City of Killeen, Texas

Pavement Design Manual (Draft)

June 2022

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1 PAVEMENT AND SUBGRADE DESIGN REQUIREMENTS

1.1 General

A. All new City streets, alleys, and rehabilitation of existing streets shall be designed and constructed in accordance with the latest editions of the City of Killeen ("City") Construction Standards and Specifications, and all applicable codes and standards.

B. The following specifies standard requirements for the pavement, subgrade, and subsurface design for roadways and alleys within the City. These standards are not intended to replace the professional judgment of the Geotechnical Engineer for any specific project. The standards may need to be expanded or modified on a case by case basis as determined necessary and appropriate by the Geotechnical Engineer, and as approved by the City.

C. Service life has been defined as the anticipated number of years that a pavement will be functionally and structurally acceptable with only routine maintenance. Flexible pavements shall be designed for a 20-year service life.

D. **Table 1-1** lists the City's standard flexible pavement and subgrade thickness and dimensions for local streets based on representative soil types around the City. These standards meet or exceed the 20-year service life in accordance with the Pavement Design Input Values per **Table 1-3 & Table 1-4**.

Table 1-1: Flexible Pavement and Subgrade Design Standards for Local Street

Street Classification	Swell Potential (PI)	Standard Section[1]		
		HMAC (in.)	Flex Base (in.)	Treated Subgrade (in.)
Local Street	High (≥41)	3	9	8
	Moderate (21-40)	3	8	8
	Low (≤20)	3	8	N/A

1. All pavement sections shall include 8 in. of scarified, moisture conditioned, and recompacted subgrade. Moisture conditioned subgrade is not required if competent rock is encountered within an 8 in. depth and when observed to be absent of pumping/heaving during proof-rolling.

1.2 Geotechnical Investigation and Report

A. **All roadways and alleys (CIP and Development) shall have a geotechnical investigation and subgrade design performed meeting the following requirements**. A custom pavement design to achieve a 20-year design life will be required for all flexible pavements.

B. For Local Street classifications only - If the subgrade modulus meets the minimum presented in **Table 1-3**, then the City's standard subgrade and pavement section for local streets can be utilized per **Table 1-1**.

C. The Geotechnical Engineer shall use the traffic parameters as shown in **Table 1-4**. If a Traffic Impact Analysis (TIA) has been performed and the traffic parameters are greater than the parameters shown in **Table 1-4**, then the greater traffic parameters shall be used. Adequate consideration must be given to heavy loads such as transit or school busses, fire trucks, solid waste trucks, and construction traffic. A review should be made of existing and/or planned bus routes, fire stations in the vicinity, schedule of solid waste and/or recycling trucks, etc. It is critical to increase traffic projections to account for the addition of construction traffic during the development of the design traffic for the roadway, either as added daily trucks, increased percentage of trucks or added ESALs.

D. Results of the geotechnical investigations, engineering analyses, and recommendations shall be presented in a Geotechnical Report for Roadways ("Report"). The Report and any subsequent re-evaluations and/or supplemental reports shall be signed and sealed by a Licensed Professional Engineer in the State of Texas, trained and qualified to provide geotechnical engineering analysis and pavement, subgrade, and subsurface design recommendations.

E. The Report shall address all items listed in the Geotechnical and Design Report for Roadways Checklist ("Checklist"). The Checklist shall be filled out completely and submitted with the Report. The Report shall include the description of project, location of project, roadway type and classification, grading plan and summary, discussion of utilities within the Project limits, and discussion of traffic input data used, including construction traffic. Any "N/A" response on the Checklist shall include a written explanation and adequate justification as deemed necessary. Additionally, the **Summary of Pavement Design Form** shall be filled out completely and submitted with the Report.

F. The City's review of the Report will be conducted as a means to verify if the pavement, subgrade, and subsurface design has been performed in general conformance to the City's requirements and shall not be considered a detailed technical review of the design for adequacy, accuracy, or completeness. The Geotechnical Engineer performing the subsurface investigation and pavement/subgrade design shall remain responsible for the technical adequacy, accuracy, and completeness of the design and shall not be relieved of any responsibility for such as a result of the City's review.

G. The information and recommendations contained in the Report and any subsequent re-evaluation and/or supplement reports must be accepted in writing prior to Release of Construction.

