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TexSys: Guide for Selecting HMA for Texas Flexible Pavements

by

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INTRODUCTION

The guide for selecting mixtures for flexible pavements will provide the designers with recommendations for selecting mix types based on factors such as traffic, speed and expected performance. The guide covers mixes such as regular dense mixes Item 340 and 341, permeable friction course (PFC) Item 342, performance design mixes Item 344 and stone matrix asphalt mixes (SMA) Item 346.

This guide is intended to provide general recommendations based on the Texas experience. This guide was developed based on the survey conducted under the project 0-4824 (Guidelines for Selecting Asphalt Mixtures and Evaluation of Polymer-Modified Mixes). In the end, an expert system (http://pavements.ce.utexas.edu/TexSys) has been developed that can be used for selecting mix types. The purpose of the expert system is to provide guidance on selection of HMA types for different applications after HMA thickness has been determined from FPS 19 or other available flexible pavement design guides.

GENERAL DESCRIPTION OF TEXAS HMA ITEMS

This guide covers the 4 major hot mix asphalt (HMA) types listed in the Department's 2004 Standard Specification book. The 4 mixture types are:

- Item 340 and 341 – Dense Graded Mixtures
- Item 342 - Permeable Friction Course (PFC)
- Item 344 - Performance Design Mixtures
- Item 346 - Stone Matrix Asphalt (SMA)

A number of factors should be considered when selecting which HMA mixture is most appropriate for the intended application. Some of the factors that should be considered are listed below:

- previous experience with similar mixture types
- volume of truck traffic, traffic flow characteristics
- pavement geometric considerations
- lift thickness of paving layers
- condition of underlying pavement
- availability of local materials
- climatic and environmental conditions
- cost (initial as well as life cycle)

- selected performance grade (P.G.) binder

It is important that the designer select the proper mixture for the intended applications. It is also very important the designer select the appropriate PG binder and aggregate properties for the intended application. A general description of each item is included in the following section.

Item 340

Description: Item 340 is a method specification for conventional dense graded mixtures. The mixtures listed in Item 340 and Item 341 are identical. In contrast to Item 340, which is a method specification, Item 341 prescribes numerous QC/QA measures. The dense graded mixtures specified in Item 340 can be used for surface, intermediate, and base layers of HMA. The Item 340 further divides the mixes in five different types. The Type A and B are typically used in the base layer while Types C, D and F are used in the surface layer. The specifications also allow Type B and C mixes to be placed in the intermediate layers. The typical aggregate gradation and asphalt content of each mix type is shown in Figure 1. The aggregate gradation suggests that the Type A is coarser mix in comparison to Type B. The figure also suggests that Type C has less 3/4 in. aggregate size in comparison to Type B mix although Type C is a coarse surface mix. If nominal aggregate sizes are compared, the nominal aggregate size of Type A mix is the highest and Type F mix is the lowest. The aggregate gradation suggests that the material retained on #4 and #8 sieves significantly varies from one mix type to another one. In terms of asphalt content, Type F requires more asphalt content than other mix types.

Typical Use: Item 340 is typically used for projects with small quantities of hot mix asphalt (HMA). Item 340 is generally not recommended for projects with more than 5,000 tons of HMA. Conventional dense graded mixtures can be used for a wide variety of applications; however, under Item 340 it is recommended that the use of dense graded mixtures be limited to miscellaneous applications such as routine maintenance work, backfilling utility cuts, driveways, and other similar applications.

Advantages: The primary advantage of dense graded mixtures compared to other mixtures is lower initial cost. Another advantage is that most contractors and HMA producers are generally familiar with the production and placement of dense graded mixtures. Dense graded mixtures have been used in Texas for over 50 years and have performed well in most applications.

The mixtures listed in Item 340 are identical to those listed in Item 341. In contrast to Item 341, which is a quality control quality assurance (QC/QA) specification, Item 340 does not prescribe QC/QA measures. This may be an advantage in miscellaneous applications where QC/QA measures are not warranted.

Disadvantages: Dense graded mixtures cannot accommodate high asphalt contents without becoming unstable and susceptible to rutting. Relatively low amounts of asphalt are typically used in dense graded mixtures, which in turn make them more susceptible to cracking and more permeable. Generally speaking, dense graded mixtures can be designed to be either highly rut resistant or highly crack resistant but not both. Dense graded mixtures are not designed to have stone on stone contact. Their

Figure 1. ITEM 340/341 Mix Information

strength/stability characteristics are derived primarily from the quality of the intermediate and fine aggregate. Attempting to "coarsen" the mix to allow for more asphalt or to make the mix more rut resistant often has an adverse effect. Coarsening the mix often leads to a dryer mix and one that is more difficult to compact, more permeable and more susceptible to segregation. The texture of dense graded surface mixtures (Type C, D, and F) is relatively low. This can affect wet weather traction depending on the aggregate type, size and mineralogy.

Dense graded mixtures are currently designed with a Texas Gyratory Compactor (TGC). The TGC has a relatively high compactive effort and unlike the Superpave Gyratory Compactor (SGC), the TGC compactive effort can not be varied to match the intended application. Therefore, the TGC tends to produce a dry lean mix regardless of the application. Ideally, one would want to design a richer mix for a low volume/low demand roadway and a leaner mix for a high volume/high demand roadway. More asphalt in the mix reduces the risk of cracking and less asphalt reduces the risk of rutting. It is possible to increase or decrease the amount of asphalt in the mixture by adjusting the target laboratory molded density down or up from the standard value of 96.0%. Seldom is the target lab density adjusted down from the standard of 96.0%; however, it is common practice to adjust the target laboratory molded density up to 97.0% or higher in order to get more asphalt into the mixture. This practice is acceptable and actually encouraged where warranted; however, it should be noted that some mixtures may become susceptible to rutting if they contain too much asphalt especially if the asphalt is relatively soft such a PG 64 -22, etc.

Under Item 340, most of the responsibilities are on the Department rather than the contractor. On projects that warrant QC/QA measures be taken, it could be risky to use Item 340 unless the department representatives are familiar with the roles and responsibilities required under method specifications.

Item 341

Description: Item 341 is a quality control quality assurance (QC/QA) specification for conventional dense graded mixtures and is similar to the Item 340.

Typical Use: Dense graded mixtures in Item 341 can be used for a wide variety of applications ranging from new construction to overlays. Dense graded mixtures may be appropriate for applications ranging from high volume (or high demand) roadways to low volume (or low demand) roadways depending on the specified binder grade, aggregate properties, etc. Dense graded mixtures can be used as base, intermediate or surface layers.

Advantages: The primary advantage of dense graded mixtures compared to other mixtures is lower initial cost. Another advantage is that most contractors and HMA producers are generally familiar with the production and placement of dense graded mixtures. Dense graded mixtures have been used in Texas for over 50 years and have performed well in most applications.

The mixtures listed in Item 341 are identical to those listed in Item 340. In contrast to Item 340, which is a method specification, Item 341 prescribes numerous QC/QA measures to be taken by both the contractor and the Department. The vast majority of the QC/QA measures are the responsibility of the contractor.

Disadvantages: Dense graded mixtures cannot accommodate high asphalt contents without becoming unstable and susceptible to rutting. Relatively low amounts of asphalt are typically used in dense graded mixtures, which in turn make them more susceptible to cracking and more permeable. Generally speaking, dense graded mixtures can be designed to be either highly rut resistant or highly crack resistant but not both.

Dense graded mixtures are not designed to have stone on stone contact. Their strength/stability characteristics are derived primarily from the quality of the intermediate and fine aggregate. Attempting to "coarsen" the mix to allow for more asphalt or to make the mix more rut resistant often has an adverse effect. Coarsening the mix often leads to a dryer mix and one that is more difficult to compact, more permeable and more susceptible to segregation.

Dense graded mixtures are currently designed with a Texas Gyratory Compactor (TGC). The TGC has a relatively high compactive effort and unlike the Superpave Gyratory Compactor (SGC), the TGC compactive effort can not be varied to match the intended application. Therefore, the TGC tends to produce a dry lean mix regardless of the application. Ideally, one would want to design a richer mix for a low volume/low demand roadway and a leaner mix for a high volume/high demand roadway. More asphalt in the mix reduces the risk of cracking and less asphalt reduces the risk of rutting. It is possible to increase or decrease the amount of asphalt in the mixture by adjusting the target laboratory molded density down or up from the standard value of 96.0%. Seldom is the target lab density adjusted down from the standard of 96.0%; however, it is common practice to adjust the target laboratory molded density up to 97.0% or higher in order to get more asphalt into the mixture. This practice is acceptable and actually encouraged where warranted; however, it should be noted that some mixtures may become susceptible to rutting if they contain too much asphalt especially if the asphalt is relatively soft such a PG 64 -22, etc.

The texture of dense graded surface mixtures (Type C, D, and F) is relatively low. This can affect wet weather traction depending on the aggregate type, size and mineralogy.

Under Item 341, there are numerous responsibilities that both the contractor and the Department have in terms of QC/QA measures. This degree of control may not be warranted on extremely small projects or miscellaneous type projects.

Item 342

Description: Item 342 is a method specification for Permeable Friction Courses (PFC). The PFC mixes are typically gap graded mixes with higher asphalt content than the conventional dense graded mixes. The aggregate gradation and asphalt content information is included in Figure 2. The gradation information suggests that the PFC mixes typically contain 3/8" and #4 sieve size materials with very little material of other size. The PFC with asphalt rubber (A-R) has more of #4 materials while PFC PG 76 has more of 3/8" material. In addition, PFC PG76 typically consists of more 1/2 in. than PFC A-R. The asphalt content of PFC A-R is higher than PFC PG76 indicating that the PFC A-R is more expensive in comparison to PFC PG76.

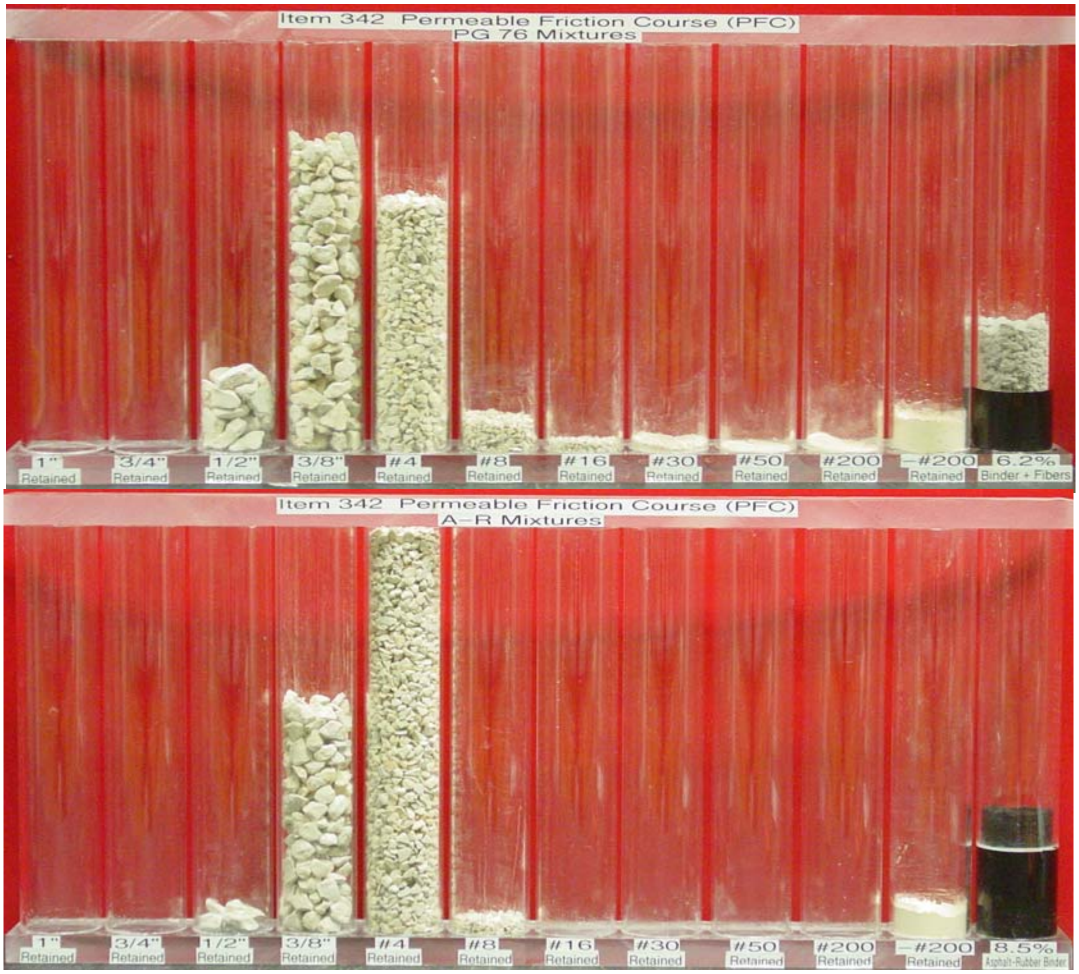

Figure 2. ITEM 342 PFC Mix Information

Typical Use: PFC mixtures are used as the surface course on high-speed roadways to optimize the safety and comfort characteristics of the roadway. For this guide, a high-speed roadway is defined as one having a posted speed limit of 45 mph or higher. The standard PFC mixture contains PG 76-22 and fibers and is recommended for the vast majority applications where PFC is used. Asphalt Rubber (A-R) PFC can be used as an alternate to the standard PFC. A-R PFC is generally more expensive than the standard PFC; however, its unique properties warrant its use in certain applications. As a general rule A-R PFC is recommend over the standard PFC when placed as an overlay on an existing concrete pavement, when a high degree of noise reduction is desired and when placed as an overlay on a pavement that has a high amount of cracking. Although both types are excellent at draining water and reducing noise, standard PFC tends to drain water better than the A-R PFC but is generally not considered to be as quite as the A-R PFC.

Advantages: As opposed to all other types of hot mix, PFC is designed to let water drain through the mixture into the underlying layer. PFC mixtures significantly reduce water spray, improve wet weather visibility and visibility of pavement markings, significantly reduce tire noise, and restore ride quality. PFC mixtures have stone on stone contact and relatively high amounts of asphalt binder. As a result, they offer good resistance to rutting and cracking. PFC mixtures are relatively easy to design and place. PFC mixtures require only a minimal amount of compaction with a static roller. This helps facilitate a smooth riding surface. PFC mixtures provide for a roadway that has a uniform yet coarse surface texture. The coarse texture and permeable mix characteristics improve wet weather traction. PFC mixtures contain approximately 20% air voids and they are typically placed only 1.5 inches thick therefore, the yield per ton of mix is relatively high.

Disadvantages: PFC mixtures typically have a higher initial cost compared to conventional dense graded mixtures. PFC mixtures contain more asphalt (6% min., 8% for min. A-R PFC) compared to conventional mixtures. The asphalt used in PFC mixtures contains a high amount of polymers (or asphalt rubber as an option). In addition to the polymers, PFC mixtures require the use of fibers (not required with asphalt rubber) and may require the use of lime. All of these additives not only add to the initial cost but they sometimes require that the producer make modifications to their typical HMA production processes.

