CHAPTER 10 – PAVEMENT DESIGN AND REPORT
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CHAPTER 10 – PAVEMENT DESIGN AND REPORT

10.1 GENERAL

The purpose of this chapter is to present the Street Structural Design Criteria required for use on all streets in the Larimer County GMA. These criteria shall be used in conjunction with **Chapter 7, Street Design and Technical Criteria**.

General Soils Investigations and Report requirements are outlined in **Chapter 5, Soils Investigations and Report**. Chapter 5 defines requirements for soil testing and backfill requirements for all cut and fill areas within the right-of-way or public easements. The Final Pavement Design Report shall include follow-up testing for subgrade soil expansion, subsurface water, and R-value, in accordance with **Table 10-2**.

10.1.1 Existing Streets

For existing streets the Local Entity Engineer may require deflection tests or other testing of the existing pavement and base structure to determine if an overlay is feasible, or if reconstruction is necessary.

10.1.2 AASHTO Design

The design criteria and procedures presented follow **American Association of State Highway and Transportation Officials (AASHTO)** 1993 Guide for the Design of Pavement Structures. Mechanistic Empirical design procedures may be substituted, if approved in advance ~~in the City of Loveland~~. The designer shall review the M.E. design criteria with the City prior to submitting the final pavement design.

Commented [SK1]: Update to reference the latest edition.

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10.1.3 Pavement Type

Streets are to be constructed of either asphaltic concrete pavement or Portland cement concrete, base course material, and subbase material (where required), placed on compacted subgrade. ~~In Loveland t~~The subgrade shall have a minimum one-foot layer of R=20 material. Refer to **Chapter 22, Construction Specifications,** for subgrade, subbase, and base course information. All new and reconstructed Arterial/Arterial intersections shall be constructed in Portland cement concrete pavement, in accordance with **Chapter 8, Intersections**. Exceptions to the Portland cement concrete pavement requirement may be granted for interim conditions described in **Chapter 8**, in the subsection **Pavement Requirements for Arterial/Arterial Intersections**.

Commented [SK4]: More discussion may be needed.

10.1.4 Treated Subgrade

The use of treated subgrade, treated base, and/or full depth asphalt pavement may be acceptable when designed and submitted by the designer, and approved by the Local Entity Engineer in accordance with these standards. The local entities for projects in Fort Collins (GMA and city limits) and Loveland (GMA only) generally will not approve full-depth asphalt pavement.

For treated subgrade, refer to **Chapter 23, Street Inspection and Testing Procedures**. For full depth asphalt refer to **Section 10.4.2 B**. The subgrade must be within 6 inches of final grade prior to any soil sampling and testing.

10.1.5 Arterial and Collector Level Intersections

The pavement thickness design for arterial and collector level intersections shall be the combined 20-year design for both directions for the shared use areas. A separate design analysis is required.

10.1.6 Roundabouts

The pavement thickness design for the circulatory roadway shall be based on the sum of the 20 year design volumes from all legs. A separate design analysis is required. Refer to **Section 8.2.17** for Roundabout design requirements.

10.1.7 Approval

A preliminary pavement design may be submitted with final construction plans. The Local Entity Engineer shall review the Final Pavement Design Report within two weeks of the submittal. The Local Entity Engineer's approval is required prior to subgrade treatment, placement of base or pavement (including curb and gutter) construction.

10.1.8 New Pavement Design

A new, revised Pavement Design investigation and report shall be required if the following conditions occur:

A. Phases

If a street is to be built in phases, (i.e., the center two lanes are built first, then at some later date more lanes are added), and it has been at least two years since the original design was completed.

B. Imported Fill Material

If any new fill material that does not match the properties of the subgrade soil is imported, the Local Entity may require a new pavement design report or additional testing to verify the acceptability of this material for roadway fill.

10.2 FINAL PAVEMENT DESIGN – SOIL INVESTIGATION REQUIREMENTS

10.2.1 Timing of Soil Borings

Soil borings shall be taken in the existing or proposed street right-of-way. Subgrade samples shall be taken upon the material that will be subgrade after the installation of the sanitary sewer, waterline, other utilities, on which the final insitu subgrade strength characteristics may be affected by their installation. The subgrade shall be at or near its final elevation, generally within 6 inches or final subgrade elevation. Any required fill material shall be placed to the subgrade elevation prior to sampling.

