Capital Area Pavement Engineers Council

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Phase 3 Report - Pavement Design Manual

FINAL

Prepared for:
CAPEC Member Agencies
City of Austin
Travis County
Williamson County
City of Pflugerville

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Industry representatives, professional associations, and other interested engineers provided input at the monthly CAPEC meetings and scheduled workshops.

Limitations

The recommended pavement design software and procedures documented in this report represent the evolution of pavement design in Central Texas at this time. It must be understood that since the software products are tools for pavement design analyses and the geotechnical procedures are tools for estimating the climatic related effects on specific subgrade soils, HVJ Associates, Inc. and the CAPEC member agencies make no warranty, express or implied. Each pavement design must be prepared by a licensed professional engineer in the State of Texas specializing in pavement and geotechnical engineering for site specific conditions.

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1 General

The Capital Area Pavement Engineers Council (CAPEC) formed by local governments funded the development of a unified approach to pavement design in central Texas. Based on historical discussions at monthly CAPEC meetings over the last few years, the critical issues to each of the members were documented as follows:

- Variety of pavement design procedures used in Central Texas area
- Common swelling clay soils problems need to be addressed
- Increase in traffic loading and stop/go patterns contribute to pavement failures
- Current technology needs to be implemented to minimize pavement failures
- Increase in initial construction costs may be offset by lower maintenance cost/longer pavement life
- Numerous material mix designs are used throughout Central Texas areas
- Design of low volume roads, such as residential streets, have different issues than highways
- Utility trenches and utilities in the pavement
- Multiple different subgrade characteristics
- Required construction sequencing

The purpose and goal of this pavement design approach are to update the pavement design program, consider entire pavement life cycle, update pavement design criteria, and consider analysis of existing expansive soils' problems in the area. The design programs are based on modern design methodologies, mechanistic components, and alternative design considerations. The pavement life cycle is addressed with a life cycle cost analysis that includes initial construction cost, maintenance costs, and potentially user costs. The design criteria takes into account the development patterns of expanding into areas of poor subgrade support and addresses truck traffic, including consideration of construction traffic. Multiple alternatives and combination of strategies shall be considered to address expansive soils.

Pavement designs that are appropriate for both traffic and soil conditions result in pavements that are maintainable over the entire useful life of the pavement structure. This is achieved with proper modification of subgrade soils as needed to meet the required performance criteria. The designer is responsible for providing a geotechnical investigation to design to site specific soil conditions. Any representative pavement sections included herein do not relieve the design engineer from the responsibility of designing a cross section that is appropriate for the site specific soil conditions to meet the required design life.

The following sections discuss the resulting design methodology recommended for implementation by member agencies.

1.1 Balanced Pavement Design Approach

The design methodology utilizes a "Top Down" design based on traffic loading and a "Bottom Up" design to obtain an improved foundation, as depicted in the figures below.

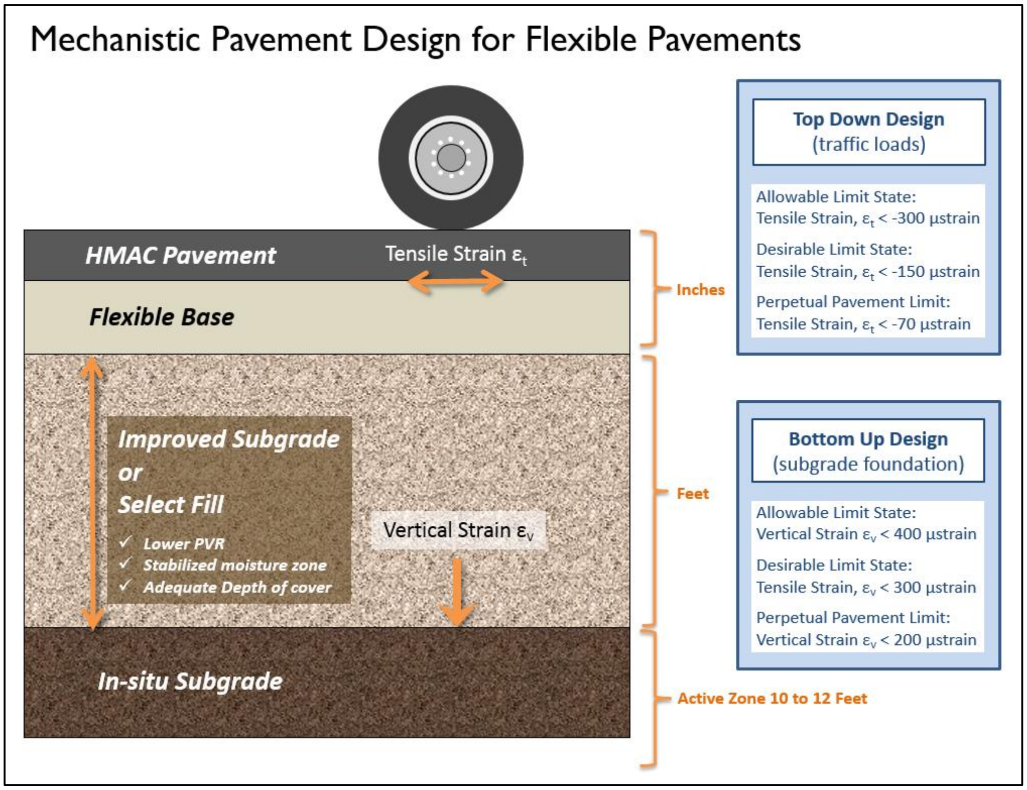

Figure 1.1 Top Down and Bottom Up Pavement Design – Flexible Pavement

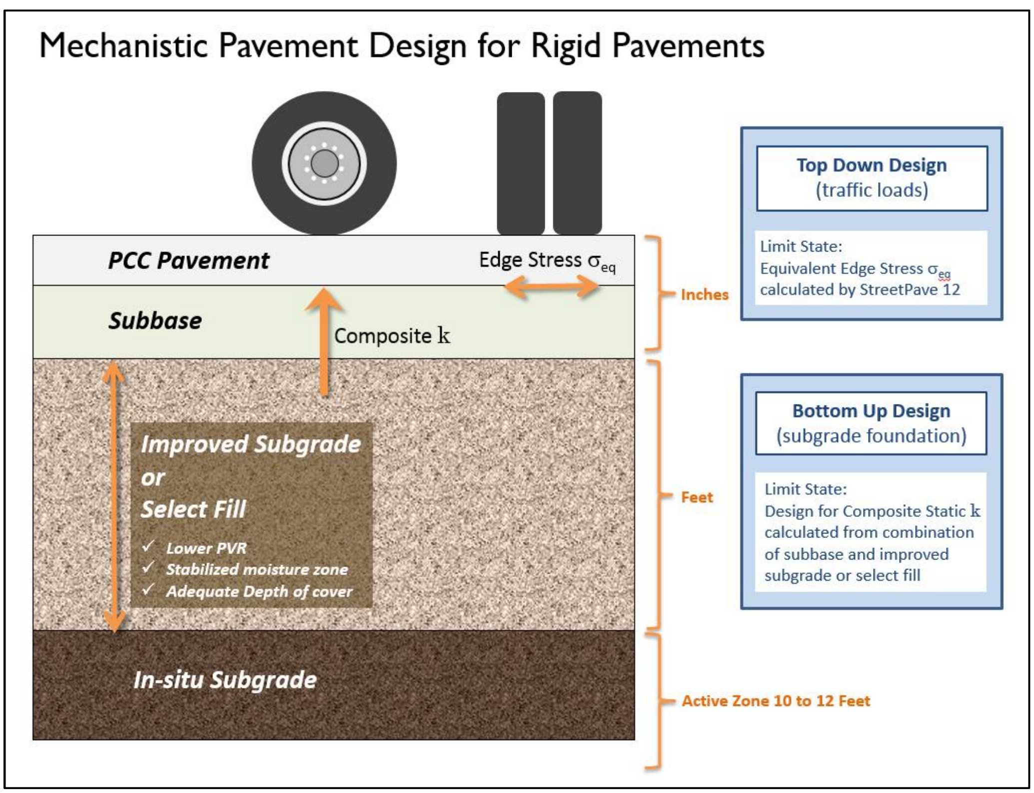

Figure 1.2 Top Down and Bottom Up Pavement Design – Rigid Pavement

The two-step design process includes an initial pavement thickness design based on traffic loads and a secondary subgrade improvement design to address environmental loads. The thickness design of both flexible and rigid pavements for traffic loading (Top Down Design), including suggested input parameters needed for the procedure, are defined herein, as are the subgrade design procedure (Bottom Up Design).

The design methodology includes a balanced pavement design to provide for longer pavement performance life. The balanced pavement designs require that the engineer:

- Design for Crack Resistance
  - Consider Environmental Stresses (Shrink/Swell) in High PI Soils
  - Consider Fatigue Cracking Criteria (Thicker Surface Layers)
  - Consider Thinner Base Layers to Offset Cost
- Develop Subgrade Improvement Strategies
  - Consider Subbase Layers
  - Recommend Combination Strategies

Thick base layers over 14" may not be a cost effective treatment to reduce stresses/strains in the pavement. The stresses at the bottom of the base layer do not justify the thick layer of very stiff base material. Improved subgrade or select fill is a better investment and a more effective layering of materials of progressively reducing stiffness in the pavement design. It is important to balance constructability, consistency and level of complexity and use an optimization process to find the most cost effective solution.

The general steps are illustrated in the design flow chart in Figure 1.3.

1.1.1 Top Down Pavement Design - General

The Top Down structural design is to be performed using modern, evolving, well-supported applications and is discussed in more detail in Section 2.

1.1.1.1 Flexible Pavement Design

The required flexible pavement design procedure is the Texas Department of Transportation's (TxDOT's) FPS21, developed with TxDOT by Texas Transportation Institute (TTI). It is available for free download here: http://pavementdesign.tamu.edu/fps21.htm. As per the FPS 21 User's Manual (Ref 1):

> "The Flexible Pavement System (FPS) is a mechanistic-empirically (M-E) based design software routinely used by the Texas Department of Transportation (TxDOT) for: (1) pavement structural (thickness) design, (2) structural overlay design, (3) stress-strain response analysis, and (4) pavement life prediction (rutting and cracking).
>
> The FPS design approach is based on a linear-elastic analysis system, and the key material inputs are the backcalculated modulus values of the pavement layers. For in place materials, these are obtained from testing with the Falling Weight Deflectometer and

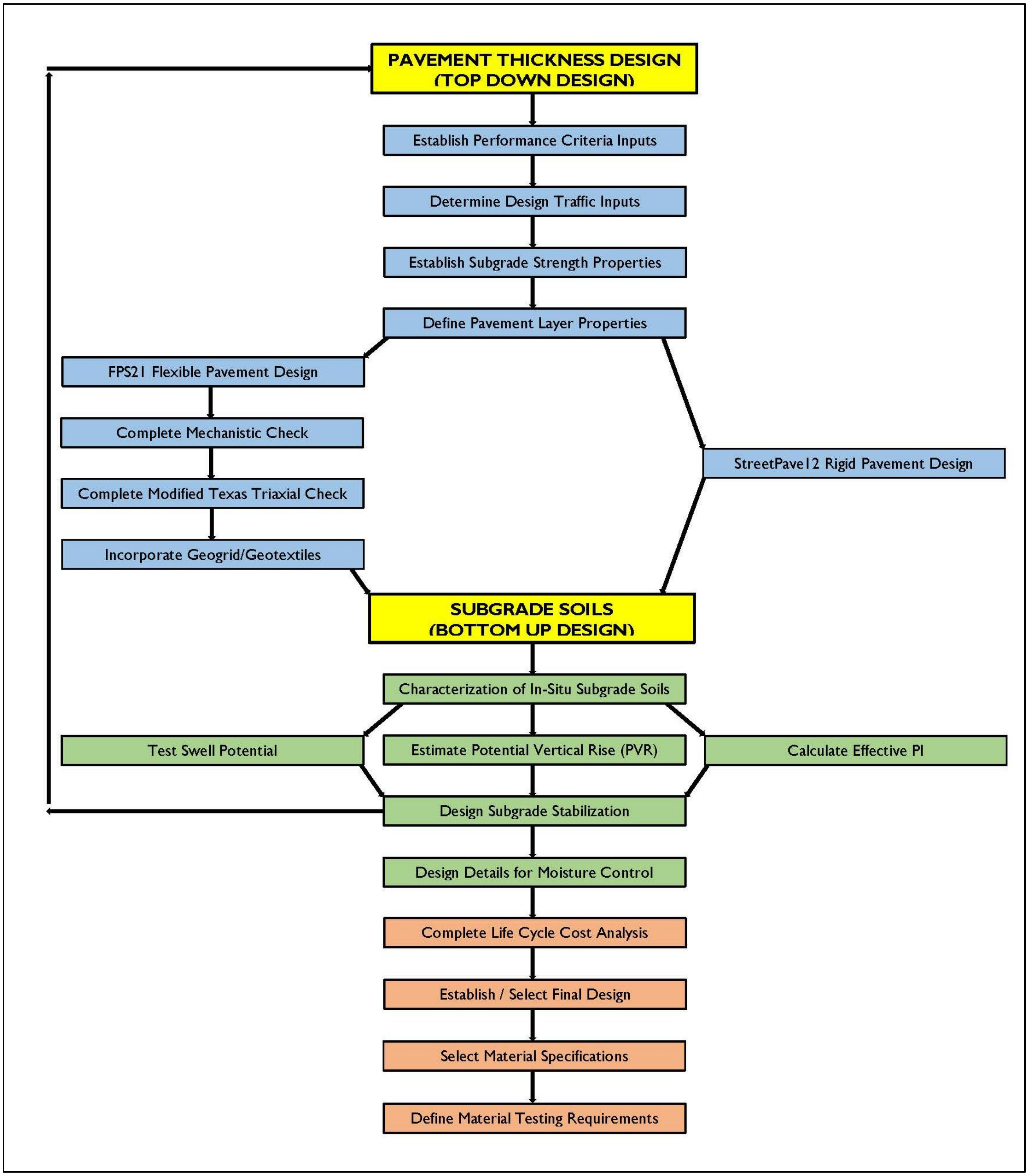

Figure 1.3 Flow Chart for Pavement Design Process

processing the data with backcalculation software such as MODULUS [6.1]. For newly placed materials, realistic average moduli values for the main structural layers in typical Texas pavements are supplied based on user experience, with recommended values also available in TxDOT's online pavement design guide. The FPS design process is comprised of the following two steps: (1) generate a trial pavement structure with proposed FPS design thicknesses, and (2) check this design with additional analysis routines, which include mechanistic performance prediction. The FPS system has an embedded design equation relating the computed surface curvature index (difference of the W1 and W2 deflections) of the pavement to the loss in serviceability (as defined in the original AASHO Road Test). As described below the design checks are principally based on either mechanistic design concepts, which computed fatigue life and subgrade rutting potential, or the Modified Texas Triaxial criteria, which evaluates the impact of the anticipated heaviest load on the proposed pavement structure."

The FPS21 design software and associated design input values were established based on collaboration with CAPEC member agencies and are discussed in detail in Section 3.

1.1.1.2 Rigid Pavement Design

The required rigid pavement design procedure is the American Concrete Pavement Association's (ACPA's) StreetPave12, developed by ACPA. StreetPave12 is available as a free download and may be used without a license for up-to 30 days; the 30 day trial copy of StreetPave12 may be obtained from http://www.acpa.org/streetpave/. A license will need to be purchased after the 30-day trial period with a serial number to register and activate the StreetPave12 software. The software may be purchased through the ACPA website or through the Cement Council of Texas (Amy Swift, aswift@cementx.org, 817-540-4437), who can facilitate a discount purchase as a member. The serial number is valid for a single user on up to two computers, and includes updates/upgrades.

StreetPave12 is based on the 1960's Portland Cement Association method and is tailored for streets and roads (not highways or interstates) with the failure models being cracking and faulting. StreetPave12 looks at the stresses at the edge of the slab generated by the traffic loads. The equation uses equivalent moment, which is different for a single, tandem or tridem axles (with and without edge support), which is dependent on concrete modulus, Poisson's ratio, thickness, and pavement support k-value. Included in the equivalent edge stress calculations are adjustment factors for the effect of axle loads and contact area, adjustments for slabs with no concrete shoulder, adjustment for the effect of truck wheel placement at the slab edge, and adjustment to account for an approximate 23.5% increase in concrete strength with age after the 28th day and reduction of one coefficient of variation to account for materials variability.

StreetPave12 limits the stress ratio to achieve a desired number of design repetitions. The program increases the thickness of the slab to bring the stress ratio low enough to achieve a certain number of traffic repetitions as illustrated in Figure 1.4 and calculated as follows:

$$Stress\ Ratio\ (SR) = \frac{Stress}{Concrete\ Strength}$$

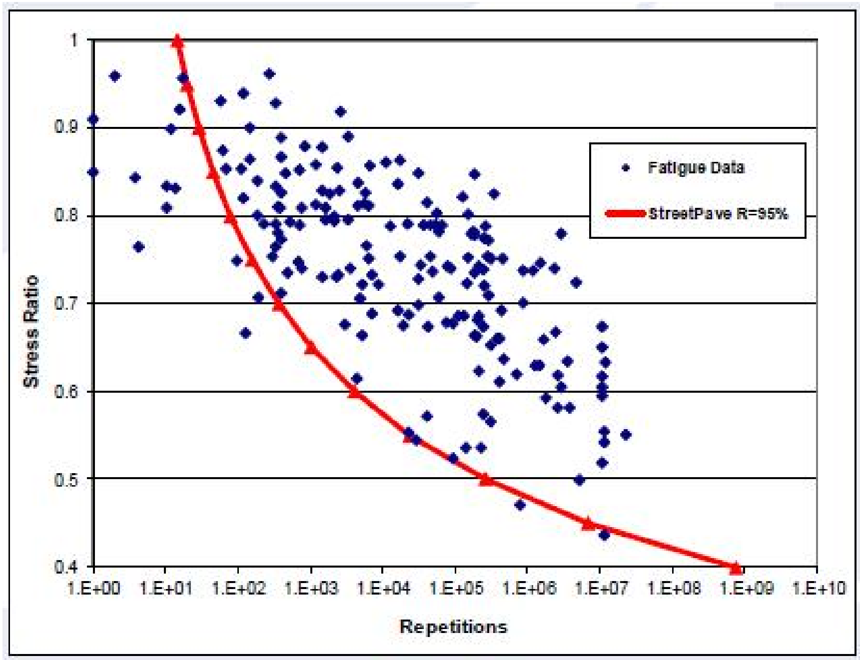

Figure 1.4 Stress Ratio Consideration in StreetPave 12

Figure courtesy of 2014 TxDOT/CCT Concrete Conference, September 30, 2014, Robert Rodden, P.E. (Ref 35)

StreetPave12 design software and associated design input values are established based on collaboration with CAPEC member agencies and are discussed in detail in Section 4.

1.1.2 Bottom Up Pavement Design - General

The bottom up pavement design is based on in-situ soils investigation, laboratory testing and analyses and is discussed in more detail in Section 5. The bottom up design is intended to primarily address shrink/swell potential resulting from basic soil characteristics and environmental changes (primarily moisture content) by designing a reduction in potential vertical rise (PVR) to acceptable limits.

Subgrade performance criteria required for the bottom up design, based on general street classification, are as follows:

- Provide an adequate depth of cover or modification of subgrade layers to limit the potential vertical rise, considering a 15 foot depth, to the following criteria:
    - Arterial / Collector PVR ≤ 2.0”
    - Local / Residential PVR ≤ 3.0”

1.2 Design Life and Performance Expectations

Level of service (LOS) or street condition is a function of numerous factors including, but not limited to: initial design, construction quality, preventive maintenance, repairs, agency budgets, traffic, weather, public expectation, and safety. To this end, the pavement design approach includes performance criteria and life cycle costs, in addition to pavement thickness/subgrade design (top down and bottom up designs), to assist in final pavement design selection.

1.2.1 Performance Criteria

The design life and performance criteria for r4ide quality and distresses detailed in the following tables must be met.

Table 1.1 - Design Life/Failure Criteria

Pavement Type	**Flexible**	**Rigid**
Design Life	20 years: 20 yr min to first overlay 10 yr min between overlays	30 years
Failure Criteria	Fatigue cracking: maximum tensile strain at bottom of all HMA layers 70 μ-strain	Faulting: If faulting criteria is not met, StreetPave will recommend dowel bars
	Rutting: maximum compressive strain at top of subgrade 200 μ-strain	Cracking: 15% of slabs for Arterials and Collectors 25% of slabs for Locals

Table 1.2 Minimum cracking and loss of ride quality (serviceability)

Criteria	**Acceptance/Warranty Period**	
	Flexible	**Rigid**
Cracking	Minimal cracking; less than 10 LF/LM	
Other Criteria	No noticeable roughness from new condition measured during construction with 10-ft straightedge test*	No noticeable roughness from new condition measured during construction with 10-ft straightedge test**

** Maximum 1/8" per foot parallel to centerline and 1/4" perpendicular to centerline (COA Specification Item 340)*

*** Maximum 1/8" per foot (COA Specification Item 360)*

The initial present serviceability index (PSI_i) and the terminal present serviceability index (PSI_t), as defined in the AASHO Road Test are key inputs to the pavement design software. The difference between these two values represents the service life of the pavement from the time of initial acceptance of the construction until the time when major structural rehabilitation or reconstruction is needed.

Table 1.3 Serviceability Indices and Associated Ride Quality

Street Classification (see Table 1.3)	PSI_i Initial Serviceability Index	PSI_t Terminal Serviceability Index
Urban Arterial High Traffic	4.2 - 4.5	3.0
Urban Arterial Low Traffic	4.2 – 4.5	3.0
Rural Arterial	4.2 – 4.5	3.0
Urban Collector High Traffic	4.2 – 4.5	3.0
Urban Collector Low Traffic	4.0 - 4.2	2.5
Rural Collector	4.0 - 4.2	2.5
Urban Local	4.0 - 4.2	2.0
Rural Local	4.0 - 4.2	2.0

Because CAPEC represents both cities and counties, street classifications considered should be general in nature but able to be further subdivided based on the governmental agency's street network system. The general guidelines for the classifications used herein are shown in the following table. Further clarifications may be provided by the governing agency.

Table 1.2 General Street Classifications for CAPEC Member Agencies

General Description	CAPEC Member Agency			
	City of Austin	Travis County	City of Pflugerville	Williamson County
Urban Arterial High Traffic	Major Arterial	Freeways, expressways and highways / Major Arterial	Freeways/ Expressways	Major Thoroughfare
Urban Arterial Low Traffic	Minor Arterial	Minor Arterial	Arterial	Urban Arterial
Rural Arterial	n/a	n/a	n/a	Rural Arterial
Urban Collector High Traffic	Primary/ Industrial Collector	Collector	Collector	Urban Collector
Urban Collector Low Traffic	Residential/ Neighborhood Collector	n/a	n/a	Urban Collector
Rural Collector	n/a	n/a	n/a	Rural Collector

General Description	CAPEC Member Agency			
	City of Austin	Travis County	City of Pflugerville	Williamson County
Urban Local	Local	Local	Local	Urban Local
Rural Local	n/a	n/a	n/a	Rural Local

1.2.2 Other Performance Related Pavement Design Considerations

Other design considerations include, but are not limited to: special attention to utility construction; lateral restraint (i.e. curb and gutter, ribbon curbs for ditch drainage, vertical barriers, etc.); maximum slopes for embankment/ditches; paved shoulders; and others. These design considerations will help address moisture control in the pavement subgrade and are discussed in more detail in Section 5.1.4.