PFC mixtures must be placed on top of a pavement that is structurally sound and relatively impermeable. A surface treatment (under seal) or level-up layer may be needed prior to placing the PFC. When used on low speed roadways, PFC mixtures can clog up more quickly thus negating the beneficial drainage characteristics. PFC mixtures tend to freeze faster and thaw slower (similar to a bridge) compared to conventional mixtures. PFC mixtures are not as resistant to high shearing forces therefore, they should be avoided on pavements where there are hard turning motions combined with braking such as short radius exit ramps, turnouts, etc.

Generally speaking, it is not good to place any type of hot mix in cool or cold weather. PFC mixtures can be particularly difficult to place in cool weather because they are placed in thin lifts and they contain a high amount of polymer modified binder. They also do not lend themselves well to applications that require a significant amount of hand work.

Item 344

Description: Item 344 is a quality control quality assurance (QC/QA) specification for performance design mixtures which includes coarse matrix high binder (CMHB) mixtures as well as Superpave (SP) mixtures.

CMHB mix types are typically designed to increase the asphalt content in comparison to SP mixes or Item 340/341 mixes. The asphalt content is generally 1% or higher of CMHB mixes in comparison to SP mixes. There are two types of CMHB mixes: coarse and fine (Figure 3). The fine mixes (CMHB-F) has more of #4 and #8 materials while coarse mixes (CMHB-C) has more of 1/2" and 3/8" sieve size material. The material between #16 and #200 sieve sizes is less in comparison to other sieve sizes for both fine and coarse mixes. As expected, the CMHB-F requires more asphalt content in comparison to CMHB-C mixes.

The SP mixes are similar to the conventional dense graded mixes (Item 340/341). Since these mixes are dense graded, the most of the aggregate sizes are present (Figure 4). The difference between the SP mix types is typically the nominal aggregate size. The other feature of SP mixes is the presence of large quantities passing #200 materials in comparison to CMHB mixes with the exception of SP-B mix. The asphalt content of SP mixes similar to that of Item 340/341 mixes.

Typical Use: Although they are typically used on medium to high volume roadways, performance design mixtures may be appropriate for applications ranging from high volume (or high demand) roadways to low volume (or low demand) roadways depending on the specified design number of gyrations (N_{design}), binder grade, aggregate properties, etc. Performance design mixtures can be used as base, intermediate or surface layers. Performance design mixtures can be used for a wide variety of applications ranging from new construction to overlays.

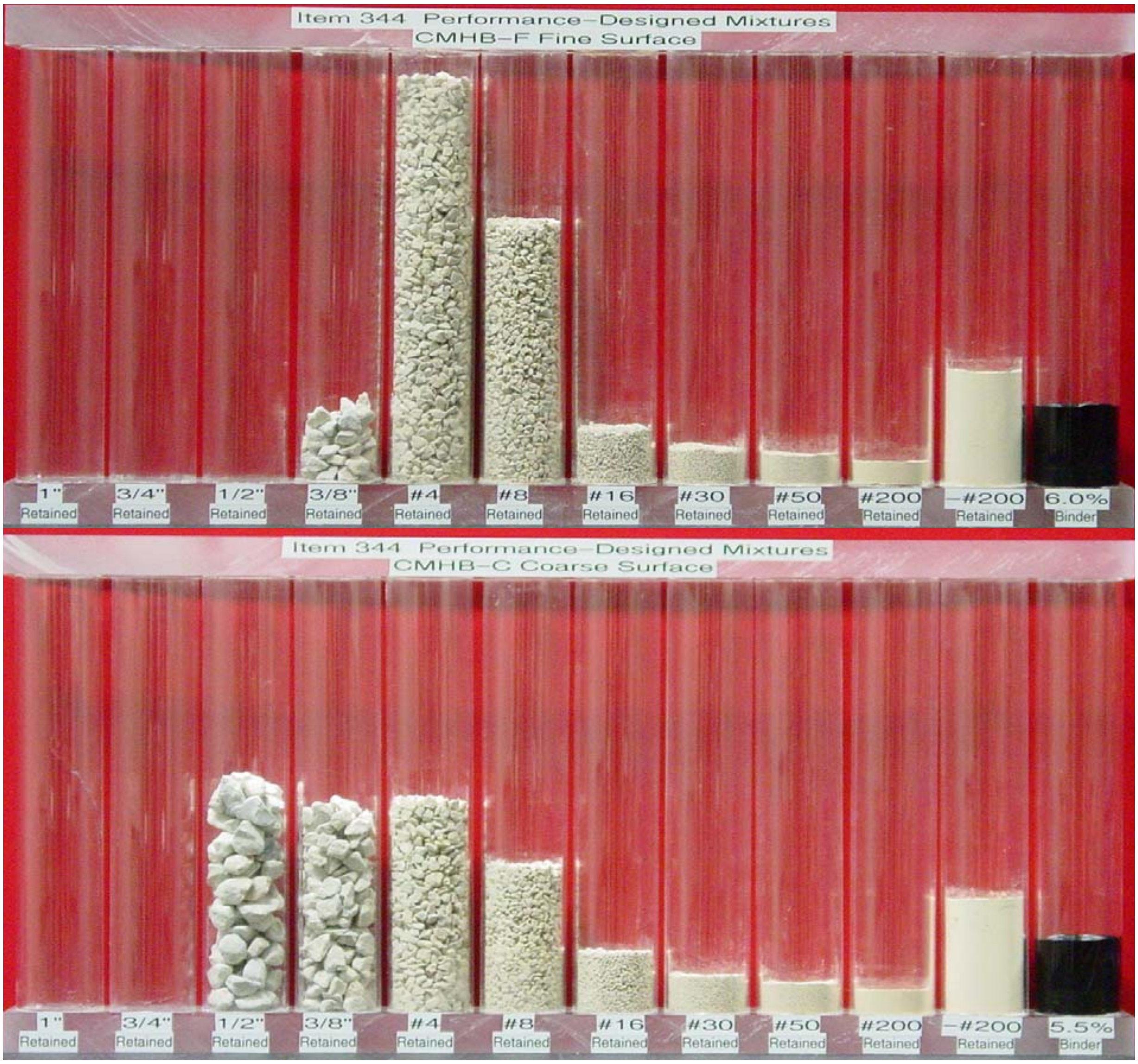

Figure 3. ITEM 344 CMHB Mix Information

Figure 4. ITEM 344 Superpave Mix Information

Advantages: As compared to Item 341, one of the primary advantages of performance design mixtures is that the mixture design procedures allows one to adjust the binder content (by adjusting the N_{design} level) depending on the intended application. For example: a mix for a low volume roadway can be designed with a low N_{design} level, which will yield a mixture that is higher in asphalt. The higher asphalt will help mitigate cracking and provided for greater durability. Conversely, a mix for a high volume roadway can be designed with a high N_{design} level, which will yield a mixture that is lower in asphalt, thus minimizing rutting.

Another advantage is that performance design mixtures can be designed coarse enough to have stone on stone contact. Achieving stone on stone contact can yield a mix that is highly resistant to rutting and have a coarse surface texture. The coarse surface texture can be beneficial in terms of wet weather traction.

Disadvantages: Compared to regular dense mixtures, performance design mixtures can be more difficult to compact. Failing to achieve proper in-place density can cause potential permeability problems and shorten the performance life of the pavement. In some cases, performance design mixtures can be "too dry" in terms of asphalt content. This can result in a mixture that is susceptible to cracking.

Compared to SMA mixtures, performance design mixtures have a gradation that is not as "gap graded" as an SMA mixture. As a result, performance design mixtures typically contain less asphalt than SMA mixtures and may therefore be more susceptible to cracking and water infiltration.

During compaction, a significant number of Superpave mixtures have experienced a phenomenon known as intermediate temperature tenderness. The mixtures may experience tenderness (or pushing) during compaction. The tenderness does not typically show up until several roller passes have been made and the mat begins to cool (usually in the 240°F range). Contractors can overcome this phenomenon by ceasing compaction once the tenderness is observed and then resuming compaction once the mat cools to approximately 180°F).

Item 346

Description: Item 346 is a quality control quality assurance (QC/QA) specification for Stone Matrix Asphalt (SMA) mixtures. The SMA mixes are further divided into two mix types SMA and SMAR. The SMA consists of fibers while SMAR consists of crumb rubber.

The SMAR can either be coarse or fine graded. The fine graded SMAR consists of large quantity of #4 sieve size material followed by #8 sieve size material (Figure 5). The other sieve sizes are present in lower quantities indicating it to be gap graded mix. The coarse graded SMAR has well distributed aggregate sizes from 1/2 in. to #8 sieve sizes and lower amounts of remaining aggregate sizes. Since rubber is present in the asphalt, the asphalt content of SMAR mixes is typically higher.

SMA mixes can be coarse (SMA-C), medium (SMA-D) or fine (SMA-F) depending on the aggregate gradation (Figure 5). The main difference between the mix types is nominal aggregate size. The SMA-C has more of 1/2 in. sieve size material while SMA-D and SMA-F does not have any. Similarly, 3/8 in. aggregate size is maximum in SMA-C while

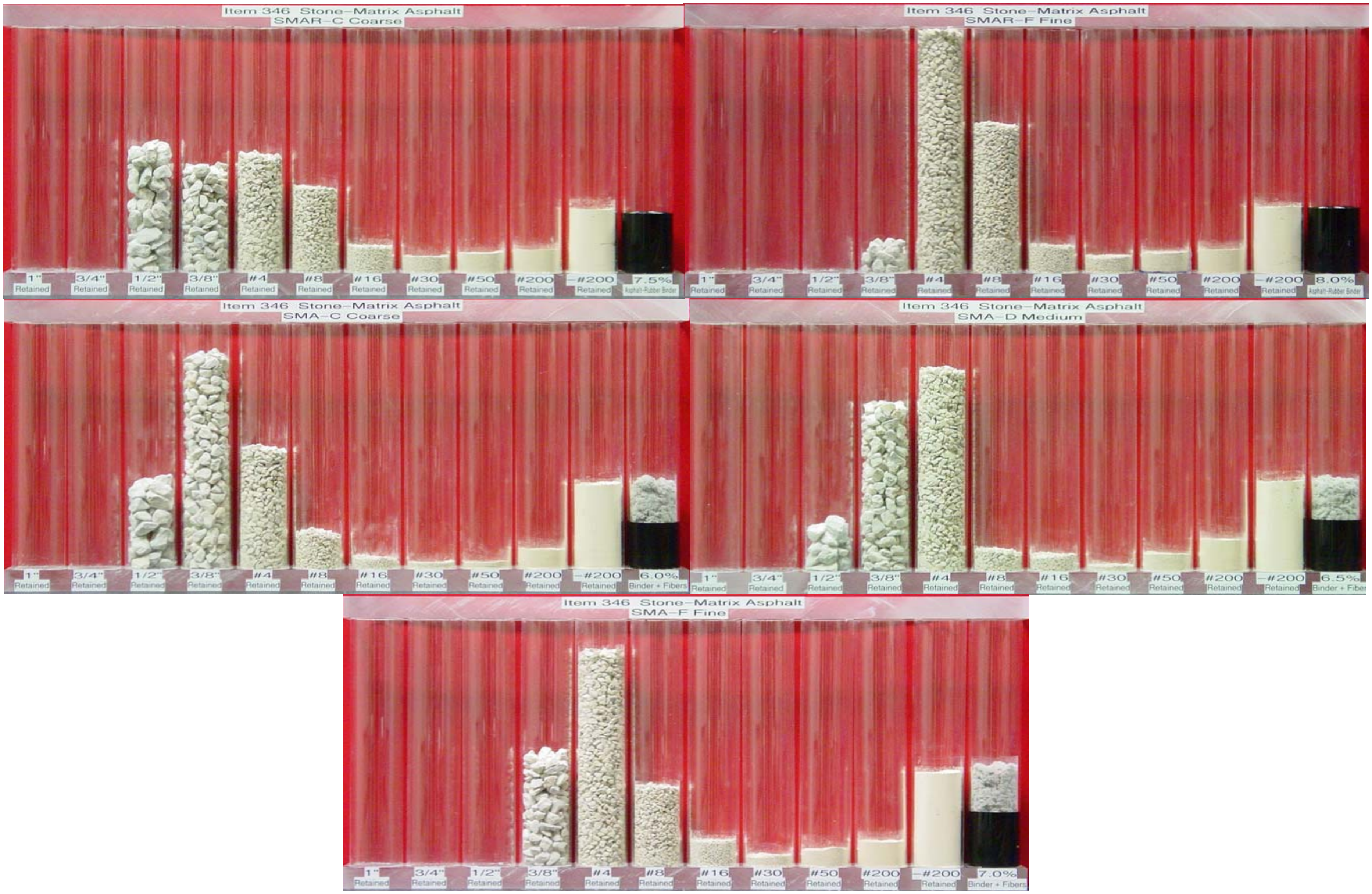

Figure 5. ITEM 346 SMA Mix Information

minimal in SMA-F mixes. The SMA mixes have typically most of the material between 1/2 in. and #8 sieve sizes. The asphalt content of SMA is also higher in comparison to conventional mix types but is less than SMAR mixes.

Typical use: SMA mixtures are typically used as a surface mix or intermediate layer in the pavement structure on high volume (or high demand) roadways. SMA mixtures are often used as the intermediate layer when PFC mix is used as the surface layer. The standard SMA mixture contains PG 76-22 and fibers and is recommended for the vast majority applications where SMA is used. Asphalt Rubber (A-R) SMA can be used as an alternate to the standard SMA. A-R SMA is generally more expensive than the standard SMA; however, it's unique properties warrant it's use in certain applications. As a general rule A-R SMA is recommend over the standard SMA when placed as an overlay on an existing concrete pavement, when a high degree of noise reduction is desired and when placed as an overlay on a pavement that has a high amount of cracking.

Advantages: SMA mixtures provide both excellent rut resistance and crack resistance. SMA mixtures have a high concentration of coarse aggregate, which facilitates stone on stone contact. The voids in the coarse aggregate skeleton are filled with fibers, mineral filler, and a relatively high amount (6% minimum) of polymer modified asphalt. This combination of materials allows for a "rich" mixture that is resistant to cracking while at the same time being highly resistant to rutting. SMA mixtures are considered to be relatively impermeable particularly when compared to performance design mixtures. SMA mixtures result in a pavement layer that has a high degree of surface texture which is beneficial in terms of wet weather traction.