Table 10-1
Flexible Pavement Design Criteria

ROAD CLASSIFICATION	20-Year Design Traffic Information		Serviceability Index (psi)			Relia-bility	Minimum Asphalt for Composite Section	Default Agregate Base Course Section	Default Full Depth Asphalt Pavement Thickness inches[2]	Min. Struct. No.[4,7]
			S_i	S_t	D		Layer, inches	Layer, inches	Layer, inches	
	EDLA[3]	ESAL	Init.	Final	psi	(%)	HMA	ABC	Min.	
LOCAL										
Resid. two lane	5	36,500	4.5	2.0	2.5	75	4.0	6.0	6.0	2.45
Resid. Cul-de-sac and single lane[5]	10	73,000	4.5	2.0	2.5	80	5.4	6.0	6.5	2.82
Indust./commercial	50	365,000	4.5	2.3	2.2	75	5.5	11.0	8.5	3.60
COLLECTOR										
Minor	25	182,500	4.5	2.3	2.2	75	5.5	7.0	7.5	3.20
Major	50	365,000	4.5	2.3	2.2	85	6.5	9.0	8.5	3.82
Indust./commercial	100	730,000	4.5	2.3	2.2	85	7.0	11.0	10.0	4.30
ARTERIAL										
Two lane	100	730,000	4.5	2.5	2.0	90	7.5	11.5	NA	4.51
Four lane	200	1,460,000	4.5	2.5	2.0	90	8.0	15.0	NA	4.90
Six lane	300	2,190,000	4.5	2.5	2.0	90	8.5	17.0	NA	5.25

NOTES:

[1] Wearing surface course shall be Grading S or SX for residential roadway classification and Grading S for collectors, arterials, and all industrial/commercial roadways.

[2] Full depth pavement may be used only on Local / Residential Class roads with written approval of the Local Entity Engineer.

[3] EDLA shall be calculated based on projected traffic uses. Minimum EDLA values are as given for the design lane. The Engineer may require greater EDLA values if warranted. City of Fort Collins will provide all EDLA numbers for City of Fort Collins projects. The EDLA for a roundabout shall include the cumulative EDLA for each entry leg. EDLA for arterial/collector intersections shall be two-way traffic.

[4] Minimum structural numbers are based on subgrade R-value = 5 and CDOT calculations ; M_R = 3,025 and Std. Deviation = 0.44 CDOT Design methods shall be used for resilient modulus calculations for all roads

[5] Single lane refers to a paved surface less than 20 feet wide, including residential alleys.

[6] Min/max lift thicknesses: Grade SX – 1 1/2"/2 1/2", Grade S - 2"/3.5", Grade SG - 3"/5" (2" Minimum surface wearing course) In Loveland, Grade SG may only be used with a variance approval.

[7] The minimum HMA section for Composite pavement s shall be 4-inches for Local, 5-inches for Collectors, and 6-inches for Arterials.

Commented [SK5]: Footnote 7 is not called out in Table 10-1. Added 7 to Min. Struct. No.

10.2.2 Frequency of Testing

A minimum of one boring shall be obtained for any roadway segment. A second boring shall be required in the trench of any installed utilities. The distance between borings shall not exceed 500 feet, two borings per location where utility trenches exist (one boring in the trench and one in compacted subgrade). Multiple samples shall be taken alternately among lanes and shall be evenly spaced. The Local Entity Engineer may require more frequent testing.

10.2.3 Depth of Borings

A. In Utility Trenches

In utility trenches, samples shall be taken to a minimum depth of 5 feet below the proposed subgrade elevation.

B. Outside of Trenches

Outside of trenches, samples shall be taken to a minimum depth of 10 feet below the proposed subgrade elevation.

C. Extra Depth

Borings shall extend deeper if bedrock or high groundwater are design concerns.

10.3 TESTING

The following tests, **Table 10-2**, are required for the Final Pavement Design testing.

