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16. Abstract

The impact of increasing overweight truck loads on Texas highways is a growing concern within the Texas Department of Transportation (TxDOT). Since pavement performance is significantly influenced by the magnitude and frequency of truck traffic loads, guidelines are needed for evaluating the capacity of existing highways to sustain routine overweight truck traffic over a specified performance period. The problem of overweight truck loads has been investigated in related TxDOT projects that led to the development of analysis procedures for evaluating superheavy load routes and load-zoning requirements. Researchers used results from these TxDOT projects to develop pavement evaluation guidelines for routine overweight truck routes that are presented in this report. In this project, researchers developed a two-stage framework that is based on using existing TxDOT capabilities for pavement evaluation, including nondestructive test methods and pavement analysis programs. Level I involves the use of pavement evaluation charts to identify the best possible route from among the alternatives considered and to determine what additional tests and analyses are needed for Level II. It is primarily intended as a screening tool to assist the engineer in identifying candidate overweight truck routes and potential problem areas. Level II involves the application of the Overweight Truck Route Analysis (OTRA) program to evaluate the structural adequacy of an existing route to carry routine overweight truck traffic over the specified performance period. Additionally, OTRA may be used to estimate the thickness of asphalt concrete overlay required to carry the expected number of truck axle loads over the specified design life based on a user-prescribed reliability level. This report presents guidelines on the application of the methodology to evaluate the suitability of using an existing route for routine overweight truck use.

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GUIDELINES FOR EVALUATING ROUTINE OVERWEIGHT TRUCK ROUTES

by

Emmanuel G. Fernando
Research Engineer
Texas Transportation Institute

and

Jeong-Ho Oh
Graduate Research Assistant
Texas Transportation Institute

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Research Project Title: Characterize the Effects of Permitted Overweight Loads on SH4/48 at the Port of Brownsville

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The Texas A&M University System
College Station, TX 77843-3135

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT), or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Dr. Emmanuel G. Fernando, P.E. # 69614.

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- Mr. Luis Carlos Peralez of the Pharr District provided invaluable assistance to the data collection activities conducted along SH4/48. Mr. Peralez provided staff and equipment for collection of falling weight deflectometer (FWD), multi-depth deflectometer and profile data at different times during the project; instrumentation of pavement sections to measure deflections under truck wheel loads; and collection of material samples for laboratory testing.
- The pavement management staff of the Pharr District, in particular, Mr. Rene Castro, collected FWD measurements, profile data and asphalt concrete cores along SH4/48.
- Mr. Niño Gutierrez and Ms. Jo Saban of the Brownsville Navigation District provided researchers access to the port for monitoring permitted trucks and static axle weight data on these trucks.
- Mr. Richard Peters, Mr. Jeff Reding, and Ms. Carolyn Markert provided weigh-in-motion (WIM) data that were used to characterize the existing truck traffic along SH4/48.

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CHAPTER I

INTRODUCTION

BACKGROUND

The impact of increasing overweight truck loads on Texas highways is a growing concern within the Texas Department of Transportation (TxDOT). Since pavement performance is significantly influenced by the magnitude and frequency of truck traffic loads, guidelines are needed for evaluating the capacity of existing highways to sustain routine overweight truck traffic over a specified performance period. The problem of overweight truck loads has been investigated in related TxDOT projects that led to the development of analysis procedures for evaluating super heavy load routes (Jooste and Fernando, 1995) and load-zoning (Fernando and Liu, 2001). Researchers used results from these TxDOT projects to develop the pavement evaluation guidelines for routine overweight truck routes that are presented in this report.

The present project, 0-4184, stemmed from recent legislative action that permitted trucks with gross vehicle weights (GVWs) of up to 125,000 lbs to routinely use a route in south Texas along the Mexican border. This route proceeds from the Veterans International Bridge to the Port of Brownsville via US77, SH4, and SH48. The portion of the route along US77 is on a new concrete pavement and includes an elevated structure over half of its length. Most of the permitted truck route runs along SH4 and SH48 in Brownsville. This project focused on studying the behavior and monitoring the performance of the asphalt concrete pavement sections along SH4/48 that are subjected to routine overweight truck traffic. About 95 percent of the permitted trucks originate from the Port of Brownsville, where the route starts at the FM511 bridge and runs along SH48 until its intersection with Boca Chica Boulevard. From there, truckers proceed along SH4 up to the US77 intersection, where they turn left to go to the Veterans International Bridge and into Mexico. Figure 1 shows the permitted truck route investigated in this project.

The payloads carried by permitted trucks are mostly coiled metal sheets, oil, and powder mineral (fluorite), which are transported from the Port of Brownsville to Mexico and vice versa. Figure 2 illustrates the types of payloads transported along the route, which was established in response to the need expressed by truckers to haul cargo at their trucks' operating capacities to improve operational efficiency. This need meant hauling in excess of

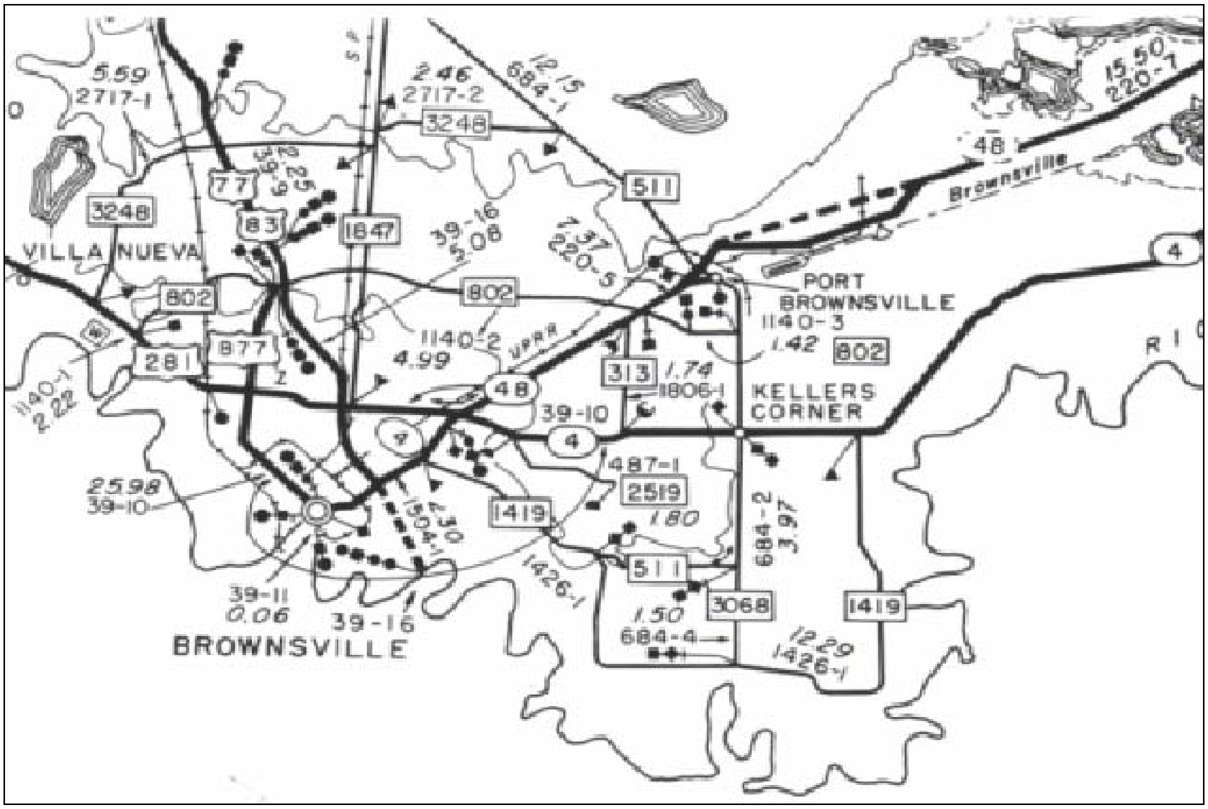

Figure 1. Overweight Truck Route along SH4/48.

Figure 2. Types of Loads Carried by Permitted Trucks.

legal limits, thus requiring permits to be issued. Table 1 presents the weight limits used along the route.

The permit fee is US $30 each way. From the time TxDOT first issued the permits in March 1998 to the end of 2002, about US $4.5 million were collected from permit sales, based on figures provided by the Brownsville Navigation District. The navigation district retains 15 percent of the funds to cover administrative costs, and the remainder goes to the TxDOT Pharr District to pay for route maintenance. On average, about 2700 permitted overweight trucks use the route per month. Considering that the route was not designed to sustain routine overweight truck traffic, the potential for accelerated pavement deterioration exists. Since it is likely that TxDOT will receive requests for similar permitted routes in the future, it becomes prudent to study the effects of routine overweight loads on SH4/48 and to develop guidelines for evaluating and/or designing routine overweight truck routes.

SCOPE OF REPORT

This report presents guidelines for evaluating whether existing pavements can sustain routine overweight truck traffic. It is organized into the following chapters:

- Chapter I provides a background to the project. It identifies the overweight truck route and the types of payloads transported by permitted trucks; explains why the route was established; presents data on the number of permitted trucks that use the route; and provides the impetus for conducting this research project.
- Chapter II presents guidelines for evaluating the suitability of using an existing route for routine overweight truck use. For this purpose, researchers adopted a two-stage framework that is based on using existing TxDOT capabilities for pavement evaluation, including nondestructive test methods and pavement analysis programs.
- Chapter III documents the development of the pavement evaluation charts incorporated in Level I of the two-stage framework presented in Chapter II. It explains the application of the charts and provides guidelines on their use.
- Finally, the appendix presents the Level I pavement evaluation charts.

Table 1. Weight Limits Used for Permitting Trucks along SH4/48.

Weight Criterion	Weight Limit (kips)
Single axle	25
Tandem axle	46
Tridem axle	60
4-axle group	70
5-axle group	81.4
Gross vehicle weight	125

CHAPTER II

PROCEDURE FOR OVERWEIGHT TRUCK ROUTE ANALYSIS

The procedure researchers developed to evaluate overweight truck routes has two levels:

- Level I involves the use of pavement evaluation charts and requires less information from the engineer compared to Level II. It is primarily intended as a screening tool to assist the engineer in identifying candidate overweight truck routes and potential problem areas. Chapter III discusses the charts in more detail.
- Level II involves the application of nondestructive test methods and pavement analysis programs to characterize the route for the purpose of using the Overweight Truck Route Analysis (OTRA) program developed in this research project. OTRA is a modification of the Program for Load-Zoning Analysis (PLZA) that is documented in earlier research reports by Fernando and Liu (1999, 2001). In this project, researchers from the Texas Transportation Institute (TTI) modified PLZA to include the capability for predicting pavement response under triple axles and to evaluate the thickness of overlay required to sustain routine overweight truck traffic for the user-specified design period. Instructions on using the computer program are given in the user's guide prepared by Fernando and Liu (2004).

This chapter presents guidelines on the application of the methodology to evaluate the suitability of using an existing route for routine overweight truck use.

METHODOLOGY FOR ANALYZING OVERWEIGHT TRUCK ROUTES

As stated previously, the first stage is primarily intended as a screening tool to identify candidate overweight truck routes and potential problem areas where additional data collection and analysis may be warranted. This stage includes the following steps:

- Establish the expected axle load magnitudes and frequency of permitted truck traffic.
- Identify possible routes that may be used by truckers to haul their payloads from the point of origin to the point of destination.
- Establish the pavement layer thicknesses and material types found along the routes.

- Use the Level I charts to conduct a preliminary assessment to identify the best possible route from among the alternatives considered, and determine what additional tests and analyses are needed for Level II.

Estimates of the expected axle load magnitudes and the frequency of permitted truck traffic can be obtained from the truckers that want to haul cargo in excess of legal load limits. They can provide information on:

- the types, sizes, and weights of payloads;
- the quantity of payloads to be transported on a daily basis; and
- the truck configurations they plan to use for hauling.

The above list is relevant in identifying candidate routes for permitting overweight trucks. Other factors to consider are the:

- presence of load-zoned roads and/or bridges;
- presence of overhead structures that place limits on the sizes of payloads that can be moved;
- route geometry (e.g., number of lanes, lane widths); and
- pavement condition based on visual surveys and/or data from the Pavement Management Information System (PMIS) database.

The presence of load-zoned bridges generally precludes the use of a route for servicing routine overweight truck traffic or the one-time movement of a superheavy load. On the other hand, it is not uncommon to see load-zoned roads used by permitted truck traffic, such as oil field trucks, timber trucks, and even superheavy loads. While it is not advisable to permit overweight trucks on load-zoned roads, the need to transport goods considered essential to the economic livelihood of an area or region often overrides this concern, particularly if no alternative routes exist that can accommodate the expected sizes and weights of loads. For example, the presence of overhead structures often dictates the route selection for moving overweight and/or oversized trucks.

The engineer should also consider pavement condition data along with observations of the existing truck traffic to identify candidate routes for permitted overweight trucks. The presence of areas exhibiting load-associated cracks along the wheel paths, permanent deformation, and/or base failures would suggest the need to look for other routes, or to repair existing distressed areas prior to permitting routine overweight truck traffic. Note that the permitted trucks constitute an addition to trucks that already use the route, and that additional and heavier wheel loads would accelerate the deterioration already taking place under existing truck traffic.

Once candidate routes are established, the engineer can further screen these routes using the Level I charts discussed in Chapter III of this report. Relative to Level II, application of these charts requires minimal information from the engineer. For each segment of a candidate route, the appropriate charts are used to estimate service life given the existing surface and base thicknesses, and the yearly number of trucks that are expected to use that segment. The charts are grouped according to the criterion used to estimate service life, i.e., fatigue cracking and rutting. Within each group, the charts are further classified according to the strength of the base and subgrade materials found along a given segment. Chapter III discusses the Level I charts in more detail. From the Level I analysis, the engineer can establish a ranking of the different routes based on predicted service life. The engineer should then consider performing a Level II analysis for the highest and second ranked routes. The Level II analysis is conducted using the OTRA program developed in this research project.

Pavement engineers can use the OTRA program to evaluate the adequacy of an existing route to sustain routine overweight truck loads over a specified design period. Additionally, the program can estimate the thickness of asphalt concrete overlay required to carry the cumulative truck axle loads expected over the design life based on fatigue and rut depth criteria. For this purpose, the program uses the predicted horizontal strain at the bottom of the asphalt layer and the vertical strain at the top of the subgrade with the Asphalt Institute (1982) equations for fatigue cracking and rutting to predict service life for the given pavement and loading conditions.

To use the program, the engineer must first characterize the route to be analyzed. This step requires characterizing the truck traffic on the route, determining pavement layer thicknesses, and evaluating material properties. Table 2 summarizes the input requirements of the computer program, while Figure 3 illustrates the flow of data through the pavement structural evaluation process. Truck traffic data can be requested from the Transportation Planning and Programming (TP&P) Division of TxDOT. The beginning and ending average daily traffic (ADT) values, directional factor, and percent trucks are normally reported by TP&P in *Traffic Analysis for Highway Design* sheets that it provides in response to requests

Table 2. Input Data Requirements for Pavement Structural Evaluation Using OTRA.