Disadvantages: SMA mixtures typically have a higher initial cost compared to other mixtures. SMA mixtures contain more asphalt (6% minimum) compared to conventional mixtures. The asphalt used in SMA mixtures contains a high amount of polymers (or asphalt rubber as an option). In addition to the polymers, SMA mixtures require the use of fibers (not required with asphalt rubber), mineral filler and may require the use of lime. All of these additives not only add to the initial cost but they often require that the producer make modifications to their typical HMA production processes. SMA mixtures may also require higher quality aggregates than conventional mixtures. SMA mixtures usually require a significant compactive effort; however, they also produce a pavement layer with a higher density compared to conventional mixtures.

Generally speaking, it is not good to place any type of hot mix in cool or cold weather. SMA mixtures can be particularly difficult to place in cool weather because they are placed in thin lifts and they contain a high amount of polymer modified binder. They also do not lend themselves well to applications that require a significant amount of hand work.

Mix Types Comparison

To identify the differences between mix types of different Items, the pictures presented in Figures 1 through 5 were combined to generate new set of figures. The PFC and SMA comparison is shown in Figure 6. The coarse mixes of different types are shown in Figure 7 and difference between coarse and fine mixes of Item 341 is shown in Figure 8.

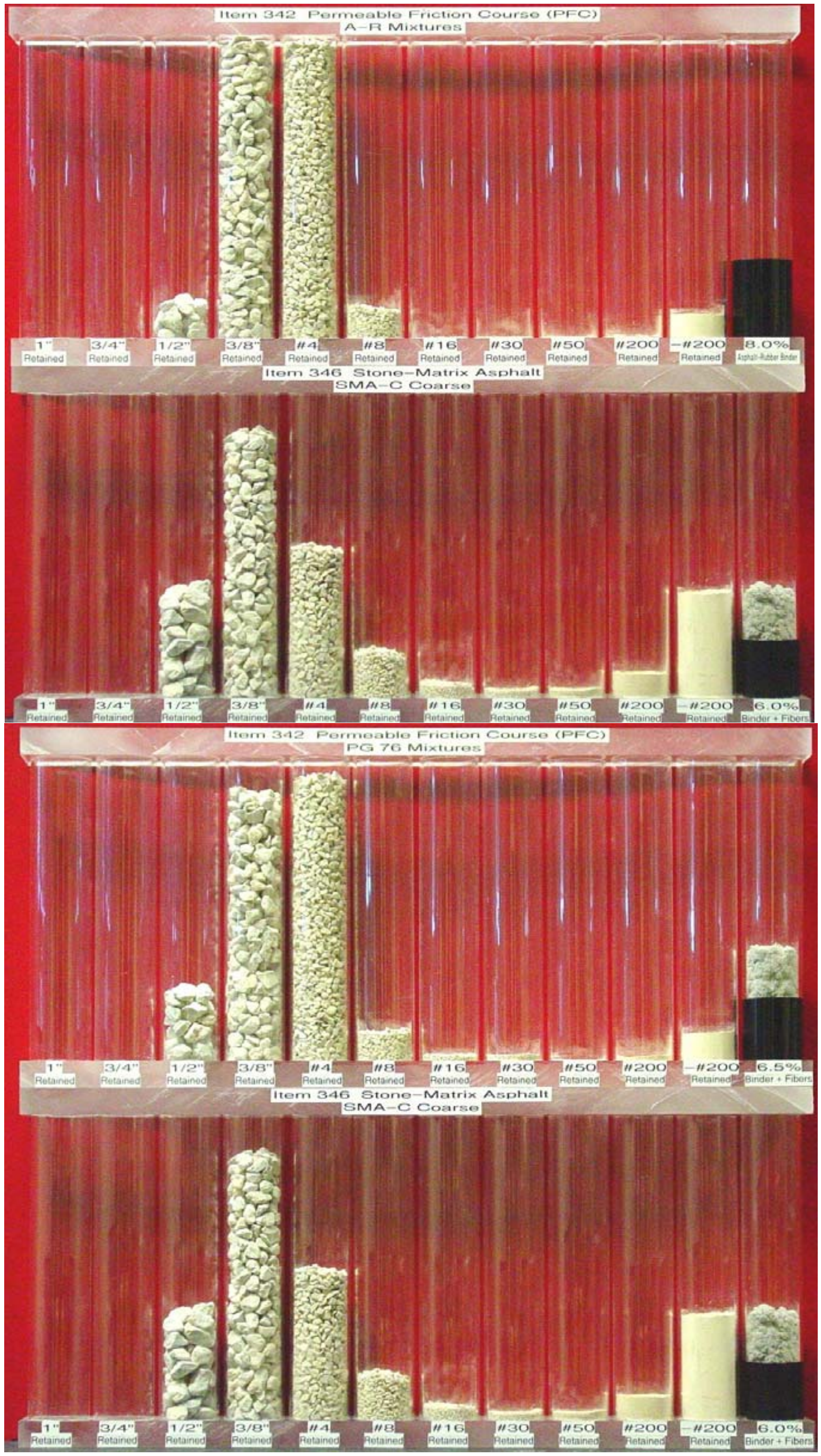

Figure 6. Comparison Between SMA and PFC Mixes

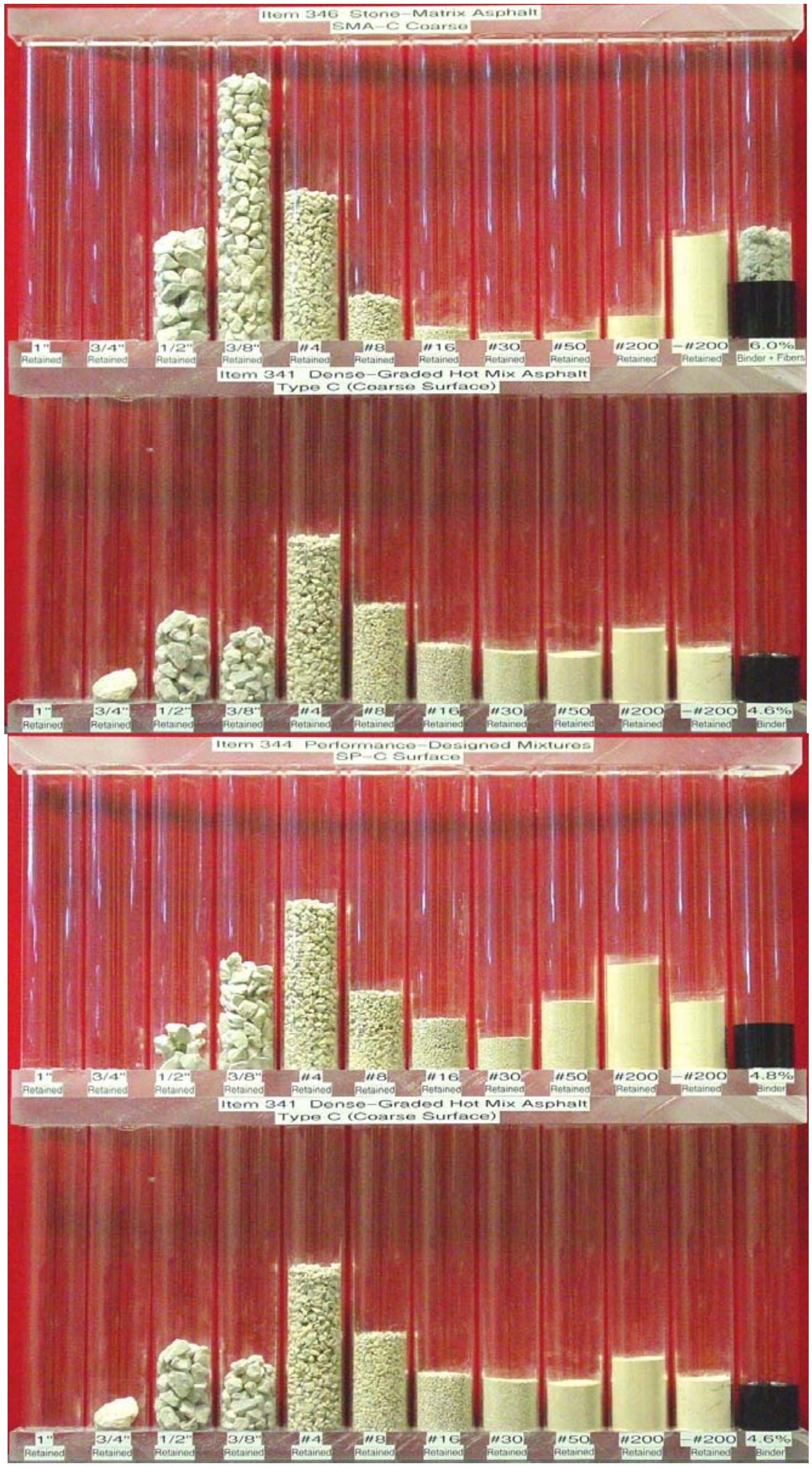

Figure 7. Comparison Between Different Coarse Mixes

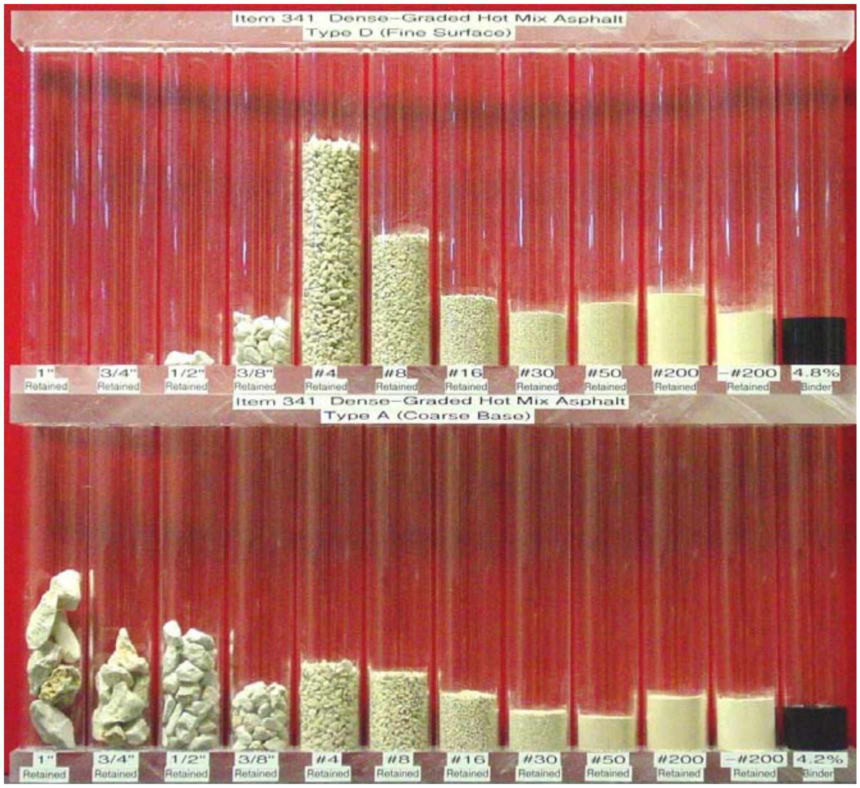

Figure 8. Comparison Between Coarse and Fine Mixes of ITEM 341

The mix information presented in Figure 6 suggests that the SMA and PFC mixes are similar in gradation. They have typically varying quantities of 3/8 in. sieve size material while the quantity of #4 sieve size materials is similar. The asphalt content is similar for SMA and PFC PG 76 mixes while it is higher for PFC A-R mix type. Both SMA and PFC PG76 mix types consist of fiber to minimize asphalt drawdown.

The mix information presented in Figure 7 suggests that the coarse mixes have similar #4 sieve size material but the 1/2 and 3/8 in. sieve size material is varying from one coarse mix type to another one. The asphalt content of SMA coarse mix is higher than other coarse mix types.

The mix information presented in Figure 8 suggests that the Type A-Coarse mix consists of larger aggregate size material in comparison to the Type D-Fine even though Type A is a base mix. The gradation presented in Figure 8 suggests that the coarser aggregate of Type A (mainly larger than 3/8 in.) is replaced with #4 sieve size material to create Type D-Fine mix. The asphalt content of Type A mix is slightly lower than Type D-Fine mix type.

GENERAL CONSIDERATIONS FOR SELECTION OF PG BINDERS FOR HMA IN TEXAS

Several guidelines have been developed for selection of the appropriate PG binder for HMA. The original criteria developed by SHRP were based principally on estimated pavement temperatures and provided means for adjusting the selection based on the speed and number of heavily-loaded vehicles. Software such as "LTPPBind," is available to assist engineers with binder g rade selection that also provides guidelines from others such as Koch Materials Co. for adjusting grade selection for traffic.

The reasons why the high temperature grade is "bumped" for increasing traffic load and slower traffic speeds are to: (1) provide a measure of insurance against rutting in the asphalt layer for pavements receiving a high volume of truck traffic, and (2) account for the reduction in binder stiffness resulting from slow moving or standing loads. Increasing the high temperature grade one level (from PG 64 to PG 70) results in a doubling in binder stiffness at the original temperature (64C). This increases the mixture stiffness (E*) by 35-50%, according to laboratory testing performed at the Asphalt Institute Research Center.

One problem with the guidelines is that they only address temperature and traffic loading, without regard to how the pavement structure responds to loads. In other words, current binder (and mixture) selection guidelines do not differentiate between thin-surfaced flexible pavements and thick asphalt pavements, although these pavements respond very differently to loading. Thick asphalt pavements develop bending strain at the bottom of the asphalt layer, dissipating the vertical strain at the top of the underlying materials in a manner similar to concrete pavements. Thin asphalt surfaces over flexible base develop minimal bending stress/strain at the bottom of the asphalt layer unless the stiffness of the surface course is much higher than the supporting layers. The approximate breakpoint between thick and thin is about 4 inches of HMA.

Increasing the stiffness of the asphalt binder and mixture to improve rutting resistance can be beneficial to the structural performance of thick asphalt pavements. Stiffer materials improve the load-spreading capability of the HMA and thus reduce the critical strains (flexural strain at the bottom of the asphalt layer and vertical compressive strain at the top of the subgrade) that influence fatigue cracking and subgrade deformation. However, stiffening the HMA in a thin, deflecting pavement structure can result in early pavement structural failure in the form of fatigue cracking since the increased stiffness of the layer may lead to the development of bending strain in the thin surface.

To put things into simple terms, materials and mixtures for thin-surfaced flexible pavements should be selected to enhance the ability to resist cracking, while materials for thick asphalt pavements should be stiffened. The trend in Western Europe is to use very low penetration asphalt binders (analogous to increases high temperature PG binders) in the asphalt base course for thick pavement structures. Specific TxDOT mixture classifications and binder selection considerations are discussed in the following paragraphs.

Thin-Surfaced Flexible Pavements

These pavements are defined as having less than 3 inches (total) of HMA over an unbound flexible base. This type of pavement structure makes up most of the Texas Farm-to-Road (FM) system, and is most appropriate when the pavement section is well-drained and there is limited funding.

