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Guide for Mechanistic-Empirical Design
OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

PART 4. LOW VOLUME ROADS

CHAPTER 1. LOW VOUME ROAD DESIGN

NCHRP

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PART 4 – LOW VOLUME ROADS

CHAPTER 1
LOW VOLUME ROAD DESIGN

Pavement structural design for low-volume roads considers two types of pavements:

1. Flexible pavements (with hot-mixed asphalt concrete [AC] surfacing/binder and flexible base course).
2. Rigid pavements (jointed plain concrete pavement [JPCP]).

This chapter covers the design of low-volume roads for flexible and rigid pavement surface types using procedures outlined in PART 3.

The primary basis for all mechanistic-based pavement performance prediction methods is cumulative axle load applications. Many city streets and county roads that fall under the low-volume category still carry significant levels of heavy vehicle traffic. The maximum number of heavy vehicles over the design life in the design lane considered for low-volume pavement design is limited to 750,000 in this Guide.

A heavy vehicle is defined as FHWA Vehicle Classes 4 to 13, which include buses, single-units (with six or more tires), and multi-trailer trucks. This level represents approximately 70 trucks and/or buses per day in the initial year that grows 4 percent compounded annually over 20 years. It is representative of a collector type urban street or rural highway with significant truck and bus traffic. The Truck Traffic Classification groups of 12, 14, 15, 16, and 17, as defined in Chapter 4 of PART 2, are applicable to low volume roadways and were used to generate the catalog of layer thickness included in this part of the Guide.

The practical minimum traffic level that should be considered for any flexible or rigid pavement during a given performance period is about 50,000 heavy vehicles (trucks and/or buses) over its design life in the design traffic lane. This level represents approximately 4 to 5 trucks and/or buses per day in the initial year that grows 4 percent compounded annually over 20 years. This is representative of a local urban street with no bus traffic or a low-volume county road with very limited truck and bus traffic.

4.1.1 DESIGN PROCEDURES

The low-volume pavement design procedures for flexible and rigid pavement rely on the design inputs, performance requirements, and procedures described in PARTS 2 and 3. A detailed design using the Design Guide software can be performed for a low volume road pavement that utilizes the materials described above. However, if resources or time do not permit this level of effort, the design of low-volume roads can be approximated using the recommendations provided in this chapter, which are based on various assumptions described herein to establish general design recommendations. These recommendations are limited in scope and should be considered as general guidance only. Ideally, the low-volume road design procedure should be calibrated by the agency to more fully ensure the validity of the design.

4.1.1.1 Design Catalog

The purpose of this section is to provide the user with a practical and relative easy means for identifying reasonable pavement structural designs suitable for low-volume roads. The catalog of designs presented here covers hot mix AC pavements and JPCP. It is important to note, however, that although the structural designs presented represent solutions using the mechanistic-empirical design procedures described in PARTS 2 and 3, they are based on a unique set of assumptions relative to design requirements and environmental conditions. The following specific assumptions apply to both flexible and rigid structural designs considered. Other detailed assumptions and limitations are given under each pavement design type.

1. All designs are based on the structural requirement for a design analysis period of 20 years. The range of traffic levels is 50,000, 250,000, and 750,000 trucks/buses in the design traffic lane over the design life. As noted above, the Truck Traffic Classification groups of 12, 14, 15, 16, and 17 are applicable to low-volume roadways.
2. All designs presented are based on either a 50- or 75-percent level of reliability, which represent a general range for design of low-volume roads.
3. The designs are for environmental conditions corresponding to two broad regions of the U.S., a northern climate (as represented by the climate in the northern Illinois/Indiana area) and a southern climate (as represented by the climate in the Atlanta, Georgia area). Of course, these two eliminates do not cover the United States and that designers can develop similar tables for their regions. The procedures in PART2 and PART 3 and the information contained in this section can be used to derive a catalog for any other climate or design inputs. Of course, these two climates do not cover the U.S. and thus designers can develop similar tables for their regions.
4. The designs are provided for five qualitative levels of subgrade soil modulus or support capability: Very Good, Good, Fair, Poor, and Very Poor. Table 4.1.1 indicates the levels of soil resilient modulus that were used for each general level along with the approximate AASHTO and Unified soil classifications. Water table levels assumed in design were 8 ft in wet regions and 40 ft in dry regions. Inputs for the various soils are provided as footnotes to Table 4.1.1.
5. The maximum allowable distress indicators and smoothness for the flexible and rigid pavement designs is based on the criteria in table 4.1.2. Note that the values in the table represent the average measurements taken along a segment of a roadway or street.

