Verification of Mechanistic-Empirical Pavement Deterioration Models Based on Field Evaluation of In-Service Pavements

Carlos Rafael Gramajo

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COMMITTEE MEMBERS:
Dr. Gerardo Flintsch, Chair
Dr. Imad Al-Qadi
Dr. Amara Loulizi

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(Abstract)

This thesis focused on using a detailed structural evaluation of seven (three flexible and four composite) high performance in-service pavements designated as high-priority routes to verify the applicability of the Mechanistic Empirical (M-E) models to high performance pavements in the Commonwealth of Virginia. The structural evaluation included: determination of layer thicknesses (from cores, GPR and historical data), pavement condition assessment based on visual survey, estimation of layer moduli from FWD analysis as well as material characterization. One of the main objectives of this study was to utilize the results from the backcalculated moduli in order to predict the performance of this group of pavement structures using the M-E Design Guide Software. This allowed a quick verification of the performance prediction models used by comparing their outcome with the current condition.

The in-depth structural evaluation of the three flexible and four composite pavements showed that all the sites are structurally sound. The investigation also confirmed that the use of GPR to determine layer thicknesses and the comparison with a minimum number of cores is a helpful tool for pavement structural evaluation. Despite some difficulties performing the backcalculation analysis for complex structures, the obtained results were considered reasonable and were useful in estimating the current structural adequacy of the evaluated structures.

The comparison of the measured distresses with those predicted by the M-E Design Guide software showed poor agreement. In general, the predicted distresses were higher than the distresses actually measured. However, there was not enough evidence to determine whether this is due to errors in the prediction models or software, or because of the use of defaults material properties, specially for the AC layers. It must be noted that although an in-depth field evaluation was performed, only Level 3 data was available for many of the input parameters. The results suggest that significant calibration and validation will be required before implementation of the M-E Design Guide.

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Acronyms

AADTT	Annual Average Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
AC	Asphalt Concrete
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
ATB	Asphalt Treated Base
CBR	California Bearing Ratio
CCI	Critical Condition Index
CRC	Continuously Reinforced Concrete
CRCP	Continuously Reinforced Concrete Pavement
CSL	Chemically Stabilized Layer
CTA	Cement Treated Aggregate
CV	Coefficient of Variation
D	Slab Thickness
D_{eff}	Effective Slab Thickness
DMI	Distance Measurement Instrumentation
ESG	Subgrade Modulus
FWD	Falling Weight Deflectometer
FWD	Falling Weight Deflectometer
GPR	Ground Penetrating Radar
GSSI	Geophysical Survey Systems, Inc
HMA	Hot Mix Asphalt
IRI	International Roughness Index
JCP	Jointed Concrete Pavement
JCP	Jointed Pavement Concrete
M-E	Mechanistic-Empirical
MR	Resilient Modulus
NCHRP	National Cooperative Highway Research Program
NDT	Non-Destructive Testing
PCC	Portland Cement Concrete

PG	Performance Grade
RMS	Root Mean Square
SN	Structural Number
SN_{eff}	Effective Structural Number
TAG	Total Analysis Group
USCS	Unified Soil Classification System
VDOT	Virginia Department Of Transportation

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Chapter 1 - INTRODUCTION

1.1. Background

This investigation focused on the use of structural evaluation results, specially Falling Weight Deflectometer (FWD) and backcalculation, for supporting pavement analysis and design. The Virginia Department of Transportation conducted a study for developing pavement designs for high-priority routes based on current and past field experience. The investigation aimed at identifying the necessary tools to effectively design pavement structures with a life span of 40 years or more. The first phase of this project included an in-depth field evaluation and analysis of high performance in-service pavements designated as high-priority routes. In addition to FWD testing, the field evaluation included Ground Penetrating Radar (GPR), and visual and video surveys of the pavement surface. Additionally, a limited number of cores were taken from each site and some of the core pits were used to perform subgrade boring. In total, eighteen pavement sections were evaluated. These sections included flexible, composite, and rigid (jointed and continuously reinforced) pavement structures. Seven of these sections were selected to be part of this thesis; these sections included three flexible pavements and four composite pavement structures.

Falling Weight Deflectometer (FWD) measurements were performed to determine the structural condition of each of the test sites evaluated and to determine in-situ modulus of the various layers. All tests were conducted using a Dynatest model 8002 FWD unit with nine sensing transducers located at 0, 203, 305, 457, 610, 914, 1219, 1524 and 1829 mm (0, 8, 12, 18, 24, 36, 48, 60 and 72 in) from the center of the loading plate. The backcalculated moduli were compared with moduli measured using laboratory tests for the pavement layers and estimated based on geotechnical studies for the subgrade.

The results obtained from the backcalculation process were used as an input for modeling pavement performance as presented in the "*Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*" (hereafter referred to as M-E Design Guide) recently developed under NCHRP 1-37A. The performance criteria of the M-E Design Guide includes load-related distress prediction models that cover Asphalt Concrete (AC) surface-down and bottom-up cracking, chemically stabilized layer fatigue fracture (for composite pavements), permanent deformation (rutting) in asphalt layers, and permanent deformation in unbound layers. The performance of the selected structures was predicted using the M-E Design Guide (version 0.701) software[1] and was compared to the distresses measured from the visual survey results to verify the applicability of the models to the studied pavements.

In addition, the results from the Non-Destructive Evaluation (NDT) were used to estimate effective (current) structural capacity of the pavements using the 1993 AASHTO Design Methodology (in terms of structural number (SN) and equivalent slab thickness (D) for flexible and composite pavements respectively). This allowed determining if the observed distresses were compatible with the pavement's effective structural capacity (SN and D) determined by this procedure.

1.2. Problem Statement

Nondestructive Testing (NDT) methods such as Falling Weight Deflectometer (FWD) complemented with other evaluation techniques are commonly used to determine the structural adequacy and condition of pavements. The results from a field evaluation, e.g. backcalculated moduli, can be used as input parameters to predict the performance of a pavement structure as a function of the accumulation of damage over time. The distress prediction models presented in the M-E Design Software can be used to estimate pavement's performance. However, the applicability of these models to Virginia's pavements has to be verified based on actual pavement performance data.

1.3. Research Objectives

This thesis focused on using a detailed structural evaluation of the pavement sections to verify the applicability of the M-E models to high performance pavements in the Commonwealth of Virginia. The structural evaluation included: determination of layer thicknesses (from cores, GPR and historical data), pavement condition assessment based on visual survey, estimation of layer moduli from FWD analysis, and material characterization. The main objective of this study was to utilize the results from the backcalculated moduli in order to predict the performance of a selected group of pavement structures using the M-E Design Software. This allowed a quick

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[1] Developed by ERES Division, Applied Research Associates and Arizona State University

verification of the performance prediction models used by comparing their outcome with the current condition determined from the visual survey.

1.4. Research Scope

This thesis is organized as follows. Chapter 2 contains a literature review regarding pavement evaluation and mechanistic-empirical analysis of flexible pavements. Chapter 3 describes the data collection and data analysis process. Chapter 4 discusses the results obtained from the analyses performed. Chapter 5 includes the findings and conclusions, and Chapter 6 provides recommendations for future research.

Chapter 2 - LITERATURE REVIEW

2.1. Introduction

The *Report Card for America's Infrastructure* [2], recently published by the ASCE, showed that more than sixty percent of the roads in the United States are in poor to mediocre condition, which translates into unnecessary expenses to the drivers for maintenance, car repairs, traffic congestions, accidents, etc. Therefore, there is a demand to improve highway conditions, capacity, and safety, not only by building new roads, but also by maintaining the existing ones in the best possible condition. Thus, it is important to *evaluate* the existing roadways to determine their structural and functional capacity, as well as to understand the failure mechanisms, enhance performance models, and take necessary actions to achieve the desired reliability.

2.2. Pavement Evaluation

The evaluation of pavements can be divided into two main groups: (1) Structural adequacy (load related distresses) and (2) Functional adequacy (safety and rideability). Both types of evaluations are used for pavement management. Since the condition of pavements deteriorates over time, it is necessary to perform periodic evaluations to develop distress history. This investigation focuses on the pavement structural evaluation using Falling Weight Deflectometer (FWD).

Frequently, structural evaluation of pavements involves three sources of information: historical data, destructive testing, and nondestructive testing (NDT). Nondestructive Testing (NDT) methods are commonly supplemented with destructive testing techniques because experience has shown that NDT techniques alone may not always provide a reasonable or accurate characterization of the *in situ* material properties, particularly for the top pavement layers [10]. The most common pavement structural evaluation procedures will be discussed in the following section.

2.2.1. Structural Evaluation

The structural evaluation relates to the assessment of those properties and features that define the response of the pavement to traffic loads. Results from the field evaluation should help assessing the overall condition of the existing pavement and identifying pavement problems. This is usually the first step in the process of pavement rehabilitation strategy selection.

2.2.2. Load Related Distresses

The performance criteria of the M-E Design Guide includes the following load-related distress: AC surface-down cracking (longitudinal cracking), AC bottom-up cracking (alligator cracking), chemically stabilized layer fatigue fracture (only for composite pavements), permanent deformation (rutting) in asphalt layers, and permanent deformation in unbound layers.

Fatigue Cracking

Fatigue cracking initiates as short longitudinal cracks that quickly spread in the wheelpath and become interconnected following a pattern that resembles chicken wire or alligator skin. This type of failure results from the repetitive bending of the HMA (Hot Mix Asphalt) layer while subjected to traffic loads.

The bending action of the pavement layer results in flexural stresses that develop at the bottom of the bound layer, this is why for more that 30 years it has been assumed that fatigue cracking initiates at the bottom of the asphalt layer and propagates to the surface (bottom-up cracking). Nevertheless, recent investigations have demonstrated that fatigue cracking may as well initiate from the top and propagate down (top-down cracking) probably due to critical tensile and/or shear stresses developed at the surface and caused by large contact pressures at the tire edges-pavement interface [10], in combination with aged (oxidized or stiff) surface layers.

Fatigue Fracture in Chemically Stabilized Layers

Fatigue fracture in the underlying chemically stabilized base layers is a distress that needs to be considered in composite pavements. Chemically stabilized layers are defined as high quality base materials treated with materials such as lime, cement or flyash; the stiffness of these layers can be reduced (and even lead to fatigue fracture) because of the development of microcracks induced by repeated applications of traffic loading. This type of failure has a significant impact on the distress progression in the overlying HMA layers.

The behavior of chemically stabilized layers is very complex to characterize, in part because fatigue cracking in the material layer is not directly observed in the surface. In some situations, the fatigue cracking in the chemically stabilized layer will result in a fraction of the cracking reflected in the HMA surface layer, a situation that might be minimized or eliminated when placing crack relief layer (e.g. unbound granular base/subbase layer). In addition, when the level of fatigue damage in the chemically stabilized base layer increases, the modulus of such layer may be degraded, causing an increase in the tensile strain of the HMA layer that will accelerate bottom-up cracking in the HMA layer itself.

Permanent Deformation (Rutting)

Rutting is defined as a surface depression in the wheelpaths caused by plastic deformations in any or all of the pavement layers and/or subgrade. Rutting is categorized into two types (1) HMA rutting and (2) Base/Subbase/Subgrade rutting.

- HMA Rutting: Premature type of rutting caused by lateral flow or plastic movement (downward and upward) of materials in mixtures with inadequate shear strength and/or large shear stress states due to traffic. It is characterized by depressions near the center of the wheelpath with shear upheavals on either side of the depression (Figure 1). Overdensification of HMA layers by heavy wheel loads may also result in bleeding or flushing in pavement surface, which is difficult to predict and measure in the laboratory.

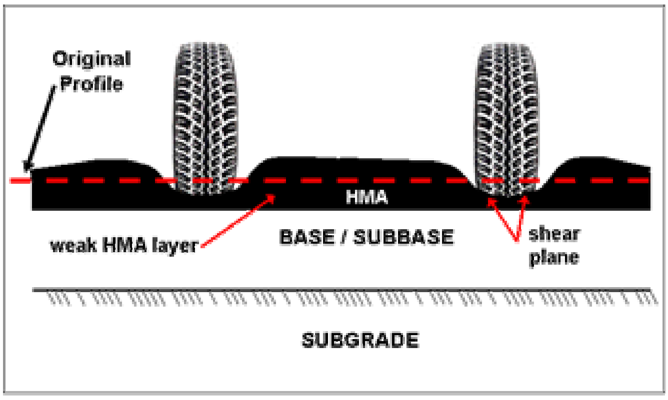


Figure 1. HMA Rutting

- Base/Subbase/Subgrade Rutting: Vertical compression caused by material densification due to excessive air voids or inadequate compaction of any of the bound or unbound pavement layers when subjected to traffic loads. It manifests as depressions near the center of the wheelpath without a hump on either side of the depression (Figure 2). The severity of the depressions caused by secondary rutting varies from low to moderate.

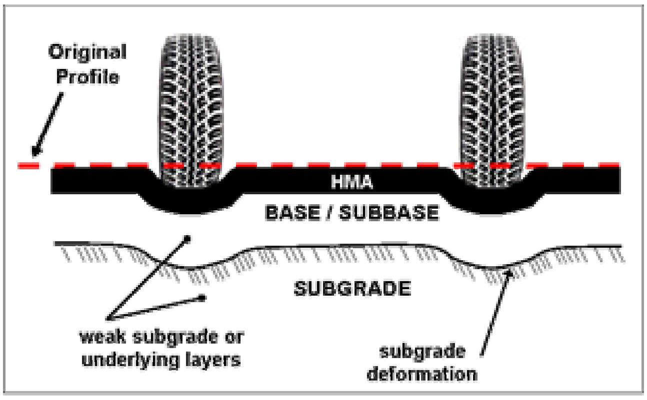


Figure 2. Base/Subbase/Subgrade Rutting

Permanent deformation is the cumulative sum of ruts occurring in all layers of the pavement system. No permanent deformation is assumed to occur for chemically stabilized materials, PCC (Portland Cement Concrete) fractured slab materials and bedrock; they are assumed to have no contribution to the total permanent deformation of the pavement system.

2.3. Destructive Structural Evaluation

Destructive testing techniques involve evaluating a specimen (pavement structure in this case) by changing its original shape or properties. The most common destructive evaluation technique in pavements is physical removal of pavement layer material by coring. Samples are usually 10 or 15 centimeters in diameter (Figure 3) and are used to identify layers of different materials and their thicknesses, and to examine general material condition. The observation of samples can supplement the information obtained from visual distress surveys and helps identifying the potential causes of structural problems (e.g. lack of bonding between layers, stripping of AC layers, and presence of defects such as cracks or voids). Laboratory tests are commonly used to characterize materials, i.e., determine material mechanical properties such as strength and modulus of different layers. Destructive testing has the advantage of allowing the observation of subsurface conditions of pavement layers and bonding within them, which usually cannot be obtained with other methods.

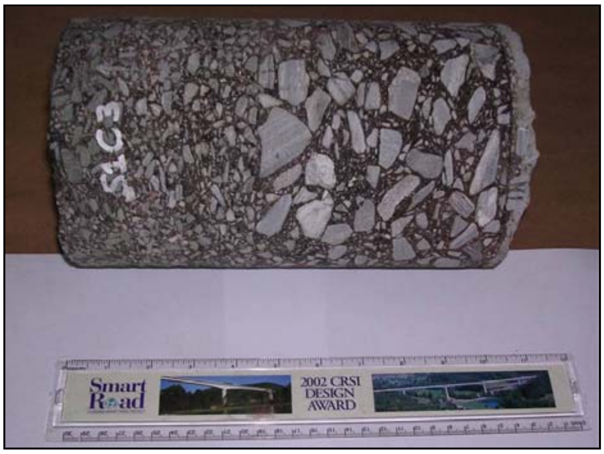


Figure 3. Core Sample

Coring and boring require a considerable amount of samples and tests to characterize the different materials that compose the pavement's structure. Thus, some limitations of this type of procedure include its intrusive nature and the disruption of trafficked areas (Figure 4), the amount of time and labor required, and its cost. However, it is generally essential to perform a destructive test program to complement NDT techniques.

Figure 4. Coring Machine and Core Extraction

2.4. Nondestructive Structural Evaluation

Nondestructive testing (NDT) involves the assessment of pavement structure and material properties by utilizing methods that will not change the structure's properties or induce damage into it. There are several available NDT techniques for use in pavement structural evaluation;

some of the most common types include visual surveys, Ground Penetrating Radar (GPR), and deflection testing (FWD). These types of technologies offer advantages like the reduction of costs, reduction of occurrence of accidents due to lane closures, faster data collection, and greater area coverage. NDT results can provide a reliable evaluation of *in situ* structural adequacy, which is needed for the selection and design of rehabilitation treatments.

The selection of NDT technologies for pavement evaluation depends on the existing budget, speed, productivity, and required quality of collected data. The NDT technologies utilized in this investigation are the following:

(1) Visual survey: Observation, measurement and mapping of pavement distresses.
(2) Ground Penetrating Radar (GPR): Determination of layer thickness and irregularities.
(3) Falling Weight Deflectometer (FWD): Determination of *in situ* pavement structural properties.

2.4.1. Visual Survey

Visual survey can vary from a windshield survey carried out from a moving vehicle to a detailed survey performed by walking the project to measure and map out the identified distresses on the pavement (including surface, shoulders, and drainage systems). The survey technique adopted for this research is based on a video of the surface taken by a high-speed, downward looking digital video camera.

The raw data collected during the survey must be processed for the pavement evaluation and analysis. Several methods are available to measure and quantify distresses and they vary from agency to agency. It is important that the quantification of the distresses (e.g. area of alligator cracking and length of longitudinal cracking at each severity level) is compatible with the distress rating tables to be used.

The identification of significant load-related surface distresses in the visual condition survey could be an indication that the pavement is approaching or has already reached the end of its service life. Examples of load related distresses for flexible pavements include fatigue cracking and rutting. The structural adequacy can be determined by comparing the severity and extent of load related distresses to specific thresholds, which depend on highway classification. An example of recommended thresholds is included in the M-E Design Guide and it is shown in Table 1.

Table 1. Distress Types and Levels for Assessing Flexible Pavement Structural Adequacy [1]

Distress Type	Highway Classification	Distress Level Regarded as:		
		Inadequate	**Marginal**	**Adequate**
Fatigue Cracking, percent of wheel path area	Interstate-Freeway	>20	5 to 20	<5
	Primary	>45	10 to 45	<10
	Secondary	>45	10 to 45	<10
Longitudinal Cracking in Wheel Path, m/km (ft/mi)	Interstate-Freeway	>201 (>1060)	50 to 201 (265 to 1060)	<50 (<265)
	Primary	>502 (>2650)	100 to 502 (530 to 2650)	<100 (<530)
	Secondary	>502 (>2650)	100 to 502 (530 to 2650)	<100 (<530)
*Reflection Cracking, crack width, cm (in)	Interstate-Freeway	>1.27 (>0.5)	0.64 to 1.27 (0.25 to 0.5)	<0.64 (<0.5)
	Primary	>1.91 (>0.75)	1.27 to 1.91 (0.5 to 0.75)	<1.27 (<0.5)
	Secondary	>1.91 (>0.75)	1.27 to 1.91 (0.5 to 0.75)	<1.27 (<0.5)
Transverse Cracking, spacing, m (ft)	Interstate-Freeway	<30 (<100)	61 to 30 (100 to 200)	>61 (>200)
	Primary	<18 (<60)	37 to 18 (60 to 120)	>37 (>120)
	Secondary	<18 (<60)	37 to 18 (60 to 120)	>37 (>120)
Rutting, mean depth of both wheel paths, cm (in)	Interstate-Freeway	>1.0 (>0.4)	0.6 to 1.0 (0.25 to 0.4)	<0.6 (<0.25)
	Primary	>1.5 (>0.6)	0.9 to 1.5 (0.35 to 0.6)	<0.9 (<0.35)
	Secondary	>2.0 (>0.8)	1.0 to 2.0 (0.4 to 0.8)	<1.0 (<0.4)
Shoving, percent of wheel path area	Interstate-Freeway	>10	1 to 10	none
	Primary	>20	10 to 20	<10
	Secondary	>45	20 to 45	<20

* Composite AC/PCC pavements

An *inadequate level* indicates that the pavement considered has failed structurally. The rate of deterioration is such that the maintenance treatments become costly, lane closures excessive, and remedial action are needed at larger scale. A *marginal level* suggests that the pavement should be considered for rehabilitation soon. In general, this allows enough time for the agency to plan, design, and implement rehabilitation activity before pavement reaches a structurally inadequate condition. An *adequate level* indicates that there is no need of any rehabilitation action, although some routine maintenance might be needed.

2.4.2. Ground Penetrating Radar (GPR)

The determination of the thicknesses of the layers that compose the pavement structure can be performed using a Ground Penetrating Radar (GPR). Layer thicknesses are determined by sending pulses of electromagnetic energy with a radar system and detecting the electrical echo produced when the pulse encounters electromagnetic discontinuities (e.g., sudden variations in material properties, existing pipes, and voids). Figure 5 illustrates a pavement structure subjected to GPR testing. An image of the profile of the layers inside the pavement system can be generated by the reflected waves that are received by the radar moving across the surface of the pavement. The result is a profile of the elapsed time between the penetration of the electromagnetic pulse into the pavement system and the back bounce to the GPR receiver. The longer period of time it takes to obtain the returning signal, the further the signal would have traveled. The true depth of layers is determined by converting this time profile into thicknesses.

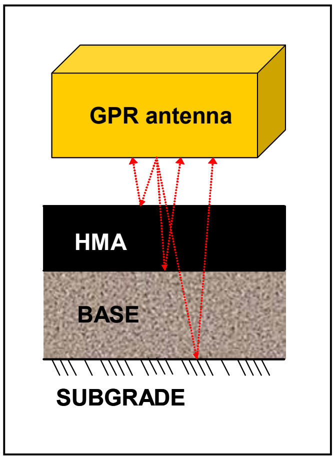


Figure 5. Pavement Structure Subjected to GPR Testing

Interpreting GPR data and profiles is not a simple task because interpretations are usually ambiguous. Few are the measurements that have such quality data that can be literally interpreted. Sometimes the analysis works better by interpolating between known values, e.g., thickness measurements between cores at different locations or extrapolations from known pavement profiles. One of the limitations in differentiating pavement layers is when the materials have similar dielectric properties, creating a difficult scenario for a type of radar that depends on the electromagnetic contrast to distinguish between material, occasionally making these interfaces invisibles.

2.4.3. Deflection Testing – Falling Weight Deflectometer (FWD)

The magnitude and shape of the pavement's surface deflection when subjected to loading reflects its structural condition and can also be used to determine the load transfer efficiency for rigid pavements. Deflection testing is a common type of pavement NDT method used to quantify the variability of pavement strength within a project, evaluate the structural adequacy of the pavement, determine the *in situ* modulus of each of the pavement layers, and determine remaining service life by characterizing the pavement response to loading for flexible (asphalt) pavements [12]. For rigid pavements, FWD tests are used to determine the concrete elastic modulus and subgrade modulus of reaction (at the slab center), void detection, and load transfer efficiency of cracks and joints. The layer properties are calculated by using static load analytical procedures and empirical performance relationships applied to the dynamic deflection data [13].

Different types of deflection testing equipment are commercially available. However, Falling Weight Deflectometer (FWD) (Figure 6) is the most frequently used device to evaluate pavements because it is the one that better simulates the load from a moving tire in both magnitude and duration [8]. These devices measure the pavement surface deflection caused by a dropping load using velocity transducers (seismometers, geophones).

Figure 6. FWD – Dynatest Model 8002

Falling weight deflectometers deliver a transient force impulse to the pavement surface. A brief description of the operation sequence is as follows:

- A weight is hydraulically lifted to a given height on a guide system and is then dropped to simulate the deformations produced by a moving tire (Figure 7).

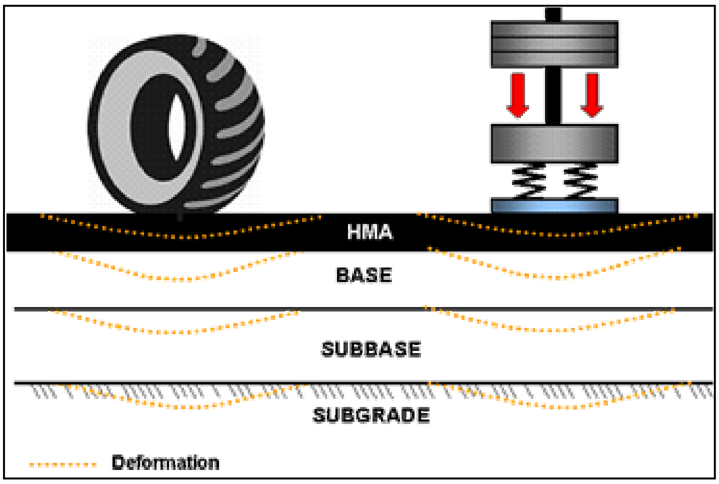


Figure 7. Deformations of Pavement Subjected to Loading

- The force of the *falling weight* is transmitted to the pavement through a circular foot plate with a diameter of 30 cm (11.8 in) (a 45 cm (17.7 in) plate can be also used when testing directly over unbound layers).
- The surface deflection caused by the impulse load is measured by deflection sensors (geophones). Usually seven to nine geophones are used; the first one mounted in the center of the loading plate and the rest positioned at various distances from it (up to 2.5m (98in) from the center of the loading plate). The loading plate and geophones are shown in Figure 8.
- Peak deflection values are recorded to be stored and displayed.

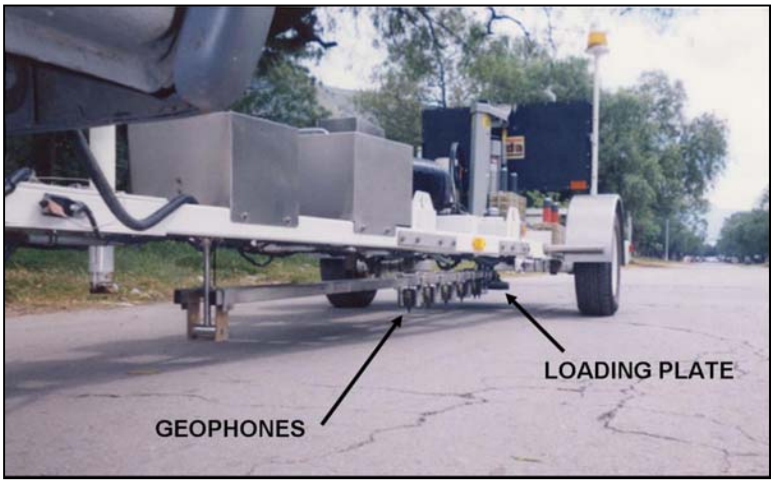


Figure 8. Loading Plate and Geophones

The applied impulse load (with duration from 20 ms to 60 ms depending on the equipment manufacturer) may be varied between 11 kN (2.5 kips) to 120 kN (27.0 kip) by modifying the mass, the drop height, or both. However, it is recommended that the FWD load should be in the range of 40 kN (9.0 kips) to 53.4 kN (12 kips) so that the layer moduli predictions will be representative of pavement response under heavy truck wheel loads. The FWD load level used for testing AC and PCC pavements may affect the backcalculated moduli obtained from the deflection data, particularly for non-linear unbound granular and subgrade materials.

2.4.4. Moduli Backcalculation

The procedure used to estimate the *in situ* elastic moduli for each pavement layer (including the subgrade) based on the measured deflections is called backcalculation. The backcalculation procedure involves calculating theoretical deflections under the applied load using assumed pavement layer moduli. These theoretical deflections are then adjusted in an iterative process until the theoretical and measured deflections reach an acceptable agreement (low Root Mean Square error - RMS) and reasonable backcalculated moduli for each layer are obtained. The RMS error is defined as the absolute difference between the measured and computed deflection basins expressed usually as percentage.

