Pavement Thickness Design

A. General

The AASHO road test (completed in the 1950s) and subsequent AASHTO *Guide for the Design of Pavement Structures* (AASHTO Design Guide) provide the basis for current pavement design practices. To design a pavement by the AASHTO method, a number of design parameters must be determined or assumed. This section will explain the parameters required to design the pavement thickness of both concrete and hot mix asphalt roadways. The same parameters can be used for input data in computer programs on pavement determinations. The program used should be based on AASHTO design methods.

Even though the AASHTO Design Guide is several years old, it is still used throughout the industry for pavement thickness design. A newer design program called the Mechanistic-Empirical Pavement Design Guide (MEPDG) is available, however, it is costly and requires a great deal of data to be effective. The MEPDG does not generate a pavement thickness, it is set up to analyze the failure potential for a given thickness design. It is not generally used by local agencies. Each of the paving associations provides software programs for calculating pavement thickness. The programs can be accessed through the respective websites of the paving associations. Users should be aware of the required inputs for the software programs, as well as the specific system defaults that cannot be changed or do not fit the project design criteria. If the program defaults do not match the project circumstances, the software program should not be used.

Historically municipalities have resorted to a one-size-fits-all approach by constructing standard pavement thicknesses for certain types of roadways without regard to traffic volumes or subgrade treatments. In an effort to show the effect of varying traffic loads and subgrade treatments on pavement thickness, this section provides comparison tables showing the various rigid and flexible pavement thicknesses calculated according to the AASHTO pavement design methodology. The ESAL and pavement thickness values shown in the tables are dependent upon the design parameters used in the calculations. The assumed parameters are described in the corresponding tables. The pavement designer should have a thorough understanding of the parameters and their reflection of actual site conditions prior to using them to select a pavement thickness. Projects that have traffic or site conditions that differ significantly from the values assumed herein should be evaluated with a site specific pavement design.

Engineers need to examine their agency’s standard pavement foundation support system based on good engineering practices and the level of service they desire for the life of both HMA and PCC pavements. It is important to understand the characteristics of the soil and what cost-effective soil manipulation can be achieved, whether an aggregate subbase is used or not. If different soil types are encountered, and an aggregate subbase is not used, properly blending and compacting the soil will help reduce differential movement and help prevent cracking. Good designs, followed by good construction practices with a proper inspection/observation program, are critical to realize the full performance potential of either pavement type.

Designs that improve the foundation will extend the pavement life, improve the level of service throughout the life of the pavement, and provide more economical rehabilitation strategies at the end of the pavement's life for both HMA and PCC pavements. Although the initial cost to construct the pavement will undoubtedly be higher than placing the pavement on natural subgrade, the overall life cycle costs will be greatly improved.

Definitions of the pavement thickness design parameters are contained in Section 5F-1, B. Section 5F-1, C defines the process for calculating ESAL values. Section 5F-1, D provides the comparison tables discussed in the previous paragraph. Finally, example calculations are shown in Section 5F-1, E.

The pavement designer should be aware of the parameters that are required for the project under design. If those project design parameters differ from the parameters used to calculate the typical pavement thicknesses provide in this section, then a specific design set to meet the specific project parameters should be undertaken.

B. Pavement Thickness Design Parameters

Some of the pavement thickness design parameters required for the design of a rigid pavement differ from those for a flexible pavement. Table 5F-1.01 summarizes the parameters required for the design of each pavement structure.

Table 5F-1.01: Summary of Design Parameters for Pavement Thickness

Section	Description	Flexible HMA	Rigid JPCP/JRCP
5F-1, B, 1	**Performance Criteria**		
	a. Initial Serviceability Index	X	X
	b. Terminal Serviceability Index	X	X
5F-1, B, 2	**Design Variables**		
	a. Analysis Period	X	X
	b. Design Traffic	X	X
	c. Reliability	X	X
	d. Overall Standard Deviation	X	X
5F-1, B, 3	**Material Properties for Structural Design**		
	a. Soil Resilient Modulus	X	
	b. Modulus of Subgrade Reaction		X
	c. Concrete Properties		X
	d. Layer Coefficients	X	
5F-1, B, 4	**Pavement Structural Characteristics**		
	a. Coefficient of Drainage	X	X
	b. Load Transfer Coefficients for Jointed		X
	c. Loss of Support		X

The following considerations should be used when designing pavement thickness for flexible and rigid pavements.

1. **Performance Criteria (Serviceability Indexes):** Condition of pavements are rated with a present serviceability index (PSI) ranging from 5 (perfect condition) to 0 (impossible to travel).

   a. **Initial Serviceability Index (Po):** The initial serviceability index (P_o) is the PSI immediately after the pavement is open. At the AASHO road test, values of 4.5 for rigid pavement and 4.2 for flexible pavement were assumed. These values are listed in the 1993 AASHTO Design Guide.

   b. **Terminal Serviceability Index (P_t):** The terminal serviceability index (P_t) is considered to be the PSI that represents the lowest acceptable level before resurfacing or reconstruction becomes necessary.

   The following values are recommended for terminal serviceability index.

   Table 5F-1.02: Terminal Serviceability Indexes (P_t) for Street Classifications

P_t	Classifications
2.00	Secondary Roads and Local Residential Streets
2.25	Minor Collectors, Industrial, and Commercial Streets
2.50	Major Collectors and Arterials

   c. **Serviceability Loss:** The predicted loss or drop in serviceability (ΔPSI) is the difference between initial and terminal serviceability (P_o - P_t). The ΔPSI is the basis for the pavement design.

2. **Design Variables:**

   a. **Analysis Period:** This refers to the period of time for which the analysis is to be conducted. The recommended analysis period is 50 years for both concrete and asphalt pavements.

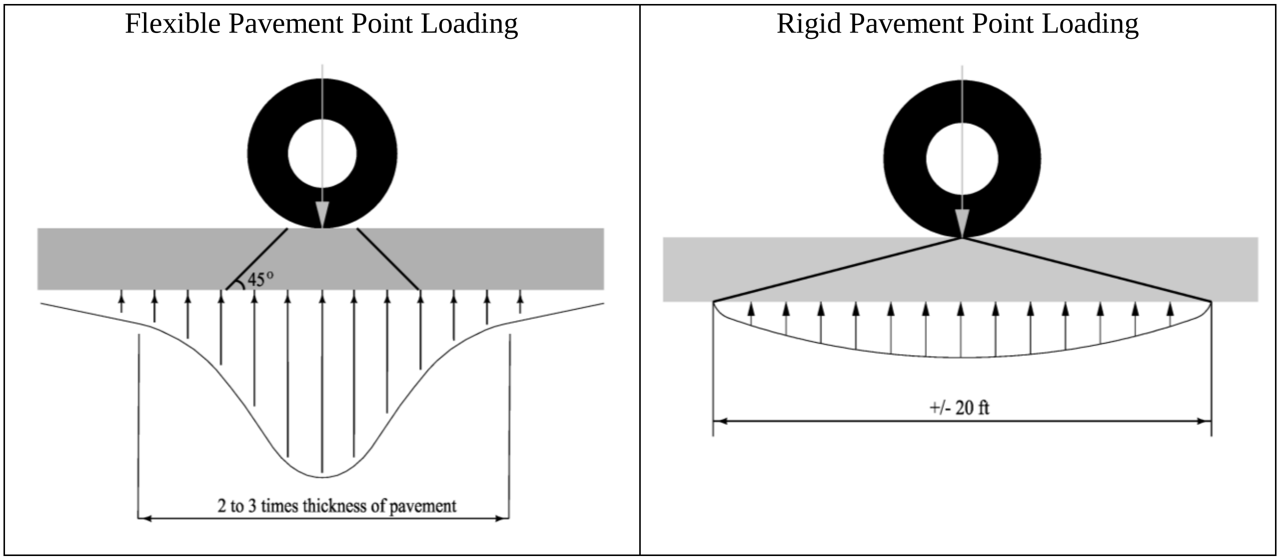
   b. **Design Traffic:** An estimate of the number of Equivalent 18,000 pound Single Axle Loads (ESALs) during the analysis period is required. This value can be estimated based on:
   - the Average Annual Daily Traffic (AADT) in the base year,
   - the average percentage of trucks expected to use the facility,
   - the average annual traffic growth rate, and
   - the analysis period.

   It should be noted that it is not the wheel load but rather the damage to the pavement caused by the wheel load that is of particular concern. As described above, the ESAL is the standard unit of pavement damage and represents the damage caused by a single 18,000 pound axle load. Therefore, a two-axle vehicle with both axles loaded at 18,000 pounds would produce two ESALs. However, since vehicle configurations and axle loads vary, AASHTO has established a method to convert different axle loads and configurations to ESALs. For example, a 34,000 pound tandem axle produces approximately 1.9 ESALs for rigid pavement (1.1 for flexible pavement). Summing the different ESAL values for each axle combination on a vehicle provides a vehicle's Load Equivalency Factor (LEF). The LEF can then be applied to the assumed truck mix and the AADT to determine ESALs.

   Section 5F-1, C details the steps involved in ESAL calculations and provides examples for both rigid and flexible pavements. ESAL tables for rigid and flexible pavements, and the corresponding assumptions used to create them, are provided for both two lane and four lane facilities.

The need for separate ESAL tables for flexible and rigid pavements is based on the inherent ability of each type of pavement to distribute a point loading. Rigid pavements have the ability to distribute the load across the slab. A point loading on a flexible pavement is more localized. This results in different ESAL factors for the two types of pavements. This is shown graphically in Figure 5F-1.01.

Figure 5F-1.01: Flexible vs. Rigid Point Loading Distribution



c. Reliability [R (%)]: Reliability is the probability that the design will succeed for the life of the pavement. Because higher roadway classification facilities are considered more critical to the transportation network, a higher reliability is used for these facilities. The following reliability values were assumed for the calculations.

