Table of Contents

List of Tables

List of Figures

SECTION 3 – PAVEMENT DESIGN

3.1 INTRODUCTION

3.1.1 Objective

The objective of this section is to provide the City of Round Rock's (the City) Roadway Designers and Geotechnical Engineers with a pavement design overview covering the design inputs, design methodology, and representative pavement sections for the various roadway classifications within the City and its jurisdiction.

This section is intended to address most pavement design considerations within the City. Deviations from the pavement design methodology or minimum design criteria set forth in this section shall be documented in the Pavement Design Report and approved by the Transportation Director.

3.1.2 Scope

The scope of this document includes design criteria and design guidance for flexible and rigid pavements constructed on city streets under the authority of the City of Round Rock, within city limits and within its Extraterritorial Jurisdiction (ETJ).

This document is not intended to cover design of pavement for highways under the authority of the Texas Department of Transportation (TxDOT) or Williamson County. For these roadways, the reader is referred to design manuals such as TxDOT's "Pavement Design Guide" or Williamson County's Criteria Manual.

3.1.3 Standard of Care

The services described in this section shall be completed under the direction of an appropriately experienced Professional Engineer registered in the State of Texas. Geotechnical engineers shall be retained to address the geotechnical-related aspects of pavement designs described in this section. Roles and responsibilities adopted for the purpose of this manual are provided below:

- Roadway Designer: Professional Civil Engineer with responsible charge for completion of the design project. The Roadway Designer is responsible for coordinating all elements of the project (civil, roadway, geotechnical, pavement, etc.), and preparing final plans and specifications required for contractors to bid on construction of the project. The Roadway Designer is also responsible for developing design traffic parameters and roadway design layouts for use by the Geotechnical Engineer and/or Pavement Engineer;
- Geotechnical Engineer: Professional Civil Engineer responsible for the geotechnical engineering-related aspects of pavement design, including subsurface investigation and subgrade treatment/ stabilization recommendations. Depending on the project, the

Geotechnical Engineer may also assume the responsibilities of the Pavement Engineer; and

- Pavement Engineer: Professional Civil Engineer responsible for the pavement design, including pavement materials selection and layer thicknesses required to support design traffic loading and life cycle cost analyses. Depending on the project, these responsibilities may be transferred to the Geotechnical Engineer.

3.1.4 References

This section has been updated significantly from the previous version of the City's Transportation Criteria Manual adopted in 2005. The bases of these updates are recent research findings presented by the Capital Area Pavement Engineering Council Initiative (CAPEC), and the more recent version of the TxDOT Pavement Design Guide (2011) and its 2016 draft revisions. Refer to the bibliography for these specific references.

3.1.5 List of Acronyms

Commonly used acronyms in this section are listed below.

ACPA	American Concrete Pavement Association
CAMPO	Capital Area Metropolitan Planning Organization
CAPEC	Capital Area Pavement Engineers Council
MSL	Mean Sea Level
NRCS	Natural Resource Conservation Service
OSHA	Occupational Safety and Health Administration
PCA	Portland Cement Association
PDR	Pavement Design Report
ROW	Right-of-Way
TxDOT	Texas Department of Transportation
USGS	United States Geological Survey

3.2 PAVEMENT DESIGN CRITERIA

3.2.1 General Criteria

All streets shall be constructed on an engineered subgrade, above which shall be placed a base layer and the pavement. Pavements shall be either Hot Mix Asphaltic Concrete (HMAC) or Concrete Pavement. For the purpose of this guide, HMAC pavements are considered "flexible pavements," and concrete pavements are considered "rigid pavements".

3.2.2 Design Life

Specific to flexible pavements, the following design periods apply:

- Pavement Design Life: 20 years;
- Time to First Overlay: 20 years; and
- Time Between Overlays: 10 years.

Rigid pavements to be constructed in public right-of-way (ROW) shall be designed for a minimum 30-year design life.

3.2.3 Design Methodology

The recommended pavement design methodology is a balanced approach that requires the Pavement Engineer to address the following:

- Design for Crack Resistance:
  - Consider environmental stresses (shrink/swell) in all soils regardless of high plasticity (‘high ‘PI’) soils;
  - Include Potential Vertical Rise (PVR) assessment calculations;
  - Consider fatigue cracking criteria in surface layers; and
  - Consider thinner base layers to offset cost (e.g., compensate with subgrade treatment or thicker HMAC/Concrete Pavement).
- Develop Subgrade Improvement Strategies (as needed):
  - Consider subbase layers; and
  - Recommend combination strategies.

3.2.4 Design Process Overview

Pavement design shall be based on the analytical process described in this section. This process will yield the required thickness of the pavement structure based on environmental and traffic conditions expected over the design life of the pavement. The Pavement Engineer should strive to produce the most cost-effective structural pavement design for the City using Life-Cycle Cost Analysis (LCCA) methodology developed by the Federal Highway Administration (FHWA).

The required pavement design software programs will provide the engineer with multiple pavement thickness options. The choice of materials to be used, the staging of construction, and design considerations all have an impact on the final pavement design selected. Prior to finalizing the pavement design, the Pavement Engineer shall coordinate with the City of Round Rock to account for such items as construction impacts (i.e., staged, urgency of completion, detours, and future widening), recycling efforts, drainage characteristics, traffic safety, and noise mitigation.

A Pavement Design Report (PDR) shall be prepared for each project. The PDR shall recommend a pavement section or sections based on analyses using traffic inputs, service factors, and subgrade conditions at the project site. The PDR shall be prepared by an appropriately experienced Professional Engineer licensed in the State of Texas.

The Design Engineer or Geotechnical Engineer shall submit a preliminary pavement design to the City for review and approval by the Transportation Director prior to finalizing the PDR and Contract Bidding Documents. The City has final approval authority for all pavement designs for streets in the public ROW.

In general, the steps for pavement design include those listed below:

1. Estimate design traffic loading and assign street classification;
2. Perform a geotechnical investigation to characterize subsurface soils: assign subgrade strength, evaluate risk of expansive soils, and identify any other geologic hazards or constraints;
3. Determine whether subgrade treatment/stabilization is required, and identify suitable alternatives;
4. Identify suitable pavement types (rigid or flexible), and develop preliminary pavement cross-section alternatives;
5. Evaluate long-term performance (fatigue, cracking, rutting, etc.) using the following software programs, and develop final pavement cross-section alternatives. The CORR's currently required software programs include:
    a. Flexible Pavement : FPS-21 by TxDOT; and
    b. Rigid Pavement: StreetPave12 by ACPA.
6. Perform Life Cycle Cost Analysis (LCCA), and develop recommended pavement cross-sections. Based on proposed street classification and requirements, the CORR may waive this requirement on a conditional basis; and
7. Prepare pavement design drawings, details, and specifications for inclusion in contract documents.

The version numbers listed above are currently available. The Pavement Engineer shall obtain and use the latest published version of the software programs for use in design. Detailed description and instructions for obtaining these software programs are provided later in this section.

3.3 TRAFFIC PARAMETERS FOR DESIGN

3.3.1 Traffic Data Collection

Traffic data must be developed for new roadways or existing roadways being widened for added capacity. Traffic data must address the variety of factors usually depicted with Traffic Impact Analyses (TIA) that predict the type and volume of future traffic. TIA should be adapted to address:

- Rather than peak hourly volumes, it is necessary to determine the full spectrum 24-hour traffic volumes and percent trucks required/ reported; and

- Rehabilitation or reconstruction of existing roadways should utilize traffic counts obtained from current traffic data and adapted to predict future volumes.

It is important that the traffic projections consider complete build-out of subdivisions and any future development that will be served by a specific street. Should the roadway's geometry require change (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 proposed roadway is along a new alignment, the anticipated traffic must be estimated for pavement design.

Resources to be consulted for obtaining existing traffic data are described below in order of precedence.

- City of Round Rock. The Roadway Designer should first contact the City's Transportation Department to verify what traffic data are available and to determine the need for collecting new traffic data. The methodology for obtaining existing and future traffic counts shall be approved by the Transportation Director prior to initiating a project. Traffic data may also be provided in the Transportation Master Plan (TMP) developed by the City.
- TxDOT. For roadways in TxDOT jurisdiction, a request for 20-year traffic projection for flexible pavements and 30-year traffic projection for rigid pavements may be made from the Traffic Section of the Transportation Planning and Programming Division (TPP) using Form 2124, Request for Traffic Data.
- CAMPO. The Capital Area Metropolitan Planning Organization (CAMPO, http://www.campotexas.org/) 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 are not available for the specific street under design.
- Software. Software such as StreetPave12 (software for rigid pavement design discussed subsequently herein) has predetermined traffic spectra and counts. These predetermined spectra are designated for "residential", "collector", "minor arterial," and "major arterial" general designated street classifications.

3.3.2 Design Basis and Required Traffic Parameters

Flexible and rigid pavement designs are developed around different traffic parameters, as described below.

- Flexible pavement design is developed around the 18 kip Equivalent Single Axle Wheel Loads (ESALs) in one direction. This parameter is the key input for FPS-21 flexible pavement design (discussed later).
- Rigid pavement design, using software such as StreetPave12, focuses on a traffic "spectrum" based on street classification rather than direct input of ESALs. In turn, Streetpave12 calculates the

design 18-kip ESALs of the specified pavement section for the given spectrum.

If both flexible and rigid pavement design alternatives are being considered, the design traffic needs to be reviewed to confirm the traffic 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 percent trucks inputs are changed to obtain the predicted ESALs.

The flexible and rigid pavement design methodologies vary somewhat regarding what is required to calculate design traffic, but in general, the following information is needed to forecast the cumulative ESAL input value needed for pavement design:

- Two-Way Average Annual Daily Traffic (ADT or AADT). ADT is a two-direction volume parameter required to generate the distribution of axle loading over time and represents vehicles per day. The beginning ADT should be determined for the year the street is opened to traffic. If a project includes reconstruction of a city street in the same configuration, current year traffic data should be obtained by performing traffic counts. For new-alignment or widening projects, opening year traffic data may be determined based on the results of a Traffic Impact Analysis (TIA), Traffic Assessment, or similar traffic study. The typical ADT ranges for each street classification are included for reference purposes and serve as a guide for ADT ranges appropriate for each classification. These minimum ADT values for each classification shall be used if traffic data is unavailable, or the results of the traffic study yield lower values. ADT is assumed to increase over time compounded according to a forecasted growth rate.
- Percentage of Trucks in ADT. This parameter represents the percentage of trucks in ADT counts, including dual-rear-tire pickups and buses with a single axle wheel load of approximately18-Kips or greater, for each street classification category.
- Traffic Growth Rate for the Design Period. This factor represents the annual traffic growth rate for a designated street classification (presented in Section 3.3.7). The representative growth rates should be used to calculate ending ADT, unless the results of a TIA or traffic study indicate a higher value.
- ESAL Factors for Each Vehicle Type. Discussed in subsequent sections.
- Traffic Distribution. Includes Directional and Design Lane Distribution Factors (discussed later).

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) and as construction traffic (for either nearby construction projects or for a new phased subdivision) must be considered. Depending on the repetition of these heavy loaded vehicles, they may significantly increase the overall ESALs being considered for design.

