TEXAS ASPHALT PAVEMENT USER GUIDE

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TXAPA

Texas Asphalt Pavement Association

Executive Summary

This guide provides up-to-date information regarding the materials, engineering, and construction of asphalt pavements. It is organized so that the reader may learn about the numerous advantages that asphalt pavements provide (Chapter 1), the materials that go into asphalt pavements (Chapter 2), the mechanics of asphalt mixture design (Chapter 3), how to design flexible pavements (Chapter 4), mix type selection (Chapter 5) asphalt mixture specifications (Chapter 6), special uses for asphalt pavements (Chapter 7), how to manage pavement systems (Chapter 8), and how to make decisions on maintenance and rehabilitation (Chapter 9).

The process for manufacturing the materials for asphalt mixtures, the production of asphalt mixtures, and the placement of the asphalt mix on the pavement are presented to acquaint the reader with an overview of how asphalt materials go from refinery and quarry to the pavement. Aggregate mining, crude oil refining to obtain liquid asphalt and rock asphalt native to Texas are discussed along with basics of asphalt mixture production and paving.

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, and the aggregates need to be selected and blended to achieve the desired gradation and quality characteristics. 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. Mixtures used in critical locations need to be subjected to performance testing for cracking and rutting potential.

The structural 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 both 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 compactability of mixtures usually dictate that the thickness of a lift be on the order of 3 to 5 times the nominal maximum aggregate size. There are a number of empirical and mechanistic methods for designing pavements. PavExpress is a method based upon the 1993 AASHTO design approach that can be done on-line with relatively little effort. Perpetual pavements may be designed with PerRoadExpress which allows the user to complete the design process all in one screen.

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 the vast majority of 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 pavements life provided that the distress in the existing pavement is minimal.

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 a number of ways of specifying materials with performance-related specifications being the most typical. TXAPA has a specification based on TxDOT Item 340 which can be used on small to medium projects. This specification may be found in Appendix A.

Asphalt pavements may be used in a number of applications outside of the normal road and airfield uses. These include porous pavements for stormwater runoff mitigation, bike paths and sidewalks, outdoor tennis and basketball courts, running tracks, hydraulic structures, landfill caps, and railroad track beds. Each of these has special considerations with respect to binders, aggregates, and mix design.

Pavement management is an important tool in the planning, budgeting, and executing pavement treatments from preservation to rehabilitation. An effective pavement management system will consider pavements at both a network and a project level. The best approach to pavement management is to collect pavement condition information such as visual surveys regularly to track the performance of segments on the road network. As pavement conditions warrant, individual projects can be designated for preservation, maintenance or rehabilitation. 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.

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 the presence of water in pavement layers and the subgrade. One approach to lowering the cost of repairing a pavement is to apply a thin asphalt overlay as a Pavement Preservation treatment before more expensive treatments are needed. If a stronger intervention is needed then maintenance and rehabilitation options need to be identified suitable for the distresses. Selection of a given option will depend upon the degree of distress (type, extent, and severity) and fiscal constraints. While temporary remedies may be affordably tempting, it must be remembered that more money will be needed to properly fix the pavement later.

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CHAPTER ONE
Asphalt Pavement a Green, Economical and Durable Choice

Asphalt pavements comprise 93% of the paved roadway miles in the U.S. (NAPA 2016). There are many benefits of asphalt pavement that will be identified and expanded upon throughout this chapter. 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" well below is a list of the "seven wonders of asphalt pavement." These "wonders" or benefits are as follows.

1. Asphalt is the most recycled material in the U.S., so asphalt, though it is black…is actually GREEN.

Asphalt is the most recycled material in the U.S. In fact, it has been common practice to incorporate recycled materials in asphalt mixtures since the late 1970s. By reusing the asphalt binder in the Recycled Asphalt Pavement (RAP), it is possible to consume less virgin binder which conserves petroleum and the reuse of aggregate allows for less mining. Currently, there are about 18 billion tons of asphalt mixtures in U.S. roadways. Virtually all of this material is available for future generations to use. By using RAP instead of discarding it into landfills, saves about 48 million cubic yards of landfill space, enough for more than 12 Dallas Cowboys Stadiums. Furthermore, waste materials from other industries such as Recycled Asphalt Shingles (RAS), can be beneficially incorporated into asphalt mixtures. Asphalt can use waste from shingle manufactures' as well as, tear-offs from damaged roofs or old roofs that need replacing. By recycling these shingles it will keep thousands and thousands of tons from being dumped into landfills. About 95 percent of the asphalt pavement that is removed is recycled back into pavement. This amounts to about 72 million tons of material annually that is saved from landfills. Recycling saves resources in terms of virgin asphalt and aggregate, resulting in a simultaneous savings in energy and cost. The "mill and fill" operation, frequently used in the surface renewal process, allows properly sized recycled material to be taken from the roadway and placed in a stockpile ready for use.

2. Asphalt produced by using warm mix processes is another GREEN aspect of asphalt. This is where asphalt is produced by using less energy and laying the asphalt at a much lower temperature.

Since 2007, the asphalt paving industry in the U.S. has moved toward increased use of Warm Mix Asphalt (WMA) in place of Hot Mix Asphalt (HMA). WMA is a collection of technologies that allow asphalt mix to be produced and placed at temperatures that are 25 to 50°F lower than HMA. Among the reasons for this movement are: 1) reduced asphalt emissions, 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 has shown that the use of WMA increased from 5 percent of the total tonnage of asphalt mix in 2009 to over 30 percent in 2014. 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 fairly stable value of about 30 percent of the mix tonnage being WMA (Hansen and Copeland, 2015). Hassan (undated) has calculated that the use of WMA provides an overall 15% reduction in environmental impacts compared to HMA which is about the same as reported by Frank (2012).

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, newly available warm mix asphalt technologies can reduce the temperatures required to produce and place the material which reduces fuel consumption as well as emissions.

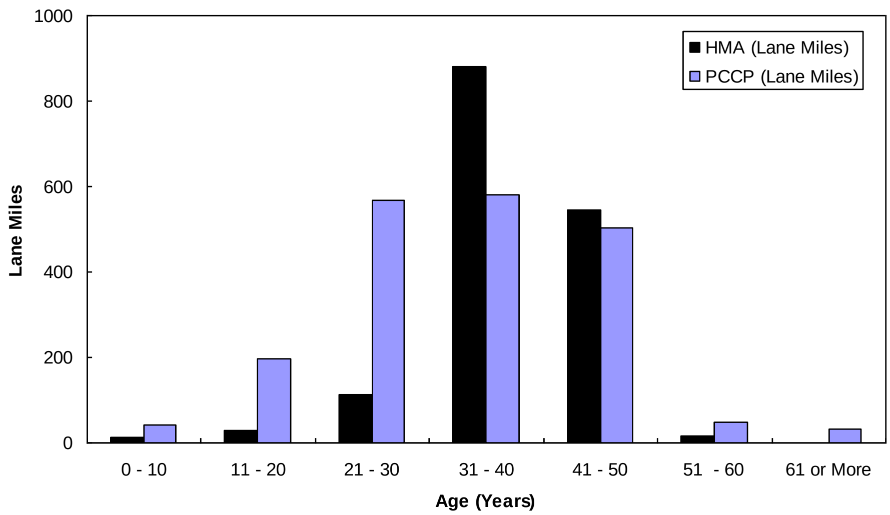
3. Asphalt is flexible and durable, so it can be used on most sub-surfaces. However, it is imperative that the engineering design and construction design take into account the subsurface characteristics to provide a sound foundation to lay the final asphalt product.

Asphalt pavements have been successfully employed over any type of 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 volume change in certain areas. Asphalt provides an additional advantage in being able to accommodate a certain amount of settlement or displacement in the underlying soil without a significant loss in serviceability.

To highlight the performance of properly designed asphalt pavements, the Asphalt Pavement Alliance has presented the Perpetual Pavement Award to agencies with pavements meeting the following criteria: The pavement has to be at least 35 years old with intervals between overlays of no less than 13 years on average. Over 100 highway and airfield pavements have received this award, and there are many more that have yet to be nominated (AI, 2015). The ability to provide long service life while avoiding the need for costly and time-consuming reconstruction is the hallmark of a Perpetual Pavement.

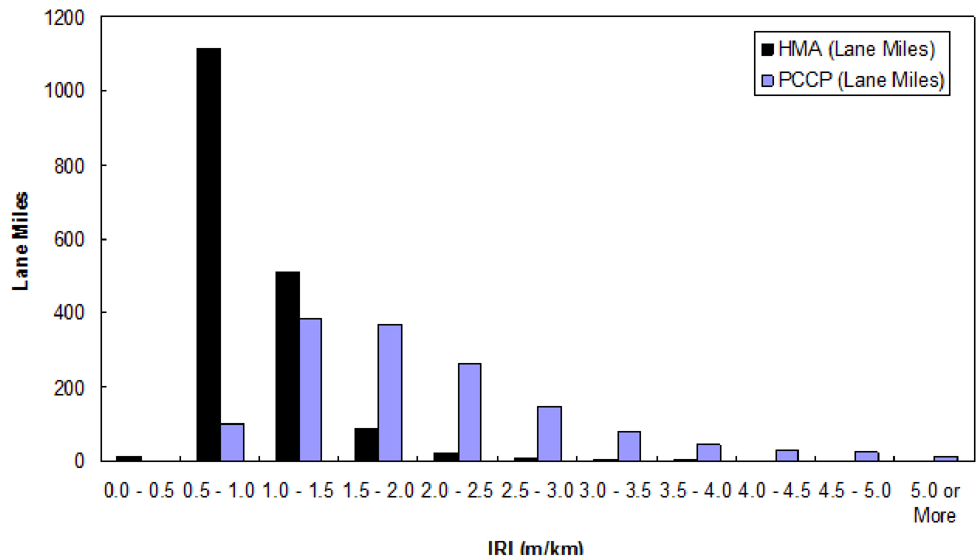
4. Asphalt is quiet and smooth. Both of these are important for neighborhoods, fuel consumption and ride enjoyment.

HMA has a proven track record when it comes to long life and smoothness. A study of asphalt pavements on Interstate highways in Oregon and Washington State shows that the average age of the HMA pavements on these systems is about the same as or older than the concrete pavements in that state (Figure 1-1). A graph showing the smoothness of interstate highways in Washington is presented in Figure 1-2. Here the International Roughness Index (IRI) versus the number of kilometers for asphalt and concrete roads illustrates that asphalt pavements are generally smoother than concrete pavements (Mahoney et al., 2007). In other words, asphalt pavements have lower IRI values. Similar results were reported in an FHWA publication (2002) where it was reported that 80 percent of the asphalt pavements had an IRI of less than 1.5 m/km whereas 80 percent of the concrete pavements had an IRI of less than 2.0 m/km. This type of asphalt pavement performance on Interstate highways has also been documented in Minnesota, Connecticut, New Jersey, Kansas, and Ohio. All of these studies have shown that well designed and built asphalt pavement structures can remain in place with only infrequent resurfacing.



Source: Mahoney et al., 2007

Figure 1-1. Age Distribution for Interstate Pavements in Washington State.



Source: Mahoney et al., 2007

Figure 1-2. International Roughness Index for Interstate Pavements in Washington State.

5. Construction can be completed quickly and driven on within hours of the final product being laid. This eases road congestion during construction and improves the efficiency for the traveling public.

Asphalt pavements allow for flexibility in construction, both in the ability to stage the construction sequence and in the ability to minimize user costs. Staging construction is often advantageous when funding levels or weather do not allow for a facility to be completed in a single year. The ability to build a substantial portion of the structure and then to finish it later helps agencies to stretch budgets to take care of more projects in tight times. Also, if construction happens to start later in the year, and finishing it would push the schedule into cold weather, then letting traffic use the road over the winter and waiting for the next season to put on the wearing course allows maximum use of the facility.

Because asphalt can be constructed during off-peak traffic times, the stages of construction 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 orders of magnitude lower with the off-peak hour option than with the full-day option.

6. Asphalt can handle both light and heavy traffic flows.

Asphalt pavements have demonstrated performance across the spectrum of traffic loadings and conditions. Asphalt is by far the most popular pavement material for low and medium traffic roadways, and has proven performance under heavy truck traffic in urban and rural settings. Even under heavy, static, and channelized loadings such as those at port facilities and commercial airports, asphalt pavements have provided excellent service. Many technological improvements in asphalt pavements have been directed at the need to handle increased loads. These improvements have included perpetual pavement design, the introduction of polymer modified binders, the development of Superpave binders and mix design, and the introduction of SMA as a premium surface material

7. Asphalt is safe and quiet—especially on heavily traveled roads.

Permeable Friction Courses (PFCs) are asphalt mixtures that allow water to flow from the top surface of the road and out to the shoulders. The main advantage of PFCs is the ability to drain water from the road surface increasing the skid resistance and reducing the 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. The road originally had a dense surface and had 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 type of surface should be considered as an elective, life-saving safety feature that should be used whenever 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, 2011

Each time a new HMA surface is applied to an existing pavement, an opportunity presents itself to renew the friction and water handling characteristics of the roadway. 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. If a PFC is applied to the surface, not only is the skid resistance and rutting resistance improved, but the amount of splash and spray during rainstorms is reduced which improves driver visibility as shown for I-35 in San Antonio in Figure 1-3. Delineation of lanes and pavement markings are enhanced with asphalt pavements.

Noise generation has become an important consideration on high-speed roadways. At speeds over 50 mph, the predominant 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 by using a Stone Matrix Asphalt (SMA) surface, and a PFC can reduce noise by up to 9 dBA (Wayson, 1998). A reduction of 3 dBA from 76 to 73 has the same effect as either reducing the traffic by half or doubling the distance from the source of the noise.

Source: Rand, 2011

Figure 1-3. PFC (Left Side) Reduces Splash and Spray in Wet Weather.

CHAPTER TWO
Introduction to Asphalt Materials and Construction

In this chapter you will learn about:

- The production of asphalt binder and limestone rock asphalt.
- The types, sources, and production of mineral aggregates.
- The processing and use of reclaimed asphalt pavements and recycled asphalt shingles.
- How asphalt mixtures are produced and placed.

Introduction

Asphalt pavements are comprised of about 95 percent aggregate and 5 percent asphalt cement by weight of the mix. By volume, a typical compacted, dense-graded mixture on the pavement is comprised of 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 a part of almost every modern day mixture and the numerous advantages of recycling were discussed in Chapter 1. Certain additives may be used 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 be able to 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 all being considerations. The mix is then designed so that the proportions of the ingredients will satisfy the requirements of the pavement to provide the desired performance and economy.

Once the mixture is designed, the proportions are then used in producing the paving mixture through an asphalt plant. After initial adjustments are made to ensure the quality of the plant-produced asphalt mixture, production begins on a large scale of 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 and their proportions have not changed. The mixture is transported to the job site via dump trucks, and there it is fed through a paving machine which places the material to its desired thickness. Next, the placed material is compacted by rollers of various types, dimensions, and weights. After compaction, the material is sampled and tested again to make sure that it has the desired characteristics for the pavement. Figure 2-1 shows a flow chart of how asphalt pavements are manufactured.

This chapter discusses the basics of the asphalt mixture materials, primarily asphalt binder, aggregates, and recycled materials and the basics of the production of mixtures and their placement on pavements. The design of asphalt mixtures is the subject of Chapter 3 and the thickness design of pavements is covered in Chapter 4.

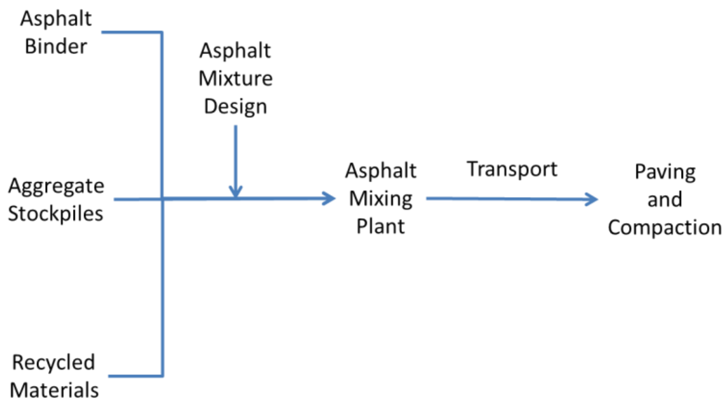


Figure 2-1. Asphalt Mixture Production and Placement.

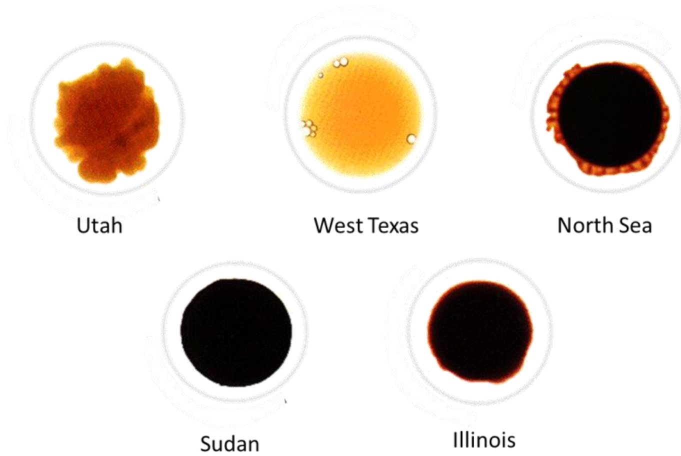
Asphalt Binder

Asphalt binders are the "black glue" that binds the aggregate in the mixture together. In addition to providing this crucial cohesion to the mixture, the binder is responsible for giving the mix lubrication so that it can be mixed, paved and compacted during construction; sealing voids in the mix giving it a low permeability to air and water; and coating the aggregate to prevent degradation under traffic and weather. The asphalt binder also provides flexibility so that 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 there is a rock asphalt which is naturally occurring material that comes from limestone quarries in Uvalde County. Manufactured binders are produced in petroleum refineries or at blending plants and may include additives that improve the asphalt's characteristics at low or high temperatures or that improve the asphalt mixtures, resistance to moisture sensitivity.

Refinery Produced Asphalt

Crude oil sources are scattered throughout the world, and while crude oil is often discussed as if it were a uniform material, it varies greatly from source to source. Figure 2-2 shows how crude oils from different locations change in terms of appearance. Generally speaking, the darker the crude oil the heavier it is, and the more likely it is to be suitable for asphalt production. Heavy crudes generally have a higher metals content, are more viscous, and 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 is aimed at producing a number of products including gas, gasoline, kerosene, fuel oils, lubricating oils and asphalt. In the past, the typical refinery used distillation towers to separate the different products by heating the crude oil and then applying a vacuum which would pull off different fractions at different levels in the towers (Figure 2-3). The material that was too heavy to be separated was called the "bottoms" and it was used to produce asphalt 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 binder such as the placement of seal coats or as patching materials. Currently, most refineries go beyond vacuum distillation. Techniques are used in further refining crude oil bottoms including solvent deasphalting and solvent extraction. Solvent deasphalting involves using propane or butane (the solvent) in stripping oils out of the vacuum tower bottoms, and solvent extraction results in a solvent stripping out the asphaltenes (very hard material), resins and oils. In both cases of solvent deasphalting and solvent extraction, the residual materials are combined with lighter flux oils to create asphalt with the desired properties.

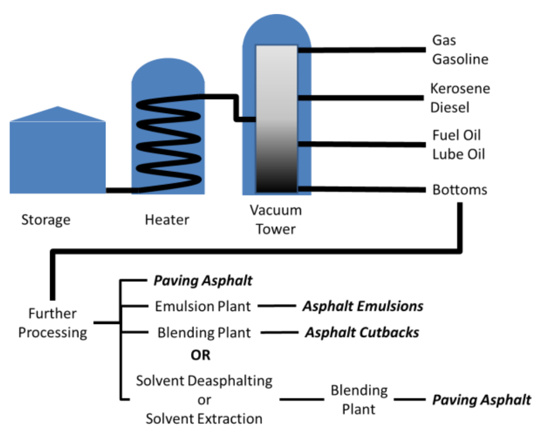


Figure 2-3. Refining and Asphalt Production Schematic.

Often times, the reconstitution of the heavy components can take place 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, polyphosphoric acid (PPA), and recycled engine oil bottoms (REOB). All of these materials have been used as additives in the past, and as is always true, the blending terminal must take care to balance the components to meet the binder specifications and ensure that the resulting binder provides the desired long-term performance properties.