H. The geotechnical investigation and pavement design shall follow the procedures as shown in **Table 1-2**, as warranted, 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 1-2: Geotechnical Test Procedures

Geotechnical Test Procedures	
Test Method	**Description**
Tex-100-E	Surveying and Sampling Soils for Highways
Tex-103-E	Determining Moisture Content in Soil Materials
Tex-104-E	Determining Liquid Limits of Soils
Tex-105-E	Determining Plastic Limit of Soils
Tex-106-E	Calculating the Plasticity Index of Soils
Tex-107-E	Determining the Bar Linear Shrinkage of Soils
Tex-110-E	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-125-E	TxDOT K-value
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 D1883	California Bearing Ratio (CBR)
ASTM D2166/D2166M-16 or AASHTO T208	Unconfined Compressive Strength
ASTM D4546	Standard Test Methods for 1-D Swell or Collapse of Soils
ASTM D4602–93	Falling Weight Deflectometer (FWD)
ASTM D4602–93	Heavy Weight Deflectometer (HWD)
ASTM D6951/D6951M – 09	Dynamic Cone Penetrometer
AASHTO T 222-78	Plate Load Test for K-Value
ASTM D4429-09	Plate Load Test for CBR
AASHTO T 307-99	Resilient Modulus

1.3 Existing Surface/Subsurface Investigation

A. Field investigation shall include the following:

1. Borings shall be drilled on center of proposed roadway, or within proposed roadway widening, at 500-foot spacing (or less) or as needed to determine the subgrade variation between known geologies. Borings shall alternate between each roadway direction to a depth of at least 15 feet below finished subgrade or until competent rock is encountered, whichever is shallower. Where existing

roadways exist, borings shall be taken within the limits of the existing roadway. A minimum of 2 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.

2. Continuous sampling shall be conducted in upper 10 feet and every 5 feet, thereafter, 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 City specifies, or the Geotechnical Engineer believes coring is warranted.
3. Bulk samples of each soil type encountered shall be collected for Laboratory Investigation.
4. Geotechnical investigation must address heavily treed areas, where such trees are to be planted or removed as tree roots can significantly alter moisture conditions of the soil underlying the pavements when roots encroach the right of way and results in expansive, soil-related movements. The removal of nearby trees can also affect the moisture state of the underlying soils. The Engineer should consider additional borings in these areas.

B. Laboratory investigation shall include the following:

1. Selected samples representative of each soil type are required to be tested to determine grain size characteristics, Atterberg limits, in-situ moisture, and potential vertical rise (PVR). Other engineering properties shall be determined, as deemed appropriate, by the Geotechnical Engineer or as requested by the City.
2. Each subgrade soil type obtained from the field shall be tested to determine the soil resilient modulus by California Bearing Ratio (CBR) or other subgrade strength testing methods listed below.
3. Soils with a Liquid Limit (LL) greater than 40 and plasticity index (PI) greater than 20 shall be considered expansive for purposes of this manual and shall require subgrade treatment. Each soil type requiring subgrade treatment shall be tested for total soluble sulfate content and organic content. A pH-lime series test shall be conducted on those soils with soluble sulfate content less than 7,000 ppm and an organic content less than 1% to determine the percent of lime by weight to stabilize the subgrade soils. Soils containing soluble sulfates of greater than 7,000 ppm should not be lime stabilized, cement stabilized, or stabilized with any other pozzolan due to the risk of sulfate-induced heave and should consider alternate subgrade treatment methods in accordance with TxDOT's Guidelines for Treatment of Sulfate-Rich Soils and Bases in Pavement Structures.
4. The estimated Potential Vertical Rise (PVR) for roadways shall be determined using TxDOT test procedure Tex-124-E, Potential Vertical Rise of Natural Subgrade Soils, and the results shall be included in the Report. An appropriate surcharge load (if any), active zone, and moisture conditions should be considered in estimating the

PVR values. Boring depths shall be sufficient to determine the active zone for the expansive soil. Other methods of determining swell may be utilized if detailed in the pavement design report and if approved.

C. A soil resilient modulus (Mr) shall be determined by geotechnical engineering analysis, or back-calculated from deflection data, or estimated based upon other soil strength or characteristic properties and correlated to the resilient modulus. Variations such as, in-situ moisture content, changing geological formations and strata, and sample depth relative to the final design grade, will impact the results of field or laboratory testing and should be taken into consideration during the determination of subgrade support for design. If correlations are used to determine the soil resilient modulus from other soil strength parameters (e.g. California Bearing Ratio, shear strength, etc.), the correlation shall be disclosed with appropriate backup information provided in the geotechnical report.

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

   1. 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;
   2. Direct Laboratory Testing
      - Resilient Modulus: AASHTO T 307-99;
   3. 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.