3.3.3 Traffic Distribution

There are two traffic distribution factors included in traffic calculations, as is described below.

- Directional distribution: 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 estimates shall be used in the traffic calculations.
- Lane distribution: The lane distribution factor depends on the number of travel lanes included on the road in each direction. Recommended lane distribution factors are presented below in Table 3-1.

Table 3-1. Recommend Lane Distribution Factors

Number of Lanes in Each Direction	Percent Traffic in Design Lane
1	100
2	80 – 100 (80)
3	60 – 80 (70)
4	50 – 75 (70)

Note:
Values in parentheses represent recommended preliminary design values when site-specific traffic data is not available.

3.3.4 Flexible Pavement Traffic Inputs

In addition to the general traffic criteria listed previously, specific traffic criteria required for the design of flexible pavements includes these described below:

- Beginning ADT: This input is for the Average Daily Traffic at the beginning of the analysis period. It is expressed as vehicles 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; and
- 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 Millions and is calculated by using the following equations:

$$ESALs = \sum AADT * GF * 365\frac{days}{year} * \%truck * TF * DDF * LDF$$

Where,

AADT = Annual Average Daily Traffic

TF = Truck Factor

DDF = Directional Distribution Factor

LDF = Lane Distributional Factor

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

GR = Annual growth rate, %

3.3.5 Rigid Pavement Traffic Inputs

In addition to the general traffic criteria listed previously, specific traffic criteria required for the design of rigid pavements includes the following:

- 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.
- Street Classification-based Traffic Spectrum: Recommended software (i.e., StreetPave12) calculates 18 Kip ESALs based on either predetermined traffic spectrums or counts or user input traffic distributions for the specific functional class of pavement for which a design is being calculated. The truck factors used in StreetPave12's calculation of 18 Kip ESALs are internal to the program and are not a user input.

3.3.6 Consideration of Construction Loading and other Heavy Loads

Occasional heavy traffic loads should be considered in the design of pavements. Occasional heavy loads can be broadly categorized as one of the following:

- Long-term periodic loading (fire trucks, transit or school buses, solid waste trucks, etc.); and
- Construction loading (initial pavement construction, pavement maintenance/rehabilitation, adjacent construction).

Estimates of long-term periodic loads can be developed by detailed traffic studies and/or by examining the proximity of existing / planned facilities and regular routes related to this type of traffic.

Estimates of construction traffic loading can be developed based on knowledge of ongoing and/or planned construction in the vicinity of the project. An example calculation of estimated additional daily ESALs due to construction traffic is provided below in Table 3-2. Examples of instances where construction loading can play a significant role in pavement design life include phased subdivisions with particular focus on streets near the start of such subdivisions (i.e., streets are constructed prior to final build-out of the subdivision and are used for subsequent construction access), and adjacent heavy construction projects (e.g., commercial and/or high-rise construction).

To the extent practicable, the Roadway Designer should develop site-specific estimates of occasional heavy loads. Occasional heavy loads should be incorporated into the pavement traffic design parameters presented in Table 3-3 by one of the following methods, selected at the discretion of the Roadway Designer:

- Increased Daily Trucks;
- Increased Percentage of Trucks; and
- Additional ESALs (similar to example in Table 3-2).

Table 3-2. Example Calculation of Construction Equipment Traffic Loading (from CAPEC 2016)

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 (hot asphalt)	80,000	4.02	20	81
	Concrete Redi-Mix Truck	61,000	6.28	20	126
Miscellaneous	Bulldozer (non-track)	58,250	0.95	10	10
	Rear end/Belly Dump	80,000	4.02	30	121
	Water Trucks	56,000	5.99	20	120
Total Potential Additional ESALs per Day of Construction:					726

3.3.7 Representative Traffic Design Parameters by Street Classification

Because traffic data is not always available, there is a need to define either ranges or minimum/maximum traffic parameters which can be developed for general categories of roadways. This is logical since the level of traffic loading typically defines various street classifications, which are used to categorize streets according to their functions.

Table 3-3 lists the representative traffic input values to be used for each street classification. These values are to be used unless otherwise directed or approved by the Transportation Director. Note that the street classifications defined here do not directly reflect the traffic categories in StreetPave12. 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.

Street classifications presented in CAPEC 2016 have been adopted for the purposes of this manual based on recent research, and are updated from the CORR street designations. Representative traffic design parameters for different street classifications are provided in Table 3-3.

Table 3-3. Representative Traffic Design Parameters by Street Classification[1]									
Street Classification	**Representative ESALs**	**General Range in ADT**	**General Range in Trucks (%)**	**General Number of Trucks/Day**	**Growth Rate (%)**	**Initial Serviceability Index, PSI_i[2]**	**Terminal Serviceability Index, PSI_t[2]**	**Design Confidence Level or Reliability (%)**	**Flexible Pavement Design: FPS-21 Design Confidence Code**
Urban Arterial (High Traffic)	9,000,000	4,000 - 25,000 (14,000)	4 - 15 (10)	160 – 3,750 (1,400)	4.0	4.5 (initial) 4.2 (overlay)	3.0	95	C
Urban Arterial (Low Traffic)	3,100,000	6,000 - 9,000 (6,000)	4 - 15 (7)	240 – 1,350 (420)	4.0	4.5 (initial) 4.2 (overlay)	3.0	95	C
Urban Collector (High Traffic)	2,600,000	2,000 - 8,000 (5,000)	3 - 10 (7)	60 – 800 (350)	4.0	4.5 (initial) 4.2 (overlay)	3.0	95	C
Urban Collector (Low Traffic)	1,000,000	2,000 - 4,000 (2,000)	3 - 10 (7)	60 – 400 (140)	3.5	4.2 (initial) 4.0 (overlay)	2.5	90	B
Urban Local	250,000	200 - 3,000 (500)	6 - 10 (6)	12 – 300 (30)	3.0	4.2 (initial) 4.0 (overlay)	2.0	90	B

Note:

1. Single values and values in parentheses represent recommended design values when site-specific traffic data is not available. However, the Pavement Engineer is strongly encouraged to examine pavement design sensitivity to traffic design parameters at the upper end of the listed range. Prior to completion of final pavement design, actual traffic values (determined by a TIA, traffic study, or other available data) should be compared to initial assumed values to verify pavement design is adequate for expected traffic, and any necessary modifications shall be incorporated into the pavement design plans and specifications.
2. PSI – Pavement Serviceability Index.

3.4 GEOTECHNICAL DESIGN CRITERIA FOR PAVEMENT SUBGRADE

3.4.1 Overview

Subgrade preparation (native soil) is a critical component of a well-designed roadway, since most construction and performance is dependent upon project subgrade properties and characteristics. The characterization and evaluation of subgrade is thus critical to the performance of pavement structures. This consideration is particularly important in the complex soil and geologic conditions of the Round Rock area. The subsurface geology of the City of Round Rock and its Extraterritorial Jurisdiction (ETJ) typically comprises of expansive soils with low to very high swell potential. The diverse subsurface conditions of Round Rock warrant particular care with regard to appropriate geotechnical investigation and proper characterization of subgrade conditions for the design of pavements.

This subsection provides review of the development of geotechnical design criteria for roadways, with focus on the expansive soil and other subsurface conditions common to Round Rock.

The Geotechnical Engineer who develops the pavement design shall refer to the specific criteria in this chapter, the additional resources listed in the Bibliography, and good industry practice when preparing pavement designs for City projects. All design criteria, design inputs, and recommendations shall be approved by the Transportation Director prior to incorporating in the project.

3.4.2 Effective Plasticity Index (PI_{eff})

Provide modifications to subgrade layers to limit the effective Plasticity Index (PI_{eff}) to the following criteria:

- Arterial/Collector: $PI_{eff} \leq 30$; and
- Local/Residential: $PI_{eff} \leq 40$.

This method calculates the Effective PI as a weighted average of the PI of the different soil strata within the upper 15 feet of the subgrade, based on PI tests according to TxDOT Tex-106E. In certain circumstances the City may permit a 10 feet depth to be considered for the effective PI calculation. Weight Factors of 3, 2, and 1 are typically used for the top 5 feet, the middle 5 feet, and the bottom 5 feet, respectively. PI_{eff} is determined by the following equation:

$$PI_{eff} = \Sigma (F_i \times D_i \times PI_i) / \Sigma (F_i \times D_i)$$

F_i = Weight Factor;

D_i = Depth of Soil Stratum within Particular Weight Factor Region; and

PI_i = Plasticity Index of Soil Stratum within Particular Weight Factor Region.

An example calculation of PI_{eff} is provided in Figure 3-1.

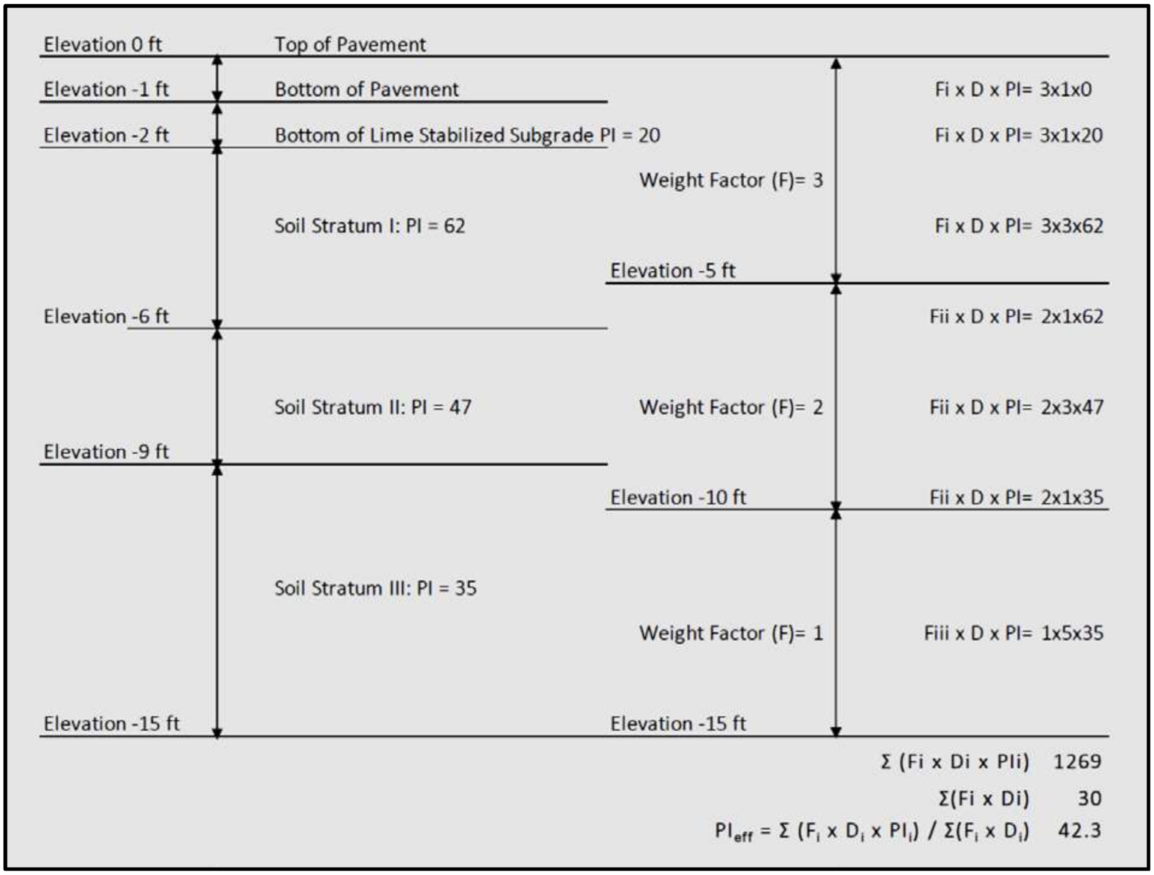

Figure 3-1. Example Calculation of Effective PI (CAPEC 2016).