Table 5F-1.03: Reliability for Flexible and Rigid Pavement Design

Street Classification	Reliability
Local Streets	80%
Collector Streets	88%
Arterial Streets	95%

d. Overall Standard Deviation (S_o): The Overall Standard Deviation is a coefficient that describes how well the AASHO Road Test data fits the AASHTO Design Equations. The lower the overall deviation, the better the equations models the data. The following ranges are recommended by the AASHTO Design Guide.

Table 5F-1.04: Overall Standard Deviation (S_o) for Rigid and Flexible Pavements

Pavement Type	Range of Values		Value Used
	Low	*High*	
Rigid Pavements	0.30	0.40	0.35
Flexible Pavements	0.40	0.50	0.45

3. Material Properties for Structural Design:

a. Soil Resilient Modulus (M_R): The important variable in describing the foundation for pavement design is the Soil Resilient Modulus (M_R). M_R is a property of the soil that indicates the stiffness or elasticity of the soil under dynamic loading.

The Soil Resilient Modulus measures the amount of recoverable deformation at any stress level for a dynamically loaded test specimen. The environment can affect pavement performance in several ways. Temperature and moisture changes can have an effect on the strength, durability, and load-carrying capacity of the pavement and roadbed materials. Another major environmental impact is the direct effect roadbed swelling, pavement blowups, frost heave, disintegration, etc. can have on loss of riding quality and serviceability. If any of these environmental effects have the potential to be present during the life cycle of the pavement, the MR should be evaluated on a season by season basis, and a seasonal modulus developed.

The purpose of using seasonal modulus is to qualify the relative damage a pavement is subject to during each season of the year and treat it as part of the overall design. An effective soil modulus is then established for the entire year, which is equivalent to the combined effects of all monthly seasonal modulus values.

For the purposes of this section, the MR value was calculated based on the proposed CBR values of 3 and 5. Previous editions of this section have included CBR values of 3, 5, and 10. The normal soils in Iowa have in situ CBR values of 1 to 3. In order to attain a soil strength of CBR of 3, it is necessary to construct a subgrade of at least 12 inches of soil mechanically compacted to a minimum of 95% Standard Proctor Density. The Iowa DOT uses a MR value of 3,000 to 3,500. That value is reasonably close to the value used in this section for a CBR of 3 when adjusted for seasonal variations (2,720).

The design charts in this section include values for CBR of 5. It is possible to reach a CBR of 5 with Iowa soils through diligent mechanical compaction of the top 12 inches of the subgrade. Generally, soils that have 45% or less silt content and plasticity indexes greater than 10 can be mechanically compacted and reach CBR of 5. Due to the fine grained nature of some Iowa soils, it may be necessary to stabilize these soils through the use of agents such as lime, fly ash, cement, and asphalt in order to achieve a CBR of 5 or greater. Stabilization requires the agent to be thoroughly distributed into the soil matrix and the soil matrix must be well pulverized to prevent clumps from remaining isolated in the soil mass. The application of the stabilizing agent will usually increase the strength properties of the soil.

It is critical that the appropriate level of construction quality control be completed that will verify the increase in soil strength matches the value used in the thickness design.

In order to successfully develop a foundation CBR of 10, it is also going to involve use of a subgrade that is stabilized with cement, fly ash, or other product. If the designer determines that a foundation will be constructed to reach a CBR of 10, then a specific pavement design should be undertaken rather than using the standard designs presented in this section. AASHTO recommends that the following correlation be used to relate the resilient modulus to the CBR. Using this equation, the corresponding MR values for CBR values of 3 and 5 are shown. For further information regarding the relationship between soil types and bearing values, see Sections 6E-1 and 6H-1. Once a CBR is selected for design, it is absolutely critical to ensure the value is reached in the field.

Without the formalized construction process of enhancing the subgrade through stabilization, it is critical to not use subgrade support values higher than a CBR of 3 or 5 for thickness design.

$$M_R = 1{,}500 \times CBR$$

CBR Value	M_R Value
3	4500
5	7500

For flexible pavement design, 1993 AASHTO Guide, Part II, Tables 4.1 and 4.2 with AASHTO Wet-Freeze Zone III criteria were used to estimate the effective M_R value taking into account seasonal variability. Frozen conditions were assumed for one-half the month of December and the months of January and February. Due to spring wetness and thawing conditions, the M_R value for the month of March and one-half of April were assumed to be 30% of normal conditions. Half of April, and all of May, October, November, and one-half of December were assumed to be wet with the support value set at 67% of normal. The remaining months of June, July, August, and September were dry months.

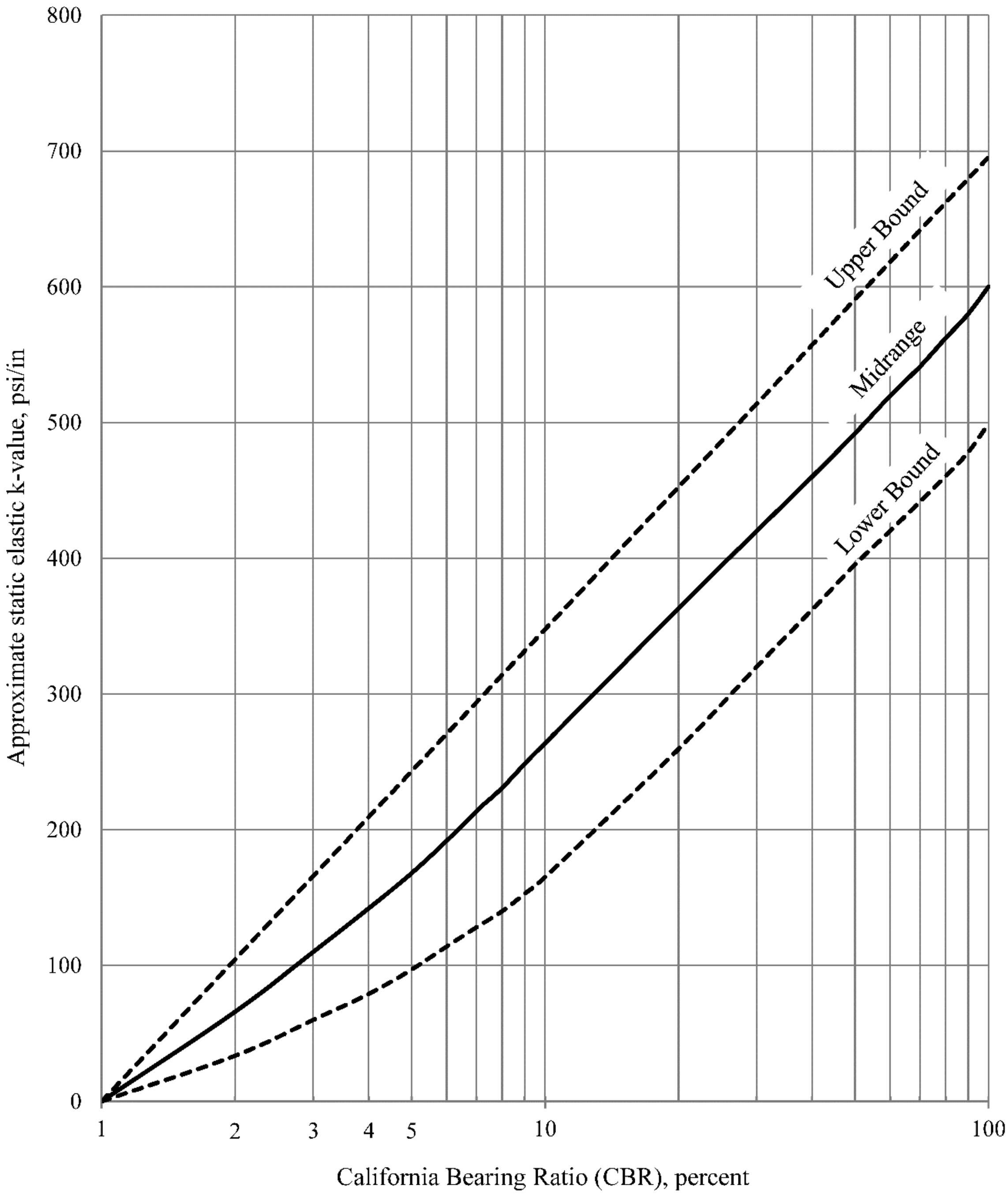
For rigid pavement design, the M_R value is used to calculate the modulus of subgrade reaction, k.

b. Modulus of Subgrade Reaction (k, k_c): Several variables are important in describing the foundation upon which the pavement rests:

- k - The modulus of subgrade reaction for the soil;
- k_c - A composite k that includes consideration of subbase materials under the new pavement
- M_R - Soil resilient modulus

1) Modulus of Subgrade Reaction, k: For concrete pavements, the primary requirement of the subgrade is that it be uniform. This is the fundamental reason for specifications on subgrade compaction. In concrete pavement design, the strength of the soil is characterized by the modulus of subgrade reaction or, as it is more commonly referred to, "k".

Figure 5F-1.01: Relationship Between CBR and k Value



Source: Adapted from *Phase I: Validation of Guidelines for k-Value Selection and Concrete Pavement Performance Prediction*, Publication No. FHWA-RD-96-198

2) Composite Modulus of Subgrade Reaction, k_c: In many highway applications the pavement is not placed directly on the subgrade. Instead, some type of subbase material is used. When this is done, the k value actually used for design is a "composite k" (k_c), which represents the strength of the subgrade corrected for the additional support provided by the subbase.

The analysis of field data completed as a part of the Iowa Highway Research Board (IHRB) Project TR-640 showed that the modulus of subgrade reaction and the drainage coefficient for 16 PCC sites, which ranged in ages between 1 and 42 years, were variable and found to be lower in-situ than typical parameters used in thickness design. This indicates a loss of support over time. This change in support is already partially reflected in the AASHTO serviceability index to a degree.

Similar to the procedures used to estimate the effective M_R value for flexible pavement design, the AASHTO Design Guide provides procedures for estimating the k_c value taking into account potential seasonal variability. The same seasonal variability assumptions used for flexible pavements were used to calculate k_c values for rigid pavements.

c. Concrete Properties: PCC - Modulus of Elasticity (E_c) and Modulus of Rupture (S'_c).