Table 10-2
Required Tests

Test	Final Pavement Design Report
Visual	X
Liquid Limit	X
Plastic Limit	X
Moisture	X
Percent Passing 200	X
Gradation (Granular Soils)	X
AASHTO or USC Classification	X
Subgrade Support R-Value	X
Swell	**Mitigation and Detailed Analysis**
Percentage of Soluble Sulfates	X
Standard Penetration Test	X
Groundwater	X
Bedrock Level	X

10.3.1 Classification Testing

Soils shall be classified visually and tested to determine the properties listed in **Chapter 5, Soils Investigations and Report**. Sands and gravel samples shall be analyzed for gradation where needed to comply with classification requirements.

10.3.2 Subgrade Support Testing

Individual subgrade or composite samples shall be tested for subgrade support value. The Subgrade Soils Investigation report shall clearly state whether or not the subgrade soil is capable of supporting the proposed construction and design traffic loads. Recommendation for subgrade stabilization, if required, shall also be provided. The Final Pavement Report shall contain specific mitigation. The following subgrade tests shall be conducted:

A. Hveem Stabilometer

The subgrade support value shall be determined using Hveem Stabilometer (R-Value). The design R-value shall be for 300 psi (2070 kPa) exudation pressure. Reported data shall include the following:

1. Test procedure reference.
2. Dry density and moisture content for each sample.
3. Expansion pressure for each sample.
4. Exudation Pressure. Corrected R-value curve showing the 300 psi (2070 kPa) design R-value.

B. Swell Tests

Swell tests shall be conducted for samples with probable expansion (volume change estimate) greater than 2 percent based on actual test results. **Table 10-3** provides a guideline for expansion potential. Surcharge pressure shall be 150 psf, or as specified by the Local Entity Engineer. Refer to **Section 5.7** for mitigation requirements.

1. Minimum number of samples. At least two samples shall be required per soils report, with one test sample within trench backfill and one outside of trench backfill. Thereafter continue with one swell test every fourth sample unless waived by the Local Entity Engineer.

Table 10-3
Expansion Potential of Subgrade Soils

% Passing No. 200 Sieve	Liquid Limit (%)	Standard Penetration Resistance (Blows/Ft)	Volume Change Estimate (% of Total)	Expansion Classification
>95	>60	>30	>10	Very High
60–95	40–60	20–30	3–10	High
30–60	30–40	10–20	1–5	Medium
<30	<30	<10	<1	Low

10.4 PAVEMENT THICKNESS DESIGN CRITERIA

Pavement design procedures in this section provide for a 20-year service life of pavement when normal maintenance is provided to keep the roadway surface in an acceptable condition.

10.4.1 Design Factors

A. Equivalent Daily Load Applications (EDLA)

Equivalent Daily Load Applications (EDLA) and Equivalent Single Axle Loads (ESAL) units are based on 18 kip (80 kN) axle loading on each design lane. All data and design procedures in this section use EDLA or ESAL units for pavement loading repetitions. Minimum EDLA and ESAL criteria for each roadway classification are given in **Table 10-1**. The values shall be increased for roadways with a traffic study showing higher traffic numbers. In Fort Collins (city limits only), the City will provide all EDLA (ESAL) numbers.

B. Design Serviceability

The Serviceability Index to be used for all Local Entity Roadways dedicated for public use is given in **Table 10-1**.

C. Minimum Pavement Section

Table 10-1 provides the default acceptable pavement sections for each roadway classification based on assumed subgrade support and traffic values. These pavement thicknesses may be used for preliminary planning purposes and cost estimates. All pavement thickness designs must be based on actual subgrade support test results (refer to **Chapter 5, Soils Investigations and Report**) and traffic projections (refer to **Chapter 4, Transportation Impact Study**) for the specific project. In specifying layer thickness, the designer shall consider how the pavement section will be physically constructed (e.g. Specify how to construct 2' of treated subgrade or the number of lifts and the grade for asphalt in a 6-inch asphalt section .)

D. Flexible Pavement Strength Coefficients

Table 10-4 contains the standard design coefficient for various pavement materials. Nonstandard design coefficients may be used, only if approved in advance by the Local Entity's Engineer. In addition, design values must be verified by pre-design mix test data and supported by daily construction tests (refer to **Chapter 23, Street Inspection and Testing Procedures**).