3.4.3 Potential Vertical Rise (PVR)

Provide modifications to subgrade layers to limit the Potential Vertical Rise (PVR), considering a 15-foot depth below the proposed pavement surface elevation, to the following performance criteria:

- Arterial/Collector: PVR ≤ 2.0; and
- Local/Residential: PVR ≤ 3.0.

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 and is based on a "free swell" conversion ratio. The required data inputs from laboratory soils testing are:

- ω = Moisture content;
- γ = Unit Weight;
- LL = Liquid Limit;
- PI = Plasticity Index; and
- % Passing the No. 40 Sieve = Fine Grained Material.

This model estimates the cumulative potential vertical rise (PVR) of the pavement section based on 15 feet of material. A sample output for the Tex-124-E is included in Figure 3-2. The spreadsheet can be downloaded from the TxDOT website. 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 passing the No. 40, and PI are all set to zero).

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.

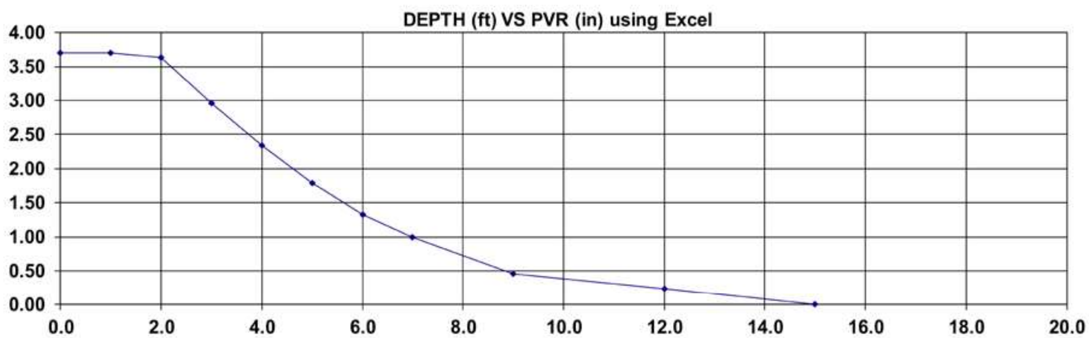

Figure 3-2. Example Calculation of PVR using TxDOT's Tex-124-E Calculation Spreadsheet (CAPEC 2016).

3.4.4 Design Subgrade Support

The subgrade design strength parameter of relevance to both flexible and rigid pavement design is 'modulus.' Resilient Modulus (M_R) is used in flexible pavement design, while Modulus of Subgrade Reaction (K) is used in rigid pavement design. The relevant subgrade modulus should be obtained by direct laboratory testing, field testing and analysis/correlations, and/or correlations with other laboratory test values.

3.4.4.1 Test Methods

The following is a list of common procedures used for developing design modulus. However, it is the responsibility of the Pavement Engineer to select the appropriate method(s) for determining design modulus.

- Field Testing:
  - Non-Destructive Testing (NDT):
    - Falling Weight Deflectometer (FWD): ASTM D4602–93 (2015);
    - Heavy Weight Deflectometer (HWD): ASTM D4602–93 (2015);
  - Dynamic Cone Penetrometer: ASTM D6951/D6951M – 09 (2015);
  - Plate Load Test for K-Value: AASHTO T 222-78; and
  - Plate Load Test for CBR: ASTM D4429-09;
- Direct Laboratory Testing:
  - Resilient Modulus: AASHTO T 307-99;
- Indirect Laboratory Testing:
  - California Bearing Ratio (CBR): ASTM D1883-16 or AASHTO T193;
  - TxDOT K-value: Tex-125-E;
  - Texas Triaxial Classification: Tex-117-E; and
  - Unconfined Compressive Strength: ASTM D2166/D2166M-16 or AASHTO T208.

3.4.4.2 Correlation Methods

Estimates of design modulus can be developed from correlations with various other types of field and laboratory tests. Although there are numerous correlations for various soil test parameters, Table 3-4 summarizes suggested correlations to be used in establishing the subgrade soil strength modulus. The Geotechnical Engineer is responsible for applying judgment in the use of such equations and assessing the validity of estimated modulus values.

Table 3-4. Summary of Subgrade Strength Correlations (adapted from CAPEC 2016)

Basis of Correlation	Equation	Origin	Comment
California Bearing Ratio (CBR) to M_R	MR = (1500)(CBR)	Heukelom & Klomp (1962)	For fine-grained non-expansive soils with soaked CBR ≤10
	MR = 2555 x $CBR^{0.64}$	NCHRP 137A	---
Dynamic Cone Penetrometer Resistance (DCP) to CBR	CBR = 292/PR1.12	ASTM D6951	---
	CBR = 1/(0.002871)(PR)	Webster, Brown and Porter, 1994	For high plasticity clay (CH)
	CBR = $1/[(0.017019)(PR)]^2$	Webster, Brown and Porter, 1994	For low plastic clay (CL)
Unconfined Compressive Strength (UCS) to M_R	MR = 143.33(UCS) + 4283.5	Hossain & Kim (2014)	---
Texas Triaxial Classification (TTC)	MR = $2161.2(TTC)^2$ - 26263(TTC) + 81981	1993 AASHTO Guide	---

Notes:

1. PR = Penetration Rate from DCP test (mm/blow)
2. UCS = Unconfined Compressive Strength
3. TTC = Texas Triaxial Classification

Typical ranges of strength and modulus values for various subgrade soil materials are presented in Table 3-5. These values are for preliminary design purposes and to assess reasonability of test results; actual field data should be developed for final design purposes. Note that the modulus values used in in FPS-21 for flexible pavement design (back-calculated modulus) are not equivalent to the Resilient Modulus or Elastic Modulus values obtained from correlations shown in Table 3-4.

Table 3-5. Typical Strength-Related Parameters for Various Subgrade Soils (adapted from CAPEC 2016)

Material (USC given where appropriate)	CBR	K-Value (pci)	UCS (psi)	Elastic or Resilient Modulus (psi)	Back-calculated Modulus use in FPS-21 (psi)
Gravel or Gravelly Soils (GW, GP, GM, GC)	20 - 100	200 – 300+	---	20,000 – 40, 000	Typically, 3 times the laboratory Resilient Modulus value; field FWD testing can determine directly.
Sandy Soils (SW, SP, SM, SC)	10 – 40	200 – 300	---	7,000 – 30,000	
Silty Soils (ML, MH)	8 – 15	200 – 300	---	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	

3.5 CRITERIA FOR GEOTECHNICAL INVESTIGATIONS

3.5.1 Commentary on the Geology and Soils of the City of Round Rock

The City of Round Rock and its Extraterritorial Jurisdiction is bisected by the Balcones Fault Zone (BFZ), a series of normal faults trending northeast-southwest and generally downthrown to the east. West of the BFZ lies the Grand Prairie Physiographic Region of Texas (an extension of the Edwards Plateau), which is typically characterized by thin, rocky soils overlying Lower Cretaceous-aged limestone, dolomitic limestone, marl, and chert units. East of the BFZ lies the Black Prairie Physiographic Region of Texas, typically characterized by thick, black, calcareous clay soils overlying Late Cretaceous-aged shales, marls, and chalk units (Housh, 2007). Abrupt variations in soil type can occur in the vicinity of BFZ and nearby areas as a result of secondary faulting. More recent Quaternary-age alluvium and terrace deposits are encountered in the vicinity of creeks and streams.

High-plasticity, expansive clay soils are prominent in the Round Rock area, and are a notorious source of distress in pavements and other structures due to their shrink/swell behavior. The distribution of potentially-expansive soils in the Round Rock area is illustrated in Figure 3-3.

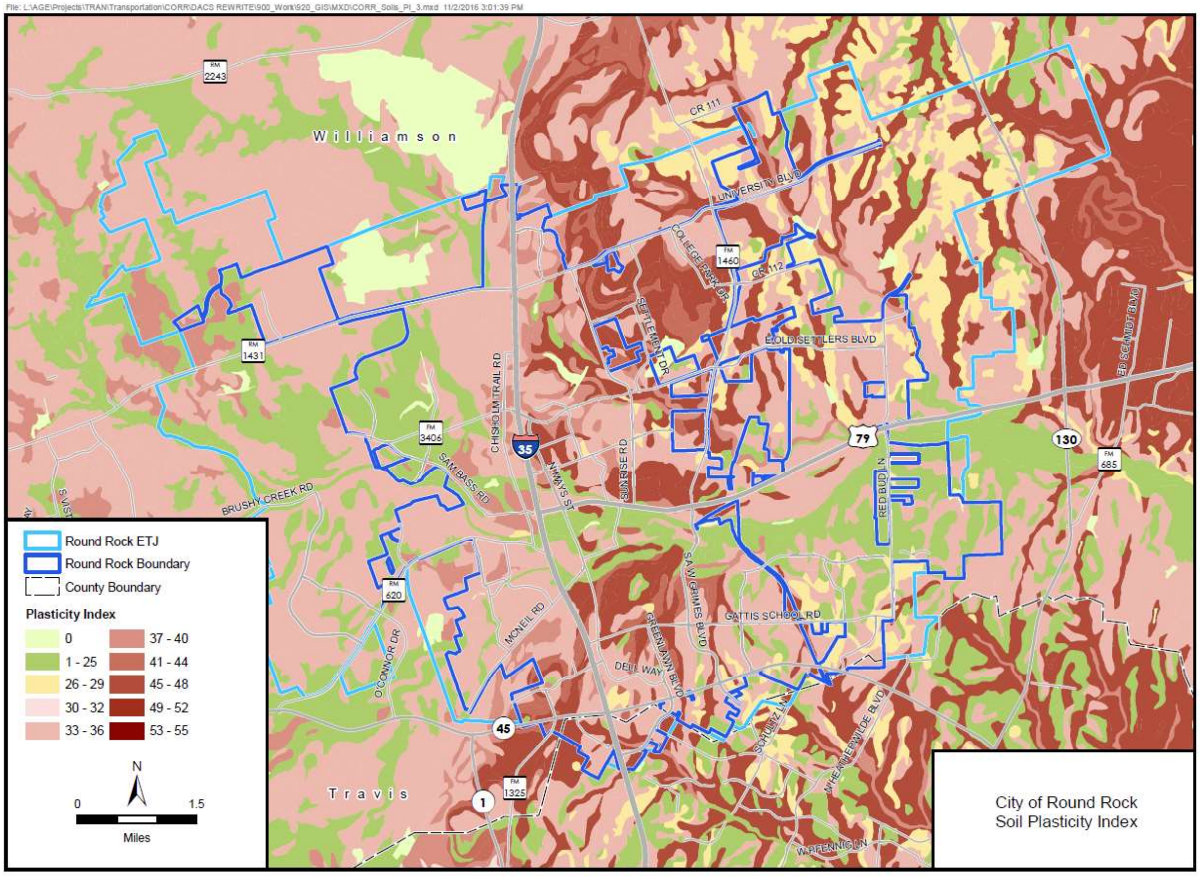

Figure 3-3. Distribution of Potentially Expansive Soils on the Basis of Plasticity Index (source: NRCS).