1.3 Life Cycle Cost Analyses (LCCA)

All pavement designs must be submitted with a Life Cycle Cost Analysis (LCCA) as defined in section 6. The LCCA period shall be a minimum of 40 years to adequately compare the various alternatives with significantly different design lives and maintenance profiles.

FHWA report FHWA-SA-98-079, Life-Cycle Cost Analysis in Pavement Design defines life-cycle cost analysis (LCCA) (Ref 3) as:

> "…an analysis technique that builds on the well-founded principles of economic analysis to evaluate the over-all-long-term economic efficiency between competing alternative investment options. It does not address equity issues. It incorporates initial and discounted future agency, user, and other relevant costs over the life of alternative investments. It attempts to identify the best value (the lowest long-term cost that satisfies the performance objective being sought) for investment expenditures."

LCCA is typically used as a decision support tool to select pavement type, determine structure and mix type (for flexible pavements), construction methods, as well as maintenance and rehabilitation strategy. LCCA includes first cost, long term costs as well as asset renewal. The initial construction cost (first cost) is based on developer contribution and/or agency (re)construction. Long term costs include routine repairs, preventative maintenance, rehabilitation, and salvage value. Each agency will need to provide agency specific assistance and guidance on maintenance unit costs and typical timing (i.e. agency specific maintenance profile) Asset renewal is reconstruction that starts the cycle again. LCCA is discussed in more detail in Section 6.

1.4 Pavement Design Report

Pavement design analyses conducted as per the criteria and procedures herein shall be documented in an engineering report prepared by a Licensed Professional Engineer. In addition to the basis of the pavement design, the engineering report shall contain the following:

- Geotechnical boring logs for borings minimum 15-ft deep, or 1 foot into rock, spaced at 500 ft up to a maximum of 1000 ft for homogeneous conditions. Shorter spacing shall be used for nonhomogeneous conditions. Boring spacing shall be justified by geotechnical engineer.

- Results of sampled and tested subgrade soils for the following:
    - Atterberg Limits (Liquid and Plastic Limits) (ASTM D4318),
    - Percent Passing No. 200 Sieve (ASTM D1140)
    - In-situ moisture content,
    - Standard Proctor (ASTM D698) for maximum density,
    - pH and sulfate content,
    - Unconfined Compressive Strength (ASTM D2166),
    - Modified Texas Triaxial Classification (Tex-117-E "Triaxial Compression for Disturbed Soils and Base Materials" Ref. 5),
    - Subgrade strength tests,
    - Proposed PVR analysis methodology (e.g., Free Swell Test ASTM D4546 or Tex 124-E),
    - Proposed treatment strategy, presence of sulfates and impact to design.
- Basis of design traffic including the Average Daily Traffic (ADT) before and after the proposed development, as well as estimates of construction traffic and truck percentage. Identify heavy loads that are expected and how the design traffic accommodates these loads.
- Life cycle cost analysis detail and results for the pavement design alternatives considered. The basis of life cycle strategies must be documented as well. Each agency will need to define the requirements for roadway acceptance for maintenance to be reflected in the life cycle cost analysis documentation.
- Recommended pavement structure and basis of recommendation, including considerations in addition to the life cycle cost analysis, such as historical performance of previous designs and construction, constructability, sustainability, etc.

1.5 Construction Procedures, Specifications and Materials Testing

Quality control is a key factor in the success of the pavement performance. As such, it is critical to adequately define the required specifications and testing to be followed during construction as well as thorough inspections at critical points during construction. Material specifications and testing requirements are currently being updated by the various agencies and need to be agency specific. The CAPEC Phase 1 report summarized TxDOT and COA specifications which are related to pavement construction quality and therefore good long term performance. All CAPEC reports are available on the CAPEC website at www.capectx.org.

All materials shall be sampled and tested by an Independent Testing Laboratory in accordance with the construction documents approved by the relevant agency. Certified copies of these test results shall be furnished to the relevant agency. Any material which does not meet the minimum required test specifications shall be removed and re-compacted or replaced unless alternative remedial action is approved in writing from the owner agency.

The following material design properties are critical inputs to the pavement design procedure and to pavement performance, however are not historically included in the pavement construction material specifications and required testing:

1) Hot Mix Asphalt Concrete (HMAC)
   a) Resilient Modulus of HMAC layers
   b) Resilient Modulus of Base/Subbase layers
   c) Resilient Modulus of Subgrade
2) Portland Cement Concrete (PCC)
   a) Flexural Strength of PCC
   b) Resilient Modulus of PCC
   c) K-value of subbase layers
   d) Resilient Modulus of Subgrade

It is recommended that material specifications consider these tests either by required testing during construction or by establishing relationships at the time of mix design preparation to allow confirmation during construction that the basis of design is being met.

2 Top Down Design

The structural design of a pavement system requires as primary design parameters, traffic loading and subgrade support strength. These two parameters are discussed below.

2.1 Design Traffic

For new roadways or existing roadways being widened for added capacity, traffic data must be developed based on a variety of factors usually depicted with Traffic Impact Analyses (TIA) that predict the type and volume of future traffic; however, rather than peak hourly volumes, it is necessary to have full spectrum 24-hour traffic volumes and percent trucks also required/reported. For rehabilitation or reconstruction of existing roadways, traffic counts may be obtained to collect current traffic data that may then be analyzed to predict future volumes. It is important that the traffic projection consider complete build-out of subdivisions and any future development that will be served by a specific street.

2.1.1 Consideration of Heavy Loads

Adequate consideration must be given to heavy loads such as transit or school busses, fire trucks, solid waste trucks, as well as construction traffic. To appropriately incorporate these loads in design, a review should be made of: existing and/or planned bus routes, fire stations in the vicinity, schedule of solid waste and/or recycling trucks, etc.

The construction of streets basically consists of three phases: rough grading (or removal of existing pavement), fine grading (which includes sub-grade preparation), and construction of the pavement structure. Compaction is also a major element including compaction of basic fill/subgrade, stabilized subgrade, aggregate base, and hot mix asphalt. A rough calculation based on typical types of equipment required for street construction is summarized in the following table.

Table 2.1 Typical Roadway Construction Equipment for Consideration

Construction Activity	Example Equipment	Assumed Weight, lbs.	Calculated Load Equivalency Factor	Assumed Number of Operations per Day	Additional ESALs per Day of Construction
Excavating existing asphalt pavement	Asphalt Milling Machine	40,550	3.44	10	35
	Road Reclaimer	53,900	10.89	10	109
Rough grading	Motor Grader	58,250	0.95	20	20
	Excavator	22,050	2.23	20	45
	Backhoe	27,110	0.50	20	10
Compacting	Vibratory Steel Drum	15,950	0.12	20	3
	Pneumatic Tired Roller	30,600	0.05	20	2
Paving	Paving Machine	43,000	2.20	20	44
	Dump Truck (For Hot Asphalt)	80,000	4.02	20	81

Construction Activity	Example Equipment	Assumed Weight, lbs.	Calculated Load Equivalency Factor	Assumed Number of Operations per Day	Additional ESALs per Day of Construction
	Concrete Redi-Mix Truck	61,000	6.28	20	126
Miscellaneous	Bulldozer (non-track)	58,250	0.95	10	10
	Rear end/Belly Dump Trucks	80,000	4.02	30	121
	Water Trucks	56,000	5.99	20	120
Total Potential Additional ESALs per Day of Construction:					726

If this mix of construction equipment was involved in the roadway construction for 30 days, the resulting additional ESALs is 21,780. If this mix of construction equipment operated for 90 days, the total added ESALs is 65,340. These are only representative examples, each design site location will have specific conditions, which need to be estimated by the design engineer.

Depending on the mix of construction equipment and the duration of the construction, the additional ESALs can be very critical for pavement design considerations especially local roadways, for which design traffic is typically underestimated. Examples include new subdivisions for which the roadways are first constructed, then expanded as each phase of the subdivision is built out. Homes constructed lot by lot for these new subdivisions as well as new apartment/condo buildings also add structural building construction traffic not considered in the roadway construction traffic in the previous table.

In summary, it is critical to increase traffic projections to account for the addition of construction traffic during the development of the design traffic for the roadway, either as added daily trucks, increased percentage of trucks or added ESALs based on similar calculations to the Table 2.1.

2.1.2 Required Traffic Data

The flexible and rigid pavement design methodologies vary somewhat regarding what is required to calculate design traffic. Required traffic parameters include the following: average annual daily traffic (AADT), number or percentage of truck volume in the ADT, design life, growth rate, directional distribution, and design lane distribution.

These parameters are used to calculate the 18 kip Equivalent Single Axle Wheel Loads (ESALs) in one direction, which is the traffic input for FPS21 flexible pavement design.

Rigid pavement design with StreetPave12 focuses on a traffic spectrum rather than the direct input of ESALs. StreetPave12 has predetermined traffic spectrums and counts; however, custom traffic spectrum should be used based on specific traffic developed for the street being designed.

There are also other types of traffic inputs, such as: axle type and load or total vehicle weight, tire load and tire pressure, which can either be used directly in the design procedure to calculate a truck factor required to calculate ESALs, or to calculate stresses/strains in pavement due to a specific load.

If both flexible and rigid pavement design alternatives are being considered, the design traffic needs to be reviewed to confirm the ESALs considered for designs are equivalent. Since calculated ESALs are one of the outputs in StreetPave12, it becomes an iterative process whereby the AADT and % trucks inputs are changed to obtain the predicted ESALs.

Traffic data may be available from agency planning departments. Site specific justification for design traffic inputs is required. Traffic data for adjacent/similar roadways and/or traffic generators within the site may be considered. Classification counts are the preferred type of traffic count to be obtained to have a breakdown by the thirteen Federal Highway Administration (FHWA) vehicle types. Additionally, transit busses and special vehicles should be added to the standard FHWA vehicle type counts. This additional data may come from external sources such as transit schedules and facility logistics data. Average daily bus counts of transit busses shall be broken down by BRT (bus rapid transit/extra heavy bus types), 40' (standard), and 30' and smaller busses.

2.1.3 Traffic Calculations

The pavement engineer collects basic traffic data and calculates the 18 kip Equivalent Single Axle Wheel Loads (ESALs) required for pavement design. In general, the following information is needed to forecast the cumulative Equivalent Single Axle Wheel Loads (ESALs) input value needed for pavement design:

- Two-Way Average Annual Daily Traffic (AADT)
- Two-Way Vehicle Classification Breakdown/Percentage of Trucks
- Traffic Growth Rate for the Design Period
- ESAL Factors for Each Vehicle Type
- Directional and Design Lane Distribution Factors

There are a few sources for Two-Way AADT volume. The Capital Area Metropolitan Planning Organization (CAMPO, http://www.campotexas.org/plans-programs/traffic-counts/) has links to count data provided by the City of Austin, TxDOT, and other local agencies, if site specific current or forecasted traffic count data is not available for the specific street under design. Additionally, as mentioned previously, StreetPave12 has predetermined traffic spectrums and counts; these predetermined spectrums as designated for "residential", "collector", "minor arterial" and "major arterial" general designated street classifications.

A specific 24-hour traffic count that includes vehicle classification breakdown is preferable as it provides current traffic data and percent trucks for the location in question. However, should the roadway's geometry be changing, e.g. widening to add capacity, or narrowing to add bicycle lanes or parking, these counts will need to be adjusted to a projected traffic level and number of lanes appropriate for the geometry changes. Additionally, if the roadway is a proposed roadway along a new alignment, the anticipated traffic must be estimated for pavement design.

In addition to the truck loads based on traffic counts, other heavy loads such as fire trucks (most likely not included in count data) especially if there is a fire station located along the street being designed, as well as construction traffic (for either nearby construction projects or for a new phased subdivision) should be considered, as previously discussed. Depending on the repetition of these heavy loaded vehicles, they may significantly increase the overall ESALs being considered for design.

Another traffic parameter required is growth rate. Based on input from current CAPEC member agencies, the following growth rates were defined for the CAPEC designated street classifications.

Table 2.2 Recommended Growth Rate

Street Classification	Growth Rate, %
Urban Arterial High Traffic	4.0
Urban Arterial Low Traffic	4.0
Rural Arterial	4.0
Urban Collector High Traffic	4.0
Urban Collector Low Traffic	3.5
Rural Collector	3.5
Urban Local	3.0
Rural Local	3.0

There are two additional factors included in traffic calculations, directional distribution and lane distribution. Directional distribution is typically considered 50% in each direction, unless the street is a one-way street for which the directional distribution factor is 100%. If the traffic data projections conclude a different split, the higher of the two should be used in the traffic calculations. The lane distribution factor is depending on the number of travel lanes included on the road. The recommendations are summarized below.

Table 2.3 Recommended Lane Distribution Factor

Number of Lanes in Each Direction	% Traffic in Design Lane
1	100
2	80 – 100
3	60 – 80
4	50 – 75

2.1.3.1 Additional Traffic Inputs - Flexible Design

Beginning ADT: This input is for the Average Daily Traffic at the beginning of the analysis period. It is expressed as Vehicle per day. This parameter is used to estimate the user delay cost during overlay at the end of each performance period (see Section 6. Life Cycle Cost Analysis).

End ADT: This input is for the Average Daily Traffic at the end of the analysis period which is generally for 20-year period. It is expressed as Vehicle per day.

18 Kip ESAL (1 direction): The 18 Kips Equivalent Single Axle Load is the damage caused by one pass of the vehicle to the pavement structure equivalent to one pass of a standard 18 Kips load. It is expressed in Million and is calculated by using the following equations.

$$ESALs = \sum AADT \times GF \times 365 \text{ days/year} \times \% \text{ truck} \times TF \times DDF \times LDF$$

Where,
AADT=Average Annual Daily Traffic
TF= Truck factor
DDF=Directional Distribution Factor
LDF=Lane Distribution Factor

$$GF = \frac{\left((1+GR)^{DL} - 1\right)}{GR}$$

GR= Annual growth rate, %

2.1.3.2 Additional Traffic Inputs - Rigid Design

Trucks per Day: This input is a two-way daily estimate of trucks at the beginning of the analysis period. The number of trucks per day may be measured in a traffic count collected for a street, or calculated based on the percent trucks of the expected initial daily traffic.

StreetPave12 calculates 18 Kip ESALs based on three different methods, which are listed in order of preference: 1) traffic counts including classification, , 2) user input traffic distributions for the specific functional class of pavement, or 3) predetermined traffic spectrums. As mentioned previously, utilization of traffic counts is the preferred method of calculating ESALs. The truck factors used in StreetPave12 calculation of 18 Kip ESALs are internal to the program and are not user input.

2.1.4 Representative Traffic Data by Street Classification

These representative values were estimated based on a review of existing COA criteria and actual traffic data from COA and Travis County for various street classifications. Representative ESALs were selected, as well as ranges of ADT, percent trucks, and trucks per day, for the suggested general street classifications and summarized in Table 2.4. Note that the street classifications defined here do not directly reflect the traffic categories in StreetPave12. <u>These values may be used for general review of pavement designs or to develop general construction cost estimates for funding considerations. The projected traffic for pavement design must be estimated based on specific site conditions for the roadway(s) being designed.</u>

Table 2.4 Representative Traffic Data by Street Classification

Street Classification	Representative ESALs	General Range in ADT	General Range in % Trucks	General Number of Trucks/Day
Urban Arterial High Traffic	9,000,000	4,000 - 25,000	4% - 15%	160 - 3,750
Urban Arterial Low Traffic	2,500,000	6,000 - 9,000	4% - 15%	240 - 1,350
Rural Arterial	1,000,000	2,000 - 9,000	7% - 15%	140 - 1,350

Street Classification	Representative ESALs	General Range in ADT	General Range in % Trucks	General Number of Trucks/Day
Urban Collector High Traffic	2,100,000	2,000 - 8,000	3% - 10%	60 - 800
Urban Collector Low Traffic	700,000	2,000 - 4,000	3% - 10%	60 - 400
Rural Collector	600,000	2,000 - 8,000	4% - 10%	80 - 800
Urban Local	150,000	200 - 3000	6% - 10%	12 - 300
Rural Local	350,000	500 - 4000	4% - 10%	20 - 400

Figure 2.3 on the next page depicts the FHWA vehicle classification system and vehicle classifications 4 thru 13 have the greatest impact to pavement design. Truck factors for central Texas and CAPEC use are based on a TxDOT study of weigh-in-motion data along the IH35 corridor (Ref 6), as shown in Table 2.5.

Table 2.5 Summary of Equivalency Factors from TxDOT Weigh Stations

Vehicle Class	Truck Factor		
	Station 513 - South of San Antonio	Station 516 - South of Salado	Factor Selected
1	n/a	n/a	0.00002
2	n/a	n/a	0.008
3	n/a	n/a	0.01
4	0.66	0.54	0.60
5	0.03	0.04	0.04
6	0.47	0.46	0.47
7	0.96	1.19	1.08
8	0.38	0.34	0.36
9	1.06	1.16	1.11
10	n/a	n/a	1.16
11	1.89	1.53	1.71
12	n/a	n/a	0.68
13	n/a	n/a	1.94

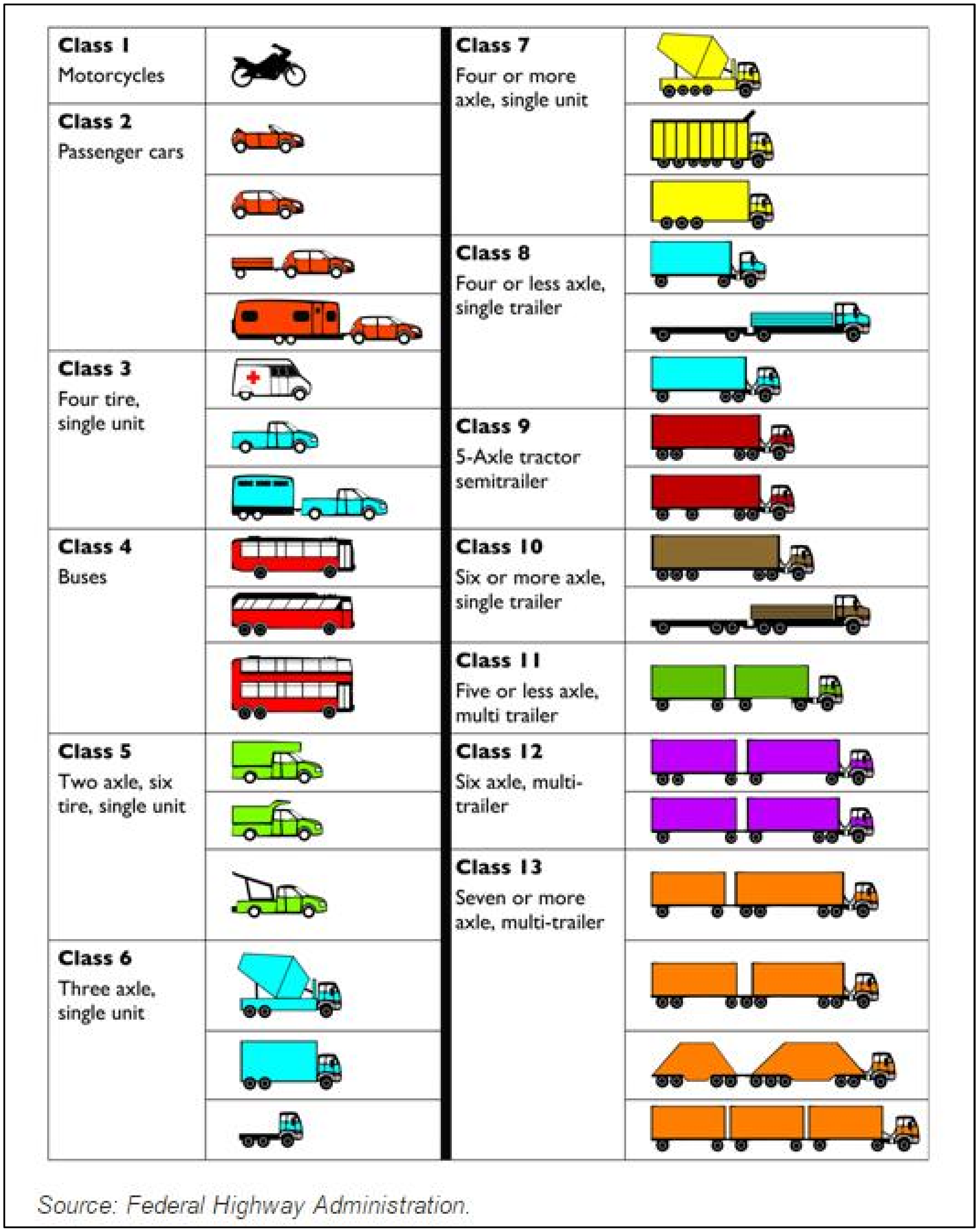

Figure 2.1 FHWA 13 Vehicle Classification

2.2 Design Subgrade Properties

The primary subgrade design parameter is strength in terms of resilient modulus. However, a number of other soils properties may be used to develop and/or confirm an appropriate value to be used for design. Historical data may be reviewed for the area in which the street is located or specific field/laboratory tests may be conducted. These methods are discussed in the following sections.

2.2.1 Historical Data from USDA Soils Map

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) operates web soil survey at the website http://websoilsurvey.nrcs.usda.gov/app/, which provides soil maps and data information for more than 95 percent of the nation's counties. This source may be used to identify the soil types included in the proposed roadway alignment. The user can define the specific area of interest to produce a soil map and the associated metadata. Specific soil information may be obtained for the defined area of interest such as soil engineering properties including Unified Soil Classification, percentage passing various sieve sizes, liquid limit (LL), plasticity index (PI), and chemical properties including pH level, and amount of gypsum with depth, an indicator of sulfates.

The steps to retrieve the engineering and chemical properties are as shown below.

- Use the Area of Interest tab to define your area of interest (AOI)
- Click the soil map tab to view or print the soil maps.
- Click the soil data explorer tab and again click the soil reports tab.
  - Under soil chemical properties tab, click chemical soil properties tab. Click the view soil report underneath the tab. Then the report can be added to the shopping chart to be included in the report.
  - Similarly above, add all the reports under soil physical properties (engineering properties, particle size and coarse fragments and physical properties) to the shopping chart.
- Using the shopping chart tab, the user can get the free custom printable report immediately or download it later.

A sample of the USDA soils report output is shown in Appendix A. Subgrade strength ranges may be estimated based on the Unified Soil Classification and other data obtained from the report. (See section 2.2.2.4) The USDA soils data report is for reference only and does not replace the need for a project specific geotechnical investigation.

2.2.2 Assessment of Subgrade Support

The subgrade design strength parameter for both flexible and rigid pavement design is modulus. Subgrade modulus shall be obtained by direct laboratory testing, field testing and analysis/correlations, as well as correlations with other laboratory test values. Variations such as, in-situ moisture content, changing geological formations and strata, and sample depth relative to the final design grade, will impact the results of field or laboratory testing and should be taken into consideration during the determination of subgrade support for design.

2.2.2.1 Direct Laboratory Testing for Subgrade Soil Modulus

The Resilient Modulus test is a repeated load Triaxial compression test that measures the material's stiffness under different conditions such as moisture, density and stress level. It is determined in accordance with AASHTO T 307-99 Determining the Resilient Modulus of Soils and Aggregate Materials. (Ref. 7)

2.2.2.2 Field Testing and Analyses for Subgrade Soil Modulus

Direct field tests that are recommended to develop subgrade strength design parameters are: 1) Non-Destructive Deflection Testing (NDT) and 2) Dynamic Cone Penetrometer (DCP).Alternative test methods are: Plate Load Tests for K-Value or CBR.