E. Portland Cement Concrete Working Stress (f^t)

The working stress (f^t) to be used in the design shall be 75 percent of that provided by third-point beam loading, which shall have a minimum laboratory 28-day strength of 600 psi based on actual tests of materials to be used.

10.4.2 Special Considerations

A. Staged Construction

This is an alternative for the Developer to provide a minimum thickness pavement during construction, and after repairs, construct the final lift of asphalt, providing for a new finished pavement surface. Minimum asphalt and aggregate base course thicknesses are given in Table 10-1.~~alternate composite sections using Grade SG hot~~

Commented [SK6]: Comments from Tom Knostman 7/12/19.

mix asphalt (HMA) may be submitted for approval with a minimum wearing course thickness of 2.0 inches. If the full pavement section is not to be placed immediately, a pavement design for staged construction may be required by the Local Entity Engineer. The staged construction design must include asphalt thickness for each proposed stage. Calculations, traffic numbers, and construction truck traffic numbers supporting the staged design must also be submitted. For staged construction, accommodations must be provided for the paved surface to drain with no water left standing on the pavement.

1. Overlay at End of Warranty Period. After the end of the two-year warranty period, (and after all Punch list repairs have been made), the Contractor shall pave a 1.5 ½ inch" SX overlay.

   The report shall instruct the Contractor to pave 0.5 ½ inch less than required pavement section at initial construction, leaving the finish asphalt 0.51/2 inch below the design crown elevation. After two years, (and after all warranty repairs have been made), the Contractor shall perform a tapered milling (0 to 1-inch depth) of the outside 4 feet of pavement along the gutters prior to placing the 1.5-½ inch SX overlay. This shall be accomplished before the Local Entity accepts the streets for full-term maintenance.

2. Manhole and Valve Settings. All manholes and valve boxes shall be set at grade for the interim paving surface. Manholes and valve boxes must be adjusted to final grade prior to placement of the final overlay. Riser rings shall not be used.

Commented [SK7]: Change all ½" to 0.5 inch (Typical)

B. Full Depth Sections

1. Loveland (city limits only). Full depth asphalt pavement sections will be considered on a case by case basis where depth of bedrock, drainage, and soil conditions are compatible with full-depth asphalt. Refer to **Chapter 22, Construction Specifications,** for minimum and maximum lift requirements. When permitted by the Local Entity Engineer, full depth asphalt pavements shall consist of one or more layers of Grade S HMA topped with one or more layers of Grade S or SX HMA placed directly on a stabilized subgrade.

2. Fort Collins (city limits only). Full depth asphalt pavement sections are generally not allowed.

C. Rehabilitating Existing Asphalt Streets

Prior to overlaying existing asphalt, the Local Entity Engineer may accept nondestructive testing to determine the amount of overlay necessary to bring the street to current standards. The method of nondestructive testing and the data obtained must be in a form compatible with the pavement management system for the Local Entity. All "pot-holes," utility trench settlement, cracking, and any similar imperfections shall be repaired to the Local Entity Engineer's satisfaction prior to overlaying. Refer to **Chapter 25, Reconstruction and Repair,** for specific requirements.

D. Special Requirements

The Local Entity Engineer may require full depth asphalt or Portland cement concrete or chemically treated base or subgrade in locations where traffic, utilities, type of construction, subsurface drainage, or time of construction would make asphalt on aggregate base impractical.

10.4.3 Pavement Structure Components

The Pavement Structure Components shall be a combination of one or more of the following courses placed on a subgrade to support the traffic load and distribute it to the roadbed. However, the pavement section must be composite in nature.

A. Subbase

The layer(s) of specified or selected material of designed thickness placed on a subgrade to support a base course, surface course, or both.

B. Base Course

The layer or layers of specified or selected material of designed thickness placed on a subbase or a subgrade to support a surface course.

C. Surface Course

One or more layers of a pavement structure designed to accommodate the traffic load; the top layer of which resists skidding, traffic abrasion and the disintegrating effects of climate. For asphalt pavement the top layer is sometimes called "Wearing Course."

10.5 PAVEMENT DESIGN PROCEDURES

10.5.1 Flexible Pavement Design

A. General

Flexible pavements are those pavements that have sufficiently low bending resistance to maintain continuous contact with the underlying structure, yet have sufficient stability to support a given traffic loading condition. An example is asphaltic concrete pavement.