3.5.2 General Requirements

A geotechnical investigation is required for all projects to gain an understanding on the nature and variability of pavement supporting subgrade soils. The investigation shall be performed by a Professional Engineer, licensed in Texas, with advanced knowledge/experience in geotechnical engineering. At the completion of the field and laboratory investigations, described below, the engineer will provide subsurface information and site-specific technical recommendations for the design of the pavement foundation layers.

3.5.3 Field Investigation

The investigation shall include soil borings and laboratory testing, and other investigative measures, if applicable. Soil borings shall be drilled to minimum depth of (i) 15 feet (below the proposed finished grade), or (ii) to intact/competent rock, whichever is less. Note that Edwards Limestone is not considered intact/competent rock due to known karst features within this unit. Similarly, high-plasticity clay shale formations (Del Rio, Eagle Ford, and Taylor) are not considered competent/intact rock due to shrink/swell potential as these units weather.

The spacing of borings along proposed alignments shall be equal to or less than 500 feet and completed on alternating sides of the roadway, if practical. A minimum of 3 borings should be performed on each project regardless of alignment length. All borings should be performed within the limits of proposed pavement, unless otherwise approved by the City.

Continuous sampling shall be conducted to the boring termination depth, including split-spoon sampling of granular soils and thin wall tube sampling of cohesive soils. Coring intact rock shall not be required for pavement design unless the Roadway Designer or the City specifies, or the Geotechnical Engineer believes coring is warranted (e.g., sites underlain by Edwards Limestone with karst potential). An example of when rock coring may be beneficial are instances in which proposed grade requires cuts into the subsurface rock, and there is interest in evaluating the rock quality to assess its potential for re-use as on-site processed aggregate for pavement sections or other structures.

3.5.4 Laboratory Investigation

Select samples shall be tested in a laboratory to determine grain size characteristics, Atterberg limits, in-situ moisture, and other engineering properties, as deemed appropriate. Bulk samples of each subgrade soil type shall be obtained from the field and tested to determine the Texas Triaxial Classification (TTC) or California Bearing Ratio (CBR). Both test methods provide results that can be correlated to the elastic modulus of the subgrade, a required input parameter for pavement design analyses. The TTC shall be the preferred method to estimate the elastic modulus of the subgrade material. The TTC (or CBR) testing may be waived if in-field pavement deflection testing is obtained or otherwise available. In this case, the deflection data is used to back calculate the subgrade elastic modulus.

Plasticity testing shall be conducted on each unique cohesive subgrade soil to determine the liquid limit (LL) and plastic limit (PL). Those soils with a LL greater than 50 and plasticity index (PI = LL-PL) greater than 20 shall be considered expansive for purposes of this manual, and candidates for subgrade treatment. Each candidate soil shall be tested for total soluble sulfate, pH, and organic content. A lime series test shall be conducted on those soils with soluble sulfate content less than 8,000 ppm and an organic content less than 2%.

The geotechnical investigation and pavement design shall use the following Test Procedures developed by the Texas Department of Transportation. Refer to the TxDOT web site for a full list of applicable test procedures related to geotechnical investigation and testing of materials related to pavement design.

Table 3-6. Geotechnical Test Procedures	
TxDOT Test Method	**Description**
Tex-100-E	Surveying and Sampling Soils for Highways
Tex-103-E or ASTM D2216	Determining Moisture Content in Soil Materials
Tex-104-E or ASTM D4318	Determining Liquid Limits of Soils
Tex-105-E or ASTM D4318	Determining Plastic Limit of Soils
Tex-106-E or ASTM D4318	Calculating the Plasticity Index of Soils
Tex-107-E	Determining the Bar Linear Shrinkage of Soils
Tex-110-E or ASTM D6913	Determining Particle Size Analysis of Soils
Tex-112-E	Admixing Lime to Reduce Plasticity Index of Soils
Tex-117-E	Triaxial Compression for Disturbed Soils and Base Materials
Tex-121-E	Soil-Lime Testing
Tex-124-E	Determining Potential Vertical Rise
Tex-128-E	Determining Soil pH
Tex-145-E	Determining Sulfate Content in Soils – Colorimetric Method
Tex-146-E	Conductivity Test for Field Detection of Sulfates in Soil
ASTM D4546	Standard Test Methods for 1-D Swell or Collapse of Soils
ASTM D1883	Standard Test Method for CBR of Laboratory Compacted Soils

3.5.5 Geotechnical Report Requirements

The geotechnical investigation data shall be compiled and summarized in a Geotechnical Data Report, which may also be incorporated into the Pavement Design Report. Whether a standalone document or included in the design report, the geotechnical content shall include the following:

1. Site Information:
    a. Description of the project and location with site location map;
    b. Topographic and drainage features;
    c. Discussion of geologic setting of the project area;
    d. Geologic map (USGS and/or Texas Bureau of Economic Geology); and
    e. Mapped surface soils within the project area (NRCS Web Soil Survey);
2. Field Investigation:
    a. Boring logs with results of laboratory index testing (moisture, gradation, Atterberg limits) at appropriate depths;
    b. Boring location plan; and
    c. Summary of encountered soils and groundwater conditions.
3. Laboratory Test Results:
    a. Laboratory test summary table and individual test reports for the following:
        i. Index Tests (Atterberg Limits including P.I., Gradation, Moisture, Natural Density);
        ii. Strength Tests (Unconfined Compression, CBR, Texas Triaxial, etc.);
        iii. Moisture-density relationship tests;

    iv. Volume change (Swell); and,
    v. Chemical analyses (pH, sulfate content, etc.).

4. Engineering Recommendations:

    a. Expansive characteristics of subgrade soils and estimated PVRs (TxDOT Test Method Tex-124-E);

    b. Recommendations for reducing the PI_{eff} and PVR to acceptable values per Section 3.4;

    c. Compatibility of subgrade soils to lime treatment and recommended lime content;

    d. Compatibility of subgrade soils to cement treatment and recommended cement content;

    e. Recommendations for alternate subgrade stabilization/treatment (e.g., geosynthetics, moisture treatment, etc.);

    f. Characterization and mitigation of groundwater, if encountered or anticipated; and,

    g. Requirements for cut and fill slopes to be incorporated in the design.

3.6 GUIDELINES FOR FLEXIBLE AND RIGID PAVEMENT DESIGN

3.6.1 General Pavement System Components

Various material layers are incorporated into properly designed flexible and rigid pavement sections. Flexible and rigid pavement systems generally consist of the sequence of material layers (top to bottom) listed in Table 3-7.

Note that “bond breakers” are always required for rigid pavements when the concrete slab directly overlies cement-treated subgrade or Lime-treated subgrade in the design pavement section. A bond breaker layer consisting of a minimum of 2 inches of HMAC is intended to prevent direct bonding between concrete slabs and cement-treated base, as bonding increases risk of pavement cracking due to the following mechanisms: (1) cracks in base reflect through slab; and/or (2) climate-induced tensile stresses in slab. Bond breaker layer is not required when asphalt-treated base is used directly under concrete slab.

Table 3-7. Typical Pavement System Components			
Material Layer	**Specification**	**Flexible Pavement**	**Rigid Pavement**
Hot Mix Asphaltic Concrete (HMAC)	TxDOT Item 340/341	X	N/A
Concrete Pavement	TxDOT Item 360	N/A	X
Bond Breaker	TxDOT Item 340/341	N/A	O
Flexible Base	TxDOT Item 247	X	N/A
Treated Base	TxDOT Item 276 (cement) / TxDOT Item 292 (asphalt)	N/A	X
Treated Subgrade: -Lime -Cement -Lime-Cement	TxDOT Item 260 TxDOT Item 275	O	O
Geosynthetics (Geogrid – Tensar TX5 or Better)	TxDOT Item 5001 TxDOT Item DMS 6240	O	O
Native Subgrade: -Proof Rolling -Recompaction (Rolling)	TxDOT Item 216 TxDOT Item 210	X	X

Notes:

1. X = Included
2. O = May be included based on design analysis results and at Engineer's Discretion

3.6.2 Factors Affecting the Selection of Flexible or Rigid Pavement

Selection of either flexible or rigid pavement is at the discretion of the Pavement Engineer, with approval by the Transportation Director. However, flexible existing pavements predominate in the City of Round Rock. The relative advantages of each pavement type are discussed below.

Flexible Pavements. The typical advantages of flexible pavements relative to rigid pavements include, but may not be limited to:

1. Lower initial construction cost;
2. Lower repair costs (per event basis);
3. Ability to increase service life with periodic maintenance (e.g., overlays); and
4. Ability to improve in stages with traffic growth.

Rigid Pavements. The typical advantages of rigid pavements relative to flexible pavements include, but may not be limited to:

1. Improved durability;
2. Longer service life;
3. Less maintenance over design life; and
4. Minimal deformation over time (i.e., no rutting).

3.6.3 Representative Pavement Material Properties

Elastic modulus parameters are used to model the various pavement layer strengths. Representative values of these parameters for use in pavement design software are provided in the following table.

Table 3-8. Representative Pavement System Components

Material Layer	Poisson's Ratio	FPS-21 Design Modulus (ksi)
Thin Overlay Mixtures (TOM)	0.35	500
Dense-graded Hot Mix Asphaltic Concrete (HMAC)	0.35	500 (<4" HMAC)(1) 650 (>4" HMAC)
Seal Coat	0.35	200
Flexible Base	0.35	40
Lime Treated Subgrade	0.3	(3x Subgrade Modulus) ≥ 20(2)
Cement Treated Subgrade	0.3	40
Cement Treated Base	0.25	150
Native Subgrade	0.4	Use back-calculated Moduli, typically 8-20 ksi.

Notes:

1. The representative pavement thickness presented in Tables 3-9 assumes a HMAC design modulus of 500 ksi.
2. The representative pavement thickness presented in Tables 3-9 assumes incorporating a lime-treated subgrade in the pavement section.

3.6.4 Representative Pavement Section by Street Category

Depending on site conditions and expected traffic volumes, thicker pavement sections may be required by the design procedures detailed in subsequent paragraphs of this section. Any representative pavement sections included herein do not relieve the Pavement Engineer from the responsibility of designing a cross section that is appropriate for the site specific soil conditions to meet the required design life of 20 years for flexible pavement or 30 years for rigid pavement.

Representative pavement sections were developed based on criteria presented in Sections 3-8 (Flexible Pavement) and 3-9 (Rigid Pavement).