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 but it focuses on high temperature properties of the original and short-term aged asphalt, and the low-temperature properties of the long-term aged binder. The intent of the PG system is to avoid problems with rutting and cracking early in the pavement's life and with cracking later on. The additives mentioned above are used to achieve specific objectives in meeting asphalt specifications. For instance, if an 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 by using a softer base asphalt binder with the desired low temperature behavior and using a polymer or PPA to achieve the needed high temperature properties. Alternatively, a small amount of REOB may be added to an asphalt to soften it at low temperatures to help resist cracking. In some instances, an anti-stripping agent may be added to the asphalt to help the binder better adhere to certain types of 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 truck, rail or barge (Walker and Davis, 2016). Rail and barge are usually reserved for shipping asphalt from the refinery to blending terminals but barges may be used also for transport to large asphalt mix producers. The vast majority of asphalt mix producers receive shipments of binder by trucks with heated tank trailers with capacities of up to 11,000 gallons. Once the tanker truck arrives at the asphalt mix plant, the shipment is loaded into either 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 very small amount 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 out of two quarries near Uvalde since 1885 and it continues to be an important 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 added for to increase its workability and storage life for cold applications. It is normally used as either a surfacing or 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 and gravel and crushed stone. Sands and gravels are water deposited materials and commonly found in current or old river beds. These materials are taken from pits in these formations (Figure 2-5). These aggregates are normally comprised largely of silica but they may come from a number of origins. Because the tumbling effect of water gives gravel a rounded shape, it usually must be crushed in order to impart angularity to resist rutting before it can be used for highway or airfield pavements. Most sand and gravel operations are located in the Panhandle and in the Rio Grande Valley (TxDOT, 2012). Although it used to be fairly common to use sand and gravel in Texas asphalt pavements, environmental regulations and the cost of crushing and processing have led to 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 located 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 of the crushed stone sources in Texas are limestone, dolomitic limestone or dolomite, although 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 mostly located in Central and Northeast Texas. East Texas is largely devoid of aggregate sources so aggregates need to be imported from other parts of the state usually by rail.

Figure 2-6. Limestone Quarry.

Quality of Aggregate

Aggregates may vary in their quality characteristics according to the requirements of the material and the structure in which they will be used. Factors including the gradation, shape, texture, cleanliness, abrasion resistance and durability are all important to asphalt mixtures, depending upon where the mix is going to be used in the pavement structure. For example, abrasion resistance is more important on the surface of the pavement for skid resistance than in the lower base layer. Having a shape that is angular and a rough surface texture are desirable to provide an interlocking of the aggregate particles that is desirable for resisting rutting as well as providing skid resistance. Aggregates that are flat and elongated may orient themselves horizontally under compaction and result in a weak mixture. Cleanliness and durability are important 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 and disintegration of the mix. Durability is the term used to describe an aggregate’s ability to resist disintegration from weathering. The gradation describes how the material size is distributed from coarse particles to fine, and it is dictated by the intended purpose of the asphalt mixture. The requirements for aggregates in asphalt mixtures are discussed in detail in Chapter 3.

Delivery of Aggregates to Asphalt Mix Plant

Some asphalt plants are located 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, however, aggregates are barged, railed, or trucked from the quarry to the asphalt plant site. Many contractors in East Texas have rail off-loading facilities on their grounds to receive the aggregates. This usually requires additional handling and processing to obtain the proper sizing for gradation.

Recycled Products

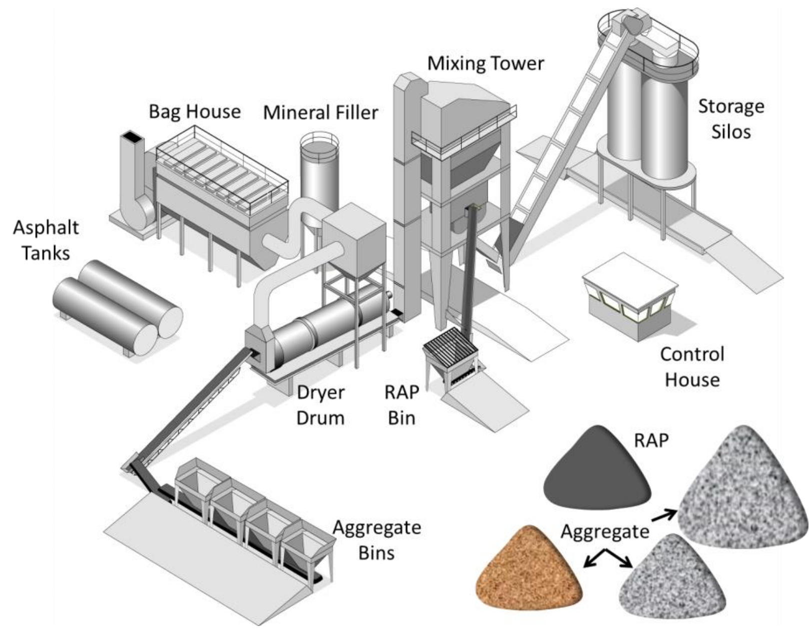
The use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) in asphalt mixtures has been a widespread practice since the mid-1980s. The use of these in mixtures is important for economics, the environment, and pavement performance. The environmental benefits were highlighted in Chapter 1. The asphalt contained in these products can be reused in asphalt mixtures as there is a blending that goes on between the recycled and virgin asphalt binders. Thus, it is possible to use less virgin asphalt in the resulting asphalt mixtures which saves money and conserves petroleum resources. Sometimes the blending between the binders may be aided through the use of recycling agents, especially if a high RAP content is desired. Since RAP contains aggregate, the amount of new aggregate in asphalt mixture will be reduced as well. 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 amount of new materials required, asphalt mixtures made with RAP and RAS are usually able to better resist rutting as they are generally stiffer mixtures.

RAP is mostly generated from milling off surfaces of pavements that need overlays. The milling machine takes up the old surface by grinding it off and depositing the material into a dump truck for transport back to the plant. At the plant, the RAP may undergo sizing and further processing to get it to the right gradation for various mixtures, after which it is stockpiled until it is used. RAS may be from either manufactured waste asphalt shingles (MWAS) that come from a factory or tear-off asphalt shingles (TOAS) that come from residential roofs that have been replaced. MWAS simply needs to be ground and sized to about 3/8 inches before use. TOAS requires processing and grinding to remove deleterious materials such gypsum board, wood and nails as well as 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, as much as 5 percent RAS may be used in mixtures according to TxDOT although most contractors limit this to 3 percent to keep the mixture from becoming too brittle.

Asphalt Mixture Production

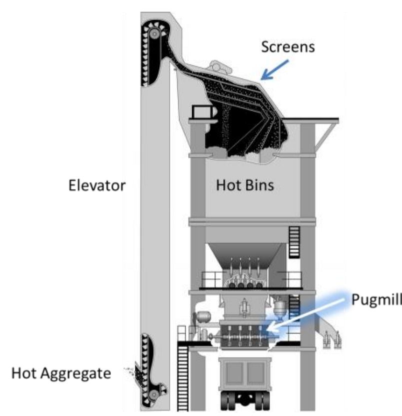
The goal of asphalt mixture production is to combine aggregates, asphalt binder, and recycled materials in the desired proportions to make an economical material that can be placed, compacted, and have the desired performance characteristics in service. The typical layout of an asphalt mixture plant site is shown in Figure 2-7. Aggregates are stored in stockpiles that are sorted according to size. RAP stockpiles may be sorted according to size but may also be stored in just one stockpile. Normally, the number of stockpiles is dictated by the space available at the plant. The asphalt binder is stored in either vertical or horizontal tanks depending upon the individual plant design. The aggregates and RAP are taken from their stockpiles and placed into bins ahead of mixing. The mixtures may be produced in either a batch plant or a continuous drum plant which are discussed below. A recent research report has shown that there are no differences in mixtures produced in either type of plant (Newcomb, et al., 2015). The choice of plant type usually reflects the production rates and flexibility desired by the plant owner.

In a batch plant (Figure 2-7), the aggregates are taken from stockpiles, placed into bins, and travel through a dryer drum prior to being screened for size and loaded into hot bins in a batching tower (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. Gates on the bins are opened, allowing the proper proportion of aggregates to be weighed prior to dropping into the pugmill. The pugmill is a container with a series of paddles in it to mix the aggregate and asphalt. After the aggregates are placed in the pugmill, they are dry mixed for a short period of time, after which the asphalt binder is fed into the pugmill through a weigh bucket. The aggregate and binder are then wet mixed and discharged from the pugmill into either into a truck or onto a slat conveyor for loading into a silo. Batch plants are suitable for any type of production but they are preferred for operations where the mix types or aggregate proportions may change frequently.



Source: USACE, 2000

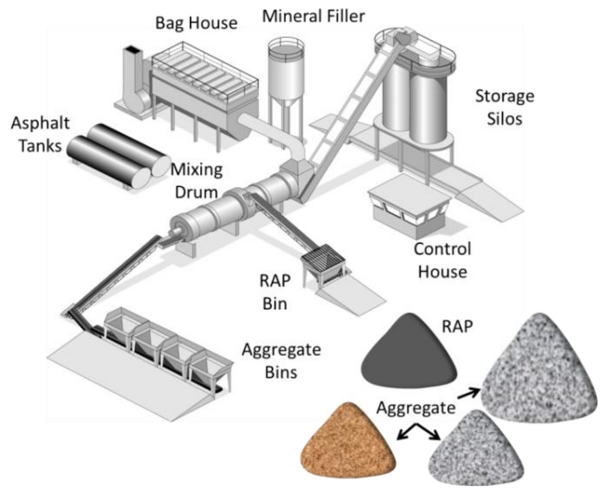
Figure 2-7. Typical Batch Plant Layout.



Source: USACE, 2000

Figure 2-8. Details of Batch Plant Mixing Tower.

Beginning in the 1970s there was a rapid and persistent increase in the number of continuous or drum mix plants (Figure 2-9) replacing batch mixing plants. In general, a continuous plant differs from a batch plant in that cold aggregates are fed onto a weigh belt in the proper proportions prior to entering the elevated end of the drum for drying. The aggregates are dried as they tumble through the drum toward the lower end where they are mixed with binder before exiting 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 directed upward against the flow of aggregate. These designs are referred to as parallel flow drum and counter flow drum, respectively. There are relatively few parallel flow plants still in service as they had 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 that is 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 in high-production operations since 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 takes place hours ahead of paving, and 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 typically 200 to 300 tons of asphalt mixture. In most cases, the material may be held for anywhere from 2 to 8 hours, although there have been cases where conditions required holding the material overnight prior to transporting it to the paving site. It is important that the mix not be allowed to cool to a point where the material at the bottom of the silo bridges the discharge chute. 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 almost as soon as it is made. It is a best practice for the dump truck to be loaded in several deposits alternating from front to back and center in order to provide better uniformity in the mixture.

Quality control tests are usually performed by contractor personnel at the plant during the production of the mix. Samples of the mixture are taken from the dump trucks or behind the paver and transported back to the contractor’s laboratory. The material is compacted using a laboratory mix compactor and tested to determine if the volume characteristics of the produced mixture is 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 at a later date in an agency or consultant laboratory which requires that the material be reheated prior to molding and testing. Care must be taken if the aggregate in the mixture has a relatively high absorption capacity as the transporting and reheating may cause differences in the test results between the quality control and quality assurance samples. Cores from the roadway may also be taken and tested to establish the density (or air voids) of the material in place. Density that is too great may indicate that the material could bleed or rut under traffic while density that is too low may mean that the material might be weak in service and easily crack or rut.

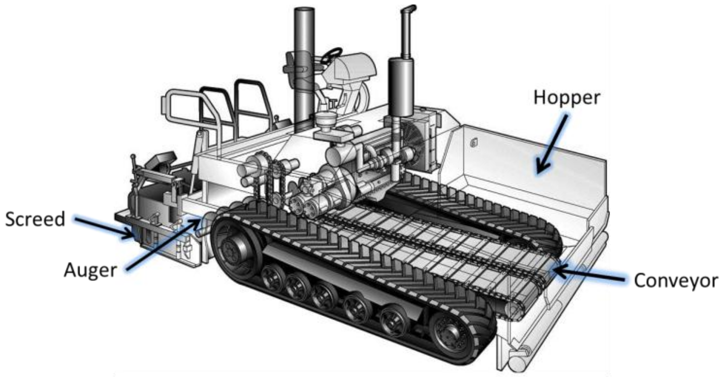
Asphalt Pavement Construction

The transport, delivery, placement, and compaction of the asphalt mixture 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. For long hauls or cooler weather, the trucks may be equipped with thick tarps to keep the mix from cooling excessively. End-dump trucks (Figure 2-10) have a hydraulic arm that raises the front of the bed causing material to flow out the gate at the rear of the truck. 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 into 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 by means of a pick-up machine which feeds the mix into the paver hopper.

Figure 2-10. End Dump Truck Discharging Mix into Paver.

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 conveyor evenly across the width of the paver. Next, the screed passes over the material to provide a surface that is level or properly sloped for surface drainage. At this point the uncompacted asphalt mat is about 10 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.

Figure 2-11. Example of Material Transfer Device.



Source: USACE, 2000

Figure 2-12. Schematic of Paving Machine.

Compaction is critically important to the performance of the pavement. The compaction process increases the density, lowers the permeability, and increases the strength of the material. There are three types of compactors or rollers used in this process: vibratory, pneumatic and static. Vibratory compactors are often made into static rollers by simply turning off the vibrator. Breakdown rolling is where the initial compaction of the asphalt mat occurs which is normally accomplished with a vibrating roller (Figure 2-13). The vibration helps the aggregate particles in the mix to pack tightly. Next comes the intermediate compaction and this may be done usually with a vibratory or pneumatic roller (Figure 2-14). The pneumatic roller has tires that knead the mixture together with front and back tires that overlap to provide a complete coverage of the pavement. Finally, the finish compaction completes the process with a static compactor that removes any marks in the surface and provides the remaining small portion of density in the mat. The choice of the combination of rollers and the number of passes each 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. The pattern providing the greatest density increase with the least effort is the pattern used for the remainder of the job.

It is normal to measure density as compaction is taking place, and this is most often done with a nuclear or non-nuclear density gauge. By constantly monitoring the pavement density, the paving crew is able to see any potential changes in the pavement that may require extra attention. Issues such as weakening in the lower pavement layers may mean that the roller pattern would need to be adjusted. It is also a common practice for an agency to take roadway cores to monitor the in-place density to ensure 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 has presented a brief overview of the process for 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 the technology of the design of asphalt mixtures, the design of pavement structures, specifications, specialty asphalt mixtures, managing pavement systems, and choosing pavement maintenance and rehabilitation methods.

CHAPTER THREE
Mix Design

In this chapter you will learn about:

- The characteristics, properties, and requirements for asphalt binders.
- The characteristics, properties, and requirements for aggregates.
- The characteristics of RAP and RAS.
- The Superpave™ mix design procedure used by TxDOT.
- The process for field validation of the mixture design.

Introduction

Asphalt mixtures may be designed to perform a variety of functions including providing durable, economical 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 following chapter, Pavement Design, will discuss thickness design and the proper selection of mixtures to create an optimum pavement section.

In this chapter, the Superpave™ system will be discussed, as this is the current method used by the Texas DOT under Item 344 in its 2014 specification. 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 in order 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 Hot Mix Asphalt Training Center in Buda, Texas.

Binders

General Characteristics of Asphalt Binders

Asphalt binders need to have a consistency which is liquid during the production and placement of mixtures, solid to semi-solid during the service life of the pavement, and provide some resistance to embrittlement due to low roadway temperatures and aging. The Superpave™ binder specification requires that testing encompass these conditions in order to be used. If the material is too viscous during production and construction, 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. If the low-temperature stiffness of the binder is too great, then premature cold-temperature cracking could result in service.

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

Modifiers are sometimes used to enhance the qualities of asphalt binder. Polymer modifiers are the most common and these are usually in the form of either a block co-polymer of styrene-butadiene-styrene (SBS) or styrene-butadiene rubber (SBR or latex). The addition of polymer modifiers is usually done to broaden the high-temperature and low-temperature range over which the asphalt binder may be specified. There are chemical modifiers to produce warm mix asphalt which improve the coating of aggregate and improve compaction at lower-than-normal temperatures. Sometimes rejuvenators and recycling agents are used to 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 present a background for the types of tests that are performed to determine their physical properties 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 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 testing is most often performed by the binder supplier and is documented in a certificate of compliance which acts as the quality control. Quality assurance testing may be done by a third-party testing laboratory.

Source: Mahoney and Muench (2012). www.pavementinteractive.org

Figure 3-1. Rolling Thin-Film Oven.

Source: Mahoney and Muench (2012). www.pavementinteractive.org

Figure 3-2. Pavement Aging Vessel.

The Performance Grade (PG) specifications for Superpave binders used in Texas (Item 300) (TxDOT, 2014) are presented in Table 3-1. The Performance Grading system is based upon a high-temperature grade and a 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 be used to illustrate the Superpave specifications for asphalt binders. There are five high-temperature PG grades in the TxDOT specification, ranging from PG 58 to PG 82 and four low temperature grades varying from −16 to −34.

Table 3-1. Superpave Requirements in TxDOT Item 300.

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,[7] Test temperature @ 10 rad/sec., °C	58			64				70				76				82		
Elastic recovery, D6084, 50°F, % Min	–	–	30	–	–	30	50	–	30	50	60	30	50	60	70	50	60	70
Rolling Thin-Film Oven (Tex-541-C)																		
Mass loss, Tex-541-C, Max, %	1.0																	
Dynamic shear, T 315: G*/sin(δ), Min, 2.20 kPa, Max, 5.00 kPa,[7] Test temperature @ 10 rad/sec., °C	58			64				70				76				82		
Pressure Aging Vessel (PAV) Residue (R 28)																		
PAV aging temperature, °C	100																	
Dynamic shear, T 315: G*sin(δ), Max, 5,000 kPa 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:[5,6] *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:[6] 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

Source: TxDOT, 2014

The Brookfield rotational viscometer (Figure 3-3) (AASHTO T 316) consists of a spindle suspended in the liquid binder inside of a heating mantel. The amount of torque required to keep the spindle rotating at a constant speed is measured, and from this a viscosity is computed. 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 3-1.

Source: Mahoney and Muench (2012). www.pavementinteractive.org

Figure 3-3. Brookfield Viscometer.

Another universal requirement of all Superpave binders is that the flash point (AASHTO T 48) of the unaged binder be equal to or higher than 445°F (230°C) to minimize the risk of fire at the plant. 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 time that the stress is applied, a phase shift or phase angle (δ) occurs which is also recorded. From G* and δ, two parameters are calculated: the rutting parameter (G*/sinδ) and the cracking parameter (G*sinδ).

The Dynamic Shear Rheometer (DSR) is used to test 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. In Table 3-1 it can be seen that the unaged binder must meet a G*/sinδ value of 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. 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).

Source: Mahoney and Muench (2012). www.pavementinteractive.org

Figure 3-4. Dynamic Shear Rheometer.

The mass loss of the binder during RTFO aging is specified as a maximum of 1 percent. This is to ensure that there will not be an excessive amount of evaporation of volatiles in the binder during the production and placement of the asphalt mixture.

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 subjected to the test temperature. The sample is subjected to simple center-point loading at a very slow 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. If the stiffness is too great (over 300 MPa), then low-temperature cracking may occur due to higher thermal stress. Likewise, if the m-value is too low (less than 0.300), then the material may not be able to 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 ductility of the material.

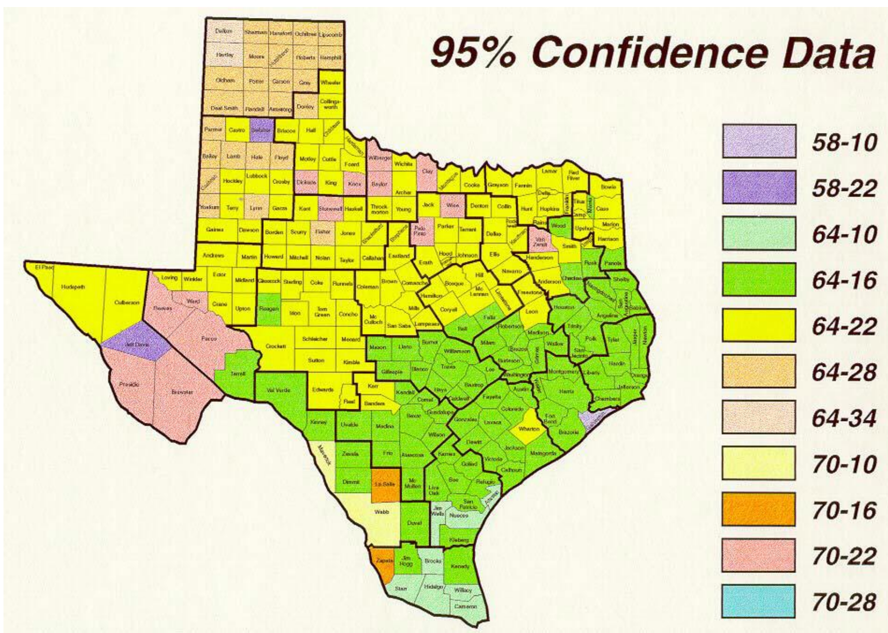
Source: Mahoney and Muench (2012). www.pavementinteractive.org

Figure 3-5. Bending Beam Rheometer.

The elastic recovery test is used to test the ability of an asphalt binder to return to its original state after it has been stretched. The test is performed using a ductility test at 10°C (50°F). The material is stretched and then cut. The percentage that the material rebounds back 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 for PG 64-22, there is no specified value for elastic recovery.