Several backcalculation algorithms and software are commercially available. Even though many of the software packages may have some similarities, the results can differ depending on assumptions, iteration technique, and backcalculation or forward calculation schemes used within the programs. Some examples include ELMOD, EVERCALC, ILLI-BACK, MODCOMP5, MODULUS, and WESDEF.

Typical Moduli Values

Backcalculated results are usually compared to typical stiffness moduli for each material, such as the ones presented in Table 2. Some of the presented values were obtained from the available literature [4], [7], [18] and others were estimated from experience. Ranges are usually specified for all materials in order to improve the reasonableness of the results.

Since the deflection testing program is performed at a particular month or season of the year, the backcalculated values are representative of only that period of the year. Correction factors should be taken into account for the seasonal changes; the best practice to obtain these factors is by performing deflection measurements at different times of the year.

Table 2. Typical Stiffness Moduli for Different Materials

Material	Initial Modulus, MPa (ksi)	Range of values, MPa (ksi)	
		Low	High
Asphalt Materials			
Hot Mix Asphalt	3,500 (500)	2,000 (300)	5,500 (800)
PCC Materials			
Intact slab	31,000 (4,500)	20,500 (3,000)	41,500 (600)
Fractured slab	3,500 (500)	700 (100)	20,500 (3,000)
Open Grade Drainage Layers			
Asphalt Stabilized	1,000 (150)	700 (100)	1,700 (250)
Cement Stabilized	1,700 (250)	1,000 (150)	2,400 (350)
Cement Stabilized Layers			
21A	5,800 (850)	4,800 (700)	13,800 (2,000)
Cement Treated Aggregate	5,800 (850)	4,800 (700)	13,800 (2,000)
Stabilized Subgrade	2,400 (350)	900 (130)	3,800 (550)
Unbound Materials			
Crushed stone/gravel, Base	350 (50)	70 (10)	1,000 (150)
Gravel or soil-agg. mix, coarse Base	200 (30)	70 (10)	700 (100)
Gravel or soil-agg. mix, fine Base	150 (20)	35 (5)	550 (80)

Spatial Frequency

Another important issue when performing FWD tests is the spacing between consecutive measurements. This spatial frequency depends on the length of the road section under investigation and level of investigation (network or project level). The spacing may vary from 50 m (165 ft) to 100 m (330 ft) for project level investigations, and between 200 m (660 ft) to 250 m (820 ft) for network level. Higher frequencies are used for research purposes. Testing may be performed in the outer wheelpath (area subjected to traffic loading) or in the center of the lane (for comparison with wheelpath results). Figure 9 shows a schematic of the stress zone of a pavement under FWD testing.

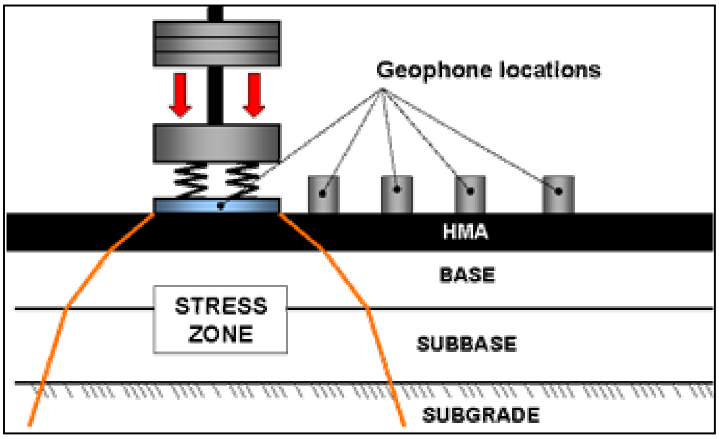


Figure 9. Stress Zone of a Pavement Subjected to FWD Testing

2.5. M-E Design Analysis for Flexible Pavements

The Mechanistic-Empirical (M-E) design presented in this section is applicable for new and reconstructed flexible pavements. For the purpose of this study, flexible pavements are defined as structures having asphalt concrete surfaces. The analysis is an iterative procedure where a *trial design* is analyzed to determine if it meets the established performance criteria, including: permanent deformation (rutting), fatigue cracking (bottom-up and top-down), chemically stabilized layer fatigue fracture (only for composite pavements), thermal cracking, and smoothness (International Roughness Index or IRI). Table 3 is a summary of the flexible pavements design process steps.

Table 3. Design Process Steps

#	Step	Description
1	Trial design for specific site conditions	Define subgrade, asphalt concrete and other paving material properties, traffic loads, climate, pavement type, and design and construction features
2	Acceptable pavement performance criteria	Establish acceptable levels of rutting, fatigue cracking, thermal cracking, and IRI at the end of the design period
3	Reliability level for each performance measure	Select desired level of reliability level for, rutting, cracking, IRI. Reliability is defined as the probability that a component or system will satisfactorily perform its specified function for the specified or required period of time under given or predicted operating conditions [13]
4	Input needed information to obtain monthly values of site conditions	Input needed information to obtain material's seasonal variation, and monthly changes in traffic and environment for the entire design period
5	Compute structural responses (stresses and strains)	Use multilayer elastic theory or finite element-based pavement response models for each axle type and load and for each damage-calculation increment throughout the design period
6	Calculate distress/damage	Calculate accumulated distress/damage at the end of each analysis period for the entire design period
7	Predict key distresses	Use M-E Guide performance models to predict distresses at the end of each analysis period throughout the design life
8	Predict smoothness (IRI)	Predict smoothness as function of: initial IRI, accumulated distresses over time, and site factors at the end of each analysis increment
9	Evaluate expected performance	Evaluate the expected trial design performance at the given reliability level.
10	Modify design	Modify design if performance criteria is not met

2.5.1. Design Inputs

The required inputs for the trial design include project site conditions, such as subgrade and material properties, presence of bedrock, traffic information and climatic data. In addition, there are design inputs related to construction, such as initial smoothness (in terms of International

Roughness Index or IRI), estimated month of construction, and estimated month that the pavement will be opened to traffic.

There are three input levels in the M-E analysis process; the input level must be selected based on the importance of the project, available information/resources, and available time. A description of the input levels is presented in Table 4.

Table 4. Description of Design Input Levels

Level	Description	Examples
1	Direct testing or measurements to obtain site and/or material inputs	- Material properties obtained through laboratory testing - Measured traffic volumes and weights at the project site
2	Determine required inputs by the application of correlations	- Estimation of unbound base or subgrade resilient modulus from CBR or R-values using empirical correlations
3	Define inputs by utilizing national or regional default values	- Determination of typical resilient modulus value from AASHTO soil classification - Determination of normalized axle weight and truck type distributions from roadway type and truck type classification

It is important to mention that it is not required that the input levels for all the parameters be the same, i.e., asphalt concrete can be obtained from laboratory testing (Level 1) and climatic information from regional data (Level 3).

The input data for new flexible pavement design is divided in six categories: (1) General information; (2) Site/project identification; (3) Analysis parameters; (4) Traffic; (5) Climate, and (6) Pavement structure. The information required within each category is explained as follows:

1. General Information: Expected design life (years), estimated month in which the base and subgrade are going to be constructed, pavement (HMA) construction month (defines time t = 0 for the HMA material aging model and thermal cracking model), expected traffic opening month, and pavement type.
2. Site/project identification: Project location and identification, pavement's functional class (principal arterial, minor arterial, major collector, minor collector, local routes, and streets).
3. Analysis parameters: Selection of some or all of the performance indicators (fatigue cracking, thermal cracking, permanent deformation and pavement smoothness) and

establishment of criteria to evaluate a design. The magnitude of allowable distresses (thresholds) recommended by the M-E Design Guide are included in Table 5.

Table 5. Allowable Distress Limits Recommended by the M-E Design Guide

Distress Type	Allowable Value
Surface-down (longitudinal cracking)	190m/km (1,000ft/mi)
Bottom-up (fatigue cracking)	25% to 50% of total lane area
Thermal cracking	190m/km (1,000ft/mi)
Fatigue fracture of CSL*	Damage index < 25%
Total permanent deformation	75mm to 125mm (0.3in to 0.5in)
Terminal Smoothness (IRI)	2.35m/km to 3.95m/km (150 to 250in/mile)

*CSL = Chemically Stabilized Layers

4. <u>Traffic</u>: The load spectra for single, tandem, tridem, and quad axles is specified utilizing the following traffic information:
    - *Basic information*: Annual Average Daily Truck Traffic (AADTT), percentage of trucks in the design direction (directional distribution factor), percentage of trucks in the design lane (lane distribution factor), and vehicles operational speed (used in the asphalt bound layers moduli calculation).
    - *Traffic Volume Adjustment*: Monthly adjustment factors, vehicle class distribution (classes 4 through 13), hourly truck-traffic distribution, and traffic growth factors.
    - *Axle Load Distribution Factors*: Percentage of the total axle applications within each load interval for a specific axle type and vehicle class (classes 4 through 13). Data provided for each month for each vehicle class.
    - *General Traffic Inputs*: Mean wheel location, traffic wander standard deviation, design lane width, number of axle types per truck class, axle configuration, and wheelbase.
5. <u>Climate</u>: The weather related factors (required as hourly averages over the design period) are: air temperature, precipitation, wind speed, percentage sunshine, and ambient relative humidity. Seasonal or constant water table depth at the project site is also considered.
6. <u>Pavement Structure</u>:
    - *Drainage and surface characteristics*: Pavement surface layer absorptivity, infiltration potential, cross slope, and length of drainage path.
    - *Layer properties*:

    - Asphalt Concrete and Asphalt Stabilized Layers: Layer thickness, Poisson's ratio, thermal conductivity, heat capacity, total unit weight. Laboratory-measured dynamic modulus (Level 1 input), mix properties (Level 2 and 3 inputs), Superpave or conventional laboratory binder test data (Level 1 input), specific PG grade, Viscosity Grade or Penetration Grade (Level 2 and 3 input), dynamic modulus from FWD backcalculation and/or predictive equations (Level 2 and 3 input), volumetric effective binder content, air voids, reference temperature for master curve development, average tensile strength at 14°F, creep compliance data, and mix coefficient of thermal contraction.
    - Chemically Stabilized Layers: Maximum design resilient modulus, minimum resilient modulus (after fatigue damage), modulus of rupture, unit weight, Poisson's ratio, thermal conductivity, and heat capacity.
    - Unbound Base/Subbase/Subgrade: Layer thickness, resilient modulus (Level 1: using nonlinear finite element code; Level 2: directly specified from FWD backcalculation or empirical relations; Level 3: specified default resilient modulus as a function of AASHTO or Unified Soil Classification), Poisson's ratio, and coefficient of lateral earth pressure (K_0).
    - Bedrock: Presence of bedrock within 3 m (10 ft) of the pavement surface influences the structural response of pavement layers; inputs for this layer include: layer thickness, unit weight, Poisson's ratio, and layer modulus.
- *Distress potential*: These are supplementary properties required for smoothness (IRI) prediction models. The prediction of the development of additional distresses affecting smoothness are used with empirical relations that are not mechanistically considered by the M-E Guide, e.g., block cracking and sealed longitudinal cracks outside the wheelpath.

2.5.2. Critical Response Variables and Pavement Response Models

There are different *critical variables* that determine the *pavement structural response* to traffic loads and environmental influences. Environmental factors may influence the structure directly (e.g., strains due to thermal expansion and/or contraction) or indirectly through effect of material properties (e.g., changes in stiffness due to temperature and/or moisture effects).

The *pavement response models* were developed to determine the *critical response variables* that affect the development of specific distresses. The output of *the pavement response models* are stresses, strains, and displacements within the pavement layers. These outputs can be used in *pavement distress prediction models* (also called transfer functions), which will determine the structure's performance. Examples of *pavement distresses* that can be predicted utilizing these *critical variables* include the following:

- HMA fatigue cracking: Tensile horizontal strain at the bottom/top of HMA layer.
- HMA rutting: Compressive vertical stresses/strains within the HMA layer.
- Unbound layers rutting: Compressive vertical stresses/strains within the base/subbase layers.
- Subgrade rutting: Compressive vertical stresses/strains at the top of the subgrade.

2.5.3. Incremental Distress and Trial Design Suitability

Critical stresses and/or strains for each distress type are estimated for an *increment* or design analysis period. An *increment* is defined as a shorter analysis period in which the target design life is divided into, starting with the traffic opening month. The basic unit for estimating the damage is one month, however, modulus values may vary rapidly during freeze and thaw conditions; therefore the analysis interval is reduced to two-week periods. These critical stress and/or strain values are converted to incremental distresses in absolute terms (e.g., incremental rut depth) or in terms of damage index (e.g., fatigue cracking). The suitability of the trial design is analyzed by summing all increments of distresses and/or damage at the end of each analysis period; this procedure is performed automatically by the M-E Design Software.

Chapter 3 - RESEARCH APPROACH

This Chapter discusses the *Data Collection* process and *Data Analysis Methodology* followed for this thesis. The *Data Collection* section explains the tests performed on seven exceptionally performing in-service pavements on high-priority routes in Virginia; these included three flexible and four composite pavements (the geographic location of each of these seven structures is depicted in Figure 10.

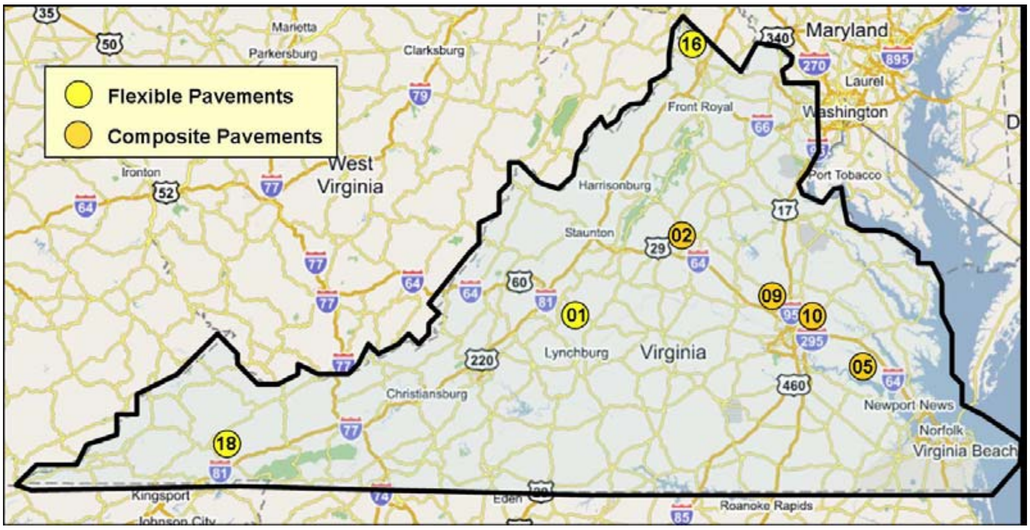


Figure 10. Location of Evaluated Flexible and Composite Pavements Sites

The field evaluation and data collection included:

- Visual and video survey of the pavement's surface,
- Ground Penetrating Radar (GPR),
- Falling Weight Deflectometer (FWD), and
- Destructive testing (cores were taken from each site and some of the core pits were used to perform subgrade boring).

The *Data Analysis Methodology* discussion follows the order in which the analysis was performed, and includes the following tasks:

- Core measurements and material characterization,
- Quantification of surface distresses,
- Determination of layer thicknesses from cores, GPR and historical data,

- Deflection analysis, backcalculation and comparison with laboratory results,
- Determination of the effective (current) structural capacity for flexible and composite pavements using the 1993 AASHTO Design Methodology (in terms of structural number (SN) and equivalent slab thickness (D), respectively), and
- Performance prediction of the selected structures and comparison of the predicted pavement damage with the actual pavement distresses observed/measured in the field.

The following sections describe the methodology used in each of these tasks.

3.1. Data Collection

Given that the evaluated sections were located mainly on interstate and other high-traffic routes, the sections lengths were set at 0.8 km (0.5 mi) to avoid excessive delays to the public during field evaluation; Table 6 shows a summary of the selected test sections and their locations.

Table 6. Selected Pavement Sites

Site #	County	Route	Direction	Milepost	Pavement Age/Surface Age (yrs)
FLEXIBLE PAVEMENTS					
01	Amherst	29	South	7.80-7.30	34 / 11
16	Frederick	81	North	21.31-21.87	39 / 13
18	Washington	81	South	1.50-1.00	5 / 3
COMPOSITE PAVEMENTS (CRCP Rehab.)					
02	Albemarle	64	East	12.99-13.37	34 / 12
05	New Kent	64	East	14.69-15.19	32 / 13
09	Henrico	295	South	5.29-5.79	23 / 6
10	Hanover	295	South	9.52-10.02	24 / 9

3.1.1. GPR Testing

Ground penetrating radar was used in this project to determine the layer thicknesses of the selected pavement. The GPR system used was a SIR-10B control unit, manufactured by Geophysical Survey Systems, Inc. (GSSI), and connected to a 1GHz air-coupled and/or a 1.5 GHz ground-coupled antenna. All GPR surveys were conducted using the test van showed in Figure 11. The van has an antenna fixture in the back that allows deployment of the GPR antennas at three different transverse locations (right wheel path, center, and left wheel path).

One or two antennas were used depending on the surveyed pavement structure. The selection of the suitable antennas and of the GPR acquisition rate for each project was based on the following criteria:

1. For the flexible sections, GPR data was collected using the air-coupled antenna at a speed ranging between 48 km/h (30 mi/h) and 65 km/h (40 mi/h).
2. For the composite sections incorporating reinforcement, GPR data was collected simultaneously by the air-coupled and the ground-coupled antennas. The test speed was limited by the ground-coupled antenna to 8 km/h (5 mi/h).

Figure 11. Antenna Used for GPR Collection

In addition, stationary GPR measurements (i.e., data collected while the GPR van was stopped) were taken near the core locations before extraction of the cores. This was done to validate the GPR thickness measurements and estimate their accuracy.

3.1.2. Visual/Video Survey

A visual survey of the pavement surface condition was performed based on a video taken by a high-speed, downward looking digital video camera. As showed in Figure 12, the digital camera used to collect the video was mounted on the GPR van. The visual survey was synchronized with the same DMI (Distance Measurement Instrumentation) used to control the GPR data acquisition.

Figure 12. Digital Camera Used for Video Survey

3.1.3. FWD Testing

Falling Weight Deflectometer (FWD) measurements were performed to determine the structural condition of each of the test sites evaluated for the Premium Pavement Project. All tests were conducted using the Virginia Department of Transportation (VDOT) Dynatest model 8002 FWD unit (Figure 13). The three main components of this system include: (1) Dynatest 8002-054 FWD Trailer; (2) Dynatest 9000 system Processor and (3) Laptop computer. The peak deflections caused by the applied load were registered by nine sensing transducers (geophones). Sensor located at 0, 203, 305, 457, 610, 914, 1219, 1524 and 1829 mm (0, 8, 12, 18, 24, 36, 48, 60 and 72 in) from the center of the loading plate were used.

Figure 13. FWD Used by VDOT

Fourteen drops were applied at each FWD testing point, including two seating drops of 40kN (9,000lbs), and three drops at each of the following load levels: 26.7kN (6,000lbs), 40kN (9,000 lbs), 53.4kN (12,000lbs) and 71.2kN (16,000lbs) respectively. The test frequency and location varied for each pavement type; but in general the frequencies used were the following:

(1) Flexible pavement tests every 15.24m (50ft) on the right wheelpath.
(2) Composite pavement tests every 15.24m (50ft) on the center of the lane (between wheelpaths).

Temperature data were collected during all FWD tests. Both the surface and air temperatures were measured using Raytek and Dynatest sensors, respectively.

3.1.4. Coring/Boring

The coring activities were customized to the material being sampled. For *flexible* material sampling, 150mm (6in) cores were taken through at least the thickness of the bound asphalt layers. The 150mm size was necessary for anticipated testing of the larger-stone base mixtures. Ten cores were extracted from each full-depth asphalt section at a distance of approximately 60m (200ft) alternating between the right wheelpath and the lane center.

Sampling of *composite* pavements was modified based on site conditions and specific pavement composition. For composite sections that contained no larger-stone asphalt base mixes, partial depth sampling for bound asphalt and full-depth sampling for concrete was done with the 100mm (4in) barrel. If the asphalt materials include a larger-stone base mix, at least some portion (generally partial depth) of the sampling was done using the 150mm barrel. Generally, at least 6-cores spaced at 90m (300ft) intervals were taken from every test section.

In addition to the coring of the bound layers of the pavement, soil sampling and testing were also conducted at each test section. The local district geology crew conducted the soil investigation activities. Soil boring was confined to two core-holes per test site. Continuous 0.45m (1.5ft) split-spoon sampling was conducted to approximately 1.35m (4.5ft) below the bottom of the bound material. All soil boring activities were completed according to established VDOT procedures and field adaptations of ASTM standard D1586. All soil descriptions were made in accordance with ASTM D2488.

3.2. Data Analysis Methodology

The methods used to analyze the data collected from the visual survey, GPR, FWD testing and coring and boring are discussed in this section as well as the purpose of including them in this research. The backcalculation procedure, the use of the M-E Design Software to predict pavement performance using input parameters obtained from the NDT evaluation (such as backcalculated moduli), and the transfer functions that the software utilizes to quantify and predict pavement damage are also considered in this section.

3.2.1. Visual Distress Quantification

The digital videos were used to obtain the current pavement distresses based on the Distress Rating Manual used by VDOT [21], [22]. The process involved analyzing the videos and manually quantifying the identified distresses with the purpose of determining the adequacy level of the structures, defined as: *inadequate, marginal* or *adequate* (see Section 2.4.1.)

3.2.2. Core Measurements and Material Characterization

The different layers observed on each of the obtained cores were visually evaluated to identify problems and measured to check the accuracy of the GPR results and to compare to historical data. In addition, some cores were used for material characterization.

Laboratory tests were performed to selected asphalt and concrete samples obtained from the coring procedure. Three 150-mm cores from each section were used to determine the resilient modulus of the asphalt in accordance to ASTM D4123. Each core provided one sample from the wearing surface and one sample from the base mix. Tests were run for 100 cycles and the last five were used to calculate the resilient modulus. The durations of the pulse load and rest period were 0.1 and 0.9 sec respectively. The applied load was chosen to induce deformations that are well above the sensitivity of the strain gauges without damaging the specimens. The applied loads were determined as 1000 N (225 lb) and 2000 N (450 lb) for the wearing surface and BM layers respectively. All tests were performed at 25°C (77°F). Specimens were stored in the laboratory at room temperature (25°C). Before being tested, specimens were placed in an environmental chamber at 25°C (77°F) for a period of 1 hour.

The concrete cores were subjected to compressive strength (f'_c) tests in accordance to ASTM C39/C39M-99. The elastic modulus of the concrete was determined utilizing the equation recommended by the American Concrete Institute (ACI):

$$E_c = 57{,}000\,(f'_c)^{1/2} \qquad (1)$$

where,

E_c = elastic modulus of the concrete (psi), and

f'_c = compressive strength of the concrete (psi).

Two cores were tested per site and they were cut to a height of 203 mm (8 in) prior to testing. A Forney compression machine was used to perform all the tests.

3.2.3. Layer Thickness Determination

Three sources of information were compared in order to obtain accurate information about the thicknesses of the different layer materials within each of the pavement structures: measured cores, GPR results and historical data. The measured cores were considered to be the most reliable source of information but unfortunately the cores were not obtained for the whole depth of the structures. In situations where the thickness of the layers could not be determined by measured cores, GPR thicknesses were utilized, followed by historical data when GPR results could not detect certain interfaces.

The raw data from GPR scans can give the approximate locations of the major layer interfaces (in time-delay units) within the pavement, these locations are not the actual layer thicknesses, they represent the amplitude reflected from each layer boundary. Figure 14 shows an example of a *linescan* view of the data collected for a flexible section. The *x*-axis in these figures represents the survey distance along the tested section. The *y*-axis represents the two-way time of travel (in nanoseconds) of the electromagnetic (EM) waves between the different layers.

The raw GPR data was analyzed by an in-house developed software that automatically estimates the layer thicknesses variations of the different layers composing each pavement section without much user interaction. For all sites, the layer thicknesses were estimated along the center of the lane and the right wheel at a spacing of 0.3 m (1 ft) starting from the beginning of the site.

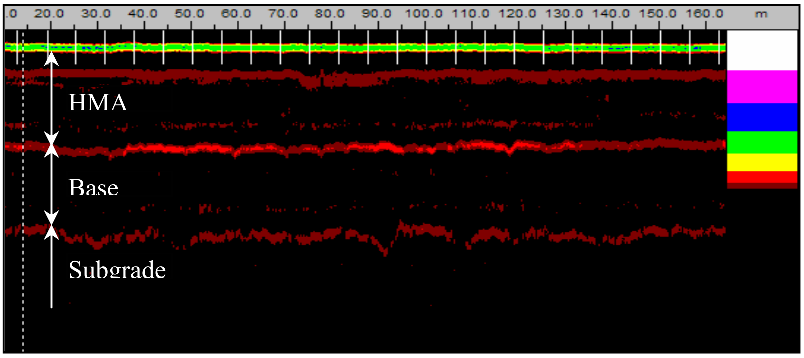


Figure 14: Raw GPR Data, Center of the Lane, Flexible Section

The raw GPR data was analyzed by an in-house developed software that automatically estimates the layer thicknesses variations of the different layers composing each pavement section without much user interaction. For all sites, the layer thicknesses were estimated along the center of the lane and the right wheel at a spacing of 0.3 m (1 ft) starting from the beginning of the site.

It should be noted that depending on the pavement structure and the dielectric constant contrast between materials of adjacent layers, some interfaces were not detected from the GPR data. Examples of structures presenting this kind of problem include different types of thin HMA layers; base layer and subgrade composed of materials having similar dielectric constants, and; interface between concrete slab/base layer and other layers underneath the concrete.

An example of the layer thicknesses comparison between measured cores, GPR results, and historical data is included in Table 7. It can be observed that even though the GPR radar couldn't distinguish between the HMA layers, the total HMA thickness is very similar to the combined thickness for HMA layers measured from the cores and also the historical data. The selection of thicknesses between historical data, GRP and cores for the rest of evaluated sites is presented in Appendix A.

Table 7. Selection of Thicknesses Between Historical Data, GPR and Cores for Site 16 (Flexible)

	HISTORICAL DATA			GPR		CORES	
Layer #	**Material**	**Thickness (mm)**	**Year**	**Material**	**Thickness (mm)**	**Material**	**Thickness (mm)**
1	SM-2C	46	1991	SM-2C	48.2	Surface Mix	39
2	I-3	10	1965	I3 + CB1 + H3	233	Base Mix	256
3	CB-1 or	33	-				
4	H-3	191	-				
5	Aggregate Base Type 1	152	-	Aggregate Base	125.4	-	-
6	Select Material Type 1	305	-	-	-	-	-
7	Subgrade	-	-	Subgrade	-	Subgrade	-

NOTE: Shaded area indicates the thickness selected for each layer

3.2.4. Deflection Analysis

The *in situ* elastic moduli for all pavement layers were backcalculated from the measured deflection at a 40 kN (9,000 lbs) load level. In addition, the variability of the deflections along the section was investigated.

Deflection Variability Analysis

Given that pavement deflections vary with load magnitude, load plate characteristics and overall pavement structure, it is recommended to express the variability in terms of the Coefficient of Variation (CV) [1], which was computed using the following equation:

$$CV = (\text{standard deviation} / \text{average})\ 100 \qquad (2)$$

Three levels of deflection variability were defined: Low (15%), Average (30%) and High (45%) for D1 (center of the loading plate, it represents the deflections of the whole pavement structure), D7 and D9 (common locations to measure the subgrade deflection).