The Modulus of Rupture (S'_c) used in the AASHTO Design Guide equations is represented by the average flexural strength of the pavement determined at 28 days using third-point loading (ASTM C 78).

The Modulus of Elasticity for concrete (E_c) depends largely on the strength of the concrete. Typical values are from 2 to 6 million psi. The following equation provides an approximate value for E_c:

$$E_c = 6{,}750\ (S'_c)$$

where:

S'_c = modulus of rupture [28 day flexural strength of the concrete using third point loading (psi)]

The approximate relation between modulus of rupture (S'_c) and compressive strength (f_c) is

$$S'_c = 2.3\ f_c^{0.667} (\text{psi})$$

d. Layer Coefficients: Structural layer coefficients (a_i values) are required for flexible pavement structural design. A value for these coefficients is assigned to each layer material in the pavement structure in order to convert actual layer thickness into the structural number (SN). These historical values have been used in the structural calculations. If specific elements, such as a Superpave mix or polymer modified mix are used, the designer should adjust these values to reflect differing quality of materials.

The following table shows typical values for layer coefficients.

Table 5F-1.05: Layer Coefficients

Component	Coefficient	Minimum Thickness Allowed
Surface / Intermediate Course		
HMA with Type A Aggregate	0.44*	1.5
Base Course		
HMA with Type A Aggregate	0.44	2
Cement Treated Granular (Aggregate) Base	0.20*	6
Soil-Cement Base	0.15	6
Crushed (Graded) Stone Base	0.14*	6
Macadam Stone Base	0.12	6
PCC Base (New)	0.50	
Old PCC	0.40**	
Crack and Seated PCC	0.25 to 0.30	
Rubblized PCC	0.24	
Cold-in-Place Recycled Asphalt Pavement	0.22 to 0.27	
Full Depth Reclamation	0.18	
Subbase Course		
Soil-Cement Subbase (10% cement)	0.10	6
Soil-Lime Subbase (10% lime)	0.10	6
Modified Subbase	0.14	4
Soil-Aggregate Subbase	0.05*	4

* Indicates coefficients taken from AASHTO Interim Guide for the Design of Flexible Pavement Structures.

** This value is for reasonably sound existing concrete. Actual value used may be lower, depending on the amount of deterioration that has occurred.

Source: AASHTO, Kansas State University, and Iowa DOT

4. Pavement Structural Characteristics:

a. Coefficient of Drainage: Water under the pavement is one of the primary causes of pavement failure. Water, either from precipitation or groundwater, can cause the subgrade to become saturated and weaken. This can contribute to pavement pumping under heavy loads.

C_d - The coefficient of drainage for rigid pavement design used to account for the quality of drainage.

M_i - The coefficient of drainage for flexible pavement design used to modify layer coefficients.

At the AASHO road test, the pavements were not well drained as evidenced by the heavy pumping that occurred on some of the test sections. The cross-sections were elevated and drainage ditches were provided. However, edge drains, which are used frequently in today's street and highway construction, were not evaluated at the AASHO road test. Edge drains are an effective deterrent to pumping and associated pavement distress.

In selecting the proper C_d or M_i value, consideration must be given to two factors: 1) how effective is the drainage, and 2) how much of the time is the subgrade and subbase in a saturated condition? For example, pavements in dry areas with poor drainage may perform as well as pavements built in wet areas with excellent drainage.

The following definitions are offered as a guide.

- Excellent Drainage: Material drained to 50% of saturation in 2 hours.
- Good Drainage: Material drained to 50% of saturation in 1 day.
- Fair Drainage: Material drained to 50% of saturation in 7 days.
- Poor Drainage: Material drained to 50% of saturation in 1 month.
- Very Poor Drainage: Material does not drain.

Based on these definitions, the C_d or M_i value for the road test conditions would be 1.00. A value of 1.00 would have no impact on pavement thickness or the number of ESALs a section would carry. Lower values increase the recommended pavement thickness; higher values decrease the recommended pavement thickness. Based on Tables 2.4 and 2.5 from the 1993 AASHTO Design Guide, the analysis assumed a fair quality of drainage and 1% to 5% exposure to saturation for the drainable base sections.

b. Load Transfer Coefficients for Jointed and Jointed Reinforced Pavements: One item that distinguishes PCC pavement is the type of joint used to control cracking and whether or not steel dowels are used in the joint for load transfer. Each of these designs provides a different level of transfer of load from one side of a pavement joint to the other. To adjust projected pavement performance for these various designs, the load transfer coefficient or "J" factor is used.

c. Loss of Support: The 1993 AASHTO Design Guide indicates that the loss of support factor is included in the design of concrete pavements to account for the potential impact arising from the erosion of the subgrade material and/or differential soil movements. Values of the factor range from 0 to 3. Application of these factors impacts the k value used in thickness design. According to the 1993 AASHTO Design Guide, Part II, Figure 3.6, with a value of 0, the k value does not change. With a value of 3, corresponding to fine grained subgrade soils, a k value of 100 becomes an effective k value of 8. From a practical standpoint, a k value less than 50 represents conditions where a person’s weight would produce noticeable deformations in the subgrade. Thus a subgrade with this level of support would never pass a proof roll test.

The use of loss of support values has a very significant impact on the thickness design for concrete pavements. In almost all cases at the AASHO road test where the concrete pavements fell below the minimum serviceability level, the cause of the failure was due to loss of support. Because the design equations were derived from this data, the reduction in serviceability is already accounted for in the design procedure. The 1993 AASHTO Design Guide, Part II, Section 2.4.3 states that experience should be the key element in the selection and use of an appropriate loss of support value.

The use of a loss of support value of 1 reduces a subgrade k value of 100 (equivalent to a CBR of 3) to an effective k value of 40 to be used in the thickness design. Since this creates a subgrade quality lower than experienced engineers would allow pavement to be placed, the design tables were developed using a loss of support value of 0. Research conducted by the Federal Highway Administration (FHWA-RD-96-198) supports using zero for the loss of support value.

Pavement design parameters within the PCC thickness design software programs often do not adequately reflect actual pavement foundation conditions except immediately after initial construction. Field data from testing completed at 16 Iowa sites showed lower coefficient of drainage values than those assumed in design, indicating that a potential migration of natural soils into the aggregate subbase over time may cause some loss of support. This in turn lowers the overall modulus of subgrade reaction. The results of the field testing indicating this loss of support due to mixing of the subgrade and subbase will need to be further validated by additional research. In order to maintain a high drainage coefficient, it is important to maintain separation between the soil subgrade and the aggregate subbase. One method of providing the separation is with a geotextile layer.

In most cases for local, low volume PCC roads, aggregate subbases do not influence thickness design to any measurable degree. According to MEPDG analysis for low volume PCC roadways (less than 1,000 ADT and 10% trucks), aggregate subbase thicknesses greater than 5 inches do not appear to improve the International Roughness Index (IRI) or reduce slab cracking.

Based on the IHRB TR-640 research with a limited data set of 16 Iowa sites, it was noted that a PCC pavement with an optimized foundation of granular subbase, subdrains, and a geotextile separation layer between the subgrade and subbase is likely to maintain a higher pavement condition index (PCI) over time than a PCC pavement on natural subgrade. The lower the variability and the higher the coefficient of drainage with an optimized foundation, the higher the pavement condition will be for a given period of time. Since the PCI prediction model from the IHRB research was developed based on a limited data set, it must be further validated with a larger pool of data. However, designers should consider the benefits of optimizing the foundations under their pavements to improve long-term serviceability.

C. Calculating ESAL Values

To estimate the design ESALs, the following procedure may be used. A more thorough analysis may also be performed using the procedures found in Appendix D of the 1993 AASHTO Design Guide or computer programs based on that procedure.

1. Obtain an estimate of the design AADT for the beginning, or base year of the analysis period.

2. Obtain an estimate of the average percentage of the AADT that will be trucks.

3. Three independent truck mix types are provided. The designer should match the truck mix type with the general characteristics of their project area’s actual truck mix. The three types are:
   - Type A: The truck mix within this type is typical for local city streets in residential or other land uses that do not include large trucks.
   - Type B: This type would typically represent the truck mix on higher volume streets. The truck type is predominantly Class 5 with lesser volumes of Class 8 and Class 9 trucks.
   - Type C: The truck mix in this type would generally involve higher volumes with the truck types being larger with a higher percentage of Class 8 and Class 9 trucks.

4. Select the base year design lane ESALs from Tables 5F-1.07 through 5F-1.10, depending upon whether the facility is two lane, four lane, rigid, or flexible. The designer may want to interpolate between the table values and the actual values of base year AADT and percent trucks, although the final pavement thickness is not often impacted by such calculations.

5. Select the growth factor from Table 5F-1.11 based on the average annual traffic growth rate and the analysis period.

6. Multiply the base year design lane ESALs, by the growth factor to obtain the total ESALs for the analysis period.

Table 5F-1.06 summarizes the inputs and calculations that went into creating Tables 5F-1.07 through 5F-1.10.