Table 3-9. Representative Flexible Pavement Sections by Subgrade Type and Street Category				
Street Classification	Existing Subgrade Conditions	Flexible Pavement Layer Thickness		
		HMAC (in.)	Flexible Base (in.)	Treated Subgrade (in.)
ARTERIALS				
Urban Arterial (High Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	8.5 (12.0)	24.0 (20.0)	12.0
	Moderate Swell	8.5 (12.0)	23.0 (16.0)	10.0
	Low Swell	8.5 (11.5)	22.0 (16.0)	10.0
Urban Arterial (Low Traffic)	Very High Swell	n/a	n/a	n/a
	High Swell	6.0 (12.0)	20.0 (20.0)	12.0
	Moderate Swell	6.0 (12.0)	19.0 (16.0)	10.0
	Low Swell	6.0 (11.5)	18.0 (16.0)	10.0
COLLECTORS				
Urban Collector (High Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	6.5	18.0	12.0
	Moderate Swell	6.0	18.0	10.0
	Low Swell	6.0	16.0	8.0
Urban Collector (Low Traffic)	Very High Swell	n/a	n/a	n/a
	High Swell	5.0	15.0	12.0
	Moderate Swell	5.0	14.0	10.0
	Low Swell	5.0	12.0	8.0
LOCALS				
Urban Local	Very High Swell	RAR	RAR	RAR
	High Swell	3.0	14.0	10.0
	Moderate Swell	3.0	10.0	10.0
	Low Swell	3.0	8.0	8.0

Notes:

1. Values in parenthesis represent Perpetual Flexible Pavement Layer Thicknesses. All Arterials are recommended to follow Perpetual Design for increased performance. The City may approve Non-Perpetual Arterials on a case-by-case basis.
2. RAR – Remove And Replace existing subgrade material with suitable non-expansive fill material per the recommendations of the geotechnical engineer.
3. Very High Swell: Subgrade with very high swelling potential, represented by PI > 50. Such cases will likely require deep treatment to reduce PVR to acceptable values.
4. High Swell: Subgrade with high swelling potential, represented by PI = 36 to 49.
5. Moderate Swell: Subgrade with moderate swelling potential, represented by PI = 20 to 35.
6. Low Swell: Subgrade with low swelling potential, represented by PI < 20.
7. The pavement sections in this table should be considered representative for each street classification. Different pavement sections may be required based on the results of a project-specific Pavement Design Report or as directed by the City.
8. All materials shall be in accordance with TxDOT Specifications.
9. Minimum HMAC pavement thickness is 2.5 inches.

Table 3-10. Representative Rigid Pavement Sections by Subgrade Type and Street Category

Street Classification	Existing Subgrade Conditions	Rigid Pavement Layer Thickness		
		Conc. (in.)	HMAC Bond Breaker (in.)	Treated Subgrade (in.)
ARTERIALS				
Urban Arterial (High Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	10.0	2.0	8.0
	Moderate Swell	9.5	2.0	8.0
	Low Swell	9.0	2.0	8.0
Urban Arterial (Low Traffic)	Very High Swell	n/a	n/a	n/a
	High Swell	9.0	2.0	8.0
	Moderate Swell	8.5	2.0	8.0
	Low Swell	8.0	2.0	8.0
COLLECTORS				
Urban Collector (High Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	7.5	2.0	8.0
	Moderate Swell	7.0	2.0	8.0
	Low Swell	6.5	2.0	8.0
Urban Collector (Low Traffic)	Very High Swell	n/a	n/a	n/a
	High Swell	7.0	2.0	8.0
	Moderate Swell	6.5	2.0	8.0
	Low Swell	6.0	2.0	8.0
LOCALS				
Urban Local	Very High Swell	RAR	RAR	RAR
	High Swell	6.0	2.0	8.0
	Moderate Swell	6.0	2.0	8.0
	Low Swell	6.0	2.0	8.0

Notes:

1. RAR – Remove And Replace existing subgrade material with suitable non-expansive fill material per the recommendations of the geotechnical engineer.
2. Very High Swell: Subgrade with very high swelling potential, represented by PI > 50. Such cases will likely require deep treatment to reduce PVR to acceptable values.
3. High Swell: Subgrade with high swelling potential, represented by PI = 36 to 49.
4. Moderate Swell: Subgrade with moderate swelling potential, represented by PI = 20 to 35.
5. Low Swell: Subgrade with low swelling potential, represented by PI < 20.
6. The pavement sections in this table should be considered representative for each street classification. Different pavement sections may be required based on the results of a project-specific Pavement Design Report or as directed by the City.
7. All materials shall be in accordance with TxDOT Specifications.
8. Minimum Rigid pavement thickness is 6 inches.

3.6.5 Pavement Design Report Criteria

The pavement design analyses, findings, and recommendations shall be compiled in a Pavement Design Report (PDR). At a minimum, the Geotechnical Report shall include the following:

- Cover sheet showing project information and signatures;
- Project Information:
  - Narrative discussing the overall project, scope of work, site particulars, drainage, and topographic features;
  - Project location map and description of proposed improvements;
  - Existing pavement section (if applicable);
  - Existing subgrade conditions (referenced from Geotechnical Report);
  - Traffic data and any adjustments;
  - Project specific factors used for selecting the pavement type; and
  - Summary of discussions with City officials and waivers received (if any);
- Pavement Design Summary:
  - Summary of all pavement design input values;
  - Design output values for typical pavement sections;
  - Recommended subgrade stabilization measures (if applicable);
  - Recommended pavement section or sections;
  - Recommended pavement related specifications (e.g., subgrade preparation, lime addition, flex base materials and compaction, HMAC, etc.);
  - Recommendations to improve drainage of subgrade/base layers (i.e., edge drains);
  - Proposed detour pavement thickness (widened pavement or separate detour);
  - If existing pavement is to be used as a detour, provide recommendations as to suitability of use and recommended traffic flow diagram; and
  - Construction recommendations including drainage and groundwater control;
- Appendices:
  - Flexible Pavement Designs: FPS-21 output with mechanistic check and modified Texas Triaxial check; and
  - Rigid Pavement Designs: Streetpave12 output.

The above listed outline shall be considered the minimum requirements. Additional information, based on existing site conditions or alternate pavement designs may be required and shall be documented in the PDR to be submitted to the City for approval.

The PDR shall address constructability issues and appropriate measures. Examples include, allowing adequate mellowing time prior to final rolling and confirmatory index testing; potential need for a double treatment process for lime treated subgrade; completion of City-required subgrade recompaction and proofrolling; and, compaction of subbase materials.

In general, the proposed pavement design should be consistent with the representative sections presented in Tables 3-9, 3-10 or 3-11. The City encourages the use of innovative techniques and materials that have a demonstrable positive impact on the pavement condition throughout the design life.

Requests for alternative pavement designs and innovative design materials should be supported in the Pavement Design Report with appropriate engineering calculations (considering traffic, environmental, and subgrade conditions), industry experience/ testing data, and any other appropriate supporting documentation that quantifies the resulting improvement in pavement design life. Alternative pavement designs and innovative design materials must be approved by the City Transportation Department prior to use.

3.7 SUBGRADE IMPROVEMENT CONSIDERATIONS

3.7.1 Design Criteria

Subgrade improvement is required whenever the geotechnical investigation indicates the presence of in-situ soils with effective plasticity index (PI_{eff}) and/or potential vertical rise (PVR) values exceeding those specified in Section 3.4, and shall be designed to reduce these parameters to acceptable values.

Subgrade improvement may also be required where weak subgrades yield pavement sections that are uneconomically thick. In general, thick base layers over 16" 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 Geotechnical Engineer is responsible for identifying when subgrade improvement is required, and which improvement alternatives should be considered. The Pavement Design Report (PDR) shall include these recommendations to improve the subgrade, if necessary.

3.7.2 Limits of Improvement

Where subgrade stabilization is provided, the stabilized subgrade and succeeding subbase and base courses shall typically extend a minimum of three feet behind the back of curb. Where subgrade stabilization is not provided, subbase and base courses shall typically extend a minimum of 24 inches behind the back of curb. Modifications to limits of improvement may be required where existing buried utilities are present.

3.7.3 Traditional Subgrade Improvement Methods

3.7.3.1 Removal and Replacement

The simplest form of subgrade improvement consists of removal of unsuitable subgrade materials and replacement with engineered, non-expansive fill. Removal and replacement can be effective to remove weak subgrade materials and/or to limit PVR and effective PI to acceptable values.

Removal and replacement depths of 18 to 24 inches are common, but greater depths may be required to limit the effective PI and PVR to acceptable values. Further, in highly-expansive geologic formations that extend to great depth, the required removal/replacement depth to meet PI and PVR criteria can exceed several feet, in which case removal/replacement may not be economically feasible.

Replacement fill should consist of engineered fill meeting recommendations of the Geotechnical Engineer. In general, engineered fill should meet $4 \leq PI \leq 15$ to limit potential for volume change.

General considerations in evaluating the feasibility of this alternative are as follows:

1. Requirements for temporary excavation slopes in accordance with OSHA criteria;
2. Availability of ROW / construction limits to meet OSHA requirements, and potential need for temporary shoring if sloping is not achievable;
3. Haul distance and cost for disposal of excavated subgrade;
4. Haul distance and cost for replacement materials;
5. Construction schedule impacts; and
6. Construction sequencing and traffic control impacts.

3.7.3.2 Lime Treatment

Lime stabilization can be an effective method of soil stabilization. Properly executed, lime stabilization will act to reduce the shrink/swell potential of clayey soils, maintain a higher strength during moisture increases, and impede infiltration into deeper strata.

In general, thorough mixing of lime with clayey soils results in mixtures that display decreased plasticity, improved workability, reduced volume change characteristics, and increased strength. Improvement in soil strength, however, does not always develop with the addition of lime. It should be noted that a number of variables, including soil type, lime type, lime percentage and curing conditions can affect the properties of soil-lime mixtures.

Lime stabilization is most effectively undertaken following bench-scale treatability testing. The type of lime treatment proposed, including additive rates, should be indicated in a mix design report (i.e., lime stabilization for strength increase or lime conditioning for plasticity reduction).

Guidelines and requirements for lime stabilization are provided below:

- Treatment Depth. The minimum depth of lime treatment shall be 8 inches, with greater depths required depending on traffic loads and the material PI.
- Strength Increase. Significant strength increase (lime stabilization) is typically associated with treatment of lime-reactive soils, typically soil with pH ≥ 7.
- Reduction of Plasticity. Reduction in plasticity (lime conditioning) is typically associated with treatment of non-lime-reactive soils. This typically applies to soils with pH ≤ 7.
- Application Rate. Most fine-grained soils can generally be conditioned/ stabilized effectively with three (3) to ten (10) percent of lime addition by weight (dry weight of soil basis). The lower percent lime additions are normally identified with lime conditioning (with minimal strength increases), while the higher percent lime additions are normally necessary to achieve lime/soil mixtures with significant strength increases.
- Mix Design. Lime treatment mixture design for the City of Round Rock shall be developed using one of the following procedures appropriate for the intended purpose of lime treatment:
    - Lime Conditioning Mix: TxDOT Test Method Tex-112-E, “Method of Admixing Lime to Reduce Plasticity Index of Soils”.
    - Lime Stabilizing Mix: TxDOT Test Method Tex-121-E, “Soil-Lime Testing”, shall be used to establish the lime content that would produce a twenty-eight (28) day unconfined compressive strength (TxDOT Test Method Tex-117-E). Minimum compressive strengths are fifty (50) psi for a lime-stabilized subgrade, and one hundred (100) psi for a lime-stabilized base layer.
- Application Rate. The actual design application rate shall be determined by the Geotechnical Engineer or Pavement Engineer on the basis of bench-scale lime series testing conducted under their direct supervision. Typical specified rate of lime solids application shall be 5% by weight (mass) for non-lime-reactive materials (pH of 7.0 or less); or 7% by weight (mass) for lime-reactive materials (pH greater than 7.0), unless indicated otherwise in the mix design process or as

directed by the City. Lime stabilization of subgrade soils shall be in slurry form unless otherwise approved by the City.