D. A Subgrade Verification Letter is required to be provided by the Geotechnical Engineer following rough cuts in the event the investigation was done prior to construction. This letter shall state if the subgrades encountered during construction are consistent with the subgrades anticipated in the geotechnical report.

E. A geotechnical re-evaluation will be required if the following situations occur or as deemed necessary:

1. If more than two months occur between the end of initial grading and beginning of liming operations or otherwise approved.
2. When conditions have changed significantly between initial grading and liming operations.
3. Subgrade Verification Letter states material encountered during construction varies from the surrounding bore results (i.e. soft pockets of sand or clay).
4. If public infrastructure is being placed on undocumented fill; and/or
5. When Contractor and/or Owner have not properly maintained moisture content during each phase of construction.

F. If required, the re-evaluation shall include additional field and laboratory testing to either confirm recommendations are still acceptable or to determine how to rectify the non-conforming condition prior to construction of the pavement section.

G. If tree species that are not approved by the City as a street tree are within 10-feet of the limits of the treated subgrade, a moisture/root-barrier extending to an appropriate depth based on the site specific geological conditions is required and the Geotechnical Engineer shall recommend the depth of the barrier.

H. If existing trees are removed within the limits of the treated subgrade, the Geotechnical Engineer shall address mitigation of this condition in the Report.

1.4 Subsurface Design

A. Provide modifications to subsurface layers to limit the effective Plasticity Index (PIeff) to the following criteria:

- Arterials and Commercial Collector PIeff ≤ 30
- Mixed Use Collector/Residential Collector/Local Street PIeff ≤ 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. 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. PIeff is determined by the following equation:

PIeff = Σ (Fi x Di x PIi) / Σ (Fi x Di)

Fi = Weight Factor;
Di = Depth of Soil Stratum within Particular Weight Factor Region; and
PIi = Plasticity Index of Soil Stratum within Particular Weight Factor Region.

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

- Arterials and Commercial Collector PVR ≤ 2.0
- Mixed Use Collector/Residential Collector/Local Street PVR ≤ 3.0

A PVR calculation spreadsheet can be downloaded from the TxDOT website. When using the spreadsheet, the pavement design thicknesses resulting from FPS21 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).

1.5 Subgrade Design

Subgrade improvement is required whenever the geotechnical investigation indicates the presence of in-situ soils with effective plasticity index (PIeff) and/or potential vertical rise (PVR) values exceeding those specified in **Section 1.4** and shall be designed to reduce these parameters to acceptable values. Limits of subgrade improvement shall extend 2’ behind the back of curb. The Geotechnical Engineer is responsible for identifying when subgrade improvement is required, and which improvement alternatives should be considered. The Geotechnical Report shall include these recommendations to improve the subgrade, if necessary.

A. Lime Treatment

Lime stabilization of at least 8 inches of subgrade is required when the soil investigation indicates that more than 2 feet of expansive subgrade soil (inclusive of the moisture conditioned subgrade) with P.I. greater than 20 exists underneath the expected pavement section. The Geotechnical Engineer shall determine the target lime content in accordance with TxDOT’s test procedure Tex-121-E. The application rate of lime shall be determined based on laboratory testing and shall be the lowest percentage of lime that provides a pH of 12.4 or greater using TxDOT’s test procedure Tex-121-E; and provides a targeted PI of 20 or less, or percentage of lime that provides the lowest PI per test procedure Tex-106-E. Lime series testing prior to application is required. Any change in field material will require additional lime series tests. The Geotechnical Engineer shall determine the treatment depth and application rate. “Structural credit” for lime treated layers may be granted for layer thicknesses of at least 8 inches or more. Unconfined compression testing using TxDOT’s test procedure Tex-121-E, Part 1 is required and must provide at least 50 psi for structural credit. In no case shall the lime be less than 20 pounds per square yard for 8 inches of lime treated subgrade.

B. Cement Treatment

Cement treated subgrade is discouraged when admixing highly expansive clay soil and must be approved if it is used for stabilization. If used, consideration could be made to using it in combination with lime. This section should not discourage or limit the use of

cement to treat granular, low plasticity soils, subbases, and/or recycled pulverized mixtures of asphalt and flexible base.

C. Remove and Replace

Remove and replace subgrade improvement method consists of removal of weak or highly expansive subgrade materials and replacement with engineered fill. Remove and replace can be effective to remove weak subgrade materials and/or to reduce PVR and effective PI to acceptable values. 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 to the desired depth may not be economically feasible, but any amount of removal and select fill replacement yields better long-term performance than none at all. Replacement fill should consist of engineered fill meeting recommendations of the Geotechnical Engineer. In general, engineered fill should meet $4 \leq PI \leq 20$ and $LL<40$ to reduce potential for volume change.