Table 5F-1.06: Truck Mixture for Urban Roadways and Determination of Truck ESAL Factor

Type A Truck Mix: Primarily buses and single axle trucks often found on low volume streets

Truck Class (Vehicle Description)		Percent of Total Trucks	Loading	Percent of Truck Class	Vehicle Weight (lbs)	Axle Type S-Single TA-Tandem	Axle Load (lbs)	ESAL Factor (per axle)		LEF (by Vehicle)	
								Rigid	Flexible	Rigid	Flexible
	Class 4 (2-axle busses, BUS)	10%	Partial Load (80% capacity)	100%	25000	Front-S	9000	0.053	0.066		
						Rear-S	16000	0.607	0.631	0.660	0.697
	Class 5 (2-axle, 6-tire trucks & busses, SU-2)	75%	Partial Load (50% capacity)	100%	20000	Front-S	6500	0.014	0.018		
						Rear-S	13500	0.294	0.326	0.308	0.344
	Class 6 (3-axle trucks, SU-3)	5%	Empty	50%	22000	Front-S	7000	0.019	0.024		
						Rear-TA	15000	0.064	0.044	0.041	0.034
			Fully Loaded	50%	46000	Front-S	12000	0.178	0.206		
						Rear-TA	34000	1.900	1.099	1.039	0.653
	Class 8 (4-axle (or less) single trailer truck, Comb-4)	5%	Empty	20%	24000	Front-S	9000	0.053	0.066		
						Rear-TA	9000	0.009	0.006		
						Trailer-S	6000	0.010	0.013	0.014	0.017
			Partial Load (50% capacity)	40%	44000	Front-S	9500	0.067	0.082		
						Rear-TA	22000	0.310	0.202		
						Trailer-S	12500	0.212	0.242	0.236	0.210
			Fully Loaded	40%	64000	Front-S	10000	0.083	0.101		
						Rear-TA	34000	1.900	1.099		
						Trailer-S	20000	1.558	1.520	1.416	1.088
	Class 9 (5-axle single trailer truck, Comb-5)	5%	Empty	20%	36000	Front-S	11000	0.124	0.147		
						Rear-TA	14000	0.048	0.033		
						Trailer-TA	11000	0.019	0.013	0.038	0.039
			Partial Load (50% capacity)	40%	58000	Front-S	11500	0.149	0.175		
						Rear-TA	24000	0.447	0.284		
						Trailer-TA	22500	0.341	0.220	0.375	0.272
			Fully Loaded	40%	80000	Front-S	12000	0.178	0.206		
						Rear-TA	34000	1.900	1.099		
						Trailer-TA	34000	1.900	1.099	1.592	0.962
								Composite LEF for Type A Truck Mix =		**0.535**	**0.492**

Table 5F-1.06 (Continued): Truck Mixture for Urban Roadways and Determination of Truck ESAL Factor

Type B Truck Mix: Predominantly single axle with some multi-axle trucks

Truck Class (Vehicle Description)		Percent of Total Trucks	Loading	Percent of Truck Class	Vehicle Weight (lbs)	Axle Type S-Single TA-Tandem	Axle Load (lbs)	ESAL Factor (per axle)		LEF (by Vehicle)	
								Rigid	Flexible	Rigid	Flexible
	Class 4 (2-axle busses, BUS)	5%	Partial Load (80% capacity)	100%	25000	Front-S	9000	0.053	0.066		
						Rear-S	16000	0.607	0.631	0.660	0.697
	Class 5 (2-axle, 6-tire trucks & busses, SU-2)	55%	Partial Load (50% capacity)	100%	20000	Front-S	6500	0.014	0.018		
						Rear-S	13500	0.294	0.326	0.308	0.344
	Class 6 (3-axle trucks, SU-3)	10%	Empty	50%	22000	Front-S	7000	0.019	0.024		
						Rear-TA	15000	0.064	0.044	0.041	0.034
			Fully Loaded	50%	46000	Front-S	12000	0.178	0.206		
						Rear-TA	34000	1.900	1.099	1.039	0.653
	Class 8 (4-axle (or less) single trailer truck, Comb-4)	5%	Empty	20%	24000	Front-S	9000	0.053	0.066		
						Rear-TA	9000	0.009	0.006		
						Trailer-S	6000	0.010	0.013	0.014	0.017
			Partial Load (50% capacity)	40%	44000	Front-S	9500	0.067	0.082		
						Rear-TA	22000	0.310	0.202		
						Trailer-S	12500	0.212	0.242	0.236	0.210
			Fully Loaded	40%	64000	Front-S	10000	0.083	0.101		
						Rear-TA	34000	1.900	1.099		
						Trailer-S	20000	1.558	1.520	1.416	1.088
	Class 9 (5-axle single trailer truck, Comb-5)	25%	Empty	20%	36000	Front-S	11000	0.124	0.147		
						Rear-TA	14000	0.048	0.033		
						Trailer-TA	11000	0.019	0.013	0.038	0.039
			Partial Load (50% capacity)	40%	58000	Front-S	11500	0.149	0.175		
						Rear-TA	24000	0.447	0.284		
						Trailer-TA	22500	0.341	0.220	0.375	0.272
			Fully Loaded	40%	80000	Front-S	12000	0.178	0.206		
						Rear-TA	34000	1.900	1.099		
						Trailer-TA	34000	1.900	1.099	1.592	0.962
						Composite LEF for Type B Truck Mix =				**0.895**	**0.677**

Table 5F-1.06 (Continued): Truck Mixture for Urban Roadways and Determination of Truck ESAL Factor

Type C Truck Mix: Mixed truck traffic with both single axle and multi-axle trucks

Truck Class (Vehicle Description)		Percent of Total Trucks	Loading	Percent of Truck Class	Vehicle Weight (lbs)	Axle Type S-Single TA-Tandem	Axle Load (lbs)	ESAL Factor (per axle) Rigid	ESAL Factor (per axle) Flexible	LEF (by Vehicle) Rigid	LEF (by Vehicle) Flexible
	Class 4 (2-axle busses, BUS)	5%	Fully Loaded	100%	25000	Front-S	9000	0.053	0.066		
						Rear-S	16000	0.607	0.631	0.660	0.715
	Class 5 (2-axle, 6-tire trucks & busses, SU-2)	30%	Fully Loaded	100%	20000	Front-S	6500	0.014	0.018		
						Rear-S	13500	0.294	0.326	0.308	0.368
	Class 6 (3-axle trucks, SU-3)	10%	Empty	50%	22000	Front-S	7000	0.019	0.024		
						Rear-TA	15000	0.064	0.044	0.041	0.034
			Fully Loaded	50%	46000	Front-S	12000	0.178	0.206		
						Rear-TA	34000	1.900	1.099	1.039	0.653
	Class 8 (4-axle (or less) single trailer truck, Comb-4)	10%	Empty	20%	24000	Front-S	9000	0.053	0.066		
						Rear-TA	9000	0.009	0.006		
						Trailer-S	6000	0.010	0.013	0.014	0.017
			Partial Load (50% capacity)	40%	44000	Front-S	9500	0.067	0.082		
						Rear-TA	22000	0.310	0.202		
						Trailer-S	12500	0.212	0.242	0.236	0.210
			Fully Loaded	40%	64000	Front-S	10000	0.083	0.101		
						Rear-TA	34000	1.900	1.099		
						Trailer-S	20000	1.558	1.520	1.416	1.088
	Class 9 (5-axle single trailer truck, Comb-5)	45%	Empty	20%	36000	Front-S	11000	0.124	0.147		
						Rear-TA	14000	0.048	0.033		
						Trailer-TA	11000	0.019	0.013	0.038	0.039
			Partial Load (50% capacity)	40%	58000	Front-S	11500	0.149	0.175		
						Rear-TA	24000	0.447	0.284		
						Trailer-TA	22500	0.341	0.220	0.375	0.272
			Fully Loaded	40%	80000	Front-S	12000	0.178	0.206		
						Rear-TA	34000	1.900	1.099		
						Trailer-TA	34000	1.900	1.099	1.592	0.962
								Composite LEF for Type C Truck Mix =		**1.302**	**0.919**

The following assumptions were made in the calculation of the ESALs and LEFs shown in Table 5F-1.06:

- The truck mix data was obtained from the Iowa DOT 2014 traffic counts using FHWA vehicle classes. Class 7, 10, 11, 12, and 13 were not included since they do not make up any significant volumes on Iowa urban roadways.
- ESAL factors for individual axles were calculated using manufacturer's vehicle weights and typical loadings.
- Concrete thickness of 8 inches, asphalt structural number of 3.25, terminal serviceability index of 2.25.
- ESAL tables were calculated with WinPas using the AASHTO equations and verified against the AASHTO design tables.

For the base year ESAL tables, the directional split for two lane facilities was set at 50/50 and for four-lane facilities, it was assumed that 60% of the trucks were in the design lane.

Table 5F-1.07: Base Year Design ESALs for Two Lane *Rigid Pavement*

% Trucks	Truck Mix Type	Two-Way Base Year AADT							
		1,000	2,000	3,000	4,000	5,000	10,000	15,000	20,000
1	A	1,000	2,000	3,000	4,000	5,000	10,000	14,500	19,500
	B	1,500	3,500	5,000	6,500	8,000	16,500	24,500	32,500
	C	2,500	5,000	7,000	9,500	12,000	24,000	35,500	47,500
2	A	2,000	4,000	6,000	8,000	10,000	19,500	29,500	39,000
	B	3,500	6,500	10,000	13,000	16,500	32,500	49,000	65,500
	C	5,000	9,500	14,500	19,000	24,000	47,500	71,500	95,000
3	A	3,000	6,000	9,000	11,500	14,500	29,500	44,000	58,500
	B	5,000	10,000	14,500	19,500	24,500	49,000	73,500	98,000
	C	7,000	14,500	21,500	28,500	35,500	71,500	107,000	142,500
4	A	4,000	8,000	11,500	15,500	19,500	39,000	58,500	78,000
	B	6,500	13,000	19,500	26,000	32,500	65,500	98,000	130,500
	C	9,500	19,000	28,500	38,000	47,500	95,000	142,500	190,000
5	A	5,000	10,000	14,500	19,500	24,500	49,000	73,000	97,500
	B	8,000	16,500	24,500	32,500	41,000	81,500	122,500	163,500
	C	12,000	24,000	35,500	47,500	59,500	119,000	178,000	237,500
6	A	6,000	11,500	17,500	23,500	29,500	58,500	88,000	117,000
	B	10,000	19,500	29,500	39,000	49,000	98,000	147,000	196,000
	C	14,500	28,500	43,000	57,000	71,500	142,500	214,000	285,000
7	A	7,000	13,500	20,500	27,500	34,000	68,500	102,500	136,500
	B	11,500	23,000	34,500	45,500	57,000	114,500	171,500	228,500
	C	16,500	33,500	50,000	66,500	83,000	166,500	249,500	332,500
8	A	8,000	15,500	23,500	31,000	39,000	78,000	117,000	156,000
	B	13,000	26,000	39,000	52,500	65,500	130,500	196,000	261,500
	C	19,000	38,000	57,000	76,000	95,000	190,000	285,000	380,000
9	A	9,000	17,500	26,500	35,000	44,000	88,000	132,000	175,500
	B	14,500	29,500	44,000	59,000	73,500	147,000	220,500	294,000
	C	21,500	43,000	64,000	85,500	107,000	214,000	321,000	427,500
10	A	10,000	19,500	29,500	39,000	49,000	97,500	146,500	195,000
	B	16,500	32,500	49,000	65,500	81,500	163,500	245,000	326,500
	C	24,000	47,500	71,500	95,000	119,000	237,500	356,500	475,000
12	A	11,500	23,500	35,000	47,000	58,500	117,000	175,500	234,000
	B	19,500	39,000	59,000	78,500	98,000	196,000	294,000	392,000
	C	28,500	57,000	85,500	114,000	142,500	285,000	427,500	570,500
14	A	13,500	27,500	41,000	54,500	68,500	136,500	205,000	273,500
	B	23,000	45,500	68,500	91,500	114,500	228,500	343,000	457,500
	C	33,500	66,500	100,000	133,000	166,500	332,500	499,000	665,500
16	A	15,500	31,000	47,000	62,500	78,000	156,000	234,000	312,500
	B	26,000	52,500	78,500	104,500	130,500	261,500	392,000	522,500
	C	38,000	76,000	114,000	152,000	190,000	380,000	570,500	760,500
18	A	17,500	35,000	52,500	70,500	88,000	175,500	263,500	351,500
	B	29,500	59,000	88,000	117,500	147,000	294,000	441,000	588,000
	C	43,000	85,500	128,500	171,000	214,000	427,500	641,500	855,500
20	A	19,500	39,000	58,500	78,000	97,500	195,000	293,000	390,500
	B	32,500	65,500	98,000	130,500	163,500	326,500	490,000	653,500
	C	47,500	95,000	142,500	190,000	237,500	475,000	713,000	950,500