Data Requirements	Methods of Getting Data
Layer thicknesses	●Ground penetrating radar ●Coring ●Dynamic cone penetrometer
Nonlinear, stress-dependent material parameters, K_1, K_2, and K_3	●Falling weight deflectometer ●Resilient modulus test, American Association of State Highway and Transportation Officials (AASHTO T-292-91) ●Correlations with physical soil properties
Truck traffic characteristics ‣ Beginning and ending ADTs for design period ‣ directional factor ‣ percent trucks ‣ average axles per truck ‣ percent single axles ‣ percent tandem axle groups ‣ percent triple axle groups ‣ design single axle load ‣ design tandem axle load ‣ design triple axle load	●Contact TP&P ●Truck counts and classifications ●Axle load measurements

from the districts or the Materials and Pavements Section of TxDOT's Construction Division. These input values are used, along with data on average axle groups per truck and the percentages of single, tandem, and triple axle groups to determine the expected cumulative number of load applications for each axle group over the specified design period. OTRA permits the user to input the truck distribution by vehicle class to determine the average axle groups per truck and the percentages of single, tandem, and triple axle assemblies. TP&P can assist in establishing this truck distribution for a given route.

As indicated in Figure 3, pavement layer thicknesses can be determined nondestructively using ground penetrating radar (GPR) supplemented, as necessary, by coring or dynamic cone penetrometer (DCP) measurements. Researchers strongly suggest a GPR survey on the route to establish the variations in layer thicknesses along the route to be analyzed. This survey should be conducted at the beginning of the evaluation for the following purposes:

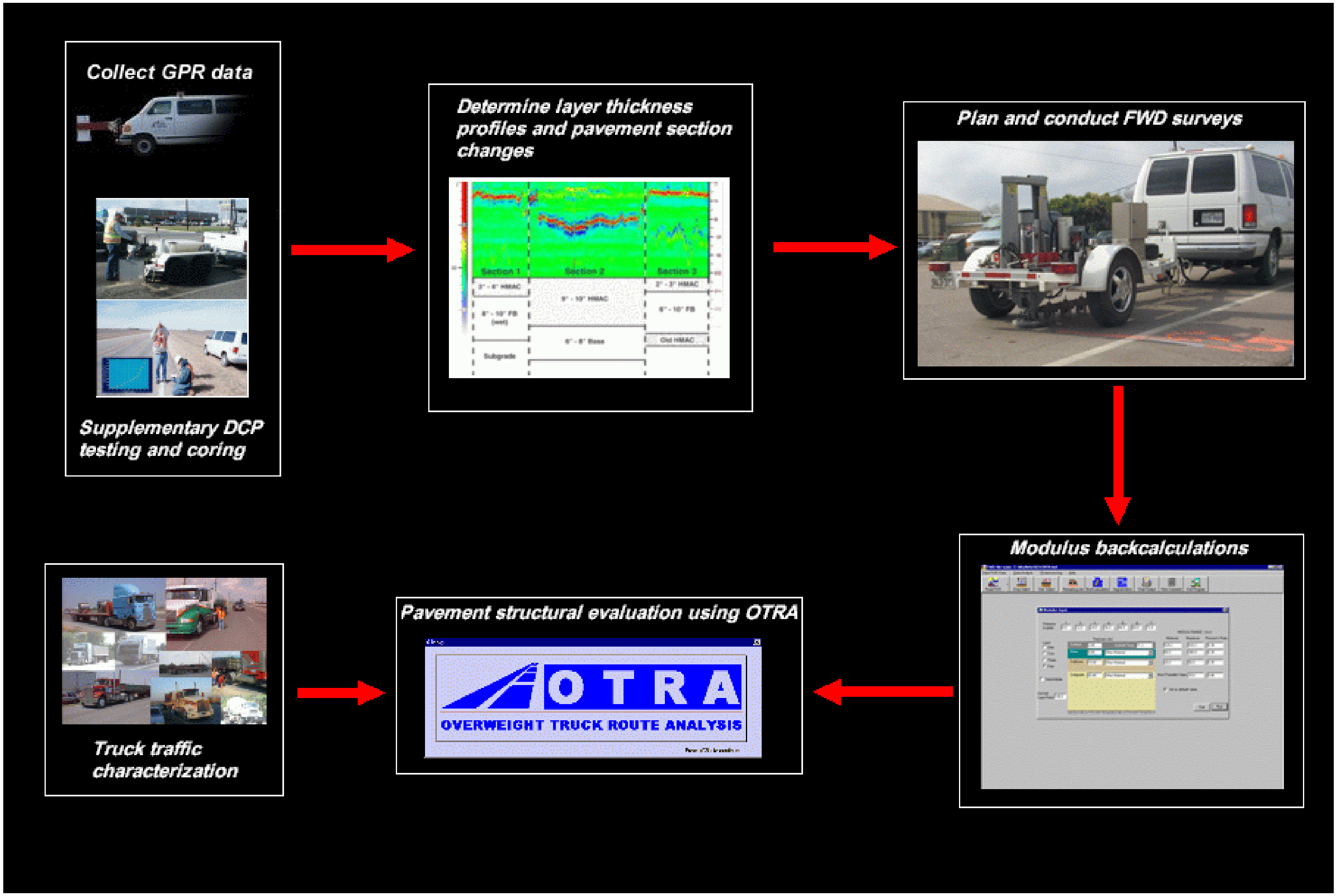

Figure 3. Data Flow through Pavement Structural Evaluation Process in OTRA.

- to detect possible changes in pavement cross-section along the route and divide the route into analysis segments, as appropriate;
- to establish the need for cores or DCP data to supplement the radar survey and identify locations where coring or DCP measurements should be made; and
- to establish the locations of falling weight deflectometer (FWD) measurements consistent with pavement section changes identified from the radar data on the route.

Additionally, a video log can be made during the radar survey to provide a record of the pavement surface condition at the time of the evaluation. GPR surveys can be scheduled with the Materials and Pavements Section, which is staffed with engineers trained to operate, maintain, and analyze radar data for pavement evaluation purposes.

The engineer should use GPR data to subdivide the route into homogeneous segments based on the predicted layer thicknesses. This segmentation may be accomplished using the cumulative difference method as described by the American Association of State Highway and Transportation Officials (1993) and as illustrated by Fernando and Chua (1994). Because of the strong influence of layer thickness on predicted pavement response and layer moduli backcalculated from FWD deflections, it is important to establish the variability in layer thickness along the route to minimize the inaccuracies caused by layer thickness variations. The segments delineated from the GPR data are subsequently used to plan the FWD survey, the purpose of which is to characterize the materials that comprise the pavement in terms of the elastic modulus. Districts now routinely perform these surveys for pavement design, forensic investigations, load-zoning, and superheavy load analysis.

FWD data are collected on each homogeneous segment following the protocol established by TxDOT (1996). For asphalt concrete pavements with surface thicknesses greater than 3 inches, pavement temperature measurements should be made to correct backcalculated asphalt concrete moduli to a standard temperature. For this purpose, TxDOT's FWDs are equipped with cordless drills and temperature probes so that asphalt layer temperatures can be measured at least once at the beginning and again at the end of the test on a given segment. Researchers recommend taking temperatures at mid-depth of the existing asphalt concrete layer. Temperature data are necessary to correct the backcalculated moduli to a reference temperature of 75 °F in the analysis program. Because of the influence of the surface modulus on predicted service life, it is important that the pavement temperature is known with a reasonable degree of confidence so that the asphalt concrete modulus can be appropriately determined.

FWD data collection may take some time depending on the frequency of testing and the length of the segment to be surveyed. In certain applications, taking pavement temperature measurements at the beginning and end of the segment will not provide enough information to consider the spatial and temporal variation in pavement temperatures during the survey. For these cases, researchers recommend taking infrared surface temperatures at least on every other station, so that pavement temperatures can be estimated using the Texas-Long Term Pavement Performance (LTPP) equation implemented in the Modulus Temperature Correction Program developed by Fernando, Liu, and Ryu (2001). This equation permits prediction of pavement temperatures for a given depth within the asphalt layer corresponding to the date and time of FWD testing. Use of this equation requires the previous day's maximum and minimum air temperatures, which are readily obtained from the local weather service and will provide a better estimate of the spatial and temporal variation of pavement temperatures along the route surveyed. The pavement temperatures measured at the beginning and end of the segment should verify the temperature predictions from the Texas-LTPP equation.

Researchers recommend storing FWD data in a separate file for each segment of the route surveyed, then analyzing each file with the MODULUS program (Michalak and Scullion, 1995) to estimate the elastic moduli of the pavement layers. The output file of the backcalculated moduli for each segment is directly input to the OTRA program to predict whether the existing pavement can sustain the expected number of axle load applications through the end of the specified design period.

To predict pavement response under loading, OTRA permits the engineer to model pavement materials as linear or nonlinear. The nonlinear material constants, K_1, K_2, and K_3 in Table 2, are the parameters of the model proposed by Uzan (1985) to characterize the stress dependency of the resilient modulus, E_r, of pavement materials. The following equation defines this model:

$$E_r = K_1 \, Atm \left(\frac{I_1}{Atm} \right)^{K_2} \left(\frac{\tau_{oct}}{Atm} \right)^{K_3} \quad (1)$$

where I_1 = first stress invariant,

τ_{oct} = octahedral shear stress, and

Atm = the atmospheric pressure = 14.5 psi.

Given the principal stresses, σ_1, σ_2, and σ_3, predicted from layered elastic theory, the first stress invariant and octahedral shear stress are determined from the following equations:

$$I_1 = \sigma_1 + \sigma_2 + \sigma_3 \quad (2)$$

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2} \quad (3)$$

The coefficients in Eq. (1) can be obtained from laboratory testing of base and subgrade specimens following the procedure adopted by the American Association of State Highway and Transportation Officials. This test method, designated as AASHTO T 292-91, is applicable for untreated base/subbase and subgrade materials. Typical values of these coefficients for different materials are provided in the user's guide for the OTRA program (Fernando and Liu, 2004). However, the authors strongly recommend conducting resilient modulus tests on samples of the materials found along the route to determine the coefficients for the nonlinear analysis, should the engineer decide to use this option.

In the application of OTRA, the user specifies the K_2 and K_3 values. The program then estimates the coefficient K_1 using these values with the backcalculated layer modulus for the material. The effects of stress dependency are more pronounced for thin-surfaced pavements, making it particularly important to model this behavior for these pavements. For thicker pavements, the effects are less pronounced. The program permits the user to model a given layer as linear elastic or nonlinear elastic. To model materials as linear elastic, the coefficients K_2 and K_3 in Eq. (1) are set to zero. For these materials, K_1 is directly determined from the FWD backcalculated moduli that are input to the computer program.

In view of the possible variations in layer thicknesses and materials along the route, different results may be obtained for the different segments established from analysis of the GPR data. The engineer may use these results to:

- identify segments that will require rehabilitation to sustain the expected number of axle load applications during the specified design period;
- establish depths of milling and overlays along the route; and
- identify weak areas (based on analysis of FWD data and visual inspection of the route) that will require additional work, such as base repairs or reconstruction.

The engineer should use the data and findings from the pavement structural evaluation to decide whether to permit routine overweight truck traffic, and if so, establish what rehabilitation measures are necessary to provide a route that will sustain the expected number of axle load applications over the specified design period, and at what cost.

Further instructions on using the OTRA program are given in the user's guide by Fernando and Liu (2004). The next chapter discusses the development and application of the Level I charts for evaluating overweight truck routes.

CHAPTER III

LEVEL I ANALYSIS PROCEDURE

INTRODUCTION

In this chapter, an analysis procedure is presented to help engineers make an initial assessment of the structural adequacy of a pavement for routine overweight truck loading. Level I of the two-stage framework for overweight truck route analysis involves the use of pavement evaluation charts to identify the best possible route from among the alternatives considered, and to determine what additional tests and analyses are needed for Level II. Application of the charts requires less data collection and analysis relative to Level II. For this purpose, the engineer can use historical data or information from previous investigations to estimate the truck traffic, and layer thickness and stiffness variations along a given route. Considering the approximate nature of the available information on the route, the Level I charts are by necessity somewhat conservative. The authors recognized that this approach can sometimes lead to inaccurate and unrealistic results. For this reason, the engineer should use the Level I charts only as a screening tool for ranking candidate routes and determining what additional tests and analyses are needed to establish a route for routine overweight truck use. The engineer, of course, has the option of using the OTRA program in Level II directly and collecting the required data for its application. This course of action is particularly appropriate in situations where historical data are suspect or where only one possible route can be considered for routine overweight truck use. Nevertheless, the authors are of the opinion that the Level I charts can be useful in establishing the test and analysis requirements for Level II. For this reason, the engineer should use the charts when their application can help identify the best possible route and establish where additional tests and analyses are warranted.

MATERIALS USED IN DEVELOPING LEVEL I CHARTS

The research team developed the Level I charts through repetitive runs of the OTRA program. In this work, researchers used OTRA to predict service life for a range of pavement structures that comprise different combinations of material types and layer thicknesses. The development of the charts followed the same approach used in an earlier TxDOT project that developed a procedure for analyzing superheavy load moves. In that project, Jooste and Fernando (1995) prepared a number of charts with which to conduct an initial assessment to determine whether a given pavement can sustain one pass of a superheavy load without developing permanent deformation. The superheavy load analysis charts covered a range of pavement structures comprising different combinations of material types and layer thicknesses. The same combinations of material types were used by researchers in the present project to develop the Level I charts for overweight truck route analysis. Table 3 summarizes the material parameters used in developing these charts. In this development, researchers assumed a nonlinear formulation. Thus, the modulus of each material varied with load magnitude and depth into the pavement. Table 3 shows the nonlinearity constants, K_1, K_2, and K_3, characterizing each material and the resulting range of modulus values from the analyses. For a given layer, the range in moduli is used to generically describe the material as stiff, weak, or stabilized. Brief descriptions of the different materials are given in the following subsections.

Asphalt Surface

As shown in Table 3, the asphalt stiffness varied from approximately 110 to 300 ksi, which the researchers considered to be at the low end of the normal range in asphalt concrete (AC) moduli. This range could represent an AC layer that has undergone some degradation due to existing traffic and environmental effects. In addition, the authors consider this low range to be appropriate for developing the charts considering the approximate nature of the available information upon which the charts are likely to be used. Following earlier work in developing the superheavy load analysis charts, the AC material was modeled as slightly nonlinear, with a K_2 value of 0.1, and a K_3 value of 0.0. Nevertheless, the modulus varied significantly over the thickness of the layer due to the range in the predicted stress variations.

Weak Base

The condition described as "weak base" was chosen to represent a non-stabilized, moisture-susceptible, granular material with a moisture content wetter than optimum. In practice, base materials such as crushed limestone, iron ore gravel, shell, or caliche are found that fall into this category. Based on the relationship between Texas Triaxial Class and modulus, the "weak base" is considered to represent a material with an approximate Texas Triaxial Class of 3.5 to 4.0 (Huang, 1993). In terms of the correlation between modulus and California Bearing Ratio (CBR) developed by Shell (Heukelom and Klomp, 1962) and illustrated in Figure 4, the approximate range of CBR for this material is within 8 to 22,

Table 3. Material Parameters Assumed in Developing Charts.