Selection of Binder Grade

The binder grade selected for use in a particular project should be based primarily on climate, and on 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 provide an acceptable performance for lower traffic volume facilities.



Source: http://onlinemanuals.txdot.gov/txdotmanuals/pdm/performance_graded_binders_pg_binders.htm).

Figure 3-6. County Level Map of Texas for Performance Grade Asphalt.

The use of a higher grade of high-temperature binder is usually only justified where there are critical roadways such as high volumes of 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. The use of 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 key roles in the strength and durability of the mixture. They must be able to withstand the production and construction processes without degradation and provide long-term resistance to environmental influences such as exposure to water and resistance to 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 important, if not more important, to the performance of the mixture than the selection of binder. The aggregate will provide the structure for supporting loads and will largely dictate the durability of the mixture. The testing of aggregates consists of 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. There are different aggregate gradations for different purposes, and they 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 to them (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 amount of material retained (not passing) the larger sieve sizes. A dense-graded fine aggregate is shown in Curve C where more material passes the larger sieves. Curve D represents a gap-graded aggregate that would typically be used in a Stone Matrix Asphalt. Gap-graded aggregates have specific sizes of aggregate missing for the purposes of creating a strong stone skeleton and allowing room for more asphalt and fine material. Superpave mixtures generally fall within the definition of dense-graded aggregates.

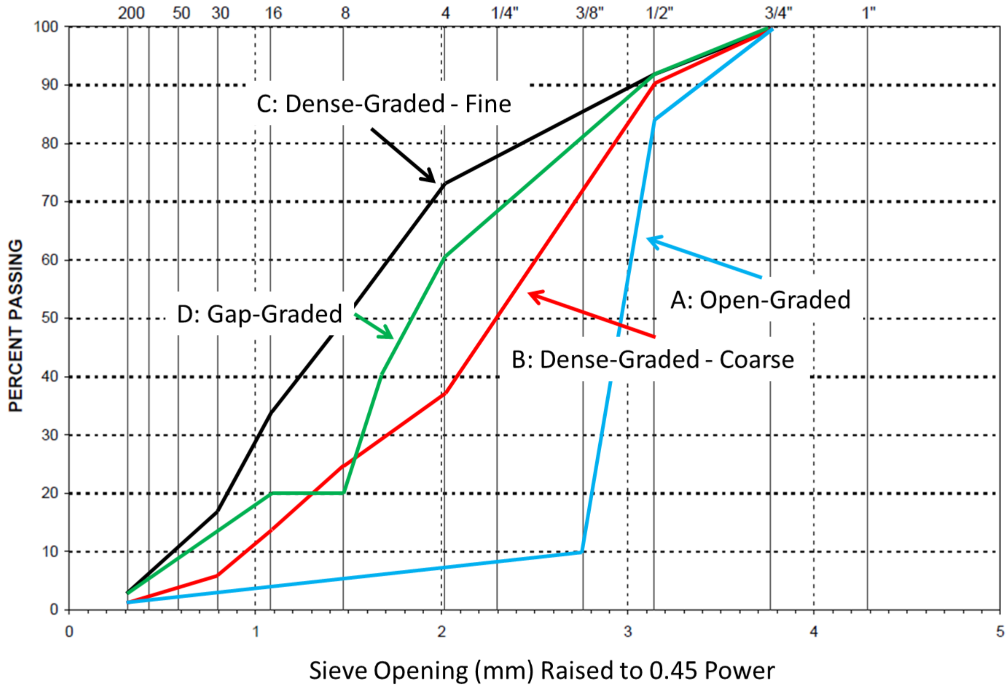


Figure 3-7. Various Aggregate Gradations Used in Flexible Pavements.

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 upon Nominal Maximum Aggregate Size (NMAS) and that depends upon the intended purpose of the mix. The VMA is the volume of space between the aggregate particles in the mix. 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 3-2 it can be seen that SP-A has a very large size aggregate with a NMAS of 1 inch and is suitable for asphalt base mixtures. SP-B mixtures may be used in either 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 suitable mixtures as well. The selection of the aggregate gradation should be based upon the expected performance of the mixture, availability of aggregate, and economic considerations. Generally speaking, mixtures with a greater NMAS are cheaper than those with smaller aggregate.

It is frequently the case that aggregate from one stockpile will not meet the requirements of the entire gradation. In fact it is common for up to five or six stockpiles to be used in the blending process. The combining of aggregate stockpiles to meet the overall gradation requires that the gradation of the aggregate in each stockpile (including the aggregate in the RAP stockpile) be evaluated. For the RAP stockpile, the asphalt is extracted from the RAP by burning it off in an ignition oven (Tex-236-F) before grading the aggregate.

Table 3-2. TxDOT Gradation VMA Requirements for Superpave Mixtures.

Sieve Size	SP-A Base	SP-B Intermediate	SP-C Surface	SP-D Fine Mixture
2"	100.0[1]	–	–	–
1-1/2"	98.0–100.0	100.0[1]	–	–
1"	90.0–100.0	98.0–100.0	100.0[1]	–
3/4"	Note[2]	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	19.0–90.0	23.0–90.0	28.0–90.0	32.0–90.0
#8	19.0–45.0	23.0–49.0	28.0–58.0	32.0–67.0
#16	1.0–45.0	2.0–49.0	2.0–58.0	2.0–67.0
#30	1.0–45.0	2.0–49.0	2.0–58.0	2.0–67.0
#50	1.0–45.0	2.0–49.0	2.0–58.0	2.0–67.0
#200	1.0–7.0	2.0–8.0	2.0–10.0	2.0–10.0
Design VMA, % Minimum				
	13.0	14.0	15.0	16.0
Production (Plant-Produced) VMA, % Minimum				
	12.5	13.5	14.5	15.5

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

Source: TxDOT, 2014

Below in Table 3-3 is an example of 3 aggregate stockpiles and one RAP stockpile that are to be used in the blending process. Stockpile 1 is relatively coarse material, Stockpile 2 has intermediate sized material, Stockpile 3 has fine material, and the RAP stockpile is dense-graded. A total of 20 percent RAP material will be used in the final mix. The target gradation will be a SP-C as noted in Table 3-2. 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.

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 a 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 probability that the gradation in production will fall outside of the gradation band requiring production to stop in order 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:

$$Combined\ \%\ No.4\ = (0.20\ X\ 17.4) + (0.40\ X\ 44.7) + (0.20\ X\ 85.4) + (0.20\ X\ 72.2) \qquad \text{(Eq. 3-1)}$$

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

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 is begun again with different stockpile percentages.

Table 3-3. 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	28.0–58.0
#16	4.8	9.3	49.1	38.5	22.2	2.0–58.0
#30	2.3	5.6	28.6	15.3	11.5	2.0–58.0
#50	0.5	2.4	17.5	9.5	6.5	2.0–58.0
#200	0.2	1.3	10.6	7.4	4.2	2.0–10.0

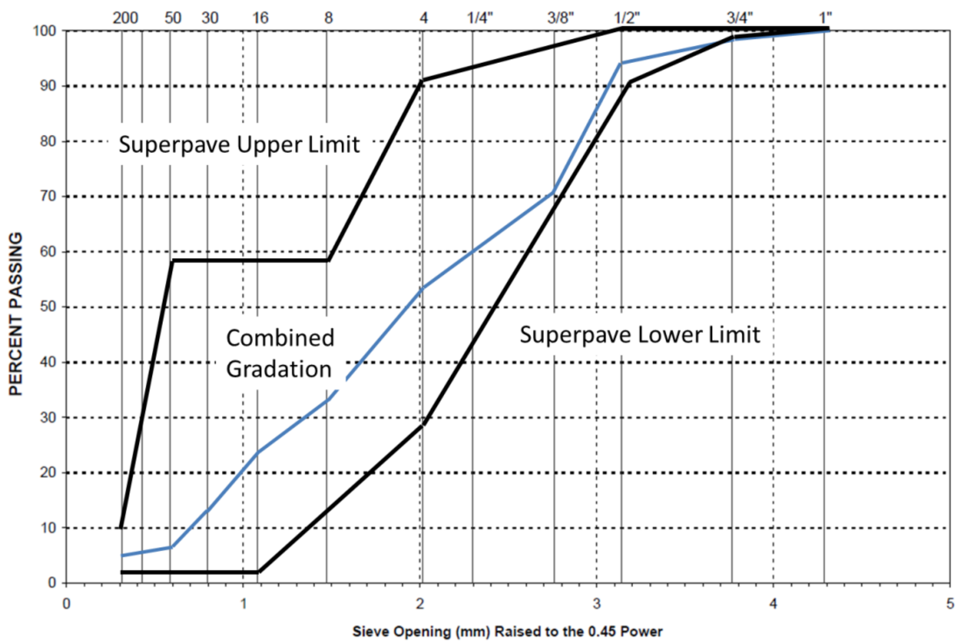
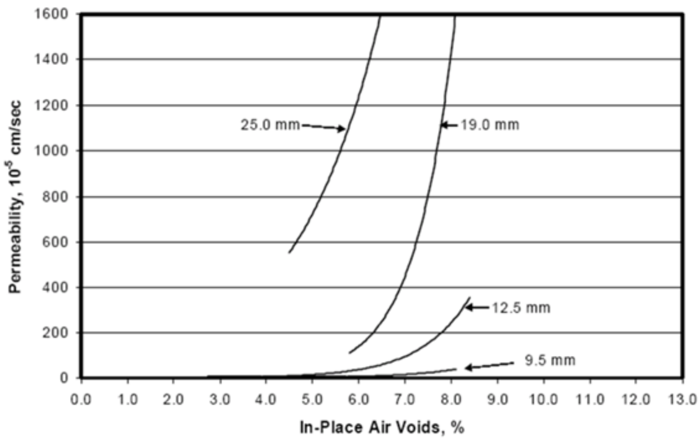


Figure 3-8. Combined Gradation of Aggregate Stockpiles in Table 3-3 and SP-C Gradation Limits.

The selection of the size and gradation of the aggregate is crucial to the performance of the pavement. The use of a large NMAS aggregate with a coarse gradation (Figure 3-7) will likely result in problems due to the permeability of the mix. A study by the National Center for Asphalt Technology (NCAT) has shown that for the same volume of air voids, the permeability can increase dramatically for larger 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 adequately fill the space between the aggregates. This will lead to low in-place density, high permeability, and difficult workability.



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, and clean in addition to having the surface texture and particle shape suitable to their function in a pavement. In Texas, a Surface Aggregate Classification (SAC) is used designate 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 3-4. 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 3-4. 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
Magnesium sulfate soundness, 5 cycles, %, Max	Tex-411-A	25
Crushed face count,[2] %, 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
Combined Aggregate[3]		
Sand equivalent, %, Min	Tex-203-F	45

3. Used to estimate the magnesium sulfate soundness loss in accordance with Section 344.2.1.1.2., "Micro-Deval Abrasion."
4. Only applies to crushed gravel.
5. Aggregates, without mineral filler, RAP, RAS, or additives, combined as used in the job-mix formula (JMF).

Source: TxDOT, 2014

Cleanliness and Presence of Dust

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 a visual inspection of the material retained on a No. 4 or No. 8 sieve. The weight percent of material that is not mineral aggregate is considered deleterious. The decantation test quantifies the amount of dust or clay coating on the coarse aggregate which may interfere with the adhesion of the asphalt to the aggregate. In the decantation test, a quantity of 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 then dried and weighed, and the percent loss is calculated. A further check on the quantity of clay-like particles is performed on the combined virgin aggregate gradation in the Sand Equivalent test (Tex-203-F). The Sand Equivalent test is performed by measuring the volume of aggregate in a graduated glass cylinder, suspending the clay particles in a calcium chloride solution and measuring the remaining volume of aggregate not suspended in the solution. Expressed as a percent of the original volume of material, the remaining volume of aggregate is the Sand Equivalent.

Wear Resistance and Durability

The wear resistance of the coarse aggregate is determined by the Los Angeles Abrasion test (Tex-410-A). In this test a portion of coarse aggregate is loaded into a 27-inch diameter drum with 6 to 12 steel balls. The drum has a ledge which forces the material and ball to fall within the drum. The weight of material retained on the No. 4 sieve is measured before and after running the drum through 500 revolutions. The difference 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 of material 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 is performed by introducing a sample of coarse aggregate into a steel jar with water and steel balls. The aggregate, water and balls are rotated at 100 rpm for 105 minutes. 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 in instances where the results of the Sodium Magnesium Sulfate test 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 important to the proper proportioning of 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:

$$Specific\ Gravity = \frac{\frac{Mass\ (g)}{Volume\ (ml)}}{Density\ of\ Water\ (\frac{g}{ml})} \qquad \text{(Eq. 3-2)}$$

The density of water is assumed to be 1.000, and so it is frequently omitted from the calculation of specific gravity.

There are three measures of specific gravity for the aggregate that 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 weight of the aggregate divided by the volume of the aggregate excluding the voids permeable to water (Figure 3-10(c)). Figure 3-10(b) shows that the effective specific gravity is the weight of the aggregate divided by the volume of the aggregate 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 section on the Superpave mix design process.

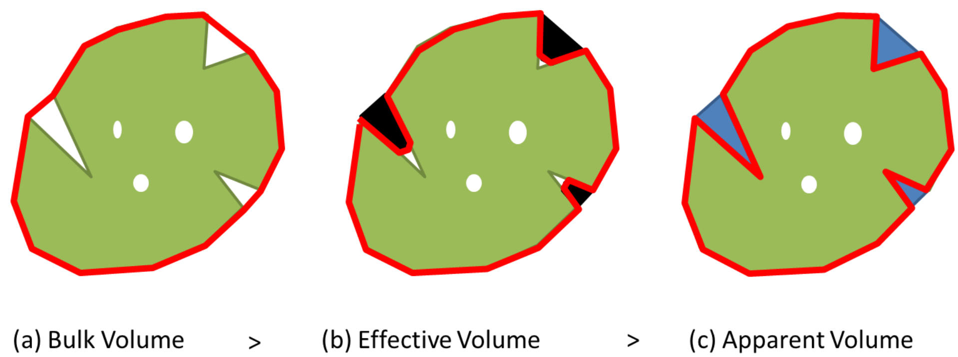


Figure 3-10. Schematic of the Definitions of Volume (within Red Outline) for Aggregate Specific Gravity.

The G_{sb} is determined using TxDOT Test Method Tex-201-F for both 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 hr after which the aggregate is towel-dried to a saturated-surface-dry (SSD) condition in which the pores are filled 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 oven dried. After drying the dry weight of the sample is recorded. Figure 3-11 shows the relationships needed to calculate the aggregate bulk specific gravity.

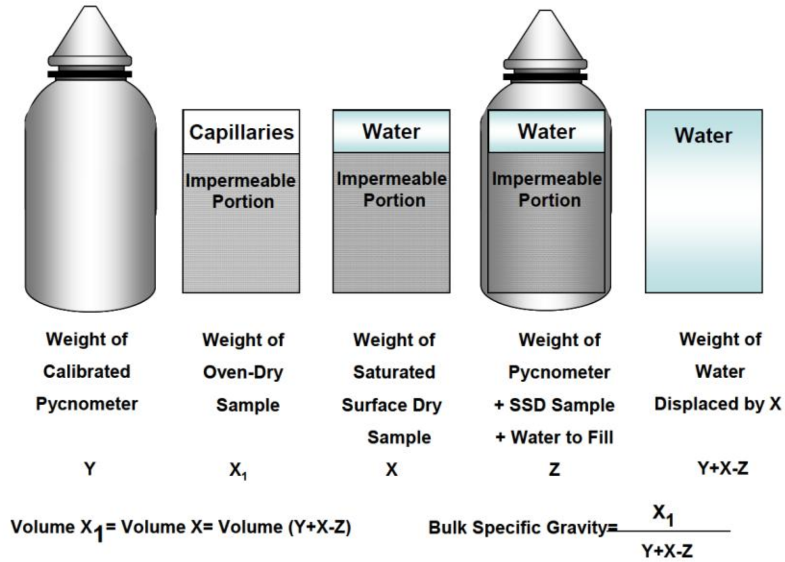


Figure 3-11. Illustration of Aggregate Bulk Specific Gravity Determination (Tex-201-F).

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 considered to be in the SSD state. The same basic process applies to the fine aggregate as for 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.

$$G_{sb} = \frac{100}{\frac{W_{CA}}{G_{CA}} + \frac{W_{FA}}{G_{FA}}} \quad \text{(Eq. 3-3)}$$

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 even though 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 up to 3.5 percent.

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

$$G_{sa} = \frac{X_1}{Y + X_1 - Z} \quad \text{(Eq. 3-4)}$$

The combined apparent specific gravity is determined in the same way the combined bulk specific gravity is calculated in Equation 3-3.

Ranges of specific gravity for different types of rock aggregates used in construction are shown in Table 3-5 (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 although they 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 3-5. 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 as a result 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 the use of 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 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 in order 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), less than 0.2 percent of all RAP from construction projects was landfilled in 2013 (NAPA, 2014) 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 68 million tons in 2013. The use of RAP has become an institution within the asphalt paving industry and is critical to the sustainability and economy of pavements.

The gradation of the RAP aggregate and the asphalt content of the RAP mix need to be accounted for in the mix design process. RAP is usually taken up from a 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 oversize materials and may be separated into different size fractions (fractionation) prior to reintroducing the material into a new mix. Usually RAP from different sources is co-mingled into the same stockpiles so it is important in mix design to sample the as-processed material that will be used in the pavement. The specific gravity of the RAP aggregate is not normally determined as the RAP aggregate is assumed to have the same specific gravity as the combined virgin aggregate to be 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 as 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 as a hazardous substance.

The asphalt binder in RAP has been aged through oxidation that occurs during the construction process 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, for mixes containing higher amounts of RAP (up to 40 percent) a lower high-temperature grade may be needed. For instance, if a PG 70-22 was planned, then the use of 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, thermoset, 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, prior to grinding to size.

Table 3-6 gives the general composition of roofing shingles; however, the exact proportions of the components varies according to manufacturer, intended climate, and the type of backing material used. The asphalts used for shingles are generally air-blown and polymer-modified, making them much stiffer than typical paving grade asphalts, having a typical penetration range of 20–70 dmm (0.1 mm) at 77°F (generally a high temperature PG grade in excess of 100). Two types of asphalts are generally used in the manufacture of shingles: one to saturate the backing material and another as the coating material (Newcomb et al., 1993). The proportions given in Table 1 generally agree with those reported by Brock (2007).

Table 3-6. Components of Asphalt Shingles.

Component	Approximate Amount, % by weight	Notes
Asphalt Cement	25–35	Fiber Saturant and Coating
Granular Material	60–70	See Table 2
Backing	5–15	Paper, Fiberglass, or Felt

Source: Newcomb et al., 1993

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 the 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 ability to carry loads without cracking or rutting is dictated by the aggregate structure and asphalt content. 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 basic 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 comprised of the aggregate and asphalt while the total volume is comprised 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 the effective asphalt since this is the portion that coats and binds the aggregate together. An understanding of these relationships is fundamental to understanding the Superpave mix design process.

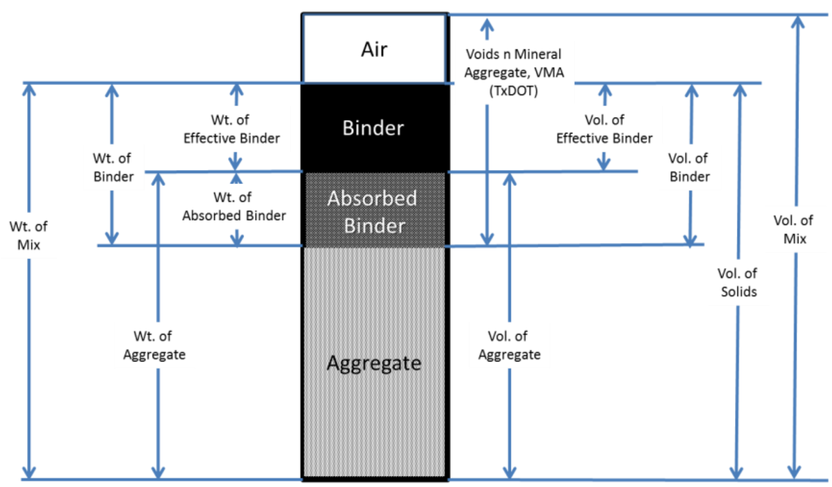


Figure 3-12. Weight-Volume Phase Diagram of Asphalt Mixture.

Preparation of Mix Design Samples

If the materials are familiar to the mix designer the initial asphalt content range for mix design is normally set as the anticipated optimum asphalt content (OAC) $\underline{+}$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 try to bracket the OAC. Extra iterations may be needed if the asphalt contents tried do not result in 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 is for determination of the maximum theoretical specific gravity (G_{mm}) of the mix. The two 4600 g samples are for bulk specific gravity (G_{mb}) measurements as well as any performance testing. The virgin aggregate, RAP and binder are heated to the appropriate mixing temperature as described in Table 3-7. Care must be taken not to overheat the RAP material.