Non-Destructive Deflection Testing (NDT) - For existing roadway pavement being evaluated for reconstruction or rehabilitation, non-destructive deflection test data may be collected on the existing pavement with equipment including the Falling Weight Deflectometer (FWD) or Heavy Weight Deflectometer (HWD). The test procedure is ASTM D4602 - 93(2015) Standard Guide for Nondestructive Testing of Pavements Using Cyclic-Loading Dynamic Deflection Equipment. (Ref. 9) The NDT data is analyzed to estimate existing subgrade strengths using the TxDOT back calculation program MODULUS (Version 6.0) considering existing pavement thicknesses, typically confirmed with pavement cores and borings.

Dynamic Cone Penetrometer (DCP) - The Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications is ASTM D6951/D6951M - 09(2015). (Ref 19) The Dynamic Cone Penetration Test provides a measure of a material's in-situ resistance to penetration. The test is performed by driving a metal cone into the ground by repeated striking it with a 17.6 lb. weight dropped from a distance of 2.26 feet. The penetration of the cone is measured after each blow and is recorded to provide a continuous measure of shearing resistance up to 5 feet below the ground surface. Test results can be correlated to California Bearing Ratios, in-situ density, resilient modulus, and bearing capacity. See section 2.2.2.4 for correlations to modulus.

Plate Load Test for K-Value – AASHTO T 222-78 Plate Load Test method (Ref 10) covers the making of non-repetitive static plate load test on subgrade soils (compacted or the natural state), base materials and flexible pavement components. See section 2.2.2.4 for correlations to modulus.

Plate Load Test for CBR – ASTM D4429-09 Standard Test Method for CBR (California Bearing Ratio of Soils in Place) (for Soil in place in field). (Ref. 11) See section 2.2.2.4 for correlations to modulus.

2.2.2.3 Laboratory Testing

Laboratory tests that are recommended to develop subgrade strength design parameters for rigid pavement design are: California Bearing Ratio or K-Value. Laboratory tests required for flexible pavement design include Modified Texas Triaxial Test and either Unconfined Compressive Strength Test or California Bearing Ratio for estimated strength values based on correlations.

California Bearing Ratio – It measures the penetration resistance of the subgrade or base course relative to a standard crushed rock. It is an empirical test developed by California Department of transportation. The CBR test can be done in accordance with ASTM standards D1883-16 (Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils) (for laboratory prepared samples) (Ref. 12) and AASHTO T193 (Standard Method of Test for the California Bearing Ratio). (Ref. 13)

K-Value – The TxDOT laboratory test procedure for Determining Modulus of Sub-Grade Reaction (K Value) is Tex-125-E. (Ref. 14)

Texas Triaxial Classification – Evaluating a material for its Texas Triaxial Classification is covered in "Tex-117-E, Triaxial Compression for Disturbed Soils and Base Materials." (Ref 5) This method determines the shearing resistance, water absorption and expansion of soils and/or soil-aggregate mixtures.

Unconfined Compressive Strength Test – This test determines the shearing resistance of the cohesive soil which may be undisturbed or remolded soils. It is determined in accordance with ASTM D2166/D2166M-16 (Standard Method for Unconfined Compressive Strength of Cohesive Soil) (Ref 15) and AASHTO T208 (Standard Method for Unconfined Compressive Strength of Cohesive Soil). (Ref. 16)

2.2.2.4 Modulus Correlations

Correlations have been researched with various other types of field and laboratory tests. Although there are numerous correlations for various soil test parameters, the table below summarizes suggested correlations to be used in establishing the subgrade soil strength modulus.

Table 2.6 Suggested Subgrade Strength Correlation Equations

Basis of Correlation	Equation	Origin	Comments
CBR to M_R	$M_R = (1500)(CBR)$	Heukelom & Klomp (1962) (Ref 17)	Only for fine-grained non-expansive soils with a soaked CBR of 10 or less.
	$M_R = 2555 \times CBR^{0.64}$	NCHRP 137A (Ref 18)	A fair conversion over a wide range of values.
DCP Test to CBR	$CBR = 292/PR^{1.12}$	ASTM D6951 (Ref 19)	PR is penetration rate, mm/blow from DCP test
	$CBR = 1/(0.002871)(PR)$	Webster, Brown and Porter, 1994 (Ref 20)	For high plasticity clay soil (CH); PR is penetration rate, mm/blow from DCP test
	$CBR = 1/[(0.017019)(PR)]^2$	Webster, Brown and Porter, 1994 (Ref 20)	For low plasticity clay soil (CL); PR is penetration rate, mm/blow from DCP test
Unconfined Compressive Strength (UCS) to M_R	$M_R = 143.33(UCS) + 4283.5$	Hossain & Kim (2014) (Ref 21)	N/A

Basis of Correlation	Equation	Origin	Comments
Texas Triaxial Classification (TTC) to M_R	$M_R = 2161.2(TTC)^2 - 26263(TTC) + 81981$	1993 AASHTO Guide (Ref 22)	N/A

2.2.2.5 Typical Ranges of Strength Values by Soil Type

Various sources were reviewed to obtain typical ranges of strength related test values for various subgrade soil materials. Ranges are summarized below for general guidance only and shall not be used in lieu of testing. The ranges below are always a function of moisture content, void ratio and density.

Table 2.7 Typical Subgrade Soil Strength Ranges

Material (USC given where appropriate)	CBR	K-Value (pci)	UCS (psi)	Elastic or Resilient Modulus (psi)
Gravel and Gravelly Soils (GW, GP, GM, GC)	20 – 100	200 - 300+	110-250	20,000 – 40,000
Sandy Soils (SW, SP, SM, SC)	10 – 40	200 - 300	19-180	7,000 – 30,000
Silty Soils (ML, MH)	8 – 15	200 - 300	5-110	5,000 – 20,000
Clay Soils, Low compressibility LL<50 (CL)	5 – 15	100 - 200	5-40	5,000 – 10,000
Clay Soils, high compressibility LL>50 (CH)	1 - 5	50 – 100	1-5	2,000 – 5,000

3 Flexible Pavement Design – FPS21 Guidelines

3.1 Basic Design Criteria Input Variables

Listed below are the basic design criteria used as an input for the FPS-21 program.

3.1.1 Length of Analysis period

Length of analysis period is the time over which each design alternative is analyzed. The length of analysis period is required to be 40 years for flexible pavement.

3.1.2 Minimum Time to First Overlay

The minimum time to first overlay can be selected by each county and agency based on their previous experience, policies, budgetary constraint and other general guidelines. 20 years is the required input as a minimum time to first overlay.

3.1.3 Minimum Time between Overlay

This parameter will be based on agency practices. Unless otherwise directed, the minimum time between overlay shall be set to 10 years.

3.1.4 Design Confidence level

Design confidence level takes into account the uncertainty due to variability in estimating traffic, material strength and construction practices to ensure that the pavement will last for design period. The confidence level shall be selected based on the functional classification of the road. The table below shows the alphabetic code used by the FPS-21 for the design confidence level and the values to be used for design.

Table 3.1 Required Design Confidence Level

Street Classification*	Representative ADT Range**	Representative ESALs at 20 Years**	FPS 21 code	Design Confidence Level (%)
Urban Arterial High Traffic	4,000 - 25,000	9,000,000	C	95
Urban Arterial Low Traffic	6,000 - 9,000	2,500,000	C	95
Rural Arterial	2,000 - 9,000	1,000,000	C	95
Urban Collector High Traffic	2,000 - 8,000	2,100,000	C	95
Urban Collector Low Traffic	2,000 - 4,000	700,000	B	90
Rural Collector	2,000 - 8,000	600,000	B	90
Urban Local	200 - 3000	150,000	B	90
Rural Local	500 - 4000	350,000	B	90

* *Street Classification will be based on the platted street designation and clarification by the governing agency*.

*** Not intended to be used in lieu of traffic calculations*

3.1.5 Present Serviceability Index

The Present Serviceability Index refers to the condition of the pavement ride quality. The selection of the suitable initial serviceability index can be made from the ranges provided in Table 2 below considering the number of factors such as reconstruction/widening vs new construction, control of grades/profiles, ditches types and other construction constraints. The following tables provide initial serviceability index vales for various surface types and the required terminal serviceability index values by street classification.

Table 3.2 Initial Serviceability Index Range

Surface Type	Allowable Initial Serviceability Index Range
Surface Treatment	4.0
Thin HMAC (≤4")	4.0 - 4.2
HMAC >4"	4.2 - 4.5

Table 3.3 Terminal Serviceability Index

Street Classification	Representative ESALs	Terminal Serviceability Index
Urban Arterial High Traffic	9,000,000	3.0
Urban Arterial Low Traffic	2,500,000	3.0
Rural Arterial	1,000,000	3.0
Urban Collector High Traffic	2,100,000	3.0
Urban Collector Low Traffic	700,000	2.5
Rural Collector	600,000	2.5
Urban Local	150,000	2.0
Rural Local	350,000	2.0

3.1.6 District Temperature Constant

This input represents the susceptibility of the asphalt binder to thermal cracking under traffic load. The default value for the Central Texas is 31.

3.1.7 Subgrade Elastic Modulus

See Section 3.4 for discussion of this input parameter.

3.1.8 Interest Rate (%)

This parameter is a required input, however is only used in the life cycle cost analysis which is not being utilized with FPS21. (See Section 6 for discussion of the required Life Cycle Cost Analysis (LCCA) software RealCost 2.5). A value of 7% may be input for the program to run.

3.2 Program Controls

Max Funds/SQ. YD, Initial Construction: 99.0 *[Note: 99.0 is default value; however FPS21 is not be to used for life cycle cost analyses; see Section 6 for more discussion]*

3.2.1 Max Thickness, Initial Construction:

99.0 *[Note: 99.0 is default value; if there are limitations on the depth of construction, it may be included here, however if too thin, there may be no acceptable solution]*

3.2.2 Max Thickness, All Overlays:

6.0 *[Note: 6.0 is default value]*

3.3 Construction and Maintenance Data/Detour Design

These input parameters are used for life cycle cost analyses which will not be utilized with FPS21 (See Section 6 for RealCost 2.5 discussion). However, FPS21 will require several of these inputs to run, whether or not the cost is considered. Inputs required, but not utilized are: overlay construction time, asphalt density and production time, lane width, and detour design inputs. See discussion below regarding inputs.

3.3.1 First Year Cost for Routine Maintenance ($/lane-mile)

This is a life-cycle costs parameter that will not be utilized. Set this number to 0.

3.3.2 Annual Incremental Increase in Maintenance Cost

This is a life-cycle costs parameter that will not be utilized. Set this number to 0.

3.3.3 Overlay Construction time, Hours/day

This input is used to evaluate traffic delay costs as a result of overlay operations required at the end of a performance period. Daily construction time typically ranges from 8-12 hrs.

3.3.4 ACP Production Rate, Tons/Hour

Typically the value ranges between 150–300 tons/hr.

3.3.5 Detour Model Selection for Future HMAC Overlays

The FPS 21 program has 5 different models for handling traffic during overlay operations, each one generating a unique user-delay related cost. Unfortunately, the built-in help screen only addresses three of the five models. The model number (1-5) is entered in this field.

CAUTION: Use of the incorrect detour model can result in excessive user delay costs or cause the program to crash, particularly when insufficient lanes are allotted for very high ADT inputs.

A short description of each model is given here.

- Model 1. Highway cross section consists of two driving lanes (one each direction) with wide (8-10 ft.) shoulders. Paving operations will block one lane at a time, with traffic in the paving direction using the shoulder or lane in that direction as the detour. Traffic in the non-paving direction is relatively unaffected, although slowing will probably be required.

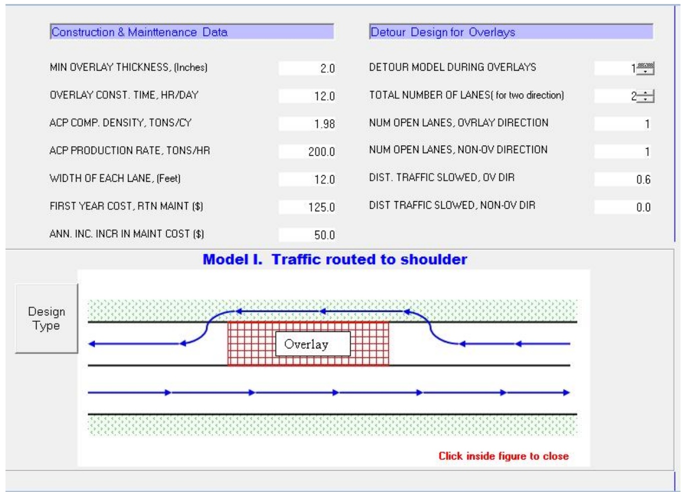

Figure 3.1 FPS Detour Model 1

- Model 2. Highway cross section consists of two driving lanes (one each direction) with narrow shoulders. Paving operations will block one direction at a time, with traffic in the paving direction being diverted into the on-coming lane using an escort. Traffic in the non-paving direction will be required to stop when traffic is escorted from the opposite direction.

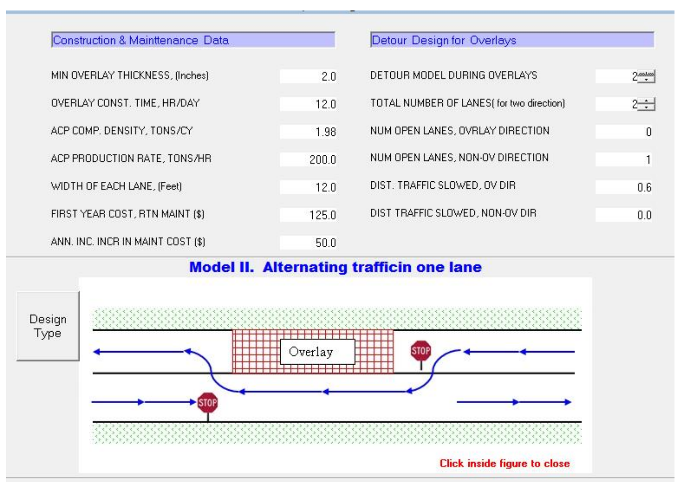

Figure 3.2 FPS Detour Model 2

- Model 3. Highway cross section consists of two or more driving lanes in each direction. Paving operations will block one driving lane at a time, requiring traffic in the paving direction to channel down into fewer lanes. Traffic in the non-paving direction may be completely unaffected if the highway is a divided facility.

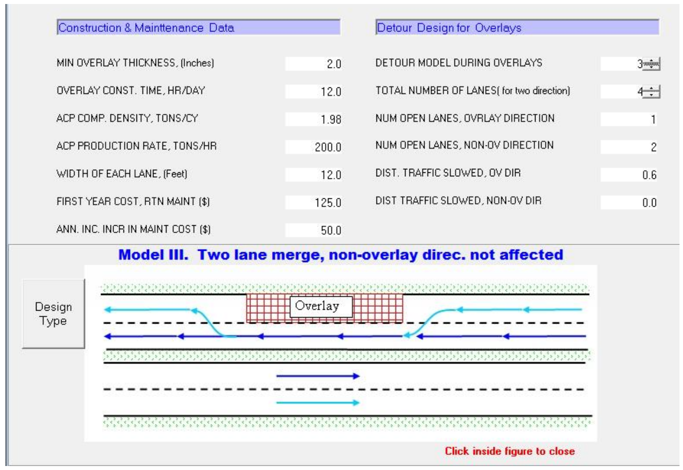

Figure 3.3 FPS Detour Model 3

- Model 4. Highway cross section consists of two or more driving lanes in each direction. Directional traffic flow in the paving direction is completely blocked, with traffic diverted to at least one lane in the opposite direction. Traffic in the non-paving direction must be channeled down into fewer lanes to accommodate opposing traffic.

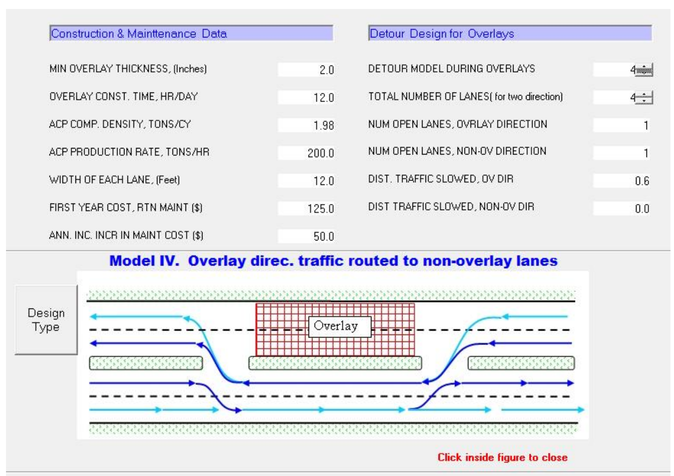

Figure 3.4 FPS Detour Model 4

- Model 5. Highway cross section consists of two or more driving lanes in each direction. Directional traffic flow in the paving direction is completely blocked, with traffic diverted around the overlay zone by special detour, alternate route, or combination of these. Traffic in the non-paving direction may be completely unaffected if the highway is a divided facility.

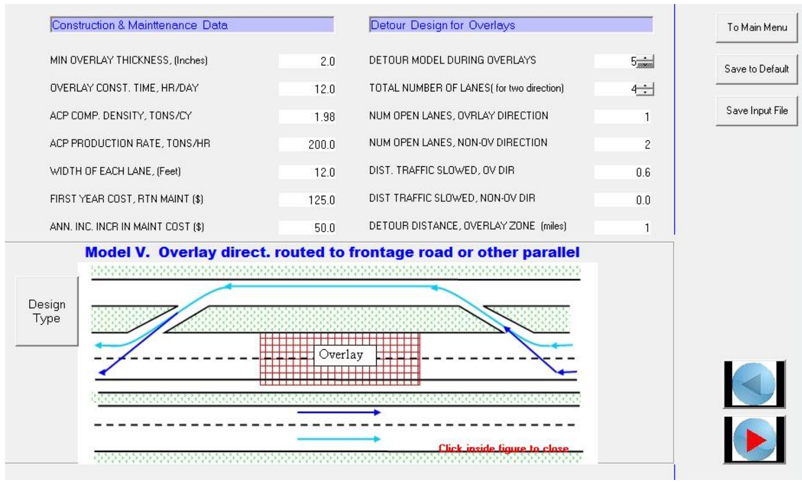

Figure 3.5 FPS Detour Model 5

For low to medium volume highways, the TxDOT Pavement Design Task Force (PDTF, 2009) recommended removing the possible cost bias in accounting for these user costs by simply selecting detour model 3 and entering the posted approach speed for all traffic speed entries in the detour area. This recommendation is supported for comparisons of flexible pavement design alternatives.

3.4 Paving Materials Information

3.4.1 Subgrade Soil Characterization Input Variables

FPS21 utilizes elastic modulus in ksi as the strength input for subgrade strength. See Section 2.2 for more discussion. Additionally Poisson's Ratio value of 0.40 shall be used for subgrade.

3.4.2 Pavement Layer Characterization Input Variables

FPS21 utilizes elastic modulus for the various pavement layer strengths. Based on the Austin District Pavement Design Standard Operating Procedure (Ref 23) that was developed to reflect central Texas paving materials, the following values are suggested:

Table 3.4 Typical Pavement Layer Characteristics

Material Properties	Typical Design Modulus	Poison's Ratio	Other Considerations
Natural Subgrade	Back-Calculated Moduli from FWD or DCP	0.4	Historical FWD data in the area can be used, if the new construction is in close proximity and the same soil formation/classification.
			Typical range is 8 to 20 ksi. DCP or FWD data must be obtained to apply a modulus outside this range

Material Properties	Typical Design Modulus	Poison's Ratio	Other Considerations
Lime Stabilized Subgrade	3 times the modulus of the natural subgrade or 20 ksi whichever is greater	0.3	Must have a UCS≥100 psi for structural credit. Otherwise, all lime treated layers are not given structural credit
			Minimum of 6 inches for construction purposes.
			Typical thickness range of 8 to 18 inches
Cement Stabilized Subgrade	40 ksi	0.3	Must have a UCS≥100 psi for structural credit. Otherwise, all lime treated layers are not given structural credit.
			Typical thickness range of 6 to 12 inches.
Cement Stabilized Base	150 ksi	0.25	Typical thickness range of 8 to 12 inches.
Flexible Base	40 ksi	0.35	Typical thickness range of 8 to 16 inches
Mechanically Stabilized Flexible Base (Geogrid Reinforced)	>40 ksi (varies)	0.35	Minimum 6 inch flexible base
Seal Coat	200 ksi	0.35	Do not assign structural credit to seal coats if used as underseal.
Dense Graded HMAC	500 ksi (≤4" Total HMAC)	0.35	Minimum total dense graded HMAC thickness of 4 inches when placed on flexible base.
			Use only for Intermediate, Level-up or Base HMAC courses. Do not specify as surface course.
	650 ksi (>4" Total HMAC)		Minimum Layer Thickness:
			Type B: 3"
			Type C: 2.5"
			Type D: 1.5"
Thin Overlay Mixtures (TOM)	500 ksi	0.35	Use "User Defined" pavement design type in FPS 21, select "Performance Mix" from material type menu when using TOMs. Use ¾" to 1"

3.4.3 Cost per Cubic Yard

The cost per CY for all new materials proposed is an input for life cycle cost analysis, for which FPS21 is not being utilized. A value of 0 may be input for each pavement layer.

3.4.4 Salvage Percentage

The salvage value for the original cost of the material that may be recovered at the end of the analysis period is related to life cycle cost analysis, for which FPS21 is not being utilized. However, a value must be input for the program to run. Therefore, the default values for the materials selected are recommended.

3.5 Design Output

The FPS21 solutions that meet the design criteria will be provided, including alternatives based on variable thicknesses (as per thickness ranges input) for the designated material layers. Each alternative will indicate the predicted life in years, based on the traffic data input.

3.6 Mechanistic Check

Mechanistic design check will provide an estimate of expected fatigue life of the HMAC layers and the full depth rut life of the structure based on the critical responses of the pavement.
FPS21 runs elastic linear analysis to calculate stress and strain at critical locations which are the critical tensile stress at the bottom of HMAC and the compressive strain at the top of the subgrade. These values are then used in the performance models to compute the number of load repetitions to either cracking or rutting failure.

The estimated number of ESALs repetitions to failure in fatigue and rutting is compared with the estimated cumulative ESALs to the end of the first performance period and if either of the rutting life or fatigue life is less than the estimates cumulative ESALs to the end of the performance period, then the FPS option could be under designed and need to be adjusted to accommodate the design traffic.

3.7 Modified Texas Triaxial Check

The Modified Texas Triaxial (Ref 5) check establishes the total combined thickness of the pavement required to prevent the shear failure in the subgrade based on the heaviest wheel load, percentage tandem axle and the Texas Triaxial class of the subgrade. The input for the Modified Texas Triaxial check are shown below:

3.7.1 The Average Ten Heaviest Wheel Loads Daily (ATHWLD)

The ATHWLD is the load carried by the dual tires at each end of the drive or trailer axles or a single wheel load on each tire of the steering axle, or the tire load on drive or trailer axles equipped with wide-base radials Table below shown the suggested ATHWLD based on the ESALs.