Layer Description	Nonlinear Material Constants			Range of Modulus (ksi)
	K_1	K_2	K_3	
Asphalt surface	10000 to 15000	0.1	0.0	110 to 300
Weak base	1500	0.6	-0.2	12 to 33
Stabilized base	15000	0.1	0.0	145 to 300
Weak subgrade	500	0.0	-0.4	7 to 10
Stiff subgrade	900	0.0	-0.4	12 to 20

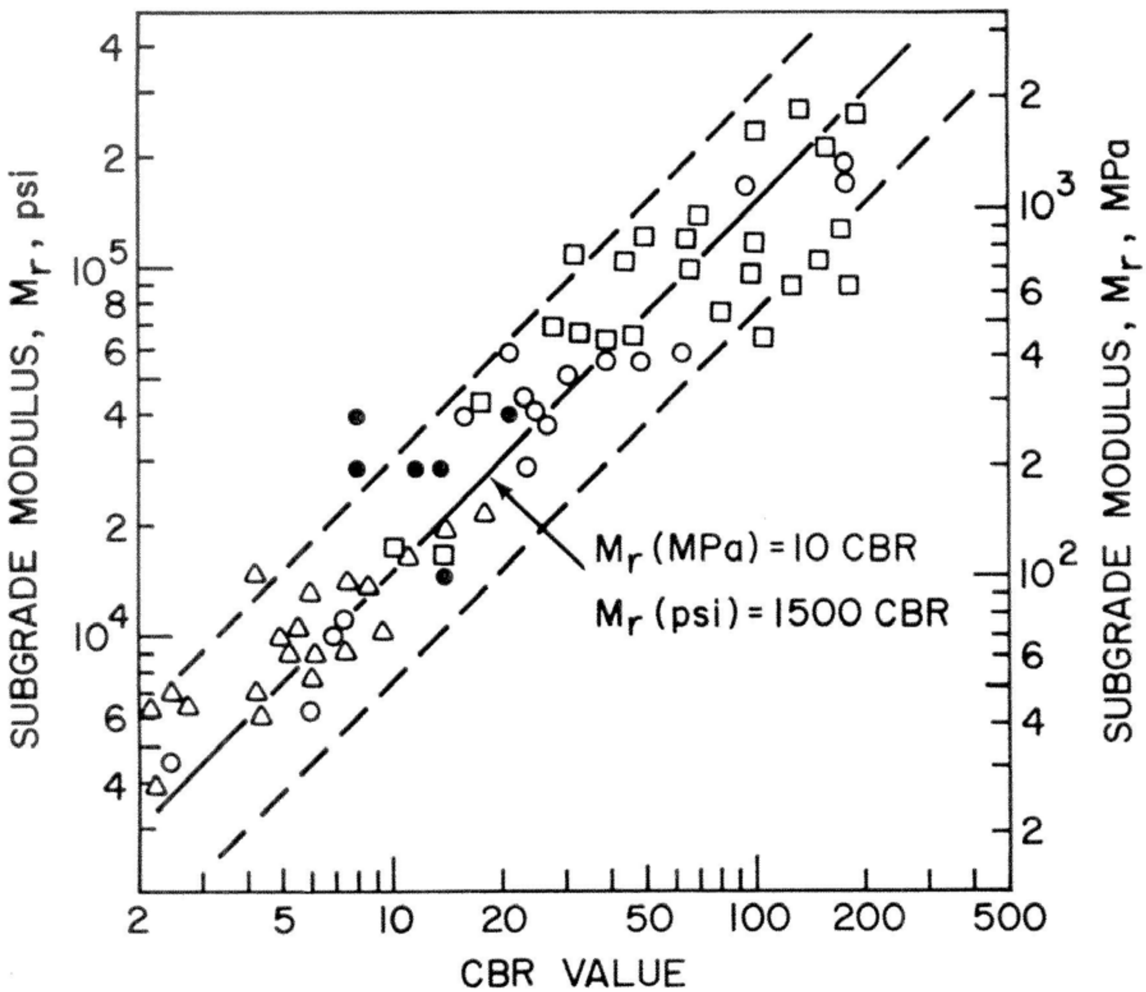

Figure 4. Relationship between Modulus and CBR (Heukelom and Klomp, 1962).

corresponding to the line defined by the equation, M_r = 1500 CBR, shown in the figure. Considering the spread of the data points about this fitted line, researchers note that the CBR can vary over a wider range of 4 to 50. Thus, users should consider the approximate nature of the relationship shown. The authors recommend the use of FWD data to characterize pavement materials for the purpose of using the Level I charts.

Stabilized Base

The base or subbase material is often modified with lime or cement to increase strength and load-carrying capacity. The stiffness and cohesion of stabilized materials can vary considerably, depending on the amount of stabilizer used, curing time, and material quality (Little, 1995). Table 3 shows the nonlinearity constants for the stabilized base material that researchers assumed in this project. The chosen constants resulted in stabilized base moduli that range from 145 to 300 ksi. These values are considered to be at the low end of the range in moduli that have been determined from laboratory or FWD data. However, researchers consider the modulus values obtained to be realistic and appropriate in developing the charts as the values reflect to some degree, possible degradation in the stabilized granular material due to traffic and environmental effects, which are also influenced by the durability of the material.

Weak Subgrade

The weak subgrade is considered to be a soft, stress-softening material that offered poor support to the overlying structure. The nonlinear coefficients that the researchers assumed for this material resulted in modulus values that range from 7 to 10 ksi. Materials that fall under this category include wet clay, poorly compacted sand, or any other material with high plasticity and relatively high moisture content (Jooste and Fernando, 1995).

Stiff Subgrade

The nonlinearity constants assumed for this material resulted in modulus values that range from 12 to 20 ksi. Researchers consider this range to be representative of fairly stiff and well compacted subgrade materials. The stiff subgrade can also denote a lightly stabilized, poor quality material.

ASSUMPTIONS ON TRAFFIC LOADS

While superheavy load analysis is concerned with evaluating whether or not a given pavement will experience shear failure under one pass of a superheavy load, overweight truck route analysis looks at the potential for premature failure under repeated applications of axle loads higher than legal, and exceeding the load magnitudes for which the pavement was originally designed. Thus, the engineer needs to characterize the existing as well as the expected overweight truck traffic to predict pavement performance along a route being considered for routine overweight truck use. The decision to permit overweight trucks can then be made on the basis of the minimum time the engineer wants to have before the route needs to be resurfaced. If the predicted service life is greater than or equal to the minimum time before the next resurfacing, routine overweight truck traffic can be permitted. Otherwise, the need for initial rehabilitation is indicated to accommodate the overweight trucks expected to use the road. Alternatively, the engineer can find and evaluate another route, or decide against permitting overweight trucks, if this is an option.

In developing the charts, researchers made the following assumptions on the distribution and load characteristics of permitted and non-permitted (legal) trucks:

- Truck traffic consists of Class 9 (3S2) and Class 10 (3S3) trucks as illustrated in Figure 5. The authors are of the opinion that this assumption is reasonable based on the observation that 3S2s are the primary trucks used by transport carriers. Thus, in developing the Level I charts, 3S2s were used to represent the legal truck traffic. In addition, researchers observed that the permitted trucks in Brownsville are either 3S2s or 3S3s. Consequently, permitted (overweight) trucks were represented by both of these classes according to the distribution given next.
- Among the permitted trucks, the researchers found 3S2s and 3S3s to comprise 45 and 55 percent, respectively, of the overweight truck traffic based on a review of the permits issued by the Port of Brownsville.
- Axle weights on permitted trucks were established based on the 90th percentile of the axle weight distributions evaluated from permits issued by the port authority. Researchers note that each truck is weighed at the port before permits are issued to verify that the axle and gross vehicle weights do not exceed the allowable limits for the overweight truck route shown in Table 1. The measured weights are then recorded on the permits. Researchers used the data to determine the weight

Class 9 Class 10

Figure 5. Truck Classes Considered in Developing Level I Charts.

corresponding to the 90th percentile of the weight distribution for each truck axle. These weights were then used to predict pavement life for the range of pavements covered by the Level I charts. Table 4 shows the representative axle weights for the legal and overweight trucks considered in developing the charts. For the legal or non-permitted trucks, researchers assumed the legal tandem axle weight limit of 34 kips for the drive and trailer axles. Researchers then established the steering axle weight such that the sum of the truck axle weights equals the legal GVW limit of 80,000 lbs.

- The weights in Table 4 are assumed to be equally distributed among the tires comprising a given axle group. Researchers used a lateral spacing of 14 inches between the dual tires at each end of the drive and trailer axles. In addition, a spacing of 48 inches was assumed between the axles of the drive and trailer axle groups. Each wheel load was represented as a uniform contact pressure of 100 psi acting over a circular area with radius equal to:

$$r = \sqrt{\frac{P}{100\pi}} \tag{4}$$

where,

r = radius of the contact area in inches, and

P = tire load in lbs.

The authors consider the preceding assumptions to be reasonable and appropriate for the intended use of the Level I charts as a tool for initial screening of alternative overweight truck routes. Application of the charts requires relatively less information from the engineer. However, if the engineer wants to use a different truck distribution or specify other representative axle group weights, the OTRA program can be used to do the analysis. If route-specific data are available, the engineer should consider using the OTRA program in lieu of the Level I charts.

Table 4. Axle Weights Used in Developing Level I Charts.

Truck Class	Axle Weight (kips)		
	Steering	Drive	Trailer
Class 9 (legal)	12	34	34
Class 9 (permitted)	12	45	46
Class 10 (permitted)	12	45	60

ANALYSES CONDUCTED TO DEVELOP CHARTS

Researchers developed charts for evaluating candidate truck routes for four different combinations of the material types presented earlier in this chapter. The combinations represent particular pavement groups identified as follows:

- Group 1: AC over weak base over weak subgrade
- Group 2: AC over weak base over stiff subgrade
- Group 3: AC over stabilized base over weak subgrade
- Group 4: AC over stabilized base over stiff subgrade

Within each group, a range of pavement structures was analyzed that covered different combinations of surface and base thicknesses. For each pavement, the allowable number of load repetitions was predicted based on the traffic load assumptions presented previously and using the Asphalt Institute (1982) performance models for fatigue cracking and rutting. These models are given by the following equations:

$$(N_f)^c = 7.95 \times 10^{-2} \left(\frac{1}{\varepsilon_{ac}}\right)^{3.29} \left(\frac{1}{E_{ac}}\right)^{0.854} \qquad (5)$$

$$(N_f)^r = 1.365 \times 10^{-9} \left(\frac{1}{\varepsilon_{sg}}\right)^{4.477} \qquad (6)$$

where,

$(N_f)^c$ = allowable number of load repetitions based on fatigue cracking,

$(N_f)^r$ = allowable number of load repetitions based on rutting,

ε_{ac} = predicted tensile strain at the bottom of the AC layer,

E_{ac} = asphalt concrete modulus, and

ε_{sg} = predicted vertical compressive strain at the top of the subgrade.

Equation (5) predicts the number of load applications prior to development of 20 percent fatigue cracking based on total pavement area, while Eq. (6) predicts the number of load repetitions to a limiting rut depth of ½ inch (Asphalt Institute, 1982). In the analyses, the strains induced under loading were determined at a number of lateral offsets beneath the wheel loads. These positions correspond to the edge and middle of the tire for the steering axle. For the tandem and triple axle assemblies, the strains were predicted at the outside tire edge, middle of the tire, inside tire edge, and midway between the dual tires of the lead axle, and at these offsets at a distance corresponding to half the axle spacing. Additionally, for the triple axle assembly, the strains were predicted at these lateral offsets beneath the dual tires of the middle axle. Researchers used the maximum predicted asphalt tensile strain and subgrade vertical compressive strain to predict the allowable number of repetitions based on fatigue cracking and rutting criteria.

The predicted allowable numbers of axle load repetitions for a given pavement and distress criterion were used to determine the unit service life consumption according to the following equation:

$$\begin{aligned}&\left[\frac{1}{(N_f)_{steering}}+\frac{1}{(N_f)_{drive}}+\frac{1}{(N_f)_{trailer}}\right]_{3S2,\,legal}\times(\%_{legal})+\\&\left[\frac{1}{(N_f)_{steering}}+\frac{1}{(N_f)_{drive}}+\frac{1}{(N_f)_{trailer}}\right]_{3S2,\,overwt.}\times(\%_{overwt.}\times\%_{3S2,overwt.})+\\&\left[\frac{1}{(N_f)_{steering}}+\frac{1}{(N_f)_{drive}}+\frac{1}{(N_f)_{trailer}}\right]_{3S3,\,overwt.}\times(\%_{overwt.}\times\%_{3S3,overwt.})\end{aligned} \qquad (7)$$

where,

$(N_f)_i$ = predicted allowable number of repetitions for the i^{th} axle of the given truck,

$\%_{legal}$ = percent of legal or non-permitted trucks,

$\%_{overwt.}$ = percent of overweight or permitted trucks,

$\%_{3S2,\ overwt.}$ = percent of overweight trucks that are 3S2s, and

$\%_{3S3,\ overwt.}$ = percent of overweight trucks that are 3S3s.

Equation (7) gives the average service life consumed per truck application, weighted according to the percentages of the different trucks considered in developing the Level I charts (Table 4). This weighted average is referred to herein as the unit service life consumption.

For each of the four pavement groups, researchers then developed charts for estimating the unit service life consumption based on fatigue cracking and rutting criteria. Equation (7) shows that this quantity is a function of the expected distribution of legal and overweight trucks, indicating that different curves might need to be established for various estimates of the expected split between legal and overweight trucks. Consequently, researchers initially examined the sensitivity of the predictions of unit service life consumption to the distribution of legal and overweight trucks. For this analysis, researchers considered the following four possible distributions:

- 80 percent legal and 20 percent overweight (80/20 split),
- 70 percent legal and 30 percent overweight (70/30 split),
- 60 percent legal and 40 percent overweight (60/40 split), and
- 50 percent legal and 50 percent overweight (50/50 split).

To show the full range of the variation in the predicted unit service life consumption with the assumed truck distribution, predictions were also made for the extreme cases of 100 percent legal (100/0 split) and 100 percent overweight (0/100 split). A 100/0 split represents the base condition, while the other extreme corresponds to a dedicated overweight truck route, which researchers consider to be an unlikely scenario. The authors note that these limiting cases were primarily considered to provide a frame of reference for evaluating the predictions corresponding to the four possible distributions identified above.

Among the overweight or permitted trucks, researchers assumed a 45/55 split between 3S2s and 3S3s as explained earlier. Figures 6 to 9 illustrate how the predicted unit service life consumption varied with the different truck distributions considered in the analysis. The figures show curves for Group 1 (weak) and Group 4 (strong) pavements, which represent the extreme cases considered in the development of the Level I charts. Note that a constant base thickness of 12 inches was used to construct the curves. All figures are drawn to the same scale for comparison purposes. From the charts shown, the following observations are made:

- For a given distress criterion, the predicted service life consumption per truck application is greater for the weak than for the strong pavements considered in the analysis (i.e., for the same layer thicknesses and traffic loads, the pavement made of weaker materials is predicted to fail earlier).