Assumes two lane roadway with 50/50 directional split of base year AADT

Table 5F-1.08: Base Year Design ESALs for Two Lane *Flexible Pavement*

% Trucks	Truck Mix Type	Two-Way Base Year AADT							
		1,000	2,000	3,000	4,000	5,000	10,000	15,000	20,000
1	A	1,000	2,000	2,500	3,500	4,500	9,000	13,500	18,000
	B	1,000	2,500	3,500	5,000	6,000	12,500	18,500	24,500
	C	1,500	3,500	5,000	6,500	8,500	17,000	25,000	33,500
2	A	2,000	3,500	5,500	7,000	9,000	18,000	27,000	36,000
	B	2,500	5,000	7,500	10,000	12,500	24,500	37,000	49,500
	C	3,500	6,500	10,000	13,500	17,000	33,500	50,500	67,000
3	A	2,500	5,500	8,000	11,000	13,500	27,000	40,500	54,000
	B	3,500	7,500	11,000	15,000	18,500	37,000	55,500	74,000
	C	5,000	10,000	15,000	20,000	25,000	50,500	75,500	100,500
4	A	3,500	7,000	11,000	14,500	18,000	36,000	54,000	72,000
	B	5,000	10,000	15,000	20,000	24,500	49,500	74,000	99,000
	C	6,500	13,500	20,000	27,000	33,500	67,000	100,500	134,000
5	A	4,500	9,000	13,500	18,000	22,500	45,000	67,500	89,500
	B	6,000	12,500	18,500	24,500	31,000	61,500	92,500	123,500
	C	8,500	17,000	25,000	33,500	42,000	84,000	126,000	167,500
6	A	5,500	11,000	16,000	21,500	27,000	54,000	80,500	107,500
	B	7,500	15,000	22,000	29,500	37,000	74,000	111,000	148,000
	C	10,000	20,000	30,000	40,000	50,500	100,500	151,000	201,000
7	A	6,500	12,500	19,000	25,000	31,500	63,000	94,000	125,500
	B	8,500	17,500	26,000	34,500	43,000	86,500	129,500	173,000
	C	11,500	23,500	35,000	47,000	58,500	117,500	176,000	234,500
8	A	7,000	14,500	21,500	28,500	36,000	72,000	107,500	143,500
	B	10,000	20,000	29,500	39,500	49,500	99,000	148,000	197,500
	C	13,500	27,000	40,000	53,500	67,000	134,000	201,000	268,500
9	A	8,000	16,000	24,000	32,500	40,500	80,500	121,000	161,500
	B	11,000	22,000	33,500	44,500	55,500	111,000	166,500	222,000
	C	15,000	30,000	45,500	60,500	75,500	151,000	226,500	302,000
10	A	9,000	18,000	27,000	36,000	45,000	89,500	134,500	179,500
	B	12,500	24,500	37,000	49,500	61,500	123,500	185,000	247,000
	C	17,000	33,500	50,500	67,000	84,000	167,500	251,500	335,500
12	A	11,000	21,500	32,500	43,000	54,000	107,500	161,500	215,500
	B	15,000	29,500	44,500	59,500	74,000	148,000	222,000	296,500
	C	20,000	40,000	60,500	80,500	100,500	201,000	302,000	402,500
14	A	12,500	25,000	37,500	50,000	63,000	125,500	188,500	251,000
	B	17,500	34,500	52,000	69,000	86,500	173,000	259,500	345,500
	C	23,500	47,000	70,500	94,000	117,500	234,500	352,000	469,500
16	A	14,500	28,500	43,000	57,500	72,000	143,500	215,500	287,000
	B	20,000	39,500	59,500	79,000	99,000	197,500	296,500	395,000
	C	27,000	53,500	80,500	107,500	134,000	268,500	402,500	536,500
18	A	16,000	32,500	48,500	64,500	80,500	161,500	242,000	323,000
	B	22,000	44,500	66,500	89,000	111,000	222,000	333,500	444,500
	C	30,000	60,500	90,500	120,500	151,000	302,000	452,500	603,500
20	A	18,000	36,000	54,000	72,000	89,500	179,500	269,000	359,000
	B	24,500	49,500	74,000	99,000	123,500	247,000	370,500	494,000
	C	33,500	67,000	100,500	134,000	167,500	335,500	503,000	670,500

Assumes two lane roadway with 50/50 directional split of base year AADT

Table 5F-1.09: Base Year Design ESALs for Four Lane *Rigid Pavement*

% Trucks	Truck Mix Type	Two-Way Base Year AADT							
		2,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000
1	A	1,000	3,000	6,000	9,000	11,500	14,500	17,500	20,500
	B	2,000	5,000	10,000	14,500	19,500	24,500	29,500	34,500
	C	3,000	7,000	14,500	21,500	28,500	35,500	43,000	50,000
2	A	2,500	6,000	11,500	17,500	23,500	29,500	35,000	41,000
	B	4,000	10,000	19,500	29,500	39,000	49,000	59,000	68,500
	C	5,500	14,500	28,500	43,000	57,000	71,500	85,500	100,000
3	A	3,500	9,000	17,500	26,500	35,000	44,000	52,500	61,500
	B	6,000	14,500	29,500	44,000	59,000	73,500	88,000	103,000
	C	8,500	21,500	43,000	64,000	85,500	107,000	128,500	149,500
4	A	4,500	11,500	23,500	35,000	47,000	58,500	70,500	82,000
	B	8,000	19,500	39,000	59,000	78,500	98,000	117,500	137,000
	C	11,500	28,500	57,000	85,500	114,000	142,500	171,000	199,500
5	A	6,000	14,500	29,500	44,000	58,500	73,000	88,000	102,500
	B	10,000	24,500	49,000	73,500	98,000	122,500	147,000	171,500
	C	14,500	35,500	71,500	107,000	142,500	178,000	214,000	249,500
6	A	7,000	17,500	35,000	52,500	70,500	88,000	105,500	123,000
	B	12,000	29,500	59,000	88,000	117,500	147,000	176,500	206,000
	C	17,000	43,000	85,500	128,500	171,000	214,000	256,500	299,500
7	A	8,000	20,500	41,000	61,500	82,000	102,500	123,000	143,500
	B	13,500	34,500	68,500	103,000	137,000	171,500	206,000	240,000
	C	20,000	50,000	100,000	149,500	199,500	249,500	299,500	349,500
8	A	9,500	23,500	47,000	70,500	93,500	117,000	140,500	164,000
	B	15,500	39,000	78,500	117,500	157,000	196,000	235,000	274,500
	C	23,000	57,000	114,000	171,000	228,000	285,000	342,000	399,000
9	A	10,500	26,500	52,500	79,000	105,500	132,000	158,000	184,500
	B	17,500	44,000	88,000	132,500	176,500	220,500	264,500	308,500
	C	25,500	64,000	128,500	192,500	256,500	321,000	385,000	449,000
10	A	11,500	29,500	58,500	88,000	117,000	146,500	175,500	205,000
	B	19,500	49,000	98,000	147,000	196,000	245,000	294,000	343,000
	C	28,500	71,500	142,500	214,000	285,000	356,500	427,500	499,000
12	A	14,000	35,000	70,500	105,500	140,500	175,500	211,000	246,000
	B	23,500	59,000	117,500	176,500	235,000	294,000	353,000	411,500
	C	34,000	85,500	171,000	256,500	342,000	427,500	513,000	599,000
14	A	16,500	41,000	82,000	123,000	164,000	205,000	246,000	287,000
	B	27,500	68,500	137,000	206,000	274,500	343,000	411,500	480,000
	C	40,000	100,000	199,500	299,500	399,000	499,000	599,000	698,500
16	A	18,500	47,000	93,500	140,500	187,500	234,000	281,000	328,000
	B	31,500	78,500	157,000	235,000	313,500	392,000	470,500	549,000
	C	45,500	114,000	228,000	342,000	456,000	570,500	684,500	798,500
18	A	21,000	52,500	105,500	158,000	211,000	263,500	316,000	369,000
	B	35,500	88,000	176,500	264,500	353,000	441,000	529,000	617,500
	C	51,500	128,500	256,500	385,000	513,000	641,500	770,000	898,000
20	A	23,500	58,500	117,000	175,500	234,000	293,000	351,500	410,000
	B	39,000	98,000	196,000	294,000	392,000	490,000	588,000	686,000
	C	57,000	142,500	285,000	427,500	570,500	713,000	855,500	998,000

Assumes four lane roadway with 50/50 directional split of two-way base year AADT and 60% of trucks in the design lane.