Table 3.5 ATHWLD as per ESALs

ESAL Ranges (in Million)	ATHWLD
< 0.9	10,000
0.9 to 10	11,500
10 to 50	13,500
> 50	14,000

3.7.2 Percentage of Tandem Axles

In FPS 21 Modified Texas Triaxial Check, the percentage of tandem axle is categorized into two categories: % Tandem Axles > 50 and % Tandem Axles < 50. When % Tandem Axles is greater than 50%, the design wheel load is increased by 30% in FPS-21 software. The TxDOT Pavement Design Task Force (PDTF, 2009) recommends a factor of 1.0 be used for all designs where traffic loading is below 5 M ESALs. Thus input the % Tandem Axles as < 50% for this design condition. For Industrial Streets in the Urban High Collector Traffic classification, >50% Tandem Axles shall be used unless data to support less Tandem Axles is provided.

3.7.3 Modified Cohesiometer Value (Cm)

Modified cohesion value is required to account for the reduction in the overall pavement thickness requirement due to the presence of better material above the subgrade. The good material above the subgrade will protect the subgrade from the shear failure. The Table below show the approved cohesiometer values for different material.

Table 3.6 Cohesiometer Values

Material Type	Cohesiometer Value (C_m)
Lime Treated Base greater than 3"thick	300
Lime Treaded Subgrade greater than 3"thick	250
Cement Treated Base greater than 3" thick	1000
Cold Mixed Bituminous Materials greater than 3" thick	300
Hot Mixed Bituminous Materials greater than 6" thick	800
Hot Mixed Bituminous Materials 4" to 6" thick	550
Hot Mixed Bituminous Materials 2" to 4" thick	300
Untreated Materials	100

3.7.4 Subgrade Texas Triaxial Class

The Subgrade Texas Triaxial Class (TTC) can be selected using three different options:

Option 1: Input based on TEX-117-E
Option 2: Enter soil PI to estimate TTC
Option 3: Select TTC based on predominate soil type

3.7.5 Modified Triaxial Check Results

If the required overall thickness of the pavement with the Modified Texas Triaxial criteria is equal to or less than the resulting section being checked, the section meets the criteria. If the required overall thickness of the pavement with the Texas Triaxial criteria is more than the section being checked, the design solution needs to be re-run to obtain an overall thickness to meet the criteria. Changes in layer thicknesses or materials which can increase the cohesiometer value may be considered.

3.8 Representative Cross Sections by Classifications

Based on the representative traffic values presented previously for the various street classifications, representative cross sections are included in the following tables for three subgrade conditions: moderate swell, high swell, and very high swell.

Table 3.7 Representative Sections by Street Classifications and Subgrade swell

Street Classification	Moderate Subgrade Swell (Subgrade Strength of 10 ksi)		High Subgrade Swell (Subgrade Strength of 5 ksi)			Very high Subgrade Swell (Subgrade Strength of 2 ksi)		
	Representative Thickness of HMAC Surface Course (In.)	Representative Thickness of Flexible Base Course (In.)	Representative Thickness of HMAC Surface Course (In.)	Representative Thickness of Flexible Base Course (In.)	Representative Thickness of Stabilized Subgrade (In.)	Representative Thickness of HMAC Surface Course (In.)	Representative Thickness of Flexible Base Course (In.)	Representative Thickness of Stabilized Subgrade (In.)
Locals								
Urban Local	2.0	14.0	2.0	8.0	10.0	2.0	12.0	12.0
Rural Local	2.0	14.0	2.0	9.0	10.0	2.0	14.0	12.0
Collectors								
Rural Collector	3.0	14.0	3.0	9.0	10.0	3.0	14.0	12.0
Urban Collector Low Traffic	3.5	14.0	3.0	10.0	10.0	3.5	14.0	12.0
Urban Collector High Traffic	5.0	14.0	6.0	10.0	10.0	6.0	14.0	12.0
Arterials								
Rural Arterial	5.0	14.0	4.5	10.0	10.0	4.5	14.0	12.0
Urban Arterial Low Traffic	5.5	14.0	6.5	10.0	10.0	6.5	14.0	12.0
Urban Arterial High Traffic	9.5	14.0	9.5	14.0	10.0	10.5	14.0	12.0

4 Rigid Pavement Design – StreetPave12 Guidelines

4.1 Input Variable Descriptions

The input variables for StreetPave12 include: traffic data, global design inputs, subgrade soil strength and concrete properties.

4.2 Traffic data

StreetPave12 calculates 18 Kip ESALs based on either predetermined traffic spectrums with counts or user input traffic distributions for the specific functional class of pavement for which a design is being calculated. The predetermined load spectrums are identified by street classifications: Residential, Collector, Minor Arterial, and Major Arteria; or ACI 330 categories: Category A, Category B, Category C and Category D. User defined custom traffic spectrum may be entered by identifying the axle load by single, tandem and tridem axle type and number of axles per 1000 trucks. These traffic spectrums establish the truck factors to be used in the ESAL calculations, which are internal to the program.

The truck traffic is then determined for the pavement design life by providing the following inputs: trucks per day (initial two-way), traffic growth rate per year (Table 2.2), design life, directional distribution, and design lane distribution (Table 2.3). From these inputs (and the load spectrum defined previously), the total trucks in the design lane over the design life is calculated and used in the thickness design. Representative traffic data by street classifications is summarized in Table 2.4 and includes ESALs, ranges of ADT, percent trucks, and trucks per day.

4.3 Global Design Inputs

The global design inputs include Terminal Serviceability and Reliability. StreetPave12 uses Terminal Serviceability to calculate the equivalent single axle loads (ESALs) carried by the pavement structure over the design life. The terminal serviceability values based on street classifications are as previously defined for flexible pavement:

Table 4.1 Terminal Serviceability Index

Street Classification	Representative ESALs at 30 Years	Terminal Serviceability Index
Urban Arterial High Traffic	9,000,000	3.0
Urban Arterial Low Traffic	2,500,000	3.0
Rural Arterial	1,000,000	3.0
Urban Collector High Traffic	2,100,000	3.0
Urban Collector Low Traffic	700,000	2.5
Rural Collector	600,000	2.5
Urban Local	150,000	2.0
Rural Local	350,000	2.0

Reliability depends on the type of roadway that is being designed. A relatively high reliability is used for high traffic, high speed roadways, while low traffic, low speed roads typically need a low level of reliability. The reliability required by street classification is shown in Table 4.2.

Table 4.2 Required Design Reliability

Street Classification	Representative ESALs	Design Reliability (%)
Urban Arterial High Traffic	9,000,000	95
Urban Arterial Low Traffic	2,500,000	95
Rural Arterial	1,000,000	95
Urban Collector High Traffic	2,100,000	95
Urban Collector Low Traffic	700,000	90
Rural Collector	600,000	90
Urban Local	150,000	90
Rural Local	350,000	90

4.4 Concrete Design Detail Inputs

The design parameters required include: percent of slabs cracked at end of design life: composite Modulus of Subgrade Reaction (Static k-value); concrete material properties; and edge support conditions.

4.4.1 Percent of Slabs Cracked at End of Design Life

This input reflects the allowable percent of concrete slab that are cracked at the end of the design life of pavement. This number could correspond to the percent of slabs that are intended to be replaced in determining future rehabilitation of pavement for life cycle cost analysis. Typically for arterials and collectors, the recommended percent of concrete slabs cracked at the end of the design life is 15%; for local roads that percentage is 25%. These percentages of cracked concrete slabs are based on studies such as FHWA-RD-97-131 "Common Characteristics of Good and Poorly Performing PCC Pavements" (Ref 24).

4.4.2 Composite Modulus of Subgrade Reaction (Static k-value)

The properties of subbase such as the modulus of elasticity and the layer thicknesses are used to calculate the composite static k-value. This value estimates the support of the layers below concrete pavement slab(s). This value may be directly measured in the field, however it is more typically calculated based on the thickness and layer strengths.

The subgrade modulus can either be given as a direct input or calculated through correlations to the CBR of subgrade. The equations developed from NRHCP 128, "Evaluation of the AASHO Interim Guide for the design of Pavement Structure" (Ref 25) are used to estimate the subgrade modulus. Refer to Table 2.7 for more details on subgrade modulus and k-value ranges based on soil type.

The subbase material types included in StreetPave12 are: Cement-Stabilized Subgrade; Lime-Stabilized Subgrade; unstabilized subbase (e.g. sand/gravel, crushed stone); Cement-Treated Subbase (CTB); Lean Concrete Subbase (LCB, Econocrete); Asphalt-Treated Subbase (ATB); and Hot-Mix or Warm-Mix Asphalt Subbase. The layer thickness and layer modulus of elasticity is input for each subbase layer and the composite k-value is thus calculated. Background details on the calculations of composite k-value are included in 1993 AASHTO Guide for Design of Pavement Structures (Ref 22) in Section 3.2.1. StreetPave12's allowable range of modulus values for each material type is generally equivalent to the material strengths included in Table 3.4. The subbase material directly under the concrete shall be non-erodible material, therefore an unstabilized subbase shall not be considered.

4.4.3 Concrete Material Properties

The 28-day flexural strength and the Modulus of Elasticity of Concrete are required for the rigid pavement design. Typical 28-day flexural strength ranges from 500-700 psi. City of Austin Item 360 requires minimum compressive strength of 4,500 psi at 28 days for concrete mix design. As per the ACPA concrete strength converter (*http://www.apps.acpa.org/apps/StrengthConverter.aspx*), a compressive strength of 4500 psi is correlated to flexural strength range of 503 to 637, based on various sources as follows:

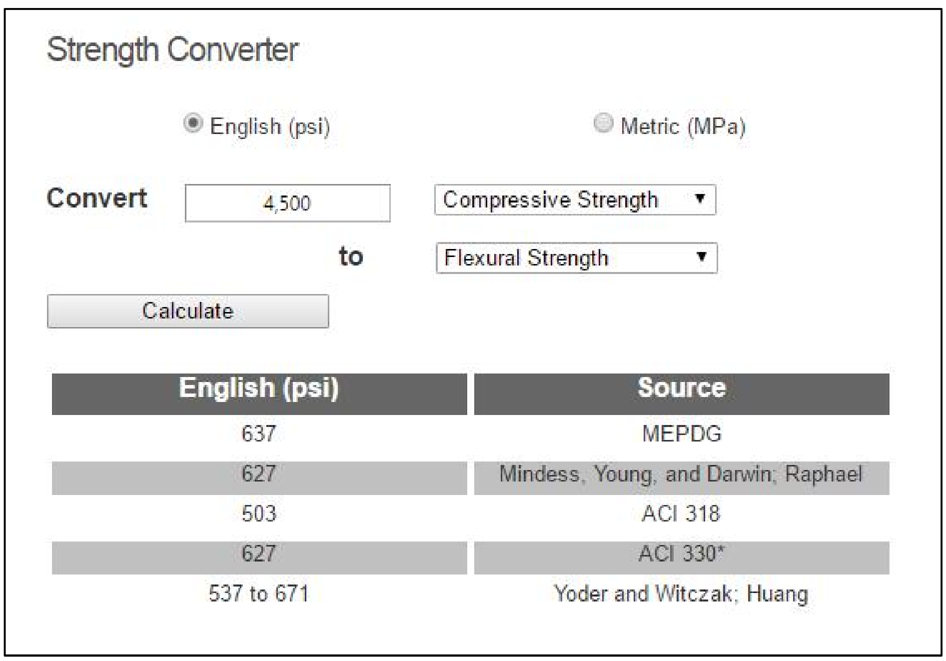

Figure 4.1 ACPA Concrete Strength Coverter Calculation

Additionally, the use of "macrofibers" may also be included for consideration of fiber-reinforced concrete mixtures. However, if macrofibers are selected for consideration in the design, additional documentation with requirements for the fiber-reinforced concrete mix design and construction specifications must be provided with the design report.

4.4.4 Edge Support

The critical load location on a concrete slab is at an unsupported edge, hence additional support will result in reduced pavement thickness. Edge support can be accomplished by specifying a concrete curb and gutter, tied concrete shoulder, or widened lane. A widened lane consists of a lane edge stripe that is placed a minimum of 1 ft. from the pavement edge. If edge support is to be provided, that should be indicated so on the design input screen.

4.5 Design Output

When the design solution is run, the StreetPave12 outputs the Rigid ESALs over the design life along with the minimum required concrete thickness for doweled and undoweled condition, with an indication of the controlling failure criteria noted. Regardless of the StreetPave12 output value, the minimum concrete pavement thickness shall be 6 inches.

Note, rigid pavement designs must include proper jointing plans and joint types to provide for successful construction and long term performance. Standard guidance is provided in ACI 325.12R-02 Guide for Design of Jointed Concrete Pavements for Streets and Local Roads (Ref 26), by ACI Committee 325, American Concrete Institute, Reapproved 2013 and ACI 330R-08 Guide for the Design and Construction of Concrete Parking Lots (Ref 27) also provides additional details which are helpful for on-street parking areas. These ACI guides will help to prevent cracking due to improperly located and constructed joints. StreetPave12 provides guidance regarding maximum joint spacing and dowel bar recommendations for jointed plain concrete pavement.

4.6 Representative Cross Sections by Classification

Based on the representative traffic values presented previously for the various street classifications, representative cross sections are included in the following tables for three subgrade conditions: moderate swell, high swell, and very high swell.

Table 4.3 Representative Sections by Street Classifications and Subgrade Swell

Street Classification	Moderate Subgrade Swell (Subgrade Strength of 10 ksi)			High Subgrade Swell (Subgrade Strength of 5 ksi)			Very high Subgrade Swell (Subgrade Strength of 2 ksi)		
	Representative Thickness of PCC Surface Course (In.)	Representative Thickness of HMAC Base Course (In.)	Representative Thickness of Stabilized Subgrade (In.)	Representative Thickness of PCC Surface Course (In.)	Representative Thickness of HMAC Base Course (In.)	Representative Thickness of Stabilized Subgrade (In.)	Representative Thickness of PCC Surface Course (In.)	Representative Thickness of HMAC Base Course (In.)	Representative Thickness of Stabilized Subgrade (In.)
Locals									
Urban Local	5.5	--	--	5.5	--	10.0	5.5	--	12.0
Rural Local	5.5	--	--	5.5	--	10.0	6.0	--	12.0
Collectors									
Rural Collector	5.5	4.0	--	6.0	4.0	10.0	6.5	4.0	12.0
Urban Collector Low Traffic	5.5	4.0	--	6.0	4.0	10.0	6.5	4.0	12.0
Urban Collector High Traffic	6.0	4.0	--	6.5	4.0	10.0	7.0	4.0	12.0
Arterials									
Rural Arterial	6.5	4.0	--	7.0	4.0	10.0	7.5	4.0	12.0
Urban Arterial Low Traffic	7.0	4.0	--	7.5	4.0	10.0	7.5	4.0	12.0
Urban Arterial High Traffic	7.5	4.0	--	8.0	4.0	10.0	8.5	4.0	12.0

5 Subgrade Soils (Bottom Up Design)

Figure 5.1 shows why subgrade evaluation is critically important in the central Texas area. Soils conditions are highly variable and many of the existing subgrades are highly expansive. These conditions are all along the IH-35 corridor and exist in other major Texas urban areas including the Dallas-Fort Worth and San Antonio metropolitan areas.

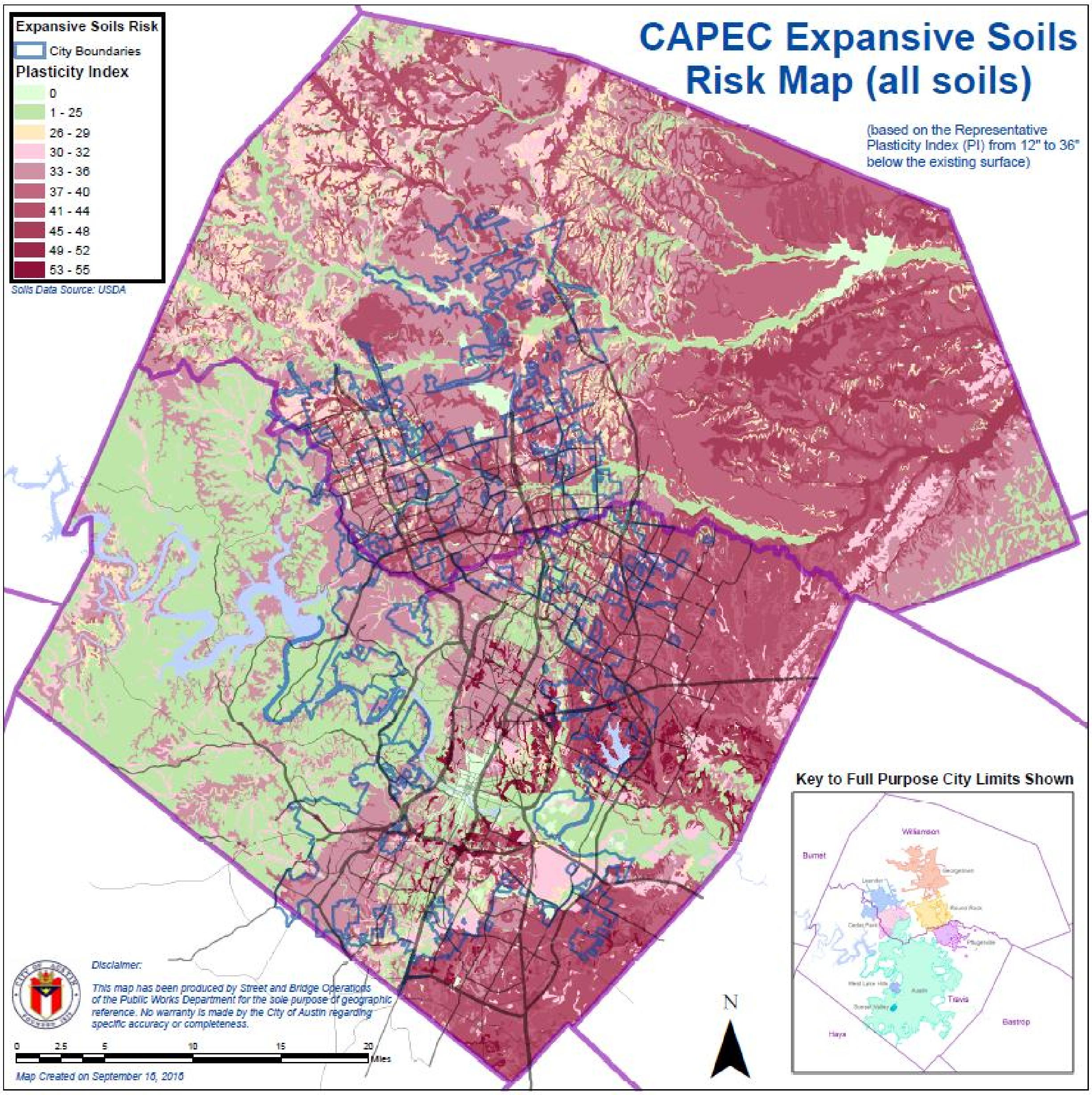

Figure 5.1 CAPEC Area Soils Map

5.1 Characterization of In-situ Subgrade Soils

It is critical to establish the properties of the subgrade soils for the Bottom Up design effort. In addition to the strength of the soil to define the subgrade support for traffic loading, other critical properties to assess the shrink/swell nature of a soil include: Liquid Limit (LL) and Plasticity Index (PI), moisture content, minus 40 and 200 sieves, and sulfate content. Based on these laboratory test results and other specialized testing, it is possible to estimate subgrade shrink/swell and determine improvement/stabilization requirements for design. Subgrade soils considered to be high swell generally have the following characteristics: PI greater than 35, LL greater than 60, and greater than 50% passing the minus 200 sieve.

5.2 Methods to Estimate Subgrade Shrink/Swell

There are several methods to estimate the shrink/swell impacts of subgrade. The required testing procedures in priority order are:

1) Free Swell Test as per ASTM4546 – 14 (Ref 28) to calculate PVR for actual soils samples.

or

2) Traditional Potential Vertical Rise (PVR) calculations as per Tex 124E for an approximation.

Newer procedures have been developed including centrifuge testing (University of Texas Centrifuge Test Method 6048A and 6048B), and forced ventilation accelerated swell/shrink test. These optional tests may also be used to support design calculations.

Sample selection and laboratory testing shall consider proposed final grades, i.e. depth of cut and fill. All geotechnical boring logs shall include accurate vertical and horizontal location.

5.2.1 Free Swell Test Model (ASTM D4546 -14 Standard Test Methods for One-Dimensional Swell or Collapse of Soils)

The free swell test (ASTM D4546 -14 Method C) will provide a good design benchmark criteria for swelling clay behavior under variations in moisture content. The free swell test method (ASTM D4546 -14 Method C) also provides an estimate of the stress applied to the pavements in addition to the "free swell".

In order to estimate the amount of swell in a profile, it is understood that the swell is a function of the overburden pressure over the depth of interest, normally modeled to 15 feet with a vertical effective stress of up to about 2,000 psf. Free swell test Method B only gives the total swell due to inundation at zero effective stress. It is helpful to determine the swell pressure in addition to the free swell particularly since this gives the pavement designer a feel for the stresses the pavement will experience due to high PI swelling clay. The swell pressure is the effective stress required to hold the sample at zero deflection. This swell pressure can be determined by running Method C of ASTM D4546 -14, whereas free swell alone is Method B.

A single sample taken from near the ground surface may not give a good representation of the soil behavior over the depth of the active moisture zone. It is preferable to run the test on three samples at each location – one in the upper 5 feet, another in the middle 5 feet, and a third in the lower 5 feet, based on changes in the soil classifications. However, 1 or 2 tests per location may be adequate to characterize more highly uniform soils based on the geotechnical engineer's judgement. These should be Shelby tube samples of the insitu soils. It is preferred to keep the samples sealed in the tubes until they reach the lab, and then extrude immediately prior to running the tests. The tests can also run tests on soils mixed with stabilizing agents to determine the effect and percentage of stabilizing agent required. Bulk samples can also be used for this testing.

Figure 5.2 shows an example calculation based assumed existing soil layer swell test results.