Table 3-7. Mixing Temperatures for Asphalt Mix Design.

Asphalt Grade[1]	Mixing Temperature[2], °F (°C)
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 substitute binder are used, then use the original PG grade for mixing temperature.
2. When using RAP or RAS, mixing temperature may be increased to 325°F to provide adequate coating.

Source: TxDOT, 2014

The heated aggregates and RAP are placed into a heated mixing bowl followed by the addition of 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 range of tolerance, then the weight of the next sample should be adjusted accordingly.

Source: FHWA, 2004.

Figure 3-13. Superpave Gyratory Compactor.

Volumetric Testing and Calculations

There are two volumetric measurements that 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 this is the weight of the mix divided by the volume of solids. This is performed on the loose mix sample that was spread out on the flat pan and left to cool. The weight of the loose mix sample in 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:

$$G_{mm} = \frac{A}{D+A-E} \qquad \text{(Eq. 3-6)}$$

Where: A = Wt. of dry sample in air

D = Wt. of calibrated pycnometer filled with water.

E = Wt. of pycnometer containing 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:

$$G_{mb} = \frac{A}{B-C} \qquad \text{(Eq. 3-7)}$$

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 total mix (VTM)) and this is simply one minus the volume of solids (G_{mb}/G_{mm}). It is calculated as a percentage by:

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

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:

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

Where: P_b = Percent binder in the mix (as a volume fraction).

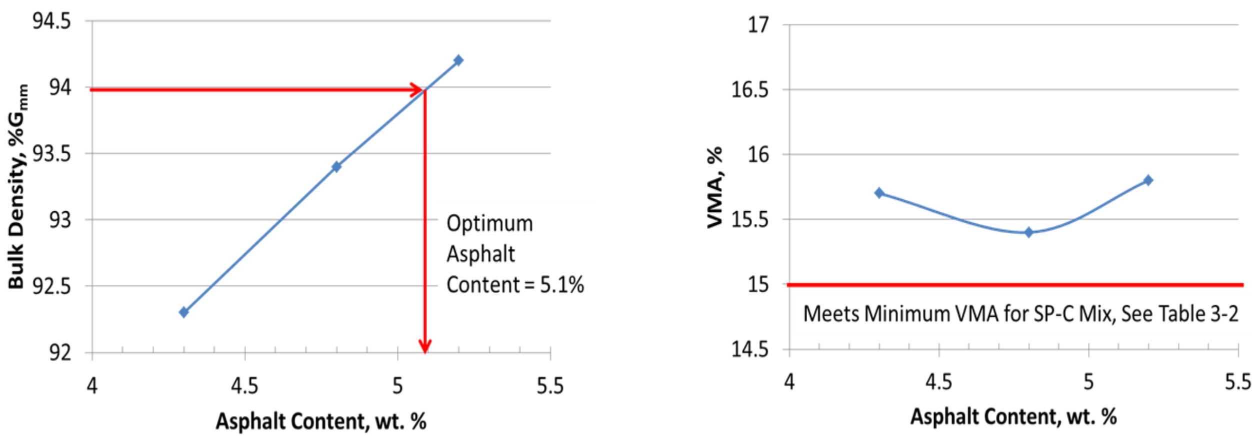
G_b = Specific gravity of binder (usually provide by asphalt supplier).

The voids in mineral aggregate (VMA) is the amount of space between aggregate particles and it is used as a measure of room available for asphalt and air voids in the mix. In most references, the VMA 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:

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

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 G_{mm} and VMA for Mix Design.

The determination of the optimum asphalt content at mix design is considered an initial step. Further refinement of the mix design is needed through the process of plant verification as will be discussed later.

Mechanical Testing and Criteria for Asphalt Mixtures

As shown in Tables 3-8 and 3-9, 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 which is 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 1.2 are the lower and upper limits for the dust to asphalt ratio. Values lower than this may indicate that the mix is over-asphalted and may be 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 77°F 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 that is susceptible to cracking while a value 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 as way of judging the moisture susceptibility of an asphalt mixture. In this test, a sample of the mix is boiled in water for a period of 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. This test may be waived by the agency engineer.

Table 3-8. 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]	–	0.6–1.6
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 3.0 mm and less than 12.5 mm.
3. Defined as % passing #200 sieve divided by asphalt binder content.
4. Used to establish baseline for comparison to production results. May be waived when approved.

Source: TxDOT, 2014

The last mechanical test is the Hamburg Wheel Tracking Test (HWTT) (Tex-242-F). 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 that is 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 3-9. TxDOT Hamburg Wheel Tracking Test Requirements for Superpave Mixtures.

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

1. May be decreased or waived when shown on the plans.
2. When the rut depth at the required minimum number of passes is less than 3 mm, the Engineer may require the Contractor to lower the Ndesign level to no less than 35 gyrations.

Source: TxDOT, 2014

Source: FHWA, 2004.

Figure 3-16. Hamburg Wheel Tracking Test.

Field Verification

As stated earlier, determination of the optimum asphalt content during mixture design serves as an initial target for asphalt plant production. Verification of the mix design should take place within the first lot of material, ideally within the first 200 tons of material. Mix should be sampled from a truck after loading and then taken to the plant laboratory. The sample should be quartered and enough material should be prepared to conduct volumetric testing for G_{mm} and G_{mb} as well as HWTT testing.

The asphalt content of the plant produced mixture should be tested according to Tex-236-F. This check on the asphalt content will validate the operation of the asphalt production process and ensure that the aggregate feeds in the plant are in proper order. It is important that the asphalt content oven results are 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 undergo changes in plant production due to handling. 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 FOUR
Pavement Design

In this chapter you will learn about:

- The important considerations in designing pavements.
- How traffic is characterized for pavement design.
- How to account for climate in pavement design.
- How to select the proper asphalt mix for applications within a pavement.
- What types of design procedures exist.
- How pavement design is done with different design procedures.

Introduction

The structural design of pavements is the practice of determining the combination of materials and their thicknesses needed to support traffic considering vehicle number 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, PaveExpress and PerRoad approaches to pavement design, and special considerations for pavement design will be discussed. Examples of designs using PaveExpress 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.

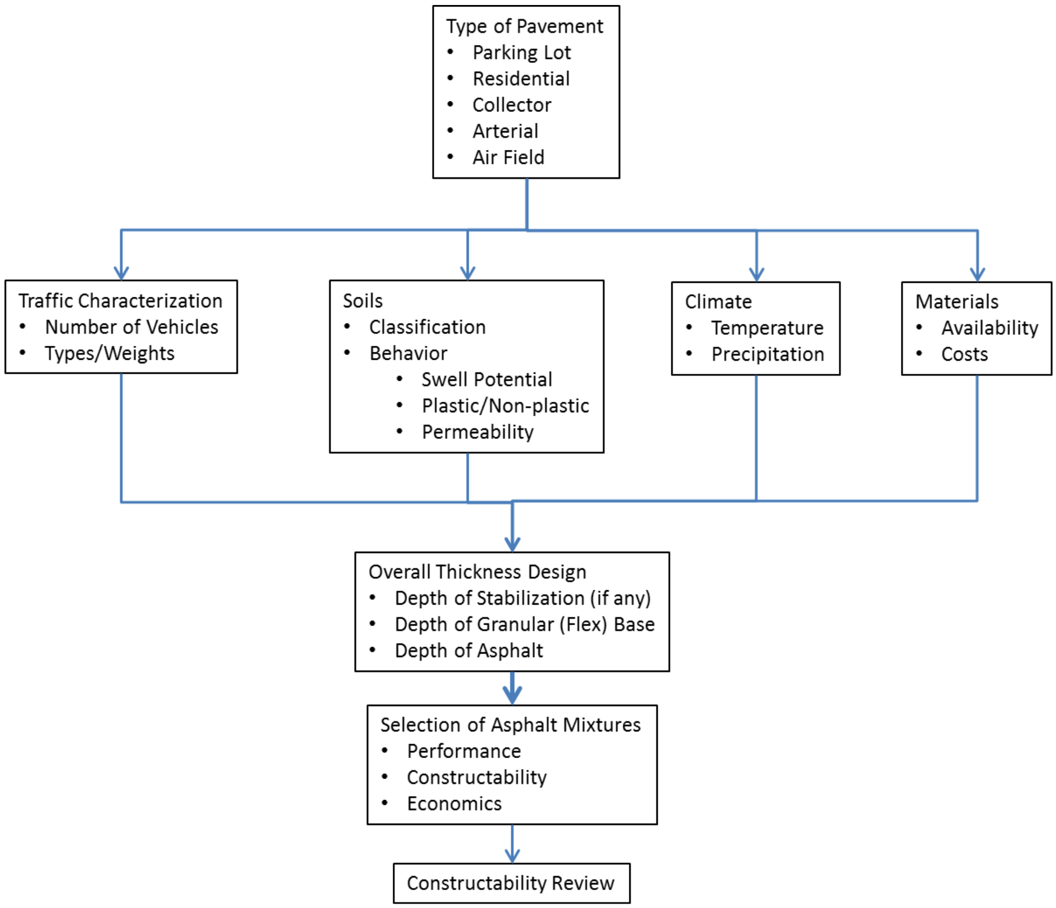


Figure 4-1. Pavement Design Process.

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 which eliminates the need for precise traffic forecasts and prevents an unneeded 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 occurring at the pavement surface, a much cheaper alternative to partial or complete reconstruction.

While flexible pavements are most frequently associated with roadways, there is a great deal of asphalt mix 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 actually 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 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 a given 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 4^{th} 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 4^{th} power, it also depends upon the pavement structure, but it does increase exponentially.

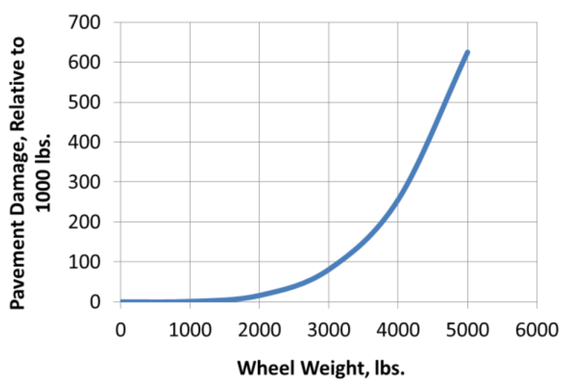


Figure 4-2. Illustration of 4^{th} Power Law.

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 the majority of 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 fairly 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 a number of 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 for 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 curb and gutter, 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.

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:

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

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.

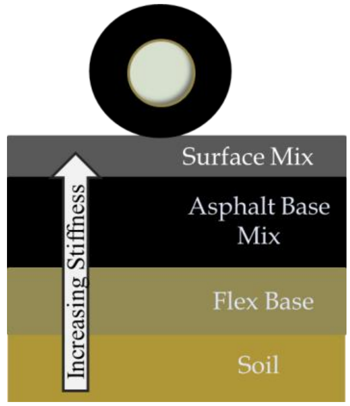


Figure 4-3. Relative Stiffness of Pavement Layers.

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 (a_i) for Various Materials.

Material	Typical Structural Coef. (a_i)	Range of a_i
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 exactly 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 through loading the pavement with a Falling Weight Deflectometer (Figure 4-5) and measuring the deflections at distances from zero to six feet out from the center of the plate. The technique for estimating the modulus values of different pavement layers is called backcalculation, and it involves matching the combination of layer moduli with the measured pavement deflection.

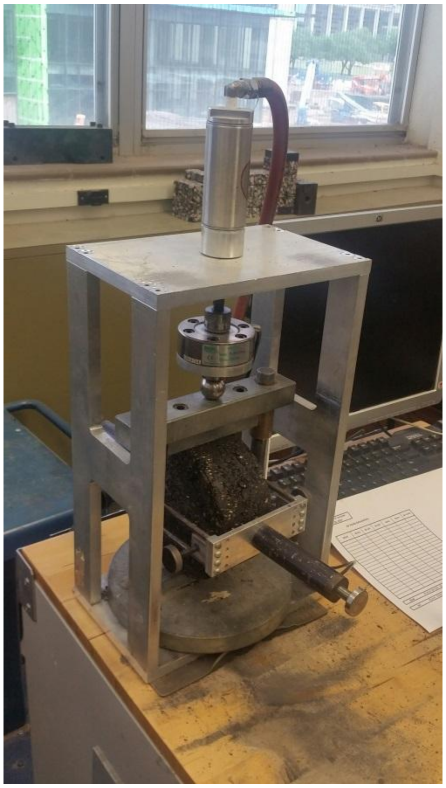


Figure 4-4. Resilient Modulus Test for Asphalt Mix.

Source: FHWA

Figure 4-5. Falling Weight Deflectometer.

For asphalt, the temperature and time of loading affect the modulus values. For normal applications, it is more important to account for temperature effects than time of loading. As shown in Figure 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 mechanistic-empirical (ME) approaches to pavement design where the seasonal, monthly, or even daily changes are used to better reflect actual pavement conditions.

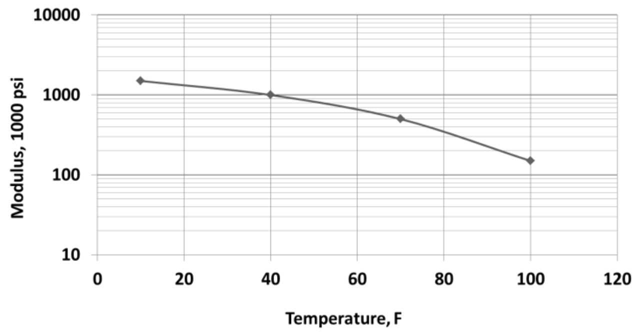


Figure 4-6. Example of How Temperature Affects Modulus (Stiffness) of Asphalt Mix.

Flex base materials are most affected by the presence of water. As moisture increases the material becomes softer and weaker as shown in Figure 4-7. The fluctuations of moisture content in base courses are very dependent upon the overall climate and seasonal rainfall. For instance, in West Texas it is likely that the material will be dry for much of the year and there is little risk in having prolonged periods of weakness. In southeast Texas, rainfall can occur in any particular season which could cause 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.

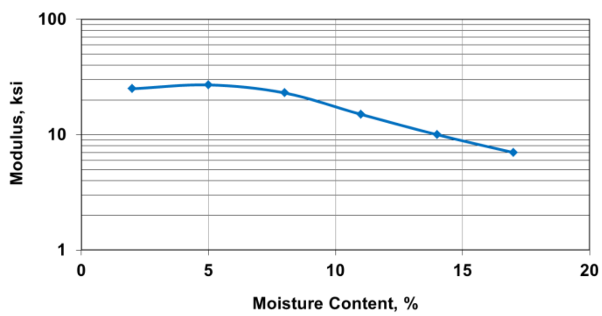


Figure 4-7. Example of How Moisture Content Affects Modulus (Stiffness) of Base.

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 clayey-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 there are any unnecessary impediments 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 mix specified. The ratio of lift thickness to NMAS should be 3:1 to 5:1. This will help ensure that the mixture can be placed and adequately compacted. Another example would be to check the stiffness of the mix against the amount of hand work that is anticipated. 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.

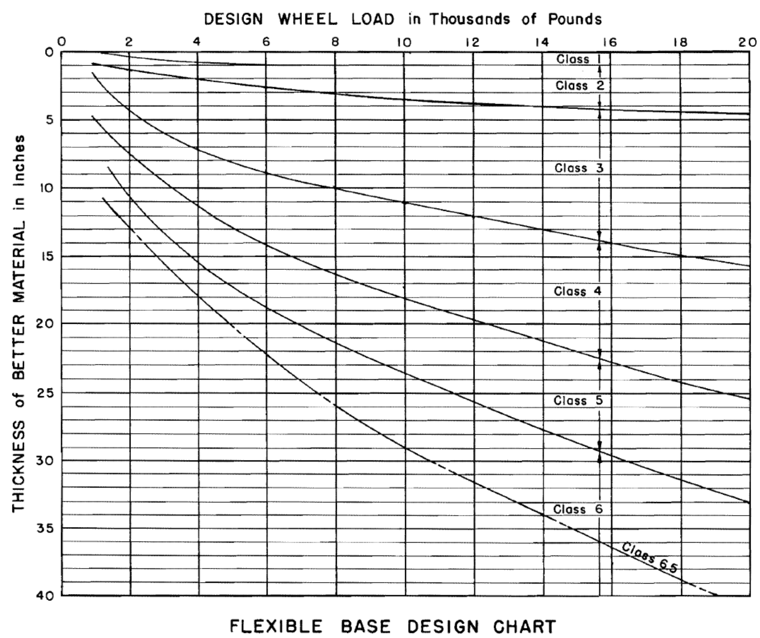
While the structural design is concerned with providing the right overall combination of materials and layer thicknesses to meet the requirements of traffic, climate and soil, selecting the proper asphalt mixture for a particular application within the pavement structure is critical to good pavement 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). Generally speaking, 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

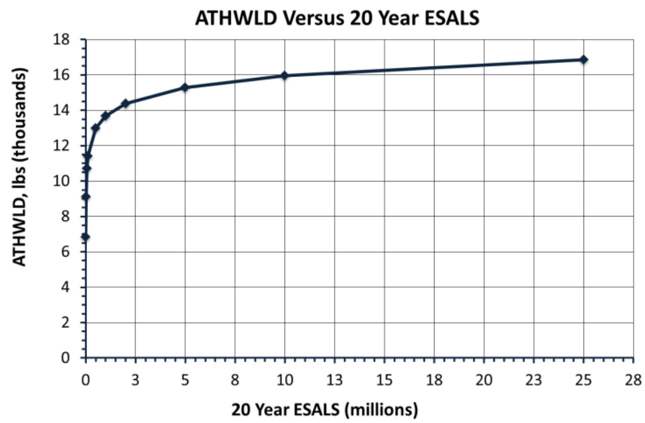
Design procedures for asphalt pavement structures fall into two very broad categories. The first is empirical methods which were developed by relating pavement thicknesses and material characteristics to observed performance under closely monitored conditions. Examples of this type of design procedure 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 PerROAD.

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.



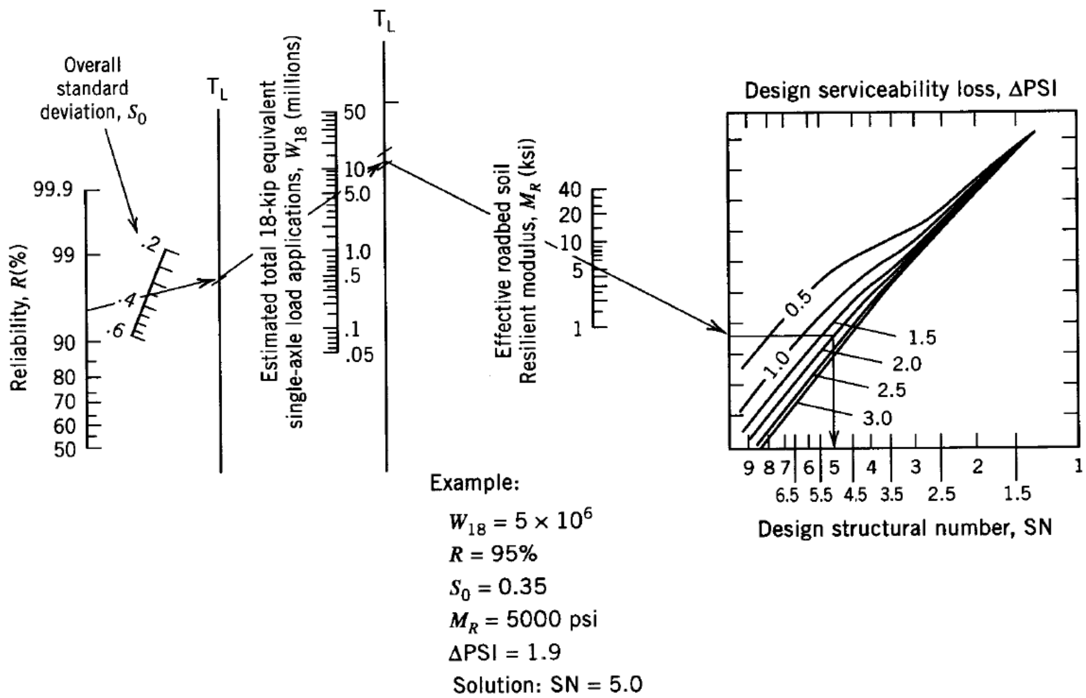
Source: Smith and Dyer, 1973

Figure 4-9. Relationship between ESAL and ATHWLD for Texas Triaxial Classification Design.

The Texas Flexible Pavement System (FPS) for design of asphalt roads was first developed in the 1970s and has evolved over time to its current version FPS-21 (Liu and Scullion, 2011). This is a mechanistic-empirical approach to pavement design using a layered elastic analysis and empirical performance equations that were 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, backcalculated 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 that may have 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 upon the original performance equation from the AASHO Road Test (AASHTO, 1993). The 1993 guide differed from earlier versions only in the way that 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 ESAL is 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 1.5 for higher functional classification roads and 2.0 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.