Table 5F-1.10: Base Year Design ESALs for Four Lane *Flexible Pavement*

% Trucks	Truck Mix Type	Two-Way Base Year AADT							
		2,000	**5,000**	**10,000**	**15,000**	**20,000**	**25,000**	**30,000**	**35,000**
1	A	1,000	2,500	5,500	8,000	11,000	13,500	16,000	19,000
	B	1,500	3,500	7,500	11,000	15,000	18,500	22,000	26,000
	C	2,000	5,000	10,000	15,000	20,000	25,000	30,000	35,000
2	A	2,000	5,500	11,000	16,000	21,500	27,000	32,500	37,500
	B	3,000	7,500	15,000	22,000	29,500	37,000	44,500	52,000
	C	4,000	10,000	20,000	30,000	40,000	50,500	60,500	70,500
3	A	3,000	8,000	16,000	24,000	32,500	40,500	48,500	56,500
	B	4,500	11,000	22,000	33,500	44,500	55,500	66,500	78,000
	C	6,000	15,000	30,000	45,500	60,500	75,500	90,500	105,500
4	A	4,500	11,000	21,500	32,500	43,000	54,000	64,500	75,500
	B	6,000	15,000	29,500	44,500	59,500	74,000	89,000	103,500
	C	8,000	20,000	40,000	60,500	80,500	100,500	120,500	141,000
5	A	5,500	13,500	27,000	40,500	54,000	67,500	80,500	94,000
	B	7,500	18,500	37,000	55,500	74,000	92,500	111,000	129,500
	C	10,000	25,000	50,500	75,500	100,500	126,000	151,000	176,000
6	A	6,500	16,000	32,500	48,500	64,500	80,500	97,000	113,000
	B	9,000	22,000	44,500	66,500	89,000	111,000	133,500	155,500
	C	12,000	30,000	60,500	90,500	120,500	151,000	181,000	211,500
7	A	7,500	19,000	37,500	56,500	75,500	94,000	113,000	132,000
	B	10,500	26,000	52,000	78,000	103,500	129,500	155,500	181,500
	C	14,000	35,000	70,500	105,500	141,000	176,000	211,500	246,500
8	A	8,500	21,500	43,000	64,500	86,000	107,500	129,000	150,500
	B	12,000	29,500	59,500	89,000	118,500	148,000	178,000	207,500
	C	16,000	40,000	80,500	120,500	161,000	201,000	241,500	281,500
9	A	9,500	24,000	48,500	72,500	97,000	121,000	145,500	169,500
	B	13,500	33,500	66,500	100,000	133,500	166,500	200,000	233,500
	C	18,000	45,500	90,500	136,000	181,000	226,500	271,500	317,000
10	A	11,000	27,000	54,000	80,500	107,500	134,500	161,500	188,500
	B	15,000	37,000	74,000	111,000	148,000	185,000	222,000	259,500
	C	20,000	50,500	100,500	151,000	201,000	251,500	302,000	352,000
12	A	13,000	32,500	64,500	97,000	129,000	161,500	194,000	226,000
	B	18,000	44,500	89,000	133,500	178,000	222,000	266,500	311,000
	C	24,000	60,500	120,500	181,000	241,500	302,000	362,000	422,500
14	A	15,000	37,500	75,500	113,000	150,500	188,500	226,000	263,500
	B	20,500	52,000	103,500	155,500	207,500	259,500	311,000	363,000
	C	28,000	70,500	141,000	211,500	281,500	352,000	422,500	493,000
16	A	17,000	43,000	86,000	129,000	172,000	215,500	258,500	301,500
	B	23,500	59,500	118,500	178,000	237,000	296,500	355,500	415,000
	C	32,000	80,500	161,000	241,500	322,000	402,500	483,000	563,500
18	A	19,500	48,500	97,000	145,500	194,000	242,000	290,500	339,000
	B	26,500	66,500	133,500	200,000	266,500	333,500	400,000	466,500
	C	36,000	90,500	181,000	271,500	362,000	452,500	543,500	634,000
20	A	21,500	54,000	107,500	161,500	215,500	269,000	323,000	377,000
	B	29,500	74,000	148,000	222,000	296,500	370,500	444,500	518,500
	C	40,000	100,500	201,000	302,000	402,500	503,000	603,500	704,000

Assumes four lane roadway with 50/50 directional split of two-way base year AADT and 60% of trucks in the design lane.

Table 5F-1.11: Growth Factor

Design Period Years (n)	Average Annual Traffic Growth Rate, Percent					
	No Growth	1%	2%	3%	4%	5%
1	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.0	2.0	2.0	2.0	2.1
3	3.0	3.0	3.1	3.1	3.1	3.2
4	4.0	4.1	4.1	4.2	4.2	4.3
5	5.0	5.1	5.2	5.3	5.4	5.5
6	6.0	6.2	6.3	6.5	6.6	6.8
7	7.0	7.2	7.4	7.7	7.9	8.1
8	8.0	8.3	8.6	8.9	9.2	9.5
9	9.0	9.4	9.8	10.2	10.6	11.0
10	10.0	10.5	10.9	11.5	12.0	12.6
11	11.0	11.6	12.2	12.8	13.5	14.2
12	12.0	12.7	13.4	14.2	15.0	15.9
13	13.0	13.8	14.7	15.6	16.6	17.7
14	14.0	14.9	16.0	17.1	18.3	19.6
15	15.0	16.1	17.3	18.6	20.0	21.6
16	16.0	17.3	18.6	20.2	21.8	23.7
17	17.0	18.4	20.0	21.8	23.7	25.8
18	18.0	19.6	21.4	23.4	25.6	28.1
19	19.0	20.8	22.8	25.1	27.7	30.5
20	20.0	22.0	24.3	26.9	29.8	33.1
21	21.0	23.2	25.8	28.7	32.0	35.7
22	22.0	24.5	27.3	30.5	34.2	38.5
23	23.0	25.7	28.8	32.5	36.6	41.4
24	24.0	27.0	30.4	34.4	39.1	44.5
25	25.0	28.2	32.0	36.5	41.6	47.7
26	26.0	29.5	33.7	38.6	44.3	51.1
27	27.0	30.8	35.3	40.7	47.1	54.7
28	28.0	32.1	37.1	42.9	50.0	58.4
29	29.0	33.5	38.8	45.2	53.0	62.3
30	30.0	34.8	40.6	47.6	56.1	66.4
31	31.0	36.1	42.4	50.0	59.3	70.8
32	32.0	37.5	44.2	52.5	62.7	75.3
33	33.0	38.9	46.1	55.1	66.2	80.1
34	34.0	40.3	48.0	57.7	69.9	85.1
35	35.0	41.7	50.0	60.5	73.7	90.3
36	36.0	43.1	52.0	63.3	77.6	95.8
37	37.0	44.5	54.0	66.2	81.7	101.6
38	38.0	46.0	56.1	69.2	86.0	107.7
39	39.0	47.4	58.2	72.2	90.4	114.1
40	40.0	48.9	60.4	75.4	95.0	120.8
41	41.0	50.4	62.6	78.7	99.8	127.8
42	42.0	51.9	64.9	82.0	104.8	135.2
43	43.0	53.4	67.2	85.5	110.0	143.0
44	44.0	54.9	69.5	89.0	115.4	151.1
45	45.0	56.5	71.9	92.7	121.0	159.7
46	46.0	58.0	74.3	96.5	126.9	168.7
47	47.0	59.6	76.8	100.4	132.9	178.1
48	48.0	61.2	79.4	104.4	139.3	188.0
49	49.0	62.8	81.9	108.5	145.8	198.4
50	50.0	64.5	84.6	112.8	152.7	209.3

Growth Factor = $\frac{[(1+r)^n]-1}{r}$ for values of n > 0

D. Determining Pavement Thickness

Once the ESALs have been determined, the pavement thickness may be determined by comparing the calculated ESAL value to Tables 5F-1.13 through 5F-1.18. These tables provide recommended pavement thicknesses for various subgrade conditions, roadway types, and pavement types. Use of the roadway classification (local, collector, and arterial) is included in Tables 5F-1.13 to 5F-1.18 in order to provide the values for terminal serviceability and reliability that are used in the pavement thickness calculations. Due to established policies in many jurisdictions across the state, the minimum pavement thickness for streets on natural subgrade was set at 7 inches for rigid pavement and 8 inches for flexible pavement. For pavements with a granular subbase, the minimum thickness was set at 6 inches for both pavement types. As noted in the thickness tables, whenever a thickness was calculated that was less than the minimum, the minimum was used.

Tables 5F-1.13 through 5F-1.18 were developed according to the guidelines of the AASHTO Design Guide. The AASHTO pavement design methodology is based upon the results of the AASHO Road Test, which was a series of full scale experiments conducted in Illinois in the 1950s. The design methodology that grew out of the Road Test considers numerous factors that affect the performance of a pavement. Table 5F-1.12 describes the assumptions used in the development of the pavement thickness tables. An explanation of each variable, as well as a recommended range, is provided in the AASHTO Guide.

For projects with unique conditions such as unusual soils, high truck volumes, significant drainage problems, or where specialized subgrade or subbase treatments are utilized, a special design may be warranted. The values in the tables above have been selected to represent typical conditions. An effort has been made not to be overly conservative in the establishment of the design parameters. For this reason, the designer is cautioned against deviating from the values presented in the tables above unless materials testing and/or project site conditions warrant such deviation.