Homogenous Sections

Each project was divided into homogeneous sections using the deflection data. The software package called TAG (Total Analysis Group) was used to perform this task. TAG was developed by VDOT to analyze FWD data and it was utilized in this project to obtain homogeneous sections for the pavement structures. Obtaining the cumulative sums of deflection allows dividing each project into sections with similar performance [27]; as an example, Figure 15 illustrates the homogeneous sections obtained for Site 02. Two FWD sensors were selected to obtain homogeneous sections: (a) Maximum deflection (sensor at 0 mm from loading plate center), and (b) Sensor 7 (sensor at 1219 mm from loading plate center). Appendix B contains the homogeneous sections for all the evaluated structures.

Layer Moduli Backcalculation

Many backcalculation programs are currently available; however, most of them are specially designed to analyze flexible (asphalt) pavements, making it difficult to find a suitable backcalculation program to evaluate composite and rigid pavements. The software package used for the backcalculation process was ELMOD version 5.1, developed by Dynatest [5]. ELMOD's approach is based on the Odemark-Boussinesq Method of Equivalent Thickness (MET). ELMOD was selected as the backcalculation software because of its flexibility in the data-input process, fast analysis, easiness in viewing results, and the ability to modify parameters to analyze different case scenarios. These capabilities make it a practical software package to use.

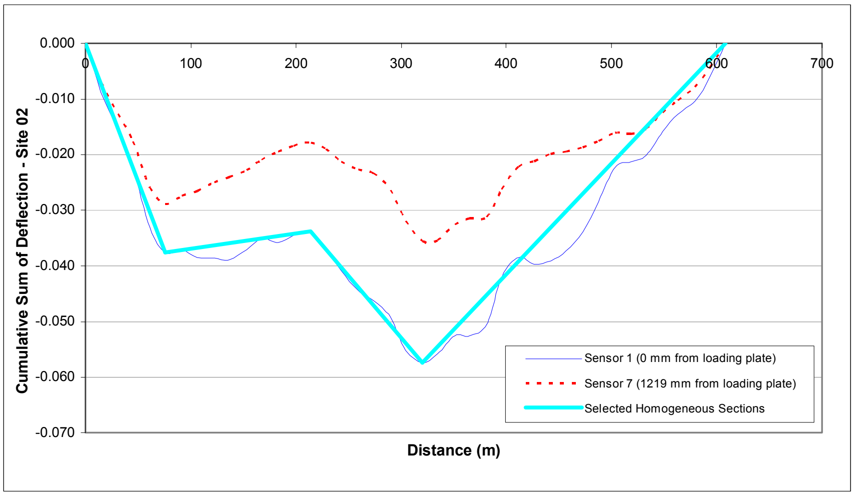


Figure 15. Homogeneous Sections Based on Cumulative Sum of Deflections – Site 2

3.2.5. Determination of Effective Structural Capacity

The structural capacity (or ability to carry loads) of the pavement changes with time and traffic. When a structural evaluation is conducted on in-service pavements, the pavement's structural capacity is defined in terms of its *effective* structural capacity. For flexible pavements, the structural capacity is measured by the *structural number* (SN); for rigid pavements, by the *slab thickness* (D); and for composite pavements it is expressed as an *equivalent slab thickness*. The various computations conducted for these estimations are presented in the following sections.

Design (Original) Structural Number (SN)

The structural number of a pavement structure can be obtained by combining the structural contribution from the each of the pavement layers, as follows [1]:

$$SN = a_1 D_1 + a_2 D_1 + a_3 D_3 + \cdots + a_n D_n \tag{3}$$

where,

D_i = total thickness of all pavement layers above subgrade (in),

a_i = layer coefficient, and

SN = structural number.

Effective Structural Number (SN_{eff}) from Condition Survey

This method of determining the effective structural number of the AC pavements involves the use of the same equation employed to calculate the *Design Structural Number* (*SN*), with the difference of using suggested layer coefficients (a_i's) that depend on the type and amount of present deterioration. Most of these suggested layer coefficients are less than the values utilized for the same materials for new construction [1].

Effective Structural Number (SN_{eff}) from NDT Evaluation

The effective structural number (SN_{eff}) of a conventional flexible pavement can also be determined from the NDT evaluation, assuming that the structural capacity of the pavement is a function of its total thickness and overall stiffness [1]. Equation (3) shows the relationship between SN_{eff}, thickness and stiffness:

$$SN_{eff} = 0.0045 D \cdot \sqrt[3]{E_p} \tag{4}$$

where,

D = total thickness of all pavement layers above subgrade (in), and

E_p = effective modulus of pavement layers above the subgrade (psi).

Design Subgrade Resilient Modulus (Design M_R)

The backcalculated subgrade resilient modulus can be used in the determination of the design M_R after applying an adjustment factor (C). This adjustment factor (C) is applied to make the value calculated consistent with the value used to represent the AASHO Road Test subgrade; a value of C of not greater than 1/3 is recommended, resulting in the following [1]:

$$Design\ M_R = C * M_R \tag{5}$$

where,

Design M_R = design subgrade resilient modulus (psi),

C = adjustment factor, 0.33 recommended, and

M_R = backcalculated subgrade resilient modulus (psi).

Effective Modulus of the Pavement (E_p)

The effective modulus of the entire pavement structure (all pavement layers above the subgrade) can be determined from the subgrade design resilient modulus, the total thickness of all layers above the subgrade, and the maximum deflection (center of the load plate), applying the following equation [1]:

$$d_0 = 1.5p \cdot a \left[\frac{1}{M_R \sqrt{1 + \left(\frac{D}{a} \sqrt[3]{\frac{E_p}{M_R}} \right)^2}} + \frac{1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a} \right)^2}}}{E_p} \right] \tag{6}$$

where,

d_0 = deflection measured at the center of the load plate, adjusted to a standard temperature of 68°F (in),

p = FWD load plate pressure (psi),

a = FWD load plate radius (in),

D = total thickness of pavement layers above subgrade (in),

M_R = design subgrade resilient modulus (psi), and

E_p = effective modulus of all pavement layers above the subgrade (psi).

Effective Slab Thickness (D_{eff})

The effective slab thickness for composite pavements is determined from visual condition survey, computed from the following equation:

$$D_{eff} = \left(D_{pcc} \cdot F_{jc} \cdot F_{dur}\right) + \left[\left(\frac{D_{ac}}{2.0}\right) \cdot F_{ac}\right] \tag{7}$$

where,

D_{eff} = effective equivalent PCC thickness of existing AC/PCC (in),
D_{pcc} = thickness of existing PCC slab (in),
D_{ac} = thickness of AC layer (in),
F_{jc} = joints and reflection cracks adjustment factor,
F_{dur} = durability adjustment factor (for "D" cracking and/or reactive aggregate), and
F_{ac} = AC quality adjustment factor (distresses related to the AC layer which are not eliminated by surface milling: rutting, stripping, shoving, weathering, and raveling).

3.2.6. M-E Design Guide Software Verification

The accumulation of damage as a function of time and traffic is the basis for the M-E design and analysis of the trial pavement structure. The analysis for this thesis was performed using version 0.701 of the M-E Design Guide software, which is available online. This software package is an *analysis* that can predict pavement performance of new and/or rehabilitated structures. The purpose of this study was to use the program to predict the performance of selected structures (listed in Table 8) utilizing different layer properties obtained from the field evaluation.

The historical data available for each structure was used to determine the date of construction of the original pavement, the overlay year, and existing traffic (see Table 8). Two types of analysis were performed, described as follows:

(1) New Pavement Design: The original structures were analyzed as **new pavement designs** from the construction year to the year of the application of the overlay, to evaluate the predicted performance for the original structure. Unfortunately, there were no historical records of the condition of the road before applying the overlay to compare with the software's output. The purpose of this analysis was to

estimate the condition of the pavement structure in the overlay year and to identify the predicted critical distresses affecting each structure.

(2) Pavement Rehabilitation: This analysis was performed by using the **rehabilitation design** option from the overlay year to present time, and continued to the end of the service life. The purpose of this analysis was to compare the current pavement condition (established from the field evaluation performed in April and May 2004) with the software's output. This was used as a preliminary verification of the distress prediction models applied to the investigated pavements. In addition, the complete after overlay analysis (until failure) helped identifying the critical distresses affecting each structure.

Table 8. Summary of Pavement Structures Analyzed

Site #	Layer	Thickness, mm (in)	Original Construction/Overlay (year/year)	Two-way AADTT (year 2004)
FLEXIBLE PAVEMENTS				
01	SM + BM	240 (9.5)	1970 / 1993	2200
	CTA	150 (6)		
	Subgrade	-		
16	SM + BM	295 (11.5)	1965 / 1991	8560
	Agg. Base + Select Material	430 (18)		
	Subgrade	-		
18	SM + BM	375 (15)	1999 / 2001	11880
	Asphalt OGDL	70 (3)		
	Agg. Base	533 (21)		
	Subgrade	-		
COMPOSITE PAVEMENTS				
02	SM + BM	115 (4.5)	1970 / 1992	3360
	CRCP	209 (8.25)		
	Subgrade	-		
05	SM + BM	108 (4.25)	1972 / 1991	1760
	CRCP	203 (8)		
	Agg. Base	150 (6)		
	Subgrade			
09	SM + BM	95 (3.75)	1980 / 1998	2000
	CRCP	216 (8.5)		
	CTA	150 (6)		
	Subgrade	-		
10	SM + BM	100 (4)	1980 / 1996	6600
	CRCP	200 (8)		
	CTA	150 (6)		
	Subgrade	-		

AADTT = Annual Average Daily Truck Traffic; **SM** = Surface Mix; **BM** = Base Mix;
CTA = Cement Treated Aggregate; **OGDL** = Open Graded Drainage Layer;
CRCP = Continuously Reinforced Concrete Pavement

The output of the analysis is automatically generated by the M-E Design software in Microsoft Excel® spreadsheets. It includes a summary of the design inputs (general information, analysis parameters, performance criteria, traffic, climate, and structure), and the predicted pavement distresses accumulated in each increment or design analysis period (usually one month) throughout the design life. The predicted pavement distresses are reported in both tabular and graphic format. The remaining service life and the critical type of distresses can be estimated from the damage accumulation charts for each distress.

Input Variables

Table 9 presents a summary of sources of information for all the input parameters used to predict pavement performance; these include historical data, field evaluation/analysis data, State specifications, default and recommended values by the M-E Design Guide, and other typical values.

Analysis Assumptions

The following assumptions were made in order to run the prediction performance analysis:

- The initial IRI after overlay was 1.0 m/km (63 in/mi) (default value recommended by the M-E Design Guide).
- The allowable limits for all the types of distresses were the ones recommended by the M-E Design Guide [10].
- Traffic will grow at a rate of 4% for all the evaluated sites during the design period.
- The vehicle class distribution for all the sites was *Principal Arterials – Interstate and Defense Routes*, with a predominantly truck traffic (74%) of single trailer trucks, more than 2% bus traffic, and less than 2% multi-trailer traffic [10].
- The properties of all the asphalt layers (asphalt mix gradation, volumetric properties, and asphalt binder) are the ones specified to use in the Commonwealth of Virginia [23], [24], [25], [26].
- The FWD backcalculated layer moduli for granular materials and subgrades are not going to change significantly during the analysis period.
- The subgrade was approximately classified - using the Unified Soil Classification System (USCS) - from the descriptions included in the boring field report.

Table 9. Input Parameters and Source of Information

Input Parameter	Source of Information
General Information	
Design life, existing pavement construction, pavement overlay construction, traffic open date	Historical data
Site/Project Identification	
Location, project ID, milepost from-to, traffic direction	Summary of selected test sites
Analysis Parameters (allowable limits)	
Initial IRI, Terminal IRI, longitudinal cracking (ft/mi), alligator cracking (%), AC thermal fracture (ft/mi), chemically stabilized layer fatigue fracture, AC rutting (in), total rutting (in)	Allowable distress values recommended by the M-E Design Guide
TRAFFIC	
Initial two-way AADTT, number of lanes per direction	Historical data
Percent of trucks in design direction, percent of trucks in design lane, operational speed (mph)	Default values for “Principal Arterials - Interstate and Defense Routes”
Traffic volume adjustment factors, monthly adjustments, vehicle class distribution, hourly distribution	Default values for Level 3 input
Traffic growth factor	Historical data or typical values for the State of Virginia
Axle load distribution factors, number of axles per truck, axle configuration, wheelbase	Default values
CLIMATE	
Climatic data	Climatic data from specific weather stations, and interpolation of weather stations from VA, MD, NC, TN, KY, and WV. Zip files available at http://trb.org/mepdg/climatic_state.htm
STRUCTURE	
Asphalt Concrete: layer thickness	Cores, GPR, and historical data
Asphalt Concrete: asphalt mix gradation, grade, binder content, air voids	Historical data and State specifications [23], [24], [25], [26]
Asphalt Concrete: surface absorptivity, reference temperature, total unit weight (pcf), Poisson’s ratio, thermal properties	Default values for Level 3 input
CRCP and Chemically Stabilized Layers: layer thickness	Cores, GPR, and historical data
CRCP and Chemically Stabilized Layers: unit weight, Poisson’s ratio, thermal properties, mix properties	Historical data and State specifications
CRCP and Chemically Stabilized Layers: strength properties	Laboratory results and backcalculated modulus
Unbound Layers: layer thickness	Cores, GPR, and historical data
Unbound Layers: Poisson’s ratio, coefficient of lateral pressure, gradation, plasticity index	Default values and State specifications
Unbound Layers: Modulus	Backcalculated modulus

Distress Models

The following structural distresses were considered: fatigue cracking (bottom-up and top-down), fatigue cracking in chemically stabilized layers, and permanent deformation (rutting). This section describes the failure mechanisms associated with these distresses and the transfer functions that the software utilizes to quantify and predict pavement damage.

Fatigue Cracking:

Bottom-up and top-down cracking models are based on the calculation of fatigue damage at the bottom of each asphalt layer and at the surface, respectively. The estimation of fatigue cracking damage is based upon Miner's Law, where the damage is given by the following equation:

$$D = \sum_{i=1}^{T} \frac{n_i}{N_i} \tag{8}$$

where,

D = damage,

T = total number of periods,

n_i = actual traffic for period i, and

N_i = traffic allowed under conditions prevailing in i.

The most common models used to predict the number of load repetitions to fatigue cracking (N_i) are a function of the tensile strain and mix stiffness (modulus). The relationship used for fatigue characterization in the M-E Design Guide is the following:

$$N_f = 0.00432 k'_1 \, C \left(\frac{1}{\varepsilon_t} \right)^{3.9492} \left(\frac{1}{E} \right)^{1.281} \tag{9}$$

where,

N_f = number of repetitions to fatigue cracking,

k'_1 = correction parameter for different asphalt layer thickness (h_{ac}) effects,

C = laboratory to field adjustment factor,

ε_t = tensile strain at the critical location, and

E = stiffness of the material.

a. Bottom-up cracking:

$$k'_1 = \frac{1}{0.000398 + \frac{0.003602}{1 + e^{(11.02 - 3.49 h_{ac})}}} \qquad (10)$$

b. Top-down cracking:

$$k'_1 = \frac{1}{0.01 + \frac{12}{1 + e^{(15.676 - 2.8186 h_{ac})}}} \qquad (11)$$

where,

h_{ac} = total thickness of the asphalt layers (in).

$$C = 10^M \qquad (12)$$

$$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right) \qquad (13)$$

where,

V_b = effective binder content (%), and

V_a = air voids (%).

The final transfer function to calculate the fatigue cracking from the fatigue damage is expressed as:

a. Bottom-up cracking (% of total lane area):

$$FC_{bottom} = \left(\frac{6000}{1 + e^{(C_1 C'_1 + C_2 C'_2 \log 10(D \cdot 100))}}\right)\left(\frac{1}{60}\right) \qquad (14)$$

where,

FC_{bottom} = bottom-up fatigue cracking, percent lane area,

D = bottom-up fatigue damage,

C_1 = 1.0,

C'_1 = -2 * C'_2,

C_2 = 1.0, and

C'_2 = -2.40874 – 39.748*$(1 + h_{ac})^{-2.856}$.

b. Top-down cracking (ft/mile):

$$FC_{top} = \left(\frac{1000}{1 + e^{(7.0 - 3.5\log 10(D \cdot 100))}} \right) (10.56) \tag{15}$$

where,

FC_{top} = top-down fatigue cracking (ft/mile), and

D = top-down fatigue damage.

***Fatigue Fracture in Chemically Stabilized Layers*:**

The relationship used in the M-E Design Guide to characterize the fatigue behavior of chemically stabilized materials is defined in the following equation:

$$\log CTB\_Damage = \frac{0.972\beta_{c1} - \left(\frac{\sigma_t}{MR} \right)}{0.0825\beta_{c2}} \tag{16}$$

where,

CTB_Damage = number of repetitions to fatigue cracking of the CSM layer,

σ_t = maximum traffic induced tensile stress at the bottom of the CSM layer (psi),

MR = 28-day Modulus of Rupture (Flexural Strength) (psi), and

β_{c1} , β_{c2} = field calibration factors.

Due to the complexity of field selection design input and the difficulty of obtaining performance data, the fatigue fracture in chemically stabilized layers and reflective cracking models have not been field calibrated. Thus, both calibration factors (β_{c1} and β_{c2}) are equal to 1.

***Permanent Deformation (Rutting) in Asphalt Mixtures*:**

The relationship used to predict rutting progression in the asphalt mixtures is based on a field calibrated statistical analysis of laboratory repeated load permanent deformation tests. The final model used in the Design Guide after a national field calibration is shown below:

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 \cdot 10^{-3.4488} T^{1.5606} N^{0.479244} \tag{17}$$

where,

ε_p = accumulated plastic strain at N repetitions of load (in/in),

ε_r = resilient strain of the asphalt material as a function of mix properties, temperature and time rate of loading (in/in),

k_1 = function of total asphalt layers thickness (h_{ac}, in) and depth (in) to computational point, to correct for the confining pressure at different depths,

T = temperature (deg F), and

N = number of load repetitions.

The depth parameter "k_1" has been introduced to adjust the rut depth prediction model based on trench studies from the MnRoad test site.

$$k_1 = (C_1 + C_2 \cdot depth)0.328196^{depth} \tag{18}$$

$$C_1 = -0.1039{h_{ac}}^2 + 2.4868h_{ac} - 17.342 \tag{19}$$

$$C_2 = 0.0172{h_{ac}}^2 - 1.7331h_{ac} + 27.428 \tag{20}$$

where,

depth = rut depth on asphalt layer, and

h_{ac} = total thickness of the asphalt layers (in).

***Permanent Deformation (Rutting) in Unbound Materials*:**

The models included in the M-E Design Guide consider the permanent deformation not only for the asphalt layers but also for unbound layers. No permanent deformation is estimated for chemically stabilized materials. Individual layer rut depths are predicted for each layer as a function of time and traffic repetitions, as follows:

$$\delta_a(N) = \beta_{CAL}\left(\frac{\varepsilon_0}{\varepsilon_r}\right)e^{-\left(\frac{\rho}{N}\right)^{\beta}}\varepsilon_v h \tag{21}$$

where,

δ_a = permanent deformation for the layer/sublayer (in),

N = number of traffic repetitions,

β_{CAL} = national calibration factor: 1.673 for granular layers; 1.35 for subgrades,

ε_0 , β , and ρ = material properties,

ε_r = resilient strain imposed in laboratory test to obtain the above listed material properties, ε_0 , β , and ρ (in/in),

ε_v = average vertical resilient strain in the layer/sublayer as obtained form the primary response model (in/in), and

h = thickness of the layer/sublayer (in).

Chapter 4 - RESULTS AND DISCUSSION

This Chapter includes the analysis of the results obtained for the three flexible (Sites 01, 16, and 18), and the four composite (Sites 02, 05, 09, and 10) pavements selected for this thesis. This analysis includes the results from the visual survey, backcalculation analysis, material characterization, and the estimation of the effective (current) structural capacity (in terms of Effective Structural Number (SN_{eff}) and Effective Equivalent Thickness (D_{eff}) for flexible and composite pavements, respectively). The results obtained from the M-E Design Guide Software, as well as software limitations identified during the analysis process, are also discussed in this Chapter.

4.1. Visual Survey and Profile Measurements

The distresses obtained from the visual survey of the pavement surface, and the longitudinal and transverse profile measurements (roughness and rutting) are presented in Table 10.

Table 10. Existing Surface Distresses and Profile Measurements

Site	Overlay Age (years)	Long. Cracking m/km (ft/mi)	Trans. Cracking, m/km (ft/mi)	Fatigue Cracking (% lane area)	Patch (#)	Potholes (#)	Rut Depth, cm (in)	IRI, m/km (in/mi)
FLEXIBLE PAVEMENTS								
01	11	45 (236)	59 (312)	0.51	0	0	0.30 (0.12)	1.53 (96.9)
16	13	33 (173)	2 (12)	0.04	0	0	0.08 (0.03)	0.64 (40.4)
18	3	0 (0)	0 (0)	0	0	0	0.25 (0.10)	1.15 (72.8)
COMPOSITE PAVEMENTS								
02	12	39 (205)	17 (90)	0.03	0	0	0.56 (0.22)	1.37 (87.1)
05	13	55 (289)	23 (120)	0.41	9	0	0.69 (0.27)	1.19 (75.3)
09	6	44 (231)	30 (156)	0.08	0	0	0.13 (0.05)	1.31 (82.8)
10	9	10 (53)	12 (24)	0.01	0	0	0.13 (0.05)	1.04 (66)

The structural adequacy of each structure was determined by applying the adequacy levels described in Table 1 to the quantified longitudinal cracking, transverse cracking, fatigue cracking, and measured rutting, as presented in Table 11.

Table 11. Adequacy Levels Based on Existing Distresses

Site #	Adequacy level for each type of distress											
	Long. Crk.			Trans. Crk.			Fatigue Crk.			Rutting		
	I	M	A	I	M	A	I	M	A	I	M	A
FLEXIBLE PAVEMENTS												
01	-	-	X	-	-	X	-	-	X	-	-	X
16	-	-	X	-	-	X	-	-	X	-	-	X
18	-	-	X	-	-	X	-	-	X	-	-	X
COMPOSITE PAVEMENTS												
02	-	-	X	-	-	X	-	-	X	-	-	X
05	-	X	-	-	-	X	-	-	X	-	-	X
09	-	-	X	-	-	X	-	-	X	-	-	X
10	-	-	X	-	-	X	-	-	X	-	-	X

I = Inadequate; **M** = Marginal; **A** = Adequate; **X** = Adequacy level

Table 11 suggests that the amount of observed and measured distresses was not significant for most of the evaluated flexile and composite pavements. This can be said because the evaluated sections fit into the *adequate* condition level for the different types of distresses, with the only exception of composite Site 05, with a *marginal* level for longitudinal cracking.

4.2. Backcalculation Results

Backcalculation is a procedure that requires significant interaction from the user to: (1) obtain reasonable backcalculated moduli, similar to the typical values for the different types of materials that compose the pavement structure; and to (2) obtain a small difference between measured and calculated deflections - usually searching for a value of root mean square (RMS) error less than 2% to 3%. Although the goodness of fit is considered important, sometimes it is considered more important to achieve reasonable moduli values than a low RMS [15].

Prior to the backcalculation analysis, the analyzed sites were tested to evaluate the need to divide them in homogeneous sections based on deflection variability. However, none of the sites showed significant differences in deflections within the section; this might be explained because the length of the pavement sections was only 800m (0.5mi) and the coefficient of variation (CV) of the measured deflections within a site is generally between low and average, as shown in Table 12 for geophones 1 (maximum deflection), 7 and 9 (subgrade deflection).

Table 12. Deflection Variability Expressed in Terms of Coefficient of Variation (CV)

Site #	D1 μm (mils)	CV*	CV level+	D7 μm (mils)	CV*	CV level+	D9 μm (mils)	CV*	CV level+
FLEXIBLE PAVEMENTS									
01	156 (6.1)	25	A	57 (2.2)	27	A	33 (1.3)	30	A
16	94 (3.7)	16	L	23 (0.9)	32	A	13 (0.5)	35	A
18	89 (3.5)	18	L	24 (0.9)	32	A	16 (0.6)	37	A
COMPOSITE PAVEMENTS									
02	96 (3.8)	14	L	44 (1.7)	21	L	30 (1.2)	24	A
05	106 (4.2)	18	L	46 (1.8)	31	A	32 (1.2)	33	A
09	96 (3.8)	25	A	37 (1.5)	23	A	26 (1.0)	22	L
10	66 (2.6)	14	L	28 (1.1)	13	L	19 (0.8)	12	L

*CV = Coefficient of Variation = (standard deviation/average) * 100
+ CV Level: Low = 1 to 22%; Average = 23 to 38%; High = 39 to 100%

In general, the backcalculated process presented some difficulties because of the complexity of the structures evaluated. Some of these difficulties are thought to be due to combination of flexible, stabilized, rigid (in the case of composite pavements), and aggregate layers that violate some of the assumptions of the Method of Equivalent Thickness model [7]: e.g. moduli not decreasing monotonously with depth. Another probable problem is a *compensating error* in the backcalculation process [3], [9], [19]. A typical example of this situation can be seen in the results for flexible Site 01 (see Table 13), were the backcalculated modulus for the asphalt layer is considered to be at a low limit, while the modulus obtained for the cement treated aggregate appeared to be overestimated. Another difficulty faced during the backcalculation analysis was the determination of the layer moduli of the asphalt layers; in many cases it was necessary to combine the thin surface layer with the thick base layer. In order to be consistent, the AC moduli presented in this investigation are the ones obtained by combining the surface and base layers. Appendix C includes plots of the backcalculated results for each layer for all the evaluated pavement structures.

Table 13 shows the moduli backcalculated for the flexible pavements. The pavement temperature presented in this table is the one estimated by ELMOD using Bells temperature prediction model [6]. Reasonable results were obtained for all the pavement layers, with low RMS values (minimum RMS error of 3.0% for Site 16 and a maximum error of 3.2% for Site 01). However, in general, it appears that the backcalculated moduli for subgrade were overestimated; this issue will be addressed later in this Chapter.

Table 13: Summary of Backcalculation Results for Flexible Pavements

MATERIAL	Pav. Temp.*, °C (°F)	Backcalculated Moduli, MPa (ksi)			RMS
		Avg.	Std. dev.	CV	
SITE 01					
SM + BM	23.4 (74.2)	3185 (462)	986 (143)	31%	3.2
Cement Treated Aggregate	-	8660 (1256)	3627 (526)	42%	
Subgrade	-	110 (16)	34 (5)	35%	
SITE 16					
SM + BM	18.4 (65.2)	4013 (582)	614 (89)	15%	3.0
Agg. Base Type I + Select Material Type I	-	683 (99)	152 (22)	22%	
Subgrade	-	248 (36)	76 (11)	29%	
SITE 18					
SM + BM	25.8 (82.8)	3909 (567)	724 (105)	19%	3.1
Asphalt Stab. OGDL Type I (2%)	-	1207 (175)	276 (40)	23%	
21B	-	634 (92)	138 (20)	22%	
Subgrade	-	317 (46)	103 (15)	32%	

* Temperature at which FWD test was performed

Composite pavements are difficult to model with any backcalculation program. Previous studies have shown that the Method of Equivalent Thickness may produce erroneous results when analyzing these types of structures; backcalculation programs may overestimate the modulus of the rigid layers and subsequently underestimate those of other layers, or vice versa. In these cases, the goodness of fit should not be the only determining factor when selecting the best model [7]. A summary of the backcalculation results obtained for the composite pavements is presented in Table 14.