- Compressive Strength. The minimum required 7-day compressive strength of lime-treated soil is 100 psi to be considered for structural credit in pavement design.
- Sulfate Content. Soils with elevated soluble sulfate content are not suitable for lime treatment due to the risk of sulfate-induced heave. The following sulfate content guidelines shall be observed when considering lime treatment:
  - Soluble Sulfate < 3,000 ppm: Subgrade is compatible with lime treatment.
  - Soluble sulfate between 3,000 ppm and 8,000 ppm: Subgrade shall be identified as generally compatible with lime treatment, though the Pavement Engineer or Roadway Designer should consult with the City for approval to use lime treated subgrade in these cases. Refer to TxDOT's "Guidelines for Modification and Stabilization of Soils and Base for Use in Pavement Structures" and "Guidelines for Treatment of Sulfate-Rich Soils and Bases in Pavement Structures" for more information.
  - Soluble sulfate > 8,000 ppm: Subgrade shall be identified as being incompatible with lime treatment.

3.7.3.3 Cement Treatment

A wide range of soil types may be stabilized using cement. The greatest effectiveness is with sands, sandy and silty soils, and clayey soils of low to medium plasticity. However, cement is difficult to mix into soils with PI >30.

Soils mixtures that are acidic, neutral, or alkaline may well respond to cement treatment; however the higher pH soils react more favorably to cement addition and undergo significant strength increases. Although some organic matter (e.g., un-decomposed vegetation) may not influence stabilization adversely, other organic compounds of lower molecular weight (e.g., nucleic acid and dextrose) act as hydration retarders and reduce strength gain.

General guidance and design criteria for cement treatment of soil subgrades are provided as follows:

- pH. Soil pH testing shall be performed to provide an indication of the impact of organics on normal hardening of the cement stabilized soil mixture in accordance with TxDOT TEX-128-E. In summary, a 10:1 mixture (by weight) of soil and cement is mixed with distilled water for a minimum of fifteen (15) minutes and the pH of the combined mixture is then measured. If the pH value is at least 12.1, then it is probable that organic matter, if present, will not interfere with normal hydration/ hardening of a soil-cement mixture. This pH measurement is a principal feature in identifying the soil mixtures that can likely be stabilized with cement and are candidates for development of a cement-soil mix design (see the mix design flow diagram presented in TxDOT 2011).

- Sulfate. Since sulfate attack is known to adversely affect some cement stabilized soil, the sulfate content of a soil should be considered in the selection of cement as a stabilizer. The impact of the sulfate factor on the mix design is also identified in TxDOT 2011, where cement stabilization of soils with sulfate contents greater than 0.9 percent is discouraged. Procedures for determining sulfate content of soils are presented in TxDOT 2011.
- Soil Plasticity and Fines Content. There are additional selection criteria based on gradation and Atterberg limits test results that should be used in establishing the acceptability of a soil mixture for cement stabilization, specifically:
  - Fine-grained soils (CL, ML, CL-ML): Plasticity Index should be less than twenty (20) and the Liquid Limit less than forty (40);
  - Sandy soils (SC, SM, SP, SW, and dual-symbols): Plasticity Index should be PI < 30;
  - Gravelly soils (GC, GM, GP, GW, and dual-symbols): Minimum of forty (40) percent passing the no. 4 sieve; and
  - All soils: Plasticity Index should not exceed the number calculated in the following equation:

$$N = \frac{50 - (\text{Percent Passing \#200 Sieve})}{4}$$

  - High-plasticity and Organic Soils (CH, MH, OL, OH): These soil types are not suitable for cement-treatment.
- Moisture-Density Relationship. The properties of cement-treated soils are principally dependent on cement content, density, moisture content and confining pressure. It should also be noted that the addition of cement to a soil mixture commonly produces a change in both the optimum water content and maximum dry density for a given compactive effort. The principal goal of the cement stabilization mixture design process is therefore the establishment of (i) the appropriate cement additive rate, and (ii) the resultant moisture-density relationship.
- Application Rate. Most soils can generally be stabilized effectively with five (5) to sixteen (16) percent of cement addition (dry weight of soil basis). The lower percent cement additions are normally identified with coarser soil mixtures (AASHTO classifications A1 and A2), while the higher percent cement additions are normally necessary for the fine-grained soils (AASHTO A6 and A7). The actual design application rate shall be determined by the Geotechnical Engineer or Pavement Engineer on the basis of bench-scale treatability testing conducted under their direct supervision.

- Mix Design. In development of a cement stabilized soil mix design for the City, the procedures specified in TxDOT Test Method Tex-120-E, “Soil-Cement Testing”, shall be used to establish the design cement content that would produce a mix that meets the durability requirements presented in TxDOT 2011. The mix design report should include the molding moisture content, the dry density to the nearest 0.1 pcf, 7-day unconfined compressive strength to the nearest psi and the recommended cement content to the nearest whole percent.
- Compressive Strength. The 7-day compressive strength associated with the recommended cement content should be used as the field control measure during construction. The 7-day compressive strength for cement stabilized soils can vary between one hundred (100) psi for fine-grained soils to more than a one thousand (1000) psi for coarse-grained soils. The minimum required 7-day compressive strength is 100 psi to be considered for structural credit in pavement design.

3.7.3.4 Lime-Cement Treatment

Cement stabilization alone is normally not desired with high plasticity soil mixtures (i.e., soils with PI > 30) because of difficulties in the mixing phase. In this instance, combinations of lime and cement can often produce an acceptable combination. Lime is initially added to the soil mixture to increase the workability and mixing characteristics of the soil, as well as to reduce its plasticity. Cement is subsequently added to the lime–soil mixture to provide rapid strength gain. The lime-cement combination stabilization of high plasticity soils is especially advantageous when rapid strength gain is required for placement during cooler weather conditions.

General guidance and design criteria for lime-cement treatment of soil subgrades are provided as follows.

- Soil Plasticity. The lime content to reduce the stabilized soil to PI < 30 should be established using TxDOT Test Method Tex-112-E, “Method of Admixing Lime to Reduce Plasticity Index of Soils”, while the TxDOT Test Method Tex-120-E, “Soil-Cement Testing”, shall be used to establish the design cement content that would produce a mix that meets the allowable durability requirements TxDOT 2011.
- Reporting. The mix design report should include the following:
  - Molding moisture content;
  - Dry density to the nearest 0.1 pcf;
  - Seven (7)-day unconfined compressive strength to the nearest psi; and
  - Recommended lime and cement additive rates to the nearest whole percent.
- Application Rate: Typical lime contents range from one (1) to three (3) percent, while the typical subsequent cement contents range from three (3) to ten (10) percent. The amount of lime and cement additions

is dependent upon the type of soil. The actual design application rate shall be determined by the Geotechnical Engineer or Pavement Engineer on the basis of bench-scale treatability testing conducted under their direct supervision.

- Quality Control. The 7-day compressive strength associated with the recommended lime and cement contents should be used as the field control measure during construction. A minimum 7-day value of 100 psi shall be required.

3.7.4 Alternative Subgrade Improvement Methods

3.7.4.1 Moisture Treatment

The objective of moisture treatment is to “pre-swell” high-plasticity expansive soil subgrades prior to pavement construction to minimize post-construction expansion potential. This method involves compacting the subgrade at a moisture content several points above optimum moisture to reduce expansion potential. This generally includes installation of a moisture barrier following wetting to protect the subgrade from natural cycles of wetting and drying.

3.7.4.2 Geogrid

The City's experience has shown that geogrids are effective at controlling environmental cracking and should be considered at the base/subgrade interface when the PI > 35. The grid holds the granular base material in a tight matrix allowing the shrinking/swelling subgrade to move and limit subgrade cracking from propagating to the pavement surface. More recently, Triaxial Geogrids have also been introduced (Tensar TX5 or better) as the recommended geogrid type for subgrade improvement. The Engineer should strongly consider the performance improvements offered by the use of triaxial geogrid in high PI soils. Triaxial Geogrid shall be installed per manufacturers recommendations. Proper overlap shall be maintained and may require zip-ties and/or pinsduring installation.

Several geogrid vendors offer software which can be used to develop an optimized design with geosynthetics by estimating a section with equivalent performance (e.g., SpectraPave by TENSAR® Corporation). The design steps are as follows:

1. Determine soil strength parameters;
2. Develop pavement thickness (criteria) with standard procedures;
3. Determine Resilient Modulus;
4. Determine Enhanced Structural Layer Coefficient for Mechanically Stabilized Layer (MSL);
5. Use Vendor Software to find geogrid optimized section equivalent to unreinforced; and
6. Check severity of swelling soils and serviceability criteria.

Geotextiles have been widely used to control the movement of fine materials and to provide moisture barriers.

General guidance and design criteria for geosynthetic applications in soil subgrades are provided as follows:

- General. The typical 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.
- Reduction of Base Layer Thickness. For pavement designs the reduction in base thickness when considering geogrid reinforcement must be supported by calculations submitted with design report and shall be limited to a maximum of 4 inches of flexible base thickness reduction unless supported by independently validated performance data that is submitted for review and approved by the City..
- Crack Reduction. 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.
- Management of Expansive Soil Conditions. The use of geogrid alone is not expected to 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 high quality geogrid.

Table 3-11 presents representative flexible pavement sections incorporating a single layer of Tensar Triaxial TX5 geogrid placed directly on top of the lime-treated subgrade layer. The thicknesses presented in Table 3-11 were developed using SpectraPave by TENSAR® Corporation, using similar geotechnical parameters that were used to develop the flexible pavement sections using the FPS-21 software and as presented earlier in Table 3-9.

Due to several variances in the calculation procedures of different software used (SpectraPave and FPS-21), it is the responsibility of the Pavement Design Engineer to evaluate project specific geotechnical parameters, traffic data and appropriate pavement types prior to determining the reduction in base layer thickness by incorporating geogrid in the pavement design.