Ideally, the thin surface should be comprised of two individual asphalt courses. This could be an asphalt surface treatment (chip seal, underseal) directly over the primed flexible base followed by an HMA surface course, or two lifts of HMA. The HMA should be a dense or fine-graded mixture with a nominal maximum size small enough to allow proper compaction during construction. Consequently, Item 340 or 341-Type D, or Item 344- Superpave-Type D (SP-D) designed at N_{design} = 75 gyrations or less would be most appropriate. Coarse-graded mixtures designed to provide superior rutting resistance should not be used for these pavement types, particularly if they are to be placed directly over a flexible base.

Asphalt binders for these mixtures should not be excessively stiff. High temperature grades above PG 70 should not be used for HMA in this type of pavement structure. On the other hand, the low temperature grade should be at least –22, even though the climatic selection criteria in some parts of Texas would allow for –16 or even –10. The reasons for doing this are to avoid excessively stiffening the mixture and to enhance resistance to cracking. In the coldest part of the state (Amarillo, Childress and Lubbock districts), -28 is the appropriate low temperature grade.

Consequently, PG binders for HMA layers used in thin-surfaced flexible pavements should include the following:

- PG 64-22 - Appropriate in most of the state, except for Panhandle districts
- PG 64-28 - Panhandle districts
- PG 70-22 - Consider for Laredo and El Paso districts due to extended high temperatures

Thick-Surface Flexible Pavements

To meet the definition, the total HMA thickness must exceed 4 inches. If the HMA is being placed directly over the finished subgrade, the minimum thickness should be 8 inches. In contrast to thin-surfaced flexible pavements, this type of pavement structure benefits from stiffening the mixtures at all levels to improve load-spreading capability and to resist rutting in the asphalt layers.

Mixtures for these types of pavements must develop good aggregate interlock as well as having a stiff asphalt binder. The criteria for assuring stone-on-stone contact that is included in Items 344 and 346 make these specifications the most appropriate for use in thick asphalt pavements. Specific mixture classifications should be selected keeping in mind the lift thickness that will be used. Since these mixtures are usually coarse-graded, the ratio of lift thickness to nominal maximum particle size should be at least 4:1.

In the recent past, stiff asphalt binders (PG 76 or 82) have been commonly used in HMA layers within 4 inches of the surface. To enhance performance of thick asphalt pavements, stiff binders should be considered for all HMA courses, particularly if the project is to be constructed under traffic. The stiffer asphalt binder will increase the complex modulus of the mixture, and it will also help the mixture resist damage if traffic must use the pavement before the entire pavement structure is completed. The result will be a pavement that responds to load similar to Portland cement concrete, but without the joints, reinforcing steel or the costs. Stiffer HMA base mixture may also allow for a reduction in the total thickness of the pavement structure, as we have seen in pavement design procedures used in the United Kingdom.

For thick asphalt pavements, the following PG binders should be considered:

- For surface and leveling course (SMA, Superpave (SP)-Type C or D, CMHB):
  - PG 76-22 (general)
  - PG 76-28 (Panhandle)
  - PG 82-16 (-22) (El Paso, Laredo)
- For base course mixtures: (SP-A, B):
  - PG 76-22 (Perpetual Pavement designs, urban sections)
  - PG 70-22 (-16) (new alignment, rural highways)

Since the temperature ranges decrease with depth, the need to distinguish between climate regions is not as important for base mixtures as for surface mixtures.

PFC (Item 342)

This item calls for either PG 76-22 or CRM Asphalt Binder. In some cases (Laredo, El Paso), PG 82 should be considered given the higher temperatures in those districts.

Inlays, Overlays, Composite Pavements

The desired attributes of the HMA layers used in these situations depend on the pavement structure being rehabilitated and the type of response to load anticipated. It is possible to convert a deflecting pavement structure to one that resists deflection through overlaying or milling and replacement. This depends on the level of support provided by the existing pavement and the thickness of the overlay to be placed.

For example, if an existing thin-surfaced FM road is being overlayed with HMA simply to improve its functional qualities, it would be appropriate to select a mixture with the same qualities described for a new thin-surfaced pavement. If the FM road is in a rapidly-developing location on the fringe of a major urban area, it would likely require a structural overlay and thus be converted from a thin-surfaced, deflecting pavement structure to one where reduced deflection is preferred. For both cases, the existing HMA should be sampled and tested to assure that it is not susceptible to moisture damage before deciding to overlay or to place a seal coat of some type.

Composite pavements, which consist of HMA placed over cement stabilized base (CSB) or concrete pavement resist deflection due to the stiffness of the concrete, but may suffer from reflection cracking at joints or cracks. Mixture and asphalt binder selection alone will not provide sufficient resistance to reflection cracking to warrant consideration. Reflection cracking is caused by movement occurring under load or from volume changes in the underlying materials. To avoid this, the movement in that material must be reduced or eliminated. Techniques for dealing with this issue are readily available, but are not the scope of this discussion.

What should be considered are resistance to rutting and the increase in load-carrying capacity provided by the overlay. Both factors suggest the use of stiff, rut resistant mixtures. Therefore, similar guidelines for selection of mixtures for thick asphalt pavements should apply to the selection of mixtures for overlaying existing CSB or concrete pavement.

Recommendations for Mix Selection

Recommendations regarding mixture selection are provided in the following three tables. Table 1 contains a listing of relative hot mix rankings. Table 2 contains a summary of mixture types, sizes, and uses. Table 3 contains a listing of recommended choices for surface mixtures based on traffic speed and volume.

Table 1. Relative Hot Mix Rankings

Mixture Characteristic	DGA (Item 340/341)	PFC (Item 342)	SP & CMHB (Item 344)	SMA (Item 346)	Determining Factors
Resistance to Rutting	2-5*	4-5	3-5	4-5	Stone on stone contact & binder stiffness
Resistance to Cracking	1-4	3-5	2-4	4-5	Total volume of asphalt in mix, binder film thickness
Resistance to Segregation	1-4	5	3-4	4-5	Gradation, uniformity & aggregate size
Resistance to Raveling	2-4	2-4	3-4	4-5	Toughness of mastic & resistance to segregation
Ability to resist high shear forces (hard turning motions)	2-4	2-4	3-4	4-5	Toughness of mastic & resistance to raveling
Resistance to Moisture Damage	2-4	3-5	3-4	4-5	Binder film thickness & potential adverse permeability
Resistance to Freeze/Thaw Damage	3-4	2-4	3-4	4-5	Binder film thickness & potential permeability
Potential Permeability	3-4	N/A	2-4	4-5	Ability to compact to a relatively high in place density
Long Term Durability	2-3	3-4	3-4	4-5	Binder film thickness & toughness
Wet Weather Traction	2-4	4-5	3-4	3-4	Texture, permeability, & resistance to hydroplaning
Wet Weather Visibility	2-3	4-5	2-4	2-4	Texture & ability to quickly drain surface water
Noise Reduction (comfort)	3-4	4-5	3-4	3-4	Ability to buffer noise & surface texture
Aesthetically Pleasing	3-4	4-5	3-4	3-5	Texture, uniformity & resistance to segregation
Ease of Compaction	2-4	4-5	2-3	3-4	Volume of mastic, VMA, & toughness
Ability to “hand work”	3-5	2-3	2-4	2-3	Aggregate gradation & binder stiffness
Affordability (Initial Cost)	4-5	2-4	3-4	2-3	Aggregates, additives & production rates

*Subjective 0 to 5 scale with 5 being the “best”

Table 2. Summary of Mixture Types, Sizes and Uses

Mixture Type/ Size	Nominal Aggregate Size	Minimum Lift Thickness (inches)	Maximum Lift Thickness (inches)	Typical location of pavement layer
Item 340/341				
Type A mix	1 ½”	3.0”	6.0”	Base
Type B mix	1”	2.5”	5.0”	Base/Intermediate
Type C mix	3/4”	2.0”	4.0”	Intermediate/Surface
Type D mix	1/2”	1.5”	3.0”	Surface layer
Type F mix	3/8”	1.25”	2.5”	Surface layer
Item 342				
PFC (PG 76 mixture)	1/2”	3/4”	1.5”	Surface
PFC (AR mixture)	1/2”	3/4”	1.5”	Surface
Item 344				
SP A	1 ½”	3.0”	5.0”	Base
SP B	1”	2.25”	4.0”	Base/Intermediate
SP C	3/4”	1.5”	3.0”	Intermediate/Surface
SP D	1/2”	1.25”	2.0”	Surface
CMHB-C	3/4”	2.0”	4.0”	Intermediate/Surface
CMHB-F	3/8’	1.5”	3.0”	Surface
Item 346				
SMA-C	3/4”	2.25”	4.0”	Intermediate/Surface
SMA-D	1/2”	1.5”	3.0”	Intermediate/Surface
SMA-F	3/8”	1.25”	2.5”	Surface
SMAR-C	3/4”	2.0”	4.0”	Intermediate/Surface
SMAR-F	3/8”	1.5”	3.0”	Surface

Table 3. Recommended Choices for Surface Mixtures based on Traffic Volume and Speed

Posted Speed	Traffic Volume / Load Demand		
	Low	**Medium**	**High**
< 45 mph	1. Dense graded mix 2. Performance design mix	1. Performance design mix 2. Dense graded mix	1. SMA 2. Performance design mix 3. Dense graded mix
45 mph or higher	1. Dense graded mix 2. Performance design mix 3. PFC	1. PFC 2. Performance design mix 3. Dense graded mix	1. PFC 2. SMA 3. Performance design mix 4. Dense graded mix

Note: A high load demand can be defined as having a high amount of cumulative axle loads, a high shear environment caused by decelerating/turning movements, slow moving or standing traffic with heavy axle loads.

DEVELOPMENT OF THE EXPERT SYSTEM: TEXSYS

The information presented in previous section suggests that TxDOT engineer needs to select a mix or set of mixes out of 26 mixes (as per TxDOT specifications) for placement in the field. Since each mix has its own benefits and limitations, it is a difficult task to select a suitable mix or set of suitable mixes for placement. This task is further complicated by the structural and functionality requirements of a project.

Therefore, a web-based application, termed TexSys was developed as an expert system for the selection of HMA in Texas for inexperienced engineers. The objective of the expert system is to provide user with a mix or list of mixes that can be used on a specific project after total thickness of HMA layer has been obtained from available design software (e.g., FPS 19).

To achieve this objective, TexSys serves as a user interface and collects information from users that would influence the selection of HMA. Information is collected by presenting the user with six different web-pages or forms. Each form presents the user with different options that may be selected to determine priorities and influence factors that should be considered in the selection of an appropriate HMA mixture.

The outcome of the expert system is a ranking applied to 26 different asphalt mixture candidates (Table 4) along with the specified thickness. Each of these candidates is a possible solution that defines the best mix for the job. Asphalt mixtures that rank highest would be the most appropriate given the user selected conditions.

The output of the expert system relies on the influence factors, which have been provided by the experienced TxDOT engineers (human experts). These factors are the most important factors influencing a district's decision regarding HMA mixture selection. The influence factors used in the expert system are:

- Structure (WStruc)
- Function (WFunc)
- Environment (WEnviro)
- Traffic (WTraffic)
- Safety (WSafety)
- Experience (WExperi)
- Cost (WCost)

It is possible that each of the listed factors may influence the selection of an HMA mixture. Some factors, however, may be more relevant than others and in certain cases it may be justified to negate the influence of one or more of these. To allow this flexibility, the influence factors are each given a weighting (WStruct, WFunc, etc.) of 0-1 depending on what the user decides to be the most relevant or critical influence factors. The sum of the weightings for all the influence factors must be 1. If a user decides that Cost (for example) should not influence decisions regarding mixture selection then it should be weighted as 0 (zero) and the balance made up with some other influence. A description of each of these influence factors is included in the following sections.

Table 4. TexSys Goals

Mix ID	Item	Course	Placement Thickness, in.	
			Minimum	Maximum
1	Item 340/341 Type C	Surface	2.00	4.00
2	Item 340/341 Type D	Surface	1.50	3.00
3	Item 340/341 Type F	Surface	1.25	2.50
4	Item 342 PFC PG76 Mixes	Surface	0.75	1.50
5	Item 342 PFC AR Mixes	Surface	0.75	1.50
6	Item 344 Superpave C (SP-C)	Surface	1.50	3.00
7	Item 344 Superpave D (SP-D)	Surface	1.25	2.00
8	Item 344 CMHB-C	Surface	2.00	4.00
9	Item 344 CMHB-F	Surface	1.50	3.00
10	Item 346 SMA-C	Surface	2.25	4.00
11	Item 346 SMA-D	Surface	1.50	3.00
12	Item 346 SMA-F	Surface	1.25	2.50
13	Item 346 SMA-RC	Surface	2.00	4.00
14	Item 346 SMA-RF	Surface	1.50	3.00
15	Item 340/341 Type B	Intermediate	2.50	5.00
16	Item 340/341 Type C	Intermediate	2.00	4.00
17	Item 344 Superpave B (SP-B)	Intermediate	2.25	4.00
18	Item 344 Superpave C (SP-C)	Intermediate	1.50	3.00
19	Item 344 CMHB-C	Intermediate	2.00	4.00
20	Item 346 SMA-C	Intermediate	2.25	4.00
21	Item 346 SMA-D	Intermediate	1.50	3.00
22	Item 346 SMA-RC	Intermediate	2.00	4.00
23	Item 340/341 Type A	Base	3.00	6.00
24	Item 340/341 Type B	Base	2.50	5.00
25	Item 344 Superpave A (SP-A)	Base	3.00	5.00
26	Item 344 Superpave B (SP-B)	Base	2.25	4.00

Structure

Asphalt mixtures are designed to serve specific purposes depending on whether the mixture will be used as a surface or base course. TexSys considers two structural properties, i.e., rutting and fatigue. The structure ranking (aStruct) is calculated considering both of these properties as:

aStruct[i] = sRut*MixRut[i] + sFat*MixCrack[i] (1)

Where

sRut	= weighting placed on rutting resistance,
sFat	= weighting placed on fatigue resistance,
MixRut[i]	= ranking of a mixture candidate in terms of rutting, and
MixCrack[i]	= ranking of a mixture candidate in terms of fatigue.

To ensure uniformity of the final solution it is necessary to ensure that the sum of weightings applied to rutting and fatigue equal unity. Equation 1 proportions the influence of rutting and fatigue to calculate an overall ranking for the candidate mixture in terms of the influence afforded by the pavement structure. In other words, if the user requires a mixture that is more rut resistant, the structural influence will tend to favor asphalt mixtures that rank high in terms of resistance to rutting.

To calculate the weighting for fatigue and rutting, information input on the TexSys forms shown in Figure 9 and Figure 10 is considered. TexSys allows the user to balance the mixture requirements in terms of rutting or fatigue resistance directly, as shown in Figure 9. Alternatively the user may indicate that either high shear resistance and/or long term durability is to be considered as a high priority requirement. Selecting high shear resistance as a high priority requirement will automatically weight rutting as 80 % and fatigue as 20 % and vice versa. If both high shear resistance and long term durability are selected as high priority requirements then TexSys reverts to the weighting scale defined previously (50:50) as both of these requirements cannot be satisfied simultaneously.