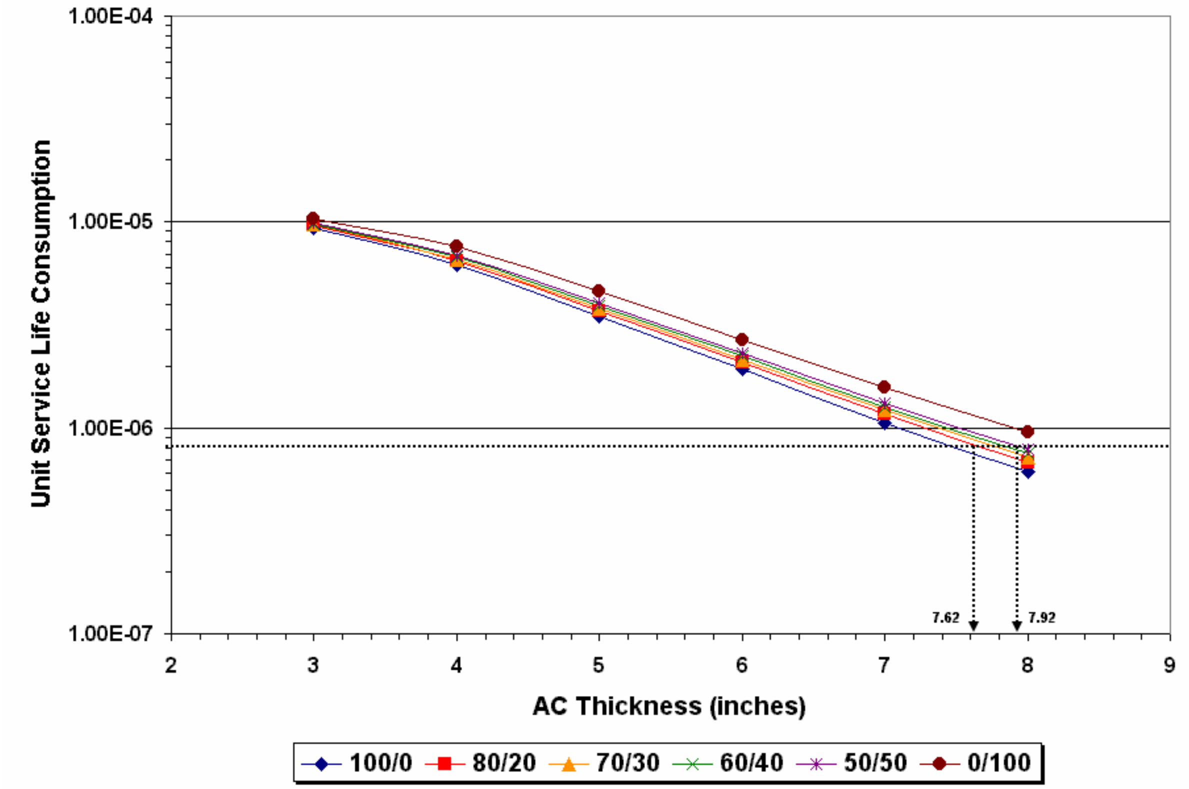

Figure 6. Effect of Truck Distribution on the Predicted Unit Service Life Consumption Based on Fatigue Cracking (Group 1 Pavements).

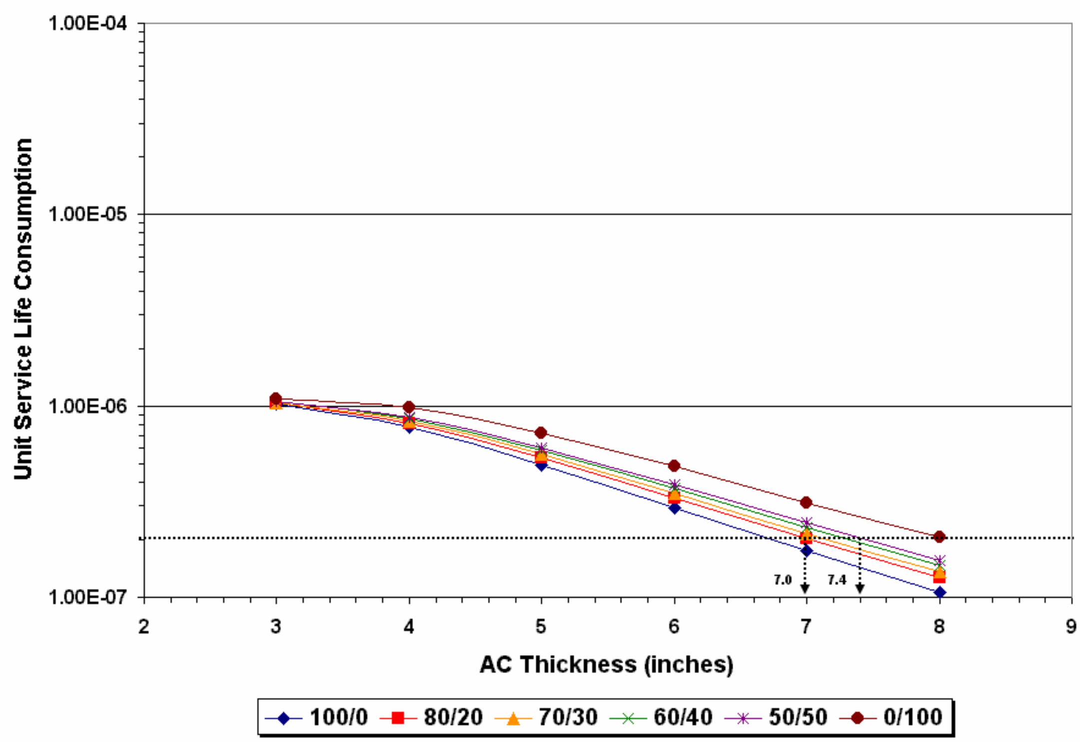

Figure 7. Effect of Truck Distribution on the Predicted Unit Service Life Consumption Based on Fatigue Cracking (Group 4 Pavements).

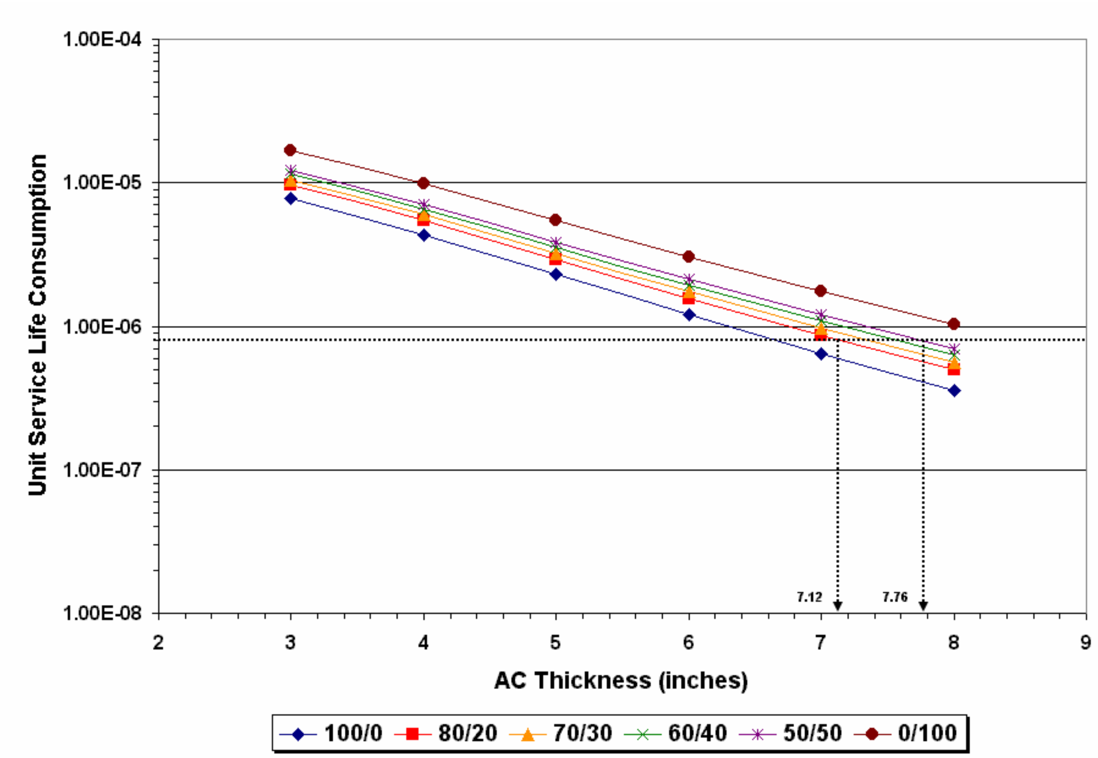

Figure 8. Effect of Truck Distribution on the Predicted Unit Service Life Consumption Based on Rutting (Group 1 Pavements).

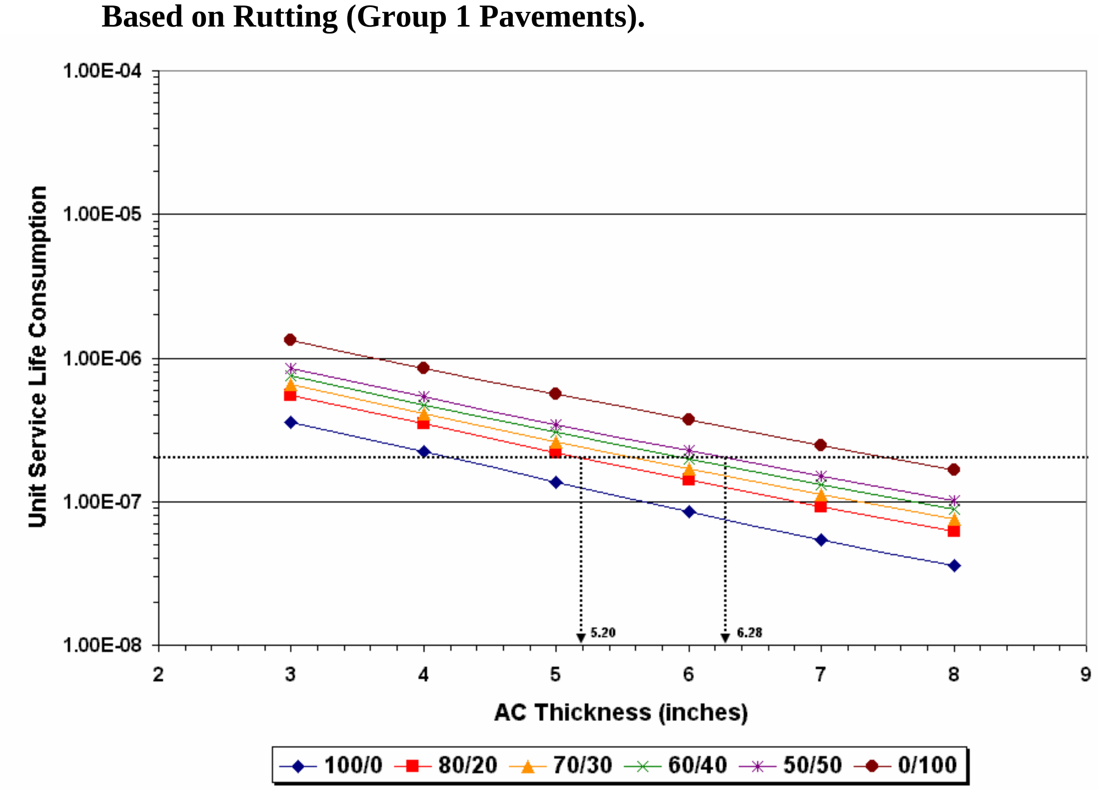

Figure 9. Effect of Truck Distribution on the Predicted Unit Service Life Consumption Based on Rutting (Group 4 Pavements).

- The predicted unit service life consumption increases with increase in the percentage of overweight trucks.
- In terms of fatigue cracking, the results indicate that the predictions are relatively less affected by the assumed distribution of legal and overweight trucks compared to the results based on rutting. In particular, Figures 6 and 7 show that the maximum variation in the required AC thickness is within half an inch over the range of truck distributions that can be expected for an overweight truck route. In contrast, the maximum variation is about 1.1 inches (Figure 9) based on rutting.

In view of the previous findings, researchers decided to develop the Level I charts using the following truck distributions:

- Because of the smaller variation in the predicted unit service life consumption based on fatigue cracking, a 50/50 split was used in constructing the Level I charts for this distress criterion. Among the four distributions considered to be realistic for overweight truck routes, this breakdown is the most conservative.
- For developing the Level I charts based on rutting, researchers decided to use an 80/20 split for cases where the expected percentage of overweight trucks is 20 or less. For cases where the percentage is above 20, curves were constructed assuming a 50/50 split. This approach considers the greater variation observed in the predicted unit service life consumption based on rutting.

Figures A1 through A4 in the Appendix show the Level I charts for fatigue cracking. Four charts are presented, one for each pavement group considered in the development work. For rutting, researchers prepared two sets of charts. The first set of four charts shown in Figures A5 to A8 is to be used when the expected percentage of overweight trucks is 20 or less. The next set of charts in Figures A9 to A12 is used when the expected percentage is above 20. The engineer can use the predicted unit service life consumption from the applicable chart to estimate pavement life given the number of trucks expected to use the route per year. Specifically, the product of the predicted service life consumed per truck application and the expected number of trucks per year gives the predicted service life consumed per year. The reciprocal of this quantity gives the estimated pavement life in years for the given distress. Figure A13 may be used to predict pavement life given the predicted service life consumed per truck application and the number of trucks expected to use the route per year. The procedure then for using the Level I charts consists of the following steps:

- Based on the information collected from preliminary investigations done to identify candidate overweight truck routes, classify the pavements found on different segments of a route into the four pavement groups considered in developing the charts. Estimate the unit service life consumption based on fatigue cracking and rutting criteria from the applicable charts.
- For each segment, use Figure A13 to estimate the pavement life for the predicted unit service life consumption and the number of trucks expected to use the route per year.
- Compare the predicted pavement lives with the desired time before the next rehabilitation or resurfacing. This step will identify the less desirable routes in terms of predicted capacity to sustain routine overweight truck traffic, or identify weak segments of a candidate route where initial rehabilitation should be considered prior to permitting overweight trucks. The need for additional tests should then be established based on the findings from the Level I analysis.

GUIDELINES FOR CLASSIFYING PAVEMENTS FOR LEVEL I ANALYSIS

Application of the charts presented in Figures A1 to A12 requires the engineer to classify a given pavement into one of the four groups considered in developing the Level I charts. This classification can be accomplished in a number of ways. If FWD deflections or backcalculated layer moduli on candidate routes are available from previous tests, the engineer can use the existing data with the range in moduli values given in Table 3 to classify the pavements found along the routes. The framework for overweight truck route analysis does permit FWD data or backcalculated moduli to be used in the Level I analysis. In the researchers' opinion, the availability of such data improves the accuracy of the analysis by reducing the uncertainty associated with the materials comprising the candidate routes. The authors note that subgrade stiffness has a significant influence on the predicted pavement life based on rutting, and to a lesser degree on the predicted fatigue life, particularly for thin pavements (Fernando and Liu, 2001). Since the subgrade modulus is relatively the easiest parameter to backcalculate from FWD deflections, a significant benefit could be derived if FWD data are available for the Level I analysis. In the absence of such data or in cases where the historical information is suspect, the engineer should collect the data needed to make informed decisions. Tools that are available are the GPR, FWD, and DCP. With GPR and FWD data, the engineer has the option to proceed with a Level I or a Level II analysis directly. If such measurements cannot be made, the engineer should consider collecting, or using available DCP data to support the analysis.