Table 14 shows that the backcalculated asphalt modulus for each of the composite pavements is at a low range while the modulus of the underneath layers, especially CRCP layers, are high. Despite these limitations, the results achieved were considered reasonable, with a lower average RMS error than flexible pavements (1.6% minimum and 3.0% maximum RMS obtained for Site 02 and Site 09, respectively).

The backcalculated subgrade moduli (E_{SG}) were compared to typical values for the types of soils encountered. The typical E_{SG} values were estimated based on an *approximate* classification of the subgrade materials using the descriptions included in the boring field report. The classification system used for this purpose was the Unified Soil Classification System (USCS) (no gradation tests were available); all materials were assumed to have a low plasticity index since there was no clear indication of the opposite.

Table 14. Summary of Backcalculation Results for Composite Pavements

MATERIAL	Pav. Temp.*, °C (°F)	Backcalculated Moduli, MPa (ksi)			RMS
		Avg.	Std. Dev	CV*	
SITE 02					
SM + BM	28.2(82.7)	2337 (339)	483 (70)	21%	1.6
CRCP	-	31785 (4610)	8294 (1203)	26%	
Subgrade	-	262 (38)	62 (9)	23%	
SITE 05					
SM + BM	18.1(64.6)	2544 (369)	324 (47)	13%	2.8
CRCP	-	26834 (3892)	6729 (976)	25%	
Aggregate #22	-	469 (68)	131 (19)	28%	
Subgrade	-	241 (35)	69 (10)	29%	
SITE 09					
SM + BM	30.1 (86.1)	1841 (267)	945 (137)	51%	3.0
CRCP	-	15851 (2299)	6233 (904)	39%	
Cement Treated Aggregate	-	2282 (331)	979 (142)	43%	
Subgrade	-	296 (43)	62 (9)	22%	
SITE 10					
SM + BM	20.0 (68)	3958 (574)	179 (26)	5%	2.8
CRCP	-	17844 (2588)	7467 (1083)	42%	
Cement Treated Aggregate	-	3723 (540)	945 (137)	25%	
Subgrade	-	365 (53)	55 (8)	15%	

The ratio between the backcalculated E_{SG} and the typical value is defined as follows:

$$E_{SG}\ Ratio = \frac{Backcalculated\ E_{SG}}{Typical\ E_{SG}} \tag{22}$$

The average backcalculated subgrade modulus is approximately 1.5 times the typical subgrade modulus for silty subgrades. In the case of clayey subgrades, the backcalculated values are, in average, 2.8 times higher than the typical values. These results suggest that the subgrade modulus may be overestimated for some of the sections. However, it should be noted that no gradation tests and complete soil classification were performed.

Table 15 includes a description of the subgrade materials, the approximate USCS classification (based on material description), typical moduli values for each of the materials [4], [8], [20], [28].

Table 15. Comparison of Typical and Backcalculated Subgrade Moduli (E_{SG})

Site #	Subgrade Description	Approx. USCS Class.	Typical E_{SG} Values MPa (ksi)			Backcalc. E_{SG} MPa (ksi)	E_{SG} Ratio
			min	max	typical		
SILTY SUBGRADES							
01	wet red, brown, gray sandy silt w/mica, fill material	ML	117 (17)	175 (26)	138 (20)	110 (16)	0.8
02	reddish-brown sandy silt w/mica	ML	117 (17)	175 (26)	138 (20)	262 (38)	1.9
05	dry silt to fine sand	ML	117 (17)	175 (26)	138 (20)	241 (35)	1.7
						Averaged Ratio	**1.5**
CLAYEY SUBGRADES							
09	<u>Bore1</u>: yellow-brown and yellow-red 50/50 silt/clay; <u>Bore2</u>: brown-mustard silty clay w/mica and conglomerate of sand/gravel/silt/clay	CL	93 (14)	165 (24)	110 (16)	296 (43)	2.7
10	Silty clay w/fine gravel	CL	93 (14)	165 (24)	110 (16)	365 (53)	3.3
16	<u>Bore1</u>: clay w/silts (10%) and gray compacted clay with gravel/sand (fill); <u>Bore2</u>: damp clay w/silts (10%)	CL	93 (14)	165 (24)	110 (16)	248 (36)	2.3
18	Orange-brown to yellow-brown sandy silty clay	CL	93 (14)	165 (24)	110 (16)	317 (46)	2.9
						Averaged Ratio	**2.8**

4.3. Material Characterization

The backcalculated modulus for the HMA layers were normalized to 25°C (77°F) using the following relationship, suggested by Li and Nazarian [14], [17]

$$E_{25} = E_t / (1.35 - 0.014t) \qquad (23)$$

where,

E_{25} = AC modulus at 25°C (MPa)

E_t = AC modulus at field temperature (MPa)

t = Asphalt field temperature (°C)

The results from laboratory tests performed to the wearing surfaces and base mixes cores for flexible and composite sections are presented in Table 16.

Table 16. Comparison of Backcalculated and Laboratory Asphalt Moduli

Site #	Asphalt Modulus (E_{AC}), MPa (ksi)				E_{AC} Ratio
	E_{AC} Backcalculation	@ ºC (ºF)	Normalized to 25ºC (77ºF)	E_{AC} Laboratory	
FLEXIBLE PAVEMENTS					
01	3185 (462)	23 (73)	3116 (452)	4064 (589)	0.77
16	4013 (582)	18 (64)	3674 (533)	5527 (802)	0.66
18	3909 (567)	26 (79)	3953 (573)	4554 (661)	0.87
				Average	**0.77**
COMPOSITE PAVEMENTS					
02	2337 (339)	28 (82)	2447 (355)	4072 (591)	0.60
05	2544 (369)	18 (64)	2320 (336)	4875 (707)	0.48
09	1841 (267)	30 (86)	1983 (288)	6720 (975)	0.30
10	3958 (574)	20 (68)	3699 (536)	3577 (519)	1.03
				Average	**0.60**

The ratio between backcalculated and measured AC moduli (E_{AC}) is given as follows:

$$E_{AC}\,Ratio = \frac{Backcalculated\ E_{AC}}{Laboratory\ E_{AC}} \tag{24}$$

In general, the backcalculated modulus for the AC layer was lower than the modulus obtained in the laboratory (with the exception of Site 10). This situation is not unusual, since generally cores that are in good condition are selected to perform the laboratory tests, which might not be the general condition of the road. On average, the backcalculated AC modulus for flexible pavements was 0.77 times the laboratory modulus; this could be due to the deterioration of the asphalt layer along the pavement section. However, most of the cores did not show evidence of deterioration, except from a couple of cores extracted from Site 16 and Site 18, which showed some bonding problems (overlay not attached to existing surface).

The backcalculated HMA modulus for composite pavements shows that in Site 02 and Site 05, these values are approximately 55% of the laboratory values. The low backcalculated moduli are believed to be produced because of the *compensating error* previously mentioned; the asphalt layer modulus might have been underestimated by the presence of a stiffer CRCP layer underneath it. The ratios for Site 09 and Site 10 (composite sections with a cement treated aggregate layer underneath the CRCP layer) are not consistent. None of the cores extracted from the composite sections showed signs of deterioration.

The comparison between the backcalculated modulus and the laboratory modulus obtained for the CRCP layers is presented in Table 17.

Table 17. Comparison of Backcalculated and Laboratory CRCP Moduli

Site #	Material below CRCP layer	CRCP modulus (E_{CRCP}), MPa (ksi)		E_{CRCP} Ratio
		Backcalculated	Laboratory	
COMPOSITE PAVEMENTS				
02	Subgrade	31785 (4610)	30275 (4391)	1.05
05	Agg. Base	26834 (3892)	32833 (4762)	0.82
09	CTA	15851 (2299)	35839 (5198)	0.44
10	CTA	17844 (2588)	28427 (4123)	0.63

Once again, the ratio between these two values is given by the following relationship:

$$E_{CRCP}\ Ratio = \frac{\underline{Backcalculated\ E_{CRCP}}}{Laboratory\ E_{CRCP}} \qquad (25)$$

The ratio between backcalculated and laboratory modulus is higher for Site 02 and Site 05 than for Site 09 and Site 10. The existence of a cement treated aggregate layer underneath the CRCP layer for the last structures may be leading to an underestimation on the stiffness of the CRCP modulus.

4.4. Effective (current) Structural Capacity

The effective structural capacity of the evaluated structures was estimated using the methodology presented in the 1993 AASHTO Guide for Design of Pavement Structures [1] described in Chapter 3. Table 18 summarizes the estimated Effective Structural Numbers (SN_{eff}). The first four columns present the SN_{eff} values estimated from the FWD data, broken down by the subgrade modulus (M_R) utilized to calculate the effective modulus of pavement layers above the subgrade (E_p). The last column includes the SN_{eff} estimated from the existing distresses. Although it is not a common practice to calculate the SN_{eff} for composite pavements using this method (it might underestimate the structural contribution of the rigid layer), it was included in this table to compare the results with the flexible pavements.

The estimated SN_{eff} were considered reasonable because the pavement structures included in this study have thicker layers than typical pavement structures. The comparison between the SN_{eff} determined from FWD data for flexible pavements shows that the results obtained by using the backcalculated subgrade modulus ($M_{R\text{-backcalc.}}$) are higher than the ones using the subgrade modulus obtained using only deflections from sensors 7, 8 and 9 ($M_{R\text{-}7}$ to $M_{R\text{-}9}$). On the other hand, the SN_{eff} estimated from the existing distresses is lower than the SN_{eff} estimated from FWD data.

Table 18. Effective Structural Number (SN_{eff})

Site #	SN_{eff} from FWD Data				SN_{eff} from Distresses
	M_{R-7}	M_{R-8}	M_{R-9}	$M_{R-backcalc.}$	
FLEXIBLE PAVEMENTS					
01	5.5	5.4	5.2	6.3	4.8
16	8.3	8.2	8.1	8.9	6.8
18	12.5	12.5	12.5	13.0	9.3
COMPOSITE PAVEMENTS					
02	7.8	7.9	7.9	6.3	6.1
05	6.7	6.8	6.8	6.3	6.1
09	8.0	8.2	8.2	7.3	7.0
10	7.8	8.0	8.0	7.2	7.0

M_{R-7} , **M_{R-8}** and **M_{R-9}**: Estimated subgrade modulus using deflection from sensors 7, 8 and 9, at 1219 mm (48 in), 1524 mm (60 in), and 1829 mm (72 in) from center of loading plate, respectively. **$M_{R-backcalc}$**: Subgrade modulus from backcalculation analysis.

For composite pavements the situation changes, the subgrade modulus obtained from empirical relationships (M_{R-7} to M_{R-9}) is higher than the one obtained by using the backcalculated subgrade modulus ($M_{R-backcalc.}$). The SN_{eff} estimated by using the backcalculated subgrade modulus ($M_{R-backcalc.}$) is almost identical to the one estimated from existing distresses.

After calculating SN_{eff}, the estimated traffic that these structures can carry before reaching a terminal serviceability index of 2.5 was estimated using the equations presented in the 1993 AASHTO Design Guide [1]. The results are presented in Table 19.

Table 19. Effective Slab Thickness (D_{eff})

Site #	Estimated Remaining Traffic, W_{18} (ESAL)	
	SN_{eff} using $M_{R-backcalc}$	SN_{eff} from Distresses
FLEXIBLE PAVEMENTS		
01	3.82×10^{7}	4.95×10^{6}
16	4.13×10^{9}	4.58×10^{8}
18	1.85×10^{11}	1.05×10^{10}
COMPOSITE PAVEMENTS		
02	2.84×10^{8}	2.21×10^{8}
05	2.35×10^{8}	1.82×10^{8}
09	1.22×10^{9}	8.71×10^{8}
10	1.78×10^{9}	1.42×10^{9}

The structural adequacy of the composite pavements was also estimated in terms of Effective Slab Thickness (D_{eff}), as shown in Table 20. This value is composed by the thickness of the rigid layer reduced based on the observed distresses, and a relative contribution of the asphalt layer (which contributes approximately 50% per inch of the rigid layer structural capacity), as presented in equation (7). This table also presents the estimated remaining traffic that these structures can carry before reaching a terminal serviceability index of 2.5.

Table 20. Effective Slab Thickness (D_{eff})

Site #	Effective Slab Thickness (D_{eff}), in	Estimated Remaining Traffic, W_{18} (ESAL)
COMPOSITE PAVEMENTS		
02	9.5	2.97×10^8
05	9.1	2.24×10^8
09	9.3	2.58×10^8
10	9.0	2.08×10^8

4.5. M-E Design Guide Software Results

The two types of analysis performed to each of the selected pavement structures using the M-E Design Guide Software included: (1) New pavement design: from the construction year until the overlay, and (2) Pavement Rehabilitation: after the overlay (see Section 3.2.6. for more details). The summary of the results from these analyses are presented in this section; Appendix D contains the output tables and plots obtained from the software.

4.5.1. Initial Construction

Figure 16 and Figure 17 present a summary of the distresses predicted by the M-E Design Guide Software from the construction year to the overlay year for flexible pavements and composite pavements, respectively. The predicted distresses for flexible pavements include longitudinal surface-down fatigue cracking, bottom-up (alligator) fatigue cracking, thermal cracking, total rutting, and roughness (in terms of IRI). The predicted distresses for composite pavements include punchouts (these structures were originally CRCP sections), and roughness.

To identify the critical type of predicted distress(es), all types of distresses were plotted in the same figure. In order to plot them together (even when they have different units) the percentage of the distress limit reached in the overlay year was used by applying the following equation:

$$\%\ \textit{Distress Limit} = \frac{\textit{Distress in overlay year}}{\textit{Distress limit}} \times 100 \qquad (26)$$

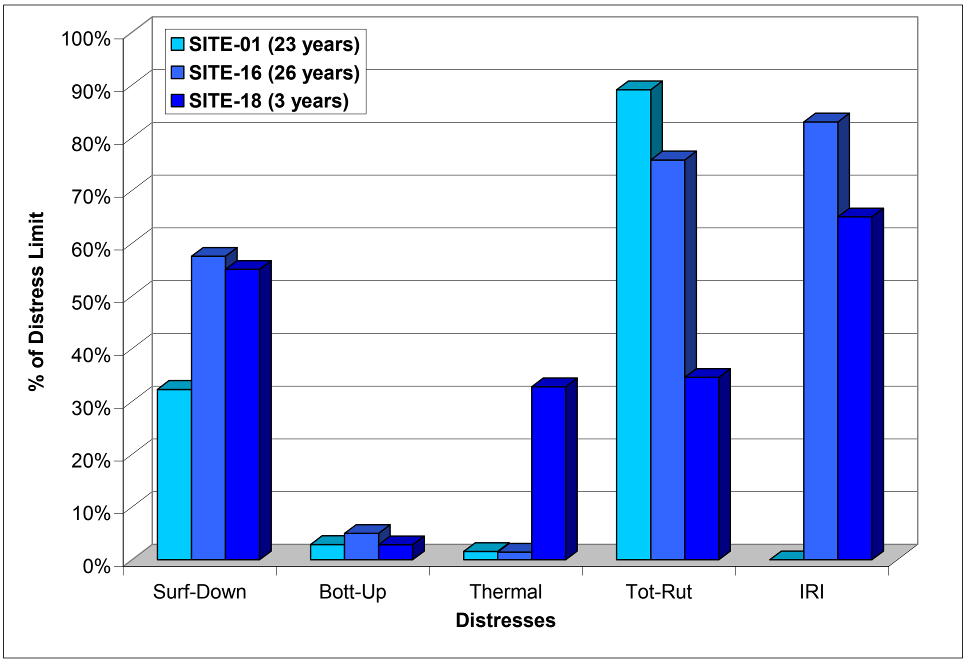


Figure 16. Summary of Predicted Distresses from Construction to Overlay Year (Flexible)

It is important to note that the inputs for the AC mix properties were specified volumetric and default values (Level 3 input level). No AC modulus is necessary as an input for this level. Figure 16 shows that the most critical predicted distress for flexible pavements were the following:

- Rutting: reaching 90% of the distress limit for Site 01, 76% for Site 16, and 35% for Site 18.
- Roughness (IRI): 83% of the limit for Site 16, and 65% for Site 18,
- Surface-down longitudinal fatigue cracking: approximately 55% for Site 16 and Site 18, and 32% for Site 01.
- Thermal cracking: Predicted to affect only Site 18.
- Bottom-up fatigue (alligator) cracking: Reaching no more than 5% of the distress limit for all the flexible pavements.

The predicted condition for Site 18 was not expected to be that deficient given that the structure is only three years old. However, this could be consistent with the actual condition; considering that the structure was overlaid just three years after construction. There is not enough evidence to determine whether the high estimation of distresses is being produced due to an error in the prediction models or the software, or because of the properties inputted for the AC layers.

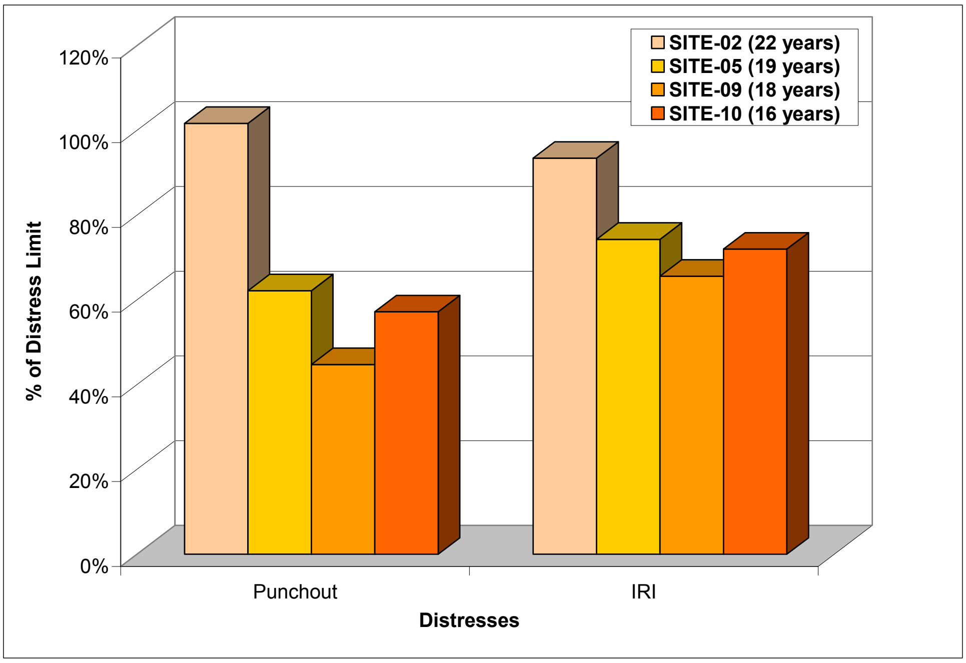


Figure 17. Summary of Predicted Distresses from Construction to Overlay Year (Composite)

Figure 17 shows the summary of the distresses predicted for the original CRCP structures. It shows that punchouts reached 100% of the distress limit is reached in Site 02, 62% in Site 05, 57% in Site 10, and 45% in Site 09. Although none of the pavements have reached 100% of the distress limit, all the sites showed significant increase in roughness.

The general trend observed for the predicted Punchouts and IRI is that, as expected, the older the pavement the more distresses it has, with the exception of Site 09, that is two years older than Site 10 and has a better predicted performance. However, this may be due to the fact that the CRCP layer for Site 09 is 1.25 cm (0.5 in) thicker than Site 10.

4.5.2. After Overlay Predicted Performance

This section compares the observed and measured distresses in April-May 2004 with those predicted by the M-E Design Guide Software after the overlay. The predicted distresses include the values at two reliability levels: 90% and 50%.

Comparison of Measured and Predicted Performance

Surface-down (longitudinal) fatigue cracking is believed to be caused by high shear pressures developed on the pavement's surface at the edge of the wheels [10]. The longitudinal cracks measured from the visual survey included mostly cracks outside the wheelpaths, but very close to the edges of the wheelpath. These were counted as surface-down cracking in order to compare them with the software's output. Figure 18 compares the observed and predicted surface-down cracks in all sections. The measured transverse cracks account for less than 56.8 m/km (300 ft/mi) in all evaluated sites. While the predicted surface-down cracking at 90% reliability in flexible Site 01 (eleven-year-old overlay) is relatively close to the observed cracks; the predicted surface-down cracking is heavily overestimated in the other two flexible sections (more than 10 and 20 times for Site 16 and Site 18, respectively).

The predictions at 90% reliability for the composite pavements showed better results in comparison to flexible pavements, with the exception of Site 10, where the predicted surface-down cracking is more than 4 times the observed cracks. However, these predicted distresses show an almost constant value of 49 m/km for (258 ft/mi) for all composite pavements, which is probably the minimum for this reliability level. No distresses were predicted at 50% reliability, with the exception of Site 16, where the predicted distress is very close to the observed distress.

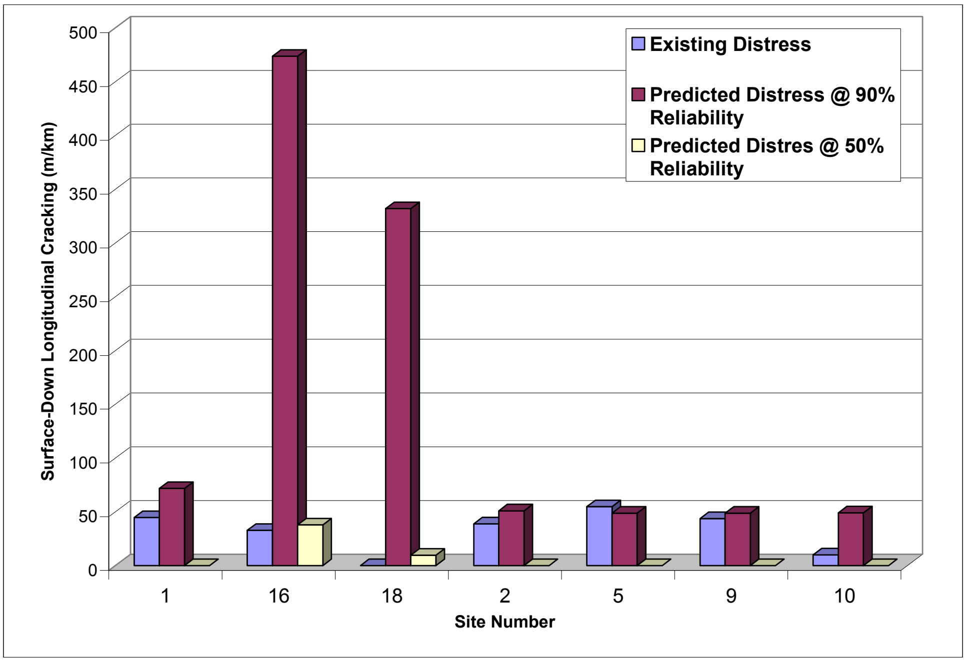


Figure 18. Predicted vs. Current Distresses – Surface-Down (longitudinal) Fatigue Cracking (m/km)

Figure 19 compares the predicted and observed bottom-up (alligator) fatigue cracking. In all cases the predicted and observed cracking are minimal. Sites 01 (flexible) and 05 (composite) are the sites affected the most by this type of distress (0.51% and 0.41% respectively). These values are far from reaching the limit value of 25% of lane area affected by alligator cracking. The model predicted no distress at 50% reliability level, and an almost constant value of 0.71% at 90% reliability, probably because this is the minimum value for this reliability level.

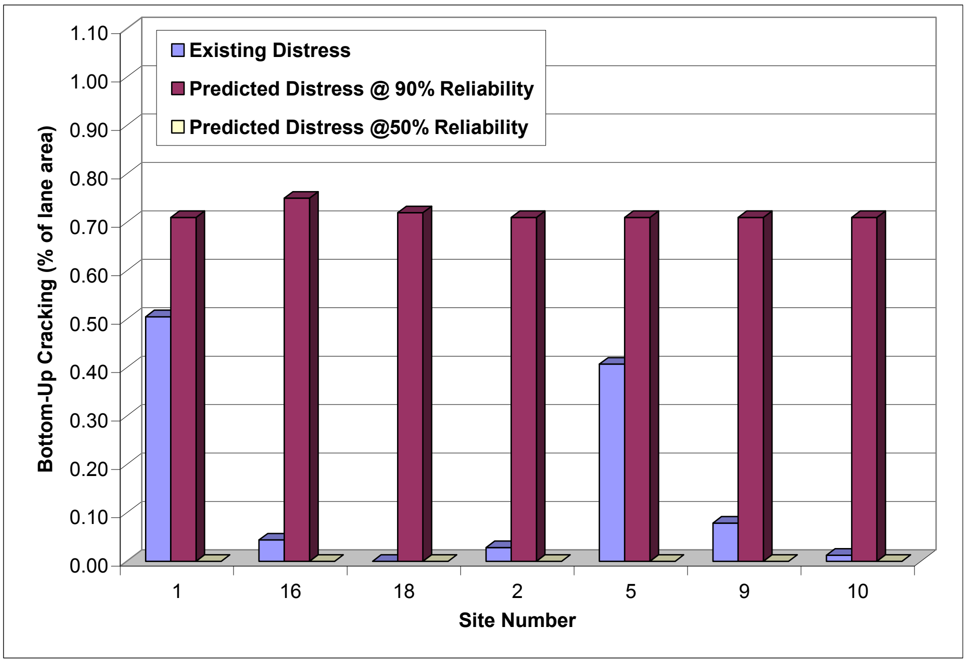


Figure 19. Predicted vs. Current Distresses – Bottom-Up (alligator) Fatigue Cracking (% of Lane Area)

Because of its geographic location, thermal cracking is not likely to be a severe problem in pavements within the Commonwealth of Virginia. However, some transverse cracks were measured in the visual survey (Figure 20), as described:

- Site 01 (flexible) has the most transverse cracking (59 m/km (312 ft/mi) of potentially thermal cracking).
- Sites 09, 05, and 02 (all composite) showed 29.5, 22.7, and 17 m/km (156, 120, and 90 ft/mi) of transverse cracking, respectively; however, these cracks might be reflective cracks from the CRCP layer.
- Site 10 (composite) has a lower number of transverse cracks per mile (4.55 m/km (24 ft/mi)) than the rest of the composite pavements, probably because its asphalt surface mix is a Stone Matrix Asphalt (SMA). This type of mix is known to have

greater asphalt content than regular mixes, and uses modified binder. Once again, these cracks might be reflective cracks from the CRCP layer underneath the AC surface.

- Site 18 (flexible): this Site does not have any existing transverse cracks because it has a relatively new overlay (3 years).

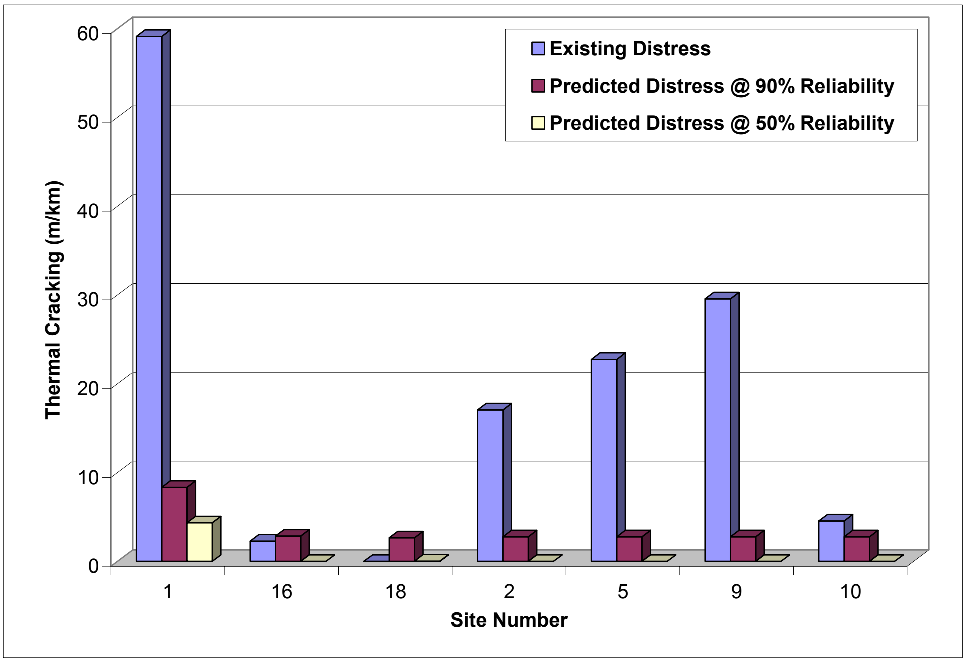


Figure 20. Predicted vs. Current Distresses – Thermal Cracking (m/km)

The M-E Design Software predicted no distress at 50% reliability level, with the exception of Site 01, and a constant value of 2.77 m/km (14.6 ft/mi) at 90% reliability in almost all the projects (with the exception of Site 01), independently of the type of structure, age, or geographic location; this may be because the predicted distress is so low that the output is showing a minimum value for all the evaluated sites.