Table 5F-1.12: Parameter Assumptions Used for Pavement Thickness Design Tables

Subbase:	**Natural**		**4" Subbase**		**6" Subbase**		**8" Subbase**		**10" Subbase**		**12" Subbase**	
CBR Value:	**3**	**5**	**3**	**5**	**3**	**5**	**3**	**5**	**3**	**5**	**3**	**5**
Rigid Pavement Parameters												
Initial Serviceability Index, P_o	4.5											
Terminal Serviceability Index, P_t	Local Roads = 2.00 Collector Roads = 2.25 Arterials = 2.50											
Reliability, R	Local Roads = 80% Collector Roads = 88% Arterials = 95%											
Overall Standard Deviation, S_o	0.35											
Loss of Support, LS	0											
Soil Resilient Modulus, M_R 1500 x CBR	4,500	7,500	4,500	7,500	4,500	7,500	4,500	7,500	4,500	7,500	4,500	7,500
Subbase Resilient Modulus, E_{SB} *Assumed	Not Applicable		30,000*									
Modulus of Subgrade Reaction k, and Composite Modulus of Subgrade Reaction, k_c Use AASHTO Chapter 3, Table 3.2 and Figures 3.3 - 3.6 to determine	105	148	228	342	239	359	254	380	269	404	285	428
Coefficient of Drainage, C_d	1.00		1.10									
Modulus of Rupture, S'_c $S'_c = 2.3 \times f_c^{0.667}$ *Assumed 4,000 psi concrete	580											
Modulus of Elasticity, E_c $E_c = 6{,}750 \times S'_c$ *Assumed 4,000 psi concrete	3,915,000											
Load Transfer, J	J = 3.1 (Pavement Thickness <8") J = 2.7 (Pavement Thickness ≥ 8")											
Flexible Pavement Parameters												
Initial Serviceability Index, P_o	4.2											
Terminal Serviceability Index, P_t	Local Roads = 2.00 Collector Roads = 2.25 Arterials = 2.50											
Reliability, R	Local Roads = 80% Collector Roads = 88% Arterials = 95%											
Overall Standard Deviation, S_o	0.45											
Layer Coefficients	Surface / Intermediate = 0.44 Base = 0.44 Granular Subbase = 0.14											
Soil Resilient Modulus, M_R 1500 x CBR	4,500	7,500	4,500	7,500	4,500	7,500	4,500	7,500	4,500	7,500	4,500	7,500
Effective Soil Resilient Modulus, MR Use AASHTO Chapter 2, Figure 2.3 to determine	2,720	4,520	2,720	4,520	2,720	4,520	2,720	4,520	2,720	4,520	2,720	4,520
Coefficient of Drainage, C_d	1.00		1.15									

The following flowchart depicts a summary of the analysis process.

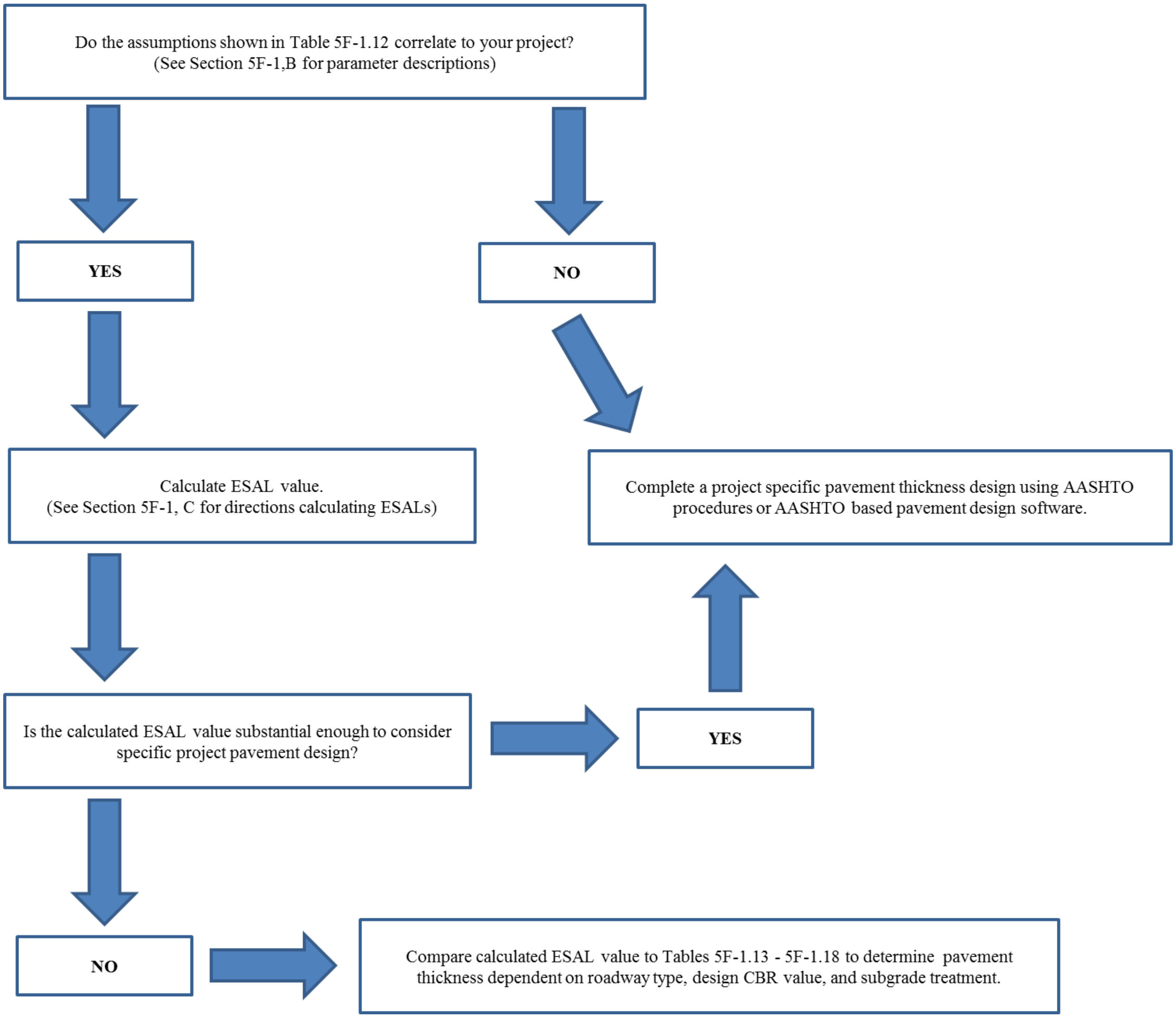


Table 5F-1.13: Recommended Thickness for Rigid Pavement - *Local Roads*

CBR	3						5					
ESAL/ Subbase	**Natural**	**4" Granular**	**6" Granular**	**8" Granular**	**10" Granular**	**12" Granular**	**Natural**	**4" Granular**	**6" Granular**	**8" Granular**	**10" Granular**	**12" Granular**
300,000	7*	6*	6*	6*	6*	6*	7*	6*	6*	6*	6*	6*
500,000	7*	6*	6*	6*	6*	6*	7*	6*	6*	6*	6*	6*
750,000	7*	6	6	6*	6*	6*	7*	6*	6*	6*	6*	6*
1,000,000	7	6	6	6	6	6	7	6	6*	6*	6*	6*
1,500,000	7.5	6.5	6.5	6.5	6.5	6.5	7.5	6.5	6	6	6	6
2,000,000	8	7	7	7	7	7	7.5	6.5	6.5	6.5	6.5	6.5
3,000,000	8	7.5	7.5	7.5	7.5	7.5	8	7	7	7	7	7

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Table 5F-1.14: Recommended Thickness for Rigid Pavement - *Collector Roads*

CBR	3						5					
ESAL/ Subbase	**Natural**	**4" Granular**	**6" Granular**	**8" Granular**	**10" Granular**	**12" Granular**	**Natural**	**4" Granular**	**6" Granular**	**8" Granular**	**10" Granular**	**12" Granular**
750,000	7	6	6	6	6	6	7	6	6*	6*	6*	6*
1,000,000	7.5	6.5	6.5	6.5	6.5	6.5	7	6	6	6	6	6
1,500,000	8	7	7	7	7	7	7.5	6.5	6.5	6.5	6.5	6.5
2,000,000	8	7.5	7.5	7.5	7.5	7	8	7	7	7	7	7
3,000,000	8	8	8	8	8	8	8	7.5	7.5	7.5	7.5	7.5
4,000,000	8.5	8	8	8	8	8	8.5	8	8	8	8	8
5,000,000	9	8	8	8	8	8	8.5	8	8	8	8	8
7,500,000	9.5	8.5	8.5	8.5	8.5	8.5	9.5	8.5	8	8	8	8
10,000,000	10	9	9	9	9	9	9.5	8.5	8.5	8.5	8.5	8.5

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Table 5F-1.15: Recommended Thickness for Rigid Pavement - *Arterial Roads*

CBR	3						5					
ESAL/ Subbase	**Natural**	**4" Granular**	**6" Granular**	**8" Granular**	**10" Granular**	**12" Granular**	**Natural**	**4" Granular**	**6" Granular**	**8" Granular**	**10" Granular**	**12" Granular**
1,000,000	7.5	7	7	7	7	6.5	7.5	6.5	6.5	6.5	6.5	6.5
1,500,000	8	7.5	7.5	7.5	7.5	7	8	7	7	7	7	7
2,000,000	8	8	7.5	7.5	7.5	7.5	8	7.5	7.5	7.5	7.5	7.5
3,000,000	8.5	8	8	8	8	8	8.5	8	8	8	8	8
4,000,000	9	8	8	8	8	8	8.5	8	8	8	8	8
5,000,000	9	8.5	8.5	8.5	8	8	9	8	8	8	8	8
7,500,000	10	9	9	9	9	9	9.5	8.5	8.5	8.5	8.5	8.5
10,000,000	10	9.5	9.5	9.5	9	9	10	9	9	9	9	9
12,500,000	10.5	9.5	9.5	9.5	9.5	9.5	10.5	9.5	9.5	9.5	9.5	9
15,000,000	11	10	10	10	10	10	10.5	9.5	9.5	9.5	9.5	9.5
17,500,000	11	10	10	10	10	10	11	10	10	10	10	10
20,000,000	11.5	10.5	10.5	10.5	10.5	10.5	11	10	10	10	10	10