A number of researchers have conducted studies that developed relationships between the penetration resistance (as determined from the DCP) and the CBR (Livneh et al., 1995 and Webster et al., 1992). For a given material, CBR is the percentage ratio of the pressure recorded at 0.1-inch penetration to the corresponding pressure for a standard, high-quality crushed rock. Table 5 shows ranges in CBR values for various soils based on road and airfield construction guidelines of the U.S. Army Engineer Waterways Experiment Station (1960).

Higher CBR values indicate stronger materials that offer greater penetration resistance relative to the standard crushed rock. As a tool for evaluating road and airfield materials, the DCP has been widely used to determine the strength profile of flexible pavements by measuring the depth of penetration per blow. Several agencies and researchers have developed correlations between CBR and the DCP penetration rate. Webster et al. (1992) compared some of the published correlations. Based on this review, the following equation was recommended:

$$log_{10} CBR \quad = \quad 2.46 - 1.12 (log_{10} DCP) \tag{8}$$

where,

DCP = penetration rate in mm/blow, and

CBR = California Bearing Ratio in percent.

Usually, DCP testing involves coring through the top asphalt layers to expose the top of the granular base where the test is commenced. The DCP is driven through the pavement to some required depth or until refusal. During the test, the depth penetrated per blow is measured and the data are subsequently plotted as illustrated in Figure 10. By identifying where slope changes occur on the penetration curve, the layering within the pavement can be established, as illustrated in Figure 10. The penetration rate for each layer can then be determined and used in Eq. (8) to predict the CBR for the given layer or material.

Table 6 shows suggested guidelines for classifying a given pavement into one of the four groups considered in developing the Level I charts. The guidelines are based on the DCP penetration rate in in/blow for a given material and information taken from the literature on typical CBR ranges for various coarse- and fine-grained materials. Thus, if DCP data are available, the engineer can establish the pavement layering as illustrated in Figure 10. From

Table 5. Typical CBR Ranges for Various Soils.

Major Division	Subdivision	Unified Soil Classification	CBR Range (%)	Value as Subgrade[1]	Value as Base[1]
Coarse-grained soils	Gravel and gravelly soils	GW	40 – 80	Excellent	Good
		GP	30 – 60	Good to excellent	Fair to good
		GM (LL < 25 and PI < 5)	40 – 60	Good to excellent	Fair to good
		GM (LL > 25 or PI > 5)	20 – 30	Good	Poor to not suitable
		GC	20 – 40	Good	Poor to not suitable
	Sand and sandy soils	SW	20 – 40	Good	Poor
		SP	10 – 40	Fair to good	Poor to not suitable
		SM (LL < 25 and PI < 5)	15 – 40	Fair to good	Poor
		SM (LL > 25 or PI > 5)	10 – 20	Fair	Not suitable
		SC	5 – 20	Poor to fair	Not suitable
Fine-grained soils	Silts and clays with liquid limit < 50	ML	≤ 15	Poor to fair	Not suitable
		CL	≤ 15	Poor to fair	Not suitable
		OL	≤ 5	Poor	Not suitable
	Silts and clays with liquid limit > 50	MH	≤ 10	Poor	Not suitable
		CH	≤ 15	Poor to fair	Not suitable
		OH	≤ 5	Poor to very poor	Not suitable

[1]When material is not subject to frost penetration

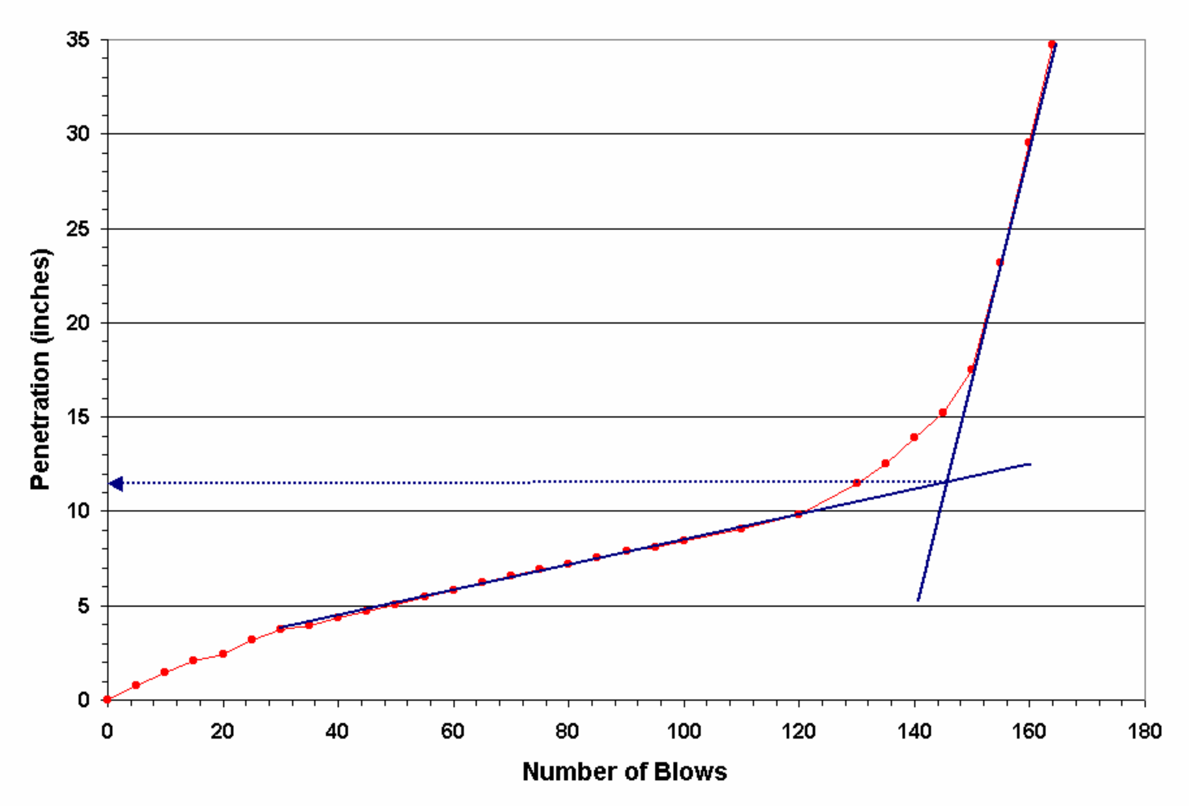

Figure 10. Establishing Pavement Layering using DCP Data.

Table 6. Classification of Pavement Materials Based on DCP Penetration Rate.

Material	DCP Penetration Rate (in/blow)
Weak base	≥ 0.12
Weak subgrade	≥ 0.55
Stabilized base	≤ 0.07
Stiff subgrade	≤ 0.33

this analysis, he/she can estimate the thickness and compute the penetration rate for each layer identified from the DCP data. The engineer can then use the penetration rates to classify a given pavement for a Level I analysis, and use the estimated thicknesses in the applicable charts (Figures A1 through A13) for predicting service life as illustrated in the hypothetical example shown in Table 7. For this example, DCP data were collected at six locations along a given route. At each location, a 1½-inch diameter core was drilled. DCP testing was subsequently conducted beginning at the top of the base.

Table 7. Illustration of Level I Analysis.

Test Location	Layer Thickness (inches)		DCP Penetration Rate (in/blow)		Pavement Group	Unit Service Life Consumption ($\times 10^{-7}$)		Predicted Life (years)[1]	
	Asphalt	Base	Base	Subgrade		Fatigue	Rutting[2]	Fatigue	Rutting
1	2.8	12.1	0.07	1.23	3	9.9	18.0	25.2	13.9
2	3.0	11.8	0.08	1.37	3	9.9	18.0	25.2	13.9
3	2.8	12.6	0.08	1.09	3	9.9	18.0	25.2	13.9
4	3.0	11.8	0.14	1.35	1	99.0	96.2	2.5	2.6
5	3.1	12.3	0.19	1.28	1	99.0	96.2	2.5	2.6
6	3.4	11.6	1.46	0.81	1	99.0	96.2	2.5	2.6

[1] 40,000 trucks expected per year (one-way)
[2] 20 percent of trucks expected to be permitted

Table 7 gives the surface thicknesses measured from the cores and the base thicknesses estimated from the DCP data. In addition, the penetration rates for the base and subgrade layers were determined and are given in the table. From the penetration rates, the pavements were classified into the groups shown in Table 7 for the Level I analysis.

The average surface and base thicknesses are 3 and 12 inches, respectively, from the data given in Table 7. To predict service life, the average layer thicknesses were used with the applicable chart to estimate the unit service life consumed per truck application for a given pavement and distress criterion. Table 7 shows the resulting estimates. Assuming that 40,000 trucks (one-way) are expected to use the route per year, the corresponding pavement life in years was estimated using Figure A13 with the predicted unit service life consumption from the previous step. If the engineer specifies a 10-year period before the next rehabilitation, the predictions in Table 7 show that the route will fail in less than 10 years. If this is the only route that is available, the results indicate that initial rehabilitation is necessary to upgrade the route so that it can sustain routine overweight truck traffic over a 10-year design period. Looking at the results in Table 7, one can see that the interval covered by the last three DCP locations is deficient in terms of its capacity to sustain routine overweight truck traffic. Thus, further tests are recommended to identify possible rehabilitation measures for upgrading that portion of the route. These tests can be part of the Level II evaluation.

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APPENDIX

LEVEL I PAVEMENT ANALYSIS CHARTS

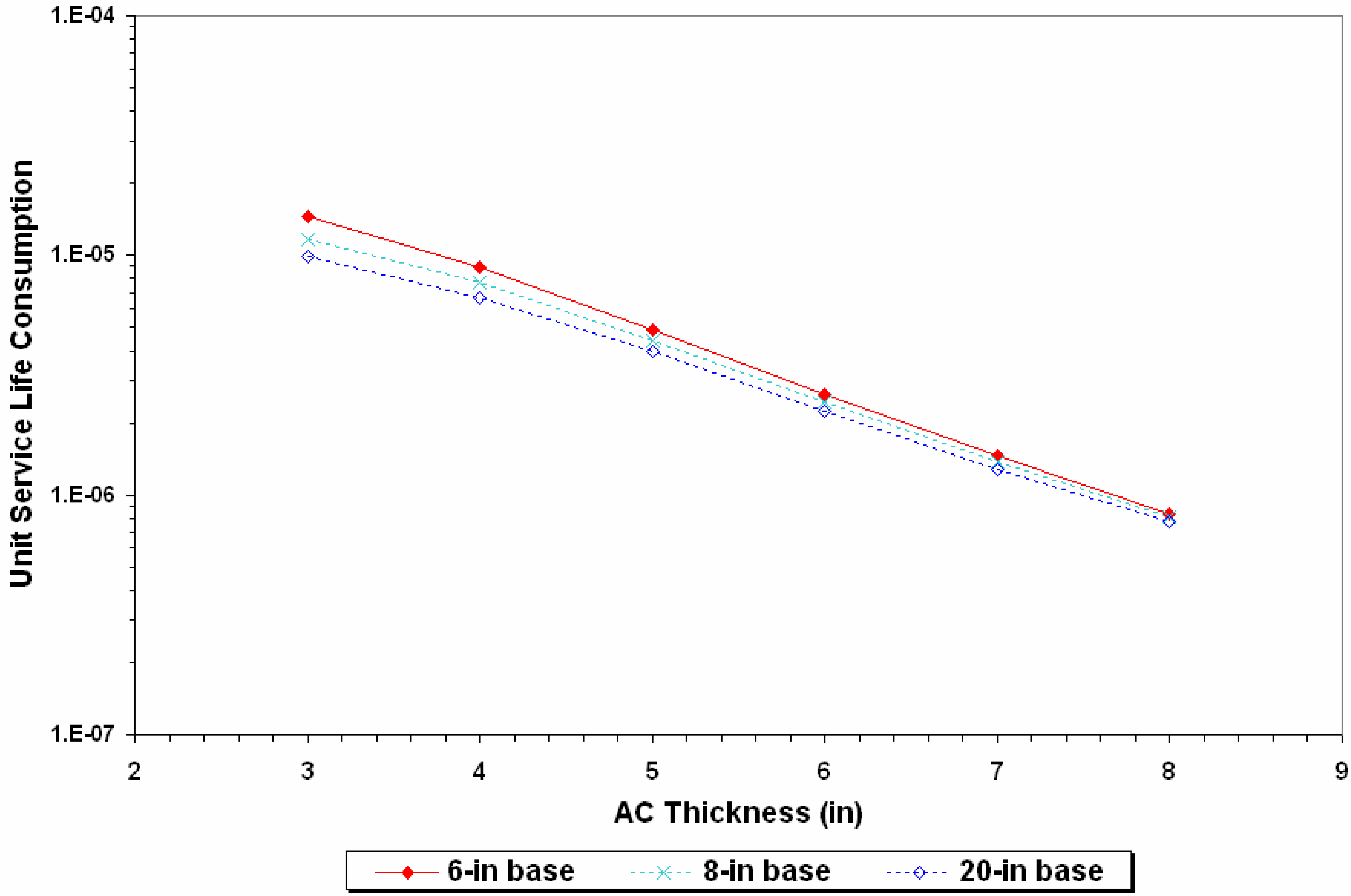

Figure A1. Chart for Predicting Unit Service Life Consumption Based on Fatigue Cracking (Group 1 Pavements).