This functionality was built into TexSys specifically to evaluate the sensitivity of the expert system to changes in the weightings applied to rutting and fatigue. As pavement engineers we desire pavements that are both resistant to rutting and fatigue. Unfortunately, given the opposing nature of these two properties, a trade-off is often required in favor of one over the other. An exception is with the use of SMA mixtures that are designed with a stone-on-stone skeletal structure that resists permanent deformation but which also have a mastic component offering fatigue resistance. SMA mixtures, however, are expensive and may not be feasible for all applications. This highlights one of the benefits of TexSys in that selections can be made and an outcome determined after which the selection can be changed to test the sensitivity of the solution in “what if” type scenarios.

TexSys can also take the pavement structure defined by the user (as shown in Figure 10) into account to adjudicate the weighting for fatigue. It does this by calculating the horizontal strain beneath the asphalt layer based on the defined layered structure. If this strain level exceeds 70 microstrain[1] then TexSys weights fatigue as 90 % and rutting as 10 %. This is considered a threshold strain level above which fatigue of the pavement layer will occur.

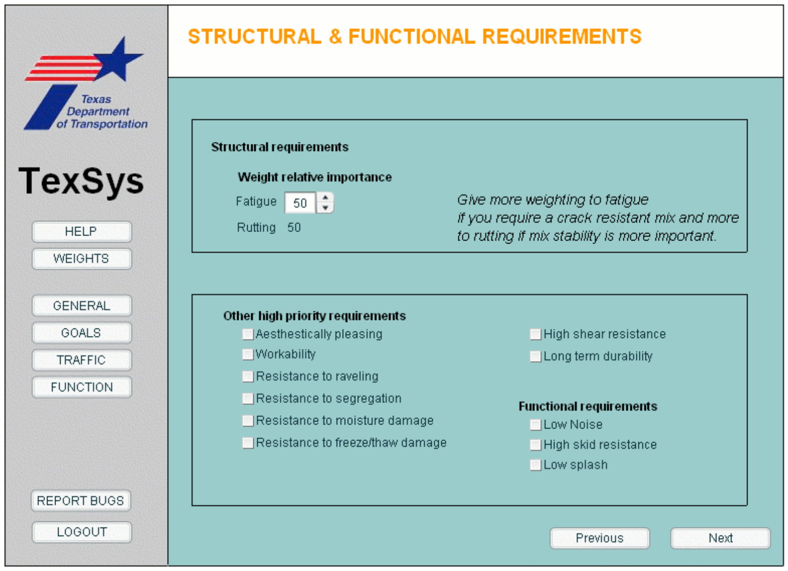

Figure 9. TexSys Structural and Functional Requirements Form

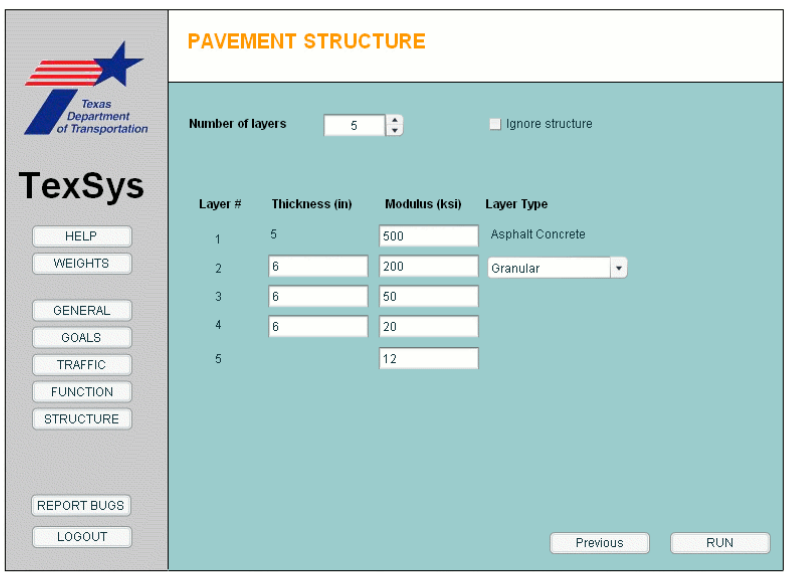

Figure 10. TexSys Pavement Structure Form

[1] This level is perhaps extreme and may be increased to say 200 microstrain in future TexSys versions.

Having determined the weightings to be applied to rutting and fatigue, the next step is to determine the mixture rankings for these properties. These mixture rankings in terms of rutting and fatigue are by default those shown in Table 5 below but these may be modified by registered users of TexSys.

Table 5. Rutting and Fatigue Mixture Related Rankings

Property	I340	I341	I342	I344	I346
Resistance to Rutting (MixRut)	7/10	7/10	9/10	8/10	9/10
Resistance to Cracking (MixCrack)	5/10	5/10	8/10	6/10	9 /10

The rankings shown in Table 5 are based on the rankings previously shown in Table 1, modified to output a number between 0 – 1 indicating the benefit of a mixture for the listed property; the closer to 1 the better the mixture. Clearly PFC and SMA mixtures will have superior rutting resistance and the latter mixture is also the better option for fatigue resistance. Applying Equation 1 to the rankings given in Table 5 results in the mixture rankings shown in Figure 11. The figure indicates that for the structural influence, SMA mixtures will always be beneficial regardless of the weighting applied to fatigue although Item 340/1 mixtures will be penalized if resistance to cracking is a priority.

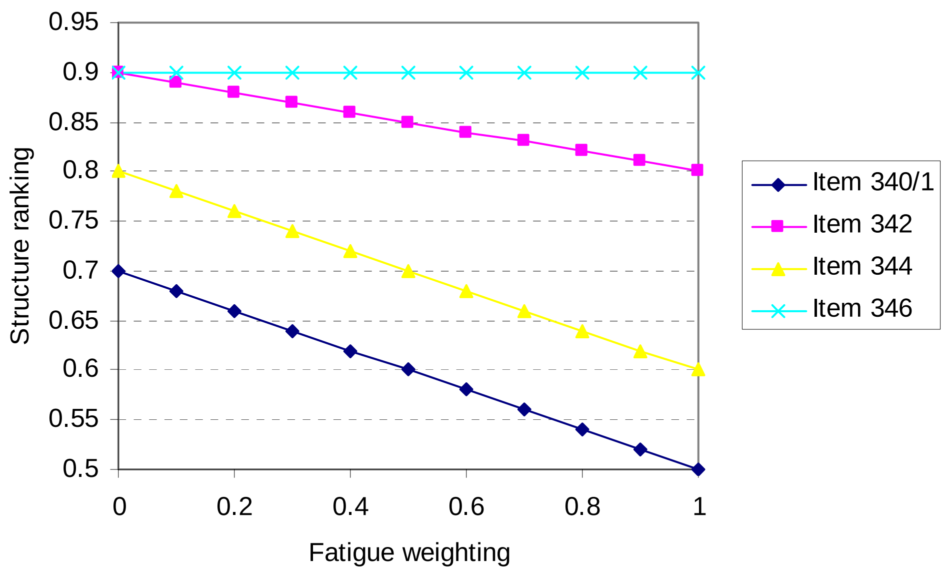

Figure 11. Structure Ranking of HMA Mixtures in terms of Fatigue Weighting

For the calculation of the tensile strain beneath the asphalt layer, TexSys uses the layer moduli and thicknesses input by the user. Layer moduli are recommended based on the user selection for base layers. The user has the option to ignore the pavement structure in the analysis.

Function

The functional properties of an asphalt mixture are typically defined for surface courses and relate to properties such as noise, skid resistance and splash and spray. TexSys considers the latter two properties as *Safety* influences but expands the function properties of the pavement to include aesthetics, workability, raveling resistance and segregation in addition to noise. The functional aspects are only included in the selection analysis if the user specifically identifies these as priorities or requirements on the form shown in Figure 9. The function ranking (aFunc) of the candidate mixtures is calculated as:

aFunc[i] = bLooks*aLooks[i] + bWork*aWork[i] + bRavel*aRav[i] + bSeg*aSeg[i] + bNoise*aNoise[i] (2)

Where

bLooks = Aesthetics weighting,
bWork = Workability weighting,
bRavel = Ravelling weighting,
bSeg = Segregation weighting,
bNoise = Noise weighting,
aLooks[i] = Ranking of mixture candidate [i] in terms of aesthetics,
aWork[i] = Ranking of mixture candidate [i] in terms of workability,
aRav[i] = Ranking of mixture candidate [i] in terms of raveling,
aSeg[i] = Ranking of mixture candidate [i] in terms of segregation,
aNoise[i] = Ranking of mixture candidate [i] in terms of noise

The mixture rankings in terms of the defined functional properties are by default those shown in Table 6 below but as with the structure rankings these may be modified by registered users.

Table 6. Mixture related Functional Property Rankings

Property/Mix Item	I340	I341	I342	I344	I346
Resistance to Segregation	5/10	5/10	10/10	7/10	9/10
Resistance to Raveling	6/10	6/10	6/10	7/10	9/10
Noise Reduction	7/10	7/10	9/10	7/10	7/10
Aesthetically Pleasing	7/10	7/10	9/10	7/10	7/10
Workability	8/10	8/10	5/10	6/10	5/10

Currently TexSys applies an equal weighting to each of the listed functional properties. The only requirement is that the sum of these weightings is unity. This approach was adopted as users must specifically indicate whether to include a functional requirement in the analysis. By default none are included and the functional influence is effectively ignored, regardless of the weighting applied to the functional influence. It is advisable therefore to select at least one of the listed functional requirements for inclusion in the analysis.

Raveling, noise and aesthetics are surface course properties and are not applied to intermediate or base course mixtures. To illustrate how TexSys works, consider the case in which the structural and functional influences alone are considered in the analysis weighted 50:50. For the structural influence the weighting applied to rutting and fatigue will also be 50:50 and workability of the mix is indicated as a priority requirement. As shown in Table 7, this results in a final ranking that is similar for the different asphalt mixture candidates.

Table 7. Example Analysis Considering Structure and Function Influence

Mix	Ranking		
	Structure	**Function**	**Final**
Item340/1	0.6	0.8	0.7
Item342	0.85	0.5	0.675
Item344	0.7	0.6	0.65
Item346	0.9	0.5	0.7

TexSys extends the analysis outlined above to consider all of the influence factors to determine the final ranking of mixtures.

Environment

Climate related factors considered in the analysis include rainfall and temperature. Different asphalt mixtures will perform differently under different climatic conditions. Porous friction course (PFC) mixtures, for example, will be appropriate under wetter conditions to reduce splash and spray. Some mixtures will also be better at resisting permanent deformation in hotter climates. These factors are considered by applying rankings to the different candidate mixtures depending on the variation in climatic conditions anticipated in the district for which the design is intended.

On the first form presented to the user, a selection of district and county must be made by the user. Once a selection is made, TexSys collects information from a weather database compiled based on records spanning 30 years, to identify the mean and standard deviation of annual rainfall as well as minimum and maximum temperatures in the selected county. This information is compared to the mean and standard deviation of rainfall and temperatures in the state of Texas. Rankings indicating the appropriateness of a candidate asphalt mixture are determined depending on the variation in rainfall and temperature of the selected county compared to the overall climate statistics in Texas.

Table 8 shows the mean (x) and variation from the mean (one and two standard deviations) of mean monthly annual rainfall and mean monthly temperatures in Texas.

Table 8. Climate Limits Applied in TexSys

Property	x-2s	x-1s	x	x+1s	x+2s
Rainfall, in	8.2	20.1	31.9	43.8	55.7
Min. Temp, °F	18.7	26.0	33.3	40.6	47.9
Max. Temp, °F	89.6	92.1	94.6	97.1	99.6

These values were used to determine limits to adjudicate the rankings for the candidate asphalt mixtures in terms of county rainfall and temperature. If, for example, the rainfall in the selected county is greater than two standard deviations from the mean annual rainfall in Texas, then this indicates that the county is particularly wet and consequently mixtures that perform better under wetter conditions will be given higher rankings. Five separate lists of rankings for the different asphalt mixtures were compiled for rainfall and minimum and maximum temperatures depending on deviation of rainfall or temperature from the mean as follows:

- Less than 2 standard deviations from the mean (d2x)
- Between 1 and 2 standard deviations less than the mean (d1x)
- Within 1 standard deviation from the mean (xxx)
- Between 1 and 2 standard deviations greater than the mean (x1d)
- Greater than 2 standard deviations from the mean (x2d)

These lists were compiled by "experts" to indicate the appropriateness of the candidate asphalt mixtures under varying climatic conditions. To accommodate changes to these lists they were developed as XML files that are referenced externally by TexSys during analysis and can therefore be changed or refined without having to recompile TexSys. Links to the lists as they currently stand are presented below but given the dynamic nature of the TexSys program these are under constant revision to balance the mixture rankings presented.

XML lists

Rainfall: http://pavements.ce.utexas.edu/TexSys/rain.xml

Maximum Temperature: http://pavements.ce.utexas.edu/TexSys/tmax.xml

Minimum Temperature: http://pavements.ce.utexas.edu/TexSys/tmin.xml

Two other aspects considered for environment include freeze/thaw and moisture susceptibility. The user may indicate either or both of these as priority factors on the form shown in Figure 9. The relative weighting for the environmental influence factor is varied depending on whether freeze/thaw and moisture susceptibility should be considered in the analysis together with annual rainfall and minimum and maximum temperature. Weighting factors were assigned as shown in Table 9 to account for this.

Table 9. Relative Weighting Factors for Environmet

Include Freeze /Thaw?	Include Moisture Susceptibility?	Weighting factors				
		Rain (fRain)	Max. Temp (fMax)	Min. Temp (fMin)	Freeze (fFreeze)	Moist (fMoist)
Yes	**Yes**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Yes	No	0.2	0.1	0.3	0.4 0	0
No	Yes	0.3	0.2	0.1	0	0.4
No	No	0.333	0.333	0.333	0	0

The environmental ranking (aEnviro) of the candidate mixtures is calculated as :

aEnviro[i] = fRain*aRain[i] + fMax*aTmax[i] + fMin*aTmin[i] + fFreeze*aFreeze[i] + fMoist*aMoist[i] (3)

where

f* = Weighting factors shown in Table 9,
aRain[i] = Ranking of mixture candidate [i] in terms of rainfall,
aTmax[i] = Ranking of mixture candidate [i] in terms of maximum temperature,
aTmin[i] = Ranking of mixture candidate [i] in terms of minimum temperature,
aFreeze[i] = Ranking of mixture candidate [i] in terms of freeze/thaw,
aMoist[i] = Ranking of mixture candidate [i] in terms of moisture susceptibility.

Mixture rankings for freeze/thaw and moisture susceptibility are shown in Table 10 below.