PerRoad 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 microstrain (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 PerRoad and PerRoadXpress software may be downloaded from the Asphalt Pavement Alliance at http://www.asphaltroads.org/why-asphalt/engineering/perpetual-pavement/.

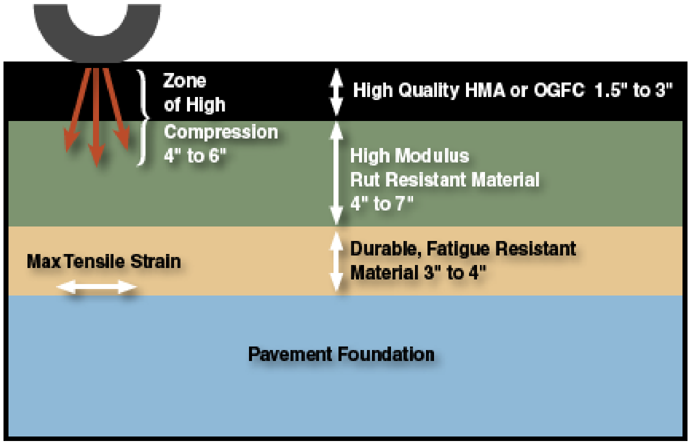
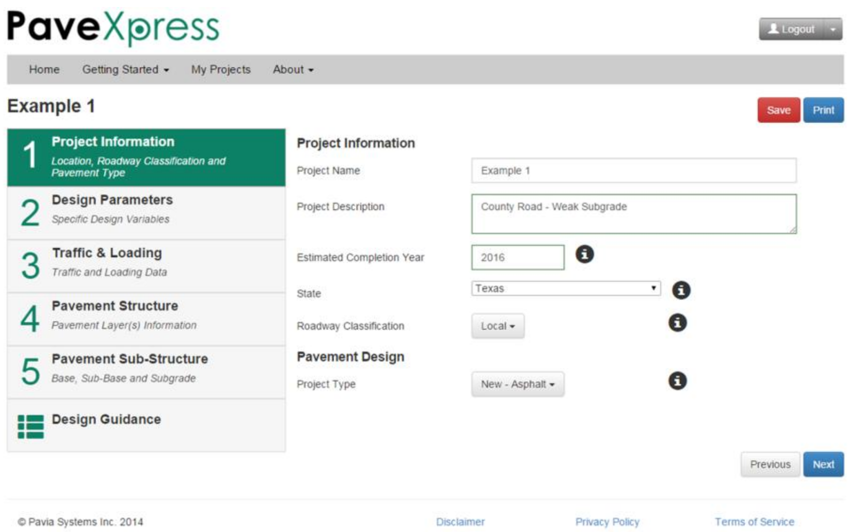


Figure 4-11. Perpetual Pavement Concept.

AASHTO has started to encourage its member states and territories to adopt its Pavement M-E software to design pavement structures (AASHTO, 2008). This newer approach differs considerably from the 1993 AASHTO design guide. Instead of using the ESAL as a measure of 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 are 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 (PaveExpress)

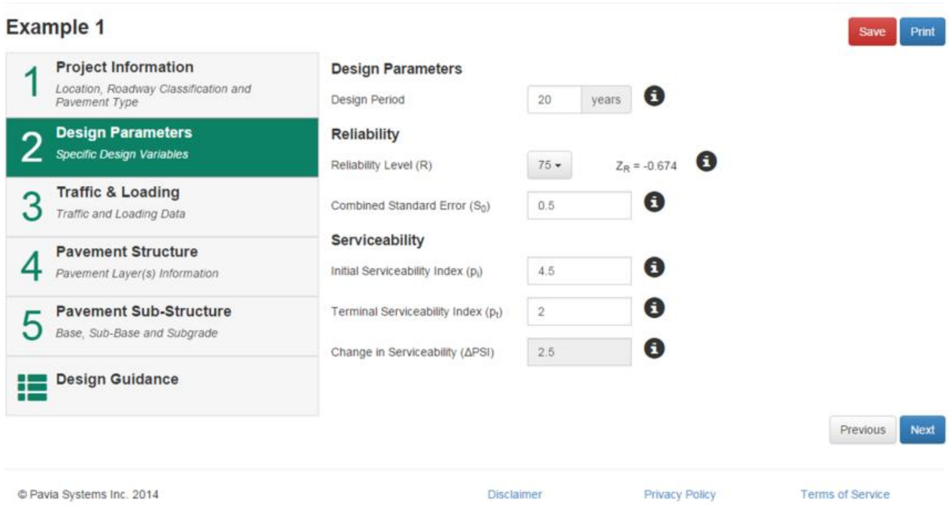
PaveExpress is an on-line tool that is available for free to design pavements according to the 1993 AASHTO design procedure. It was developed by Pavia Systems, Inc. and it can be found at app.pavexpress.com (Pavia Systems, 2014). As you enter the site it will allow you to establish a user name (e-mail address) and a password in order 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 of time 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

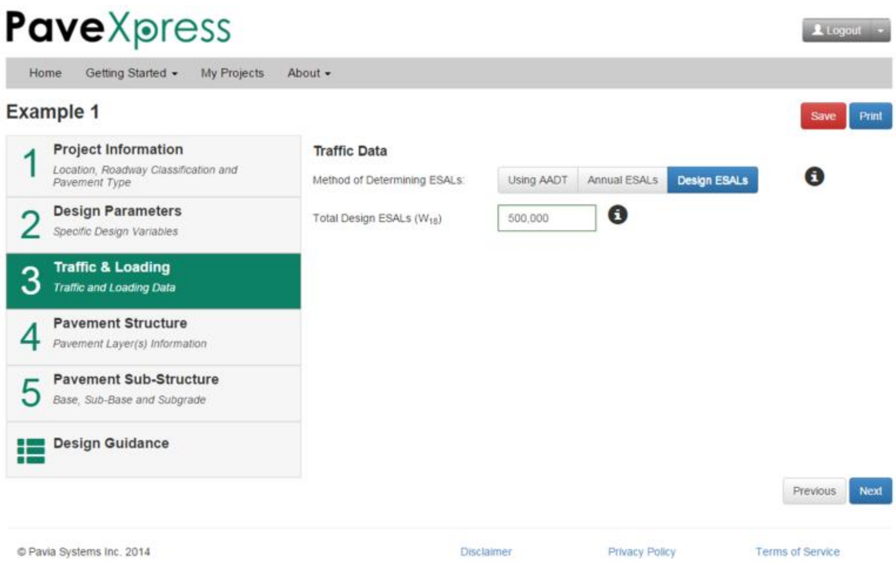
Figure 4-13. PavExpress Design Parameters Screen.

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

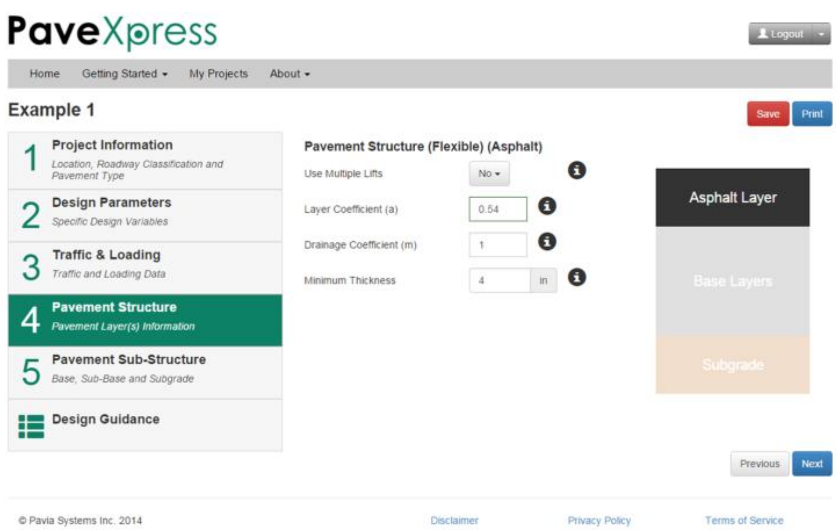
Traffic and loading calculations are done on the third input screen (Figure 4-14). This screen allows for the calculation of ESALs over the design life of the pavement. This may done in three different ways by clicking one of the three tabs: 1) Using the current annual average daily traffic (AADT) (one-direction 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 the design ESALs. For instance, a 4% annual growth rate is essentially the same as doubling the traffic every 10 years. For the purpose of 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 on the basis of 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.

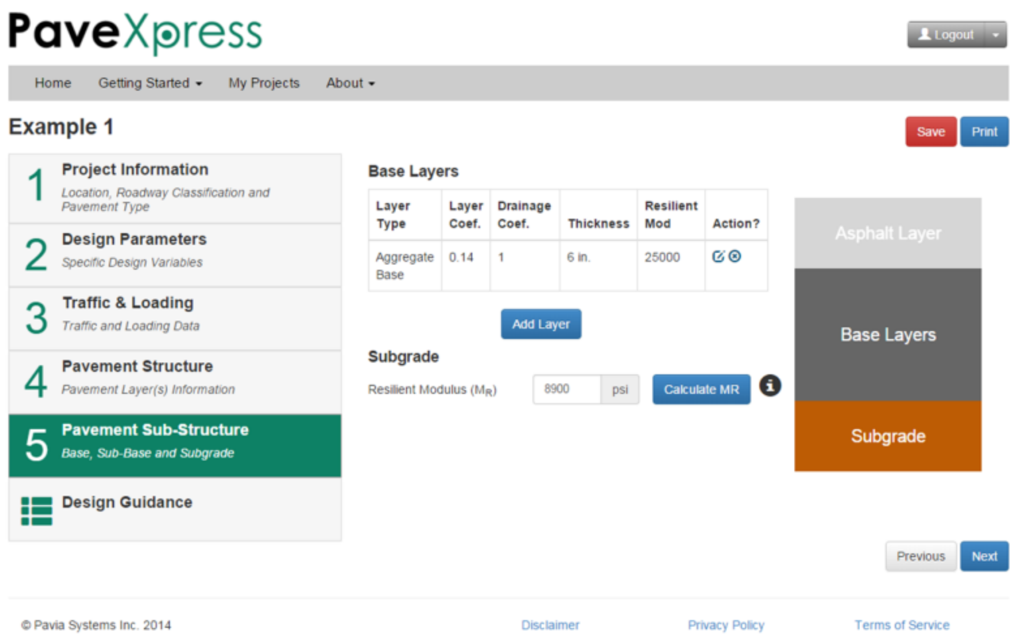


Source: Pavia Systems, 2014

Figure 4-15. Asphalt Layer Structural Information Screen.

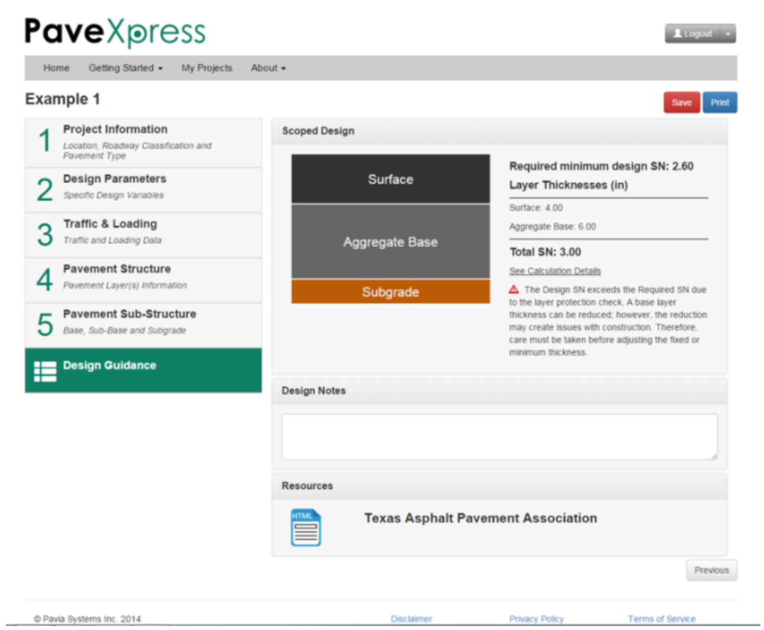
The Pavement Substructure screen (Figure 4-16) is used to input the information concerning the soils and any unbound base (flex base) materials used in the pavement section. In this example, a flex base six inches thick will be used with a modulus of 25,000 psi that is typical of many granular base materials. 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 particular 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.

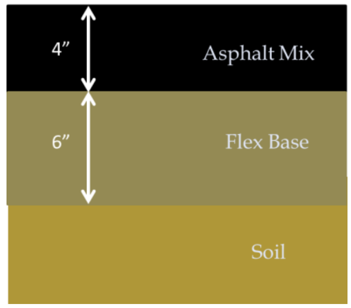
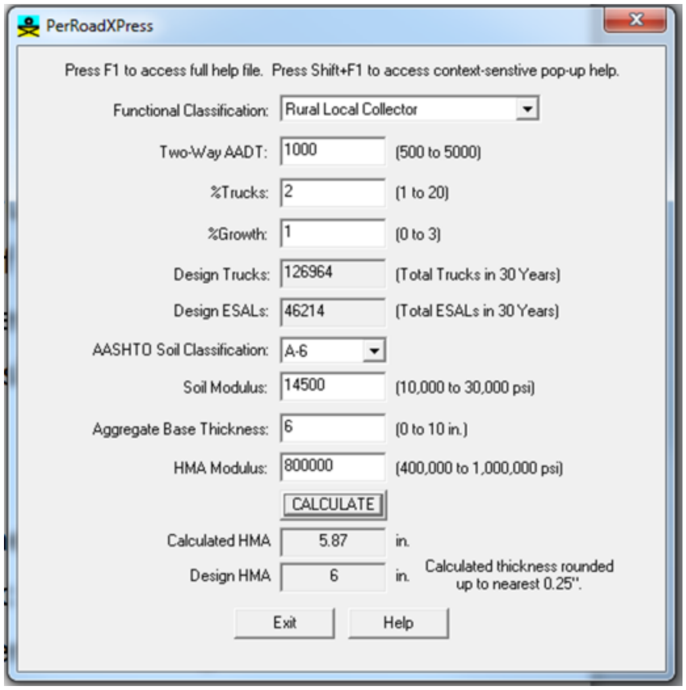


Figure 4-18. Final Cross-Section Design for PavExpress Example.

Pavement Thickness Design Example (PerRoadXpress)

PerRoadXpress is an easy-to-use program for the design of Perpetual Pavements that may be downloaded from the Asphalt Pavement Alliance at http://www.asphaltroads.org/why-asphalt/engineering/perpetual-pavement/ (Timm, 2008). 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.

The inputs used for this example are shown in Figure 4-19. Again, we will consider the case of a low-volume county road (rural local collector) with a one-way annual average daily traffic (AADT) of 1000 vehicles of which two percent are trucks. The anticipated annual growth is one percent. The design number of trucks and total ESAL for 30 years are automatically calculated. The soil for this example is an AASHTO Classification A-6 which is a low-plasticity clay and the soil modulus is automatically entered. In this case, we assume the base thickness is six inches and the modulus of the asphalt mix is 800,000 psi. The design thickness for the asphalt layer is six inches. The final design cross-section is shown in Figure 4-20.



Source: Timm, 2008

Figure 4-19. Input/Output Screen for PerRoadXpress.

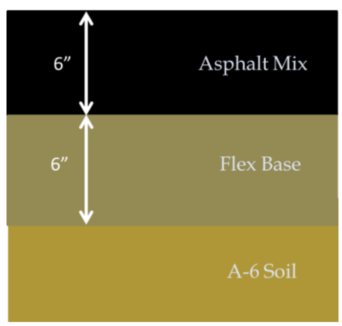


Figure 4-20. Final Cross-Section for PerRoadXpress Example.

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 both 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 compactability of mixtures usually dictate that the thickness of a lift be on the order of 3 to 5 times the nominal maximum aggregate size. There are a number of empirical and mechanistic methods for designing pavements. PavExpress is a method based upon the 1993 AASHTO design approach that can be done on-line with relatively little effort. Perpetual pavements may be designed with PerRoadExpress which allows the user to complete the design process all in one screen.

CHAPTER FIVE
Mix Type Selection

In this chapter you will learn about:

- Factors to be considered when selecting an asphalt mixture for a given application in a pavement.
- How to determine the appropriate lift thickness for the mix being compacted.
- The characteristics and uses for:
  - Dense-graded asphalt mixtures.
  - Permeable friction course mixtures.
  - Stone matrix asphalt mixtures.
  - Thin overlay mixtures.
  - Thin bonded permeable friction course mixtures.
- An example of how to apply mix type selection in design.

Introduction

Recommendations for mix type selection are found in the TXAPA publication, *Asphalt Pavement Mix Types*, and the National Asphalt Pavement Association's (NAPA) publication IS-128, *HMA Pavement Mix Type Selection Guide* (Garcia and Hansen, 2001). TxDOT information on asphalt mix types may be found at: http://onlinemanuals.txdot.gov/txdotmanuals/pdm/hot_mix_asphalt_concrete_pavement_mixtures.htm. 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 performance of the roadway. This guide presents the methodology and mix types for use in Texas for a variety of 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 considerations of user costs and economy of the pavement. 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 become an inconvenience to road users as congestion builds. Selecting a pavement surface such as an 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). DGA mixtures will suffice for lower volume pavements such as most commercial, private, or local roads since the first cost is lower.

The weight of vehicles is important in a number of scenarios that are not necessarily considered high volume. The NAPA guidelines listed above for traffic levels should be used in this instance. For instance, oil field traffic may be the majority of 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 strong pavement surface such as 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 porous friction course (TBPFC) 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.

Climate

Generally speaking 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 PBPFC. 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 back 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 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 is in need of 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 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 Different Types of DGA Mixtures.

	Nominal Maximum Aggregate Size, mm (TxDOT Item 340 Classification)	Minimum Lift Thickness, in.	Maximum Lift Thickness, in.
Fine Gradation	9.5 (F)	1.00	2.00
	12.5 (D)	1.50	2.50
	19.0 (C)	2.25	4.00
	25.0 (B)	3.00	5.00
Coarse Gradation	9.5 (F)	1.25	2.00
	12.5 (D)	1.50	3.00
	19.0 (C)	2.25	4.00
	25.0 (B)	3.00	5.00

Source: Garcia and Hansen, 2001

Types of Mixes Used in Texas

Dense-Graded Asphalt (DGA)

The specification for DGA mixtures in Texas may be found in Items 340 and 341. 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 may be designed using Superpave or Texas Gyratory mix design methods. 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. All but low-tonnage projects (less than 5000 tons) in which DGA is used should be constructed under a quality control/quality acceptance (QC/QA) specification.

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 344. 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 rain storms. 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 comprised 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 considered to be 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 PFCs. An additional advantage of this mix is that research on the evaluation of storm water 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. They are comprised of a gap-graded aggregate-on-aggregate structure that creates room for a rich, strong mastic comprised of a polymer modified asphalt (normally PG 76-22), fibers, and mineral fillers. The minimum asphalt content for this mixture is 6 percent 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. 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 70-22 or PG 76-22). The aggregate should come from a quarry known to produce hard, low polish value rock. TxDOT Item 347 requires TOMs to meet minimum requirements for the overlay tester and Hamburg wheel tracking test.

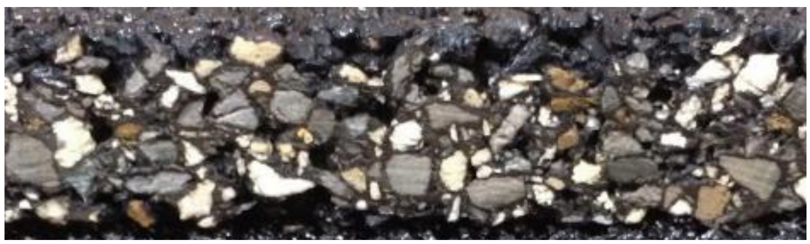


Figure 5-4. Thin Overlay Mix.

Thin Bonded Permeable Friction Course (TBPFC)

A TBPFC 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. 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 TBPFC. The TBPFC 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 TBPFC 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 Porous 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.

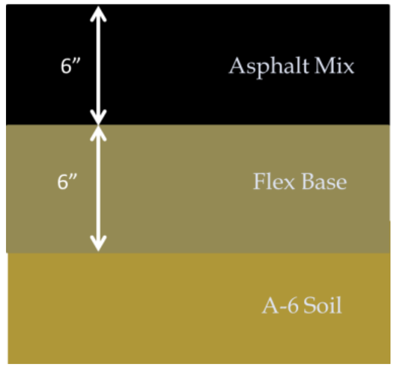


Figure 5-6. Pavement Cross Section from PerRoad Express Example in Chapter 4.

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 the vast majority of 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 pavements life provided that the distress in the existing pavement is minimal.