<u>Flexible Pavement Design Catalog</u>

A detailed design of an HMA pavement for a low-volume road project can always be conducted using the Design Guide software. Design inputs should be in accordance with PART 2. If this is not possible, tables 4.1.3 and 4.1.4 present an illustrative catalog of flexible pavement design for low-volume roads in two climatic regions which may be used as a model to develop other similar design tables. Table 4.1.3 is based on the 50-percent reliability level, and table 4.1.4 is based on a 75-percent level. Other regions may show somewhat different results. Therefore, these results should be considered as approximate only. All of these designs meet the performance criteria in table 4.1.2.

Table 4.1.1. Subgrade soil resilient modulus values, Mr (psi), at optimum moisture content that were utilized in the derivation of design catalog tables for flexible and rigid pavements for low-volume roads (the mean values were used).

General Level of Subgrade Support	AASHTO and Unified Soil Classification	Broad Mr Range and Mean Mr at Optimum Moisture Content
Very Good	Coarse grained: Gravel and gravelly soils A-1-a, A-1-b GW, GP, GM, GW-GM, GP-GC	25,000 to 45,000 psi Mean = 39,000 psi
Good	Coarse grained: Sand and sandy soils A-2-4, A-3 GC, SM, GW-GC, GP-GM, GP-GC	20,000 to 40,000 psi Mean = 33,000 psi
Fair	Fine grained: Mixed silts and clays A-2-7, A4, A-2-5, A-2-6 SC, SP-SM, SP, SW-SM, SP-SC, SW-SC	15,000 to 30,000 psi Mean = 26,000 psi
Poor	Fine grained: Low compressibility A-5, A-6 ML, CL	10,000 to 25,000 psi Mean = 18,000 psi
Very Poor	Fine grained: high compressibility A-7-5, A-7-6 CH, MH	5,000 to 14,000 psi Mean = 10,000 psi

Note: Subgrade properties for the above soil classes are as follows:
Very Poor (PI=30, No. 200=85%, No. 4=95%, D60=0.02 mm)
Poor (PI=15, No. 200=75%, No. 4=95%, D60=0.04 mm)
Fair ((PI=7, No. 200=30%, No. 4=70%, D60=1.0 mm)
Good (PI=5, No. 200=20%, No. 4=61%, D60=3.0 mm); this would meet most agency material specifications for an aggregate subbase material.
Very Good (PI=1, No. 200=5%, No. =47%, D60=8.0 mm); this would be representative of a good quality base material.

Table 4.1.2. Performance criteria for low volume flexible and rigid pavements used to derive the design catalog for low volume roads.

Pavement Type	Performance Indicator	Criteria
Flexible	Smoothness, IRI* Wheelpath Rutting Fatigue Cracking	200 in/mile 0.60 in. 45% of wheelpaths
Rigid JPCP	Smoothness, IRI* Joint Faulting Slab Cracking	200 in/mi 0.15 in 45% slabs

* Initial IRI assumed to be 100 in/mi for urban street construction due to utilities and other constraints.

Table 4.1.3. Example of flexible pavement design catalog for low volume roads—recommended HMAC thicknesses for three levels of trucks/bus traffic, five levels of subgrade soil quality, two levels of aggregate bases, two levels of subgrade improvements, and two climatic zones at 50 percent reliability.*

Design Reliability: 50 percent								
Climatic Region	**Chicago (freeze)**				**Atlanta (non-freeze)**			
Frost Penetration into Subgrade and Frost Classification of Soil (For non-frost susceptible soils, use the non-freeze climate cells.)	**Yes. Soils Subject to Freeze-Thaw Weakening**				**No All Soils.**			
Stabilized Subgrade or Improved Foundation Layer	**No**		**Yes**		**No**		**Yes**	
Type of Aggregate Base Material	**Crushed Stone**	**Pit Run**	**Crushed Stone**	**Pit Run**	**Crushed Stone**	**Pit Run**	**Crushed Stone**	**Pit Run**
Relative Quality of Subgrade Soil	**Low Traffic: 50,000 Trucks/Buses**							
Very good	2-6	2-6	NA	NA	2-6	2-6	NA	NA
Good	2-6	2-6	NA	NA	2-6	2-6	NA	NA
Fair	2-8	2-8	NA	NA	2-8	2-8	NA	NA
Poor	2-8	2-8	2-6	2-6	2-8	2-8	2-6	2-6
Very poor	3 ½-8	3 ½-8	2-6	2-6	2-8	2 ½-8	2-6	2-6
	Medium Traffic: 250,000 Trucks/Buses							
Very good	2-6	2 ½-6	NA	NA	2-6	2 ½-6	NA	NA
Good	2-6	2 ½-6	NA	NA	2-6	2 ½-6	NA	NA
Fair	2 ½-8	3 ½-8	NA	NA	2-8	2 ½-8	NA	NA
Poor	3 ½-8	4-8	2-6	2 ½-6	2 ½-8	3-8	2-6	2 ½-6
Very poor	4 ½-9	5-9	2 ½-6	3-6	3 ½-9	4 ½-9	2 ½-6	3-6
	High Traffic: 750,000 Trucks/Buses							
Very good	3 ½-6	4-6	NA	NA	3 ½-6	4-6	NA	NA
Good	3 ½-6	4-6	NA	NA	3 ½-6	4-6	NA	NA
Fair	4-8	5-8	3 ½-6	4-6	3 ½-8	4 ½-8	3 ½-6	4-6
Poor	5-8	5 ½-8	3 ½-6	4 ½-6	4-8	4 ½-8	3 ½-6	4 ½-6
Very poor	6-10	6 ½-10	4-6	4 ½-6	5-10	6-10	4-6	4 ½-6