Figure 21 compares the measured and predicted total rutting (defined as the summation of the rutting in AC layers, unbound base and subgrade) for the seven evaluated sites.

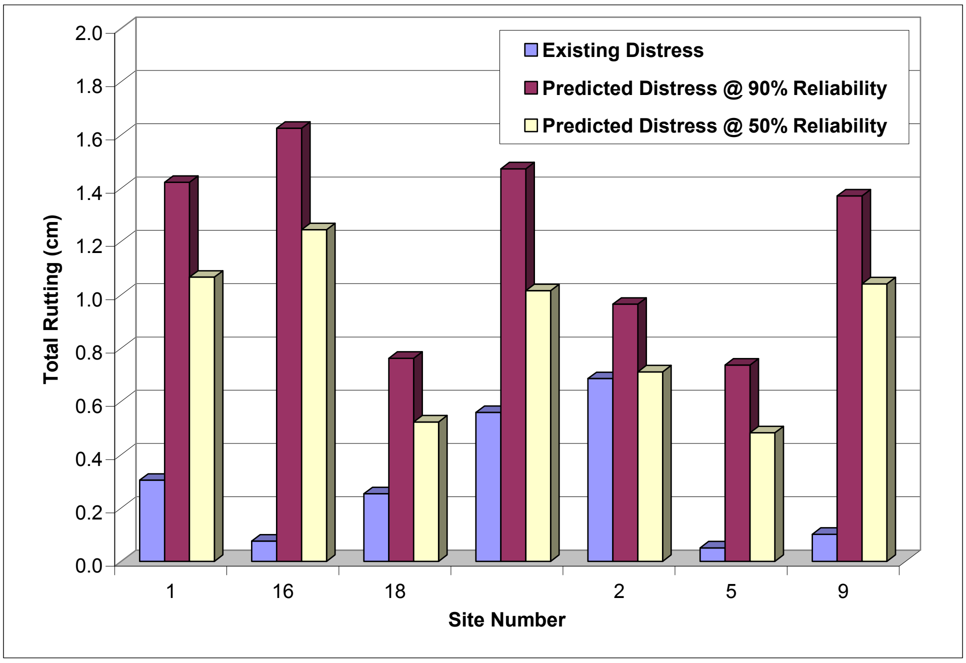


Figure 21. Predicted vs. Current Distresses – Total Rutting (cm)

The following observations can be drawn from the figure:

- Even in the flexible pavement most affected by rutting (Site 01), the *measured* rut depth is only 30 mm (0.12 in) thirteen years after applying the overlay. This can be considered as an outstanding performance considering that this value is almost 6 times less than the rutting allowable limit of 1.91 cm (0.75 in).
- The composite pavements also show good performance even though they show slightly higher *measured* ruts of 69 mm (0.27 in) and 56 mm (0.22 in) for Sites 05 and 02 respectively.
- The *predicted* results show higher levels of ruts depth for all of the Sites; the output files from the software analysis indicate that the total rutting for all the Sites is mainly produced by the deformation of the AC layer.

One of the reasons why the software is predicting higher rutting for the AC layers could be because the properties of these layers were inputted as Level 3 (default values, see Section 2.5.1.). These include the aggregate gradation of the asphalt mix, the binder's grade, and general volumetric properties such as effective binder content, air voids and total unit weight, etc. The software help indicates that direct inputs of the strength or stiffness of the asphalt mix or binder can be input at Level 1 and Level 2. The user can input the results from the dynamic modulus test, and specific properties of the binder's grade (softening point, absolute and kinematic viscosity, specific gravity, penetration, etc.). However, Level 3 was used for the asphalt layer properties because no dynamic modulus tests were performed to the asphalt cores, and the software crashed when trying to input asphalt properties of similar mixes as Level 1.

The smoothness of the pavement structures was measured in terms of the International Roughness Index (IRI), as shown in Figure 22.

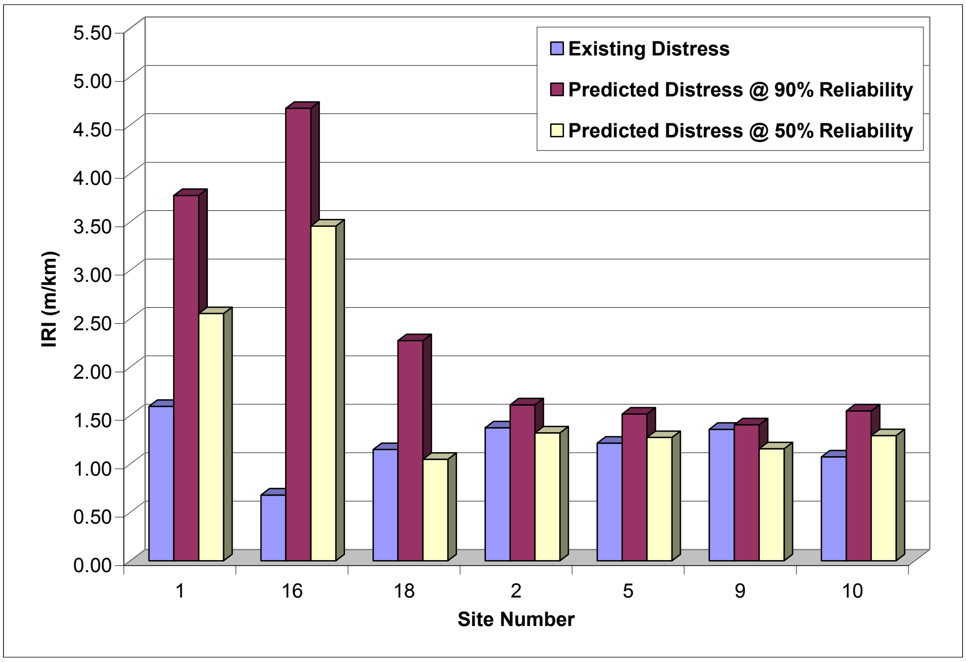


Figure 22. Predicted vs. Current Distresses – IRI (m/km)

The analysis of this figure is presented following:

- Site 01 is the flexible pavement site with the highest *measured* IRI value of 1.53 m/km (96.9 in/mi), followed by Site 18 with 1.15 m/km (72.8 in/mi), and Site 16 with 0.64 m/km (43 in/mi).
- The *measured* IRI is similar for the four composite pavement sites, having a value of 1.37 m/km (87.1 in/mi) for Site 02, 1.31 m/km (82.8 in/mi) for Site 09, 1.19 m/km (75.3 in/mi) for Site 05, and 1.04 m/km (66.0 in/mi) for Site 10.
- These IRI values show that all the sites are performing satisfactorily, considering that some agencies accept an IRI value of 1.26 m/km (80 in/mi) for new structures [20],

and that most of the evaluated pavements have a surface layer at least five years old.

- The *predicted* IRI for flexible pavements at 90% reliability are higher than the measured values, especially for Sites 01 and 16.
- In the case of composite pavements, the predicted values at 90% reliability closer to the measured IRI.
- The *predicted* IRI for flexible and composite pavements at 50% reliability are very close to the measured IRI, with the exception of flexible Sites 01 and 16.

Critical Distress Identification

In order to identify the critical type of distress(es) affecting the pavement structures investigated, Figure 23 was created.

Similarly to the previous section, all the types of distresses for all Sites were plotted in the same figure. The percentage of the distress limit reached in year 2004 was computed using the following equation:

$$\text{\% Distress Limit in 2004} = \frac{\text{Distress in 2004}}{\text{Distress limit}} \times 100 \qquad (27)$$

Figure 23 depicts the flexible pavements in different blue tones, while the composite pavements are shaded with orange colors. One of the first things that can be seen from this figure is that most of the distresses have not reached 50% of the threshold. The most critical distress for flexible pavements is again surface-down cracking, followed by thermal cracking, total rutting, and bottom-up fatigue cracking.

A detailed analysis of the *observed* and *measured* distresses in 2004 is presented following:

- Site 01 (flexible): is the flexible pavement in the worst general condition. It is important to remember that this structure is 34 years old and was overlaid 11 years ago.
- Site 16 (flexible) has an older overlay (13 years) and higher traffic level than Site 01 but shows better performance. Even though no historical data on the previous pavement pre-overlay condition is available. Site 16 may be performing better

because its AC layer is 5 cm (2 in) thicker than Site 01, and because it has a thick aggregate layer of 43 cm (18 in) in comparison to 15 cm (6 in) of Cement Treated Aggregate for Site 01.

- The observed critical distresses for flexible pavements are: bottom-up cracking (Site 02), total rutting (Sites 02 and 05), surface-down fatigue cracking (Sites 05, 09, and 02), and thermal cracking (Sites 05 and 02) in decreasing order.
- The composite pavements in the worst general condition are Site 05 and Site 02. These sites have the highest measured rutting.
- Even though Sites 09 and 10 have similar structure, similar age and are located close from each other, Site 10 is performing better even with a higher level of traffic. It is suspected that the enhanced performance is due to the SMA surface used on this Site.

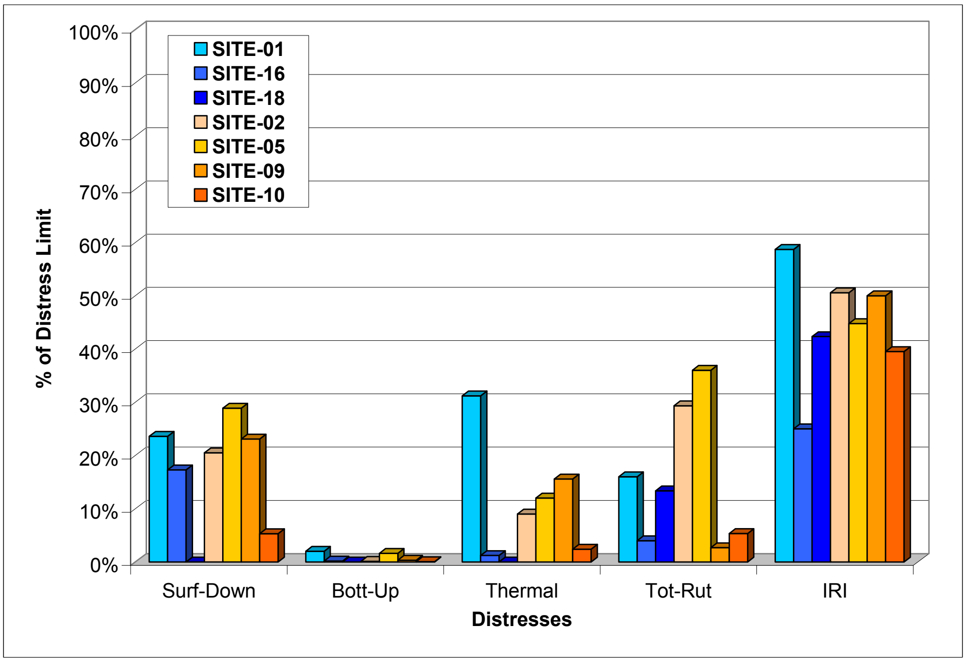


Figure 23. Summary of Existing Distresses in 2004

4.6. M-E Design Guide Software Limitations and Troubleshooting

During the analysis, some problems and limitations with the software were encountered. However, time constrains of the project did not allow to conduct a detailed evaluation of the software, or a thorough troubleshooting of the problems encountered. Some of the problems are listed as follows:

- If *traffic opening month* is not one month after the CRCP is placed, the program will give an error with the punchout model.
- When the rehabilitation analysis was performed for a relatively complex structure, or for a long life period (greater than 20 years), the program crashed and the following error message prompted out: "*Error – Failure to open modulus.tmp and fatigue.tmp. Apads MFC. Application has encountered a problem and needs to close. We are sorry for any inconvenience*".
- It was observed that in the *Rehabilitation Levels 2* and *3* it is allowed to enter the backcalculated layer moduli for the asphalt layers (even for *Level 3 Input*); however, unreasonable results were obtained, i.e. the predicted asphalt moduli were extremely low, consequently, a high occurrence of distresses was predicted. The results presented on this thesis are based on the use of *Rehabilitation Level 3* without allowing the input of the backcalculated layer moduli for the asphalt layers in *Level 3 Input*, therefore just default values and values established in road construction specifications were used, making the results less accurate.
- When trying to input the asphalt properties as *Level 1 Input* the following error occurred: "*Modulus.exe has encountered a problem and needs to close*".
- The program was not able to estimate the IRI for a structure with an AC surface over a CTA layer. It is believed that this happened because the fatigue model for the chemically stabilized layer is not yet calibrated.
- The IRI model was not sensitive to different structures and ages; it appeared to be using default values.

Chapter 5 - FINDINGS AND CONCLUSIONS

The structural analysis of three flexible and four composite pavement structures allowed determining the structural adequacy of each of the pavement structures. This analysis also provided some of the inputs required to predict pavement performance using the M-E Design Guide Software. The comparison of the measured and predicted distresses allowed a preliminary verification of the M-E Design Guide capabilities and the adequacy of its models for predicting the performance of pavement structures in the Commonwealth of Virginia. This chapter presents the main findings and conclusion from the investigation.

5.1. Findings

Following are the main findings concerning the structural adequacy of the evaluated pavement sections, and the verification of the M-E Design Guide Software:

- The amount of observed and measured distresses was not significant in most of the evaluated flexible and composite pavements. The evaluated sections fitted into the *adequate* condition level for the different types of measured distresses, with the only exception of composite Site 05, with a *marginal* level for longitudinal cracking.
- In general, the backcalculation process presented some difficulties because of the complexity of some of the structures evaluated, especially the composite pavements. The problems are believed to be due to departure from some of the assumptions used by the software, e.g. moduli not decreasing with depth, and compensating errors. In addition, the thin HMA surface layers had to be combined with the HMA base.
  - The backcalculation for the flexible pavements produced reasonable moduli for all the pavement layers and good RMS error values (ranging from 3.0% to 3.2%).
  - The results achieved for the composite sections were also considered reasonable and the RMS error was lower than for the flexible pavements (1.6% to 3.0%). However, the backcalculated moduli for the asphalt layers were relatively low.
  - The backcalculated subgrade moduli were in general higher than the typical values reported in the literature. The computed values were 1.5 times higher than the

average typical modulus for silty soils, and 2.8 times higher than the average typical modulus for clayey soils.

  - The backcalculated HMA moduli were generally lower than the resilient modulus obtained in the laboratory (with the exception of Site 10).
  - The backcalculated modulus of the CRCP section was similar to the modulus estimated from compressive strength test on extracted cores for the composite pavements without an ATB layer, but the backcalculated moduli were lower than the lab results in the case of composite pavements with an ATB layer.

- The visual survey conducted in 2004 suggests that the most critical distress for the flexible pavements is longitudinal (probably surface-down) cracking, followed by rutting and transversal (thermal) cracking. For the composite pavements, the most critical distress was rutting, followed by longitudinal (probably surface-down) cracking, and transversal (thermal) cracking. No significant amount of bottom-up (alligator) cracking was observed in any of the evaluated sections.
- The estimation of the effective structural adequacy (in terms of SN_{eff} for flexible and D_{eff} for composite pavements) shows that the evaluated sites are structurally sound.
- The distresses predicted by the M-E Design Software at 90% reliability were in general higher than those measured on the overlaid pavements. On the other hand, minimal or no surface-down, bottom-up fatigue, or thermal cracking were predicted at 50% reliability on any of the sites.
- The *predicted* IRI for flexible and composite pavements at 50% reliability are very close to the measured IRI, with the exception of flexible Sites 01 and 16.

5.2. Conclusions

The in-depth structural evaluation of the three flexible and four composite pavements showed that all the sites are structurally sound. The investigation also confirmed that the use of GPR to determine layer thicknesses and the comparison with a minimum number of cores is a helpful tool for pavement structural evaluation. Despite some difficulties performing the backcalculation analysis for complex structures, the obtained results were considered reasonable and were useful in estimating the current structural adequacy of the evaluated structures.

The comparison of the measured distresses with those predicted by the M-E Design Guide software showed poor agreement. In general, the predicted distresses were higher than the distresses actually measured. However, there was not enough evidence to determine whether this is due to errors in the prediction models or software, or because of the use of defaults material properties, specially for the AC layers. It must be noted that although an in-depth field evaluation was performed, only Level 3 data was available for many of the input parameters. The results suggest that significant calibration and validation will be required before implementation of the M-E Design Guide.

Chapter 6 - RECOMMENDATIONS

The recommendations included in this Chapter are intended to enhance the data collection and analysis process for future in-depth field evaluations, as well as to improve the understanding of the use of the M-E Design Guide Software.

Recommendations for Data Collection

The extensive filed investigations allowed recommending some potential improvements to the pavement evaluation procedures that may be applied in future similar projects:

- In order to determine the thickness of the existing layers accurately it is recommended to keep comparing the thicknesses obtained from the coring process, GPR, and Historical Data because these methods complement each other.
- It would be useful to perform some basic strength tests on the granular layers and subgrade to obtain more information about these layers because the historical data is not always available and/or reliable. A simple device that allows estimating the CBR and resilient modulus values is, for example, the Dynamic Cone Penetrometer [11], [16].
- To understand the behavior of the subgrade soil it is recommended to at least run a complete soil classification. The gradation and type of subgrade are also important inputs required to perform the analysis using the M-E Design Software.
- Having historical records of the condition of the road before applying the overlay, as well as measurements of the longitudinal and transverse profiles before and after the overlay could help in understanding the development of current distresses and pavement performance.
- Despite the difficulties with the FWD backcalculation for complex pavement structures, it is recommended to continue using this method to estimate layer moduli and the structural adequacy of the pavement structure.

Recommendation for Future Research

The *national calibration factors* used on the distress prediction models do not seem to apply to the structures considered for this thesis. Calibration of the performance models to the conditions in the Commonwealth of Virginia is recommended.

It is suspected that the predicted results achieved from the M-E Design Software were affected by the default asphalt layer properties used. The input information used was mostly default values and typical values specified by the Commonwealth of Virginia (input Level 3), even after performing an in-depth evaluation. It is recommended to perform a complete characterization of the AC materials (including dynamic modulus, volumetric properties, etc.) to asses the effect of using measured properties on the prediction of pavement performance.

References

[1] American Association for State Highway and Transportation Officials (AASHTO), "Guide for Design of Pavement Structures", 1993.

[2] ASCE, ASCE Renewing America's Infrastructure – A Citizen's Guide – Report Card for America's Infrastructure, http://www.asce.org/reportcard/2005/page.cfm?id=30

[3] Bredenhann, S., and van de Ven, M., Application of Artificial Neural Networks in the Back-Calculation of Flexible pavement Layer Moduli from Deflection Measurements, In *8th Conference on Asphalt Pavements for Southern Africa (CAPSA '04)*, ISBN Number 1-920-01718-6, Sun City, South Africa, September 2004.

[4] Cost - Transport, Final Draft Report of COST Action 336 – Falling Weight Deflectometer, Lisbon, June 1999.

[5] Dynatest, ELMOD 4 for Windows, http://www.dynatest.com/software/elmod_4.htm#.

[6] Federal Highway Administration, Temperature Predictions and Adjustment Factors for Asphalt Pavement, Publication No. FHWA-RD-98-085, Virginia, June, 2000.

[7] Flintsch, G., Appea, A., Al-Qadi, I., and Loulizi, A., "Backcalculation Validation Through Field Instrumentation Response at the Virginia Smart Road", Virginia Tech Transportation Institute, presented for the Second International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control, Auburn, Alabama, USA.

[8] Foinquinos, R., Roesset, J. and Stokoe II, K., Response of Pavement Systems to Dynamic Loads Imposed by Nondestructive Tests, *Transportation Research Record 1504*, pp 57-67, 1995.

[9] George, K., Soil Stabilization Field Trial - Interim Report III. Department of Civil Engineering, University of Mississippi, November, 2003.

[10] Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures – Final Report (1-37A), National Cooperative Highway Research Program (NCHRP), Transportation Research Board (TRB) and National Research Council (NRC), March 2004.

[11] Herath, A., et al., The Use of Dynamic Cone Penetrometer to Predict Resilient Modulus of Subgrade Soils.

[12] Hoffman, M. S., and M. R. Thompson. Comparative Study of Selected Nondestructive Devices. *Transportation Research Record 1293*, TRB, National Research Council, Washington, DC, 1991, pp. 12-23.

[13] Hudson, R., Haas, R., and Uddin, W., “Infrastructure Management: Integrating Design, Construction, Maintenance, Rehabilitation, Renovation”, McGraw Hill, United States of America, 1997.

[14] Li, Y., and Nazarian, L., Evaluation of Aging of Hot Mix Asphalt Using Wave Propagation Techniques. In *STP 1265*, ASTM, Philadelphia, PA, 1994.

[15] Mehta, Y., and Roque, R., “Evaluation of FWD Data for Determination of Layer Moduli of Pavements, ASCE Journal of Materials in Civil Engineering, Vol. 15, No. 1, Feb 1 2003.

[16] Minnesota Department of Transportation, User Guide to the Dynamic Cone Penetrometer, Office of Minnesota Road Research, Minnesota, 1996, 20 pp.

[17] Saeed, A., and Hall, J., Comparison of Non-Destructive Testing Devices to Determine In-Situ Properties of Asphalt Concrete Pavement Layers, Transportation Research Board, Washington, D.C., 2003.

[18] Strategic Highway Research Program, “SHRP’s Layer Moduli Backcalculation Procedure (SHRP-P-655)”, National Research Council, Washington, DC 1993.

[19] Ullidtz, P., Coetzee, N., Analytical Procedures in Nondestructive Testing Pavement Evaluation. In *Transportation Research Record 1482.* Transportation Research Board, Washington, D.C., 1995.

[20] US Army Corps of Engineers and Federal Aviation Administration, Hot-Mix Asphalt Paving Handbook 2000.

[21] Virginia Department of Transportation, A Guide To Evaluating Pavement Distress Through The Use Of Video Images, Maintenance Division, Revised on 08/23/01.

[22] Virginia Department of Transportation, Development and Implementation of Pavement Condition Indices for the Virginia Department of Transportation (Phase I and II, Flexible and Rigid Pavements), Maintenance Division, 2002.

[23] Virginia Department of Transportation, Road and Bridge Specifications for the Commonwealth of Virginia, Richmond, July 1982.

[24] Virginia Department of Transportation, Road and Bridge Specifications for the Commonwealth of Virginia, Richmond, January 1991.

[25] Virginia Department of Transportation, Road and Bridge Specifications for the Commonwealth of Virginia, Richmond, January 1994.

[26] Virginia Department of Transportation, Road and Bridge Specifications for the Commonwealth of Virginia, Richmond, 2002.

[27] Virginia Department of Transportation, TAG User’s Manual and Technical Documentation, Version 1.0, Materials Division – Pavement Design and Evaluation Section, November 2001.

[28] Washington Department of Transportation (WSDOT), Pavement Guide – Pavement Analysis Computer Software and Case Studies, Volume 3, Washington State, February 1995.