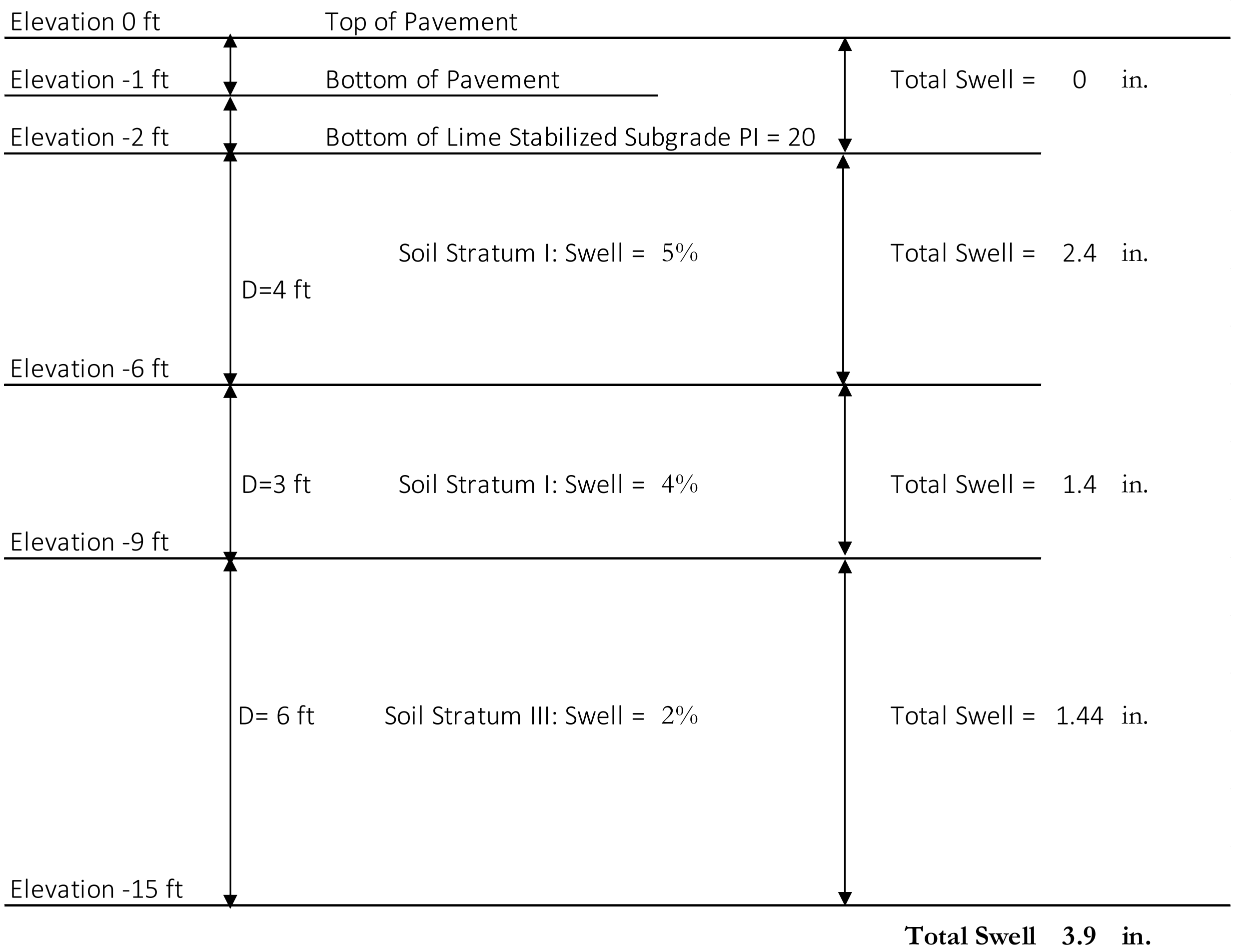

Figure 5.2 Example of PVR Calculation from Swell Testing

5.2.2 Potential Vertical Rise (PVR) Model (TxDOT Tex-124-E)

This traditional method to estimate the swell potential of fine grained clay soils is based on the historical work of TxDOT and uses correlations of Plasticity Index (PI) to develop an estimate of swelling. It is based on McDowell's 1959 method (Ref 29, 30) and is based on a "free swell" conversion ratio. The required data inputs from laboratory soils testing are:

ω = Moisture content
LL = Liquid Limit
PI = Plasticity Index
% < No. 40 Sieve = Fine Grained

A sample output for the Tex-124-E is included in Figure 5.3. The spreadsheet can be downloaded from the TxDOT website.

This model estimates the cumulative potential vertical rise (PVR) of the pavement section based on the CAPEC required 15 feet of material. The required inputs for Tex-124-E are layer thickness, w (moisture content), γ (unit density), Liquid Limit (LL), Plasticity Index (PI), and % passing No.40 sieve. When using the spreadsheet, the pavement design thicknesses resulting from FPS21 or StreetPave12 shall be included as the top layer with an assumption of no swell, i.e. Inputs for liquid limit. Moisture content, percent < No. 40, and PI are set to zero.

As provided in Section 1, subgrade performance criteria required for the bottom up design to be considered for PVR are as follows:

- Provide an adequate depth of cover to limit the potential vertical rise:
  - Arterial / Collector PVR $\leq$ 2.0"
  - Local /Residential PVR $\leq$ 3.0"

If calculated PVR exceeds the criteria provided, adjustments should be made to the design of the subgrade as per section s 5.4 and 5.5 to meet the required criteria, unless otherwise directed by the agency.

PVR Data BH

Depth to Bottom of Layer [ft]	Average Load [psi]	Liquid Limit (LL)	Dry 0.2LL+9	Wet 0.47LL+2	Percent Moisture	Dry Avg Wet	Percent -No.40	Plasticity Index (PI)	Percent Volume Swell	Percent Free Swell	PVR [in] Top of Layer	PVR [in] Bottom of Layer	Differential Swell [in]	Modified -No.40 Factor	Modified Density Factor	PVR in Layers [in]	Total PVR [in]
0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**3.70**
1.0	0.5		9.0	2.0		Dry			0.0	0.0	**0.00**	**0.00**	0.00	0.00	1.00	0.00	**3.70**
2.0	1.5	40	17.0	20.8	26.1	Wet	50.0	20	1.4	4.1	**0.00**	**0.12**	0.12	0.50	1.00	0.06	**3.64**
3.0	2.5	74	23.8	36.8	26.1	Dry	100.0	62	15.6	19.3	**0.74**	**1.42**	0.68	1.00	1.00	0.68	**2.96**
4.0	3.5	74	23.8	36.8	26.1	Dry	100.0	62	15.6	19.3	**1.42**	**2.04**	0.62	1.00	1.00	0.62	**2.35**
5.0	4.5	74	23.8	36.8	26.1	Dry	100.0	62	15.6	19.3	**2.04**	**2.60**	0.56	1.00	1.00	0.56	**1.79**
6.0	5.5	74	23.8	36.8	26.1	Dry	90.0	62	15.6	19.3	**2.60**	**3.10**	0.51	0.90	1.00	0.46	**1.33**
7.0	6.5	62	21.4	31.1	18.7	Dry	90.0	47	13.5	17.1	**2.70**	**3.07**	0.38	0.90	1.00	0.34	**0.99**
9.0	8.0	47	18.4	24.1	18.7	Dry	85.0	47	13.5	17.1	**3.07**	**3.71**	0.63	0.85	1.00	0.54	**0.45**
12.0	10.5	47	18.4	24.1	19.3	Dry	85.0	35	9.6	12.9	**2.55**	**2.81**	0.26	0.85	1.00	0.22	**0.23**
15.0	13.5	47	18.4	24.1	19.3	Dry	85.0	35	9.6	12.9	**2.81**	**3.08**	0.28	0.85	1.00	0.23	**0.00**

Fields are chart inputs | Fields are final answers per layer | Final Total PVR for the borehole

Note: PVR calculations are based on future pavement grade being the same as present grade. Bold numbers are interpolated and extrapolated values.

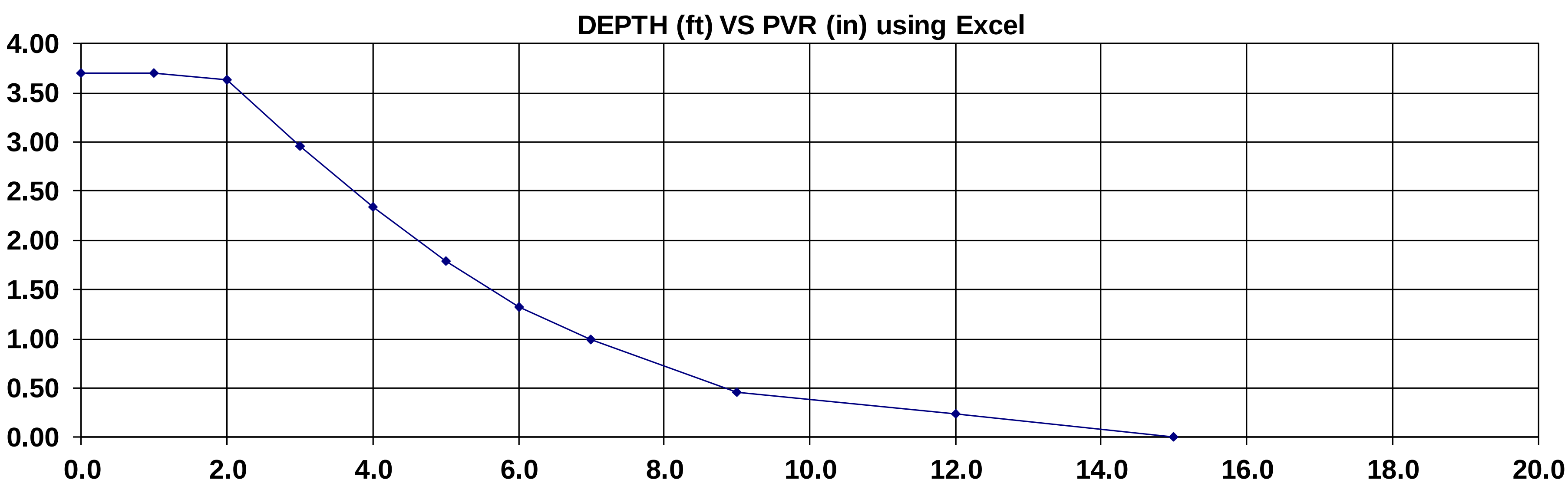

Figure 5.33 Sample Tex-124-E PVR Calculation Spreadsheet

5.2.3 University of Texas Centrifuge Test Method 6048A and 6048B

Method UT 6048A is based on the use of an available database of swell test results on central Texas clay materials (Ref 32 and 33). Results of the TxDOT testing completed and published in March of 2013 were for clay soils from 5 select sites around Austin in Travis County, including:

a) Eagle Ford Clay for Intersection of Hester's Crossing and IH 35 in Round Rock
b) Black Taylor Clay from excavation research project in Manor
c) Tan Taylor Clay from Intersection of SH 71 and Riverside Drive in Austin
d) Houston Black Clay from Highway 79 in Hutto
e) Soil 5 (Generic Backfill Material) from a TxDOT Austin District project site

The database in Ref 33 contains a spreadsheet which includes 138 test results for the clay soils cited above and may be reviewed to assess the swell potential and calculate PVR for soils matching the fundamental laboratory properties provided in the table. Test Method 6048A is soil-specific (suitable for preliminary prediction) and 6048B is project-specific (suitable for final design).

Method UT 6048B uses project-specific sampled materials and requires three laboratory centrifuge tests, which has been developed for TxDOT use. This test method directly measures the PVR value. Use of Method UT 6048B would require the local testing laboratories to have a centrifuge, which is not common at this time.

5.2.4 Forced Ventilation Accelerated Swell/Shrink Test Model

The Forced Ventilation Accelerated Swell/Shrink Test Model is based on the work of Dr. Robert Gilbert. PE, at the University of Texas at Austin. This method uses an air drying method to evaluate the shrink-swell potential of the subgrade sample. The resulting test specimen shows the types of cracks that form in the subgrade material due to shrinkage. It may provide a good visualization of the type of distress that we are trying to minimize/eliminate in the flexible pavement design.

Four (4) Austin Chalk samples and nine (9) Navarro and Taylor clay samples were initially tested with repetitive cycles of sample swelling and shrinking and published at 2006 ASCE Fourth International Conference on Unsaturated Soils. Normal stress is applied to the soil corresponding to in-situ stress. Swelling is accomplished by inundating the specimen with water. Shrinking is accomplished by using forced ventilation (air circulation under a nominal pressure of 5 psi).
This test is intended to provide a practical indicator of vertical displacement under the limit of possible moisture conditions. It complements the conventional swell test in the following ways:

- It captures the drying cycle, which is where most structural distress tends to occur.
- It attempts to mimic realistic conditions by allowing the soil to crack when drying under the overburden stress (meaning that the change in void volume during drying is not entirely manifested as a change in vertical displacement as it is in a conventional swell test during swelling since the sample in a swell test is initially fit snug within the oedometer ring).

- It is insensitive to the moisture content of the soil at the time of sampling, in contrast to a swell test where the amount of swell measured is going to be affected by the initial water content at the start of the test (e.g., if an undisturbed sample is obtained when the soil is at its wettest state, then theoretically no swell would be measured in a swell test).

5.3 Subgrade Design Parameters by Swell Category

Ranges in various subgrade soil properties are provided in the following table as general guidance, however not intended to replace any soils testing on site specific locations.

Table 5.1 General Range of Subgrade Soil Properties

	Low Swell	Moderate Swell	High Swell	Very High Swell
Soil Classification	Rock, Gravels, Sands, Silt	Lean Clay, Clayey Sands, Sandy Clays	Lean Clay, Fat Clay, Shale	Fat Clay, Shale
Range in PI (%)	NP < PI < 20	$20 \leq$ PI < 35	$35 \leq$ PI < 45	PI $\geq$ 45
Range in LL (%)	0 - 45	45 - 60	60 - 70	> 70
Range in -200 sieve (%)	0 - 100	30 - 100	50 - 100	80 - 100

5.4 Selection of Subgrade Improvement Methods

These following strategies, which may be combined to be effective, include, but are not limited to the following:

- Lime Stabilization
- Portland Cement Stabilization
- Lime Cement Stabilization
- Lime or Cement-Fly Ash Stabilization
- Subgrade Moisture Treatment
- In-situ mixing with lower PI materials to reduce swell characteristics
- Removal and replacement with lower PI materials
- Use of Geosynthetics

TxDOT flow charts shown in Figure 5.4 (Ref 38) and Figure 5.5 (Ref 37) have been thoroughly researched and developed for use to evaluate and guide soil stabilization. These guidelines shall be considered for the CAPEC pavement designs process.

Additional factors to consider when selecting subgrade improvement method(s) include: pH values; construction time; rehabilitation vs new construction; confined construction area; utility depths; use of moisture barrier; and multiple methods to minimize variability in the improved materials.

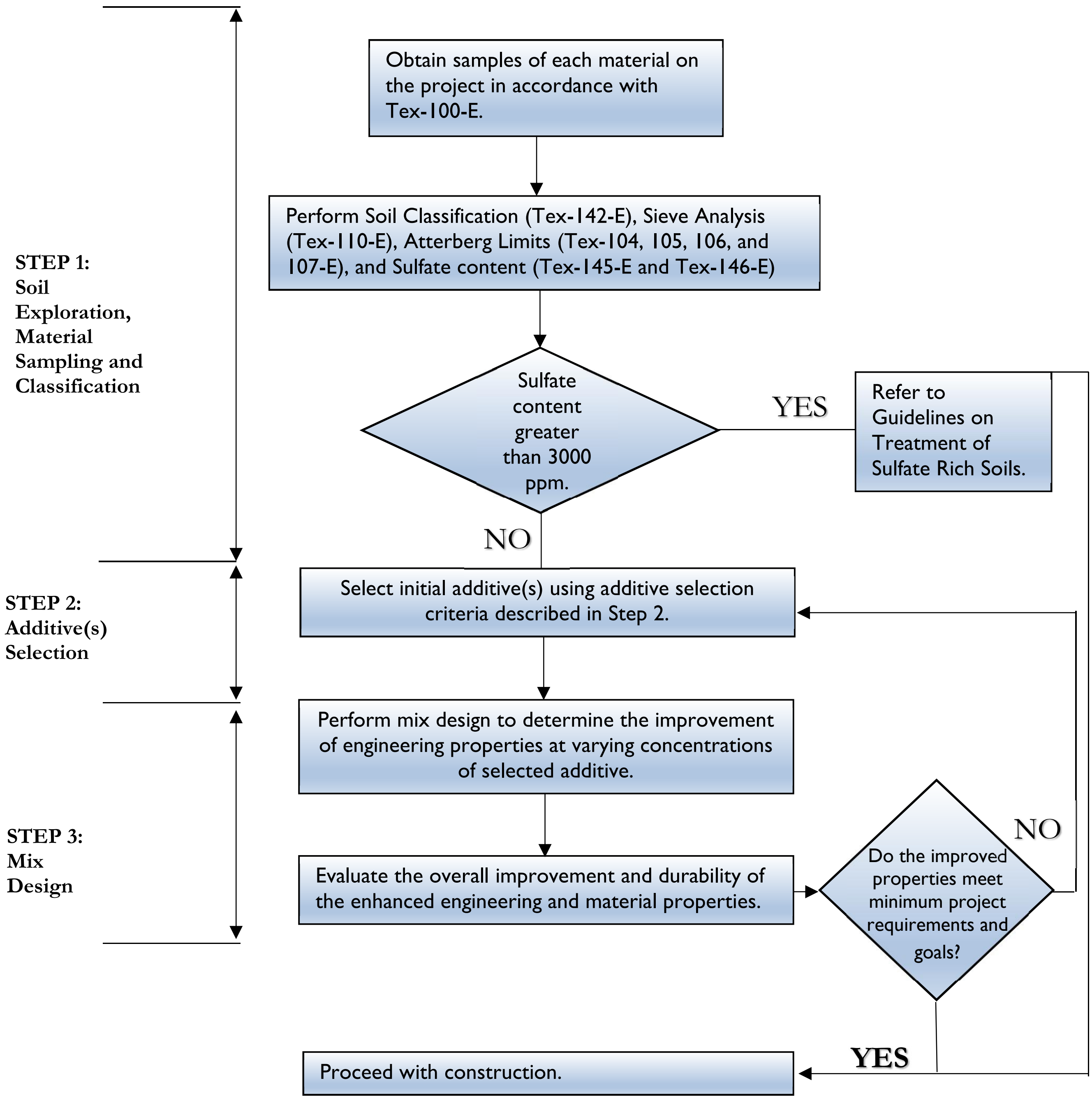

Figure 5.4 TxDOT Flowchart for Subgrade Soil Treatment

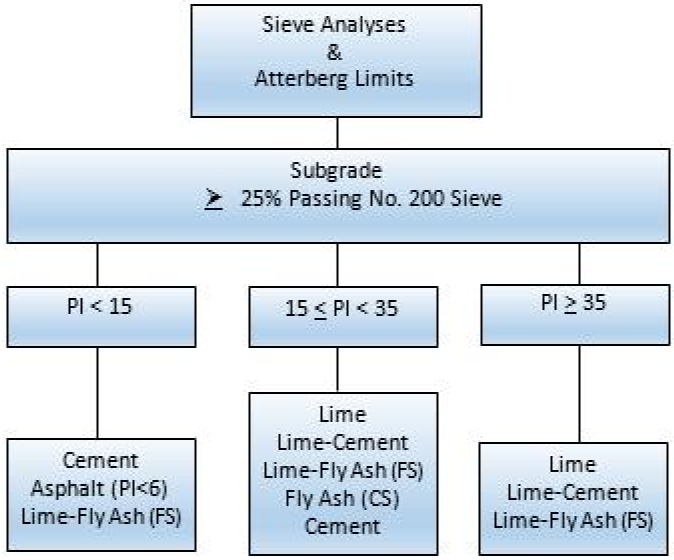

Figure 5.5 TxDOT Flowchart for Subgrade Stabilization Alternatives

5.5 Traditional Stabilization Methods

5.5.1 Lime Stabilization

The TxDOT "Guidelines for Modification and Stabilization of Soils and Base for use in Pavement Structures" (Ref 38) provides guidance on when to select lime stabilization and describes the steps necessary for determining the correct % of lime for the specific soil.

ASTM D6276 - 99a(2006)e1 - Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement for Soil Stabilization describes the mix design procedure. The test indicates the soil-lime proportion needed to maintain the elevated pH equal to 12.4 or greater, necessary for sustaining the reactions required to stabilize a soil.

Field tests at the time of construction must be completed on the site specific soils to determine what construction process to follow. Finally the resulting free swell should be less than 1%. If higher strength is desired cement can also be added and unconfined compressive strength is typically to be 160 psi or greater.

5.5.2 Cement Stabilization

The TxDOT "Guidelines for Modification and Stabilization of Soils and Base for use in Pavement Structures" (Ref 38) recommends that Portland cement alone can be considered if the PI is < 35. The PCA "Guide to Cement-Modified Soil (CMS)" provides guidelines for: Silt-clay classified materials, which are defined as soil/aggregate mixtures containing more than 35% percent material passing a No. 200 sieve, and Granular classified soil materials, which are defined as soil/aggregate mixtures containing less than 35% percent material passing a No. 200 sieve.

High levels of sulfates or chlorides negatively affect the use of cement stabilization for high PI swelling clay subgrade soils and the guidelines are the same as for lime stabilization as described above. Mix designs should be prepared for the specific in-situ soil which is being considered for stabilization. Typically a PI reduction and a minimum unconfined compression test result are specified. A maximum unconfined compression test should also be specified for thinner HMAC pavements to prevent reflection cracking.

Cement stabilization is not recommended under normal circumstances when addressing swelling soils; however if other performance requirements dictate stabilization for strength, cement may be considered. There will be a significant increase in mechanical work required to blend the cement with high swell soils.

5.5.3 Lime-Cement Stabilization

Lime and cement in combination may also be utilized for stabilization of high plasticity soils (PI>35). In this approach the lime is use first to obtain a more friable and workable mixture and reduce the plasticity of the material. Portland cement is then to provide rapid strength gain. It is important to maintain the correct moisture content during curing of the stabilized layer to insure desired strengths are achieved.

5.5.4 Lime or Cement-Fly Ash Stabilization

Fly ash is a by-product of coal combustion and its components and properties depend on the specific coal and combustion process used. The TxDOT Guidelines for Modification and Stabilization of Soils and Base for Use in Pavement Structures identifies two classes of fly ash: Class FS and Class CS. Class FS requires the use of an activator such as lime or cement for a pozzolanic reaction to occur. Class CS can bind materials together without lime or cement. Fly ash provides a longer and slower strength gain than Portland cement. Its use as a stabilizing agent is proven, however a specific mix design must be developed to determine whether or not to use it in combination with lime or cement or to use it independent of other stabilizing agents.

This material can be seasonally unavailable since its production is dependent on the level of activity at the local coal burning power plants and when production is slowed, availability is impacted in the two plants located in the central Texas area, Deely Plant in San Antonio and the Fayette Plant in La Grange. Additionally, availability may be impacted if TxDOT has a large highway construction project utilizing fly ash from the local producers. Finally in the future the electrical generation industry is moving away from coal fired power plants, which may also affect availability.

5.6 Mechanical Modification Methods

There are various mechanical stabilization methods to be considered to address subgrade shrink/swell, such as: moisture treatment, in-situ blending with lower PI materials, removal and replacement, addition of gap graded or other low cost subbase layer, addition of geogrid, etc.

5.6.1 Moisture Treatment

Moisture treatment of high PI soils is another technique which has been successfully used to mitigate shrink/swell potential. The concept is to compact the high PI fat clay materials at 3 to 6% above optimum, based on the Standard Proctor moisture density relationship. Compacting and establishing the soil moisture content slightly above the optimum moisture level, reduces the soil affinity for additional moisture. Deep treatment can be accomplished by injection, but the results are less controlled and are more variable and must be proven prior to use.

Swelling soils are pre-swelled to prevent further expansion after paving. This assumes a moisture barrier of some type is provided to protect/retard the soil material from natural wetting and drying cycle. Moisture treatment can minimize roadway distortion and post-construction longitudinal and edge cracking if the moisture can be stabilized. The process can be expensive due to the amount of mechanical work required and the difficulty in capping off the layer once the desired moisture content is achieved.

The depth of moisture treatment is determined as a function of the free swell test or modeling the soils as “wet” in the Tex-124-E PVR spreadsheet. Establishing and maintaining moisture control in the critical zone of moisture fluctuation is important.