D. Moisture Treatment

Moisture treatment is discouraged and shall not be used unless approved by the City Engineer.

E. Geogrid

Geogrid design can be considered to assist with mitigating environmental cracking. Stabilization with geogrid base reinforcement designed for "structural credit" will be considered based on the geotechnical engineering report. The geotechnical engineer shall provide sufficient documentation that justifies the magnitude of structural credit that can be taken depending on the type of geogrid utilized. Otherwise, no structural credit will be allowed. The City has final approval of accepting a reasonable amount of structural credit.

1.6 Flexible Pavement Design

A. The FPS21 software program, (or the latest TxDOT FPS version) shall be used for the design of flexible pavement. FPS21 is a mechanistic-empirical design procedure that provides for multiple pavement design strategies. Refer to the Flexible Pavement Design System FPS21: User's Manual and the TxDOT Pavement Design Guide for documentation concerning this software and methodology for developing pavement strategies.

B. All pavement design shall be in accordance with City's Technical Specification, Standard Details, and General Notes unless otherwise approved. All pavement sections must be designed using the Pavement Design Input Values contained in **Table 1-3 and Table 1-4,** at a minimum. It is the Geotechnical Engineer's responsibility to ensure those input values are applicable based on actual conditions

    1. The section shall be based on a Geotechnical Engineer's recommendation and must be based on a 20-year design life.

2. All flexible pavement layer thicknesses shall be rounded up to the nearest inch, with the exception of surface asphalt course which shall be rounded to the nearest half-inch.
3. A minimum of 2" hot mix asphalt is required for all flexible pavement sections.

C. A printout of the FPS21 design inputs and outputs must be included in the Report. A mechanistic and a triaxial check must be performed and the results must be printed and attached to the Report.

D. The Geotechnical Engineer may design full depth hot mix asphalt sections for projects including widenings, turn lanes, and fast track operations. Full depth HMAC sections must be designed in accordance with all requirements of this Manual and using the Pavement Design Input Values contained in **Table 1-4**

Table 1-3: Typical Pavement Design Input Values for Flexible Pavements – All Classifications

Design Input	
Pavement Design Life	20 years
Time To First Overlay	20 years
Time Between Overlays	10 years
Subgrade Modulus High PI (≥41)	4 ksi*
Subgrade Modulus Moderate PI (21-40)	9 ksi*
Subgrade Modulus Low PI (≤20)	18 ksi*

*Maximum

Table 1-4: Pavement Design Input Values for Flexible Pavements – By Classification

	Street Classification					
Design Input	**Principal Arterial**	**Minor Arterial**	**Commercial Collector & Marginal Access**	**Mixed Use Collector**	**Residential Collector**	**Local Streets**
Initial ADT (vehicles)	22,000	14,500	12,000	7,500	2,800	550
Final ADT (vehicles)	48,000	32,000	24,000	15,000	5,000	1,000
Growth Rate	4.00%	4.00%	3.50%	3.50%	4.00%	4.00%
% Trucks	9%	9%	9%	8%	5%	3%
Truck Factor	0.92	0.84	0.62	0.62	0.53	0.4
# of Lanes	6	5	4	3	2	2
Directional Distribution	0.5	0.5	0.5	0.5	0.5	0.5
Lane Distribution	0.7	0.8	0.8	0.8	1	1

Initial Serviceability Index	4.2	4.2	4.2	4.2	4.2	4.2
Terminal Serviceability Index	2.5	2.5	2.5	2.5	2	2
Confidence (%)	95%	95%	95%	95%	90%	80%
Design Lane ESAL	**7,500,000**	**5,000,000**	**3,000,000**	**1,500,000**	**500,000**	**100,000**

1.7 Rigid Pavement Design

Should Rigid Pavements be selected as a recommendation for the City's consideration and acceptance, a Geotechnical Engineering Report for Roadways shall be prepared. All rigid pavement sections shall be prepared using a design life of at least 30 years. Above Section 1.3 *Existing Surface/Subsurface Investigation* shall be included as part of the Report and pertinent traffic input information from Table 1-4, extrapolated to 30 years, shall be utilized in the rigid pavement design. The report shall clearly present all assumptions utilized in the Consultant's design as well as the program utilized to develop the recommended sections. The American Concrete Paving Association (ACPA) program StreetPave 12 or the latest available version is recommended for use.