Appendix A – Determination of Layer Thickness from Cores, GPR, and Historical Data

Appendix A – Determination of Layer Thicknesses from Cores, GPR, and Historical Data

FLEXIBLE PAVEMENTS:

Table A-1. Site 01 (Flexible)

	HISTORICAL DATA			GPR		CORES	
Layer #	**Material**	**Thickness mm (in)**	**Year**	**Material**	**Thickness mm (in)**	**Material**	**Thickness mm (in)**
1	SM-2A	38 (1.5)	1993	SM2A + S6	58 (2.3)	Surface Mix	115 (4.5)
2	S-6	30 (1.2)	1981				
3	S-5	unknown	1970	S-5	198.1 (7.8)	Base Mix	125 (4.9)
4	-	-	-	-	-	Cement Treated Aggregate	150 (5.9)
4	Subgrade	-	-	Subgrade	-	Subgrade	-

SM: Asphalt surface mix layer; **S**: Asphalt surface layer
NOTE: Shaded area indicates the thickness selected for each layer

Table A-2. Site 16 (Flexible)

	HISTORICAL DATA			GPR		CORES	
Layer #	**Material**	**Thickness mm (in)**	**Year**	**Material**	**Thickness mm (in))**	**Material**	**Thickness mm (in)**
1	SM-2C	46 (1.8)	1991	SM-2C	48.2 (1.9)	Surface Mix	39 (1.5)
2	I-3	10 (0.4)	1965	I3 + CB1 + H3	233 (9.2)	Base Mix	256 (10.1)
3	CB-1 or H-2	33 (1.3)	-				
4	H-3	191 (7.5)	-				
5	Aggregate Base Type 1	152 (6.0)	-	Aggregate Base	125.4 (4.9)	-	-
6	Select Material Type 1	305 (12.0)	-	-	-	-	-
7	Subgrade	-	-	Subgrade	-	Subgrade	-

SM: Asphalt surface mix layer; **I**: Asphalt intermediate layer; **CB**: Asphalt base layer; **H**: Asphalt base layer
NOTE: Shaded area indicates the thickness selected for each layer

Table A-3. Site 18 (Flexible)

	HISTORICAL DATA			GPR		CORES	
Layer #	Material	Thickness mm (in)	Year	Material	Thickness mm (in)	Material	Thickness mm (in)
1	SM-2A	51(2.0)	2001	SM2B	58.9 (2.3)	Surface Mix	55 (2.2)
2	IM-1A	64 (2.5)	1999	IM1A	30.1(1.2)	Base Mix (IM + BM)	319 (12.6)
3	BM-3	254 (10.0)	1999	BM3	246.9 (9.7)		
4	OGDL-Type1 (2%)	76 (3.0)	1999	OGDL	51.4 (2.0)	OGDL (asphalt)	70 (2.8)
5	21B	533 (21.0)	1999	-	-	-	-
6	Subgrade	-	-	Subgrade	-	Subgrade	-

SM: Asphalt surface mix layer; **IM**: Asphalt intermediate mix layer; **BM**: Asphalt base mix layer; **OGDL**: Open graded drainage layer; **21B**: Aggregate base layer

NOTE: Shaded area indicates the thickness selected for each layer

COMPOSITE PAVEMENTS:

Table A-4. Site 02 (Composite)

	HISTORICAL DATA			GPR		CORES	
Layer #	Material	Thickness mm (in)	Year	Material	Thickness mm (in)	Material	Thickness mm (in)
1	SM-2C	38 (1.5)	1992	SM-2C	51.7 (2.0)	Surface Mix	41(1.6)
2	BM-2	74 (2.9)	1992	BM-2	70.9 (2.8)	Base Mix	74 (2.9)
3	CRCP	203 (8.0)	1970	CRCP	159.8 (6.3)	CRCP	209 (8.2)
4	Subgrade	-	-	Subgrade	-	Subgrade	-

SM: Asphalt surface mix layer; **BM**: Asphalt base mix layer; **CRCP**: Continuously reinforced concrete pavement

NOTE: Shaded area indicates the thickness selected for each layer

Table A-5. Site 05 (Composite)

	HISTORICAL DATA			GPR		CORES	
Layer #	Material	Thickness mm (in)	Year	Material	Thickness mm (in)	Material	Thickness mm (in)
1	SM-2C	38 (1.5)	1991	SM2C + IM1B	115 (4.5)	Surface Mix	44 (1.7)
2	IM-1B	102 (4.0)	1990			Base Mix	67 (2.6)
3	CRCP	203 (8.0)	1972	CRCP + Base	339.4 (13.4)	CRCP	196 (7.7)
4	Aggregate Size 22	152 (6.0)	1972			-	-
5	Subgrade	-	1972	-	-	-	-

SM: Asphalt surface mix layer; **IM**: Asphalt intermediate mix layer; **CRCP**: Continuously reinforced concrete pavement

NOTE: Shaded area indicates the thickness selected for each layer

Table A-6. Site 09 (Composite)

	HISTORICAL DATA			GPR		CORES	
Layer #	**Material**	**Thickness mm (in)**	**Year**	**Material**	**Thickness mm (in)**	**Material**	**Thickness mm (in)**
1	SM-2D	51(2.0)	1998	SM-2D	87.6 (3.4)	Surface	95 (3.7)
2	CRCP	203 (8.0)	1980	CRCP	244.2 (9.6)	CRCP	216 (8.5)
3	21A (4%)	152 (6.0)	1980	-	-	-	-
4	Subgrade	-	-	Subgrade	-	Subgrade	-

SM: Asphalt surface mix layer; **21A**: Cement treated aggregate layer; **CRCP**: Continuously reinforced concrete pavement
NOTE: Shaded area indicates the thickness selected for each layer

Table A-7. Site 10 (Composite)

	HISTORICAL DATA			GPR		CORES	
Layer #	**Material**	**Thickness mm (in)**	**Year**	**Material**	**Thickness mm (in)**	**Material**	**Thickness mm (in)**
1	SMA	38 (1.5)	1996	SMA + IM1A	99.3 (3.9)	Surface Mix	40 (1.6)
2	IM-1A	51(2.0)	1996			Base Mix	59 (2.3)
3	CRCP	203 (8.0)	-	CRCP	211.5 (8.3)	CRCP	203 (8.0)
4	CTA	152 (6.0)	-	-	-	-	-
5	Subgrade	-	-	Subgrade	-	Subgrade	-

SM: Asphalt surface mix layer; **IM**: Asphalt intermediate mix layer; **CRCP**: Continuously reinforced concrete pavement; **CTA**: Cement treated aggregate
NOTE: Shaded area indicates the thickness selected for each layer

Appendix B – Homogeneous Sections Based on Cumulative Sums of Deflections

Appendix B – Homogeneous Sections Based on Cumulative Sums of Deflections

FLEXIBLE PAVEMENTS:

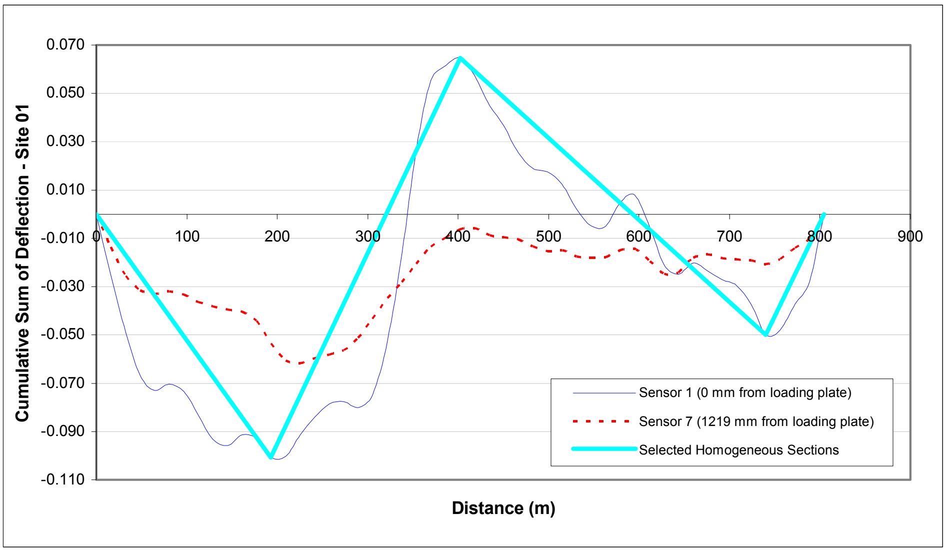


Figure B-1. Homogeneous Sections – Site 01

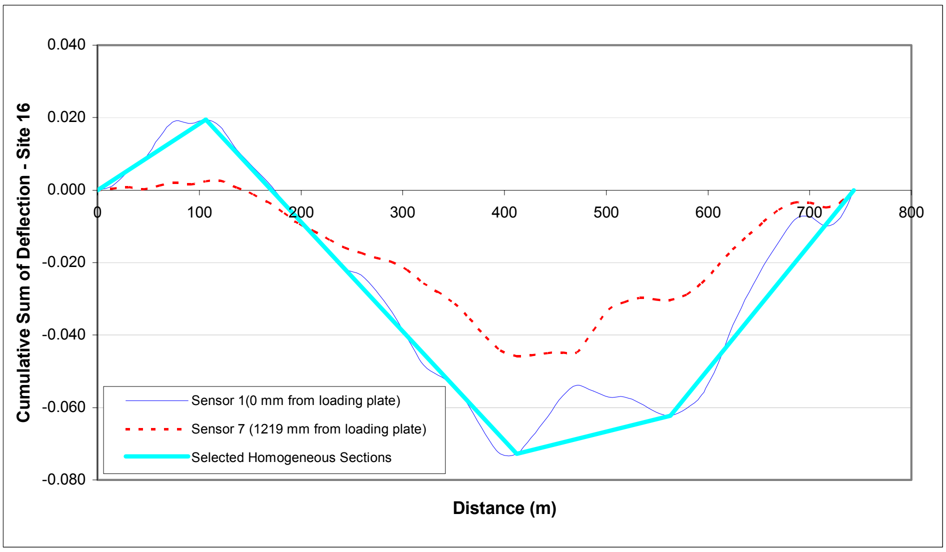


Figure B-2. Homogeneous Sections – Site 16

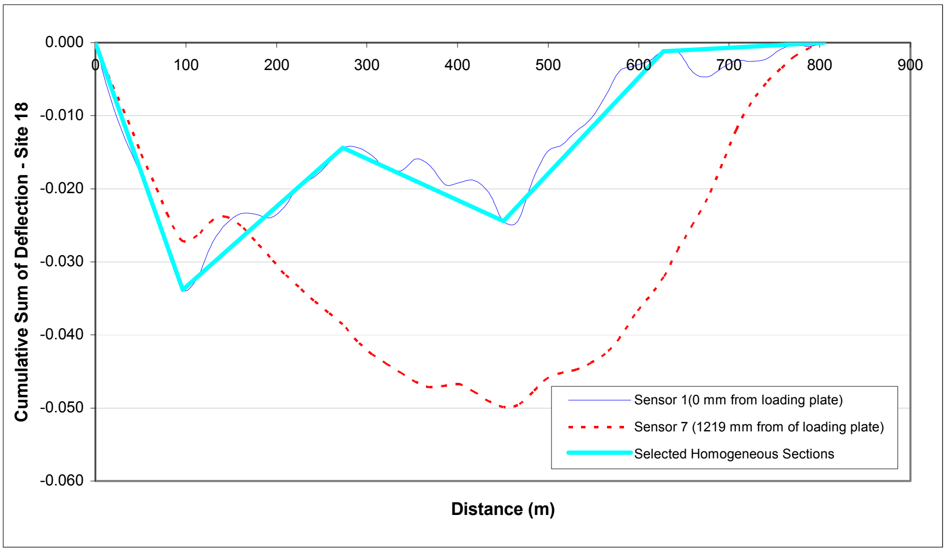


Figure B-3. Homogeneous Sections – Site 18

COMPOSITE PAVEMENTS:

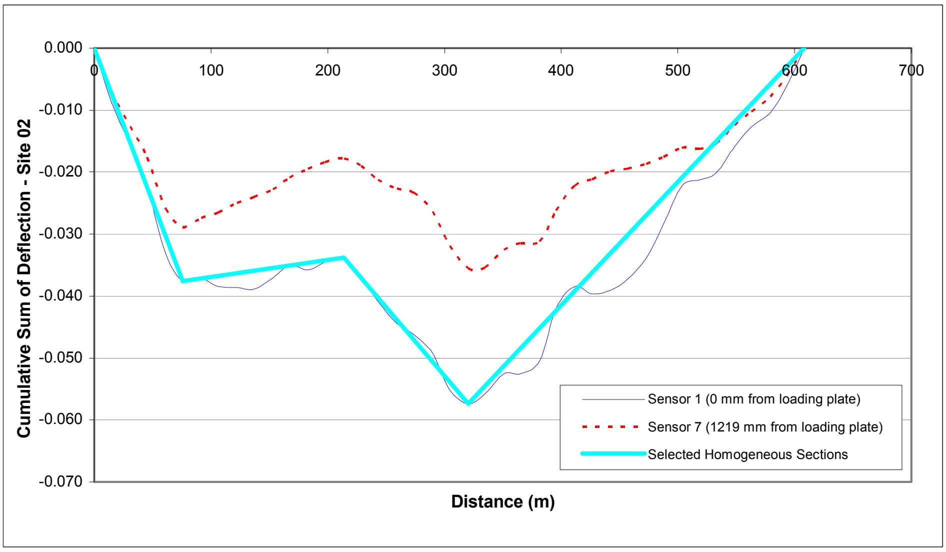


Figure B-4. Homogeneous Sections – Site 02

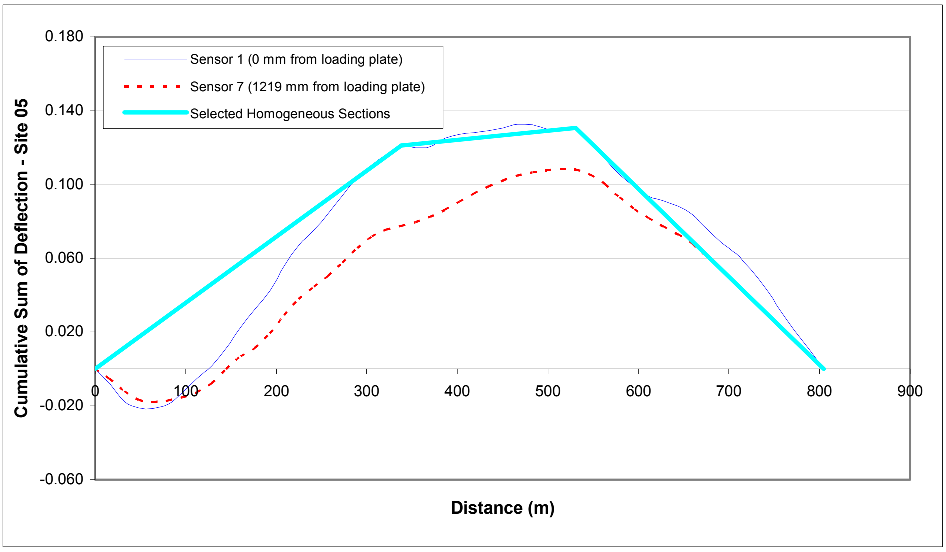


Figure B-5. Homogeneous Sections – Site 05

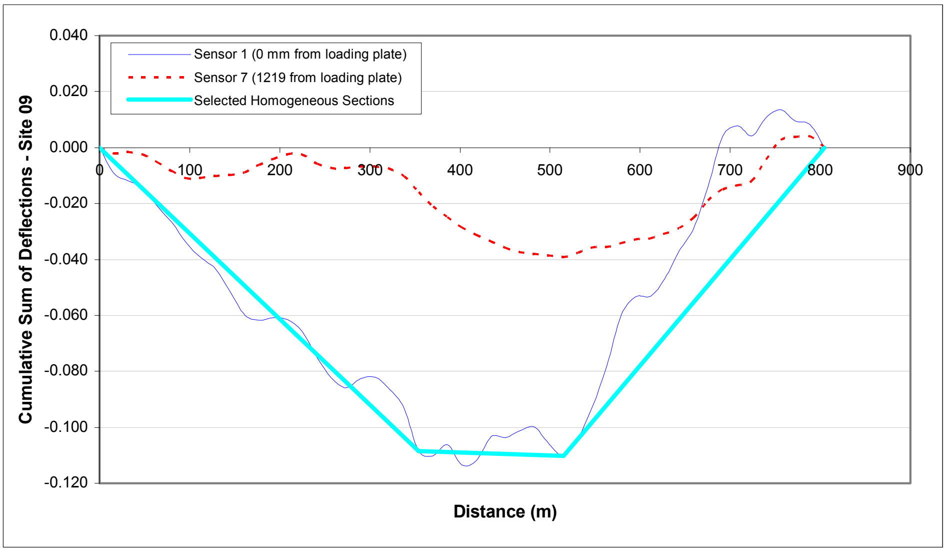


Figure B-6. Homogeneous Sections – Site 09

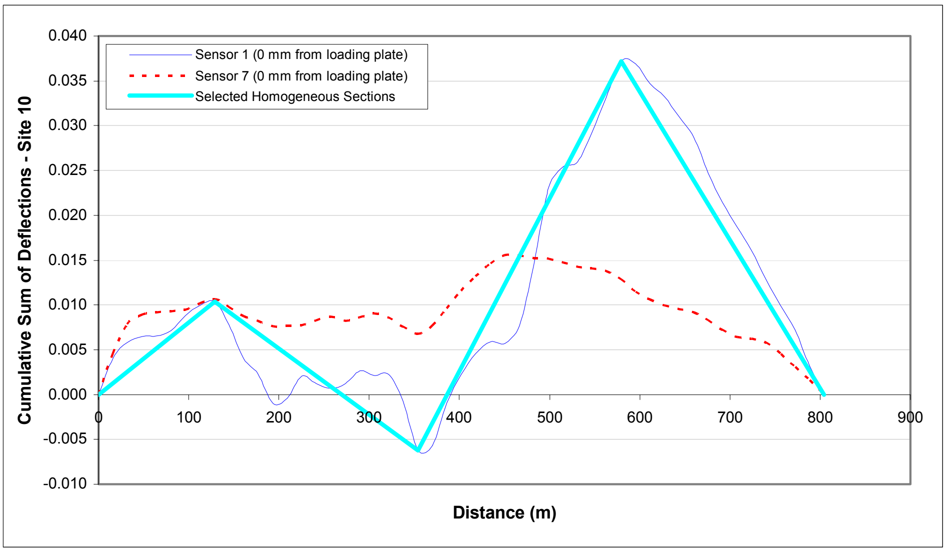


Figure B-7. Homogeneous Sections – Site 10

Appendix C – Backcalculation Results ELMOD 5.1

Appendix C – Backcalculation Results ELMOD 5.1

FLEXIBLE PAVEMENTS:

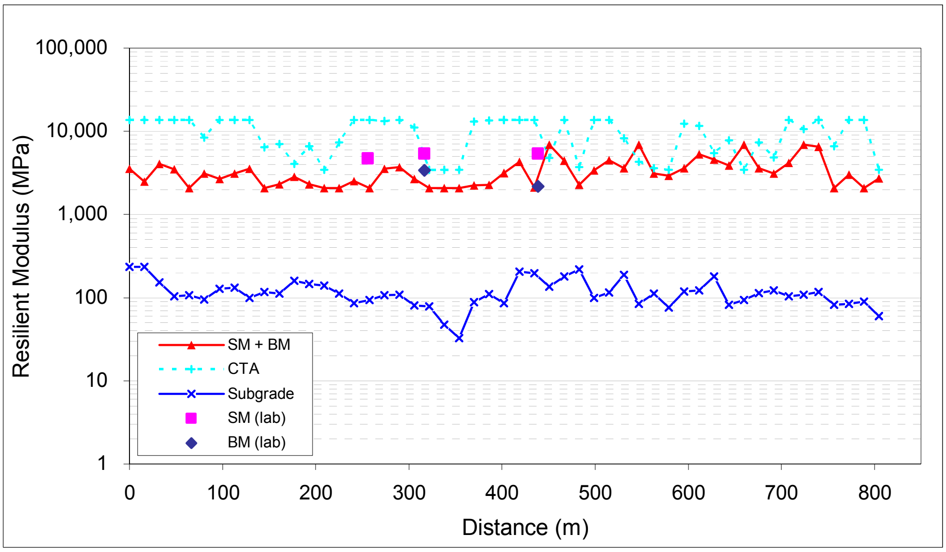


Figure C-1. Backcalculation Results – Site 01

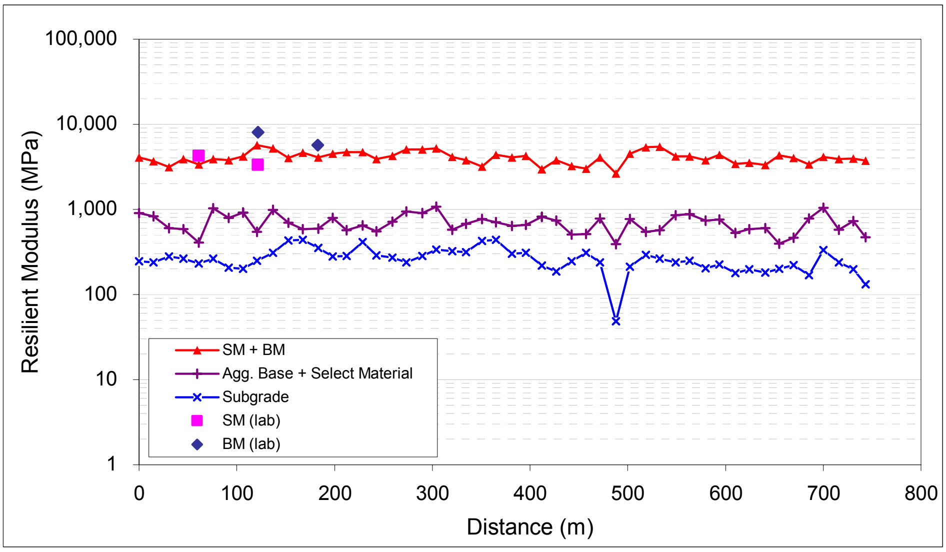


Figure C-2. Backcalculation Results – Site 16

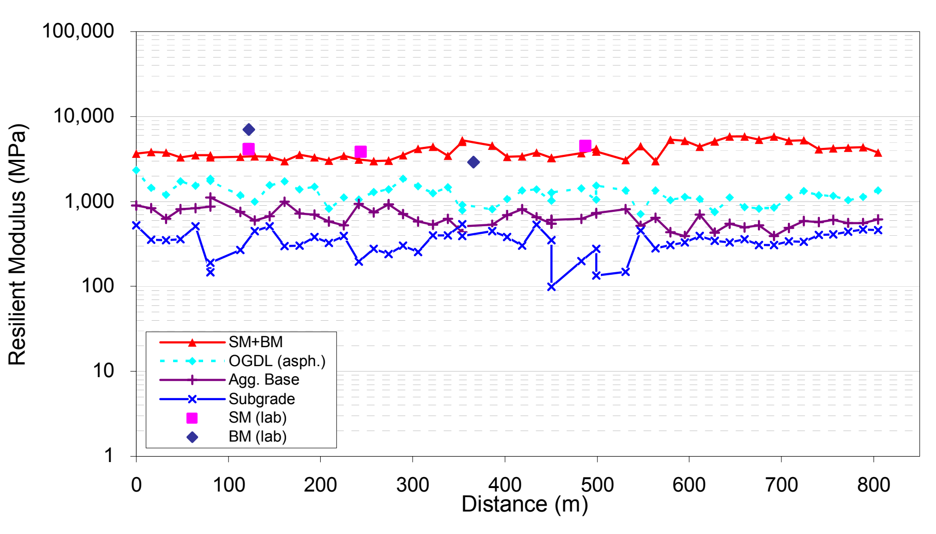


Figure C-3. Backcalculation Results – Site 18

COMPOSITE PAVEMENTS:

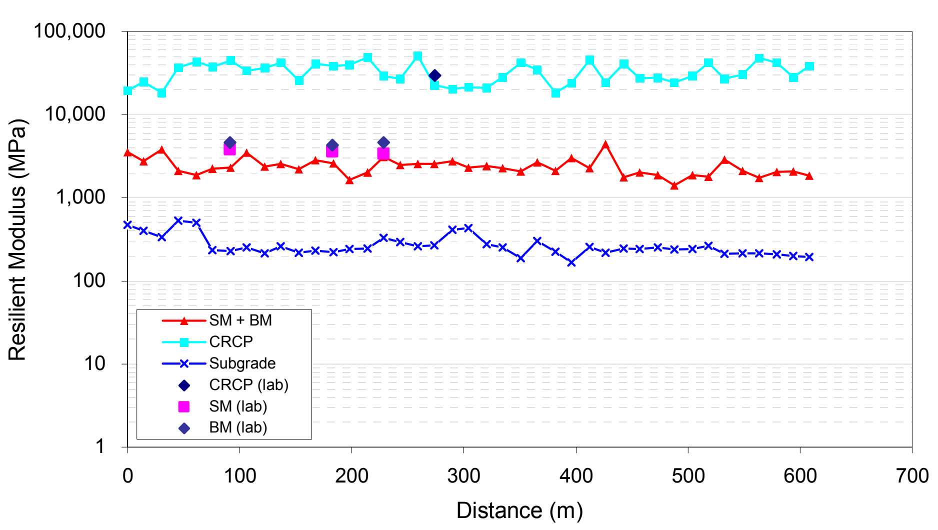


Figure C-4. Backcalculation Results – Site 02

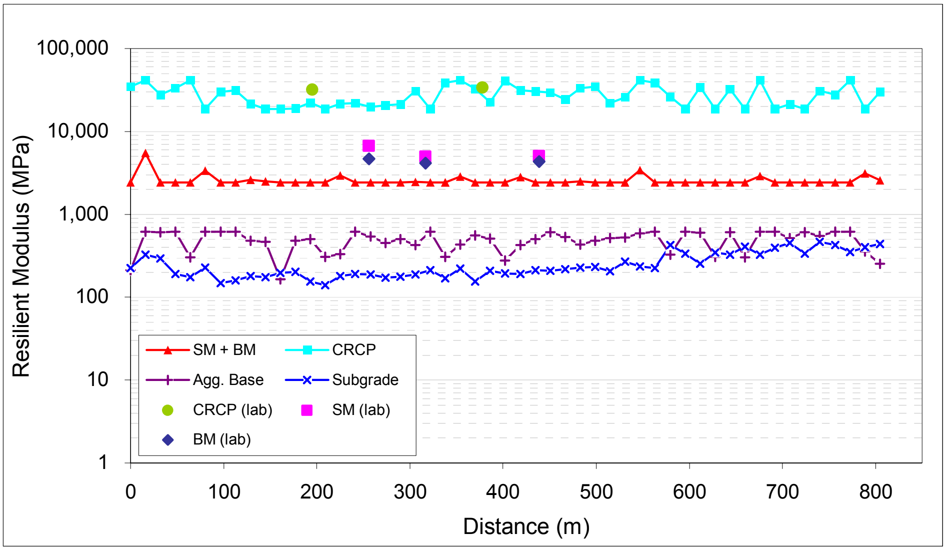


Figure C-5. Backcalculation Results – Site 05

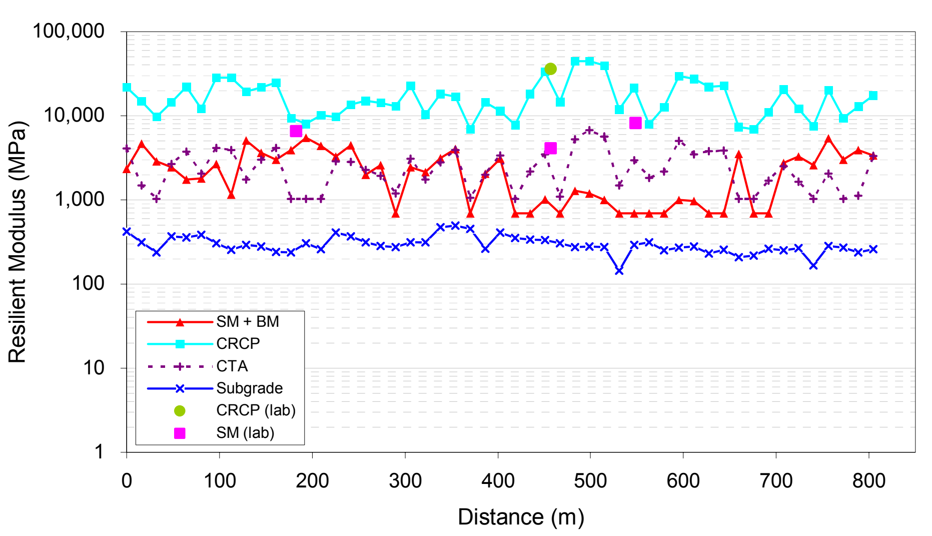


Figure C-6. Backcalculation Results – Site 09

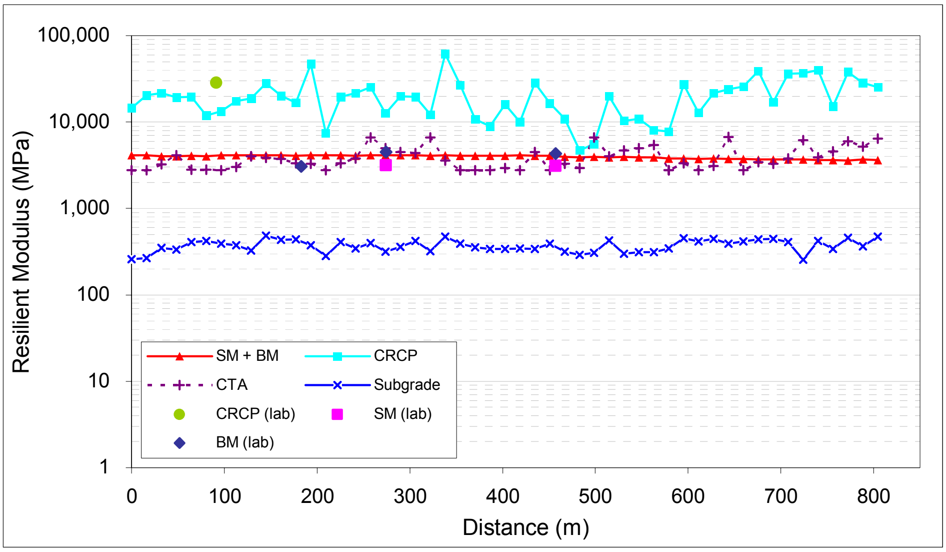


Figure C-7. Backcalculation Results – Site 10

Appendix D – M-E Design Software Output

Appendix D – M-E Design Software Output

Project: SITE01-New Design.dgp

General Information

Design Life	25 years
Base/Subgrade construction:	August, 1970
Pavement construction:	September, 1970
Traffic open:	September, 1970
Type of design	Flexible

Description:
(RUN 1: Original Design) o Route: 29 South o County: Amherst (number 5) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Flexible, 10-15 years o Traffic: TT 1,100, AADT 20,000 (one way traffic) o AC overlay 1.5in ; HMA 8in; CTA 6in o Subgrade: wet red, brown, gray sandy silt w/mica, fill material