Table 10. Mixture Rankings for Freeze/thaw and Moisture Susceptibility

Property	1340	1341	1342	1344	1346
Resistance to Moisture Damage	6/10	6/10	8/10	7/10	9/10
Resistance to Freeze/Thaw Damage	7/10	7/10	6/10	7/10	9 /10

Traffic

The influence of traffic on the selection of an appropriate design mixture was determined in terms of traffic volume and speed based on the trends as indicated in Table 3. Traffic information is collected from the user on the form shown in Figure 12. As shown in the figure, specific volumes of traffic were associated with the different roadway categories i.e. farm-to-market (FM), state highways (SH), US highways (US) and interstate highways (IH). As for the environmental influence, an XML sheet was developed to rank the appropriateness of candidate asphalt mixtures in terms of traffic volume and speed. This is under constant revision: http://pavements.ce.utexas.edu/TexSys/traffic.xml.

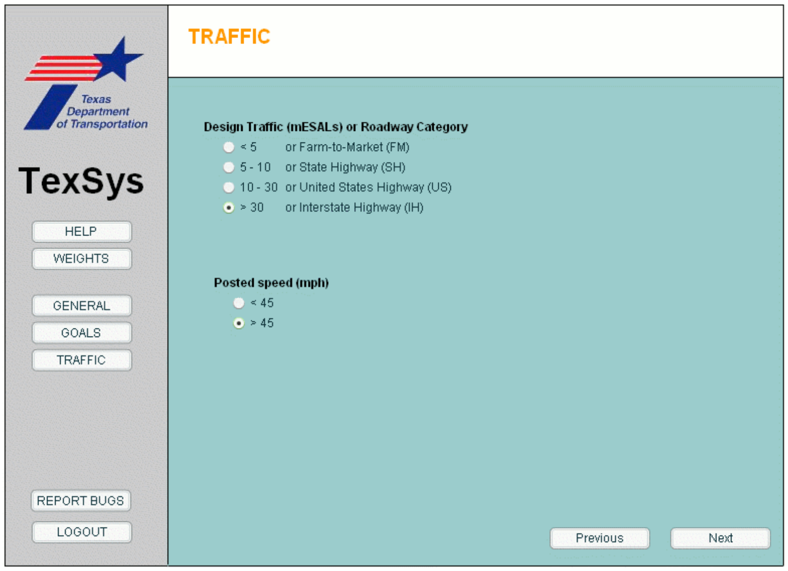

Figure 12. TexSys Traffic Information Form

Safety

Safety was indicated as a factor influencing the selection of HMA. TexSys considers two HMA mixtures related safety aspects i.e. splash and spray and skid resistance. Splash and spray can affect the visibility of drivers under wet conditions and the skid resistance of an asphalt mixture affects the traction of the tires to the road surface under braking and cornering at high speeds. These properties must be indicated by the user as being priority requirements on the TexSys form shown in Figure 9. The weighting factors applied to these properties are increased to 0.8 from 0.5 if these are selected as priority requirements. Safety rankings (aSafety[i]) of the candidate mixtures are calculated as:

$$\mathbf{aSafety[i] = aSkid*bTract[i] + aSplash*bVisi[i]} \qquad (4)$$

where

aSkid[i] = Ranking of mixture candidate [i] in terms of skid resistance,
aSplash[i] = Ranking of mixture candidate [i] in terms of splash and spray,
bTract = Weighting applied to wet weather traction,
bVisi = Weighting applied to wet weather visibility.

Mixture rankings for wet weather traction and visibility are shown in Table 11 below. Safety rankings are only applied to surface course mixtures.

Table 11. Mixture Rankings for Skid Resistance and Splash and Spray

Property	1340	1341	1342	1344	1346
Wet Weather Traction	6/10	6/10	9/10	7/10	7/10
Wet Weather Visibility	5/10	5/10	9/10	6/10	6 /10

Experience

The survey of the districts indicated that if a district was satisfied with the performance of a particular mixture that it would strongly reconsider using it again. In fact, past performance experience ranked second only to engineering judgment as being an important factor influencing a district's decision to select an HMA mixture. To address this in a TexSys analysis, it was decided to link TexSys to a lettings database populated with design and construction information system (DCIS) data including costs and quantities of HMA let in Texas.

When the user selects a county, TexSys queries the lettings database for all asphalt mixtures let in the selected county. The quantities (tonnage) of the individual mixtures are summated and expressed as a percentage of all mixtures used in the county. This is an indicator of the district's experience with any particular mixture. If a county has not let any particular asphalt mixture, then the ranking of that mixture is assigned a value of zero, which heavily penalizes asphalt mixtures never before used in the county.

To illustrate how experience is applied in TexSys consider the quantities of HMA mixtures let in Travis county between 1994 and 2006. These are shown in Table 12 by mixture type.

From the table it can be seen that the highest quantity of any mixture let is for Item 341 Type C, followed by Item 341 Type A mixtures. There is a low percentage of Item 341 Type D mixtures and no Item 344 Superpave mixtures (0 %). These percentages are applied directly within TexSys as mixture rankings for experience.

Given that the approach applied in TexSys, discourages the use of new mixtures in a district, users are encourage to experiment with the weighting of the experience influence.

Table 12. Quantities of HMA let in Travis County, Austin District, Texas

Mix	Quantity (tons)	Percentage (Ranking)
Item340TYA	294329.5	8.6%
Item340TYB	102090.1	3.0%
Item340TYC	135396.1	4.0%
Item340TYD	2863.9	0.1%
Item341TYF	154356.4	4.5%
Item341TYA	654347.9	19.2%
Item341TYB	297554.6	8.7%
Item341TYC	1514290.0	44.3%
Item341TYD	16032.7	0.5%
Item342PFC-PG	23844.0	0.7%
Item344CMHB-C	154356.4	4.5%
Item346SMA-D	66072.4	1.9%
Total	**3415533.8**	**100%**

Cost

The cost factor is addressed in a manner similar to experience in that the lettings database is queried to extract costs for mixtures used in the selected county. The costs are expressed as a percentage and subtracted from 1 to represent a mixture ranking in terms of cost. If a particular mixture is not used in the selected county, then the cost ranking of that mixture is assigned the average cost ranking for all mixtures used in the county.

Given that costs of HMA mixtures in the lettings database are not necessarily current and that these may fluctuate it was decided to also express mixture cost rankings in terms of a general affordability scale as shown in Table 13. The final cost rankings for the candidate mixtures are calculated as the average of the rankings in this table and the cost rankings determined from the lettings database. As with the experience factor discussed above, the influence of cost should be considered carefully so as not to exclude potentially better mixtures.

Table 13. Mixture Rankings in terms of Mixture Affordability

Property	I340	I341	I342	I344	I346
Affordability	9/10	9/10	6/10	7/10	5/10

Final Ranking

A final judgment regarding the best mix for the job can only be made once all the influence factors are considered. The final solution is therefore a summation of rankings applied to the different properties underlying each influence factor after these have been weighted. The expert system uses each of the influence factors and calculates the final ranking of the different mixtures [i=1 to 26] (Table 4) by summating the weighted influence factors as follows:

aFinal[i] = aStruct[i]*WStruct + aFunc[i]*WFunc +
aEnviro[i]*WEnviro + aTraffic[i]*WTraffic + aSafety[i]*WSafety + (5)
aExp[i]*WExperi + aCost[i]*WCost

where aStruct[i], aFunc[i], etc are rankings applied to the different influence factors for the different asphalt mixture candidates [i]. A ranking indicates the appropriateness or "favorability" of a mixture given a set of conditions. The higher the ranking, the better the mixture would be for the job at hand. This formulation allows rankings applied to the candidate mixtures (in terms of the influence factors) to be proportioned in order to determine the overall ranking of each candidate. The interdependence of influence factors used in overall ranking is shown in Figure 13.

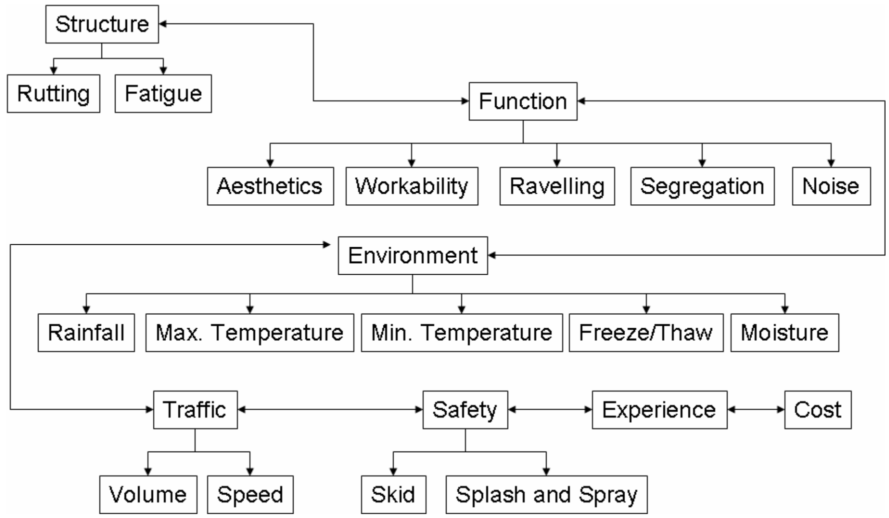

Figure 13. TexSys Influence Factors and their Properties

TexSys: Example 1: Input and Solution

The developed expert system: TexSys collects information from the user via screens that require input. This information is gathered and stored and latter used to calculate a final ranking for each TxDOT mixture item to indicate the benefit or appropriateness of a mixture given the user selected conditions.

The following inputs screens are included in TexSys:

- General
- Goals
- Traffic
- Function
- Structure

To better explain the expert system and input requirements, an example is included in the discussion for each of the input forms and the identified solution is discussed at the end.

General

The user is required to input a design thickness (as determined using a pavement structure design program i.e. FPS19, AASHTO 2002 etc). The user must also indicate the county in which the mix will be used. The user can also indicate type of construction (i.e. new construction or overlay) and total quantity required. Once selections have been made, TexSys works behind the scenes to configure variables that will be used in the final calculation of weighting factors for the different mixtures. If the total quantity selected is greater than 5,000 tons then TexSys will consider Item 341 mixtures in lieu of Item 340 mixtures and vice versa.

If the user selects overlay construction instead of new construction then only surfacing and intermediate layers are included in the final calculation of goals. The decision to include intermediate mixtures was made to allow for level-up if required.

The example shown in Figure 14 is for Travis County in Austin District. The design thickness is 8 in. with the assumption that it is a new construction and amount of material to be placed is more than 5,000 tons.

Goals

This page allows the user to select which mixtures should be included in the analysis (Figure 15). All are included by default. If the user selected overlay construction form the *General* page then the base mixtures will not be included in the analysis. The mixtures for different layers can be accessed by clicking on the layer text. The form only shows mixtures for one layer at time. In this example, it was decided to include all of the 26 mixes for evaluation.

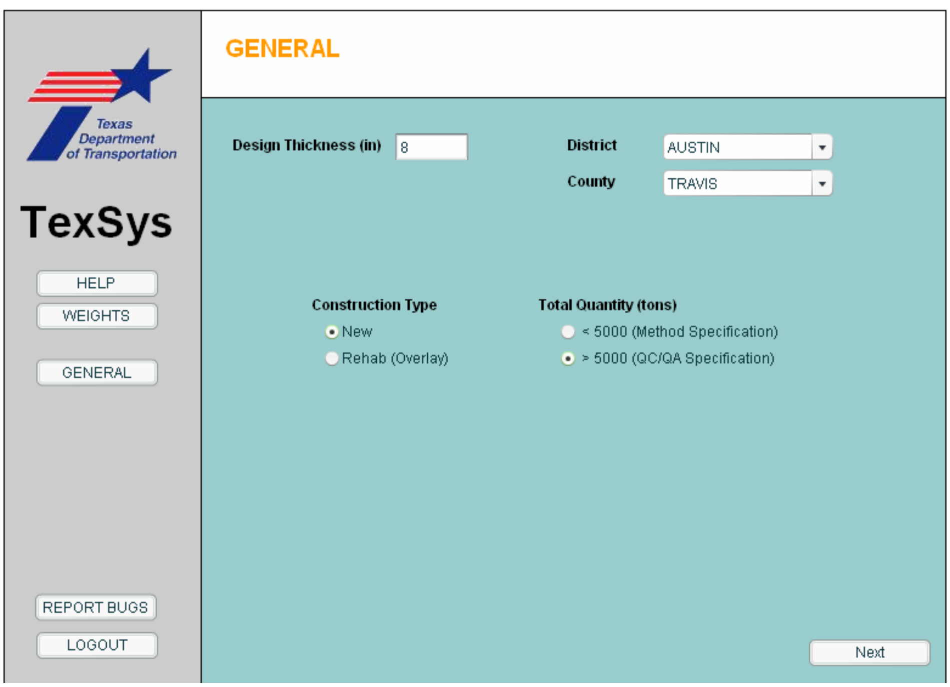

Figure 14. TexSys General Form

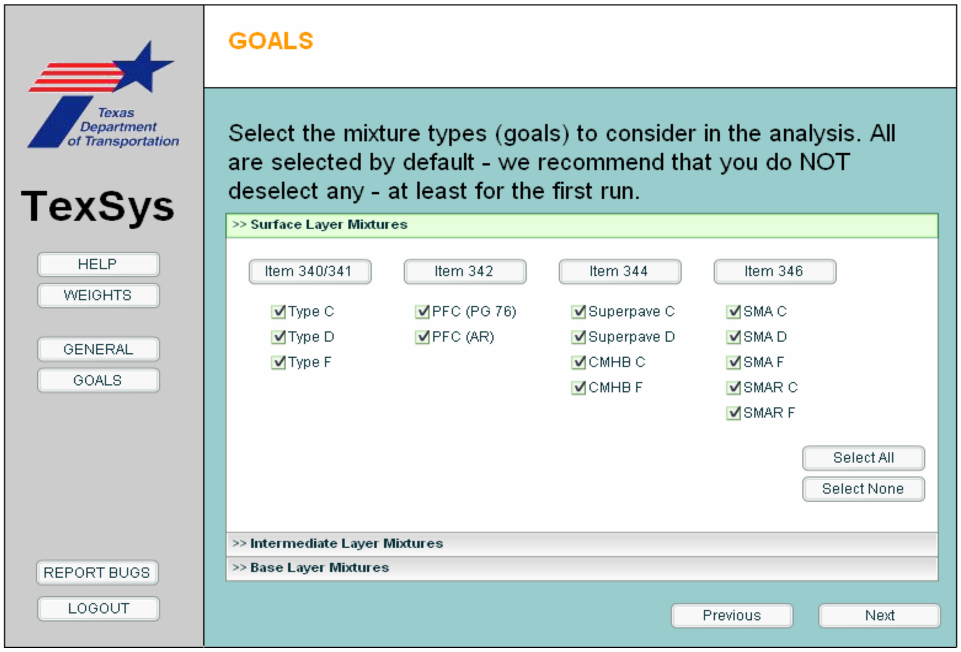

Figure 15. TexSys Mixture Types Selection (Goals) Form

Traffic

On the *Traffic* page the user can select design traffic (or road category) to which the mixture will be subjected as well as the posted speed on the road for which the mixture is intended. Asphalt mixtures respond differently to the volume of traffic and traffic speed to which they are subjected. This response is addressed by TexSys when calculating the final solution.