Table 3-11. Representative Flexible Pavement Sections by Subgrade Type and Street Category (with Tensar Triaxial TX5 Geogrid)				
Street Classification	Existing Subgrade Conditions	Flexible Pavement Layer Thickness		
		HMAC (in.)	Flexible Base (in.)	Treated Subgrade (in.)
ARTERIALS				
Urban Arterial (High Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	8.5	18.0	12.0
	Moderate Swell	8.5	17.0	10.0
	Low Swell	8.5	16.0	10.0
Urban Arterial (Low Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	6.0	14.0	12.0
	Moderate Swell	6.0	13.0	10.0
	Low Swell	6.0	12.0	10.0
COLLECTORS				
Urban Collector (High Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	6.5	12.0	12.0
	Moderate Swell	6.0	12.0	10.0
	Low Swell	6.0	10.0	8.0
Urban Collector (Low Traffic)	Very High Swell	RAR	RAR	RAR
	High Swell	5.0	11.0	10.0
	Moderate Swell	5.0	9.0	8.0
	Low Swell	5.0	7.0	8.0
LOCALS				
Urban Local	Very High Swell	RAR	RAR	RAR
	High Swell	3.0	10.0	8.0
	Moderate Swell	3.0	10.0	As Needed
	Low Swell	3.0	7.0	As Needed

Notes:

1. RAR – Remove And Replace existing subgrade material with suitable non-expansive fill material per the recommendations of the geotechnical engineer.
2. Very High Swell: Subgrade with very high swelling potential, represented by PI > 50. Such cases will likely require deep treatment to reduce PVR to acceptable values.
3. High Swell: Subgrade with high swelling potential, represented by PI = 36 to 49.
4. Moderate Swell: Subgrade with moderate swelling potential, represented by PI = 20 to 35.
5. Low Swell: Subgrade with low swelling potential, represented by PI < 20.
6. The pavement sections in this table should be considered representative for each street classification. Different pavement sections may be required based on the results of a project-specific Pavement Design Report or as directed by the City.
7. All materials shall be in accordance with TxDOT Specifications.
8. Minimum HMAC pavement thickness is 2.5 inches.
9. Pavement sections are based on Tensar Triaxial TX5 Geogrid and SpectraPave software.

3.8 FLEXIBLE PAVEMENT DESIGN PROCEDURE

3.8.1 Methodology Overview

The FPS-21 software program shall be used for the design of flexible pavement. FPS-21 is a mechanistic-empirical design procedure that provides for multiple pavement design strategies. These strategies allow the Pavement Engineer to input various pavement layer thicknesses, material properties, traffic loading conditions, and cost considerations (initial and future). New construction, overlay options, and reconstruction strategies are provided as available options. The Roadway Designer will then select a design strategy based on cost, constructability, user delay, past performance, and City of Round Rock preferences based on budgetary constraints. Refer to the Flexible Pavement Design System (FPS) 21: User's Manual and the TxDOT Pavement Design Guide for documentation concerning this software and methodology for developing pavement strategies.

3.8.2 Pavement Section Model Options

TxDOT's FPS 21 software allows for seven basic design types as shown in Table 3-12. Although the number of distinct layers is limited to that shown in the table, the user can consolidate two or more layers if needed. However, the combining of layers will require assumption of a consolidated modulus. The Pavement Engineer should seek approval from the City prior to consolidating layers.

Table 3-12. FPS-21 Pavement Section Options

Layer No.	Design Type						
	1	2	3	4	5	6	7
Layer 1	Surface Treatment	HMAC Surface	HMAC Surface	HMAC Surface	HMAC Surface	HMAC Overlay	User Defined (less than 7 layers)
Layer 2	Flexible Base	Flexible Base	Asphalt-Treated Base	Asphalt-Treated Base	Flexible Base	Existing HMAC	
Layer 3	Subgrade	Subgrade	Subgrade	Flexible Base	Treated Subgrade	Subgrade	
Layer 4	---	---	---	Subgrade	Subgrade	Subgrade	

Notes:
1. The flexible pavement design examples presented in this manual use Design Type 5 as the recommended pavement section.

The most common pavement design options are Types 1, 2 and Type 5. However, Design Type 3 may be evaluated as an alternate pavement design, for example at intersections where minimizing traffic closures would be a consideration.

The pavement designer shall use historical bid-based data, adjusted for inflation, to develop cost inputs for the program.

3.8.3 FPS-21 Software Inputs

Key material inputs include back-calculated in-place materials, using the MODULUS 6 software with the Falling Weight Deflectometer (FWD) data, and realistic average moduli values for newly placed materials used for the main structural layers. FPS 21 includes a mechanistic design check for fatigue life and subgrade rutting potential. The Modified Texas Triaxial design check evaluates the impact of the anticipated heaviest wheel load on the proposed pavement structure.

Unless otherwise approved by the Transportation Director, the following design inputs should be used to develop flexible pavement thickness designs:

Table 3-13. Required FPS-21 Analysis Inputs

Input Parameter	Units	Input Value	Comment
BASIC DESIGN CRITERIA			
Length of Analysis Period	Yrs	20	
Min Time to First Overly	Yrs	20	
Min Time Between Overlays	Yrs	10	
Design Confidence Level Code	-	See Table 3-3	
Initial Serviceability Index	-	See Table 3-3	
Final (Terminal) Serviceability Index (P1)	-	See Table 3-3	
Serviceability Index After an Overlay (P2)	-	See Table 3-3	
District Temperature Constant	-	31.0	Typical for TxDOT District 14
Subgrade Elastic Modulus	Ksi	See Table 3-5.	
Interest Rate or Time Value of Money	%	7	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
PROGRAM CONTROLS AND CONSTRAINTS			
Number of Summary Output Pages	8 designs/ page	User preference	
Max Funds available per SY for Initial Design	$	99	Use sufficiently high value to maximize output design combinations.
Maximum Allowed Thickness of Initial Construction	Inches	99	Default value; use to constrain design to meet profile limitations or total number of designs.
Accumulated Max Depth of All Overlays (excluding level-up)	Inches	6	Use to constrain design to meet profile limitations.
TRAFFIC DATA			
Beginning ADT	Veh./ day	See Table 3-3	Two-direction volume parameter used to generate user delay costs during overlay.
Ending ADT	Veh./ day	See Table 3-3	Same as above at end of 20-year analysis period. Assumed to increase linearly over time.
One-Direction 20-yr 18-kip ESAL	millions	See Table 3-3	If the analysis period is other than 20 years, internal equations will adjust and correct for specified analysis period.
Average Approach Speed to Overlay Zone	MPH	Site dependent	Typically the posted speed limit.
Average Speed Through Overlay Zone (Overlay Direction)	MPH	Site dependent	Based on detour model used. Used to estimate user delay costs during overly. Can be set equal to Average Approach Speed to prevent calculation of user delay costs.
Average Speed Through Overlay Zone (Non-overlay Direction)	MPH	Site dependent	

Table 3-13. Required FPS-21 Analysis Inputs			
Input Parameter	**Units**	**Input Value**	**Comment**
Proportion of ADT Arriving Each Hours of Construction	%	4	
Percent Trucks in ADT	%	See Table 3-3	Used to convert traffic (of all vehicle types) into the 18-kip equivalent single axle loadings used for pavement structural design.
CONSTRUCTION AND MAINTENANCE DATA / DETOUR DESIGN			
Minimum Overlay Thickness	Inches	2.0	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
Overlay Construction Time	Hours / Day	12	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
Asphaltic Concrete Compacted Density	Tons / CY	1.9	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
Asphaltic Concrete Production Rate	Tons / Hr	200	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
Width of Each Lane	Feet	12	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
First Year Cost of Routine Maintenance	Dollars/ Lane-Mile	0	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
Annual Incremental Increase in Maintenance Cost	Dollars/ Lane-Mile	0	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
DETOUR DESIGN FOR OVERLAYS			
Detour Model Used During Overlaying	-	-	Based on Street Classification Type
Total Number of Lanes of the Facility	-	-	Based on Street Classification Type
Number of Open Lanes in Restricted Zone (Overlay direction)	-	-	Based on Street Classification Type
Number of Open Lanes in Restricted Zone (Non-overlay direction)	-	-	Based on Street Classification Type
Distance Traffic is Slowed (Overlay Direction)	Miles	0.6	
Distance Traffic is Slowed (Non-overlay direction)	Miles	0.0	
Detour Distance around Overlay Zone	Miles	1.0	
PAVING MATERIALS INFORMATION			
Cost per Cubic Yard	$/CY	0	Used to generate user delay costs during overlay. Cost analysis to be performed using FHWA LCCA when possible.
Layer Modulus		See Table 3-8.	Estimate using the TTC or CBR data provided by the geotechnical investigation. Alternatively, the elastic modulus may be back calculated using pavement deflection data. Note that Layer Modulus (EFPS) is not equal to Resilient Modulus (MR).
Poisson Ratio		See Table 3-8.	

Table 3-13. Required FPS-21 Analysis Inputs			
Input Parameter	**Units**	**Input Value**	**Comment**
Min Depth -Asphalt Conc Pvmt -Flexible Base -Stabilized Subgr -Subgrade		- 2.5 8 8 200	Varies such that the Mechanistic Design check provides optimum tensile strains for HMAC surface and compressive strains for Treated subgrade
Max Depth -Asphalt Conc Pvmt -Flexible Base -Stabilized Subgr -Subgrade		- 12 18 12 200	Varies such that the Mechanistic Design check provides optimum tensile strains for HMAC surface and compressive strains for Treated subgrade
Salvage Pct. -Asphalt Conc Pvmt -Flexible Base -Stabilized Subgr -Subgrade		- 30 75 90 90	Depends on the requirements of the CORR Pavement Maintenance Department

3.8.4 Modified Texas Triaxial Check

The modified Texas Triaxial Check establishes the minimum total combined pavement thickness required to prevent general shear failure in the subgrade. This is based on the following input parameters:

- Average Ten Heaviest Wheel Loads (ATHWLD). Defined as one of the following: (1) load carried by the dual tires at each end of the drive or trailer axles; (2) a single wheel load on each tire of the steering axle; or (3) tire load on drive or trailer axles equipped with wide-base radials. The following values are recommended based on ESAL range:
  - ESALs < 900,000: ATHWLD=10,000; and
  - ESALs < 10,000,000: ATHWLD=11,500.
- Percentage of Tandem Axles. The following input categories apply:
  - Tandem axles < 50%: No adjustment to wheel load required. This option should be selected for projects with design ESALs < 5,000,000; and
  - Tandem axles > 50%: FPS-21 internally increases wheel load by 30%.
- Modified Cohesiometer Value (C_m). This parameter accounts for the presence of engineered material (lime-treated subgrade, subbase, etc.) above native subgrade which will protect subgrade from shear failure. The following values are recommended for various materials:
  - Lime-Treated Base >3" thick 300;
  - Lime-Treated Subgrade >3" thick 250;
  - Cement Treated Base >3" thick 1000;
  - Cold Mixed Bituminous materials > 3" thick 300;
  - HMAC > 6" thick 800;

- HMAC between 4” and 6” thick 550;
- HMAC between 2” and 4” thick 300; and
- Untreated materials 100.

- Subgrade Texas Triaxial Class (TTC). This shall be estimated either based on Tex-117-E, or input of soil PI and program’s internal correlations.

3.8.5 Evaluating Results of FPS-21

Results of FPS-21 should be examined to ensure the following criteria are met:

1. Mechanistic Check:
   a. Rutting: $ESAL_{Design} \leq ESAL_{Rutting\ Life}$;
   b. Cracking: $ESAL_{Design} \leq ESAL_{Crack\ Life}$;
   c. Limiting Tensile Strain in HMAC: ≤ 70 με (Arterial Streets Only)
   d. Limiting Compressive Strain in Subgrade: ≤ 200 με (Arterial Streets Only)
2. Modified Texas Triaxial Check: $Thickness_{(FPS\ Design)} \geq Thickness_{(Modified\ Triaxial\ Required)}$

As indicated above, all Arterial streets shall be designed to meet the limiting tensile and compressive strain requirements of Perpetual Flexible Pavements as described in the FPS-21 User’s Manual and TxDOT Pavement Design Guide Manual (2011). These criteria were established based on the expectation that the 20-year design life to first overlay could result in significant traffic loading distress/deformation, and similar to Perpetual Pavements, limiting the predicted strains should serve to extend pavement life to meet minimum performance criteria.