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	62	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location:	SITE 01	
Project ID:	SITE O1	
Section ID:		
	Principal Arterials - Interstate and Defense Routes	
Date:	2/13/2005	
Station/milepost format:	Miles: 0.000	
Station/milepost begin:		7.8
Station/milepost end:		7.3
Traffic direction:	South bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	580
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

Month	Vehicle Class									
	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site01-01B
Latitude (degrees.minutes)	37.57
Longitude (degrees.minutes)	-79.06
Elevation (ft)	628
Depth of water table (ft)	23

Structure--Design Features

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	3

General Properties

General

Reference temperature (F°):	70

Volumetric Properties as Built
Effective binder content (%): 11
Air voids (%): 4.3
Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix
Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 12
Cumulative % Retained #4 sieve: 45
% Passing #200 sieve: 5

Asphalt Binder
Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 2 -- Asphalt concrete

Material type: Asphalt concrete
Layer thickness (in): 5

General Properties
General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 10
Air voids (%): 6
Total unit weight (pcf): 162

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix
Cumulative % Retained 3/4 inch sieve: 21
Cumulative % Retained 3/8 inch sieve: 40
Cumulative % Retained #4 sieve: 57
% Passing #200 sieve: 4

Asphalt Binder
Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 3 -- Cement Stabilized

General Properties
Material type: Cement Stabilized
Layer thickness (in): 6
Unit weight (pcf): 150
Poisson's ratio: 0.2

Strength Properties
Elastic/resilient modulus (psi): 1256000

Thermal Properties
Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Layer 4 -- ML

Unbound Material: ML
Thickness(in): 12

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 17000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Layer 5 -- ML

Unbound Material: ML
Thickness(in): Semi-infinite

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 17000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Distress Model Calibration Settings - Flexible

AC Fatigue Level 3 (Nationally calibrated values)

k1	0.00432
k2	3.9492
k3	1.281

AC Rutting Level 3 (Nationally calibrated values)

k1	-3.4488
k2	1.5606
k3	0.4791

Thermal Fracture

Level 3 (Nationally calibrated values)

k1	5
Std. Dev. (THERMAL):	0.2474 * THERMAL + 10.619

CSM Fatigue

Level 3 (Nationally calibrated values)

k1	1
k2	1

Subgrade Rutting

Level 3 (Nationally calibrated values)

Granular:

k1	1.673

Fine-grain:

k1	1.35

AC Cracking

AC Top Down Cracking

C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.0001)))

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*1

IRI

IRI Flexible Pavements with GB

C1 (GB)	0.0463
C2 (GB)	0.00119
C3 (GB)	0.1834
C4 (GB)	0.00384
C5 (GB)	0.00736
C6 (GB)	0.00115
Std. Dev (GB)	0.387

IRI Flexible Pavements with ATB

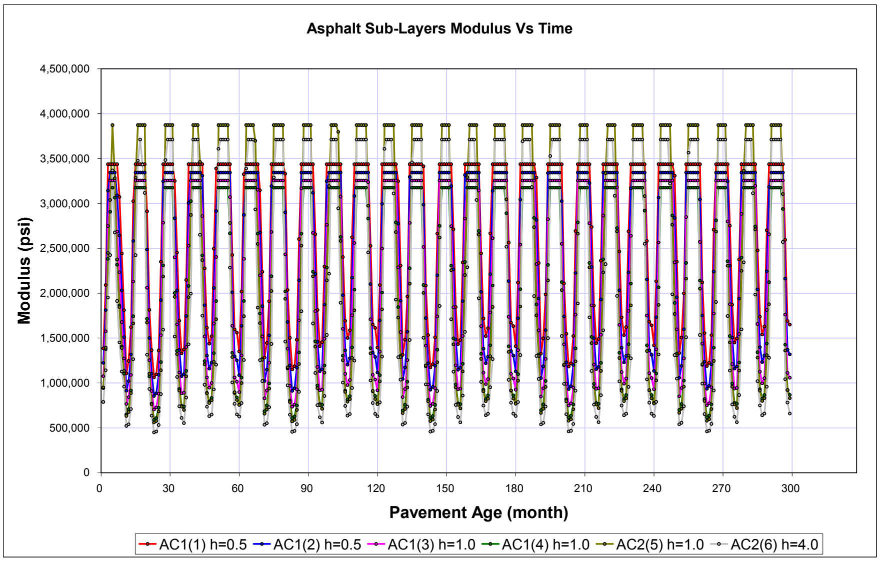
C1 (ATB)	0.009995
C2 (ATB)	0.000518
C3 (ATB)	0.00235
C4 (ATB)	18.36
C5 (ATB)	0.9694
Std. Dev (ATB)	0.292

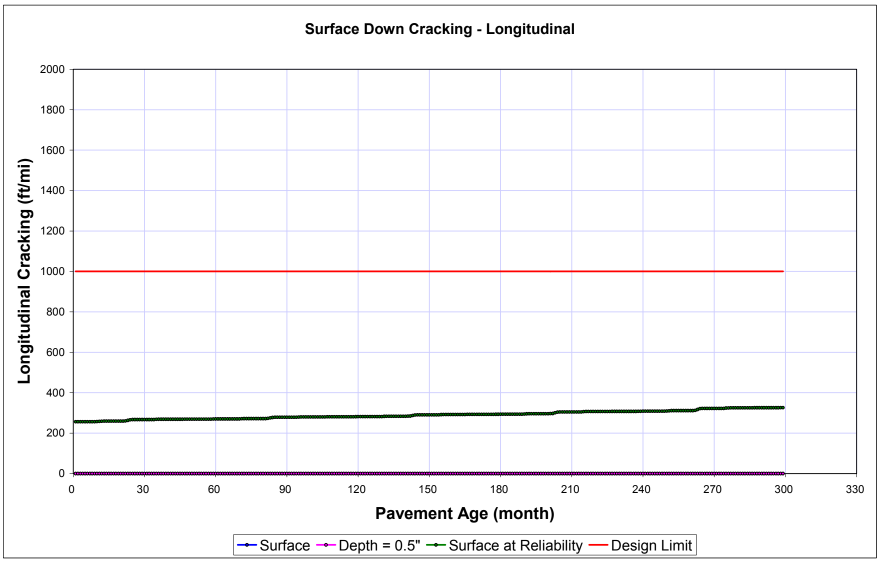
IRI Flexible Pavements with CSM

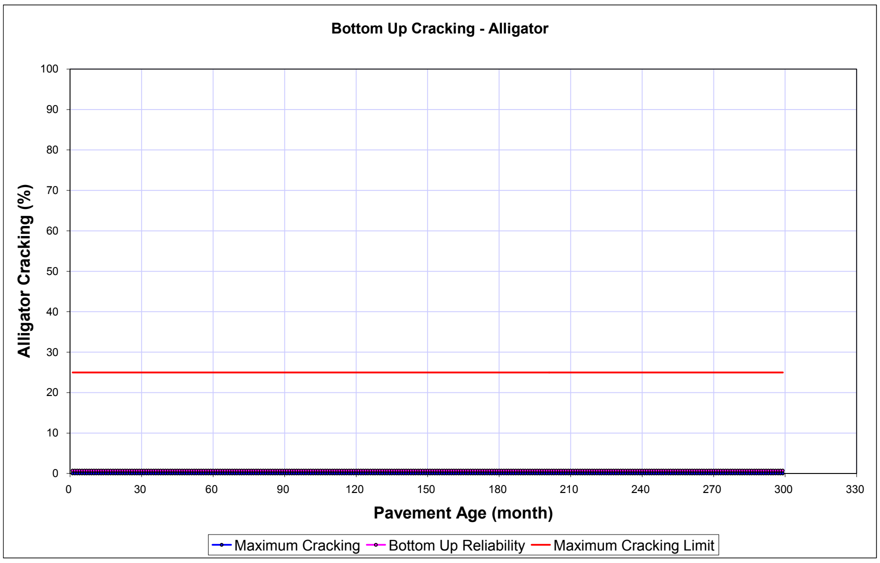
C1 (CSM)	0.00732
C2 (CSM)	0.07647
C3 (CSM)	0.000145
C4 (CSM)	0.00842
C5 (CSM)	0.000212
Std. Dev (CSM)	0.229

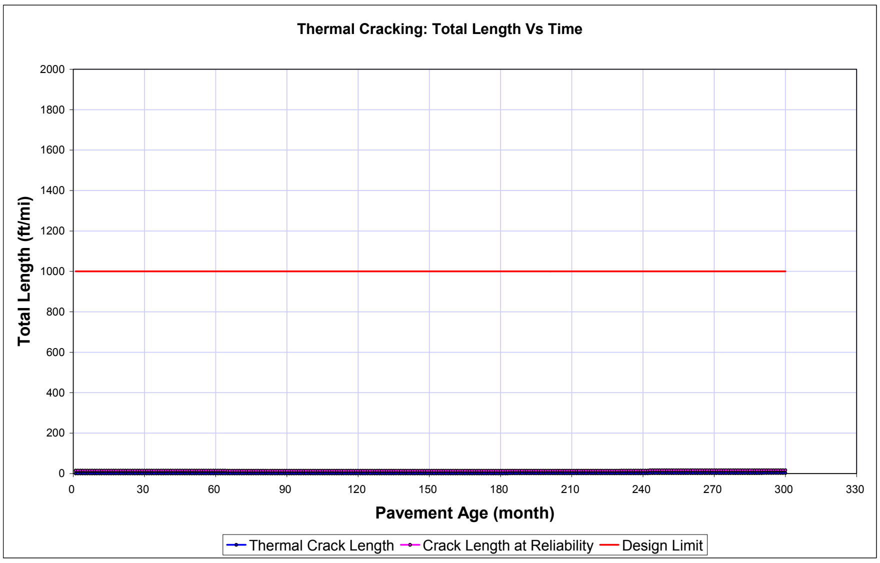
Project: SITE01-New Design.dgp
Reliability Summary

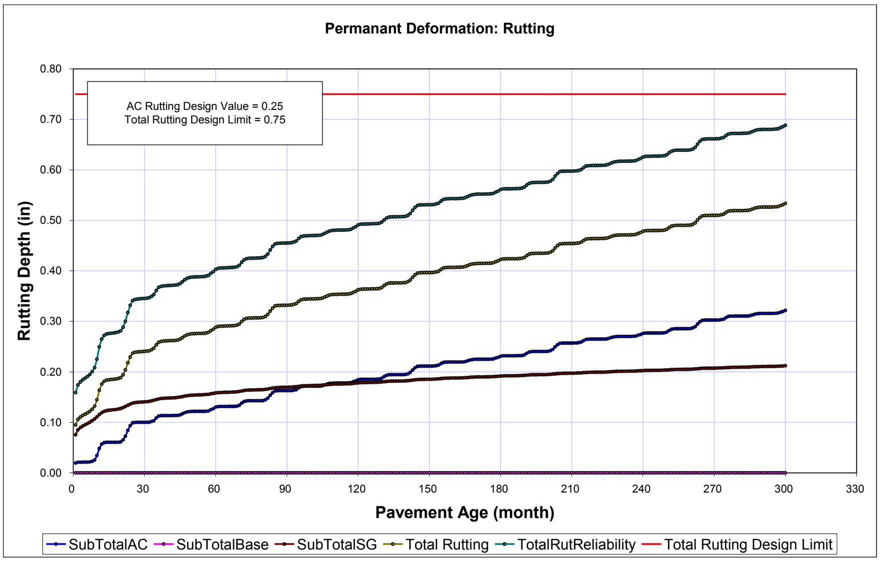
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	0	-1.#J	Fail
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	0.1	99.999	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	2	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.32	22.65	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.53	96.34	Pass

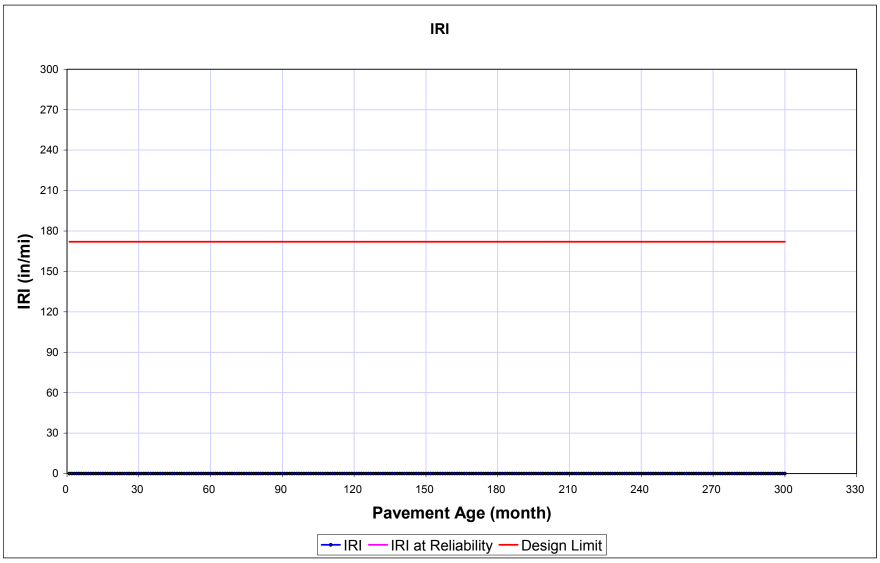

Asphalt Sub-Layers Modulus Vs Time


Surface Down Cracking - Longitudinal


Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
30
60
90
120
150
180
210
240
270
300
330
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
30
60
90
120
150
180
210
240
270
300
330
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
30
60
90
120
150
180
210
240
270
300
330
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
300
270
240
210
180
150
120
90
60
30
0
0
30
60
90
120
150
180
210
240
270
300
330
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE01-Rehabilitation.dgp

General Information

Design Life	20 years
Existing pavement construction:	September, 1970
Pavement overlay construction:	September, 1993
Traffic open:	October, 1993
Type of design	Flexible

Description:
o Route: 29 South o County: Amherst (number 5) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Flexible, 10-15 years o Traffic: TT 1,100, AADT 20,000 (one way traffic) o AC overlay 1.5in ; HMA 8in; CTA 6in o Subgrade: wet red, brown, gray sandy silt w/mica, fill material

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location: SITE 01
Project ID: SITE O1
Section ID:
Principal Arterials - Interstate and Defense Routes
Date: 2/13/2005

Station/milepost format: Miles: 0.000
Station/milepost begin: 7.8
Station/milepost end: 7.3
Traffic direction: South bound

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt: 1429
Number of lanes in design direction: 2
Percent of trucks in design direction (%): 50
Percent of trucks in design lane (%): 80
Operational speed (mph): 60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): 12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft): 8.5
Dual tire spacing (in): 12

Axle Configuration

Single Tire (psi): 120
Dual Tire (psi): 120

Average Axle Spacing

Tandem axle(psi): 51.6
Tridem axle(psi): 49.2
Quad axle(psi): 49.2

Climate

icm file: site01-02test3
Latitude (degrees.minutes) 37.57
Longitude (degrees.minutes) -79.06
Elevation (ft) 628
Depth of water table (ft) 23

Structure--Design Features

Structure--Layers

Layer 1 -- Asphalt concrete

Material type: Asphalt concrete
Layer thickness (in): 1.5

General Properties
General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 11
Air voids (%): 4.3
Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix
Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 12
Cumulative % Retained #4 sieve: 45
% Passing #200 sieve: 5

Asphalt Binder
Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 2 -- Asphalt concrete (existing)

Material type: Asphalt concrete (existing)
Layer thickness (in): 8

General Properties
General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 10
Air voids (%): 6
Total unit weight (pcf): 163

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix
Cumulative % Retained 3/4 inch sieve: 21
Cumulative % Retained 3/8 inch sieve: 40
Cumulative % Retained #4 sieve: 57
% Passing #200 sieve: 4

Asphalt Binder
Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 3 -- Cement Stabilized

General Properties
Material type: Cement Stabilized
Layer thickness (in): 6
Unit weight (pcf): 150
Poisson's ratio: 0.2

Strength Properties
Elastic/resilient modulus (psi): 1256000

Thermal Properties
Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Layer 4 -- ML

Unbound Material:	ML
Thickness(in):	12

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	17000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Layer 5 -- ML

Unbound Material:	ML
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	17000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Distress Model Calibration Settings - Flexible

AC Fatigue	Level 3 (Nationally calibrated values)
k1	0.00432
k2	3.9492
k3	1.281

AC Rutting	Level 3 (Nationally calibrated values)
k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture	Level 3 (Nationally calibrated values)
k1	5
Std. Dev. (THERMAL):	0.2474 * THERMAL + 10.619

CSM Fatigue	Level 3 (Nationally calibrated values)
k1	1
k2	1

Subgrade Rutting	Level 3 (Nationally calibrated values)
Granular:	
k1	1.673
Fine-grain:	
k1	1.35

AC Cracking

AC Top Down Cracking	
C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking	
C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))

CSM Cracking	
C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11

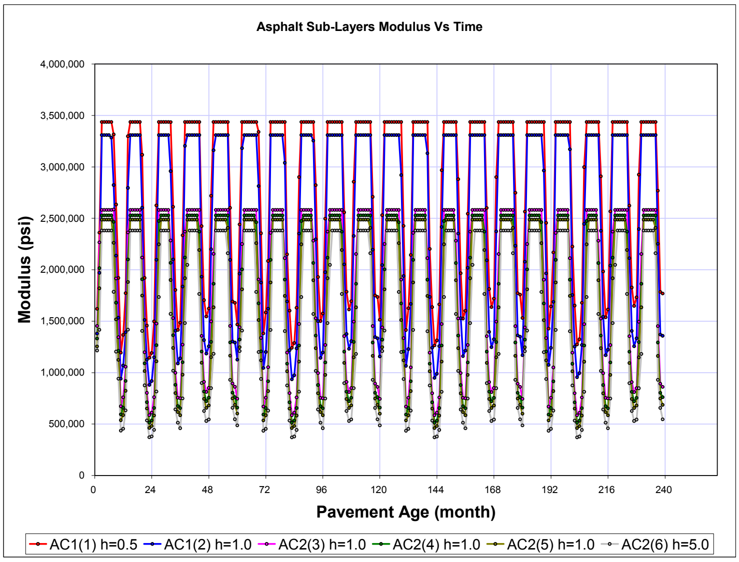
IRI

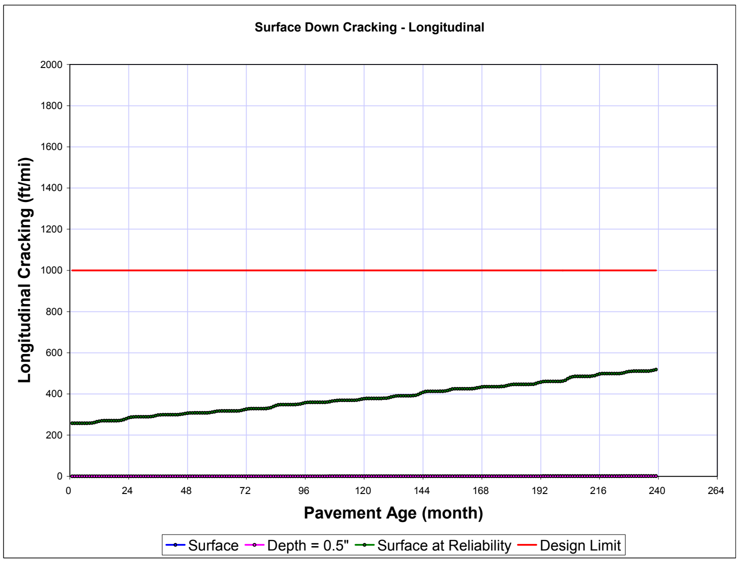
IRI Rehabilitation over Flexible	
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723
C5 (Flexible)	0.011241
C6 (Flexible)	9.04244
Std. Dev (Flexible)	0.179

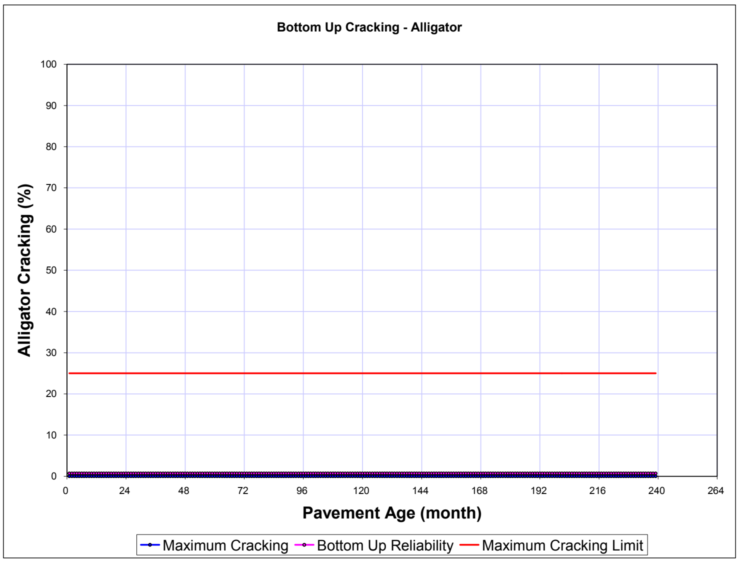
IRI Rehabilitation over Rigid	
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

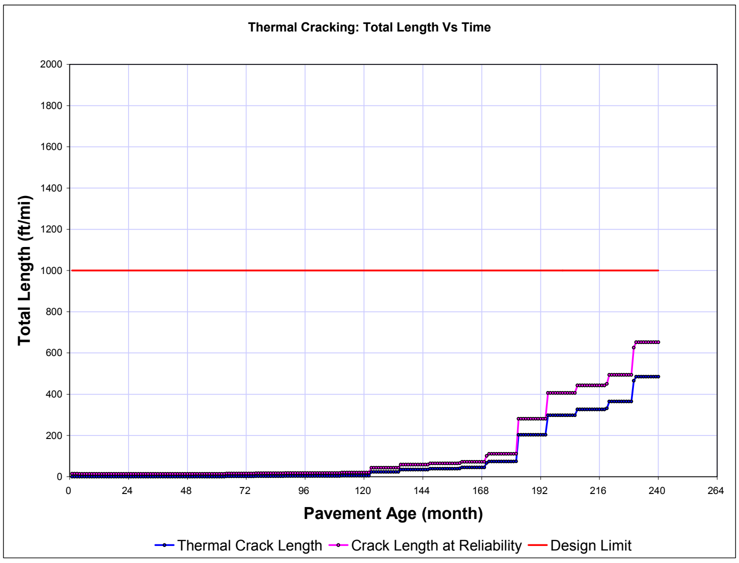
Project: SITE01-Rehabilitation.dgp
Reliability Summary

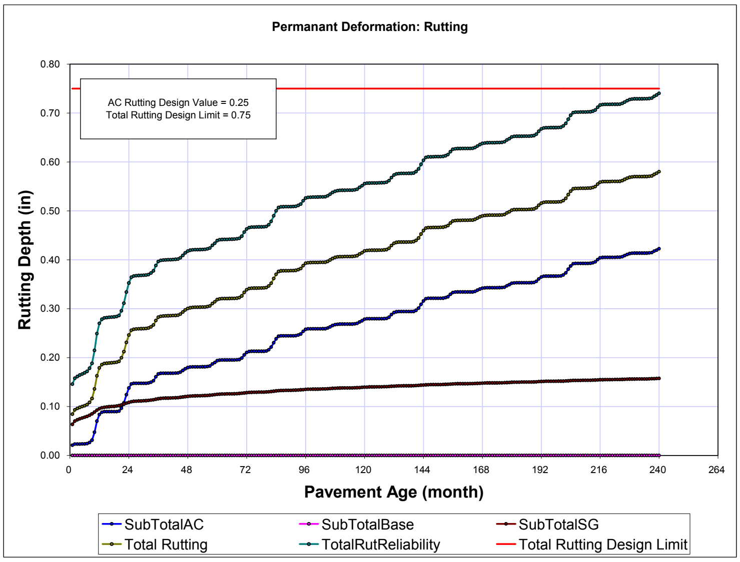
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	245.1	11.24	Fail
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	1.3	99.31	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	485	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.42	5.5	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.58	91.29	Pass

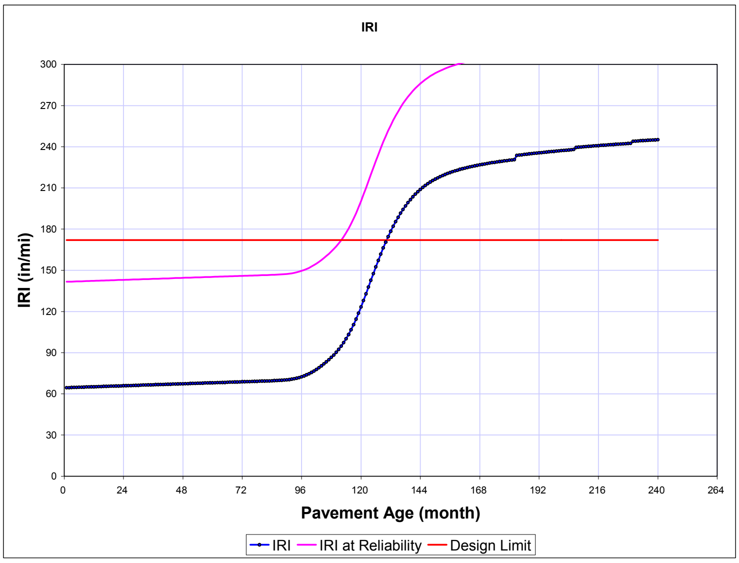





Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
0
30
60
90
120
150
180
210
240
270
300
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE16-New Design.dgp

Description:
o Route: 81 North o County: Frederick, Winchester (number 34) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Flexible, older than 20 years w/surface older than 10 years o AC overlay 1.8in HMA:9.7in Agg Base+Select Mat'l: 18in o Subgrade: B1: clay w/silts (10%) and gray compacted clay with gravel/sand (fill) B2: damp clay w/silts (10%)

General Information

Design Life	15 years
Base/Subgrade construction:	August, 1965
Pavement construction:	September, 1965
Traffic open:	October, 1965
Type of design	Flexible

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location: SITE 16
Project ID: SITE 16
Section ID:
Principal Arterials - Interstate and Defense Routes
Date: 2/13/2005

Station/milepost format: Miles: 0.000
Station/milepost begin: 21.37
Station/milepost end: 21.87
Traffic direction: North bound

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	1854
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%
Class 13	0.3%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%
10:00 am	5.9%	10:00 pm	3.1%
11:00 am	5.9%	11:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site16-01D
Latitude (degrees.minutes)	36.26
Longitude (degrees.minutes)	-77.43
Elevation (ft)	248
Depth of water table (ft)	15

Structure--Design Features

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	1.8

General Properties
General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 11
Air voids (%): 4.5
Total unit weight (pcf): 145

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix
Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 12
Cumulative % Retained #4 sieve: 45
% Passing #200 sieve: 5

Asphalt Binder
Option: Conventional viscosity grade
Viscosity Grade AC 30
A 10.6316 (correlated)
VTS: -3.548 (correlated)

Layer 2 -- Asphalt concrete

Material type: Asphalt concrete
Layer thickness (in): 7.9

General Properties
General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 10
Air voids (%): 6
Total unit weight (pcf): 163

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix
Cumulative % Retained 3/4 inch sieve: 21
Cumulative % Retained 3/8 inch sieve: 40
Cumulative % Retained #4 sieve: 57
% Passing #200 sieve: 4

Asphalt Binder
Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 3 -- Crushed stone

Unbound Material: Crushed stone
Thickness(in): 18

Strength Properties
Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 90000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	1
Passing #200 sieve (%):	10
Passing #4 sieve (%):	54
D60 (mm):	9