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Roadway Construction Inspector Checklist

Project Name: _____

Inspector Name:_____

Date Started: _____ Date Completed: _____

COMPLETE	N/A	
		1. SUBGRADE PREPERATION
☐	☐	A. Demolition – Existing improvements (pavements, curbs, utilities) properly removed and backfilled, if applicable.
☐	☐	B. Stripping and Grubbing – Topsoil and vegetation properly removed and resulting voids properly backfilled, if applicable.
☐	☐	C. Proofrolling – Proof rolled subgrade prior to placement of fills or following cuts. Areas of observed deflection adequately repaired, if applicable.
☐	☐	D. Moisture Conditioning – Subgrade properly moisture conditioned and compacted to specified depth. Depth _____in.
☐	☐	E. Plasticity Index – Plasticity Index testing of subgrade material completed to determine if treatment is needed. Subgrade Treatment Method, if applicable: _____
☐	☐	F. Lime/Cement Application Determination – pH and sulfate content testing completed to determine application rate and mellowing period, if applicable.
☐	☐	G. Lime/Cement Treatment –Treatment properly performed and subgrades adequately compacted. Depth _____in. Rate _____lbs/s.y.
☐	☐	H. Remove and Replace Depth of material over excavated _____in. Backfill Material Description or reference: _____
COMPLETE	N/A	2. FLEXIBLE BASE PREPARATION
☐	☐	A. Flexible base material meets specifications.
☐	☐	B. Flexible Base Placement – Flexible base is adequately compacted and was placed in appropriate lift thicknesses. Lift Thickness _____in.
COMPLETE	N/A	3. FLEXIBLE PAVEMENT OPERATIONS
☐	☐	A. Seal Coat – Seal coat properly placed on prepared flexible base, if applicable. Application rate _____gal/sq yd
☐	☐	B. Tack Coat – Tack Coat placed between pavement lifts, if applicable. Application rate _____gal/sq yd
☐	☐	C. Pavement Type – Pavement type identified coming from plant and is in accordance with project requirements. Type _____.
☐	☐	D. Placement Lifts - Pavement placed and compacted in proper lifts Lift Thickness_____in.
☐	☐	E. Compaction and Coring – Compaction measured during placement and core samples recovered for verification testing.

Inspector Signature: _____ Date: _____

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Pavement Design Construction Plan Review Checklist

Project Name: _____

Geotechnical Engineer/Firm:_____

City Reviewer: _____ Date Reviewed: _____

City Reviewer shall use this form to compare construction plan details to Summary of Pavement Design Form and/or Geotechnical Report. Any item marked revise must be submitted for revision to Design Engineer.

COMPLETE	N/A	REVISE	1. TITLE SHEET
☐	☐	☐	A. Roadway Classification
☐	☐	☐	B. Location of Project

COMPLETE	N/A		2. PROPOSED PAVEMENT SECTION
☐	☐	☐	A. Proposed Typical Section
☐	☐	☐	B. Moisture Conditioning Depth
☐	☐	☐	C. Subgrade Treatment Type
☐	☐	☐	D. Lime/Cement Thickness (inches)
☐	☐	☐	E. Lime/Cement Application Rates
☐	☐	☐	F. Geogrid Type
☐	☐	☐	G. Flexbase Thickness (inches)
☐	☐	☐	H. HMAC Thickness (inches)

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Summary of Pavement Design Form

Project Name: _____

Geotechnical Engineer/Firm: _____

Report Date: _____ Date Received: _____

Geotechnical Engineer must fill out this form completely, and submit with the Report. A proposed typical section detail must be provided.

1. DESIGN INPUT VALUES

Roadway Classification: _____

Calculated Effective PI: _____

Calculated Effective PVR: _____

Pavement Design Input Value Deviation(s): _____

2. DESIGN RECOMMENDATIONS:

Moisture Conditioning Depth (inches): _____

Subgrade Treatment: _____ Lime, Lime/Cement, Cement, Remove and Replace

Lime/Cement Thickness (inches): _____

Lime/Cement Application Rates: _____

Alternate Subgrade Treatment (Y/N): _____ If yes, describe

Flexbase Thickness (inches): _____

HMAC Thickness (inches): _____

3. PROPOSED TYPICAL SECTION – ATTACH TO THIS FORM

Miscellaneous Items and Notes:

_____

_____

_____

_____

_____

_____

Geotechnical Engineer Signature: _____ Date: _____