For this example, it is assumed that the new construction is for Interstate Highway (Figure 16) and the traffic volume is more than 30 million ESALs. Since it is major highway, it is assumed that the speed is more than 45 mph.

Functions

This page is split between structural and function aspects impacting mixture selection. The user has the option of promoting rut resistant mixtures over crack resistant mixtures (and vice versa) by indicating the relative importance of one over the other. A number of "high priority" requirements are also listed but these are not selected by default. If the user selects a specific requirement then this selection is considered in the final solution i.e. certain mixtures are weighted more heavily while other are "punished" to satisfy the user selected requirement.

For this example, it was decided to leave everything at default and not to specify any functional requirements (Figure 17).

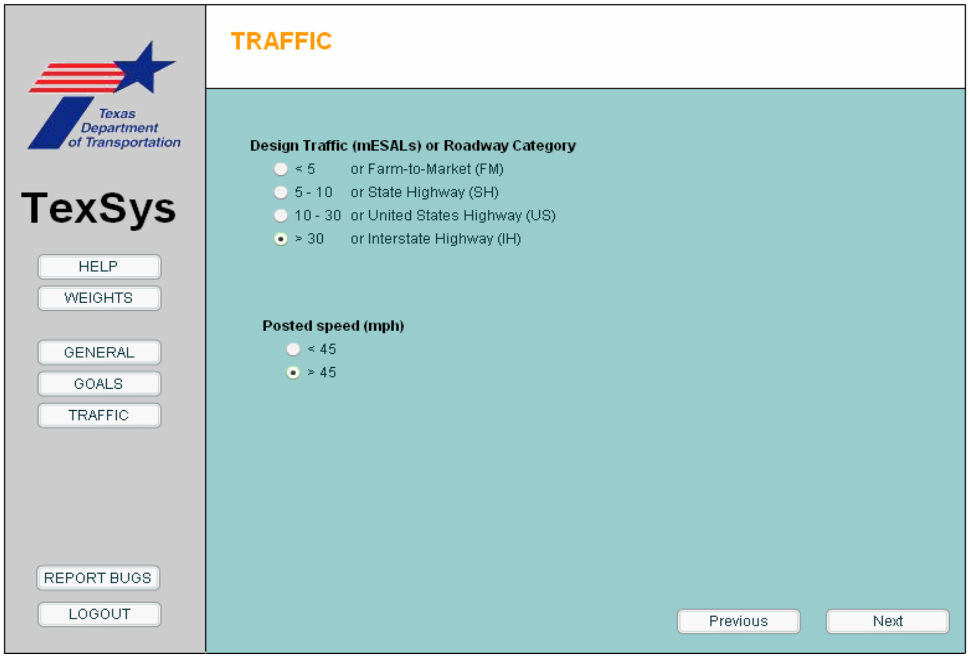

Figure 16. TexSys Traffic Input Requirement Form

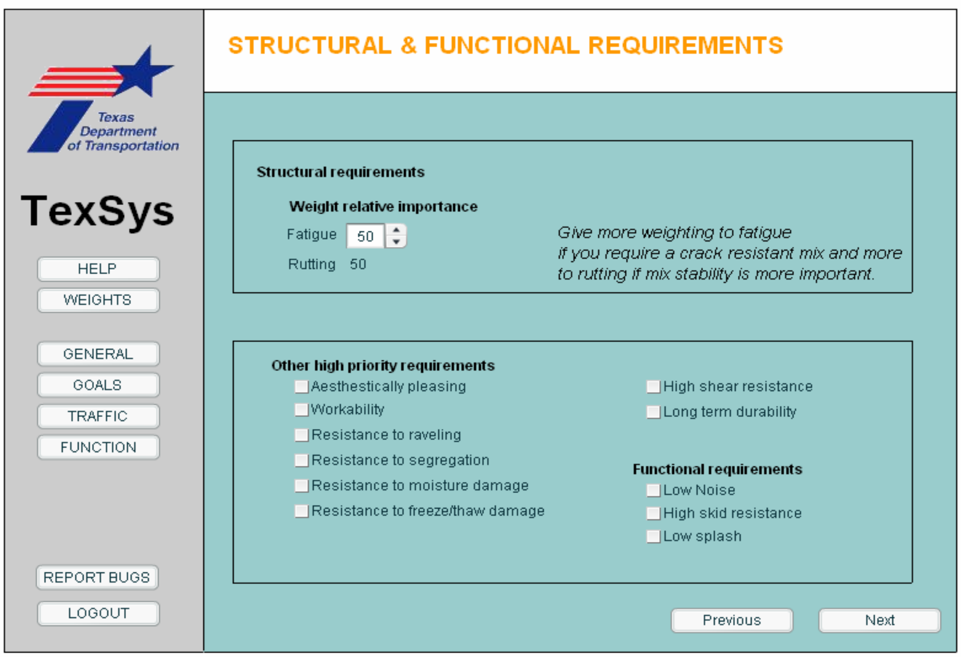

Figure 17. TexSys Structural and Functional Requirements Form

Structure

In the last input page the user can indicate the pavement structural information. This page serves two purposes:

- Based on the structure defined, TexSys calculates whether the asphalt layer is subjected to tensile strains and hence whether fatigue of the layer is an issue to consider in mixture selection.
- Based on the type of layer underlying the asphalt layer, TexSys will adjudicate mixture precedence.

Tensile strain beneath the asphalt layer is calculated using a FORTRAN compiled program based on the ELSYM5 engine♣. Poisson's ratio for all layers is assumed to be 0.35. Layer moduli are recommended based on the user selection for base layers. Moduli values can be changed. The user has the option to ignore the pavement structure in the analysis.

For this example, it was assumed that the underneath structure has four different layers and moduli of layers varies from 75 to 12 ksi (Figure 18).

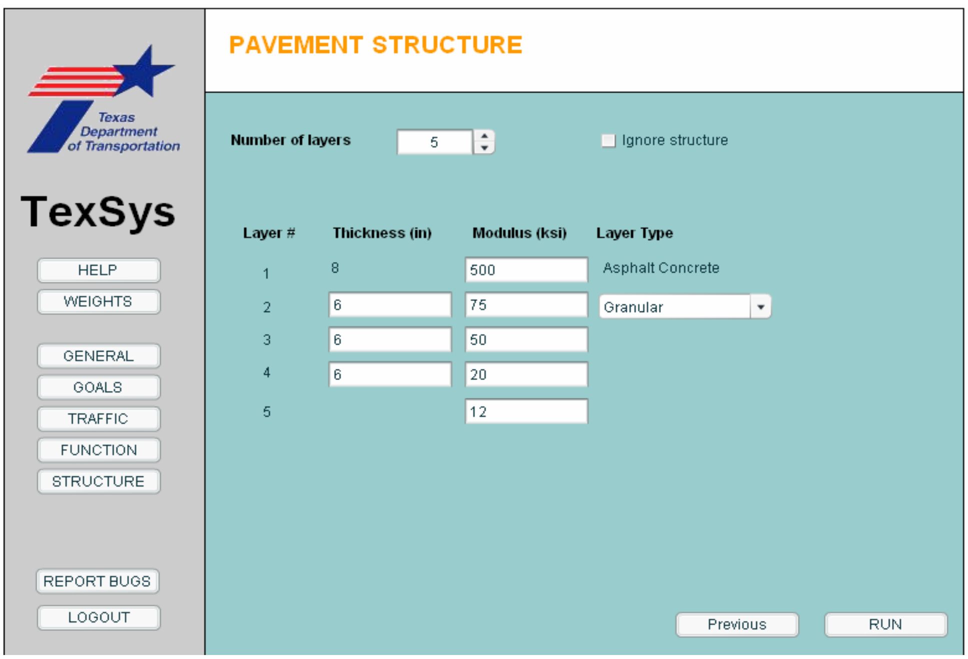

Figure 18. TexSys Pavement Structure Form

♣ This feature cannot be implemented in the web-based application as it currently stands given a major security risk that results. The strain calculation is done by an executable file on the server but in order for the PHP script to run this executable it must provide open access to the server file system – which could potentially allow a hacker open access to the server. For this reason this feature is not implemented.

Solution

Once the user has finalized selections on the various forms presented, the analysis can be done and TexSys applies Equation 5 to determine rankings for the different mixtures in terms of the stated influence factors. After completing the analysis, the user is presented with the final rankings for each of the different mix types, as shown in the *Solution* page (Figure 19). This allows the user to check the ranking as calculated by TexSys and select a surfacing, intermediate and base mixture (if not an overlay) for a thickness recommendation which is shown on the *Final* page (Figure 20). The user has the option of changing selections or changing inputs and recalculating final solutions.

The *Solution* page (Figure 19) suggests that Type C (ITEM 340) is the most suitable surface layer mix with a ranking value of 0.60 closely followed by PFC PG 76 with a ranking value of 0.59. The most unsuitable mix for the surface layer is Type F (ITEM 340) with a ranking value of 0.39. In terms of Intermediate layer, the most suitable mix is again Type C with a ranking value of 0.57 while Type A is the most suitable base mix with a ranking value of 0.49. Although Type C is the most suitable mix for surface layer, it was decided to select PFC PG 76 mix type to minimize the splash which was not specified in functional form.

The *Final* page (Figure 20) shows the recommended design thickness of each mix layer. The results of the analysis suggest that 0.75 in. of the surface layer should be with PFC PG 76 mix type. The proposed intermediate layer of 2 in. should be placed with Type C mix while the 5.25 in. of base layer should be placed with Type A mix.

The rankings shown are relative but are indicative of the intuitive appropriateness of the mixture for the job given the uniformity applied throughout the process. A mixture with a ranking closer to 1 will indicate that this mixture rated high for each of the influence factors considered, while those closer to 0 ranked poorly throughout. A final recommendation regarding layer thicknesses is made if the user selects a surface, intermediate and base mixture (if not an overlay) as shown in Figure 15. The layer thickness limits shown in Table 2 are applied, dividing the design thickness across the surface, intermediate and base layers if necessary.

TexSys: Example 2: Input and Solution

To further explain the expert system, another example is provided. The second example is for the El Paso County within El Paso District. It is an overlay construction of 2 in. for US 54 with a traffic volume of 10-30 million ESALs and more than 5,000 tons is expected to be placed. It is assumed that the underneath structure is in good condition; therefore, can be ignored. In addition, no specific functional requirements are specified.

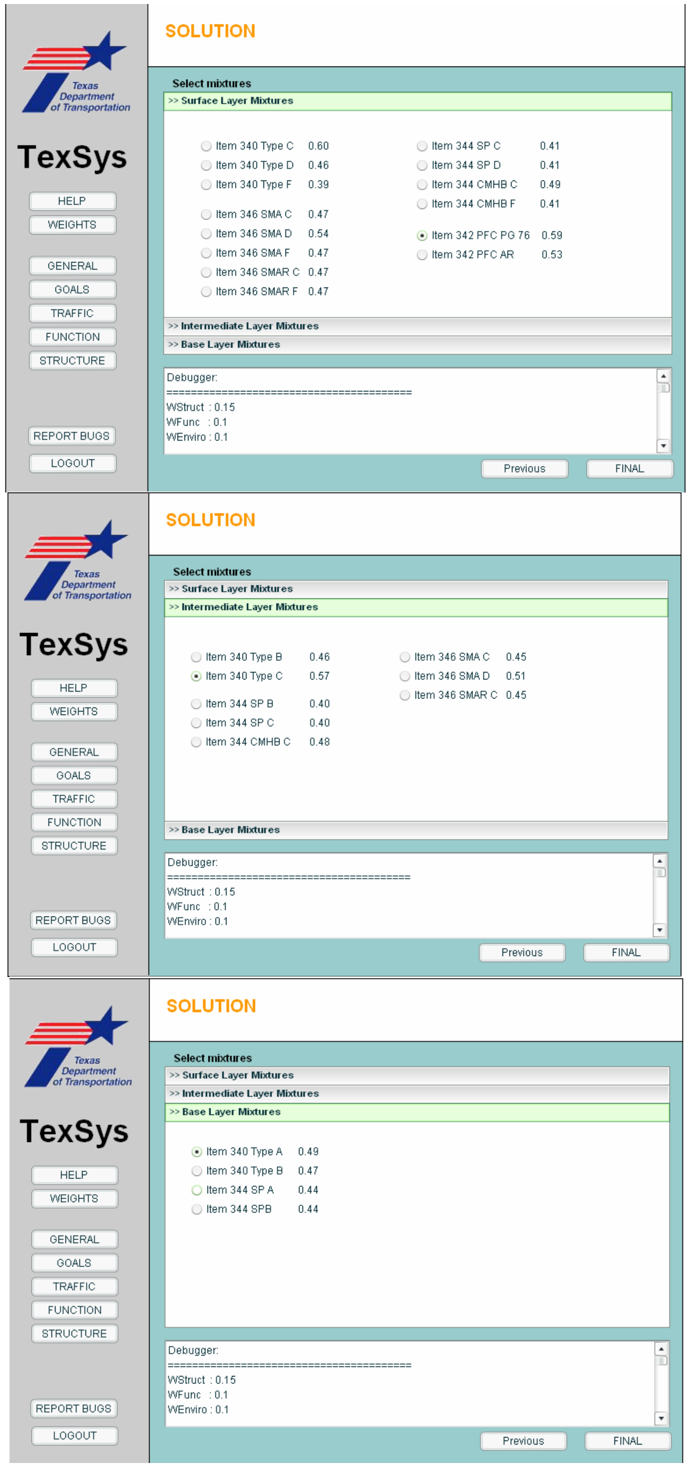

Figure 19. TexSys Solution Page

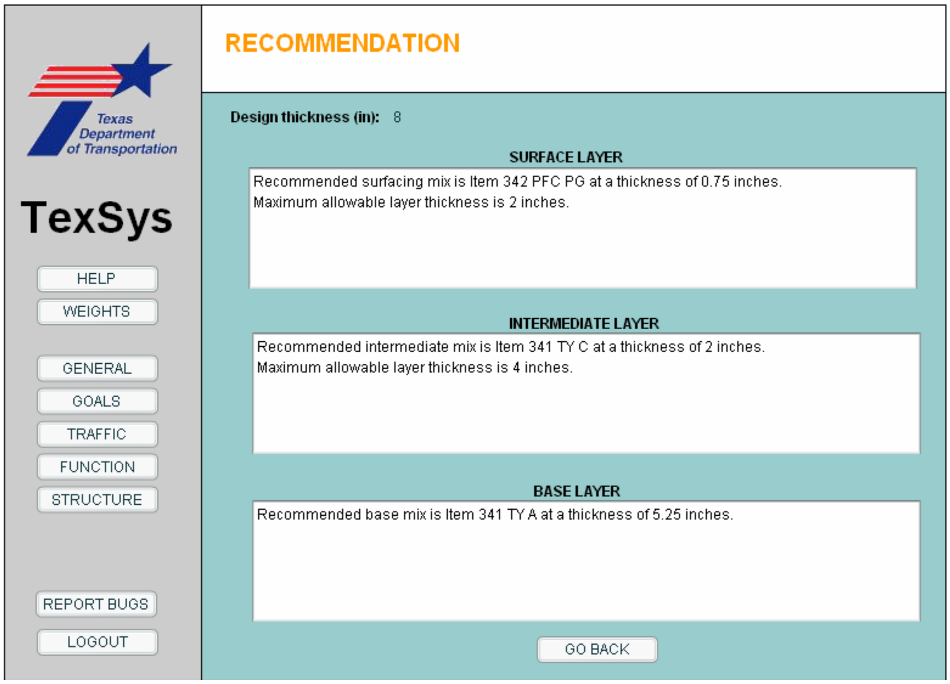

Figure 20. TexSys Layer Thickness Recommendation

The input forms for the Example 2 are included in Figures 21 through 24 and the solution is included in Figures 25 and 26 . Since the construction is for an overlay, the intermediate and base layer options are suppressed, as shown in Figure 22. Again for this example, it was decided to select all of the available surface mixtures. The solutions page (Figure 25) suggests that the most suitable mix is PFC AR with a ranking value of 0.61 followed by Type D with a ranking value of 0.56. As a user, it was decided that Type D is the preferable choice of mix. Therefore, the recommendation shown in Figure 26 suggests that 2 in. of Type D can be placed as an overlay.