B. Procedure

Computer generated printouts and/or other design calculations must be included with the design submittal. The following procedure should be used in determining the structural number and thickness of the pavement being designed:

1. Confirm the roadway classification and corresponding EDLA. The predicted volumes in the traffic impact study must be used whenever they exceed the minimum EDLA values given in **Table 10-1**.

2. Determine the serviceability index (SI) and reliability for the roadway classification (**Table 10-1**).

3. Convert the R-value to a Resilient Modulus for each soil subgrade type identified in the exploration using the **CDOT equations 2.1 and 2.2** as detailed in Section 2.5 of the latest edition of the CDOT ~~2007~~ ~~P~~Pavement Design Manual.

4. Determine the required structural numbers using **AASHTO** pavement design software or nomographs from **AASHTO** along with soil support test results and EDLA values previously determined. If used, copies of the nomograph determinations must be included with the design submittal.

5. Once the required structural number (SN) has been determined, the design thickness of the pavement structure can also be determined by the software that uses the general equation:

   SN = A1D1M1 + A2D2M2 + A3D3M3 + . . .

   Where:

   A1 = Hot Mix Asphalt (HMA) Strength Coefficients

   A2, A3, … = Strength Coefficients of Additional Pavement Components

   The strength coefficients for various components of the pavement structure are given in **Table 10-4**.

   D1 = Thickness of Hot Mix Asphalt (HMA)

   D2, D3, … = Thickness of Additional Pavement Component Sections

   M1, M2, . . . = Drainage Coefficient

   Total HMA thickness selected shall not be less than the minimum specified in **Table 10-1**, and the aggregate base course thickness selected shall not exceed 2.0 times the total HMA thickness selected.

6. The standard deviation for design of asphalt pavements shall be 0.44.

7. The design must reference any mitigation measures required when the subgrade contains swelling soils. Refer to **Chapter 5, Soils Investigations and Report**. Design reports recommending permeable layers in the pavement system must present the measures to be used to ensure adequate drainage of such layers and to maintain separation of the layers from the swelling soils.

Commented [DB8]: Update Volume?

Commented [SK9]: Reference latest edition of CDOT Pavement Design Manual

Table 10-4
Pavement Strength Coefficients

Pavement Structure Component **Conventional Materials**	Design Strength Coefficients (Per Inch of Material)[3]	Limiting Test Criteria
Plant Mix Seal Coat	0.25	
Hot Bituminous Pavement	0.44	R 90+
Existing Bituminous Pavement	0.24	See Note 1
Aggregate Base Course	0.11	R>72
Existing Aggregate Base Course	0.10	R>69
Granular Subbase Course	0.07	R>50
Recycled Asphalt/Concrete Pavement Subbase Course	0.07	R>50
Chemically Treated Subgrades[2] (or Approved Substitute)		**Compressive Strength of Field Specimen**
Cement Treated Subgrade	0.23	7 day, 650–1000 psi
Fly Ash Treated Subgrade	0.10	7 day, 150 psi @ 70°±
Lime Treated Subgrade	0.14	7 day, 160 psi, PI <6
Kiln Dust Treated Subgrade	0.10	7 day, 150 psi, PI <6

NOTES:
1. Greater strength coefficient may be considered if derived from deflection data collected on the existing street in compliance with procedures outlined in the Asphalt Institute Manual MS-17.
2. Strength coefficient is only acceptable if material is properly mixed and field tests correlate with laboratory results. Strength Coefficient shall be reduced by 50 percent if field test correlations are not performed.
3. The credited thickness of chemically treated subgrade shall be 2-inches less than the maximum specified tilling depth (e.g. 12-inches of fly ash stabilization will get a 10-inch strength credit. Chemical soil stabilization shall not proceed between October 31 and April 1 without the Local Entity Engineer's approval, due to freeze thaw issues with frozen subgrade. Minimum tilling depth shall be 12-inches to meet subgrade scarifying requirements.

10.5.2 Rigid Pavement Design

A. General

Rigid pavements are those that possess a high bending resistance and distribute loads over a large area of foundation soil. Examples include Portland cement concrete pavement or Portland cement concrete surfaced with asphalt.