3.9 RIGID PAVEMENT DESIGN PROCEDURE

3.9.1 Methodology Overview

Rigid pavement designs shall be developed utilizing the most recent version of American Concrete Pavement Association's (ACPA's) StreetPave12. The software may be obtained from http://www.acpa.org/streetpave/. StreetPave12 is based on the 1960's Portland Cement Association (PCA) method and is tailored for streets and roads (not highways or interstates) with the failure models being: (1) cracking; and (2) faulting. Description of software analysis methods for these two failure modes are provided below.

3.9.1.1 Cracking Analysis

StreetPave12 performs pavement cracking analysis by examining the stresses at the edge of the slab generated by the traffic loads. The software uses the concept of equivalent moment due to traffic loads, which differs for single, tandem, or tridem axle loading, and considers cases with and without pavement edge support. The calculated moment depends on pavement thickness, concrete elastic modulus, Poisson's ratio, 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 increases in concrete strength with age after the 28th day (approximately 23.5%), and reduction of one coefficient of variation (COV) to account for materials variability.

The software methodology is based on empirical data in which the occurrence of pavement fatigue (i.e., cracking) is related to the number of traffic load repetitions and a parameter termed Stress Ratio (SR). The SR is expressed as follows:

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

StreetPave12 internally limits the Stress Ratio (SR) to a value below which fatigue is predicted to occur, as illustrated in Figure 3-4, to achieve the target traffic load repetitions design value. The program achieves this by iteratively increasing thickness of the concrete slab until an acceptable SR is obtained.

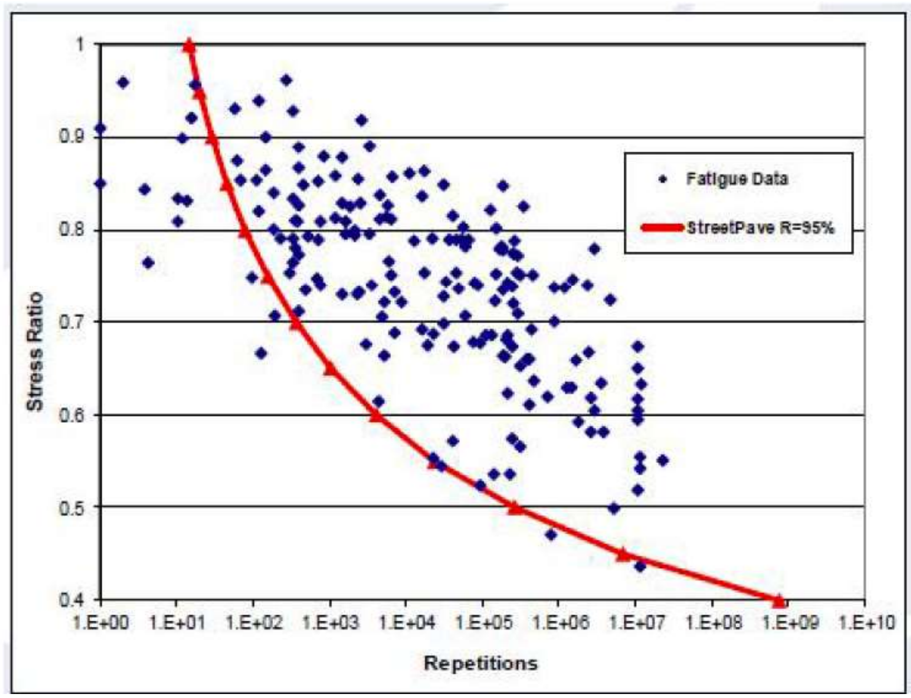

Figure 3-4. StreetPave12 Cracking Analysis Methodology (from CAPEC 2016, after Rodden 2014).

3.9.1.2 Faulting Analysis

Faulting refers to the failure mode by which the adjacent pavement slabs shift vertically relative to each other at a joint, forming a "bump". StreetPave12 performs pavement faulting analysis using empirical methods developed from field performance data developed in the 1980's from sites in Wisconsin, Minnesota, North Dakota, Georgia, and California. StreetPave12 internally increases concrete slab thickness until faulting is not predicted to occur. Note that in pavements where dowels are used at pavement joints, the faulting failure mode is precluded from occurring, and failure is controlled by cracking only.

3.9.2 Pavement Section Model Options

StreetPave12 permits modelling of several different pavement layer types. Layers underlying the slab are internally referred to as "subbase types", but include both treated subgrade and subbase materials. The optional materials are listed below. While asphalt-based subbases are required for use as bond breaker layer, the LCB, ATB, and asphalt subbase materials are not commonly used in Round Rock area for pavement support, and other materials (lime- and cement-treatment) should be given first consideration.

- Cement-Stabilized Subgrade: Permitted in combination with non-erodible subbase;
- Lime-Stabilized Subgrade: Permitted in combination with non-erodible subbase;

- Unstabilized subbase (e.g., crushed stone): Not permitted (erodible subbase);
- Cement-Treated Subbase (CTB): Recommended;
- Lean Concrete Subbase (LCB): Permitted upon approval by City;
- Asphalt-Treated Subbase (ATB): Recommended; and
- Hot-Mix or Warm-Mix Asphalt Subbase: Permitted upon approval by City.

3.9.3 Traffic Spectrums

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. These traffic spectrums establish the truck factors to be used in the ESAL calculations, which are internal to the program.

- Predetermined Traffic Spectrums. Predetermined spectrums are identified by street classifications as follows:
  - Residential: ACI 330 Category A;
  - Collector: ACI 330 Category B;
  - Minor Arterial: ACI 330 Category C; and
  - Major Arterial: ACI 330 Category D.
- User-Defined Traffic Spectrums. Custom traffic spectrums are entered by identifying the axle load by single, tandem, and tridem axle type, and number of axles per 1000 trucks.

3.9.4 Traffic Inputs

The truck traffic over the pavement design life is calculated and use in pavement thickness design based on the traffic spectrums defined previously and by providing the following inputs parameters:

- Trucks per day See Table 3-3
- Traffic growth rate per year See Table 3-3
- Design life 30 years
- Directional distribution See Table 3-3
- Design lane distribution See Table 3-1.

3.9.5 Pavement Layer Inputs

The primary input parameters for pavement layers required include the following:

- 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. Alternatively, this input could be viewed as the percent of slabs that are intended to be replaced in determining future rehabilitation of pavement for life cycle cost analysis. Design values for different street classifications shall be as follows, based on findings of FHWA-RD-97-131 “Common Characteristics of Good and Poorly Performing PCC Pavements”:

  - Arterials 4%;
  - Collector Streets: 15%; and
  - Local Streets: 25%.

- 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 modulus of subgrade reaction (K-value). This value estimates the support of the layers below the concrete slab. While field measurements are recommended, the k-value is more typically calculated based on the thickness and layer strengths as described below.
  - Subgrade Modulus: can either be given as a direct field-measured input, or calculated through correlations presented previously with appropriate use of engineering judgment. The equations developed from NRHCP 128, “Evaluation of the AASHTO Interim Guide for the Design of Pavement Structure” is used to estimate the subgrade modulus. Refer to Table 3-4 for more details on subgrade modulus and k-value ranges based on soil type.
  - Subbase Modulus: 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 Section 3.4.4. 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.
- 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. Concrete pavement shall be constructed to TxDOT Item 360 “Concrete Pavement”, therefore use Class “P” concrete with flexural strength of 570 psi at 28 days.
- Edge Support. The critical load location on a concrete slab is at an unsupported edge. Consequently, reduced pavement thickness can be achieved by providing additional edge support such as 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 foot from the pavement edge. If edge support is to be provided, that should be indicated so on in the PDR and design plans.

3.9.6 Evaluating the Results of Streetpave12

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. The results of Streetpave12 should be examined to ensure appropriate pavement design recommendations are documented in the PDR:

- Calculated design ESALs meet project criteria;
- Controlling failure mechanism;
- Maximum joint spacing;
- Whether or not dowel bars are required, and bar diameter;
- Whether or not edge support is required; and
- Regardless of the StreetPave12 output value, the minimum concrete pavement thickness shall be 6 inches.

All construction joints in a rigid pavement section must be dowelled for successful long term performance. StreetPave12 provides guidance regarding maximum joint spacing and dowel bar recommendations for jointed plain concrete pavement. These recommendations shall be compared to the following ACI guidance documents to avoid cracking due to improperly located and constructed joints:

- ACI 325.12R-02 Guide for Design of Jointed Concrete Pavements for Streets and Local Roads, by ACI Committee 325, American Concrete Institute, Reapproved 2013; and
- ACI 330R-08 Guide for the Design and Construction of Concrete Parking Lots.

Concrete pavement shall be in accordance with TxDOT Standard “Concrete Pavement Contraction Design-CPCD”.

3.10 LIFE CYCLE COST ANALYSIS

3.10.1 Overview

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. .The pavement designer shall use historical bid-based data, adjusted for inflation, to develop cost inputs for the program.

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 are 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.

3.10.2 Procedure

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 in electronic format 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. 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 concrete alternatives on the same cost basis. Input variables are as follows:

3.10.3 Criteria

These are the analysis criteria which determine the analysis guidelines by which the program calculates costs. Requirements for several of the variables are as follows:

- Analysis Period (Years) – a minimum of a 40 year analysis period, with the initial cross section designed for 20 years until the first overlay.
- Discount Rate – This value is determined using the estimated interest rate (%) and inflation rate (%).
- User Cost Computation Method (Calculated or Specified) – default built-in models are recommended to calculate the user delay costs.

- Probability Functions – The deterministic option should be used instead of one of the probability functions.

3.11 DESIGN AND IMPLEMENTATION OF CONSTRUCTION QUALITY CONTROL PROGRAM

3.11.1 General

Construction 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 contained in the PDR and/or Geotechnical Report should be incorporated into the design documents and adhered to in the field during construction.

3.11.2 Qualifications

The testing laboratory and field technicians shall hold the proper accreditation and Certificate of Qualification as appropriate for the scope of the project, and shall be approved by the City of Round Rock.

3.11.3 Field Testing Procedures

All materials shall be sampled and tested by a Testing Laboratory independent of the Contractor in accordance with the approved design documents. Certified copies of 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 City.

3.11.4 Design of Testing Program

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. Consequently, the Geotechnical Engineer and Pavement Engineer must determine the required types of field tests which can be practically and expediently performed and be reliably correlated to the following parameters.

- Hot Mix Asphalt Concrete (HMAC):
    - Resilient Modulus of HMAC layers;
    - Resilient Modulus of Base/Subbase layers; and
    - Resilient Modulus of Subgrade; and
- Concrete Pavement:
    - Flexural Strength of concrete pavement;
    - Resilient Modulus of concrete pavement;
    - K-value of subbase layers; and
    - 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.