These two examples explain the expert system (TexSys) and suggest that the user has the flexibility of selecting appropriate mixes and can be used for the selection of mixes after the design thickness has been identified. The developed software and user information is available on the internet at the following address: http://pavements.ce.utexas.edu/TexSys.

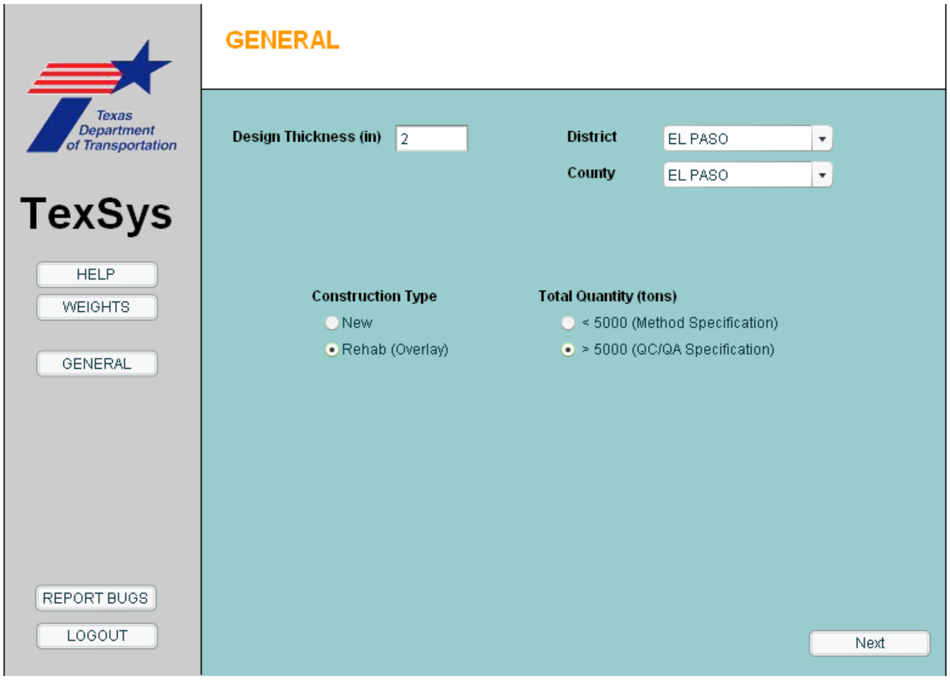

Figure 21. TexSys General Form for El Paso District Example

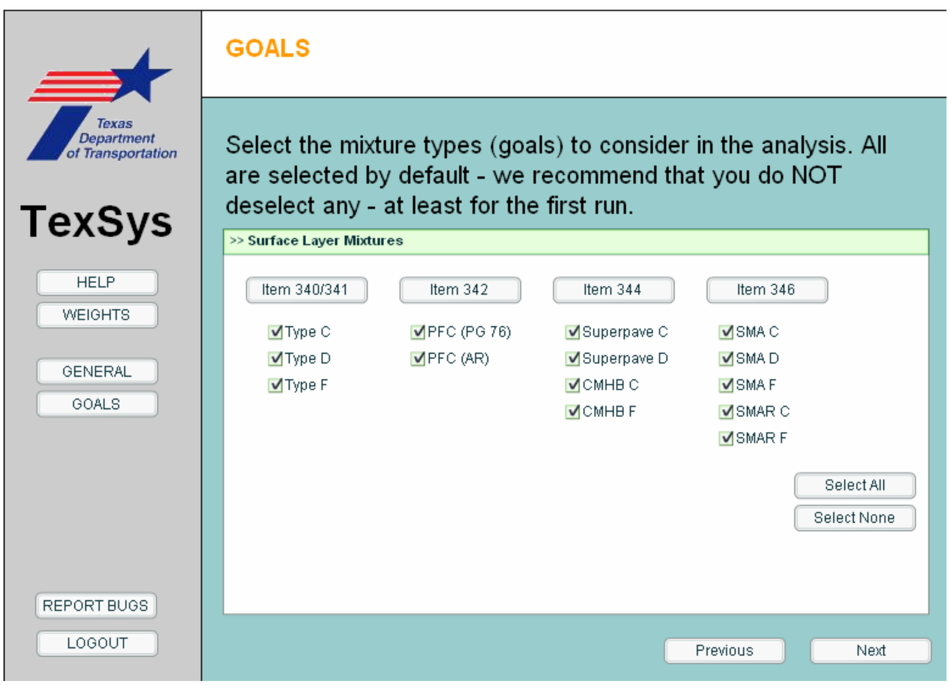

Figure 22. TexSys Mixture Types Selection Form for El Paso District Example

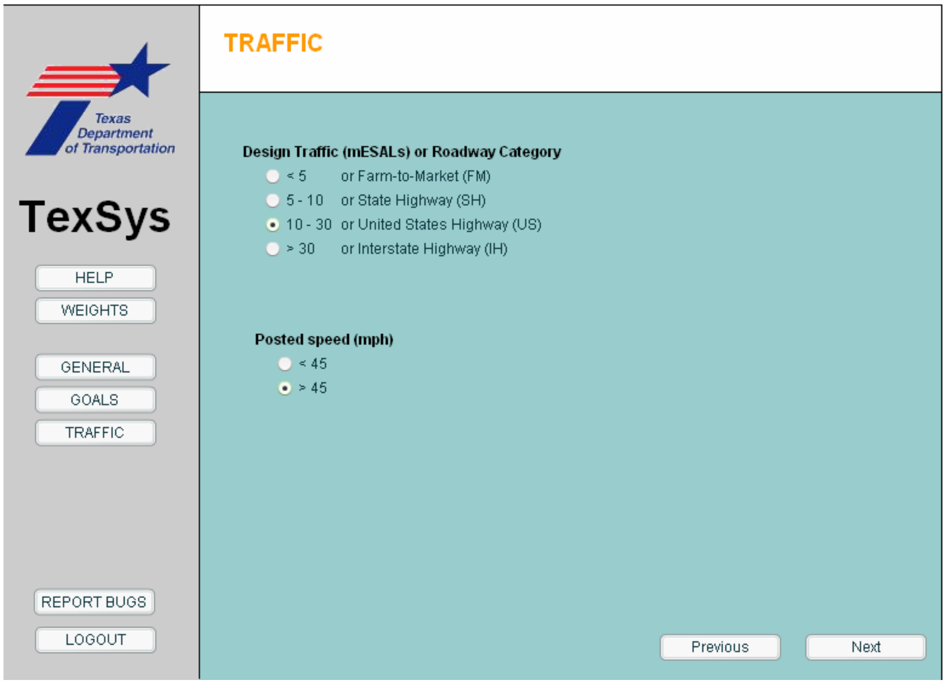

Figure 23. TexSys Traffic Input Requirement Form for El Paso District Example

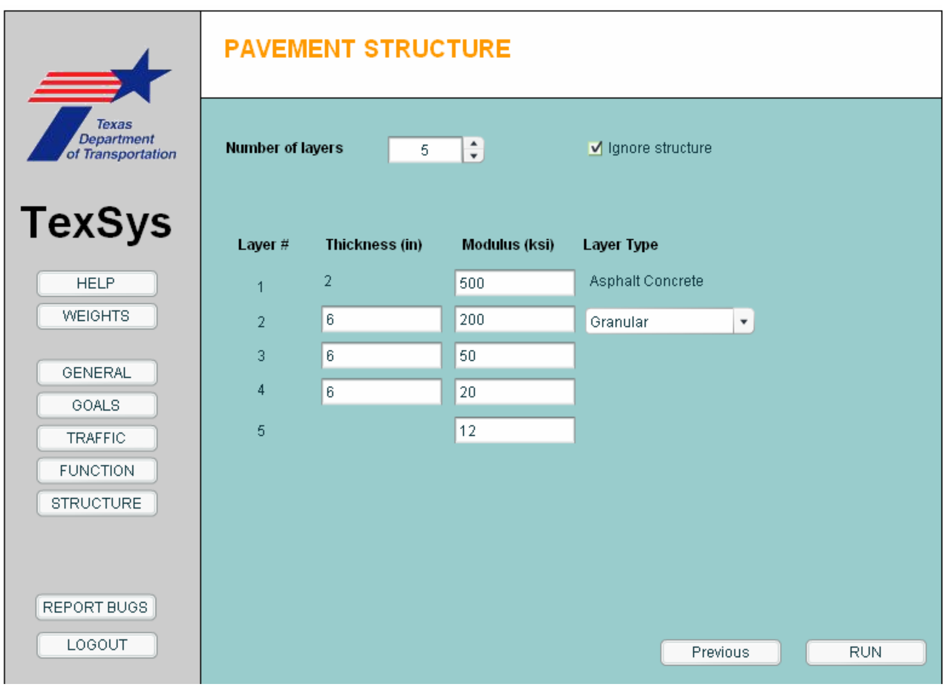

Figure 24. TexSys Pavement Structure Form for El Paso District Example

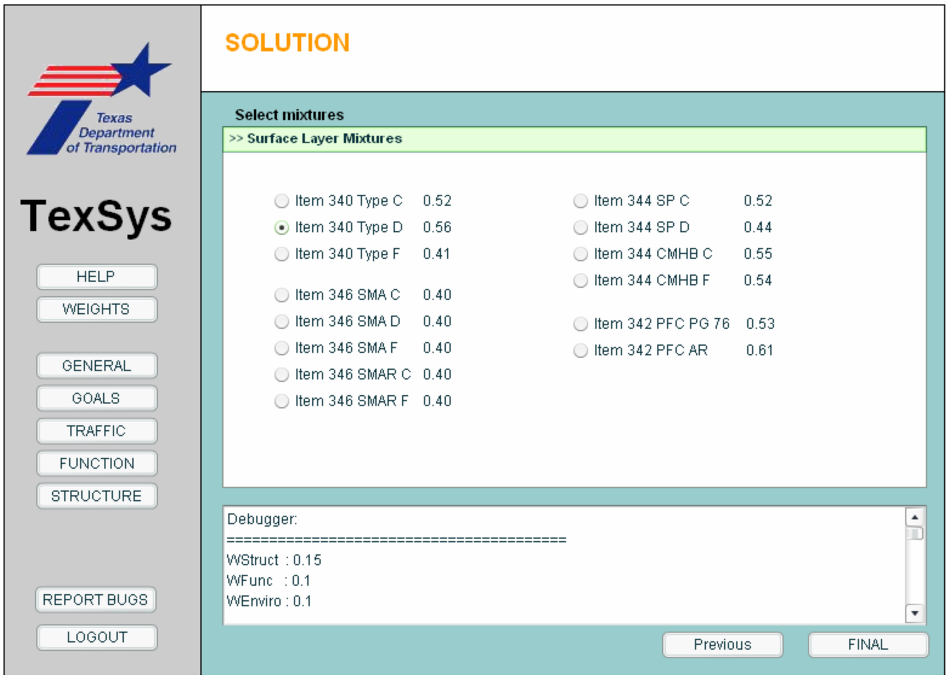

Figure 25. TexSys Solution Page for El Paso District Example

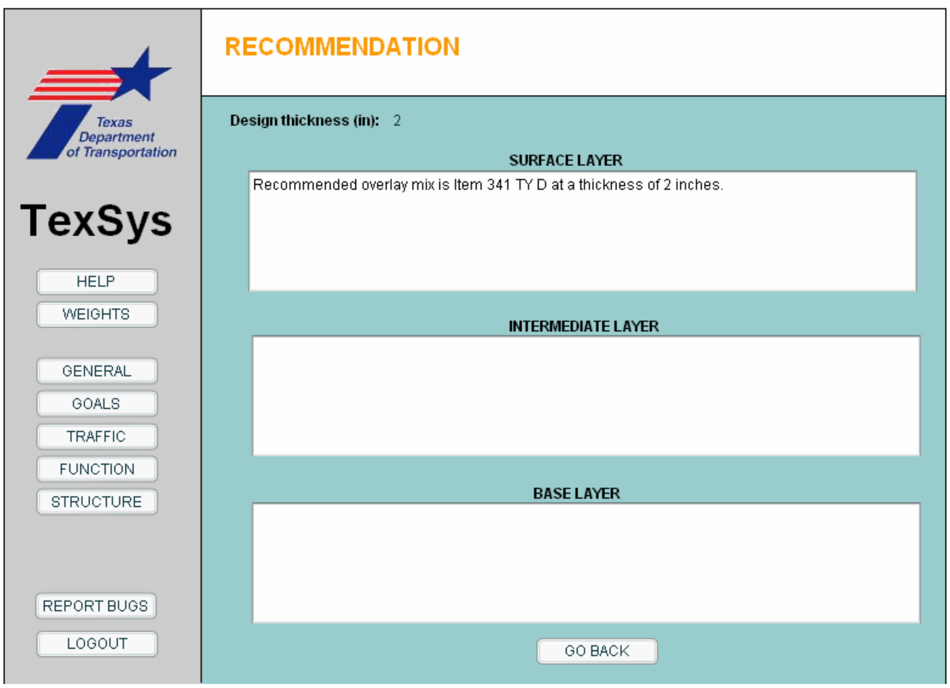

Figure 26. TexSys Layer Thickness Recommendation for El Paso District Example.