CHAPTER SIX
Asphalt Mixture Specifications

In this chapter you will learn about:

- The purpose of specifications.
- The different types of specifications.
- The role of statistics in specifications.
- The certification of technicians and the accreditation of laboratories.
- Contract methods.
- Acceptance of materials.
- Asphalt mixture specifications in Texas.
  - TxDOT specifications.
  - TXAPA 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 described work. 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. 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 a given 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 a number of 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 product, materials and method, end result, quality assurance and performance. Statistics are parts 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, in particular, 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 meets 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 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 a period of time. Performance of an asphalt mixture is typically described in terms of changes in 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 and state level. Advances in technology will likely be needed to develop useable 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 specification 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 specification.
- 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 work load.
- Reasonable lot sizes are used.
- 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.
- Numbers 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.

A detailed discussion of the use of statistics in specification development is available in AASHTO Recommended Practice R9 “Acceptance sampling Plans for Highway Construction” and other publications.

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 for sampling and testing materials while the laboratories in which the testing is performed are accredited.

Certification

A technician is typically certified by some agency or organization to insure that the individual is proficient 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 for individual test methods. Certification programs may or may not include proficiency testing in the certified person's laboratory on a regular basis.

National and state organizations are available to certify individuals. A number of 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 considered to be 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 insure that a quality system is in place and operating. The AASHTO Accreditation Program (AAP) administered by the AASHTO Materials Reference Laboratory (AMRL) 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 design consultant before the construction contract is advertised. The contractor then **bid**s the project and, if selected, **build**s the project. This is the traditional form of contracting in the 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 that is 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. Each of these elements is established by the public agency.

Acceptance of Materials

The types of specifications identified above (proprietary product, materials and method, end result, quality assurance and performance) all have been used to specify asphalt mixtures. These specifications are often included in a more comprehensive plan for acceptance of materials. These material acceptance plans assure, with reasonable risks, that the materials meet the specification. 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 relatively little potential variation as they are incorporated into the project. Examples of these types of materials are asphalt cements, cutback asphalts, emulsified asphalt and chemical modifiers of asphalt binders. Properties of 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 is 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 the 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 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 are 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 discharge 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 agency** 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 commonly 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 define test method variability as well.

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	2.5-4.5	3.0
No. 16 to No. 50	1.0-2.5	1.7
No. 100 to No. 200	0.5-1.5	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 a number of 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 (2014) 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.

Item		Description
No.	**Title**	
340	Dense Graded Hot Mix Asphalt (Small Quantities)	Dense-graded mixture designed with Texas Gyratory Compactor. Typically used for projects less than 5,000 tons.
341	Dense Graded Hot Mix Asphalt	Dense-graded mixture designed with Texas Gyratory Compactor.
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.
344	Superpave Mixtures	Dense-graded mixture designed with Superpave Gyratory Compactor
346	Stone Matrix Asphalt	Gap-graded mixture with high asphalt binder content, improved durability and friction. Designed with Superpave Gyratory Compactor.
347	Thin Overlay Mixtures	Open-graded mixture with small maximum size aggregate and typically used in lifts ¾ inch or less. Designed with either Texas Gyratory Compactor or Superpave Gyratory Compactor.
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, 2014

TxDOT has three specifications for dense-graded hot and warm mix asphalt. Specification Items 340 and 341 are dense-graded mixtures designed with the Texas Gyratory compactor while Item 344 are dense-graded mixtures designed with the Superpave Gyratory compactor.

Item 340 is typically used for less than 5,000-ton projects and more of a method specification as compared Item 341 which is a quality assurance type of specification. Gradations for the mixtures identified in these specifications were given in Chapter 3 and their typical applications were explained.

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

TXAPA Specification

The TXAPA specification (TXAPA, 2016) was developed for use on local government or private projects. The specification will be summarized below using the key elements of specifications as identified above. This summary will also provide more detail as to the tests and methods used in Texas specifications.

Description

The specification describes dense graded hot and warm mixes which are suitable for use on local government projects or private projects. The specification is based on TxDOT Item 340.

Materials

Aggregates The specification identifies requirements for aggregates: coarse, intermediate and fine sizes. The specification also details a blending procedure for aggregates to provide high friction pavement surfaces. Aggregate tests for coarse aggregates include the following:

- Deleterious material.
- Decantation.
- Mico-Deval.
- Los Angeles abrasion.
- Magnesium sulfate soundness.
- Crushed face count.
- Flat and elongated particles.

Linear shrinkage and sand equivalent are also requirements for fine aggregates and combined aggregates.

The TxDOT Bituminous Rated Source Quality Catalog (BRSQC), Texas Aggregate Quality Monitoring Program (AQMP) and Surface Aggregate Classification system are utilized in this specification to control the quality and for acceptance of aggregates.

Mineral fillers and baghouse fines are also addressed in this specification.

Asphalt Binder PG graded binders are specified in Texas as Item 300 “Asphalts, Oils and Emulsions,” Tack coats allowed by the specification include; CSS-1H, SS-1H and PG binders.

Additives that facilitate mixing, compaction or improve the quality of the asphalt mixture are allowed when approved. These additives include; lime, liquid antistrip agents, warm mix asphalt, reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS). The quantity of RAP and RAS allowed in the asphalt mixture is limited in quantity by the specification.

Equipment

Equipment required for mixing, placing and compacting is defined in Item 320 "Equipment for Asphalt Pavement."

Construction

Certification Sampling and testing personnel are required to be certified and for the tests to be performed in an accredited laboratory. Mixture designs are also performed by certified personnel.

Reporting, Testing and Responsibilities These responsibilities are defined by the specification including the timeliness of the reporting.

Mixture Design The Superpave gyratory compactor is used for mixture design. The mixture design process includes the following:

- Determination of the number of gyrations for compaction.
- Laboratory molded density.
- Aggregate gradation limits.
- Tensile strength.
- Hamburg Wheel Test Rutting depth.
- Job Mix Formula adjustments.
- Production operations including storage and heading of materials as well as mixing and discharge of materials.
- Hauling operations.
- Placement operations including weather conditions, tack coat and laydown.
- Compaction.
- Production acceptance that is based on mixture sampling, asphalt binder sampling, production testing (gradation, lab molded volumetric properties, moisture content, asphalt binder content, Hamburg Wheel testing and tack coat sampling and testing).
- Rejection of individual loads of asphalt mixture.
- Placement Acceptance that is based on sampling, testing for in-place air voids, identification of irregularities and ride quality.

Measurement

Measurement is by the ton of composite asphalt mixture including asphalt binder, aggregates and additives.

Payment

Payment is paid at the unit bid price for the asphalt mixture. Pay adjustments are not utilized for the mixtures but may be used for ride quality.

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 numerous drafts of the specification that will be required.

Trial implementation of the specification is necessary. Implementation on trial projects without the use of pay factors followed by implementation on trial projects with the use of pay factors is recommended before formal adoption of the specification. The ultimate decision as to the content of the specification 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 responsibilities of the inspector and provide guidelines for the inspection process. Some agencies supply inspector check lists that are very useful to insure completeness of inspection tasks.

Contractor quality control plans can include often include inspector guidelines to insure 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 a number of contracting methods which are available but design-bid-build is the most widely used. Likewise, there are a number of 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 Item 340 which can be used on small to medium projects. This specification may be found in Appendix A.

CHAPTER SEVEN
Specialty Uses

In this chapter you will learn about:

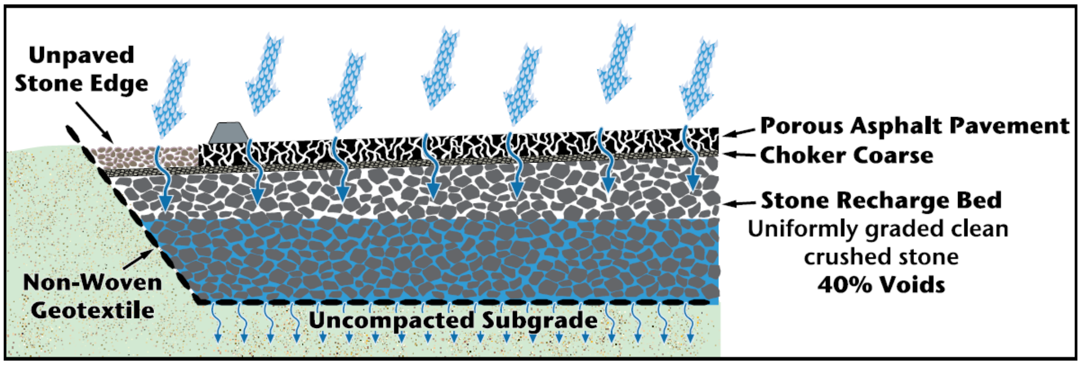
- Porous pavement for stormwater runoff mitigation.
- Pedestrian and recreational uses including bicycle paths and sidewalks, tennis and basketball courts, and running tracks.
- Other uses including environmental liners, hydraulic structures, agricultural applications, and railroad track beds.

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 particularly sensitive 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 the use of porous pavements. Porous pavements allow water to pass through the pavement surface into an open stone reservoir that has 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 in places where detention ponds are not practical due to land area constraints. Before deciding upon using 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 smooth which appeals to bicycle riders, skate boarders, roller bladers 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.

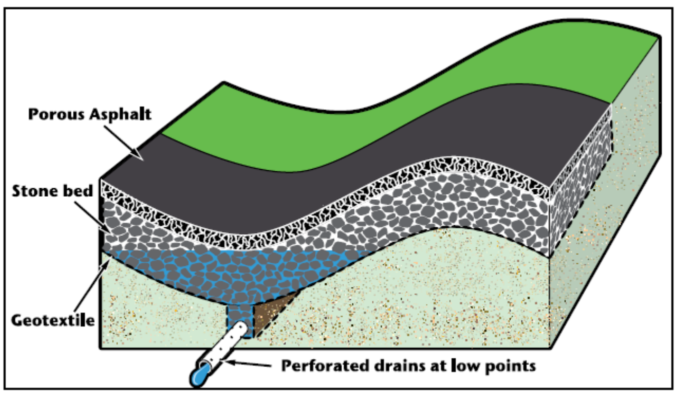
Courtesy of Kent Hansen

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 a minimum of 2.5 inches for light traffic on a high quality soil to 6.5 inches for heavy traffic on a 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 of asphalt for heavy traffic and 2 inches for light or medium traffic. In areas where swelling clays are prevalent, the typical practices for soil stabilization or remediation apply (NAPA, 2002).

Asphalt mixtures for paths should be designed primarily for durability. The use of 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 sized 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 in order to provide color and contrast for line markings. Porous asphalt is also an option for either type of court to provide for 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. Generally speaking, 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, 2016). 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 landfill. 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).

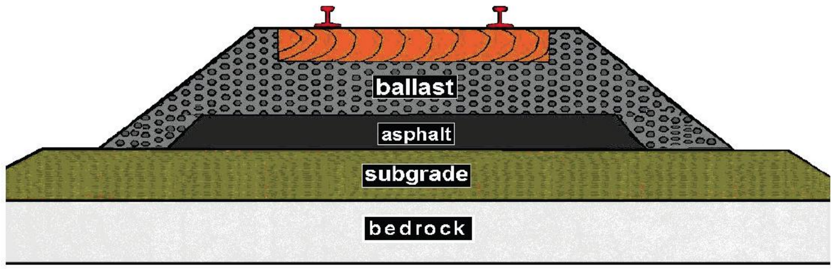
The Asphalt Institute’s manual MS-12 (Asphalt in Hydraulics) provides guidance on the design of asphalt mixtures for both permeable and impermeable mixtures.

Agricultural Applications

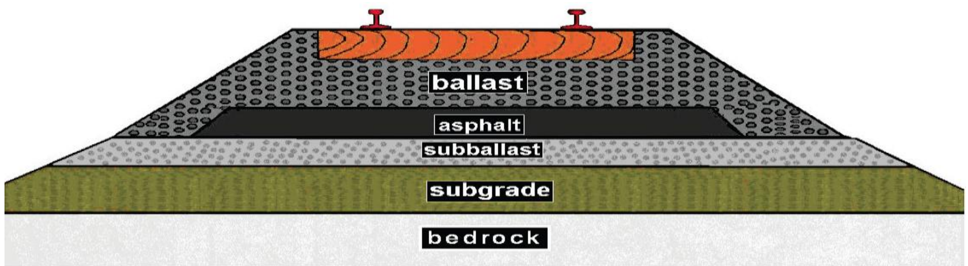
Asphalt mixes have been used to pave cattle pens, feed lots, silage platforms, bunker silos and stack silos. Paving around these areas can help keep both cattle and equipment cleaner. Cleaner cattle will improve hygiene and help reduce disease, and cleaner equipment will reduce maintenance costs. Additionally, 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 subballast and as a ballastless track bed. In the subballast 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 subballast layer. The asphalt layer acts as 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 subballast. Additionally, the subballast acts as a construction platform for many of the 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 fairly high quality soils, the asphalt can be placed directly on top of the compacted subgrade (Figure 7-7(a)). For poor quality soils, a subballast 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 Subballast on Subgrade.



(b) Asphalt Subballast 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 serves as the support for 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 the construction of the track as there are fewer operations involved.

As high-speed rail comes to the U.S., asphalt subballast 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 EIGHT
Managing Pavements

In this chapter you will learn about:

- The reason for pavement management.
- How a pavement management system works at the network and project levels.
- How a pavement rating system works.

(This chapter is taken in large part 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.

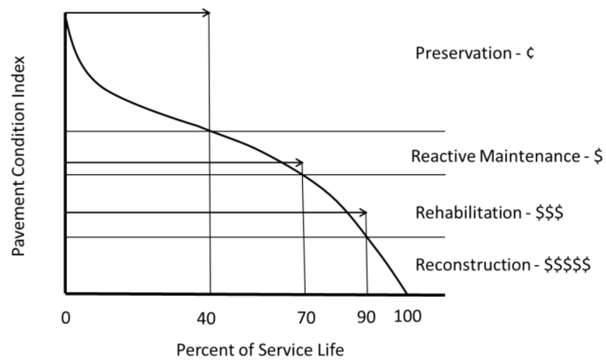


Figure 8-1. Effect of Treatment Timing on Repair Costs.

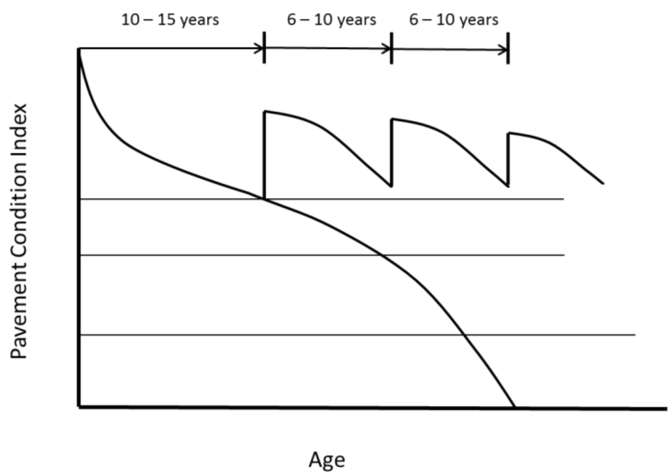


Figure 8-2. Illustration of Keeping a "Good" Pavement Good through Pavement Preservation.

General Description

Pavement management practices are based on the concept of finding a cost-effective combination of treatments to apply at any given time to provide the desired level of service. Pavement management systems (PMS) that can evaluate various strategies use the expected impact of maintenance and rehabilitation treatments on the future performance of the road surface to 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 primarily 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 are 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. The need to minimize data collection cost 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 maintenance and rehabilitation needs of project-level sections and are used in aggregate to determine the overall health of the network. The system needs are defined in terms of the percent of the system needing preservation, maintenance, and rehabilitation. The needs of the system are considered in light of 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 condition on the basis of the amount of improvement being done under the current budget. As a last step, the pavement models that have been 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.

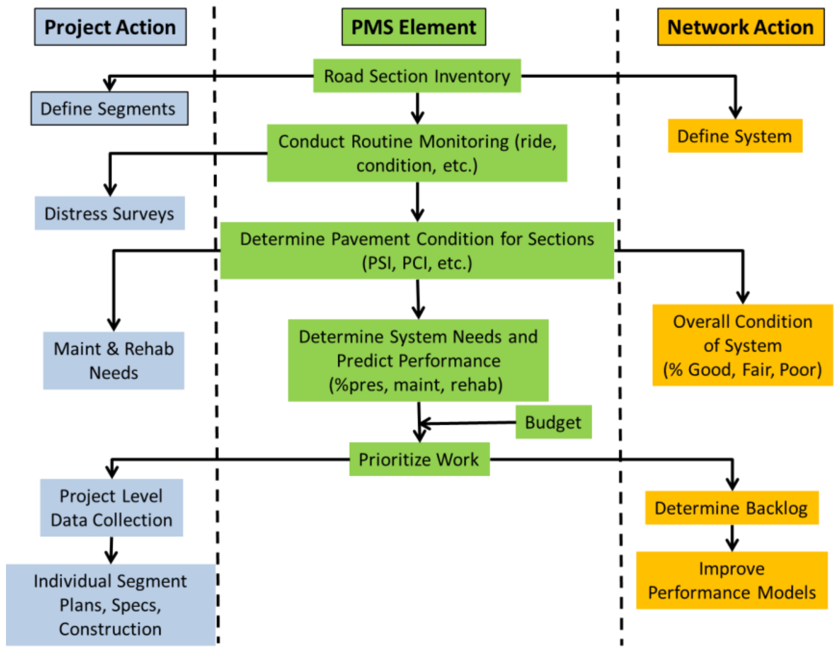


Figure 8-3. Relationship between Project- and Network-Level Activities and PMS Elements.

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 percent of network in poor condition will increase to 15 percent. Decreasing funding by 10 percent will increase the percent of network in poor condition to 17 percent. Even increasing funding by 10 percent will result in a network that has increased poor conditions. At 20 percent funding, the percent of amount 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.

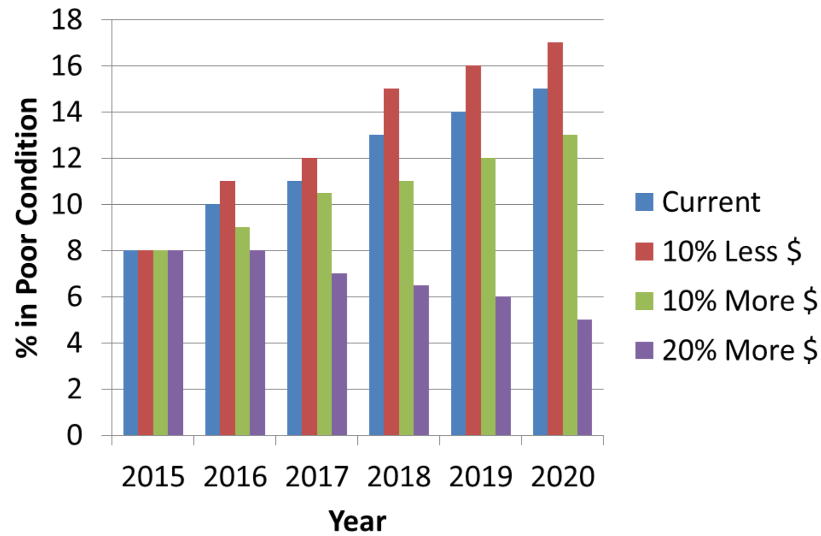


Figure 8-4. Example of Analysis of Funding Impacts on Road Conditions.

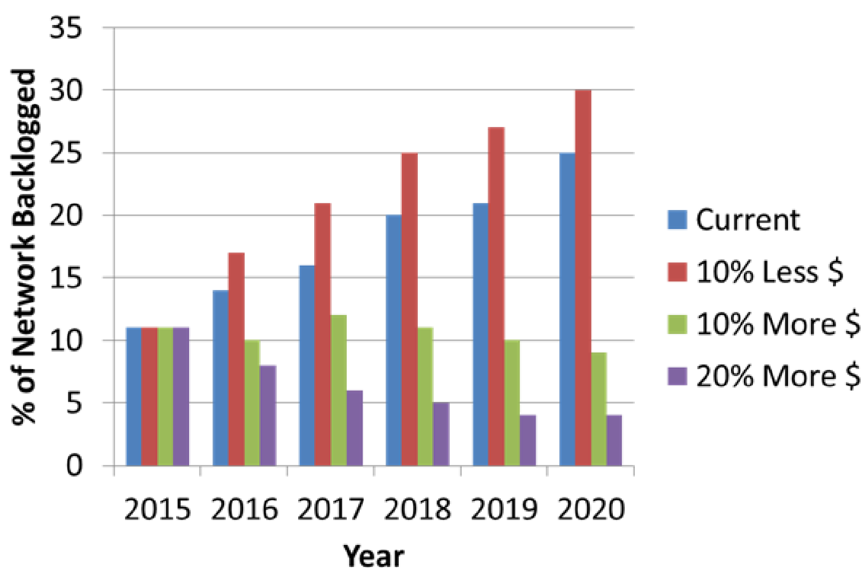


Figure 8-5. Example of Analysis of Funding Impacts on Backlogged Work.