* Notes:

- These designs have met the performance criteria in table 4.1.2 for smoothness, fatigue cracking, and rutting.
- The values provided in the cells above represent the thickness of the HMA layer and aggregate base layer.
- The above designs include the effects of moisture changes, frost, and freeze-thaw cycling on performance, however, the design does not consider directly the prevention of frost heaving or swelling soils. This should be considered separately for local areas if desired.
- Designs based on the asphalt binder in the HMA wearing surface meeting the P-G binder specification.
- The thickness of the improved subgrade layer was assumed to be 8 inches, and the modulus of the improved subgrade was assumed to be about 2 times greater than the modulus of the subgrade soil selected for design.
- For drier climates than those identified above, use the layer thickness and flexible pavement cross section for the wet climates. If a more precise solution is desired, use the program to calculate the layer thickness requirements.

Table 4.1.4. Example of flexible pavement design catalog for low-volume roads—recommended HMAC thicknesses for three levels of trucks/bus traffic, five levels of subgrade soil quality, two levels of aggregate bases, two levels of subgrade improvements, and two climatic zones at 75 percent reliability.*

Design Reliability: 75 percent								
Climatic Region	**Chicago (freeze)**				**Atlanta (non-freeze)**			
Frost Penetration into Subgrade and Frost Classification of Soil (For non-frost susceptible soils, use the non-freeze climate cells.)	**Yes. Soils Subject to Freeze-Thaw Weakening**				**No All Soils.**			
Stabilized Subgrades or Improved Foundation Layer	**No**		**Yes**		**No**		**Yes**	
Type of Aggregate Base Material	**Crushed Stone**	**Pit Run**	**Crushed Stone**	**Pit Run**	**Crushed Stone**	**Pit Run**	**Crushed Stone**	**Pit Run**
Relative Quality of Subgrade Soil	**Low Traffic: 50,000 Trucks/Buses**							
Very good	2-6	2-6	NA	NA	2-6	2-6	NA	NA
Good	2-8	2-8	NA	NA	2-8	2-8	NA	NA
Fair	2-8	2-8	NA	NA	2-8	2-8	NA	NA
Poor	2 ½-8	2 ½-8	2-6	2-6	2-8	2-8	2-6	2-6
Very poor	3 ½-8	3 ½-8	2-6	2-6	2-8	3-8	2-6	2-6
	Medium Traffic: 250,000 Trucks/Buses							
Very good	2 ½-6	3-6	NA	NA	2 ½-6	3-6	NA	NA
Good	2 ½-8	3-8	NA	NA	2 ½-8	3-7	NA	NA
Fair	3-8	4-8	NA	NA	2 ½-8	3 ½-8	NA	NA
Poor	4-9	4 ½-9	2 ½-6	3-6	3-9	3 ½-9	2 ½-6	3-6
Very poor	5-10	5 ½-10	3-6	3 ½-6	4-10	5-10	3-6	3 ½-6
	High Traffic: 750,000 Trucks/Buses							
Very good	4-6	4 ½-6	NA	NA	4-6	4 ½-6	NA	NA
Good	4-8	4 ½-8	NA	NA	4-8	4 ½-8	NA	NA
Fair	4 ½-8	5-8	4-6	4 ½-6	4 ½-8	5-8	4-6	4 ½-6
Poor	5 ½-10	6-10	4 ½-6	5-6	4 ½-10	5-10	4 ½-6	5-6
Very poor	6-12	6 ½-12	4 ½-8	5-8	5 ½-12	6-12	4 ½-8	5-8