5.6.2 In-Situ Blending with Lower PI Material

Mechanical mixing with lower PI materials has been used in the past to reduce the average shrink/swell characteristics of the in-situ subgrade foundation materials. This process can be cost effective if there are readily available lower PI materials within the limits of construction and blending effectively reduces the PVR to acceptable levels.

5.6.3 Removal and Replacement

Complete removal and replacement of high PI materials may be a cost effective alternative depending on a number of factors such as haul distance for the replacement materials, haul distance for the disposal of the high PI materials, cost of replacement materials, and construction labor, equipment and fuel considerations.

5.6.4 Adding Gap Graded or Other Low Cost Subbase Layer

Available non-standard subbase materials may be considered where the cost of higher quality materials makes their use unaffordable. These materials shall not be used under the pavement asphalt or concrete surface, but may be considered in the lower layers of the pavement section to address subgrade improvement. For example, flexible base materials can be considered under TxDOT Item 247 Type D or E Grade 4 where the engineer specifies the gradations on the plans.

5.6.5 Geosynthetics

Geosynthetics which includes both geogrids and geotextiles are a complex topic because of the great variety of products, quality of products, their many different functions, and a multiplicity of design procedures developed by various creators. A full treatment of these diverse pavement enhancement products was not possible in the initial phases of the CAPEC study. Pavement designers are expected to evaluate the functional needs of the pavement section, select the appropriate solutions, design and specify them correctly. Appropriate justifications for the selection, use, and design of geosynthetics must be included in the pavement design submittal. Despite these concerns, the appropriate use of one or more geosynthetics products is encouraged as part of the solution to smoother, long-lasting pavements with limited cracking on expansive soils.

Historically, geotextiles have been widely used to control the movement of fine materials and to provide moisture barriers. Before the development of geogrids, these products were widely used to encapsulate insitu subgrades. Geotextiles were also used to retard the reflection of underlying rock, utility trenches, and cracked pavement. By including a geotextile separator/filter (see TXDOT DMS 6200 Filter Fabric) at the subgrade interface to prevent upward migration of fines, fines reduction is possible, thus greatly increasing the overall drainage and performance of the pavement section.

Geogrid has been used in the Austin area for base layer thickness reduction and pavement structural enhancement. Additionally, it has been used over high plasticity clay soils (especially in areas with high sulfate content) to minimize reflective cracking caused by post-construction environmental shrink/swell, or as a factor of safety to extend pavement service life.

TxDOT experience and research (Ref 31) has shown that geogrids are effective at controlling environmental cracking and should be considered at the base/subgrade interface when the PI > 35, i.e. high swelling soils. The grid holds the unbound material in a tight matrix allowing the shrinking subgrade to move and limit subgrade cracking from propagating to the pavement surface. The TxDOT Departmental Material Spec (DMS) DMS 6270 – Biaxial Geogrid for Environmental Cracking and/or DMS 6240 - Geogrid For Base/Embankment Reinforcement provides material requirements. More recently, triaxial (triangular) geogrids have also been introduced as a structural enhancement for flexible pavements. The engineer should strongly consider geogrids in high PI soils in combination with other treatments as summarized herein to enhance performance life.

The general approach to approving the use of any geosynthetic should be based on its intended function and justified with an appropriate selection process and/or design procedure. The primary functions of these products is typically tensile reinforcement, drainage, moisture control, separation, or a combination of these. Each should be appropriately designed and clearly justified for its functional purpose(s).

The recommended design approach for using a geogrid is as follows:
1) Develop pavement thickness (criteria) with standard procedures.
2) Determine enhanced structural layer coefficient for mechanically stabilized layer (MSL).
3) Find geogrid optimized section equivalent to unreinforced section.
4) Document design procedures and software used to include in pavement design report.
5) Check severity of swelling soils and serviceability criteria.

One geogrid design approach is to reduce the base layer thickness rather than incorporating a thicker layer of material that has low volume change potential. This is an important advantage since there will be specific situations that limit the overall depth of the pavement section, and will necessitate considerations of geogrid to offset the required additional base thickness. For CAPEC designs the reduction in crushed stone base thickness when considering geogrid reinforcement must be supported by calculations submitted with design report. The reduction shall be limited to a maximum of 4 inches of flexible base thickness (but in no case will the reinforced flexible base thickness be less than the minimum in Table 3.4), until more central Texas performance data is available.

Although there are some superior products and product research in the marketplace, the consideration of requiring any proprietary products or design procedures could not be supported. However, since it is often clear that some companies and have developed and documented high quality products, the pavement design engineer should be able to provide convincing justifications for the selection of better products for use in the final design.

Preference should be given to geosynthetic pavement reinforcement products which have the following:

1) Full-scale laboratory and in-ground testing of pavement structures reinforced with the specific product being proposed.

2) Design method utilized for incorporating the product being proposed must have undergone a full calibration and validation with the specific product.
3) Testing methods, performance testing, and products used must have been reviewed by a third party recognized by AASHTO as a pavement engineering services firm.
4) Third party must validate that the products being proposed and the methodology used are in full compliance with AASHTO R50-09 Geosynthetic Reinforcement of Aggregate Base Course of Flexible Pavement Structures, set proper boundary conditions, and provide design predictions that correspond to performance testing validation results.
5) Validation testing conducted must have been performed at an Accelerated Pavement Testing (APT) Facility in the United States in accordance with NCHRP Report 512 guidelines.
6) Assessment report by the third party validator shall accompany the submittal along with a qualifications summary of the third party reviewer.

The use of geogrid alone is not expected to completely eliminate cracking and distortion, but is expected to help to manage pavements on expansive clays and potentially on subgrades with poor bearing capacity. Geogrids should limit crack widths and minimize differential distortion by spreading out both subgrade swelling forces and occasional pavement overloads on softer spots. However, stabilization and moisture control strategies are highly encouraged in addition to the consideration of the use of a geogrid product meeting the appropriate specification. Geogrids do not provide layer separation (to control migration of fines) nor do they provide a moisture barrier. These functions may be provided by geotextiles or stabilized layers.

5.6.6 General Guidelines for Stabilization Methods

Subgrade treatment alternatives are summarized in Table 5.3.

Table 5.3 Subgrade Treatment Alternatives

Subgrade Treatment Alternative	Low Swell	Moderate Swell	High Swell	Very High Swell
Admixture Stabilization Methods:				
Lime Stabilization		√	√	√
Portland Cement Stabilization	√	√	*	*
Lime - Cement Stabilization		√	√	√
Lime - Fly Ash Stabilization	√	√	√	√
Mechanical Modification Methods:				
Subgrade Moisture Treatment		√	√	√
Blending with Lower PI Select Fill Material			√	√
Replacement With Lower PI Materials			√	√
Adding Low Cost Subbase Layer			√	√

Use of Geosynthetics**Cement stabilization is not recommended under normal circumstances when addressing swelling soils; however if other performance requirements dictate stabilization for strength, cement may be considered. There will be a significant increase in mechanical work required to blend the cement with high swell soils.*

5.7 Design to Control Moisture Fluctuation

The following moisture control design strategies, which may be combined to be more effective, include, but are not limited to the following: address/account for poor drainage, use of curb and gutter and ribbon curbs for ditch drainage, sidewalk adjacent to back of curb, paved shoulders, maximum ditch slopes, etc. The design objective of these control measures is to minimize the moisture content from fluctuating in the moisture critical zone which is 10 to 15 feet in central Texas.

Horizontal or vertical moisture barriers of sufficient width or depth to minimize moisture migration into and out of the subgrade soils.

- Although 4 foot vertical barriers may be adequate, vertical barriers of 6 to 10 feet are often required to be effective. Vertical barriers could be constructed of slurry walls at the back of curb
- Contiguous sidewalks and driveways placed at the time of roadway construction are highly desirable and is considered a horizontal barrier.
- An acceptable design with moisture barriers must be used in combination with at least one other strategy discussed herein.
- Manufactured plastic tree root barriers between tree wells and pavement have been effective in the urban environment.
- Plastic sheeting could be considered, although it may not durable, therefore may have a limited life.
- Mylar might be considered under the curb to back of sidewalk, if the sidewalk is offset from the curb, to potentially provide a horizontal barrier.

When electing to use moisture barriers, documentation shall be provided to verify successful use of the proposed strategy. The designer may consider references such as FHWA NHI-05037 Geotechnical Aspects of Pavements Reference Manual Chapter 7 (Ref 33).

Additional design elements which should be considered to extend the horizontal moisture zone of influence: extension of base/stabilized subgrade beyond pavement section, use of curb and gutter or ribbon curb, and consideration of plastic sheeting (although this material may not be durable and have limited life).

6 Life Cycle Cost Analysis (LCCA)

LCCA is an engineering economic analysis that allows engineers to quantify the differential costs of alternative investment options for a given project. LCCA can be used to compare alternate pavement sections or pavement types (flexible versus rigid) on new construction and rehabilitation projects. LCCA considers all agency expenditures and user costs throughout the life of the facility, not just the initial capital construction investment, and allows for cost comparison of options with varying design lives to be compared on an equivalent basis.

The intended results of the LCCA is to lower the life cycle costs and increase the Level of Service throughout the life of the street. As a consequence, the first cost will be increased and additionally may cause some difficulty during reconstruction in developed areas. In many cases the first cost of initial construction is born by the developer and the life cycle costs of street maintenance is born by the agency (and public). The user "cost" and the impact and inconvenience for premature street repairs need to be considered. A balance must be reached between private development and public agency and public user costs, since the public perception overall regarding street conditions affects both the developer and the agency.

LCCA is required with more than one design alternative. Alternative flexible pavement designs that are equivalent sections are expected to have same life cycle costs and may fall back to first cost. However if reconstruction/rehabilitation options have different life cycle profiles, the cost will be affected. The CAPEC member agencies will provide life cycle profiles and associated costs.

Pavement options shall be compared using the FHWA's LCCA program RealCost 2.5 (deterministic procedure) (Ref 3). FHWA references (Technical Bulletin, User's Manual, and Primer are available on the FHWA's LCCA Web page (www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.htm) or by request from the FHWA's Office of Asset Management. The input parameters are discussed in more detail in Section 6.4. Complete details are provided in the Real Cost 2.5 User's Manual (Ref 4). RealCost 2.5 reports life cycle costs on a total project cost. User costs may also be included.

The FHWA's LCCA program RealCost 2.5 is a simplified system that allows the user to enter up to 24 unique activities over the life cycle of 2 different alternatives. It can compare HMAC and PCC alternatives on the same cost basis. Input variables are as follows:

6.1 Project Details

These inputs are a description of the project level specifics and include:

a. **State Route –** Enter Street or County Road name
b. **Project Name –** Enter the proposed project common name
c. **Region –** Enter Council District, Subdivision, or Precinct
d. **County –** Enter County where project is located
e. **Analyzed By –** Enter name of engineer or staff member preparing the solution
f. **Mileposts –** Enter Beginning and Ending Mileposts as estimated base on the project stationed length.

g. **Comments –** A text box is available to enter additional analysis details and or assumptions.

6.2 Analysis Options

These are the analysis criteria which determine the analysis guidelines by which the program calculates costs. Notes on several of the variables as specified by CAPEC are as follows:

a. **Analysis Period (Years) –** CAPEC requires a minimum of a 40 year analysis period.

b. **Discount Rate –** This value is determined using the estimated interest rate (%) and inflation rate (%)

c. **User Cost Computation Method (Calculated or Specified) –** CAPEC recommends allowing the built in models calculate the user delay costs

6.3 Summary of Inputs

Other variable definitions and details are included in the exhibits below which are from the RealCost 2.5 User's Manual.

Table 6.1 Summary of Inputs for RealCost 2.5

Option/Input	Description	FHWA Recommendation
Analysis Period	The number of years over which the alternatives will be compared.	35 to 40 years
Discount Rate	The rate by which future expenditures will be discounted to present value. This is entered as a decimal number.	Real discount rate of 3% to 5%
Beginning of Analysis Period	Sets the first year of the analysis period. RealCost expenditure diagrams draw their dates from this field and the analysis period field. This can also be referred to as the base year for the analysis.	Year the project will be undertaken
Include Agency Cost Remaining Service Life	Indicates whether the remaining service life value will include a prorated share of agency costs if the service life of an improvement extends beyond the analysis period.	Checked (Yes)
Include User Costs in Analysis	Indicates whether user costs will be included in the analysis and displayed in the results.	Checked (Yes)
User Cost Computation Method	Directs RealCost to either 1) calculate user costs ("Calculated") based upon input data in accordance to best-practice methods or 2) utilize inputted user costs ("Specified") values when calculating user life-cycle costs.	Calculated
Traffic Direction	Directs RealCost to calculate user costs for the "inbound" lanes, the "outbound" lanes, or "both" inbound and outbound lanes.	
Include User Cost Remaining Service Life	Indicates whether the remaining service life value will include a prorated share of user costs if the service life of an improvement extends beyond the end of the analysis period.	Checked (Yes)

6.4 Traffic Data

These inputs provide the required project specific details which are to be used in the calculations which estimate the user delay costs. Variable definitions and details are provided below in the exhibit below from the RealCost 2.5 User's Manual.

Table 6.2 RealCost 2.5 Traffic Data

Input	Description
AADT in Both Directions	This is the annual average daily traffic in the construction or base year of the analysis. This is the total AADT for both directions.
Single Unit Trucks	The percentage of the AADT that is single unit trucks.
Combo Trucks	The percentage of the AADT that is combination trucks.
Annual Growth Rate of Traffic	The percentage by which "AADT in both directions" increases each year.
Normal Operations Speed Limit	Speed limit in normal operating conditions (the time periods between agency work zones).
Normal Number of Lanes Open	Number of roadway lanes available under normal operating conditions.
Queue Dissipation Capacity	Capacity of each lane during queue dissipation operating conditions.
Normal Free Flow Capacity	Capacity of each lane under normal operating conditions.
Free Flow Capacity Calculator	This button opens a form that calculates free flow lane capacities based upon the *Highway Capacity Manual*, 3rd Ed.
Maximum AADT in both Directions	Caps the traffic growth at this number. If traffic grows beyond this value, this value is substituted for the computed future AADT figure and future user costs are calculated based upon this maximum AADT figure. This is used to prevent growth beyond possible capacity.
Maximum Queue Length	Models the effects of self-imposed detours (traffic exiting from the work zone route yet still incurring some user costs). Queue-related user costs, which are based upon queue length, are calculated with this figure instead of the calculated queue length. However, all vehicles, even those that detour, are charged queue costs.
Rural or Urban Traffic	Allows the choice between two hourly traffic distributions. Default values for these distributions (the defaults are accessible in the software) are taken from the Texas Transportation Institute's MicroBENCOST.

6.5 Value of User Time

The cost values of user time are specified based on the type of vehicle. RealCost 2.5 can model these costs as deterministic or probabilistic values. There are three basic costs as follows:

a. **Value of Time for Passenger Cars ($/Hour) –** This includes all the passenger vehicle costs for fuel, oil, tire wear, antifreeze, maintenance, depreciation, and driver. These costs are used to compute user costs associated with delays in traffic due to initial and future construction delays.

b. **Value of Time for Single Unit Trucks ($/Hour) -** This includes all the single unit delivery truck costs for fuel, oil, tire wear, antifreeze, maintenance, depreciation, and driver. These costs are used to compute user costs associated with delays in traffic due to initial and future construction delays.

c. **Value of Time for Combination Trucks ($/Hour) -** This includes all the combination truck (tractor/semi-trailer and multiple trailers) costs for fuel, oil, tire wear, antifreeze, maintenance, depreciation, and driver. These costs are used to compute user costs associated with delays in traffic due to initial and future construction delays.

d. **Traffic Hourly Distributions by Hour of the Day –** These distributions are built into the program as defaults, but can also be input by the use if specific values are known. Variable definitions and details are provided below in the exhibit below from the RealCost 2.5 User's Manual.

Table 6.3 RealCost 2.5 Value of User Time

Input	Description
AADT Rural %	The percentage of the AADT that is traveling on the roadway, in both directions, during the indicated hour under the rural traffic distribution.
Inbound Rural %	The percentage of that hour's traffic that is traveling inbound on the route under the rural traffic distribution. The formula: **(AADT Rural %) x (Inbound Rural %)** describes the percentage of the AADT traveling in the inbound direction for the indicated hour. Note: The same interpretations apply to the urban components of Figure 15.
Restore Defaults	Returns all values on this form to their original, as delivered, default values. Default values for these distributions are taken from MicroBENCOST, software produced by the Texas Transportation Institute. MicroBENCOST, which is used to calculate benefits and costs of transportation improvements, includes an hourly traffic distribution that has been adopted as a default traffic distribution for RealCost.

6.6 Alternative Level Data Entry

As noted earlier two alternatives, each with up to 24 activities in the complete life cycle can be entered into RealCost 25. Variable definitions and details are provided below in the exhibit below from the RealCost 2.5 User's Manual.

Table 6.4 RealCost 2.5 Alternative Activities

Input	Description	Notes
Alternative Description	Name of this alternative.	
Activity Description	Name of this activity.	
Agency Construction Cost	Agency costs that will be included in the life-cycle cost analysis for this activity of this alternative.	Thousands of dollars
Service Life	Service life of the activity. This field defines how many years after this activity the next activity will take place.	Years
User Costs	This field allows direct entry of user costs. The field is accessible only when the User Cost Computation Method field on the Analysis Options form is set to Specified. When this field is set to Calculated it will be presented in gray font and will not be accessible.	1) Thousands of dollars 2) Inaccessible if User Cost is set to Calculated.
Maintenance Cost	Cost of minor, scheduled maintenance that is performed between major activities. These minor activities incur no user costs. Their purpose is to allow for the inclusion of the agency costs of minor activities such as preventive maintenance. In order to remove minor routine maintenance from the analysis, set the value of this field to zero (0).	1) Thousands of dollars 2) Enter zero (0) if not being used.
Maintenance Frequency	Cyclical frequency of minor maintenance. This frequency only applies during the service life of the specific major activity that it is described for and expires as soon as the next major activity begins.	Enter zero (0) if not being used.
Work Zone Length	How long the actual work zone is. This is measured from the beginning to the end of the reduced speed area (where the work zone speed limit is in effect).	Miles

Work Zone Duration	Number of days that the work zone will be affecting traffic. For example, if the work zone is in effect 5 days a week for 3 weeks, this value would be 15.	Days
Work Zone Capacity	Vehicular capacity of one lane of the work zone for 1 hour.	Vehicles per hour per lane
Work Zone Speed Limit	Posted speed limit within the work zone.	Miles per hour
Lanes Open in Each Direction During Work Zone	Number of lanes open in the work zone area when the work zone is in effect. The number of lanes open applies to each direction.	
Work Zone Hours	Hours each day of the Work Zone Duration during which the work zone is in effect. During these hours, capacity is limited to Work Zone Capacity. Work zone timing may be modeled separately for inbound and outbound traffic. Up to three separate periods of work zone can be modeled for each day. For example, to model a work zone that is in effect from 9:00 AM to 3:00 PM and from 8:00 PM to 5:00 AM, enter these numbers: 00 05 09 15 20 24	Use a 24-hour clock

6.7 Probability Functions

The RealCost 2.5 software allows the user to estimate the life cycle cost based on seven different statistical distributions of the traffic data. CAPEC requires the deterministic option be used instead of one of the probability functions.

6.8 RealCost 2.5 Typical Outputs ($/SY)

The following is a summary output from RealCost 2.5 for the deterministic analysis. Probabilistic analysis outputs are similar in format and both output types include graphical information.

RealCost Total Cost - Deterministic				
	Alternative 1: HMAC OVER FLEX BASE WITH LSS		Alternative 2: PCC ALTERNATIVE	
Total Cost	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	*$580.00*	*$128.10*	*$556.00*	*$116.43*
Present Value	**$515.61**	**$122.89**	**$553.89**	**$116.43**
EUAC	$26.31	$6.27	$28.26	$5.94
Lowest Present Value Agency Cost		Alternative 1: HMAC OVER FLEX BASE WITH LSS		
Lowest Present Value User Cost		Alternative 2: PCC ALTERNATIVE		

Figure 6.1 RealCost 2.5 Output

7 References

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APPENDIX A

USDA SOILS REPORT OUTPUT

United States Department of Agriculture

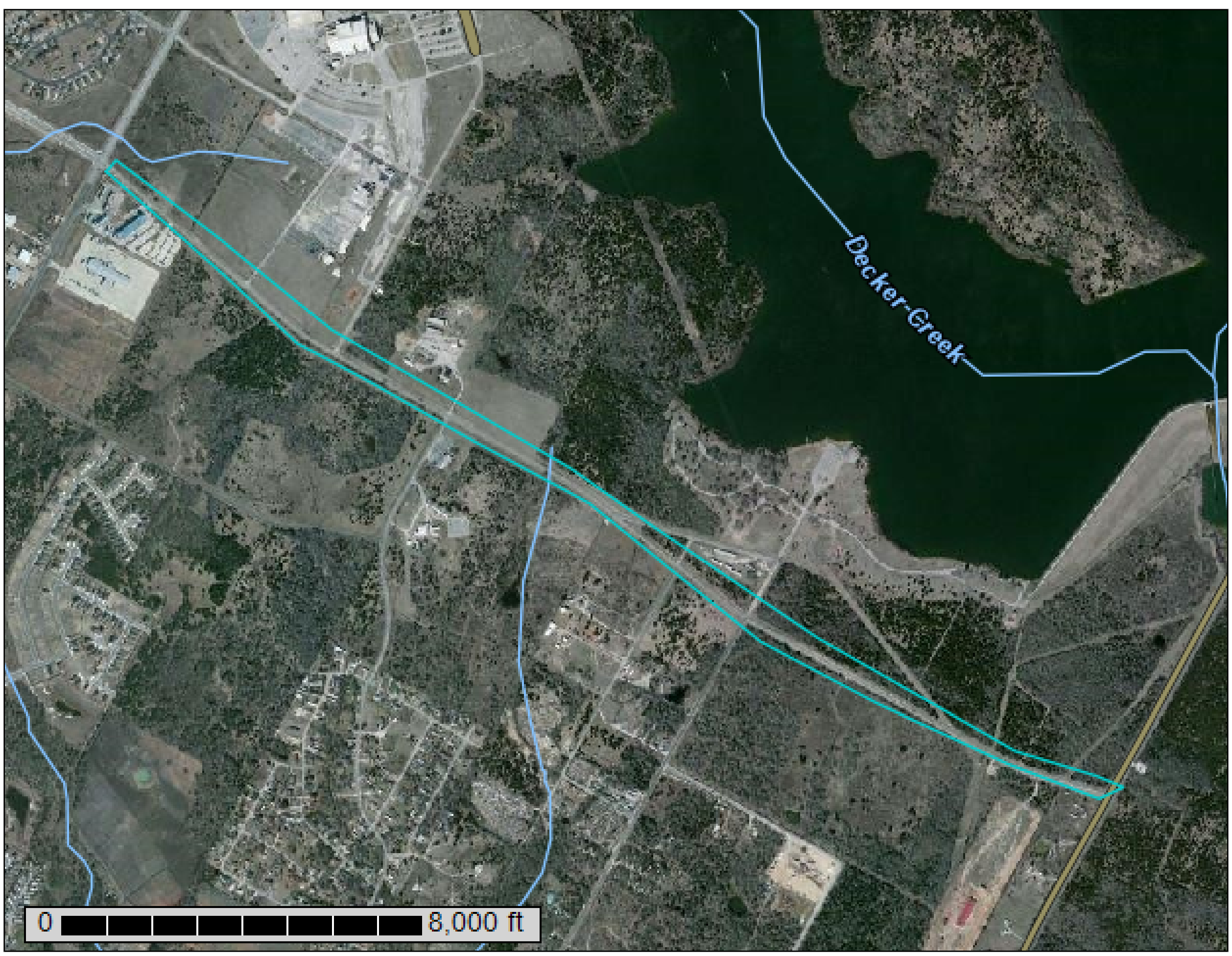
NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