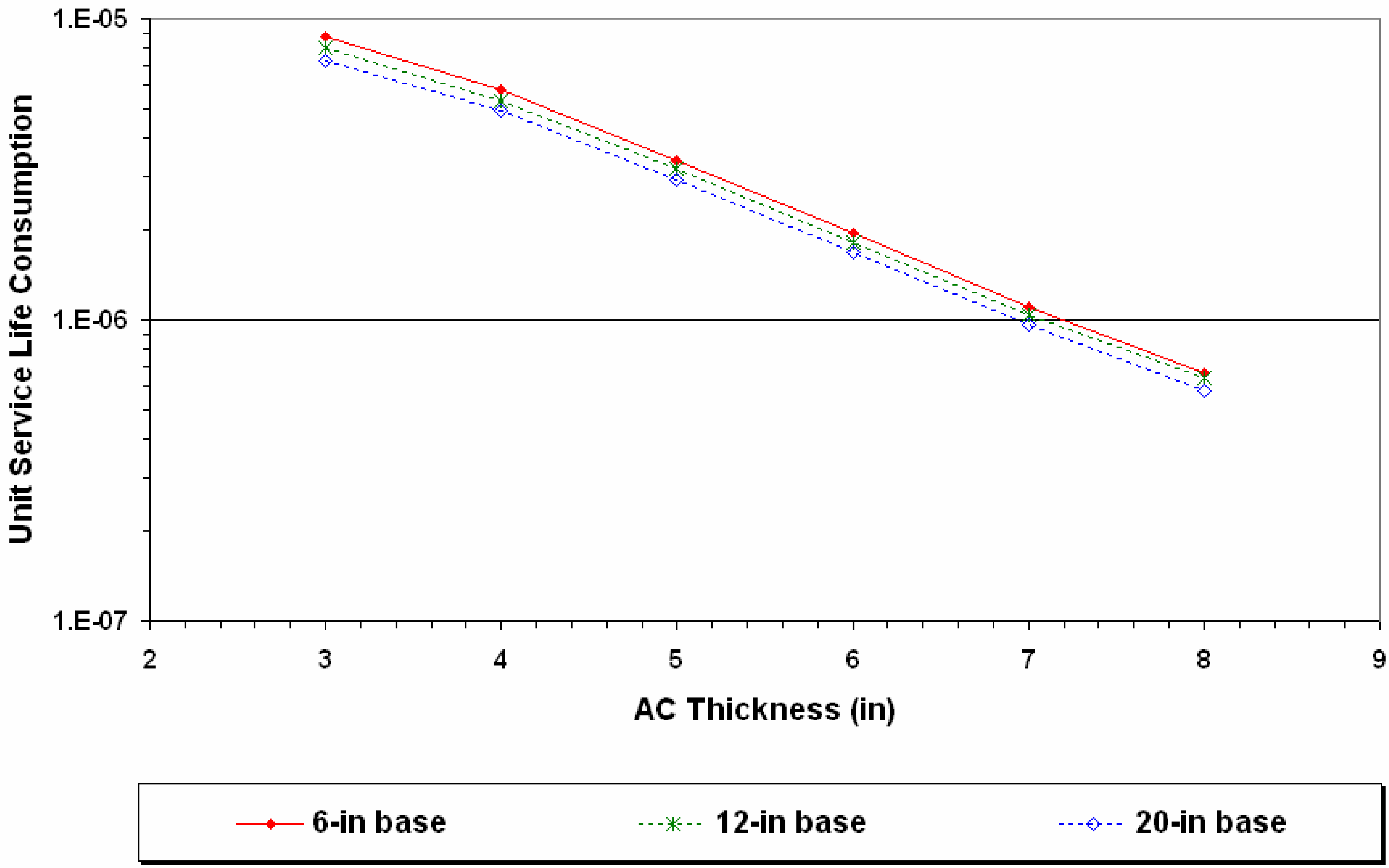

Figure A2. Chart for Predicting Unit Service Life Consumption Based on Fatigue Cracking (Group 2 Pavements).

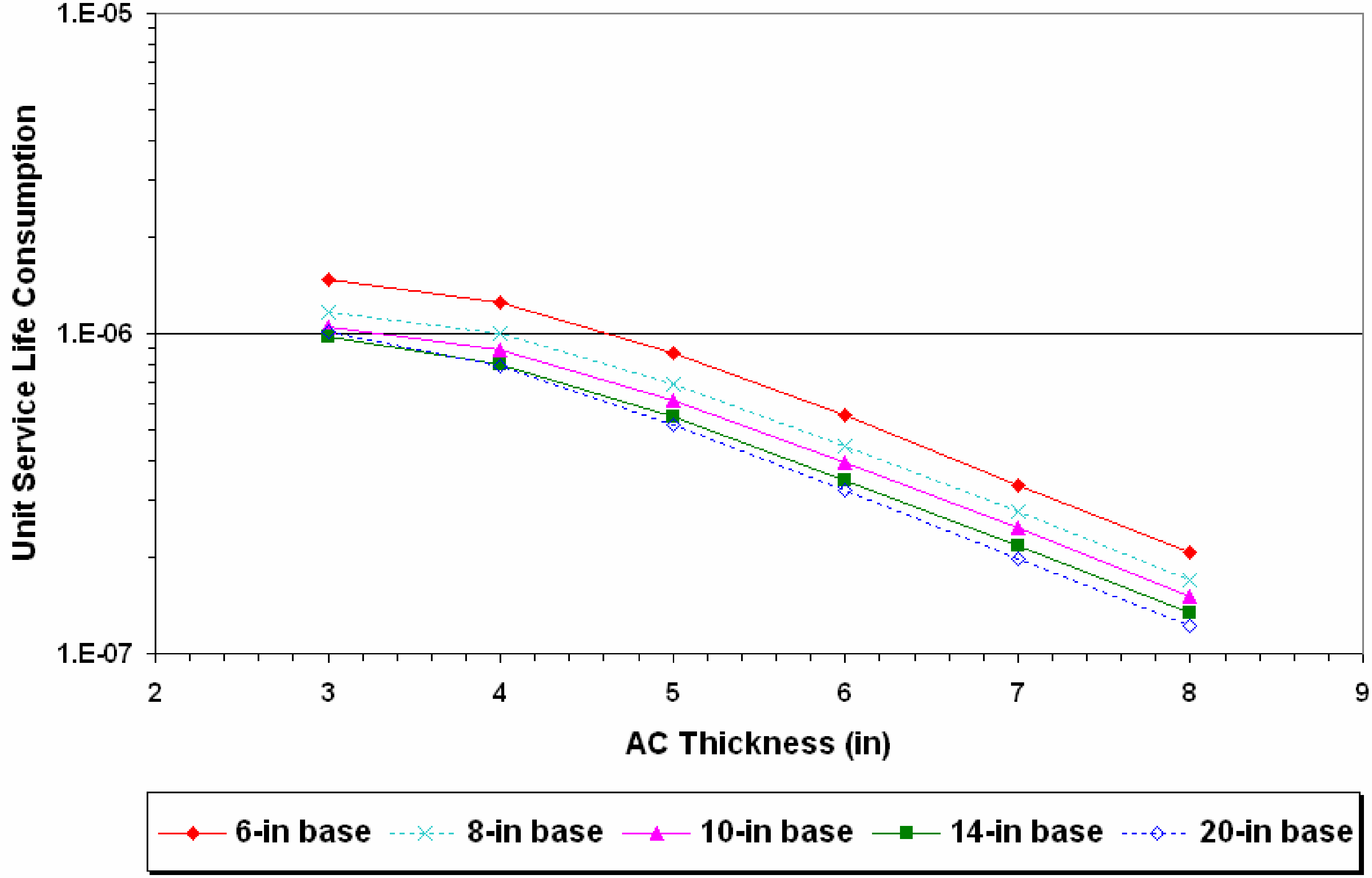

Figure A3. Chart for Predicting Unit Service Life Consumption Based on Fatigue Cracking (Group 3 Pavements).

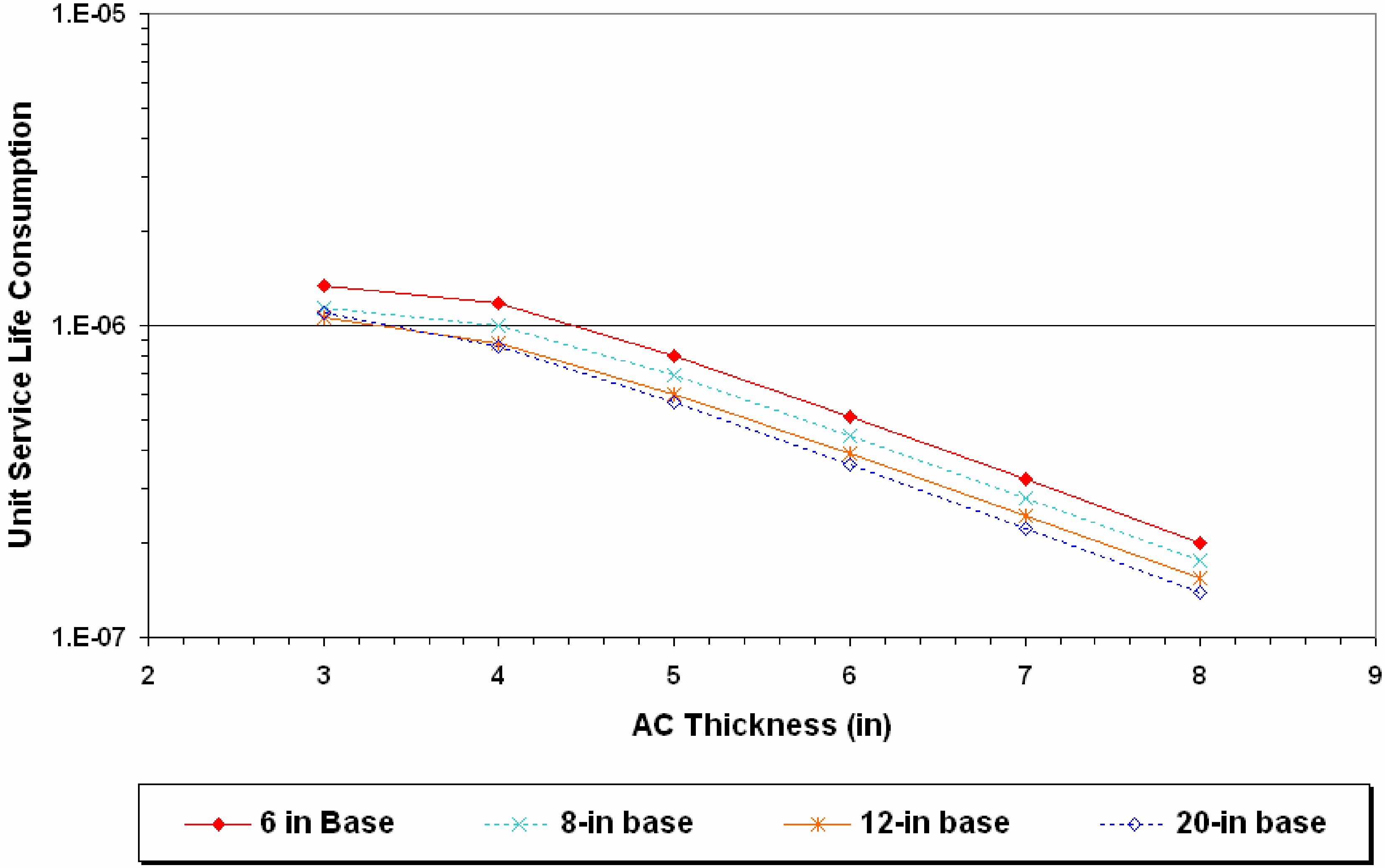

Figure A4. Chart for Predicting Unit Service Life Consumption Based on Fatigue Cracking (Group 4 Pavements).

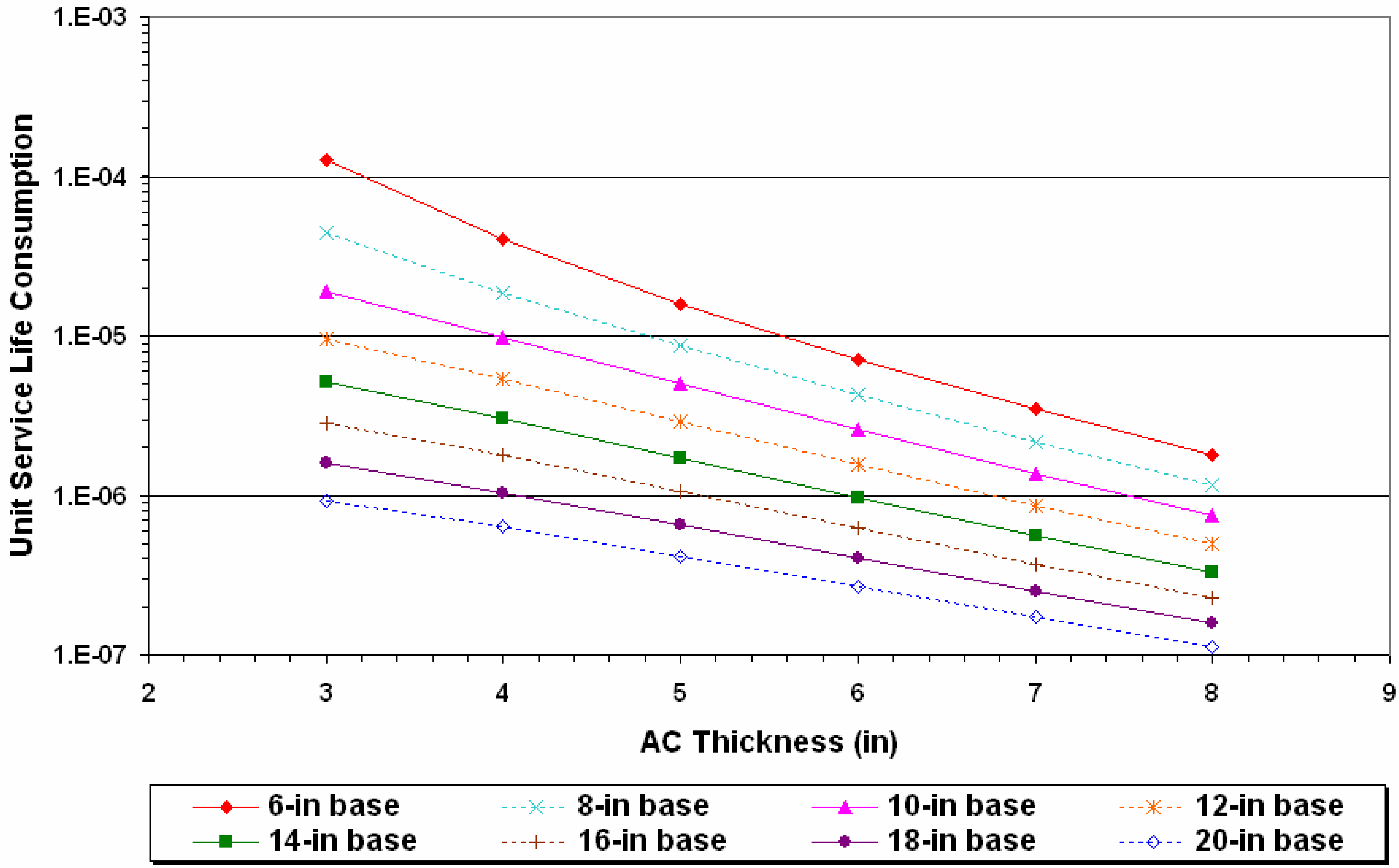

Figure A5. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks ≤ 20 (Group 1 Pavements).