Project Level

The establishment of the network inventory will result in the identification of 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 deterioration of the performance 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, identification of possible design, maintenance, rehabilitation, and reconstruction strategies, and selection of the most cost-effective strategy within imposed constraints. This requires considerable detailed data. However, much of the 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.

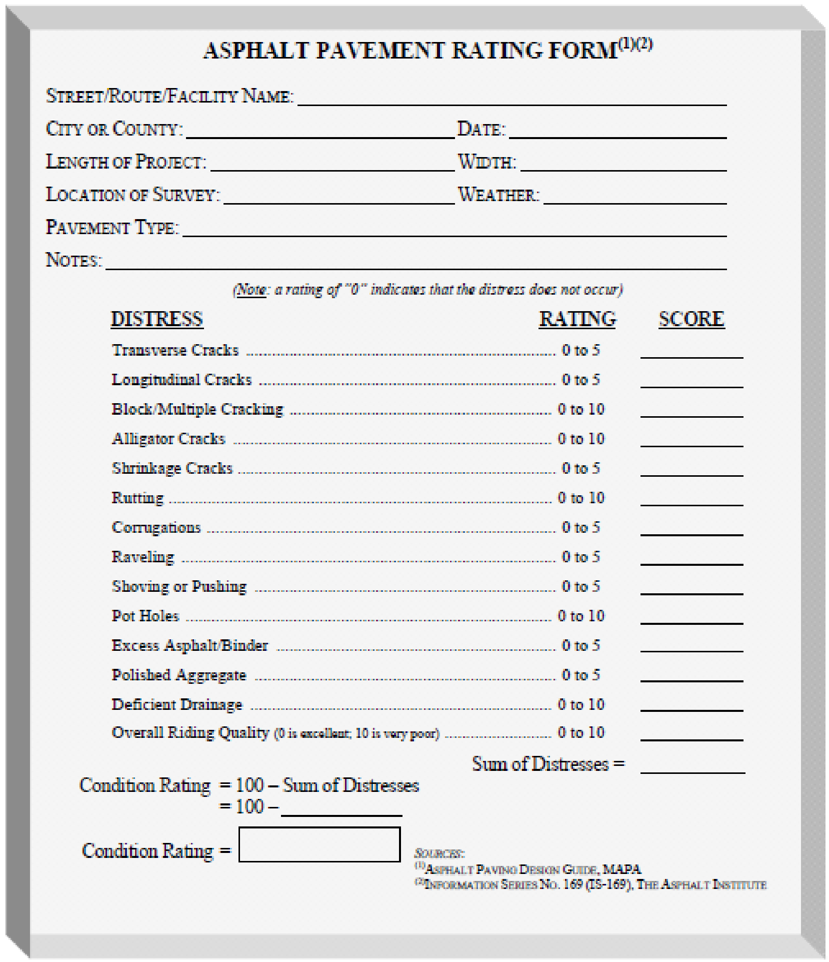
Rating Pavements

Pavement condition assessment begins with collecting data to determine the type, amount, and severity of surface distress, structural integrity, ride quality, and skid resistance of the pavement. 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 condition at a local government level is normally 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 effective 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 take into account 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 a large number of 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 at 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 are normally collected to define the condition of each individual management section identified in the inventory.

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 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 NINE
Pavement Maintenance and Rehabilitation

In this chapter you will learn about:

- Definitions related to maintenance and rehabilitation.
- How to select maintenance and rehabilitation alternatives.
- Typical maintenance activities.
- Rehabilitation of flexible and rigid pavements.
- Life cycle costing and life cycle assessment.
- Typical Maintenance and Rehabilitation Alternatives.

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 the presence of water in pavement layers and the subgrade. Pavement managements systems (Chapter 7) include definitions for several types of distress used as measures of 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 measure 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, 2010; TxDOT, 2014b). 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 for Pavement Rehabilitation varies considerably among public agencies. Definitions for pavement preservation, maintenance, and rehabilitation are summarized below. Note that different definitions are used by different agencies. As stated above, funding categories are based on these definitions in most states. 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: recondition, rebuild, 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, 2014b)
- **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 stabilize 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, 2014b).
- **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, 2014b). 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. In general, routine maintenance includes those activities performed on an everyday basis by public agencies forces. Preventive and preservation activities are those activities typically performed by contractors (TxDOT, 2014b).
- **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 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 with 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 past experience and availability of materials, equipment and trained work force. New maintenance and rehabilitation materials and techniques are being developed and should be considered as they are proven and become available.

The amount of time and expense associated with 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 brief 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 is dependent on the expected funding and workforce requirements for the project. 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 activities associated with 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 the 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 as well as a summary of distress type, extent and severity information.

Ground Penetrating Radar. Ground penetrating radar (GPR) has proven to be a useful tool to determine the thickness of the various pavement layers along a section of highway and to locate areas of the pavement that may be wet. This device can be operated at highway speeds, the data reduction is fast and the output from the GPR 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 of these 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 results 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 backcalculation 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 the 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 & perhaps GPR
Preventive Maintenance	1 & 2	GPR/FWD & 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 design ESALs for all state routes. The development of ESALs for roadways in local government entities is performed a number of 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 a number of engineering related factors as well as a wide variety of others including financial constraints, work force 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 a number of 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 specification Item 300-Asphalt, Oils and Emulsions (TxDOT, 2014). These materials will not be discussed at length in this document. Table 18 of Item 300 (TxDOT, 2014) 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 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, 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	
340	Type D & F	Dense graded mixture - small projects - Texas Gyratory Compactor	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

A number of 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 Item 300 of TxDOT standard specifications (TxDOT, 2014).

Shallow and Deep Patches

The area to be repaired should be large enough to include all of 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 general 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 of these causes of pavement distress, a greater thickness precludes future distress of a similar type. A 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 in order 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 a variety of different types of pavement distress. Thin overlays only marginally increase the load carrying capability of the roadway and should not be used to repair pavements that have damage caused 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. A number of 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-wheelpath)	Crack depth in surface layer only	Mill to crack depth, clean and tack
Longitudinal Cracking (wheelpath)	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 (2014) 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 the application of 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, 2010).

Figure 9-6. Chip Seal.

Chip seals are used for a number of reasons in pavement maintenance including:

- Seal the exiting 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 has little or no structural strength itself but by water out of the structure it enables the inherent strength of the pavement and the subgrade to be preserved.

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 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 is based on traffic volumes and was implemented in 2010. The selection process for seal coat binders 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 cements 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 cements are used on all levels of traffic. Item 300 of the TxDOT standard specifications (TxDOT, 2014) contain 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 be 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

The Modified Kearby Design Method is used by TxDOT to establish asphalt binder application rates and aggregate distribution rates. The TxDOT (2010) *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, 2010).

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.

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

A number of 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 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

A number of 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 are 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 a number of 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 make decisions concerning viable alternatives that have 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

Table 9-8 provides a guide for 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 is not identified. Note that public agencies use a variety of alternatives depending on availability of financial resources, equipment, materials and workforce capability.

Selection of a maintenance or rehabilitation alternative is often difficult 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 type of 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 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 remove 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

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APPENDIX A
Texas Asphalt Pavement Association
Specification for Local Agencies

Asphalt Pavement Mixtures for Local Governments

1. DESCRIPTION

Construct a hot-mix asphalt (HMA) pavement layer composed of a compacted, dense-graded mixture of aggregate and asphalt binder mixed hot in a mixing plant. This specification is intended for local government Asphalt Paving projects. The term Engineer refers to either the Engineer in charge of enforcing this specification or a Certified Technician working under the Engineer's direction. These specifications are based upon Item 340 of the Texas Department of Transportation (TxDOT).

2. MATERIALS

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

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 when the Contractor makes a source or formulation change, and may require a new laboratory mixture design, trial batch, or both. The Engineer may sample and test project materials at any time during the project to verify specification compliance in accordance with Item 6, "Control of Materials."

2.1. **Aggregate**. Furnish aggregates from sources that conform to the requirements shown in Table 1 and as specified in 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 listed in Table 1. Document all test results on 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 given in Tex-200-F, Part II.

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

For sources not listed on the TxDOT BRSQC:

- build an individual stockpile for each material;
- request the Engineer test the stockpile for specification compliance; and
- once approved, do not add material to the stockpile unless otherwise approved.

Provide aggregate from non-listed sources only when tested by the Engineer and approved before use. Allow 30 calendar days for the Engineer to sample, test, and report results for non-listed sources.

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

2.1.1.1. **Blending Class A and Class B Aggregates**. Class B aggregate meeting all other requirements in Table 1 may be blended with a Class A aggregate to meet requirements for Class A materials. 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 when blending Class A and B aggregates to meet a Class A requirement. Blend by volume if the bulk specific gravities of the Class A and B aggregates differ by more than 0.300. Coarse aggregate from RAP and Recycled Asphalt Shingles (RAS) will be considered as Class B aggregate for blending purposes.

The Engineer may perform tests at any time during production, when the Contractor blends Class A and B aggregates to meet a Class A requirement, to 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. The Engineer will use the TxDOT mix design Excel 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 using the gradations supplied by the Contractor on the mixture design report as an input for the Excel template; however, a failing spot check will require confirmation with a stockpile gradation determined by the Engineer.

2.1.2. **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 from organic impurities.

The Engineer may test the intermediate aggregate in accordance with Tex-408-A to verify the material is free from 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).

2.1.3. **Fine Aggregate**. Fine aggregates consist of manufactured sands, screenings, and field sands. Fine aggregate stockpiles must meet the gradation requirements in Table 2. Supply fine aggregates that are free from organic impurities. The Engineer may test the fine aggregate in accordance with Tex-408-A to verify the material is free from organic impurities. No more than 15% of the total aggregate may be field sand or other uncrushed fine aggregate. Use fine aggregate, with the exception of 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

Property	Test Method	Requirement
Coarse Aggregate		
SAC	Tex-499-A (AQMP)	As shown on the plans
Deleterious material, %, Max	Tex-217-F, Part I	1.5
Decantation, %, Max	Tex-217-F, Part II	1.5
Micro-Deval abrasion, %	Tex-461-A	Note[1]
Los Angeles abrasion, %, Max	Tex-410-A	40
Magnesium sulfate soundness, 5 cycles, %, Max	Tex-411-A	30
Crushed face count,[2] %, 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
Combined Aggregate[3]		
Sand equivalent, %, Min	Tex-203-F	45

1. Not used for acceptance purposes. Optional test used by the Engineer as an indicator of the need for further investigation.
2. Only applies to crushed gravel.
3. Aggregates, without mineral filler, RAP, RAS, or additives, combined as used in the job-mix formula (JMF).

Table 2
Gradation Requirements for Fine Aggregate

Sieve Size	% Passing by Weight 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 sufficiently dry, free-flowing, and free from 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 in Table 3.

Table 3
Gradation Requirements for Mineral Filler

Sieve Size	% Passing by Weight 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 specified on the plans.

2.5. **Tack Coat.** Furnish CSS-1H, SS-1H, or a PG binder with a minimum high-temperature grade of PG 58 for tack coat binder in accordance with Item 300, “Asphalts, Oils, and Emulsions.” Specialized or preferred tack coat materials may be allowed or required when shown on the plans. Do not dilute emulsified asphalts at the terminal, in the field, or at any other location before use.

The Engineer will obtain at least one sample of the tack coat binder per project in accordance with Tex-500-C, Part III, and test it to verify compliance with Item 300, “Asphalts, Oils, and Emulsions.” The Engineer will obtain the sample from the asphalt distributor immediately before use.

2.6. **Additives**. Use the type and rate of additive specified when shown on the plans. Additives that facilitate mixing, 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.

2.6.1. **Lime and Liquid Antistripping Agent**. 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.

2.6.2. **Warm Mix Asphalt (WMA)**. Warm Mix Asphalt (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 TxDOT Material Producer List (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 below 275°F.

TxDOT-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.

2.7. **Recycled Materials**. Use of RAP is permitted unless otherwise shown on the plans. Use of RAS is only permitted in Intermediate and Base layers. Do not exceed the maximum allowable percentages of RAP and RAS shown in Table 4. The allowable percentages shown in Table 4 may be decreased or increased when shown on the plans. Determine asphalt binder content and gradation of the RAP and RAS stockpiles for mixture design purposes in accordance with Tex-236-F. The Engineer may verify the asphalt binder content of the stockpiles at any time during production. Perform other tests on RAP and RAS when shown on the plans. Asphalt binder from RAP and RAS is designated as recycled asphalt binder. Calculate and ensure that the ratio of the recycled asphalt binder to total binder does not exceed the percentages shown in Table 5 during mixture design and HMA production when RAP or RAS is used. Use a separate cold feed bin for each stockpile of RAP and RAS during HMA production.

Surface, intermediate, and base mixes referenced in Tables 4 and 5 are defined as follows:

- **Surface**. The final HMA lift placed at or near the top of the pavement structure;
- **Intermediate**. Mixtures placed below an HMA surface mix and less than or equal to 8.0 in. from the riding surface; and
- **Base**. Mixtures placed greater than 8.0 in. from the riding surface.

2.7.1. **RAP**. RAP is salvaged, milled, pulverized, broken, or crushed asphalt pavement. Crush or break RAP so that 100% of the particles pass the 2 in. sieve. Fractionated RAP is defined as 2 or more RAP stockpiles, divided into coarse and fine fractions.

The coarse RAP stockpile will contain only material retained by processing over a 3/8-in. or 1/2-in. screen unless otherwise approved. The fine RAP stockpile will contain only material passing the 3/8-in. or 1/2-in. screen unless otherwise approved. The Engineer may allow the Contractor to use an alternate to the 3/8-in. or 1/2-in. screen to fractionate the RAP. The maximum percentages of fractionated RAP may be comprised of coarse or fine fractionated RAP or the combination of both coarse and fine fractionated RAP.

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.

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Table 4
Maximum Allowable Amounts of RAP[1]

Maximum Allowable Fractionated RAP[2] (%)			Maximum Allowable Unfractionated RAP[3] (%)		
Surface	**Intermediate**	**Base**	**Surface**	**Intermediate**	**Base**
20.0	30.0	40.0	10.0	10.0	10.0

1. Must also meet the recycled binder to total binder ratio shown in Table 5.
2. Up to 3% RAS may be used separately or as a replacement for fractionated RAP.
3. Unfractionated RAP may not be combined with fractionated RAP or RAS.

2.7.2. **RAS**. Use of post-manufactured RAS or post-consumer RAS (tear-offs) is permitted unless otherwise shown on the plans. Up to 3% RAS may be used separately or as a replacement for fractionated RAP in accordance with Table 4 and Table 5. RAS is defined as processed asphalt shingle material from manufacturing of asphalt roofing shingles or from re-roofing residential structures. Post-manufactured RAS is processed manufacturer's shingle scrap by-product. Post-consumer RAS is processed shingle scrap removed from residential structures. Comply with all regulatory requirements stipulated for RAS by the TCEQ. RAS may be used separately or in conjunction with RAP.

Process the RAS by ambient grinding or granulating such that 100% of the particles pass the 3/8 in. sieve when tested in accordance with Tex-200-F, Part I. Perform a sieve analysis on processed RAS material before extraction (or ignition) of the asphalt binder.

Add sand meeting the requirements of Table 1 and Table 2 or fine RAP to RAS stockpiles if needed to keep the processed material workable. Any stockpile that contains RAS will be considered a RAS stockpile and be limited to no more than 5.0% of the HMA mixture in accordance with Table 4.

Certify compliance of the RAS with TxDOT DMS-11000, "Evaluating and Using Nonhazardous Recyclable Materials Guidelines." Treat RAS as an established nonhazardous recyclable material if it has not come into contact with any hazardous materials. Use RAS from shingle sources on the TxDOT MPL. Remove substantially all materials before use that are not part of the shingle, such as wood, paper, metal, plastic, and felt paper. Determine the deleterious content of RAS material for mixture design purposes in accordance with Tex-217-F, Part III. Do not use RAS if deleterious materials are more than 0.5% of the stockpiled RAS unless otherwise approved. Submit a sample for approval before submitting the mixture design. The Engineer will perform the testing for deleterious material of RAS to determine specification compliance.

2.8. **Substitute Binders**. Unless otherwise shown on the plans, the Contractor may use a substitute PG binder listed in Table 5 instead of the PG binder originally specified, 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 Binders"; and
- 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 only be allowed at the discretion of the Engineer if the Hamburg Wheel test results are between 10.0 mm and 12.5 mm.

Table 5
Allowable Substitute PG Binders and Maximum Recycled Binder Ratios

Originally Specified PG Binder	Allowable Substitute PG Binder	Maximum Ratio of Recycled Binder[1] to Total Binder (%)		
		Surface	Intermediate	Base
HMA				
76-22[2]	70-22 or 64-22	20.0	20.0	20.0
	70-28 or 64-28	30.0	35.0	40.0
70-22[2]	64-22	20.0	20.0	20.0
	64-28 or 58-28	30.0	35.0	40.0
64-22[2]	58-28	30.0	35.0	40.0
76-28[2]	70-28 or 64-28	20.0	20.0	20.0
	64-34	30.0	35.0	40.0
70-28[2]	64-28 or 58-28	20.0	20.0	20.0
	64-34 or 58-34	30.0	35.0	40.0
64-28[2]	58-28	20.0	20.0	20.0
	58-34	30.0	35.0	40.0
WMA[3]				
76-22[2]	70-22 or 64-22	30.0	35.0	40.0
70-22[2]	64-22 or 58-28	30.0	35.0	40.0
64-22[4]	58-28	30.0	35.0	40.0
76-28[2]	70-28 or 64-28	30.0	35.0	40.0
70-28[2]	64-28 or 58-28	30.0	35.0	40.0
64-28[4]	58-28	30.0	35.0	40.0

1. Combined recycled binder from RAP and RAS.
2. Use no more than 20.0% recycled binder when using this originally specified PG binder.
3. WMA as defined in Section 340.2.6.2., "Warm Mix Asphalt (WMA)."
4. When used with WMA, this originally specified PG binder is allowed for use at the maximum recycled binder ratios shown in this table.

3. EQUIPMENT

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

4. CONSTRUCTION

Produce, haul, place, and compact the specified paving mixture. In addition to tests required by the specification, Contractors may perform other QC tests as deemed necessary. At any time during the project, the Engineer may perform production and placement tests as deemed necessary in accordance with Item 5, "Control of the Work." Schedule and participate in a pre-paving meeting with the Engineer on or before the first day of paving unless otherwise directed.

4.1. **Certification**. Personnel certified by the Hot Mix Asphalt Center certification program 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.

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

Test Description	Test Method	Contractor	Engineer	Level[1]
1. Aggregate and Recycled Material Testing				
Sampling	Tex-221-F	✓	✓	1A/1B
Dry sieve	Tex-200-F, Part I	✓	✓	1A
Washed sieve	Tex-200-F, Part II	✓	✓	1A
Deleterious material	Tex-217-F, Parts I & III	✓	✓	1A
Decantation	Tex-217-F, Part II	✓	✓	1A
Los Angeles abrasion	Tex-410-A		✓	TxDOT QM
Magnesium sulfate soundness	Tex-411-A		✓	TxDOT QM
Micro-Deval abrasion	Tex-461-A		✓	2
Crushed face count	Tex-460-A	✓	✓	2
Flat and elongated particles	Tex-280-F	✓	✓	2
Linear shrinkage	Tex-107-E	✓	✓	2
Sand equivalent	Tex-203-F	✓	✓	2
Organic impurities	Tex-408-A	✓	✓	2
2. Asphalt Binder & Tack Coat Sampling				
Asphalt binder sampling	Tex-500-C, Part II	✓	✓	1A/1B
Tack coat sampling	Tex-500-C, Part III	✓	✓	1A/1B
3. Mix Design & Verification				
Design and JMF changes	Tex-204-F	✓	✓	2
Mixing	Tex-205-F	✓	✓	2
Molding (SGC)	Tex-241-F	✓	✓	1A
Laboratory-molded density	Tex-207-F	✓	✓	1A
VMA[2] (calculation only)	Tex-204-F	✓	✓	2
Rice gravity	Tex-227-F	✓	✓	1A
Ignition oven correction factors[3]	Tex-236-F	✓	✓	2
Indirect tensile strength	Tex-226-F	✓	✓	2
Hamburg Wheel test	Tex-242-F	✓	✓	2
4. Production Testing				
Mixture sampling	Tex-222-F	✓	✓	1A
Molding (SGC)	Tex-241-F		✓	1A
Laboratory-molded density	Tex-207-F		✓	1A
VMA[2] (calculation only)	Tex-204-F		✓	1A
Rice gravity	Tex-227-F		✓	1A
Gradation & asphalt binder content[3]	Tex-236-F		✓	1A
Moisture content	Tex-212-F		✓	1A
Hamburg Wheel test	Tex-242-F		✓	2
5. Placement Testing				
Trimming roadway cores	Tex-207-F	✓	✓	1A/1B
In-place air voids	Tex-207-F		✓	1A/1B
Establish rolling pattern	Tex-207-F	✓		1B
Ride quality measurement	Tex-1001-S	✓	✓	Note[4]

1. Level 1A, 1B, and 2 are certification levels provided by the Hot Mix Asphalt Center certification program.
2. Voids in mineral aggregates.
3. Refer to Section 340.4.8.3., "Production Testing," for exceptions to using an ignition oven.
4. 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, Testing, and Responsibilities.** Use TxDOT -provided Excel templates or other Engineer approved data sheets to record and calculate all test data pertaining to the mixture design. The Engineer will use mutually agreed upon worksheets for any production and placement testing. Obtain the latest version of the Excel templates at http://www.txdot.gov/inside-txdot/forms-publications/consultants-contractors/forms/site-manager.html

The maximum allowable time for the Engineer to exchange test data with the Contractor is as given in Table 7 unless otherwise approved. The Engineer will immediately report to the Contractor any test result that requires suspension of production or placement or that fails to meet the specification requirements.