B. Procedure

Computer generated printouts and/or other design calculations must be included with the design submittal.

The design of rigid pavements is a function of structural quality of the subgrade soil (R-value), traffic (EDLA), and the strength of the concrete (working stress). In comparison to the strength of the concrete slab, the structural contributions of underlying layers to the capacity of the pavement are relatively insignificant. Therefore, the use of thick bases or subbases under concrete pavement to achieve greater structural capacity is considered to be uneconomical and is not recommended. However, street sections with landscape medians may require a drainage layer section to provide positive drainage from the median to an acceptable outlet. In all cases, subgrade shall be stable as determined by proof-rolling requirements outlined in **Chapter 22, Construction Specifications**, concerning final proof-rolling.

The following procedure should be used in determining the structural number and thickness of the pavement being designed:

1. Confirm roadway classification and corresponding EDLA. The predicted volumes in the traffic impact study must be used whenever they exceed the minimum EDLA values given **Table 10-1**.
2. Determine the serviceability index of the roadway classification from **Table 10-1**.
3. The reliability factor for design of all concrete pavements shall be 90 percent.
4. The working stress of the concrete is to be obtained from laboratory tests. For preliminary design see **Section 10.4.1 E**.
5. The standard deviation for design of concrete pavements shall be between 0.30 and 0.40.
6. Determine the structural numbers using **AASHTO** pavement design software. Nomographs of the **AASHTO** parameters may be used instead. If used, copies of the nomograph determinations must be included with the design submittal.
7. Determine the slab thickness. A minimum thickness of 6 inches must be provided.
8. Refer to **Section 10.3**. Design must reference any mitigation measures required when the subgrade contains sulfates.

C. Joint Design

The construction plans for rigid pavement areas shall include a joint pattern layout for each street or alley. All joints and joint filling in rigid pavement shall be designed and detailed in accordance with the current Colorado Department of Transportation Standard Plans (M&S Standards).

10.6 PAVEMENT DESIGN REPORT

The pavement design report shall be prepared by or under the supervision of and signed and stamped by a Professional Engineer registered in the State of Colorado. The report shall make a recommendation for a typical pavement structural section based on known site soil conditions and the valid traffic impact study (refer to **Chapter 4, Transportation Impact Study**).

10.6.1 Required Information for Pavement Design Report

A. List of Required Info

1. Vicinity map to locate the investigated area.
2. Scaled drawings showing the location of final borings.
3. Final Plat with street names.

4. Scaled drawings showing the estimated extent of subgrade soil types and EDLA for each street classification.

5. Pavement design alternatives for each street classification.

6. Tabular listing of sample designation, sample depth, Group Number, liquid limit, plasticity index, percent passing the No. 200 sieve, **AASHTO** Classification, Group Index and soil description. Refer to **Chapter 5, Soils Investigations and Report**.

7. R-value test results of each soil type used in the design. Refer to **Chapter 5, Soils Investigations and Report**.

8. Swell/consolidation tests. Refer to Chapter 5, Soils Investigations and Report.

9. Identification of any samples that were consolidated to create composite samples for testing purposes. Refer to **Chapter 5, Soils Investigations and Report**.

10. Borrow source identification.

11. Pavement design computer printouts or nomographs properly drawn to show Soil Support - EDLA - SN. Refer **to Sections 10.4.1 A** and **10.5.1 B** and **Table 10-1**.

12. Design calculations for all phases of soil report.

13. Design coefficient used for asphalt, base course, etc. Refer to **Table 10-4**.

14. Mix design test results as discussed in **Chapter 23, Street Inspection and Testing Procedures**, where chemical stabilization has been approved by the Local Entity Engineer.

15. A discussion of potential subgrade soil problems including, but not limited to:

    a. Heave or settlement prone soils.

    b. Frost susceptible soils.

    c. Ground water.

    d. Drainage considerations (surface and subsurface).

    e. Cold weather construction (if appropriate).

    f. Soluble sulfates in subgrade.

    g. Other factors or properties that could affect the design or performance of the pavement system.

16. Recommendations to alleviate or mitigate the impact of problems discussed in the previous paragraph. Also refer to **Chapter 5, Soils Investigations and Report**.

17. Professional Engineer Stamp