Travis County, Texas



July 22, 2016

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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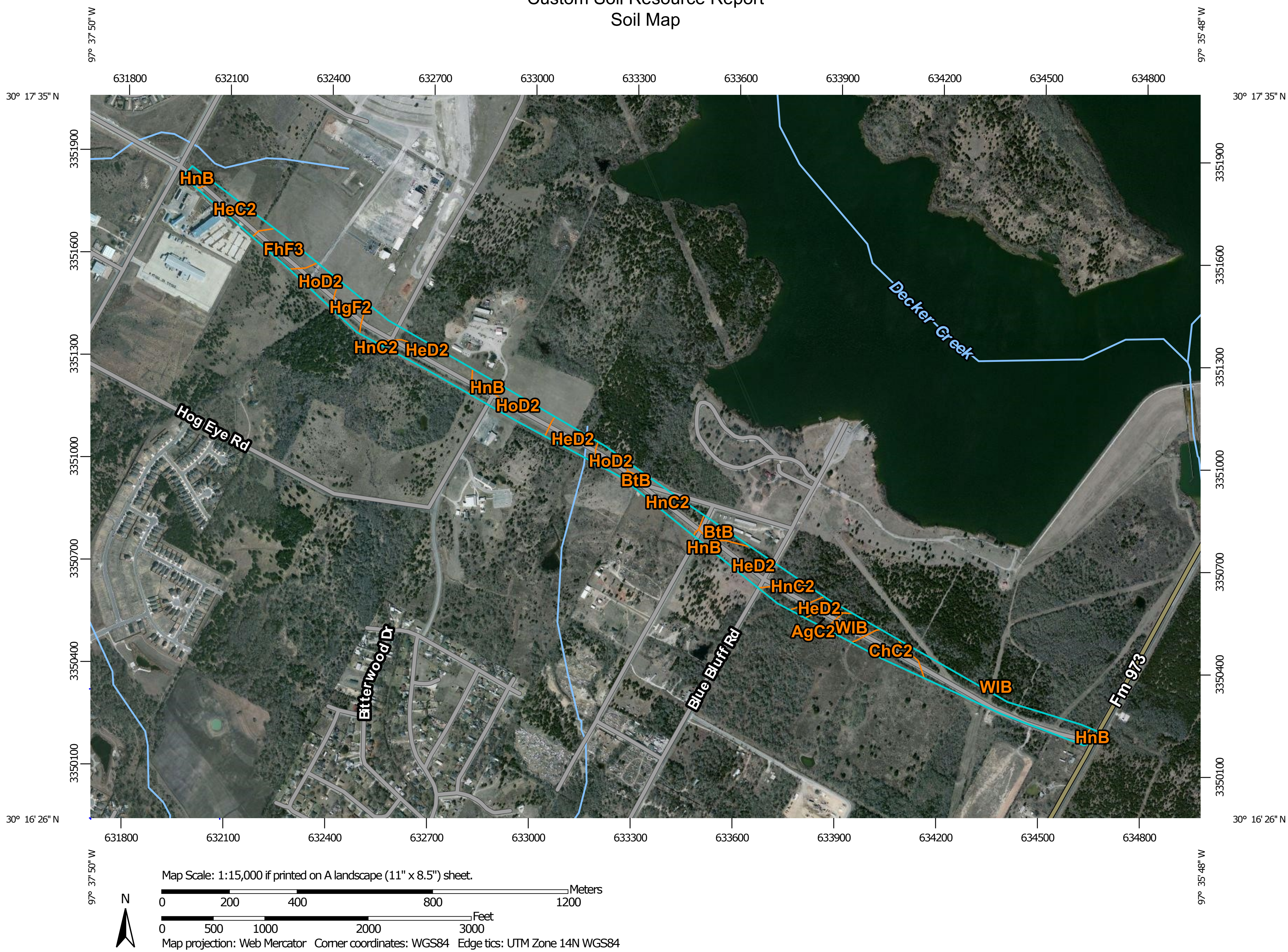
Contents

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Soil Map


97° 37' 50" W
97° 35' 48" W
30° 17' 35" N
30° 16' 26" N
631800
632100
632400
632700
633000
633300
633600
633900
634200
634500
634800
3351900
3351600
3351300
3351000
3350700
3350400
3350100
HnB
HeC2
FhF3
HoD2
HgF2
HnC2
HeD2
HnB
HoD2
HeD2
HoD2
BtB
HnC2
BtB
HnB
HeD2
HnC2
HeD2
AgC2
WIB
ChC2
WIB
HnB
Decker Creek
Hog Eye Rd
Bitterwood Dr
Blue Bluff Rd
Fm 973
Map Scale: 1:15,000 if printed on A landscape (11" x 8.5") sheet.
Meters
0
200
400
800
1200
Feet
0
500
1000
2000
3000
N
Map projection: Web Mercator Corner coordinates: WGS84 Edge tics: UTM Zone 14N WGS84

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features

- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Travis County, Texas
Survey Area Data: Version 16, Sep 24, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Feb 18, 2010—Feb 13, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Travis County, Texas (TX453)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
AgC2	Altoga silty clay, 3 to 6 percent slopes, moderately eroded	0.7	1.4%
BtB	Burleson gravelly clay, 1 to 3 percent slopes	1.4	2.8%
ChC2	Chaney fine sandy loam, 2 to 5 percent slopes, moderately eroded	2.9	5.6%
FhF3	Ferris-Heiden complex, 8 to 20 percent slopes, severely eroded	2.6	5.1%
HeC2	Heiden clay, 3 to 5 percent slopes, eroded	2.8	5.5%
HeD2	Heiden clay, 5 to 8 percent slopes, eroded	13.9	27.2%
HgF2	Heiden gravelly clay, 8 to 20 percent slopes, moderately eroded	2.2	4.2%
HnB	Houston Black clay, 1 to 3 percent slopes	2.5	4.8%
HnC2	Houston Black clay, 3 to 5 percent slopes, moderately eroded	6.4	12.6%
HoD2	Houston Black gravelly clay, 2 to 8 percent slopes, moderately eroded	7.0	13.7%
WlB	Wilson clay loam, 1 to 3 percent slopes	8.6	16.9%
Totals for Area of Interest		**51.0**	**100.0%**

Soil Information for All Uses

Soil Reports

The Soil Reports section includes various formatted tabular and narrative reports (tables) containing data for each selected soil map unit and each component of each unit. No aggregation of data has occurred as is done in reports in the Soil Properties and Qualities and Suitabilities and Limitations sections.

The reports contain soil interpretive information as well as basic soil properties and qualities. A description of each report (table) is included.

Soil Chemical Properties

This folder contains a collection of tabular reports that present soil chemical properties. The reports (tables) include all selected map units and components for each map unit. Soil chemical properties are measured or inferred from direct observations in the field or laboratory. Examples of soil chemical properties include pH, cation exchange capacity, calcium carbonate, gypsum, and electrical conductivity.

Chemical Soil Properties

This table shows estimates of some chemical characteristics and features that affect soil behavior. These estimates are given for the layers of each soil in the survey area. The estimates are based on field observations and on test data for these and similar soils.

Depth to the upper and lower boundaries of each layer is indicated.

Cation-exchange capacity is the total amount of extractable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. Soils having a low cation-exchange capacity hold fewer cations and may require more frequent applications of fertilizer than soils having a high cation-exchange capacity. The ability to retain cations reduces the hazard of ground-water pollution.

Effective cation-exchange capacity refers to the sum of extractable cations plus aluminum expressed in terms of milliequivalents per 100 grams of soil. It is determined for soils that have pH of less than 5.5.

Soil reaction is a measure of acidity or alkalinity. It is important in selecting crops and other plants, in evaluating soil amendments for fertility and stabilization, and in determining the risk of corrosion.

Calcium carbonate equivalent is the percent of carbonates, by weight, in the fraction of the soil less than 2 millimeters in size. The availability of plant nutrients is influenced by the amount of carbonates in the soil.

Gypsum is expressed as a percent, by weight, of hydrated calcium sulfates in the fraction of the soil less than 20 millimeters in size. Gypsum is partially soluble in water. Soils that have a high content of gypsum may collapse if the gypsum is removed by percolating water.

Salinity is a measure of soluble salts in the soil at saturation. It is expressed as the electrical conductivity of the saturation extract, in millimhos per centimeter at 25 degrees C. Estimates are based on field and laboratory measurements at representative sites of nonirrigated soils. The salinity of irrigated soils is affected by the quality of the irrigation water and by the frequency of water application. Hence, the salinity of soils in individual fields can differ greatly from the value given in the table. Salinity affects the suitability of a soil for crop production, the stability of soil if used as construction material, and the potential of the soil to corrode metal and concrete.

Sodium adsorption ratio (SAR) is a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water extract from saturated soil paste. It is the ratio of the Na concentration divided by the square root of one-half of the Ca + Mg concentration. Soils that have SAR values of 13 or more may be characterized by an increased dispersion of organic matter and clay particles, reduced saturated hydraulic conductivity and aeration, and a general degradation of soil structure.

Chemical Soil Properties–Travis County, Texas								
Map symbol and soil name	**Depth**	**Cation-exchange capacity**	**Effective cation-exchange capacity**	**Soil reaction**	**Calcium carbonate**	**Gypsum**	**Salinity**	**Sodium adsorption ratio**
	In	*meq/100g*	*meq/100g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
AgC2—Altoga silty clay, 3 to 6 percent slopes, moderately eroded								
Altoga, eroded	0-5	15-30	—	7.9-8.4	30-70	0	0	0
	5-24	15-30	—	7.9-8.4	40-75	0	0	0
	24-60	10-30	—	7.9-8.4	40-75	0	0	0
BtB—Burleson gravelly clay, 1 to 3 percent slopes								
Burleson	0-16	40-60	—	5.6-8.4	0-5	0	0.0-2.0	0
	16-42	40-60	—	5.6-8.4	2-8	0	0.0-4.0	0-1
	42-60	40-60	—	7.4-8.4	2-15	0	0.0-4.0	0-2
ChC2—Chaney fine sandy loam, 2 to 5 percent slopes, moderately eroded								
Chaney, eroded	0-6	5.0-10	—	5.6-7.3	0	0	0.0-2.0	0
	6-24	15-30	—	5.6-7.3	0	0	0.0-2.0	0
	24-54	15-30	—	5.6-8.4	0-2	0-2	0.0-2.0	0
	54-60	15-30	—	5.6-8.4	0-2	0-2	0.0-2.0	0

Chemical Soil Properties–Travis County, Texas								
Map symbol and soil name	**Depth**	**Cation-exchange capacity**	**Effective cation-exchange capacity**	**Soil reaction**	**Calcium carbonate**	**Gypsum**	**Salinity**	**Sodium adsorption ratio**
	In	*meq/100g*	*meq/100g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
FhF3—Ferris-Heiden complex, 8 to 20 percent slopes, severely eroded								
Ferris, severely eroded	0-6	40-60	—	7.9-8.4	0-5	0	0.0-2.0	0
	6-36	40-60	—	7.9-8.4	2-30	0	0.0-2.0	0-1
	36-60	20-45	—	7.9-8.4	0-15	0-5	0.0-2.0	1-5
Heiden, severely eroded	0-6	20-45	—	7.9-8.4	0-30	0	0.0-2.0	0-2
	6-15	20-45	—	7.9-8.4	10-40	0-1	0.0-2.0	0-2
	15-50	20-45	—	7.9-8.4	20-40	0-5	0.0-2.0	2-12
	50-80	20-40	—	7.9-8.4	25-55	0-5	0.0-2.0	2-10
HeC2—Heiden clay, 3 to 5 percent slopes, eroded								
Heiden, moderately eroded	0-13	38-62	—	7.9-8.4	0-5	0	0.0-2.0	0-2
	13-22	36-60	—	7.9-8.4	2-35	0-1	0.0-2.0	0-2
	22-58	36-56	—	7.9-8.4	5-35	0-5	0.0-2.0	2-12
	58-80	24-37	—	7.9-8.4	15-40	0-5	0.0-2.0	2-12
HeD2—Heiden clay, 5 to 8 percent slopes, eroded								
Heiden, moderately eroded	0-8	38-62	—	7.9-8.4	0-5	0	0.0-2.0	0-2
	8-22	36-60	—	7.9-8.4	2-35	0-1	0.0-2.0	0-2
	22-44	36-56	—	7.9-8.4	5-35	0-5	0.0-2.0	2-12
	44-80	24-37	—	7.9-8.4	15-40	0-5	0.0-2.0	2-12

Chemical Soil Properties–Travis County, Texas								
Map symbol and soil name	**Depth**	**Cation-exchange capacity**	**Effective cation-exchange capacity**	**Soil reaction**	**Calcium carbonate**	**Gypsum**	**Salinity**	**Sodium adsorption ratio**
	In	*meq/100g*	*meq/100g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
HgF2—Heiden gravelly clay, 8 to 20 percent slopes, moderately eroded								
Heiden, eroded	0-6	20-45	—	7.9-8.4	0-30	0	0.0-2.0	0-2
	6-12	20-45	—	7.9-8.4	10-40	0-1	0.0-2.0	0-2
	12-48	20-45	—	7.9-8.4	20-40	0-5	0.0-2.0	2-12
	48-80	20-40	—	7.9-8.4	25-55	0-5	0.0-2.0	2-10
HnB—Houston Black clay, 1 to 3 percent slopes								
Houston black	0-6	40-51	—	7.4-8.4	10-30	0	0.0-2.0	0
	6-70	40-51	—	7.4-8.4	15-35	0-3	0.0-2.0	0
	70-80	38-55	—	7.4-8.4	25-35	0-5	0.0-2.0	0-2
HnC2—Houston Black clay, 3 to 5 percent slopes, moderately eroded								
Houston black, moderately eroded	0-6	40-51	—	7.4-8.4	10-30	0	0.0-2.0	0
	6-70	40-51	—	7.4-8.4	15-35	0-3	0.0-2.0	0
	70-80	38-55	—	7.4-8.4	25-35	0-5	0.0-2.0	0-2
HoD2—Houston Black gravelly clay, 2 to 8 percent slopes, moderately eroded								
Houston black, eroded	0-8	30-60	—	7.4-8.4	10-30	0	0.0-2.0	0
	8-24	30-60	—	7.4-8.4	15-35	0	0.0-2.0	0
	24-80	20-45	—	7.4-8.4	30-40	0	0.0-4.0	0-2

Chemical Soil Properties–Travis County, Texas								
Map symbol and soil name	**Depth**	**Cation-exchange capacity**	**Effective cation-exchange capacity**	**Soil reaction**	**Calcium carbonate**	**Gypsum**	**Salinity**	**Sodium adsorption ratio**
	In	*meq/100g*	*meq/100g*	*pH*	*Pct*	*Pct*	*mmhos/cm*	
WIB—Wilson clay loam, 1 to 3 percent slopes								
Wilson	0-6	20-30	—	5.6-7.3	0	0	0.0-2.0	0-2
	6-42	20-30	—	5.6-7.8	1-10	0-4	0.0-4.0	2-8
	42-60	20-30	—	6.6-8.4	1-20	2-15	2.0-8.0	4-10

Soil Physical Properties

This folder contains a collection of tabular reports that present soil physical properties. The reports (tables) include all selected map units and components for each map unit. Soil physical properties are measured or inferred from direct observations in the field or laboratory. Examples of soil physical properties include percent clay, organic matter, saturated hydraulic conductivity, available water capacity, and bulk density.

Engineering Properties

This table gives the engineering classifications and the range of engineering properties for the layers of each soil in the survey area.

Hydrologic soil group is a group of soils having similar runoff potential under similar storm and cover conditions. The criteria for determining Hydrologic soil group is found in the National Engineering Handbook, Chapter 7 issued May 2007(http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba). Listing HSGs by soil map unit component and not by soil series is a new concept for the engineers. Past engineering references contained lists of HSGs by soil series. Soil series are continually being defined and redefined, and the list of soil series names changes so frequently as to make the task of maintaining a single national list virtually impossible. Therefore, the criteria is now used to calculate the HSG using the component soil properties and no such national series lists will be maintained. All such references are obsolete and their use should be discontinued. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to a seasonal high water table, saturated hydraulic conductivity after prolonged wetting, and depth to a layer with a very slow water transmission rate. Changes in soil properties caused by land management or climate changes also cause the hydrologic soil group to change. The influence of ground cover is treated independently. There are four hydrologic soil groups, A, B, C, and D, and three dual groups, A/D, B/D, and C/D. In the dual groups, the first letter is for drained areas and the second letter is for undrained areas.

The four hydrologic soil groups are described in the following paragraphs:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Depth to the upper and lower boundaries of each layer is indicated.

Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. "Loam," for example, is soil that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If the content of particles coarser than sand is 15 percent or more, an appropriate modifier is added, for example, "gravelly."

Classification of the soils is determined according to the Unified soil classification system (ASTM, 2005) and the system adopted by the American Association of State Highway and Transportation Officials (AASHTO, 2004).

The Unified system classifies soils according to properties that affect their use as construction material. Soils are classified according to particle-size distribution of the fraction less than 3 inches in diameter and according to plasticity index, liquid limit, and organic matter content. Sandy and gravelly soils are identified as GW, GP, GM, GC, SW, SP, SM, and SC; silty and clayey soils as ML, CL, OL, MH, CH, and OH; and highly organic soils as PT. Soils exhibiting engineering properties of two groups can have a dual classification, for example, CL-ML.

The AASHTO system classifies soils according to those properties that affect roadway construction and maintenance. In this system, the fraction of a mineral soil that is less than 3 inches in diameter is classified in one of seven groups from A-1 through A-7 on the basis of particle-size distribution, liquid limit, and plasticity index. Soils in group A-1 are coarse grained and low in content of fines (silt and clay). At the other extreme, soils in group A-7 are fine grained. Highly organic soils are classified in group A-8 on the basis of visual inspection.

If laboratory data are available, the A-1, A-2, and A-7 groups are further classified as A-1-a, A-1-b, A-2-4, A-2-5, A-2-6, A-2-7, A-7-5, or A-7-6. As an additional refinement, the suitability of a soil as subgrade material can be indicated by a group index number. Group index numbers range from 0 for the best subgrade material to 20 or higher for the poorest.

Rock fragments larger than 10 inches in diameter and 3 to 10 inches in diameter are indicated as a percentage of the total soil on a dry-weight basis. The percentages are estimates determined mainly by converting volume percentage in the field to weight percentage.

Percentage (of soil particles) passing designated sieves is the percentage of the soil fraction less than 3 inches in diameter based on an ovendry weight. The sieves, numbers 4, 10, 40, and 200 (USA Standard Series), have openings of 4.76, 2.00, 0.420, and 0.074 millimeters, respectively. Estimates are based on laboratory tests of soils sampled in the survey area and in nearby areas and on estimates made in the field.

Liquid limit and *plasticity index* (Atterberg limits) indicate the plasticity characteristics of a soil. The estimates are based on test data from the survey area or from nearby areas and on field examination.

References:

American Association of State Highway and Transportation Officials (AASHTO). 2004. Standard specifications for transportation materials and methods of sampling and testing. 24th edition.

American Society for Testing and Materials (ASTM). 2005. Standard classification of soils for engineering purposes. ASTM Standard D2487-00.

Absence of an entry indicates that the data were not estimated. The asterisk '*' denotes the representative texture; other possible textures follow the dash. The criteria for determining the hydrologic soil group for individual soil components is found in the National Engineering Handbook, Chapter 7 issued May 2007(http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba).

Engineering Properties–Travis County, Texas														
Map unit symbol and soil name	**Pct. of map unit**	**Hydrologic group**	**Depth**	**USDA texture**	**Classification**		**Fragments**		**Percentage passing sieve number—**				**Liquid limit**	**Plasticity index**
					Unified	**AASHTO**	**>10 inches**	**3-10 inches**	**4**	**10**	**40**	**200**		
			In				*Pct*	*Pct*					*Pct*	
AgC2—Altoga silty clay, 3 to 6 percent slopes, moderately eroded														
Altoga, eroded	95	B	0-5	Silty clay	CH, CL	A-7-6	0- 0- 0	0- 0- 0	95-98-100	95-98-100	90-95-100	70-85-99	45-53-60	22-29-36
			5-24	Silty clay, silty clay loam	CH, CL	A-6, A-7-6	0- 0- 0	0- 0- 0	95-98-100	95-98-100	90-95-100	70-85-99	36-46-55	18-26-33
			24-60	Silty clay, silty clay loam, loam	CH, CL	A-6, A-7-6	0- 0- 0	0- 0- 0	95-98-100	95-98-100	90-95-100	58-79-99	32-44-55	15-24-33
BtB—Burleson gravelly clay, 1 to 3 percent slopes														
Burleson	90	D	0-16	Gravelly clay	CH	A-7-6	0- 0- 0	0- 3- 5	80-90-100	60-70-80	60-70-80	55-68-80	56-66-75	33-41-49
			16-42	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 1- 1	90-95-100	90-95-100	90-95-99	80-90-99	51-63-75	34-44-54
			42-60	Clay, silty clay, clay loam	CH	A-7-6	0- 0- 0	0- 1- 2	90-95-100	80-90-100	75-87-99	67-83-98	51-63-75	34-44-54

Engineering Properties–Travis County, Texas														
Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification		Fragments		Percentage passing sieve number—				Liquid limit	Plasticity index
					Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
			In				*Pct*	*Pct*					*Pct*	
ChC2—Chaney fine sandy loam, 2 to 5 percent slopes, moderately eroded														
Chaney, eroded	95	C	0-6	Fine sandy loam	CL-ML, ML, SM	A-4	0- 0- 0	0- 0- 0	95-98-100	90-95-100	80-88-95	45-55-65	16-23-30	NP-4 -7
			6-24	Clay, sandy clay	CH, CL, SC	A-6, A-7-6	0- 0- 0	0- 0- 0	90-95-100	90-95-100	90-95-100	43-64-85	39-50-60	24-33-42
			24-54	Sandy clay, clay, sandy clay loam	CH, CL, SC	A-6, A-7-6	0- 0- 0	0- 0- 0	90-95-100	90-95-100	80-90-100	45-65-85	25-40-55	11-26-40
			54-60	Channery clay, sandy clay loam, sandy clay	CH, CL, SC, SC-SM	A-2, A-4, A-6, A-7-6	0- 0- 0	0- 0- 0	90-95-100	90-95-100	80-90-100	25-55-85	25-43-60	6-23-40
FhF3—Ferris-Heiden complex, 8 to 20 percent slopes, severely eroded														
Ferris, severely eroded	60	D	0-6	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	92-96-100	92-96-100	75-88-100	75-88-100	51-64-76	35-45-55
			6-36	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	92-96-100	92-96-100	75-88-100	72-86-100	51-65-78	35-46-56
			36-60	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	92-96-100	92-96-100	85-93-100	75-88-100	61-81-100	42-59-75
Heiden, severely eroded	35	D	0-6	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	95-98-100	90-95-100	80-90-100	75-87-99	51-66-80	32-44-55
			6-15	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	95-98-100	90-95-100	80-90-100	75-87-99	51-66-80	32-44-55
			15-50	Clay, silty clay	CH, CL	A-7-6	0- 0- 0	0- 0- 0	95-98-100	90-95-100	75-88-100	70-80-90	49-65-80	32-44-55
			50-80	Clay	CH, CL	A-7-6	0- 0- 0	0- 0- 0	92-96-100	92-96-100	85-93-100	70-80-90	49-65-80	32-44-55