Subsequent mix 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
Production Testing			
Gradation	Engineer	Contractor	4 working days
Asphalt binder content			
Laboratory-molded density			
VMA (calculation)			
Hamburg Wheel test			
Moisture content			
Binder tests			
Placement Testing			
In-place air voids	Engineer	Contractor	4 working days of completion of the project

4.3. **Mixture Design**.

4.3.1. **Design Requirements**. Compact the mixture using a Superpave Gyratory Compactor (SGC). Use the Superpave mixture design procedure given in Tex-204-F, Part IV, when using a SGC. Design the mixture to meet the requirements listed in Tables 1, 2, 3, 4, 5, 8, 9, and 10.

4.3.1.1. **Design Number of Gyrations (Ndesign) When The SGC Is Used**. Design the mixture at 50 gyrations (Ndesign). Use a target laboratory-molded density of 96.0% of the maximum specific gravity to design the mixture. However, adjustments can be made to the Ndesign value as noted in Table 9. The Ndesign level may be reduced to no less than 35 gyrations as agreed between the Engineer and the Contractor.

Use an approved laboratory to perform the Hamburg Wheel test in accordance with Tex-242-F, and provide results with the mixture design, or provide the laboratory mixture and request that the Engineer perform the Hamburg Wheel test. The Engineer will be allowed 10 working days to provide the Contractor with Hamburg Wheel test results on the laboratory mixture design.

The Engineer will provide the mixture design when shown on the plans. The Contractor may submit a new mixture design at any time during the project. The Engineer will verify and approve all mixture designs (JMF1) before the Contractor can begin production.

Provide the Engineer with a mixture design report using the TxDOT-provided Excel template or other approved data sheet. Include the following items in the report:

- the combined aggregate gradation, source, specific gravity, and percent of each material used;
- asphalt binder content and aggregate gradation of RAP and RAS stockpiles;
- the target laboratory-molded density (or Ndesign level when using the SGC);
- results of all applicable tests;
- the mixing and molding temperatures;
- the signature of the Level 2 person or persons that 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 Weight or Volume) and VMA Requirements

Sieve Size	A Coarse Base	B Fine Base	C Coarse Surface	D Fine Surface	F Fine Mixture
2"	100.0[1]	–	–	–	–
1-1/2"	98.0–100.0	100.0[1]	–	–	–
1"	78.0–94.0	98.0–100.0	100.0[1]	–	–
3/4"	64.0–85.0	84.0–98.0	95.0–100.0	100.0[1]	–
1/2"	50.0–70.0	–	–	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	30.0–50.0	40.0–60.0	43.0–63.0	50.0–70.0	70.0–90.0
#8	22.0–36.0	29.0–43.0	32.0–44.0	35.0–46.0	38.0–48.0
#30	8.0–23.0	13.0–28.0	14.0–28.0	15.0–29.0	12.0–27.0
#50	3.0–19.0	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	2.0–7.0
Design VMA, % Minimum					
Note 2	12.0	13.0	14.0	15.0	16.0
Production (Plant-Produced) VMA, % Minimum					
Note 2	12.0	13.0	14.0	15.0	16.0

1. Defined as maximum sieve size. No tolerance allowed.
2. Determining VMA calculation by ignition oven the Contractor shall supply the Engineer-approved laboratory's correction factors for AC content. Correction factors that do not yield statistically consistent results then the contractor shall incur the expense to have the Engineer-approved laboratory's run new correction factors and adjust to their oven.

Table 9
Laboratory Mixture Design Properties

Mixture Property	Test Method	Requirement
Design gyrations (Ndesign for SGC)	Tex-241-F	50[1]
Indirect tensile strength (dry), psi	Tex-226-F	85–200[2]

1. Adjust within a range of 35–50 gyrations when shown on the plans or specification, when VMA does not meet minimum requirements or when 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 3.0 mm and less than 12.5 mm.

Table 10
Hamburg Wheel Test Requirements

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

1. May be decreased or waived when shown on the plans.
2. When the rut depth at the required minimum number of passes is less than 3 mm, the Engineer may require the Contractor lower the Ndesign level (SGC) to no less than 35 gyrations.

4.3.2. **Job-Mix Formula Approval**. The job-mix formula (JMF) is the combined aggregate gradation, target laboratory-molded density (or 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. When WMA is used, document the additive or process used and recommended rate on the JMF1 submittal. Furnish a mix design report (JMF1) with representative samples of all component materials and request approval to produce the trial batch. Provide approximately 10,000 g of the design mixture and request that the Engineer perform the Hamburg Wheel test if opting to have the Engineer perform the test. The Engineer will verify JMF1 based on plant-produced mixture from the trial batch unless otherwise determined. The Engineer may accept an existing mixture design previously used on a project with similar mixture design requirements and may waive the trial batch to verify JMF1. Provide split samples of the mixtures and blank samples used to determine the ignition oven correction factors. The Engineer will determine the aggregate and asphalt correction factors from the ignition oven used for production testing in accordance with Tex-236-F.

Provide an SGC at the Engineer's field laboratory for use in molding production samples if the SGC is used to design the mix.

The Engineer may perform Tex-530-C and retain the tested sample for comparison purposes during production.

4.3.3. **JMF Adjustments**. If JMF adjustments are necessary to achieve the specified requirements, 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 Table 4 and Table 5;
- meet the master gradation limits shown in Table 8; and
- be within the operational tolerances of the current JMF listed in Table 11.

The Engineer may adjust the asphalt binder content to maintain desirable laboratory density near the optimum value while achieving other mix requirements.

Table 11
Operational Tolerances

Description	Test Method	Allowable Difference Between Trial Batch and JMF1 Target	Allowable Difference from Current JMF Target
Individual % retained for #8 sieve and larger	Tex-200-F or Tex-236-F	Must be within master grading limits in Table 8	±6.0[1]
Individual % retained for sieves smaller than #8 and larger than #200			±4.0[1]
% passing the #200 sieve			±2.0[1]
Asphalt binder content, %	Tex-236-F	±0.5	±0.5
Laboratory-molded density, %	Tex-207-F	±1.0	±1.5
VMA, %, min	Tex-204-F	Note[2]	Note[2]

1. When within these tolerances, mixture production gradations may fall outside the master grading limits; however, the % passing the #200 will be considered out of tolerance when outside the master grading limits.
2. Mixture is required to meet Table 8 requirements.

4.4. **Production Operations**. Perform a new trial batch when the plant or plant location is changed. Take corrective action and receive approval to proceed after any production suspension for noncompliance to 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 on the mixture design report; or
- RAS stockpile used in the mix is more than 2.0% higher than the value shown on the mixture design report.

4.4.1. **Storage and Heating of Materials**. Do not heat the asphalt binder above the temperatures specified in Item 300, "Asphalts, Oils, and Emulsions," or outside the manufacturer's recommended values. Provide the Engineer with daily records of asphalt binder and hot-mix asphalt discharge temperatures (in legible and discernible increments) in accordance with Item 320, "Equipment for Asphalt Concrete Pavement," 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.

4.4.2. **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 350°F (or 275°F for WMA) and is not lower than 215°F. The Engineer will not pay for or allow placement of any mixture produced above 350°F. All loads rejected based on the infrared thermometer will be verified by a calibrated thermocouple thermometer.

Produce WMA within the target discharge temperature range of 215°F and 275°F when WMA is required. Take corrective action any time the discharge temperature of the WMA exceeds the target discharge range. 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. The Engineer may determine the moisture content 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. The Engineer will obtain the sample immediately after discharging the mixture into the truck, and will perform the test promptly.

4.5. **Hauling Operations**. Clean all truck beds before use to ensure that mixture is not contaminated. Use a release agent shown on the TxDOT MPL to coat the inside bed of the truck when necessary.

Use equipment for hauling as defined in Section 340.4.6.3.2., "Hauling Equipment." Use other hauling equipment only when allowed.

4.6. **Placement Operations**. Collect haul tickets from each load of mixture delivered to the project and provide the Engineer's copy to the Engineer approximately every hour, or as directed. Use an infrared 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 and an approximate station number or GPS coordinates on each ticket unless otherwise directed. 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 the 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 with lane lines, 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 in Table 12 to determine the compacted lift thickness of each layer when multiple lifts are required. The thickness determined is based on the rate of 110 lb./sq. yd. for each inch of pavement unless otherwise shown on the plans.

Table 12
Compacted Lift Thickness and Required Core Height

Mixture Type	Compacted Lift Thickness Guidelines		Minimum Untrimmed Core Height (in.) Eligible for Testing
	Minimum (in.)	Maximum (in.)	
A	3.00	6.00	2.00
B	2.50	5.00	1.75
C	2.00	4.00	1.50
D	1.50	3.00	1.25
F	1.25	2.50	1.25

4.6.1. **Weather Conditions**. Place mixture when the roadway surface temperature is at or above 50°F unless otherwise approved. Measure the roadway surface temperature with an infrared thermometer. The Engineer may allow mixture placement to begin before the roadway surface reaches the required temperature if conditions are such that the roadway surface will reach the required temperature within 2 hr. of beginning placement operations. Place mixtures only when weather conditions and moisture conditions of the roadway surface are suitable as determined by the Engineer. The Engineer may restrict the Contractor from paving if the ambient temperature is likely to drop below 32°F within 12 hr. of paving.

4.6.2. **Tack Coat**. 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 the tack coat in a uniform manner to avoid streaks and other irregular patterns. Apply a thin, uniform tack coat to all contact surfaces of curbs, structures, and all joints. 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. Roll the tack coat with a pneumatic-tire roller to remove streaks and other irregular patterns when directed.

4.6.3. **Lay-Down Operations**.

4.6.3.1. **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.

4.6.3.2. **Hauling Equipment**. Use belly dumps, live bottom, or end dump trucks to haul and transfer mixture.

4.6.3.3. **Screed Heaters**. Turn off screed heaters, to prevent overheating of the mat, if the paver stops for more than 5 min.

4.7. **Compaction**. Compact the pavement uniformly to contain between 3.8% and 9.5% in-place air voids.

Furnish the type, size, and number of rollers required for compaction as approved. Use a pneumatic-tire roller to seal the surface unless excessive pickup of fines occurs. 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 with rollers. The Engineer may require rolling with a trench roller on widened areas, in trenches, and in other limited areas.

Complete all compaction operations before the pavement temperature drops below 160°F unless otherwise allowed. The Engineer may allow compaction with a light finish roller operated in static mode for pavement temperatures below 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.

4.8. **Production Acceptance**.

4.8.1. **Production Lot**. Each day of production is defined as a production lot. Lots will be sequentially numbered and correspond to each new day of production. Note that lots are not subdivided into sublots for this specification.

4.8.2. **Production Sampling**.

4.8.2.1. **Mixture Sampling**. The Engineer may obtain mixture samples in accordance with Tex-222-F at any time during production.

4.8.2.2. **Asphalt Binder Sampling**. The Engineer may obtain or require the Contractor to obtain 1 qt. samples of the asphalt binder at any time during production from a port located immediately upstream from the mixing drum or pug mill in accordance with Tex-500-C, Part II. The Engineer may test any of the asphalt binder samples to verify compliance with Item 300, "Asphalts, Oils, and Emulsions."

4.8.3. **Production Testing**. The Engineer will perform the production testing listed in Table 13 at the frequency listed in the TxDOT *Guide Schedule of Sampling and Testing* and this specification or at a rate of every 2000 square yards of paving or other agreed testing rate. The Engineer may suspend production if the results of three consecutive production tests do not meet specifications or are outside operational tolerances listed in Table 11. Take immediate corrective action if the Engineer's laboratory-molded density on any sample is less than 95.0% or greater than 98.0%. 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.

The Engineer may use alternate methods for determining the asphalt binder content and aggregate gradation if the aggregate mineralogy is such that Tex-236-F does not yield reliable results. Use the applicable test procedure if an alternate test method is selected.

Table 13
Production and Placement Testing

Description	Test Method
Individual % retained for #8 sieve and larger	Tex-200-F or Tex-236-F
Individual % retained for sieves smaller than #8 and larger than #200	
% passing the #200 sieve	
Laboratory-molded density	Tex-207-F
Laboratory-molded bulk specific gravity	
In-Place air voids	
VMA	Tex-204-F
Moisture content	Tex-212-F, Part II
Theoretical maximum specific (Rice) gravity	Tex-227-F
Asphalt binder content	Tex-236-F
Hamburg Wheel test	Tex-242-F
Recycled Asphalt Shingles (RAS)[1]	Tex-217-F, Part III
Asphalt binder sampling and testing	Tex-500-C
Tack coat sampling and testing	Tex-500-C, Part III

1. Testing performed by the Engineer or designated laboratory.

4.8.3.1. **Voids in Mineral Aggregates (VMA)**. The Engineer may determine the VMA for any production lot. Take immediate corrective action if the VMA value for any lot is less than the minimum VMA requirement for production listed in Table 8. Suspend production and shipment of the mixture if the Engineer's VMA result is more than 0.5% below the minimum VMA requirement for production listed in Table 8. In addition to suspending production, the Engineer may require removal and replacement or may allow the lot to be left in place without payment.

4.8.3.2. **Hamburg Wheel Test**. The Engineer may perform a Hamburg Wheel test at any time during production. In addition to testing production samples, the Engineer may obtain cores and perform Hamburg Wheel tests on any areas of the roadway where rutting is observed. Suspend production until further Hamburg Wheel tests meet the specified values when the production or core samples fail the Hamburg Wheel test criteria in Table 10. Core samples, if taken, will be obtained from the center of the finished mat or other areas excluding the vehicle wheel paths. The Engineer may require up to the entire lot of any mixture failing the Hamburg Wheel test to be removed and replaced at the Contractor's expense.

If the Engineer's Hamburg Wheel test results in a "remove and replace" condition, the Contractor may request that the Engineer confirm the results by re-testing the failing material using a mutually agreed upon third party laboratory. The third party laboratory will perform the Hamburg Wheel tests and determine the final disposition of the material in question.

4.8.4. **Individual Loads of Hot-Mix**. The Engineer can 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. This request is to be made 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. **Placement Acceptance**.

4.9.1. **Placement Lot**. A placement lot is defined as the area placed during a production lot (one day's production). Placement lot numbers will correspond with production lot numbers.

4.9.2. **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, parking lots requiring discontinuous paving operations and other similar areas. These areas should be designated at the pre-pave meeting prior to the beginning of the project. Miscellaneous areas also include level-ups and thin overlays when the layer thickness specified on the plans is less than the minimum untrimmed core height eligible for testing shown in Table 12. The specified layer thickness is based on the rate of 110 lb./sq. yd. for each inch of pavement unless another rate is shown on the plans. Compact miscellaneous areas in accordance with Section 340.4.7., "Compaction." Miscellaneous areas are not subject to in-place air void determination. If cores are tested in miscellaneous areas for acceptance they should contain between 3.8% and 12.0% in-place air voids.

4.9.3. **Placement Sampling**. The Engineer will test at the frequency listed in the TxDOT *Guide Schedule of Sampling and Testing* or one correlating core test every 2000 square yards. Provide the equipment and means to obtain and trim roadway cores on site. On site is defined as in close proximity to where the cores are taken. Obtain the cores within three working days of the time the placement lot is completed unless otherwise approved. Obtain one 6-in. diameter core at each location selected by the Engineer for in-place air void determination unless otherwise shown on the plans. Mark the cores for identification, measure and record the untrimmed core height, and provide the information to the Engineer. The Engineer will witness the coring operation and measurement of the core thickness.

Visually inspect each core and verify that the current paving layer is bonded to the underlying layer. Take corrective action if an adequate bond does not exist between the current and underlying layer to ensure that an adequate bond will be achieved during subsequent placement operations.

When the Contractor or Engineer obtains the core, verify that the core heights meet the minimum untrimmed value listed in Table 12 then trim the cores immediately in accordance with Tex-207-F. Use a permanent marker or paint pen to record the date and lot number on each core as well as the designation. The Engineer may require additional information to be marked on the core and may choose to sign or initial the core. The Engineer will take custody of the cores immediately after they are trimmed and will retain custody of the cores until the testing is completed.

The Engineer and the Contractor may mutually agree to have the trimming operations performed at an alternate location such as a laboratory or other similar location. In such cases, the Engineer will take possession of the cores immediately after they are obtained from the roadway and will retain custody of the cores until testing is completed.

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 with other methods when approved.

4.9.4. **Placement Testing.** The Engineer may measure in-place air voids at any time during the project to verify specification compliance.

4.9.4.1. **In-Place Air Voids**. The Engineer will measure in-place air voids in accordance with Tex-207-F and Tex-227-F. Cores not meeting the height requirements in Table 12 will not be tested. Before drying to a constant weight, cores may be pre-dried using a Corelok or similar vacuum device to remove excess moisture. The Engineer will use the corresponding theoretical maximum specific gravity to determine the air void content of the core.

The Engineer will use the vacuum method to seal the core if required by Tex-207-F. The Engineer will use the test results from the unsealed core if the sealed core yields a higher specific gravity than the unsealed core. After determining the in-place air void content, the Engineer will return the cores and provide test results to the Contractor.

Take immediate corrective action when the in-place air voids exceed the range of 3.8% and 9.5% to bring the operation within these tolerances. The Engineer may suspend operations or require removal and replacement if the in-place air voids are less than 2.7% or greater than 10.0%. The Engineer will allow paving to resume when the proposed corrective action is likely to yield between 3.8% and 9.5% in-place air voids. Areas defined in Section 340.9.2., "Miscellaneous Areas," are not subject to in-place air void determination.

4.9.5. **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 and 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 one day while the Contractor is taking appropriate corrective action.

4.9.6. **Ride Quality**. Use Surface Test Type A to evaluate ride quality in accordance with Item 585, "Ride Quality for Pavement Surfaces," unless otherwise shown on the plans.

5. MEASUREMENT

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 Item 520, "Weighing and Measuring Equipment."

6. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under Section 340.5., “Measurement,” will be paid for at the unit bid price for “Dense Graded Hot-Mix Asphalt (SQ)” of the mixture type, SAC, and binder specified. These prices are full compensation for surface preparation, materials including tack coat, placement, equipment, labor, tools, and incidentals.

Trial batches will not be paid for unless they are included in pavement work approved by the Engineer.

Pay adjustment for ride quality, if applicable, will be determined in accordance with Item 585, “Ride Quality for Pavement Surfaces.”

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APPENDIX B
Flexible Pavement Distress Identification

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 hot mix asphalt permanent deformation.

Raveling-Raveling is a loss of fine and/or coarse aggregate from the surface of the pavement. Reveling 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 quantities and/or excessive application of chips 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 if 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.

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 area and on 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 located in the wheel paths. On some pavements, alligator cracking may start as a series of small transverse cracks only in the wheel paths. In other pavements, alligator cracking may start as a discontinuous longitudinal cracks located at the edges of the wheel path.

Transverse Cracking-Transverse cracking is an indicator of 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, low 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 will crack in a transverse cracking 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 be the initiation of alligator cracking and hence an indication of inadequate pavement structural section for the amount of traffic using the facility (fatigue cracking). This pattern of cracking 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 a number of 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 that is performed to maintain the condition of the transportation system 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 that is comprised of both routine and preventive maintenance (FHWA, 2016).

Routine Maintenance

FHWA-Routine maintenance encompasses work that is performed in reaction to an event, season, or over all deterioration of the transportation asset. This work requires regular reoccurring attention. States cannot use Federal-aid funds for routing maintenance.

TxDOT-Pavement related work to include restoration of pavement serviceability including: recondition, rebuild, 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, 2014b)

Major Maintenance

TxDOT-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 stabilize 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, 2014b).

Preventive Maintenance

FHWA-Preventive maintenance is a cost effective means of extending the useful life of the highway. Preventive maintenance is a proactive approach to extend the useful life of the highway. 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 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, 2014b).

Preservation

FHWA-Preservation consists of work that is 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 do restore the overall condition of the transportation facility. 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 and improve safety and motorist satisfaction while saving 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 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. In general, routine maintenance are those activities performed on an everyday basis by public agencies forces. Preventive and preservation activities are those activities typically performed by contractors (TxDOT, 2014b).