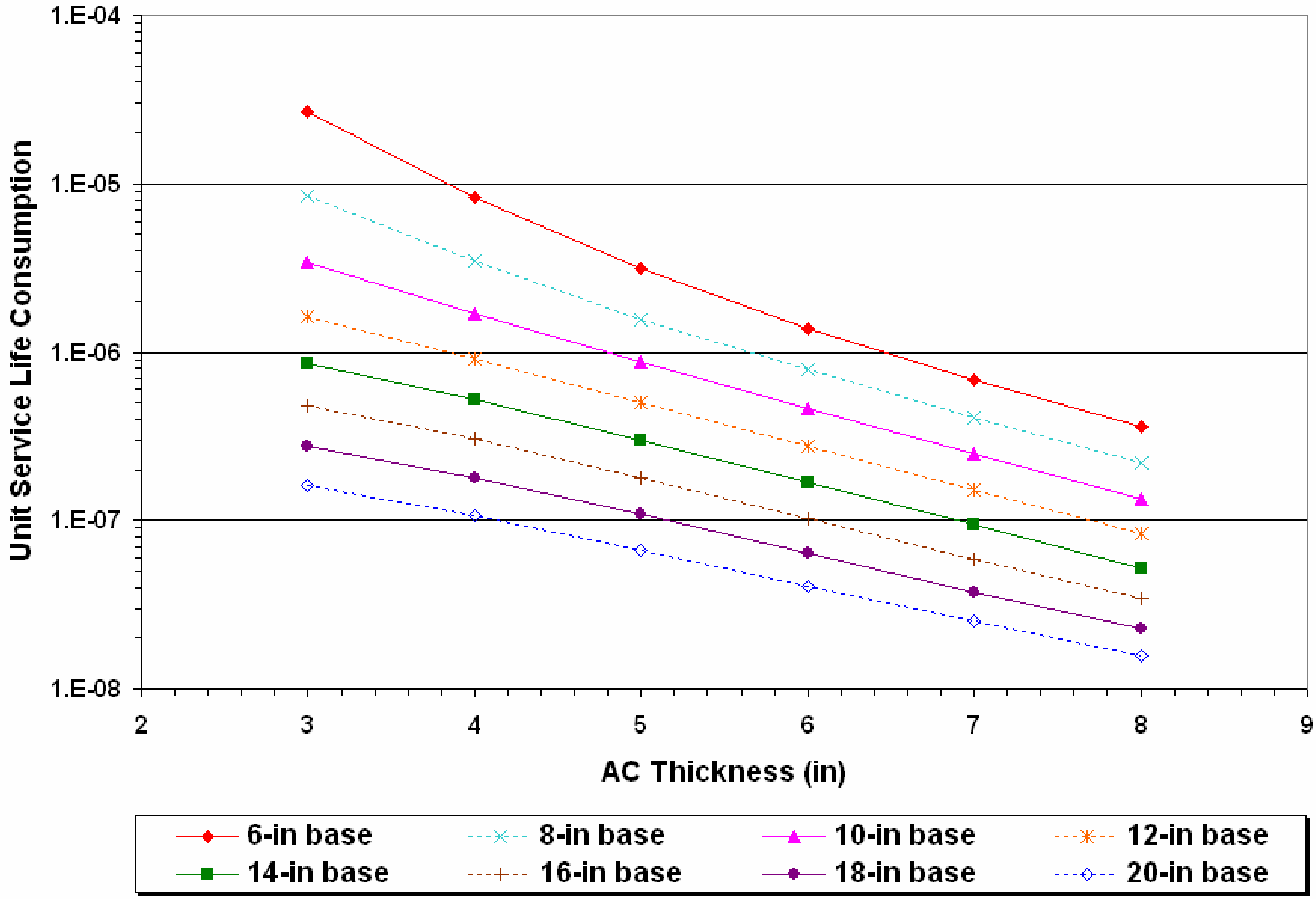

Figure A6. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks ≤ 20 (Group 2 Pavements).

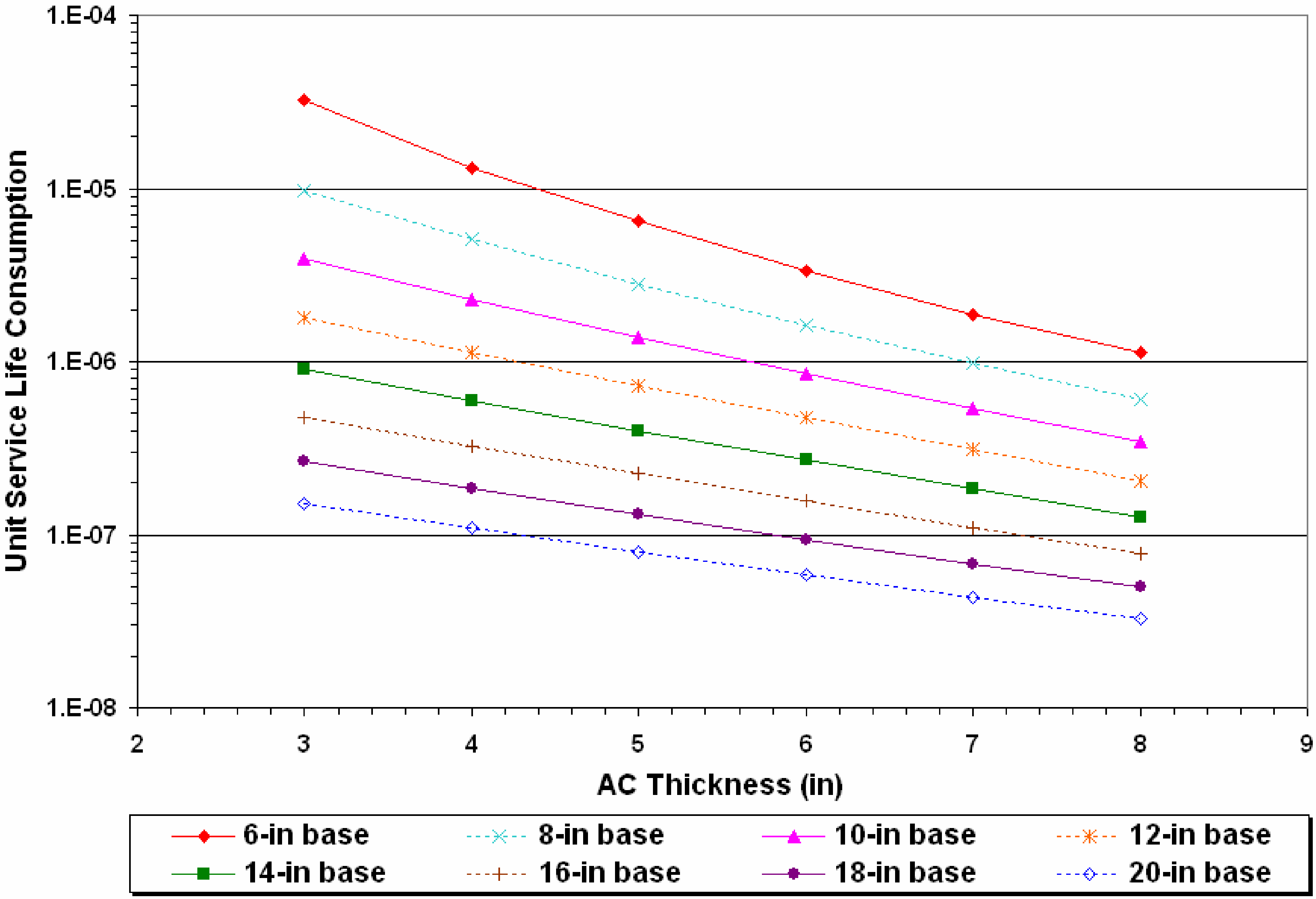

Figure A7. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks ≤ 20 (Group 3 Pavements).

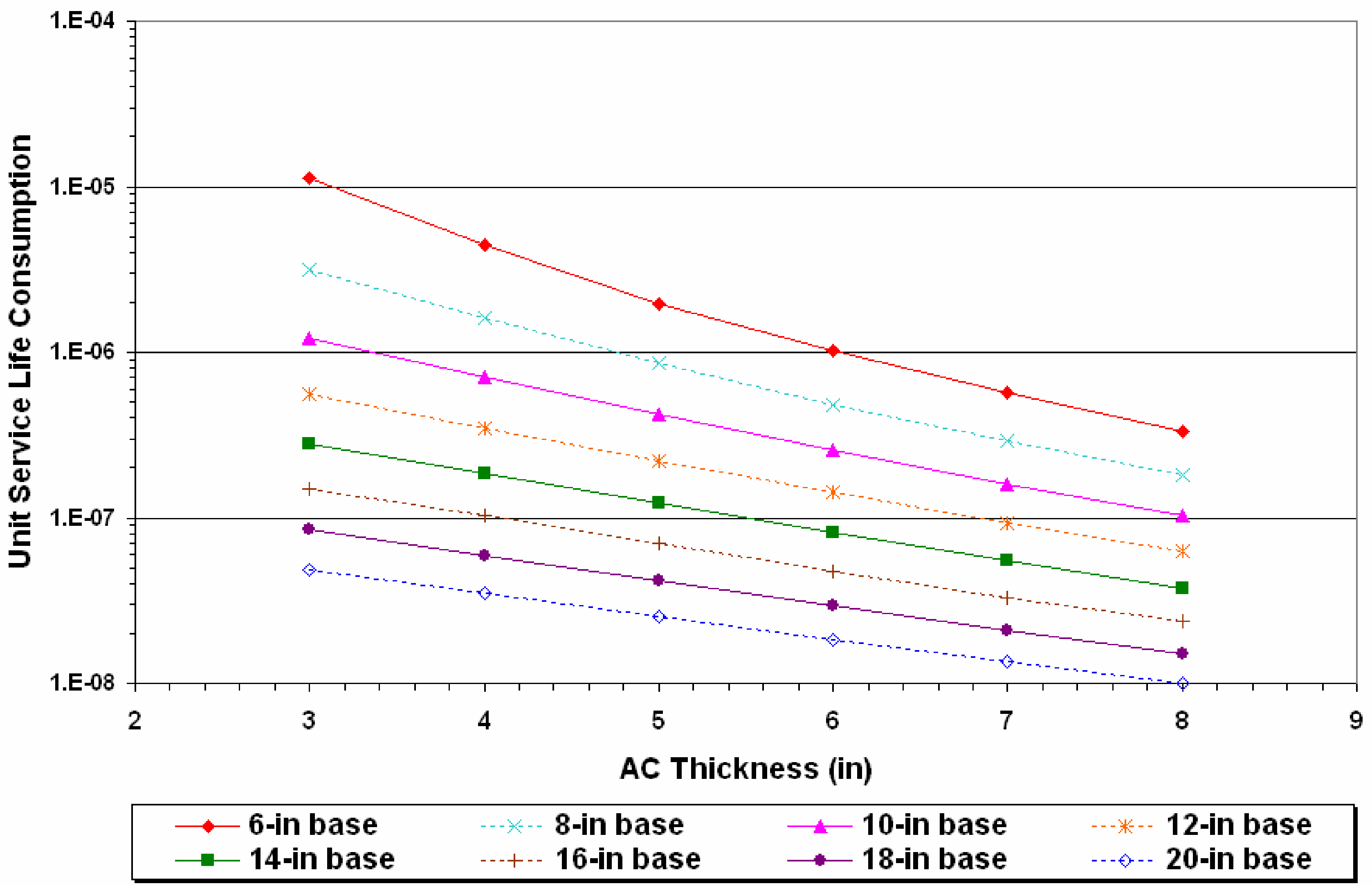

Figure A8. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks ≤ 20 (Group 4 Pavements).

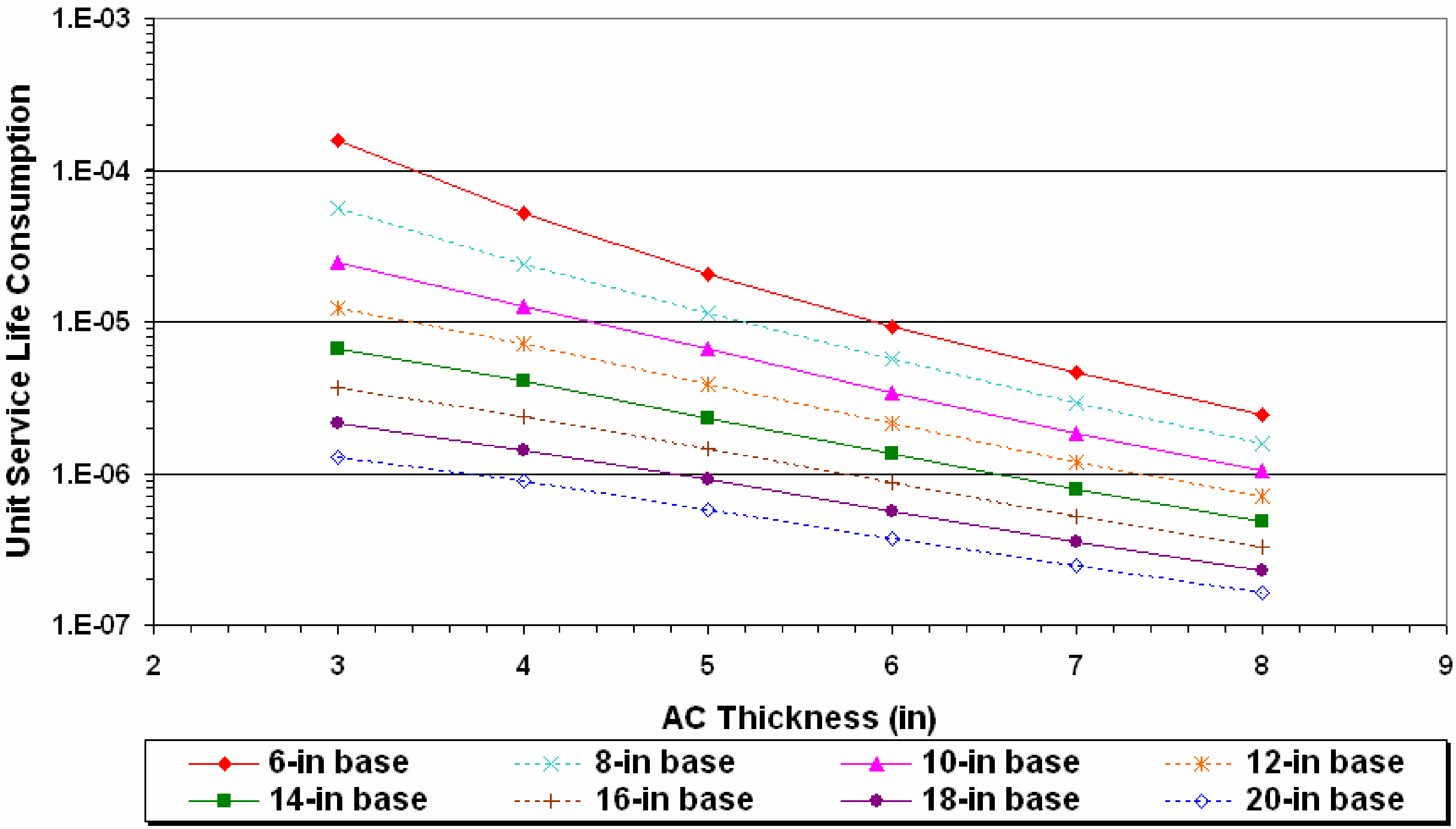

Figure A9. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks > 20 (Group 1 Pavements).