Engineering Properties–Travis County, Texas														
Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification		Fragments		Percentage passing sieve number—				Liquid limit	Plasticity index
					Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
			In				*Pct*	*Pct*					*Pct*	
HeC2—Heiden clay, 3 to 5 percent slopes, eroded														
Heiden, moderately eroded	85	D	0-13	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	90-96-100	80-94-100	65-81-94	50-60-80	30-40-55
			13-22	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	90-96-100	80-94-100	65-81-98	50-60-80	30-40-55
			22-58	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	90-96-100	80-94-100	65-81-98	50-60-80	30-40-55
			58-80	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	98-100-100	97-100-100	86-98-100	71-86-95	50-70-80	30-45-55
HeD2—Heiden clay, 5 to 8 percent slopes, eroded														
Heiden, moderately eroded	85	D	0-8	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	90-96-100	80-94-100	65-81-94	50-60-80	30-40-55
			8-22	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	90-96-100	80-94-100	65-81-98	50-60-80	30-40-55
			22-44	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	90-96-100	80-94-100	65-81-98	50-60-80	30-40-55
			44-80	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	98-100-100	97-100-100	86-98-100	71-86-95	50-70-80	30-45-55

Engineering Properties–Travis County, Texas														
Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification		Fragments		Percentage passing sieve number—				Liquid limit	Plasticity index
					Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
			In				*Pct*	*Pct*					*Pct*	
HgF2—Heiden gravelly clay, 8 to 20 percent slopes, moderately eroded														
Heiden, eroded	95	D	0-6	Gravelly clay	CH	A-7-6	0- 0- 0	0- 5- 10	55-68-80	55-68-80	55-68-80	50-63-75	58-74-90	34-47-60
			6-12	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	95-98-100	90-95-100	80-90-100	75-87-99	51-66-80	32-44-55
			12-48	Clay, silty clay	CH, CL	A-7-6	0- 0- 0	0- 0- 0	95-98-100	90-95-100	75-88-100	70-80-90	49-65-80	32-44-55
			48-80	Clay, silty clay	CH, CL	A-7-6	0- 0- 0	0- 0- 0	92-96-100	92-96-100	85-93-100	70-80-90	49-65-80	32-44-55
HnB—Houston Black clay, 1 to 3 percent slopes														
Houston black	80	D	0-6	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	92-96-100	81-92-100	71-81-90	63-70-76	34-44-49
			6-70	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	98-98-100	96-96-100	85-92-100	74-81-90	58-70-76	38-44-49
			70-80	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	94-96-100	86-92-100	74-88-100	65-78-95	61-71-75	37-45-50
HnC2—Houston Black clay, 3 to 5 percent slopes, moderately eroded														
Houston black, moderately eroded	90	D	0-6	Clay	CH	A-7-6	0- 0- 0	0- 0- 0	96-98-100	92-96-100	81-92-100	71-81-90	63-70-76	38-44-49
			6-70	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	98-98-100	96-96-100	85-92-100	74-81-90	63-70-71	38-44-49
			70-80	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	94-96-100	86-92-100	74-88-100	65-78-95	61-71-75	37-45-50

Engineering Properties–Travis County, Texas														
Map unit symbol and soil name	Pct. of map unit	Hydrologic group	Depth	USDA texture	Classification		Fragments		Percentage passing sieve number—				Liquid limit	Plasticity index
					Unified	AASHTO	>10 inches	3-10 inches	4	10	40	200		
			In				*Pct*	*Pct*					*Pct*	
HoD2—Houston Black gravelly clay, 2 to 8 percent slopes, moderately eroded														
Houston black, eroded	95	D	0-8	Gravelly clay	CH	A-7-6	0- 0- 0	0- 3- 5	55-68-80	55-68-80	55-68-80	50-63-75	58-74-90	34-47-60
			8-24	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	98-99-100	98-99-100	92-96-100	88-93-97	58-78-98	37-55-72
			24-80	Clay, silty clay	CH	A-7-6	0- 0- 0	0- 0- 0	94-97-100	93-97-100	87-94-100	84-92-99	51-75-99	32-55-78
WIB—Wilson clay loam, 1 to 3 percent slopes														
Wilson	95	D	0-6	Clay loam	CL	A-6, A-7-6	0- 0- 0	0- 0- 0	95-98-100	85-93-100	80-90-100	60-78-96	38-44-49	20-25-30
			6-42	Silty clay, clay, clay loam	CH, CL	A-7-6	0- 0- 0	0- 0- 0	90-95-100	80-90-100	80-90-100	65-81-96	43-50-56	26-32-37
			42-60	Silty clay, clay, silty clay loam	CH, CL	A-6, A-7-6	0- 0- 0	0- 0- 0	95-98-100	90-95-100	85-93-100	70-83-96	38-52-65	24-36-48

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APPENDIX B

SAMPLE FPS21 OUTPUT

TEXAS DEPARTMENT OF TRANSPORTATION

F P S21-1.3 *FLEXIBLE PAVEMENT SYSTEM* *Release:7-1-2015*

PAVEMENT DESIGN TYPE # 5 -- ACP + FLEX BASE + STAB SBGR OVER SUBGRADE

PROB	DIST.-14	COUNTY-227	CONT.	SECT.	JOB	HIGHWAY	DATE	PAGE
001	**Austin**	**TRAVIS**	**1234**	**1**	**1**	**0**	**5/4/2017**	**1**

COMMENTS ABOUT THIS PROBLEM

CAPEC - Urban Collector Low Traffic
HMAC over Flexible Base
Traffic - 700,000 ESALs
Subgrade Modulus - 2 ksi

BASIC DESIGN CRITERIA

LENGTH OF THE ANALYSIS PERIOD (YEARS)	40.0
MINIMUM TIME TO FIRST OVERLAY (YEARS)	20.0
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	8.0
DESIGN CONFIDENCE LEVEL (90.0%)	B
SERVICEABILITY INDEX OF THE INITIAL STRUCTURE	4.2
FINAL SERVICEABILITY INDEX P2	2.5
SERVICEABILITY INDEX P1 AFTER AN OVERLAY	4.0
DISTRICT TEMPERATURE CONSTANT	31.0
SUBGRADE ELASTIC MODULUS by COUNTY (ksi)	2.00
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	7.0

PROGRAM CONTROLS AND CONSTRAINTS

NUMBER OF SUMMARY OUTPUT PAGES DESIRED (8 DESIGNS/PAGE)	3
MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)	99.00
MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)	99.0
ACCUMULATED MAX DEPTH OF ALL OVERLAYS (INCHES) (EXCLUDING LEVEL-UP)	6.0

TRAFFIC DATA

ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)	4000.
ADT AT END OF TWENTY YEARS (VEHICLES/DAY)	7959.
ONE-DIRECTION 20YEAR 18 kip ESAL (millions)	0.700
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE(MPH)	35.0
AVERAGE SPEED THROUGH OVERLAY ZONE (OVERLAY DIRECTION)(MPH)	35.0
AVERAGE SPEED THROUGH OVERLAY ZONE (NON-OVERLAY DIRECTION) (MPH)	35.0
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)	5.0
PERCENT TRUCKS IN ADT	10.0

PAVEMENT DESIGN TYPE # 5 -- ACP + FLEX BASE + STAB SBGR OVER SUBGRADE

PROB	DIST.-14	COUNTY-227	CONT.	SECT.	JOB	HIGHWAY	DATE	PAGE
001	**Austin**	**TRAVIS**	**1234**	**1**	**1**	**0**	**5/4/2017**	**2**

INPUT DATA CONTINUED

CONSTRUCTION AND MAINTENANCE DATA

MINIMUM OVERLAY THICKNESS (INCHES)	2.0
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	12.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	1.98
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	200.0
WIDTH OF EACH LANE (FEET)	12.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE-MILE)	125.00
ANNUAL INCREMENTAL INCREASE IN MAINTENANCE COST (DOLLARS/LANE-MILE)	50.00

DETOUR DESIGN FOR OVERLAYS

TRAFFIC MODEL USED DURING OVERLAYING	2
TOTAL NUMBER OF LANES OF THE FACILITY	2
NUMBER OF OPEN LANES IN RESTRICTED ZONE (OVERLAY DIRECTION)	0
NUMBER OF OPEN LANES IN RESTRICTED ZONE (NON-OVERLAY DIRECTION)	1
DISTANCE TRAFFIC IS SLOWED (OVERLAY DIRECTION) (MILES)	0.60
DISTANCE TRAFFIC IS SLOWED (NON-OVERLAY DIRECTION) (MILES)	0.00
DETOUR DISTANCE AROUND THE OVERLAY ZONE (MILES)	0.00

PAVING MATERIALS INFORMATION

LAYER	CODE	MATERIALS NAME	COST PER CY	E MODULUS	POISSON RATIO	MIN. DEPTH	MAX. DEPTH	SALVAGE PCT.
1	A	ASPH CONC PVMT	115.00	500000.	0.35	3.50	4.00	30.00
2	B	FLEXIBLE BASE	37.00	50000.	0.35	14.00	14.00	75.00
3	C	STABILIZED SUBGR	15.00	6000.	0.30	12.00	12.00	90.00
4	D	SUBGRADE(200)	2.00	2000.	0.40	200.00	200.00	90.00

Texas Department of Transportation

TEXAS DEPARTMENT OF TRANSPORTATION

F P S21-1.3 *FLEXIBLE PAVEMENT SYSTEM* *Release:7-1-2015*

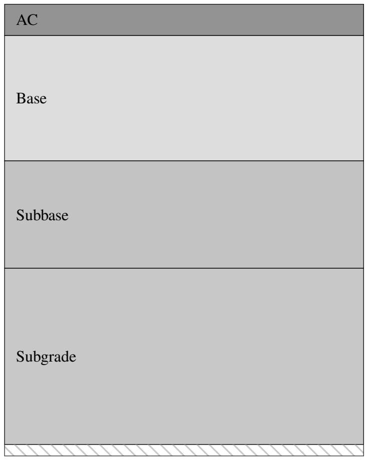
PAVEMENT DESIGN TYPE # 5 -- ACP + FLEX BASE + STAB SBGR OVER SUBGRADE

PROB	DIST.-14	COUNTY-227	CONT.	SECT.	JOB	HIGHWAY	DATE	PAGE
001	**Austin**	**TRAVIS**	**1234**	**1**	**1**	**0**	**5/4/2017**	**3**

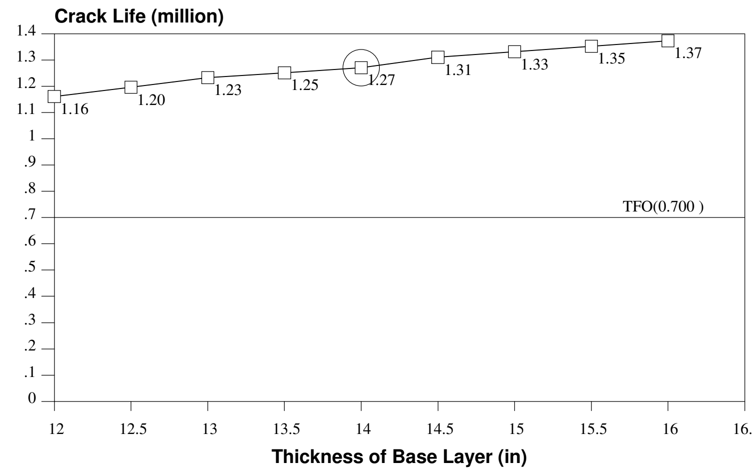
C. LEVEL B SUMMARY OF THE BEST DESIGN STRATEGIES
IN ORDER OF INCREASING TOTAL COST

	1
MATERIAL ARRANGEMENT	ABC
INIT. CONST. COST	30.57
OVERLAY CONST. COST	0.00
USER COST	0.00
ROUTINE MAINT. COST	1.41
SALVAGE VALUE	-1.25
TOTAL COST	30.73
NUMBER OF LAYERS	3
LAYER DEPTH (INCHES)	
D(1)	3.50
D(2)	14.00
D(3)	12.00
NO.OF PERF.PERIODS	1
PERF. TIME (YEARS)	
T(1)	40.
OVERLAY POLICY(INCH) (INCLUDING LEVEL-UP)	

THE TOTAL NUMBER OF FEASIBLE DESIGNS CONSIDERED WAS 2



	Thickness (inches)	Modulus (ksi)	Poisson's Ratio	Material Name
AC	3.50	500.00	0.35	ASPH CONC PVMT
Base	14.00	50.00	0.35	FLEXIBLE BASE
Subbase	12.00	6.00	0.30	STABILIZED SUBGR
Subgrade	200.00	2.00	0.40	SUBGRADE(200)



Fatigue Crack Model:

$$N_f = f_1(\varepsilon_t)^{-f_2}(E_1)^{-f_3}$$

f_1 =7.96E-02

f_2 = 3.291

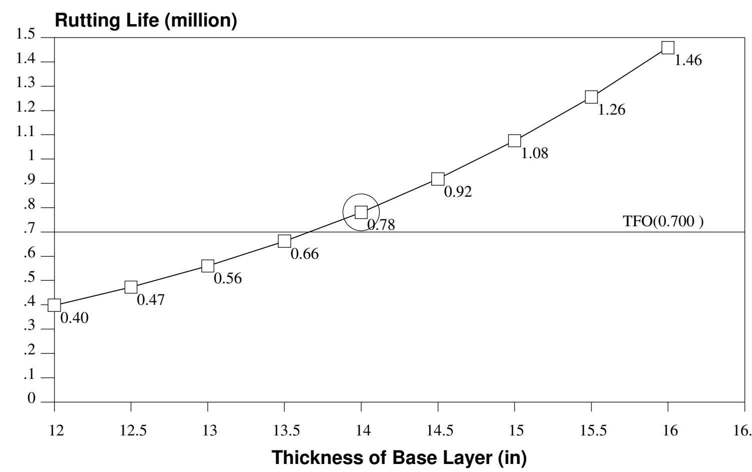
f_3 = .854

Rutting Model:

$$N_d = f_4(\varepsilon_v)^{-f_5}$$

f_4 =1.37E-09

f_5 = 4.477



TFO(Traffic to 1st Overlay): 0.70 (million)

Crack Life: 1.27 (million) ε_τ = 215.00 ($\mu\varepsilon$)

Rut Life: 0.78 (million) ε_v = -506.00 ($\mu\varepsilon$)

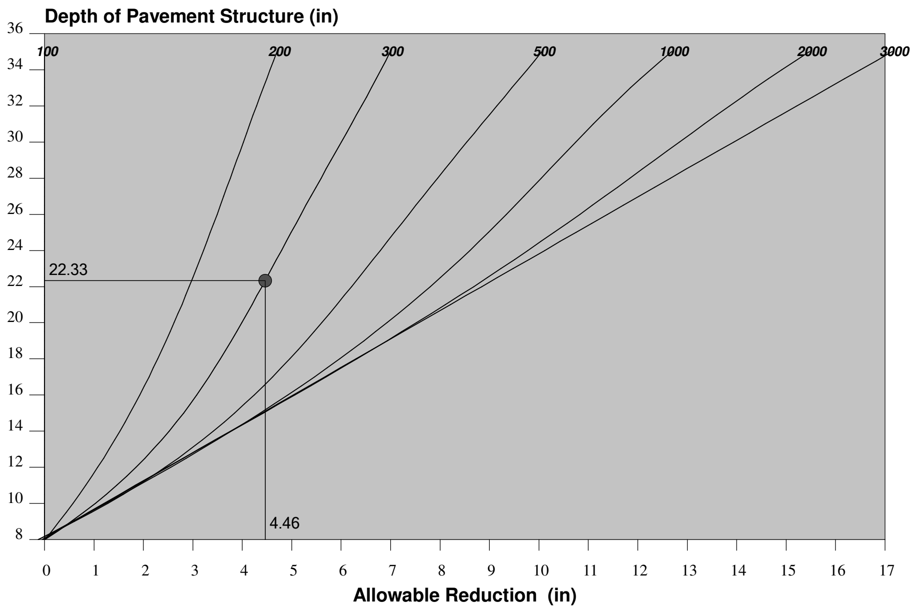
Traffic to 1st Overlay is calculated by analysis period: 40years and 18 kips:.70millions.
Also the start ADT:4000.0 and ending ADT:7959.0

Mechanistic Check Conclusion:

The design is OK !

FPS 21 Mechanistic Design Check Output (FPS21-1.3Release:7-1-2015)			
Highway	0	Problem	001
C-S-J	1234 - 1 - 1	Date	5/4/2017
District	Austin	County	TRAVIS
Design Type:Asphalt concrete + Flexible Base + Stabilized Subgrade over Subgrade			

	Thickness (inches)	Modulus (ksi)	Poisson's Ratio	Material Name
ASPH CONC PVMT	3.50	500.00	0.35	ASPH CONC PVMT
FLEXIBLE BASE	14.00	50.00	0.35	FLEXIBLE BASE
STABILIZED SUBGR	12.00	6.00	0.30	STABILIZED SUBGR
SUBGRADE(200)	200.00	2.00	0.40	SUBGRADE(200)
Bed Rock		200.00	0.15	Bed Rock



Thickness Reduction Chart for Stabilized Layers

INPUT PARAMETERS:

The Heaviest Wheel Loads Daily (ATHWLD)	10000.0 (lb)
Percentage of TandemAxles	40.0 (%)
Modified Cohesionmeter Value	300.0
Design Wheel Load	10000.0 (lb)
Subgrade Texas Triaxial Class Number (TTC)	5.80

TTC is based on Texas County Soil Database for (TRAVIS)

For soils type : clay of high plasticity, fat clay(CH)

RESULT:

Triaxial Thickness Required	22.3 (in)
The FPS Design Thickness	29.5 (in)
Allowable Thickness Reduction	4.5 (in)
Modified Triaxial Thickness	17.9 (in)

TRIAXIAL CHECK CONCLUSION:

The Design OK !

FPS 21 Triaxial Design Check Output (FPS21-1.3Release:7-1-2015)			
Highway	0	Problem	001
C-S-J	1234 - 1 - 1	Date	5/4/2017
District	Austin	County	TRAVIS

Design Type:Asphalt concrete + Flexible Base + Stabilized Subgrade over Subgrade

APPENDIX C

SAMPLE STREETPAVE 12 OUTPUT

DowelCondition

StreetPave 12

Report for Concrete Pavement Design

Project Name: Urban Collector Low Traffic 2 ksi
Route:
Location:
Project Description:
Owner/Agency:
Design Engineer:

Recommended Concrete Pavement Design

Min. Required Thickness = 6.13 in
Design Thickness = 6.50 in
Max. Joint Spacing = 13 ft
Failure Controlled By = Cracking

*Because the doweled thickness is less than 8 in. and cracking is the predicted cause of failure, dowel bars typically would not be recommended for the design details you provided.

Rounding Considerations:

Thickness Adjustment	Thickness (in.)	Reliability at Specified Design Life (%)	Theoretical Life at Specified Reliability (yrs)
Rounded-Down	6.00	99.9	21
None (As-Designed)	6.13	90	30
Rounded-Up (Recommended)	6.50	99.9	59

Inputs

Design Life: 30 years

Reliability

Reliability: 90 %
Percent of Slabs Cracked at End of Design Life: 15 %

Traffic

Traffic Category: Collector
Direction Distribution: 50
Design Lane Distribution: 100
Trucks per Day (two-way, at time of construction): 230 per day

Truck Traffic Growth: 3.5 % per year
Rigid ESALs = 708,806

Support Conditions

Subgrade

Specified Resilient Modulus of the Subgrade: 2,000 psi

Subbase

Top Layer:	Hot-Mix or Warm-Mix Asphalt Subbase			
		Modulus:	500,000	psi
		Thickness :	4	in
Layer 2:	Lime-Stabilized Subgrade			
		Modulus:	20,000	psi
		Thickness:	12	in
Layer 3:	Not Selected			
		Modulus:	0	psi
		Thickness:	0	in

Composite Modulus of Subgrade Reaction (k-Value):

k = 233 psi/in

Concrete Properties

28-Day Flexural Strength (MR):	620	psi
Macrofibers in Concrete?	No	
Residual Strength:	N/A	%
Modulus of Elasticity (E):	5,000,000	psi

Modulus of Elasticity (E) = 6750 x MR

Design Features

Load Transfer Devices (Dowel Bars)? Yes

Diameter = Not Recommended

Edge Support Provided? Yes
(e.g., tied concrete shoulder, curb and gutter, or widened lane)

DowelCondition

Fatigue & Erosion Calculations

Traffic Category: Collector			Cracking Analysis			Faulting Analysis		
Axle Load, kips	Axles per 1000 Trucks	Expected Repetitions	Stress Ratio	Allowable Repetitions	Fatigue Consumed	Power	Allowable Repetitions	Erosion Consumed
				Single Axles				
26	0.07	152	0.657	1453	10.45	20.692	675767	0.02
24	1.6	3469	0.609	5465	63.49	17.631	1257769	0.28
22	2.6	5638	0.561	30371	18.56	14.815	2747341	0.21
20	6.63	14376	0.513	294981	4.87	12.244	8276413	0.17
18	16.61	36016	0.465	6549342	0.55	9.918	75469966	0.05
16	23.88	51780	0.416	521530287	0.01	7.837	unlimited	0
14	47.76	103560	0.367	unlimited	0	6	unlimited	0
12	116.76	253176	0.318	unlimited	0	4.408	unlimited	0
10	142.7	309423	0.268	unlimited	0	3.061	unlimited	0
8	233.6	506526	0.217	unlimited	0	1.959	unlimited	0
				Tandem Axles				
44	1.16	2515	0.469	4857446	0.05	15.357	2309680	0.11
40	7.76	16826	0.429	144305812	0.01	12.692	6516890	0.26
36	38.79	84110	0.388	unlimited	0	10.28	42968945	0.2
32	54.76	118739	0.348	unlimited	0	8.123	unlimited	0
28	44.43	96340	0.307	unlimited	0	6.219	unlimited	0
24	30.74	66655	0.265	unlimited	0	4.569	unlimited	0
20	45	97576	0.223	unlimited	0	3.173	unlimited	0
16	59.25	128475	0.181	unlimited	0	2.031	unlimited	0
12	91.15	197645	0.138	unlimited	0	1.142	unlimited	0
8	47.01	101934	0.094	unlimited	0	0.508	unlimited	0
				Tridem Axles				
62	0	0	0.427	170678053	0	16.147	1833694	0
56	0	0	0.388	unlimited	0	13.173	5180222	0
50	0	0	0.349	unlimited	0	10.502	32657352	0
44	0	0	0.309	unlimited	0	8.132	unlimited	0
38	0	0	0.27	unlimited	0	6.066	unlimited	0
32	0	0	0.229	unlimited	0	4.301	unlimited	0
26	0	0	0.189	unlimited	0	2.84	unlimited	0
20	0	0	0.147	unlimited	0	1.68	unlimited	0
14	0	0	0.105	unlimited	0	0.823	unlimited	0
8	0	0	0.062	unlimited	0	0.269	unlimited	0
			Total Fatigue Used %:		**98**	**Total Erosion Used %:**		**1.31**