* Notes:

- These designs have met the performance criteria in table 4.1.2 for smoothness, fatigue cracking, and rutting.
- The values provided in the cells above represent the thickness of the HMA layer and aggregate base layer.
- The above designs include the effects of moisture changes, frost, and freeze-thaw cycling on performance, however, the design does not consider directly the prevention of frost heaving or swelling soils. This should be considered separately for local areas if desired.
- Designs based on the asphalt binder in the HMA wearing surface meeting the P-G binder specification.
- The thickness of the improved subgrade layer was assumed to be 8 inches, and the modulus of the improved subgrade was assumed to be about 2 times greater than the modulus of the subgrade soil selected for design.
- For drier climates than those identified above, use the layer thickness and flexible pavement cross section for the wet climates. If a more precise solution is desired, use the program to calculate the layer thickness requirements.

The pavement sections shown for each condition is based on the total number of truck and bus applications in the design traffic lane over the design life, as summarized below:

- High—750,000 (typical of primary and secondary arterial routes or streets with significant trucks and buses, approximately 70 per day first year)
- Medium—250,000 (typical of primary and secondary collector routes or streets and county roads with fewer trucks and buses, approximately 23 per day first year)
- Low—50,000 (typical of local streets or county roads with little truck traffic, approximately 4-5 per day first year)

These designs represent conventional flexible pavement structures. A conventional flexible pavement structure is defined as one with a relatively thin hot mix asphalt wearing surface over an unbound aggregate base material. Other designs, such as full-depth hot mix AC, could also be developed. The assumptions inherent in these design catalogs are as follow:

1. Two aggregate base materials were used to determine the layer thickness in each cell of tables 4.1.3 and 4.1.4. The crushed stone material is assumed to be a high quality material that is not susceptible to damage from freeze-thaw cycling. A maximum elastic or resilient modulus of 45,000 psi and a Poisson's ratio of 0.35 were assumed for the crushed stone. A pit run gravel was the other material used to prepare the catalog of layer thickness. This base material is a good quality base that consists of crushed and uncrushed aggregate particles. A maximum resilient modulus of 35,000 psi and a Poisson's ratio of 0.35 were assumed for the pit run aggregate base.
2. The asphalt binder for all hot mix asphalt surface and base mixtures is assumed to meet the P-G binder specification. The hot mix asphalt surface and base mixtures were assumed to be designed and placed in accordance with the Superpave volumetric mix design procedure.
3. The thickness of the improved subgrade or foundation layer was assumed to be 8 inches. The resilient modulus for the improved foundation was assumed to be about two-times greater than the modulus of the subgrade soils selected for design. A Poisson's ratio of 0.45 was assumed for this material and for the subgrade soils.
4. The subgrade soils identified or categorized as very good and good were assumed to be non-frost susceptible.

Rigid Pavement Design Catalog

A detailed design of JPCP for a low-volume road project can always be conducted using the Design Guide software. Design inputs should be in accordance with PART 2. If this is not possible, tables 4.1.5 and 4.1.6 present an illustrative catalog of JPCP designs for low-volume roads in two climatic regions which may be used as a model to develop other similar design tables. Table 4.1.3 is based on the 50-percent reliability level, and table 4.1.4 is based on a 75-percent level. Other regions may show somewhat different results. Therefore, these results should be considered as approximate only. All of these designs meet the performance criteria in table 4.1.2.

Table 4.1.5. Example of rigid pavement (JPCP) design catalog for low-volume roads—recommended PCC thickness for three levels of heavy vehicle traffic, five levels of subgrade soil quality, with and without a tied shoulder/lane, with and without a granular base, and two climatic zones at 50 percent reliability.*

Design Reliability: 50 percent								
Climatic Region	**Chicago (freeze)**				**Atlanta (non-freeze)**			
Edge Support*	**No**		**Yes**		**No**		**Yes**	
Granular Base Course	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Relative Quality of Subgrade Soil	**Low Traffic: 50,000 Trucks/Buses**							
Very good	5.0 in	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Good	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fair	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Very poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Medium Traffic: 250,000 Trucks/Buses							
Very good	6.0 in	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Good	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Fair	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Poor	6.5	6.0	6.0	5.5	6.0	6.0	6.0	5.5
Very poor	6.5	6.0	6.0	5.5	6.5	6.0	6.0	5.5
	High Traffic: 750,000 Trucks/Buses							
Very good	6.5 in	6.0	6.0	6.0	6.0	5.5	6.0	5.5
Good	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5
Fair	6.5	6.0	6.0	6.0	6.0	5.5	6.0	5.5
Poor	7.0	6.5	6.5	6.0	6.5	6.0	6.0	5.5
Very poor	7.5	7.0	7.0	6.0	6.5	6.5	6.5	5.5

* Notes:

- These designs meet the performance criteria in table 4.1.2 for smoothness, faulting, and cracking.
- The above designs include the effects of moisture changes, frost, and freeze-thaw cycling on performance, however, the design does not consider directly the prevention of frost heaving or swelling soils. This should be considered separately for local areas if desired.