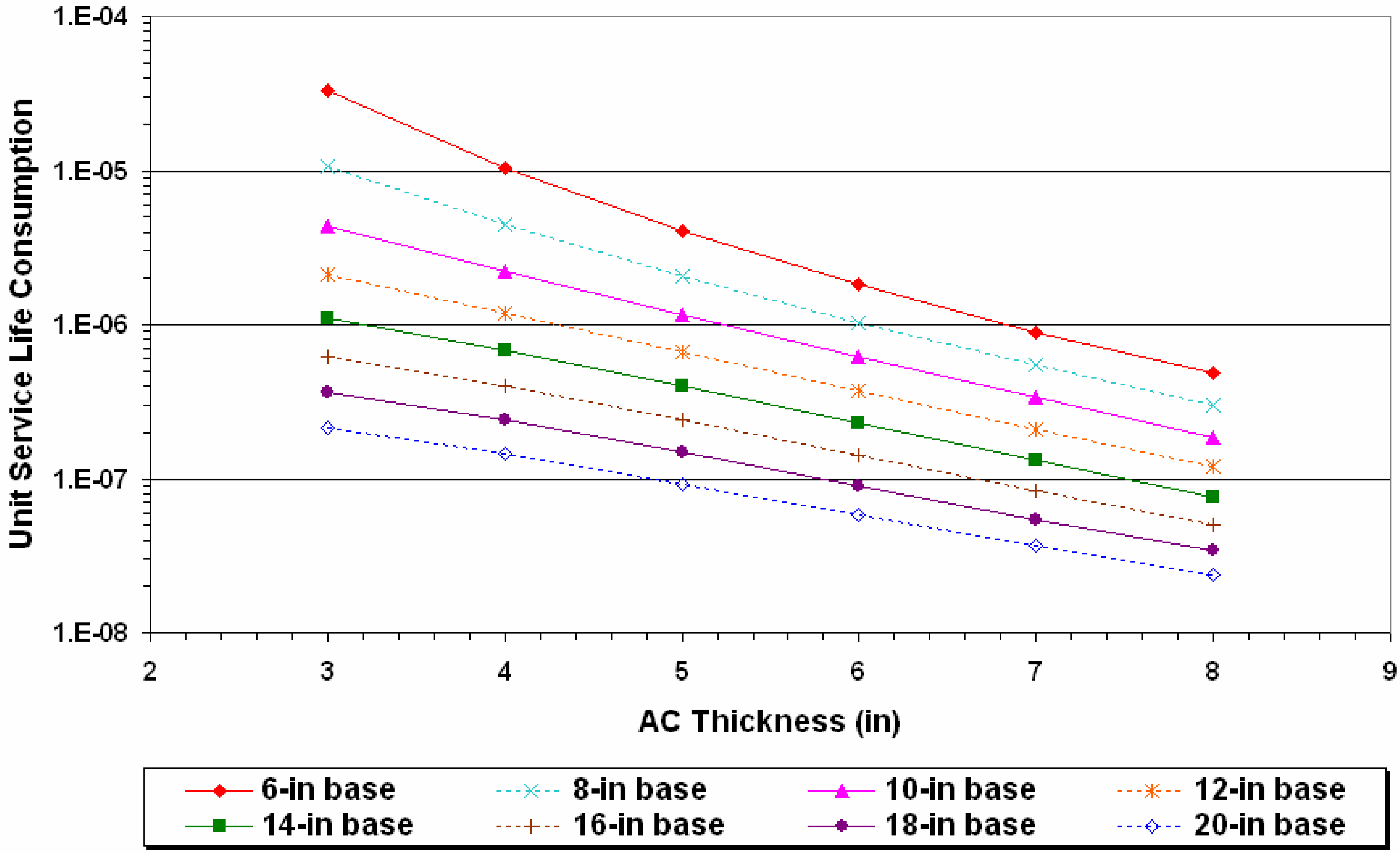

Figure A10. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks > 20 (Group 2 Pavements).

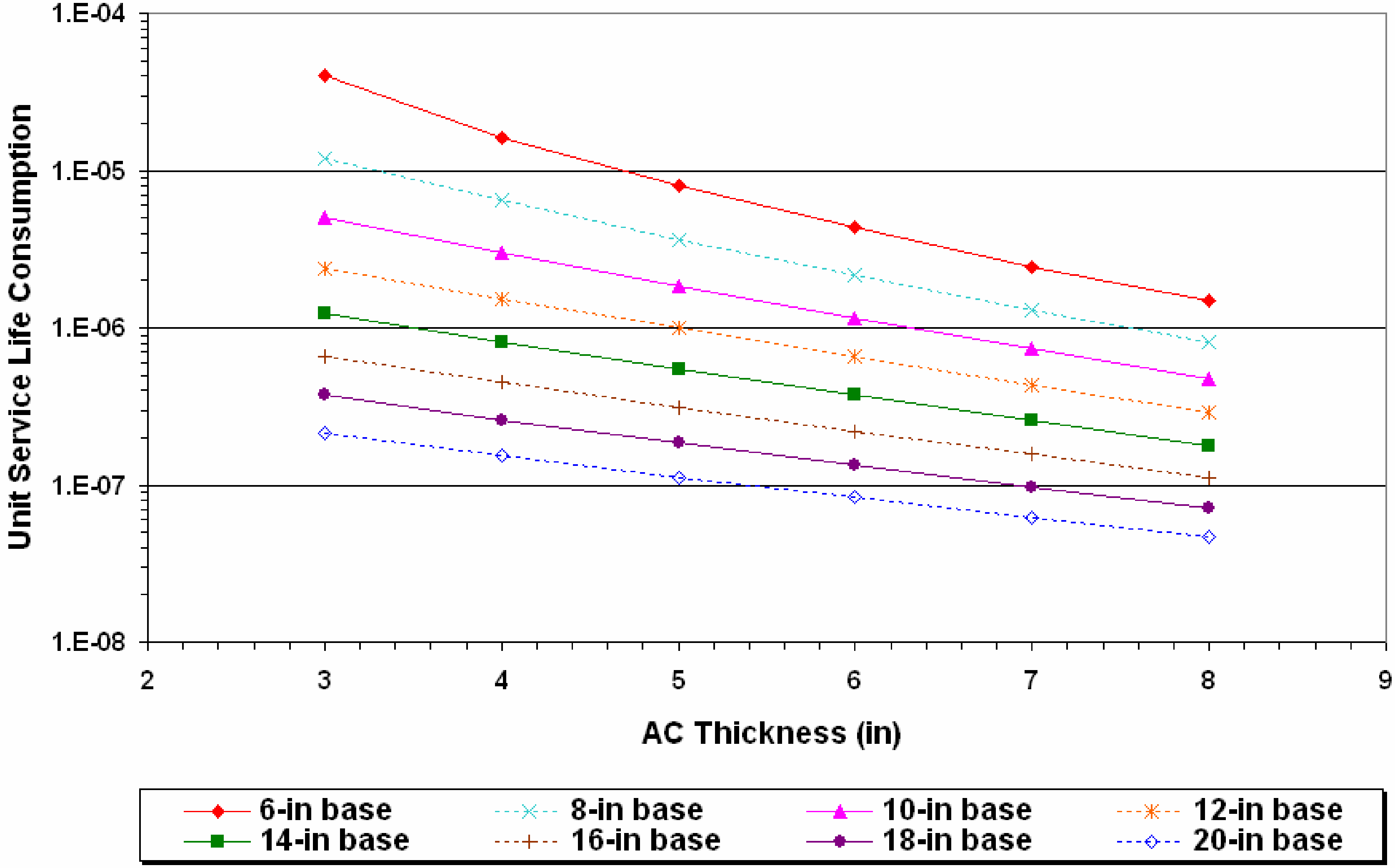

Figure A11. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks > 20 (Group 3 Pavements).

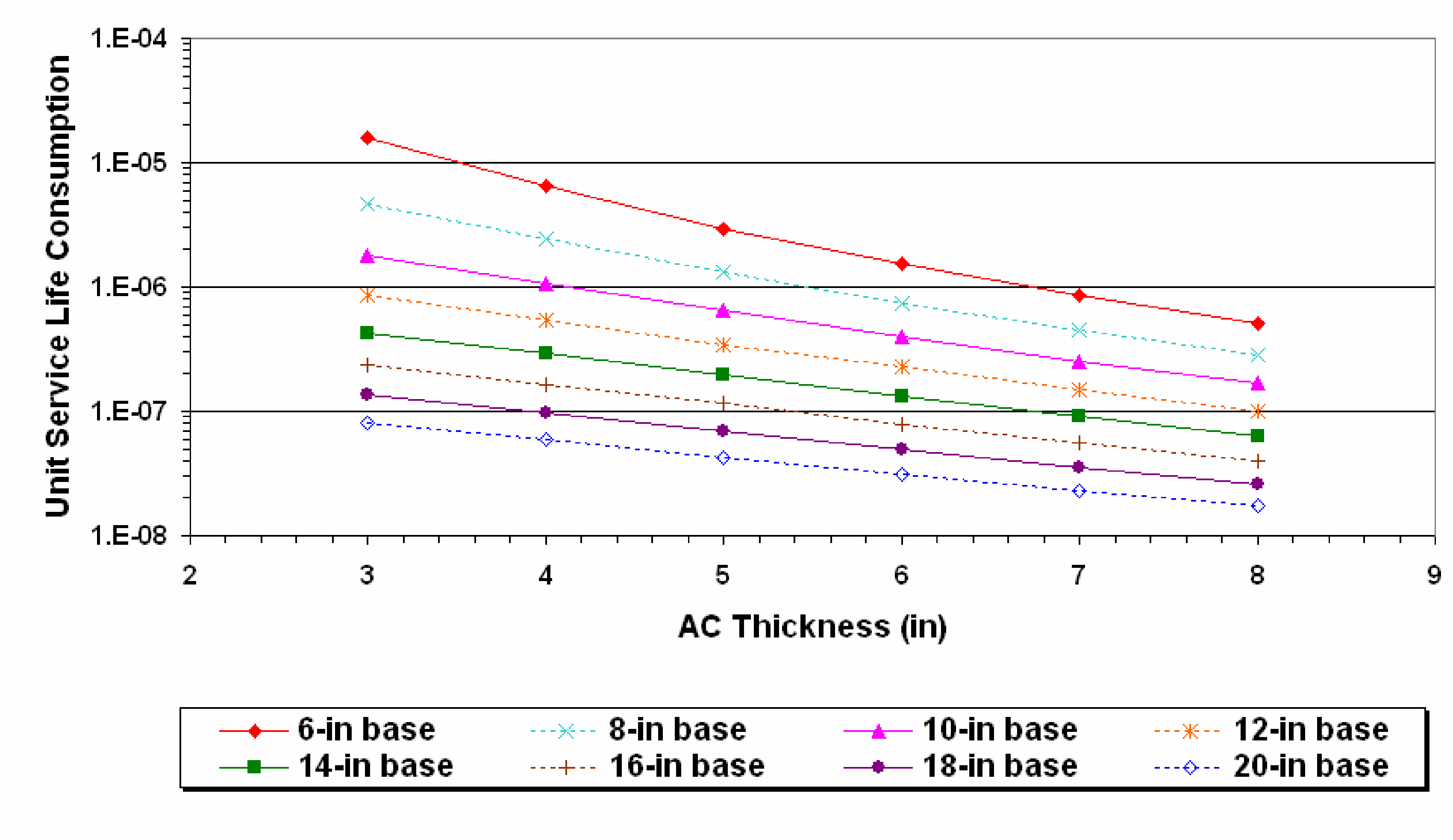

Figure A12. Chart for Predicting Unit Service Life Consumption Based on Rutting when Percent Overweight Trucks > 20 (Group 4 Pavements).

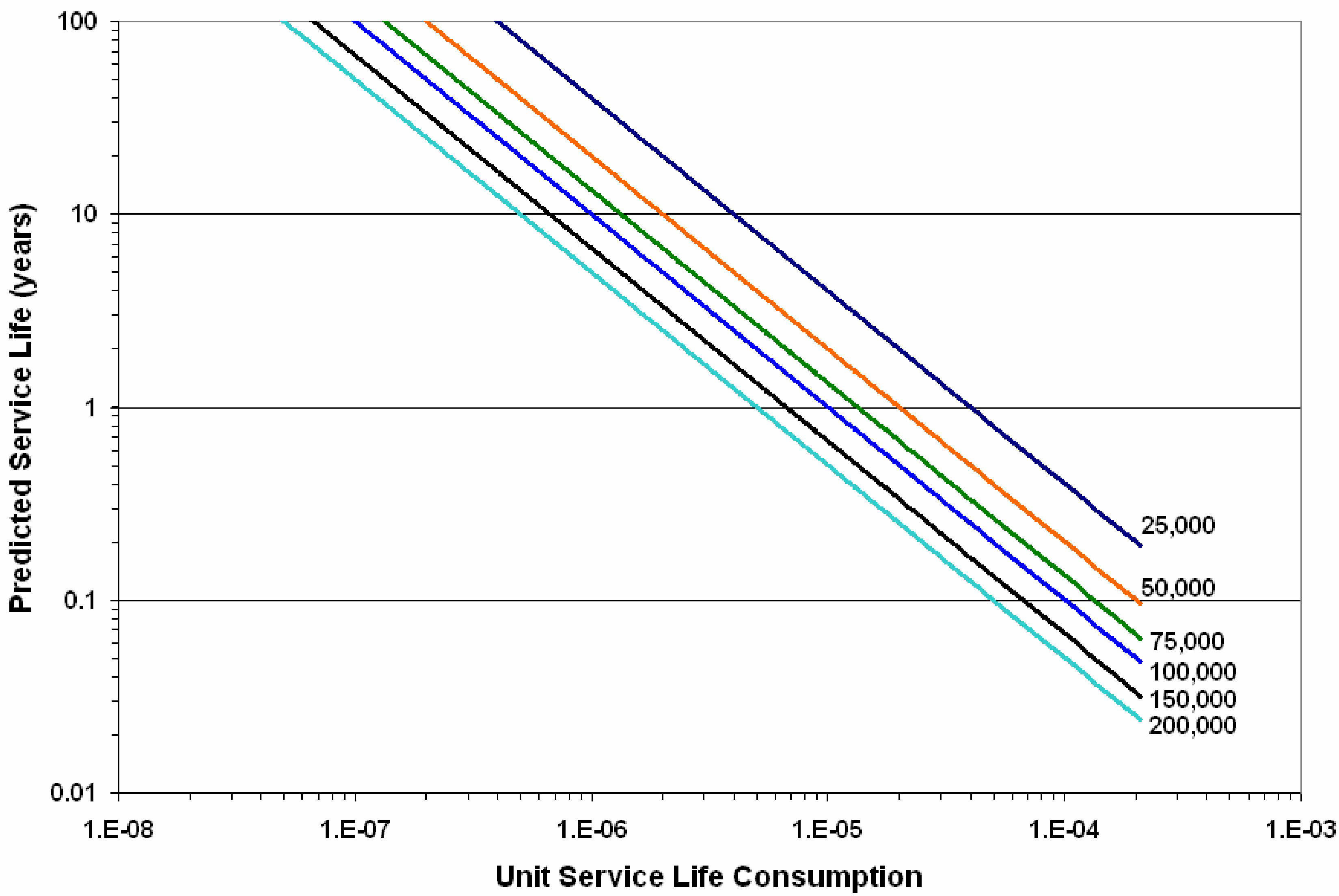

Figure A13. Chart for Predicting Pavement Life Given Unit Service Life Consumption and Expected Number of Trucks/Year.