Table 5F-1.16: Recommended Thickness for Flexible Pavement - *Local Roads*

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
300,000	8.5	7	6.5	6*	6*	6*	8*	6	6*	6*	6*	6*
500,000	9.5	8	7	6.5	6*	6*	8	6.5	6*	6*	6*	6*
750,000	10	8.5	7.5	7	6	6*	8.5	7	6	6*	6*	6*
1,000,000	10	8.5	8	7.5	6.5	6	8.5	7	6.5	6*	6*	6*
1,500,000	11	9.5	8.5	8	7	6.5	9	7.5	7	6	6*	6*
2,000,000	11	9.5	9	8.5	7.5	7	9.5	8	7.5	6.5	6	6*
3,000,000	12	10.5	9.5	9	8	7.5	10	8.5	8	7	6.5	6*

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Table 5F-1.17: Recommended Thickness for Flexible Pavement - *Collector Roads*

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
750,000	10.5	9	8.5	7.5	7	6	9	7.5	6.5	6	6*	6*
1,000,000	11	9.5	9	8	7.5	6.5	9.5	8	7	6.5	6*	6*
1,500,000	11.5	10	9.5	8.5	8	7.5	10	8.5	7.5	7	6	6*
2,000,000	12	10.5	10	9	8.5	7.5	10.5	9	8	7.5	6.5	6
3,000,000	13	11.5	10.5	10	9	8.5	11	9.5	8.5	8	7	6.5
4,000,000	13.5	12	11	10.5	9.5	9	11.5	10	9	8.5	7.5	7
5,000,000	13.5	12	11.5	10.5	10	9.5	11.5	10	9.5	9	8	7.5
7,500,000	---	13	12	11.5	10.5	10	12.5	11	10	9.5	8.5	8
10,000,000	---	13.5	12.5	12	11	10.5	13	11.5	10.5	10	9	8.5

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Table 5F-1.18: Recommended Thickness for Flexible Pavement - *Arterial Roads*

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
1,000,000	12	11	10	9.5	8.5	8	10.5	9	8	7.5	6.5	6
1,500,000	13	11.5	10.5	10	9	8.5	11	9.5	9	8	7.5	6.5
2,000,000	13.5	12	11	10.5	10	9	11.5	10	9	8.5	8	7
3,000,000	14	12.5	12	11	10.5	9.5	12	10.5	10	9	8.5	7.5
4,000,000	---	13	12.5	11.5	11	10.5	12.5	11	10.5	9.5	9	8
5,000,000	---	13.5	13	12	11.5	10.5	13	11.5	11	10	9.5	8.5
7,500,000	---	---	13.5	13	12	11.5	13.5	12	11.5	10.5	10	9.5
10,000,000	---	---	---	13.5	13	12	14	12.5	12	11.5	10.5	10
12,500,000	---	---	---	14	13.5	12.5	---	13	12.5	11.5	11	10
15,000,000	---	---	---	---	13.5	13	---	13.5	12.5	12	11.5	10.5
17,500,000	---	---	---	---	14	13	---	14	13	12.5	11.5	11
20,000,000	---	---	---	---	---	13.5	---	14	13.5	12.5	12	11

E. Pavement Thickness Design Calculations

Example #1 - Two Lane Roadway, PCC
AADT = 1,000
Trucks = 2%, Type A truck mix
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.07) = 2,000
Growth Factor (from Table 5F-1.11) = 84.6
2,000 ESALs X 84.6 = 169,200 ESALs

By referring to Table 5F-1.13 and rounding up the ESAL calculation to 300,000 (see below), the pavement thickness alternatives are either 6 inches or 7 inches depending on the CBR value and the subbase treatment selected.

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
300,000	7*	6*	6*	6*	6*	6*	7*	6*	6*	6*	6*	6*
500,000	7*	6*	6*	6*	6*	6*	7*	6*	6*	6*	6*	6*
750,000	7*	6	6	6*	6*	6*	7*	6*	6*	6*	6*	6*

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Example #1 - Two Lane Roadway, HMA
AADT = 1,000
Trucks = 2%, Type A truck mix
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.08) = 2,000
Growth Factor (from Table 5F-1.1) = 84.6
2,000 ESALs X 84.6 = 169,200 ESALs

By referring to Table 5F-1.16 and rounding up the ESAL calculation to 300,000 (see below), the pavement thickness alternatives range from 6 inches to 8.5 inches depending on the CBR value and subbase treatment selected.

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
300,000	8.5	7	6.5	6*	6*	6*	8*	6	6*	6*	6*	6*
500,000	9.5	8	7	6.5	6*	6*	8	6.5	6*	6*	6*	6*
750,000	10	8.5	7.5	7	6	6*	8.5	7	6	6*	6*	6*

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Example #2 - Two Lane Roadway, PCC
AADT = 5,000
Trucks = 4%, Type B truck mix
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.07) = 32,500
Growth Factor (from Table 5F-1.11) = 84.6
32,500 ESALs X 84.6 = 2,749,500 ESALs

By referring to Table 5F-1.14 and rounding up the ESAL calculation to 3,000,000 (see below), the pavement thickness alternatives range from 7.5 inches to 8 inches depending on the CBR value and subbase treatment selected.

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
750,000	7	6	6	6	6	6	7	6	6*	6*	6*	6*
1,000,000	7.5	6.5	6.5	6.5	6.5	6.5	7	6	6	6	6	6
1,500,000	8	7	7	7	7	7	7.5	6.5	6.5	6.5	6.5	6.5
2,000,000	8	7.5	7.5	7.5	7.5	7	8	7	7	7	7	7
3,000,000	8	8	8	8	8	8	8	7.5	7.5	7.5	7.5	7.5
4,000,000	8.5	8	8	8	8	8	8.5	8	8	8	8	8
5,000,000	9	8	8	8	8	8	8.5	8	8	8	8	8

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Example #2 - Two Lane Roadway, HMA
AADT = 5,000
Trucks = 4%, Type B truck mix
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.08) = 24,500
Growth Factor (from Table 5F-1.11) = 84.6
24,500 ESALs X 84.6 = 2,072,700 ESALs

By referring to Table 5F-1.17 and rounding down the ESAL calculation to 2,000,000 (see below), the pavement thickness alternatives range from 6 inches to 12 inches depending on the CBR value and subbase treatment selected.

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
750,000	10.5	9	8.5	7.5	7	6	9	7.5	6.5	6	6*	6*
1,000,000	11	9.5	9	8	7.5	6.5	9.5	8	7	6.5	6*	6*
1,500,000	11.5	10	9.5	8.5	8	7.5	10	8.5	7.5	7	6	6*
2,000,000	12	10.5	10	9	8.5	7.5	10.5	9	8	7.5	6.5	6
3,000,000	13	11.5	10.5	10	9	8.5	11	9.5	8.5	8	7	6.5
4,000,000	13.5	12	11	10.5	9.5	9	11.5	10	9	8.5	7.5	7

* Represents the minimum thickness based on established policies of local jurisdictions; the calculated value is less.

Example #3 - Four Lane Roadway, PCC
AADT = 15,000
Trucks = 5%, Type C truck mix
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.09) = 107,000
Growth Factor (from Table 5F-1.11) = 84.6
107,000 ESALs X 84.6 = 9,052,200 ESALs

By referring to Table 5F-1.15 and rounding up the ESAL calculation to 10,000,000 (see below), the pavement thickness alternatives range from 9 inches to 10 inches depending on the CBR value and subbase treatment selected.

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
1,000,000	7.5	7	7	7	7	6.5	7.5	6.5	6.5	6.5	6.5	6.5
1,500,000	8	7.5	7.5	7.5	7.5	7	8	7	7	7	7	7
2,000,000	8	8	7.5	7.5	7.5	7.5	8	7.5	7.5	7.5	7.5	7.5
3,000,000	8.5	8	8	8	8	8	8.5	8	8	8	8	8
4,000,000	9	8	8	8	8	8	8.5	8	8	8	8	8
5,000,000	9	8.5	8.5	8.5	8	8	9	8	8	8	8	8
7,500,000	10	9	9	9	9	9	9.5	8.5	8.5	8.5	8.5	8.5
10,000,000	10	9.5	9.5	9.5	9	9	10	9	9	9	9	9
12,500,000	10.5	9.5	9.5	9.5	9.5	9.5	10.5	9.5	9.5	9.5	9.5	9

Example #3 - Four Lane Roadway, HMA
AADT = 15,000
Trucks = 5%, Type C truck mix
Annual Growth Rate = 2%
Design Period = 50 years

Base Year Design ESALs (from Table 5F-1.10) = 75,500
Growth Factor (from Table 5F-1.11) = 84.6
75,500 ESALs X 84.6 = 6,387,300 ESALs

By referring to Table 5F-1.18 and rounding the ESAL calculation to 7,500,000 (see below), the pavement thickness alternatives range from 9.5 inches to 13.5 inches depending on the CBR value and subbase treatment selected.

CBR	3						5					
ESAL/ Subbase	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular	Natural	4" Granular	6" Granular	8" Granular	10" Granular	12" Granular
1,000,000	12	11	10	9.5	8.5	8	10.5	9	8	7.5	6.5	6
1,500,000	13	11.5	10.5	10	9	8.5	11	9.5	9	8	7.5	6.5
2,000,000	13.5	12	11	10.5	10	9	11.5	10	9	8.5	8	7
3,000,000	14	12.5	12	11	10.5	9.5	12	10.5	10	9	8.5	7.5
4,000,000	---	13	12.5	11.5	11	10.5	12.5	11	10.5	9.5	9	8
5,000,000	---	13.5	13	12	11.5	10.5	13	11.5	11	10	9.5	8.5
7,500,000	---	---	13.5	13	12	11.5	13.5	12	11.5	10.5	10	9.5
10,000,000	---	---	---	13.5	13	12	14	12.5	12	11.5	10.5	10

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