*** Edge support can be provided by adequately tied PCC lane, shoulder, or curb and gutter.

Table 4.1.6. Example of rigid pavement (JPCP) design catalog for low-volume roads—recommended PCC thickness for three levels of heavy vehicle traffic, five levels of subgrade soil quality, with and without a tied shoulder/lane, with and without a granular base, and two climatic zones at 75 percent reliability.*

Design Reliability: 75 percent								
Climatic Region	**Chicago (northern)**				**Atlanta (southern)**			
Edge Support* **	**No**		**Yes**		**No**		**Yes**	
Granular Base Course	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**
Relative Quality of Subgrade Soil	**Low Traffic: 50,000 Trucks/Buses**							
Very good	5.0 in	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Good	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Fair	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Very poor	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Medium Traffic: 250,000 Trucks/Buses							
Very good	6.0 in	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Good	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Fair	6.0	5.5	5.5	5.0	6.0	5.5	5.5	5.0
Poor	6.5	6.0	6.0	5.5	6.5	6.0	6.0	5.5
Very poor	6.5	6.0	6.0	5.5	6.5	6.0	6.0	5.5
	High Traffic: 750,000 Trucks/Buses							
Very good	6.5**	6.0**	6.0**	6.0**	6.5	6.0	6.0	6.0
Good	6.5**	6.0**	6.0**	6.0**	6.5	6.0	6.0	6.0
Fair	6.5**	6.0**	6.0**	6.0**	6.5	6.0	6.0	6.0
Poor	7.0**	6.5**	6.5**	6.0**	7.0	6.5	6.5	6.0
Very poor	7.5**	7.0**	7.0**	6.0**	7.5	7.0	6.5	6.0

* Notes:

- These designs meet the performance criteria in table 4.1.2 for smoothness, faulting, and cracking.
- The above designs include the effects of moisture changes, frost, and freeze-thaw cycling on performance, however, the design does not consider directly the prevention of frost heaving or swelling soils. This should be considered separately for local areas if desired.

** This design requires dowels at transverse joints to satisfy faulting requirements.

*** Edge support can be provided by adequately tied PCC lane, shoulder, or curb and gutter.

Table 4.1.5 is based on a 50-percent design reliability level. Table 4.1.6 is based on a 75-percent design reliability level. These levels represent a reasonable range for low-volume roads. The assumptions inherent in these design catalogs are as follows:

1. The JPCP may be designed with or without an unbound aggregate base course. If the option to use a base is chosen, it consists of 5 inches of high quality granular material.

Note that the upper 12-in of subgrade must always be compacted to optimum density with obviously soft spots regraded and recompacted.

2. Mean PCC modulus of rupture (MR) is 650 psi (third point loading, 28-day).
3. Mean PCC elastic modulus (E_c) is 4,000,000 psi (28-day)
4. Transverse joint spacing is related to slab thickness in the following manner.

   Slab thickness (in inches) * 2 = Joint spacing (in feet)

   For example, a slab thickness of 6 in requires a maximum joint spacing of 12 ft. This relationship has been used in development of the catalog.
5. The longitudinal joint load (deflection) transfer from an adequately tied PCC traffic lane, shoulder, or curb and gutter is assumed to be 50 percent long term.
6. Dowels are not required at transverse joints unless specifically indicated in the tables to control faulting or smoothness levels.
7. The designs are for environmental conditions corresponding to two broad regions of the U.S., northern climate (as represented by the climate associated with Chicago) and southern climate (as represented by Atlanta). The procedures in PART 2 and PART 3 can be used to derive a catalog for any other climate or design inputs. Joint faulting is higher in colder and wetter climates. Slab cracking is higher in areas of with higher solar radiation, as exists in the southern portions of the U.S.
8. The total heavy vehicle volumes in the design traffic lane over the 20-year design life are:

   - High—750,000 (typical of collectors with significant trucks and buses, approximately 70 per day first year)
   - Medium—250,000 (typical of collectors with fewer trucks and buses, approximately 23 per day first year)
   - Low—50,000 (typical of local streets or low volume county roads with very few trucks, approximately 4-5 per day first year)