asphalt binder shot rates and/or excessive chip application during construction, as well as inadequate rolling during construction. Cool and cold weather under high traffic volumes, as well as stopping and turning traffic movements, accelerate chip loss.

Bleeding: Bleeding is the presence of excess asphalt binder on the surface of an asphalt pavement. Bleeding in hot mix asphalt-surfaced pavement is often associated with high asphalt binder content, changes in aggregate gradation (especially the finer fractions of the aggregate), and stripping of the asphalt binder from the aggregate. High traffic volumes and high pavement temperatures accelerate this potential performance problem.

Bleeding in seal coats or chip seals typically results from excess asphalt binder and perhaps excess stone placed during construction. High traffic volumes and high pavement temperatures, as well as stopping and turning traffic movements, accelerate this behavior. Sometimes aggregate may be punched into the underlying layer resulting in the appearance of bleeding.

Shoving/Corrugations: Shoving and corrugations are typically located at or near areas on the pavement that are subjected to shear stresses associated with decelerating or accelerating traffic. These locations are at stop/start areas, turn lanes and in corners. Heavy traffic stop/start areas such as bus stops are particularly prone to this type of distress.

Alligator Cracking: Alligator or chicken wire cracking is an indication that the pavement structural design is inadequate for the traffic volumes and weight using the facility. In general, the base and or surfacing course materials are not sufficient in thickness. Since

traffic loads are in the wheel path, this distress is in the wheel paths. Alligator cracking may start on some pavements as a series of small transverse cracks only in the wheel paths. In other pavements, alligator cracking may start as discontinuous longitudinal cracks located at the edges of the wheel path.

Transverse Cracking: Transverse cracking (across the roadway, perpendicular to the direction of traffic) indicates cracking associated with the environment. Rapid temperature drops starting at relatively low temperatures, causes transverse cracking in asphalt pavements. Pavements with oxidized or harder asphalt binders in pavements will crack at higher, lower temperatures than others with less oxidation and hardening. Traffic volumes will accelerate the presence of transverse cracks. This type of cracking is present in the west Texas area.

Transverse cracking is also commonly associated with the use of Portland cement-stabilized bases and subgrades. After hydration and drying, Portland cement hydration products crack in a transverse pattern. Lime-stabilized materials can also cause transverse cracking.

Longitudinal Cracking-Wheel Path: Longitudinal cracking can occur at the edges of the wheel path. This type of cracking can initiate alligator cracking and, hence, indicate an inadequate pavement structural section for traffic using the facility (fatigue cracking). This cracking pattern is often associated with the top-down form of fatigue cracking and is not continuous along all wheel paths.

Another cause of longitudinal cracking at or near the wheel path is segregation caused by the laydown machine. Segregation of the hot mix asphalt near the center line of the paved width as well as at the edges of the “tunnels” moving the hot mix asphalt from the “hopper” to the “horizontal auger” can cause longitudinal cracking. This form of longitudinal cracking is associated with construction practices and not pavement structural inadequacy.

Longitudinal cracking resulting from reflection cracking from construction joints in the lower levels of hot mix asphalt pavement and base courses can cause longitudinal types of cracking. Reflection cracking resulting from cracks present in the old pavement is also a source of longitudinal as well as transverse cracking.

Longitudinal Cracking-near edge of pavement: Longitudinal cracks often form within 6 to 8 ft. of the paved surface edge in areas where subgrade soils have relatively high plastic

index values (greater than about 30). This type of cracking pattern is very typical in the area east of a line from San Antonio to the Dallas-Ft. Worth area (greater central Texas). These cracks are associated with volume change of soils caused by fluctuations in moisture contents (shrinkage cracking).

Potholes: Potholes are localized pavement failures caused by several factors including inadequate structural design, materials selection and design problems and construction problems. Potholes can be an indication of the overall adequacy of the pavement and their presence as well as general location should be noted.

Edge drop-off/disintegration: One of the common problems associated with Farm to Market roadways subjected to oil and gas development and production traffic is edge drop-off and disintegration. Roads with narrow travel lanes and/or narrow shoulders experience considerable amounts of drop-off and disintegration under truck traffic. Shoulder drop-off often leads to paved surface raveling or disintegration from the outside edge inward.

Appendix C: Maintenance Definitions

Maintenance

FHWA

Maintenance describes work performed to maintain the transportation system's condition or to respond to specific conditions or events that restore the highway system to a functional state of operation. Maintenance is a critical component of an agency's asset management plan, comprising routine and preventive maintenance (FHWA, 2016).

Routine Maintenance

FHWA

Routine maintenance encompasses work performed in reaction to an event, season, or overall deterioration of the transportation asset. It requires regular, recurring attention. States cannot use Federal Aid funds for routine maintenance.

TxDOT

Pavement-related work to include restoration of pavement serviceability, including reconditioning, rebuilding, level-up, and overlay. This would include, but not be limited to, pavement repair, crack seal, bituminous level-ups with light overlays to restore rideability (overlays not to exceed total average depth of 2 inches), additional base to restore rideability and seal coats (TxDOT, 2020)

Major Maintenance

TxDOT

Pavement-related work is needed to strengthen the pavement structure for current and projected future traffic usage. Work should include restoring pavement serviceability or roadways. This would include, but not be limited to, reconditioning and stabilizing base and subgrade, adding base, level up, overlays, and seal coats. Pavement widening can be considered major maintenance if done to correct a maintenance problem (TxDOT, 2020).

Preventive Maintenance

FHWA

Preventive maintenance is a cost-effective means of extending the useful life of the highway. It is a proactive approach. State Departments of Transportation may use Federal-aid funds for preventive maintenance, provided the respective FHWA Division Administrator agrees that the activity is a cost-effective means of extending the useful life of a Federal-aid highway. Federal-aid funds cannot be used for preventive maintenance on non-Federal-aid, off-system highways (FHWA, 2016).

TxDOT

Pavement-related work was performed to prevent major deterioration of the pavement. Work would normally include, but not be limited to, milling or bituminous level-ups to restore rideability, light overlays (overlays not to exceed a total average depth of 2 inches), seal coats, crack sealing, and micro-surfacing. Preparatory work such as milling, repairs, or level-up may also be performed (TxDOT, 2020).

Preservation

FHWA

Preservation consists of work planned and performed to improve or sustain the condition of the transportation facility in a state of good repair. Preservation activities generally do not add capacity or structural value but restore the transportation facility's overall condition. The federal MAP-21 legislation adds preservation to the definition of construction in 23 U.S.C. 101. As such, preservation work is eligible and encouraged under the National Highway Performance Program and the Surface Transportation Program. Preservation is a critical component of an agency’s asset management plan to achieve and sustain a desired safe state of good repair over the lifecycle of the assets (FHWA, 2016).

NCPP

Pavement preservation is a cost-effective set of practices that extend pavement life, improve safety and motorist satisfaction, and save public tax dollars (NCPP, 2016).

TxDOT

Pavement preservation is the extension of the life of good pavements via the application of timely preventive maintenance treatments, performed at the optimal time to preserve a pavement’s condition throughout its service life or to extend the life of the pavement and to reduce the amount of water infiltrating the pavement structure, protecting the pavement

system, slowing the rate of deterioration and correcting surface deficiencies. In general, routine maintenance is performed daily by public agencies forces. Preventive and preservation activities are typically performed by contractors (TxDOT, 2020).