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	122.3 (derived)
Specific gravity of solids, Gs:	2.67 (derived)
Saturated hydraulic conductivity (ft/hr):	285 (derived)
Optimum gravimetric water content (%):	11.2 (derived)
Calculated degree of saturation (%):	82.8 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11.4
b	1.72
c	0.518
Hr.	371

Layer 4 -- CL

Unbound Material:	CL
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	36000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Flexible

AC Fatigue

Level 3 (Nationally calibrated values)

k1	0.00432
k2	3.9492
k3	1.281

AC Rutting

Level 3 (Nationally calibrated values)

k1	-3.4488
k2	1.5606
k3	0.4791

Standard Deviation Total Rutting (RUT): 0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture

Level 3 (Nationally calibrated values)

k1	5

CSM Fatigue

Level 3 (Nationally calibrated values)

k1	1
k2	1

Subgrade Rutting

Level 3 (Nationally calibrated values)

Granular:

k1	1.673

Fine-grain:

k1	1.35

AC Cracking

AC Top Down Cracking

C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.0001)))

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*1

IRI

IRI Flexible Pavements with GB

C1 (GB)	0.0463
C2 (GB)	0.00119
C3 (GB)	0.1834
C4 (GB)	0.00384
C5 (GB)	0.00736
C6 (GB)	0.00115
Std. Dev (GB)	0.387

IRI Flexible Pavements with ATB

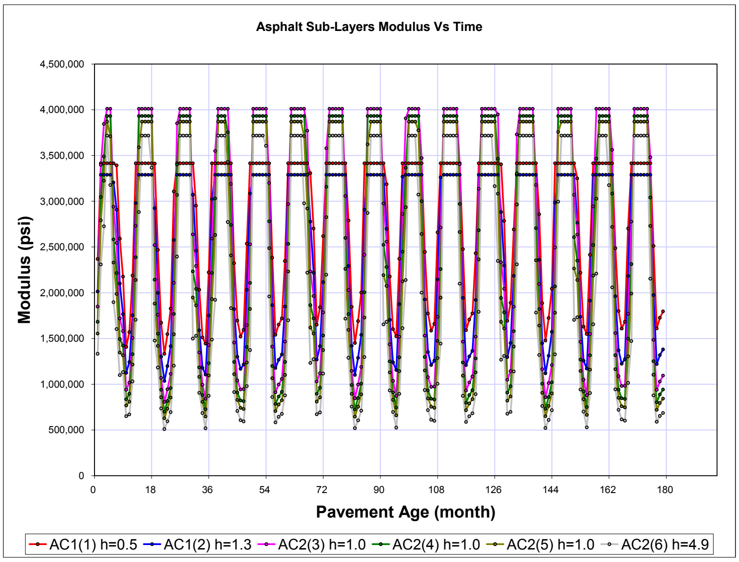
C1 (ATB)	0.009995
C2 (ATB)	0.000518
C3 (ATB)	0.00235
C4 (ATB)	18.36
C5 (ATB)	0.9694
Std. Dev (ATB)	0.292

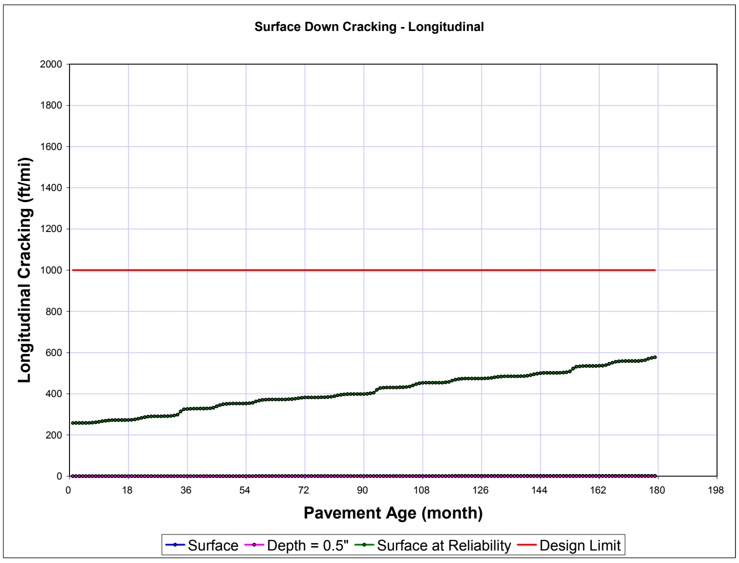
IRI Flexible Pavements with CSM

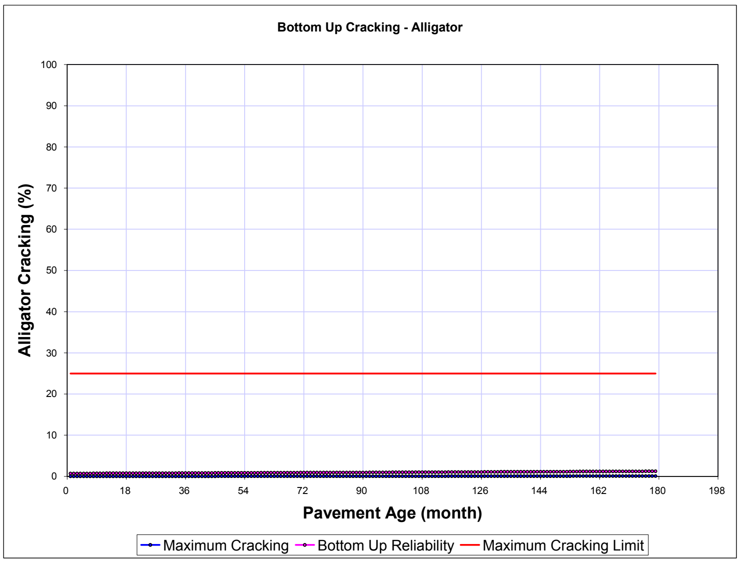
C1 (CSM)	0.00732
C2 (CSM)	0.07647
C3 (CSM)	0.000145
C4 (CSM)	0.00842
C5 (CSM)	0.000212
Std. Dev (CSM)	0.229

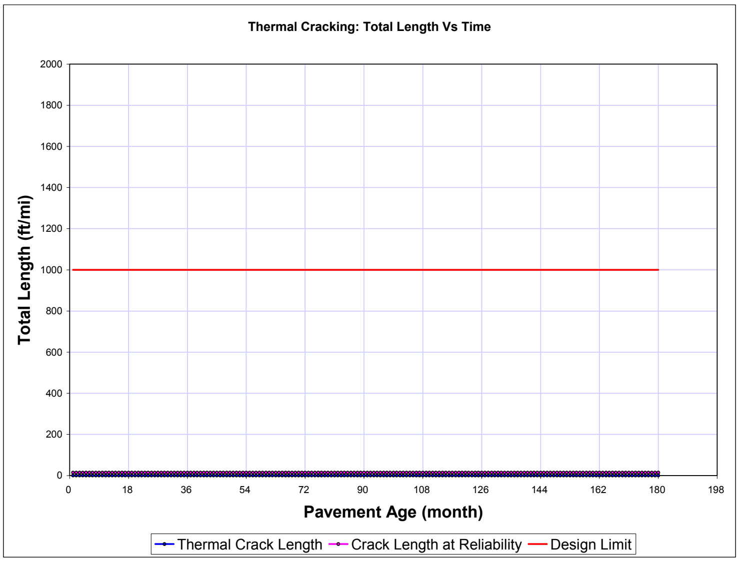
Project: SITE16-New Design.dgp
Reliability Summary

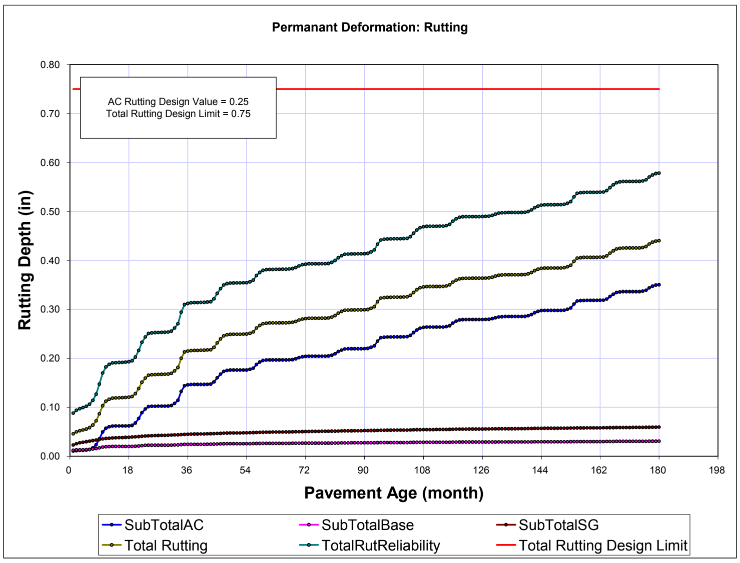
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	111.1	99.29	Pass
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	1.8	98.67	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0.1	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.35	15.61	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.44	99.8	Pass

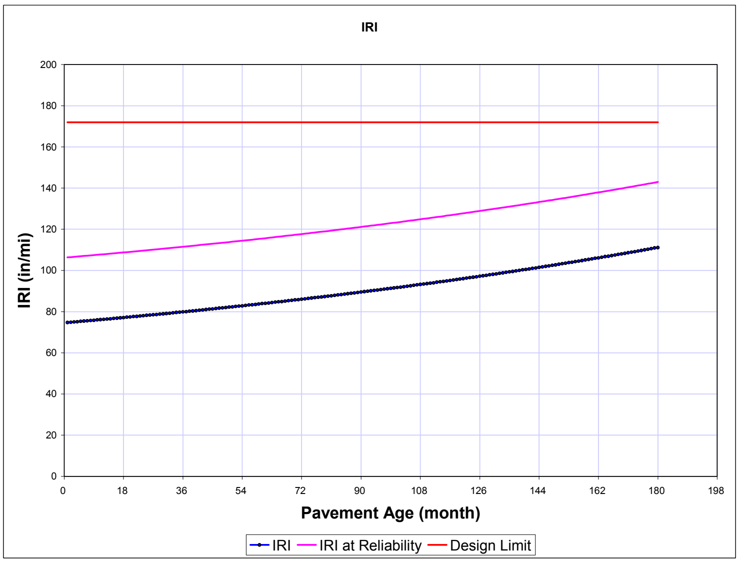





Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
200
180
160
140
120
100
80
60
40
20
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE16 - Rehabilitation.dgp

General Information

Design Life	20 years
Existing pavement construction:	September, 1965
Pavement overlay construction:	September, 1991
Traffic open:	September, 1991
Type of design	Flexible

Description:
o Route: 81 North o County: Frederick, Winchester (number 34) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Flexible, older than 20 years w/surface older than 10 years o AC overlay 1.8in HMA:9.7in Agg Base+Select Mat'l: 18in o Subgrade: B1: clay w/silts (10%) and gray compacted clay with gravel/sand (fill) B2: damp clay w/silts (10%)

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location:	SITE 16
Project ID:	SITE 16
Section ID:	
	Principal Arterials - Interstate and Defense Routes
Date:	2/13/2005

Station/milepost format:	Miles: 0.000
Station/milepost begin:	21.37
Station/milepost end:	21.87
Traffic direction:	North bound

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	5141
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors

(Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site16
Latitude (degrees.minutes)	39.174
Longitude (degrees.minutes)	-78.1749
Elevation (ft)	1557
Depth of water table (ft)	15

Structure--Design Features

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	1.8

General Properties

General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 11
Air voids (%): 4.5
Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 12
Cumulative % Retained #4 sieve: 45
% Passing #200 sieve: 5

Asphalt Binder

Option: Conventional viscosity grade
Viscosity Grade AC 30
A 10.6316 (correlated)
VTS: -3.548 (correlated)

Layer 2 -- Asphalt concrete (existing)

Material type: Asphalt concrete (existing)
Layer thickness (in): 9.7

General Properties

General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 11
Air voids (%): 8.5
Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve: 21
Cumulative % Retained 3/8 inch sieve: 40
Cumulative % Retained #4 sieve: 57
% Passing #200 sieve: 4

Asphalt Binder

Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 3 -- Crushed stone

Unbound Material: Crushed stone
Thickness(in): 18

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	90000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	1
Passing #200 sieve (%):	10
Passing #4 sieve (%):	54
D60 (mm):	2

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	122.3 (derived)
Specific gravity of solids, Gs:	2.67 (derived)
Saturated hydraulic conductivity (ft/hr):	37 (derived)
Optimum gravimetric water content (%):	11.2 (derived)
Calculated degree of saturation (%):	82.8 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11.4
b	1.72
c	0.518
Hr.	371

Layer 4 -- CL

Unbound Material:	CL
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	36000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Flexible

AC Fatigue	Level 3 (Nationally calibrated values)
k1	0.00432
k2	3.9492
k3	1.281

AC Rutting

	Level 3 (Nationally calibrated values)
k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture

	Level 3 (Nationally calibrated values)
k1	5
Std. Dev. (THERMAL):	0.2474 * THERMAL + 10.619

CSM Fatigue

	Level 3 (Nationally calibrated values)
k1	1
k2	1

Subgrade Rutting

	Level 3 (Nationally calibrated values)
Granular:	
k1	1.673
Fine-grain:	
k1	1.35

AC Cracking

AC Top Down Cracking

C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11

IRI

IRI Rehabilitation over Flexible

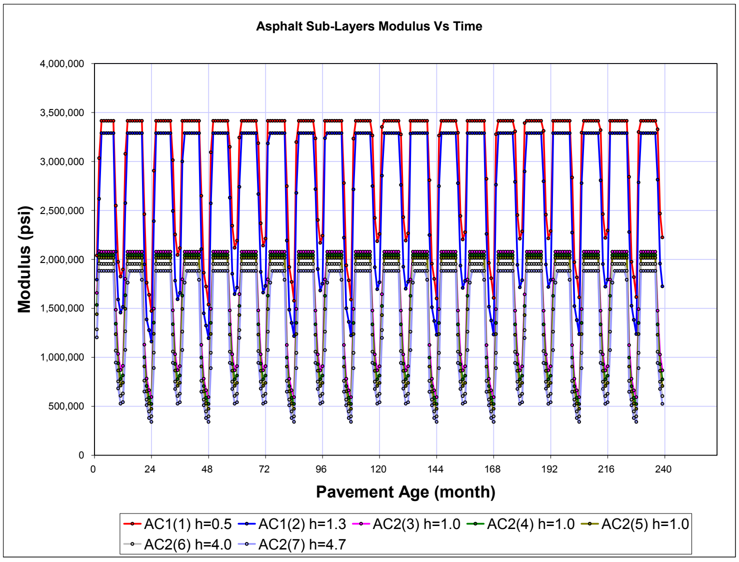
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723
C5 (Flexible)	0.011241
C6 (Flexible)	9.04244
Std. Dev (Flexible)	0.179

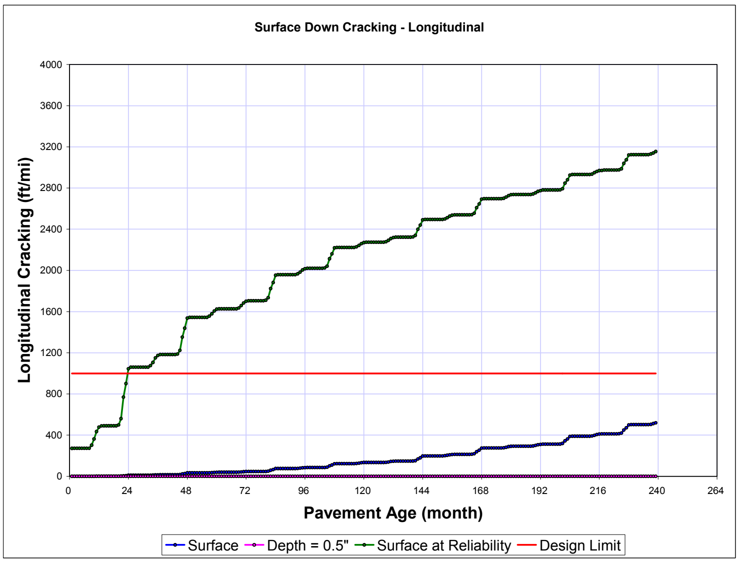
IRI Rehabilitation over Rigid

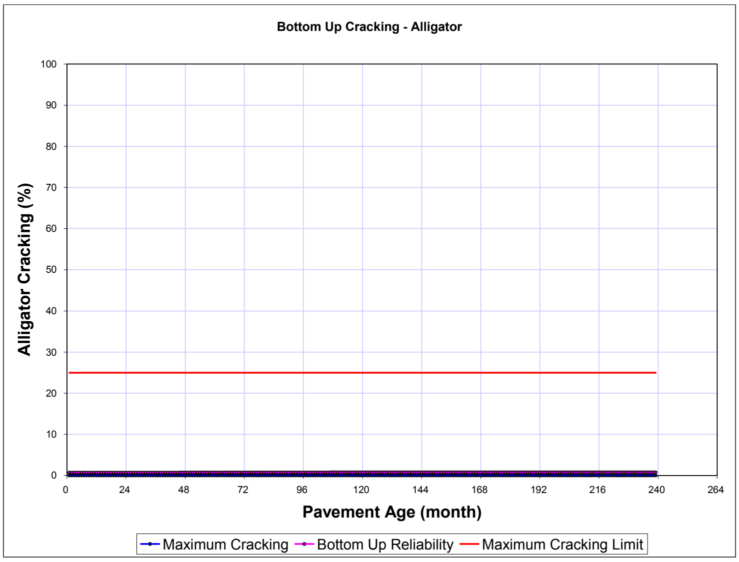
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

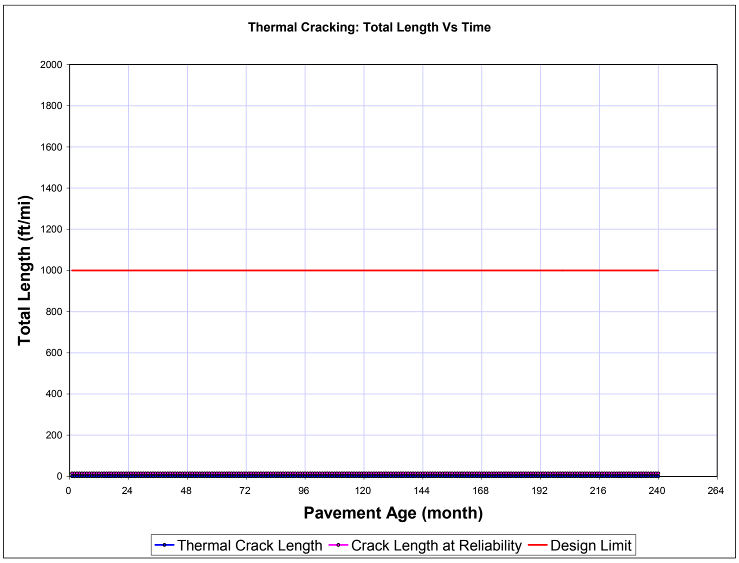
Project: SITE16-Rehabilitation.dgp
Reliability Summary

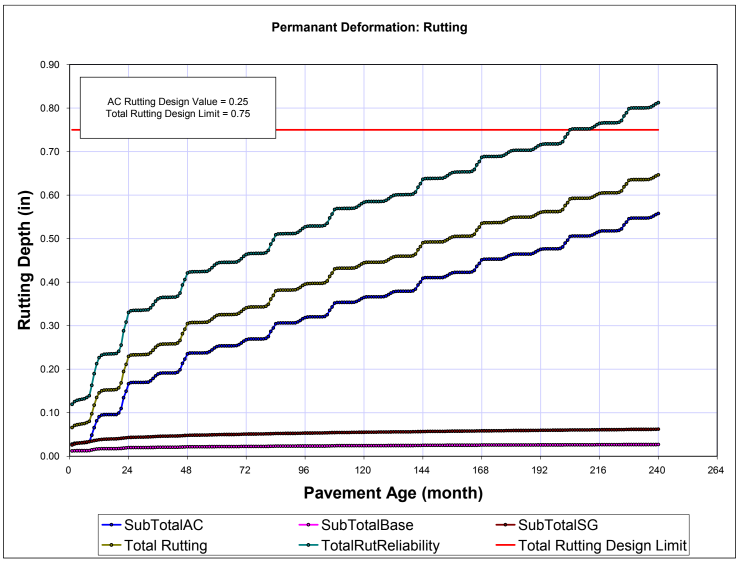
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	239.4	13.14	Fail
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	526	59.11	Fail
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.56	0.6	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.65	78.8	Fail

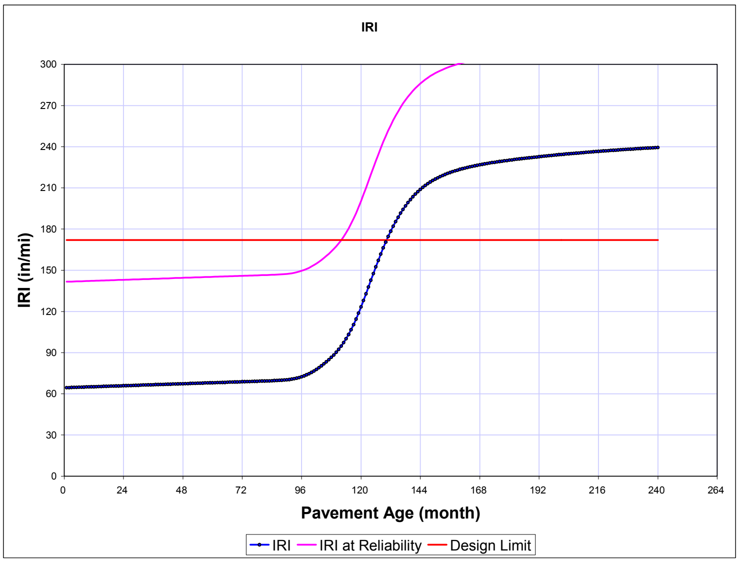





Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
0
30
60
90
120
150
180
210
240
270
300
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE18-New Design.dgp

General Information

Design Life	15 years
Base/Subgrade construction:	August, 1999
Pavement construction:	September, 1999
Traffic open:	September, 1999
Type of design	Flexible

Description:
o Route: 81 South o County: Washington (number 95) o Length: 2640 ft o Number of lanes in each direction: 3 o Pavement Category: Flexible, 0-5 years o Traffic: TT 5,940 & AADT 20,000 (one way traffic) o AC overlay: 2in HMA:13in; Asphalt OGDL: 3in Agg. Base: 21in o Subgrade: orange-brown to yellow-brown sandy silty clay

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location:	Washington, VA
Project ID:	SITE18
Section ID:	
	Principal Arterials - Interstate and Defense Routes
Date:	2/28/2005

Station/milepost format:	Miles: 0.000	
Station/milepost begin:		1.5
Station/milepost end:		1
Traffic direction:	South bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	9764
Number of lanes in design direction:	3
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	75
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site18A-01
Latitude (degrees.minutes)	36.7
Longitude (degrees.minutes)	-81.99
Elevation (ft)	2050
Depth of water table (ft)	15

Structure--Design Features

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	13

General Properties

General

Reference temperature (F°): 70

Volumetric Properties as Built

Effective binder content (%): 11

Air voids (%): 4.5

Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67

Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve:	21
Cumulative % Retained 3/8 inch sieve:	40
Cumulative % Retained #4 sieve:	57
% Passing #200 sieve:	4

Asphalt Binder

Option:	Conventional viscosity grade
Viscosity Grade	AC 20
A	10.7709 (correlated)
VTS:	-3.6017 (correlated)

Layer 2 -- Permeable aggregate

Unbound Material: Permeable aggregate

Thickness(in): 3

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	150000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	1
Passing #200 sieve (%):	1
Passing #4 sieve (%):	25
D60 (mm):	10

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	122 (derived)
Specific gravity of solids, Gs:	2.66 (derived)
Saturated hydraulic conductivity (ft/hr):	302 (derived)
Optimum gravimetric water content (%):	11 (derived)
Calculated degree of saturation (%):	81.4 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11
b	1.92
c	0.506
Hr.	358

Layer 3 -- Crushed stone

Unbound Material: Crushed stone

Thickness(in): 21

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	90000

ICM Inputs

Gradation and Plasticity Index
Plasticity Index, PI: 1
Passing #200 sieve (%): 10
Passing #4 sieve (%): 54
D60 (mm): 9

Calculated/Derived Parameters
Maximum dry unit weight (pcf): 122.3 (derived)
Specific gravity of solids, Gs: 2.67 (derived)
Saturated hydraulic conductivity (ft/hr): 285 (derived)
Optimum gravimetric water content (%): 11.2 (derived)
Calculated degree of saturation (%): 82.8 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11.4
b	1.72
c	0.518
Hr.	371

Layer 4 -- CL

Unbound Material: CL
Thickness(in): Semi-infinite

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.4
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 46000

ICM Inputs

Gradation and Plasticity Index
Plasticity Index, PI: 15
Passing #200 sieve (%): 75
Passing #4 sieve (%): 95
D60 (mm): 0.1

Calculated/Derived Parameters
Maximum dry unit weight (pcf): 107.9 (derived)
Specific gravity of solids, Gs: 2.73 (derived)
Saturated hydraulic conductivity (ft/hr): 3.25e-005 (derived)
Optimum gravimetric water content (%): 18.6 (derived)
Calculated degree of saturation (%): 87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Flexible

AC Fatigue

Level 3 (Nationally calibrated values)

k1	0.00432
k2	3.9492
k3	1.281

AC Rutting

Level 3 (Nationally calibrated values)

k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture

Level 3 (Nationally calibrated values)

k1	5

CSM Fatigue	Level 3 (Nationally calibrated values)
k1	1
k2	1

Subgrade Rutting	Level 3 (Nationally calibrated values)
Granular:	
k1	1.673
Fine-grain:	
k1	1.35

AC Cracking

AC Top Down Cracking	
C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking	
C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.0001)))

CSM Cracking	
C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*1

IRI

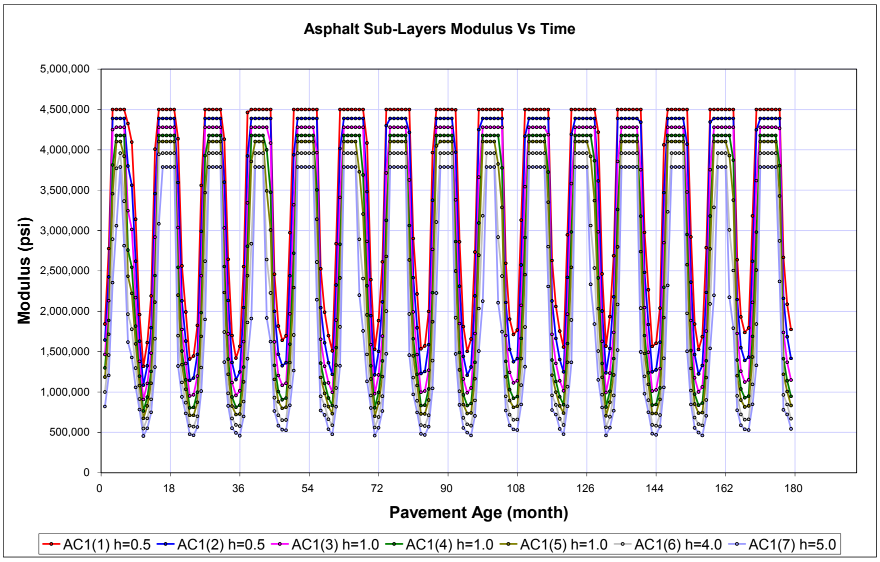
IRI Flexible Pavements with GB	
C1 (GB)	0.0463
C2 (GB)	0.00119
C3 (GB)	0.1834
C4 (GB)	0.00384
C5 (GB)	0.00736
C6 (GB)	0.00115
Std. Dev (GB)	0.387

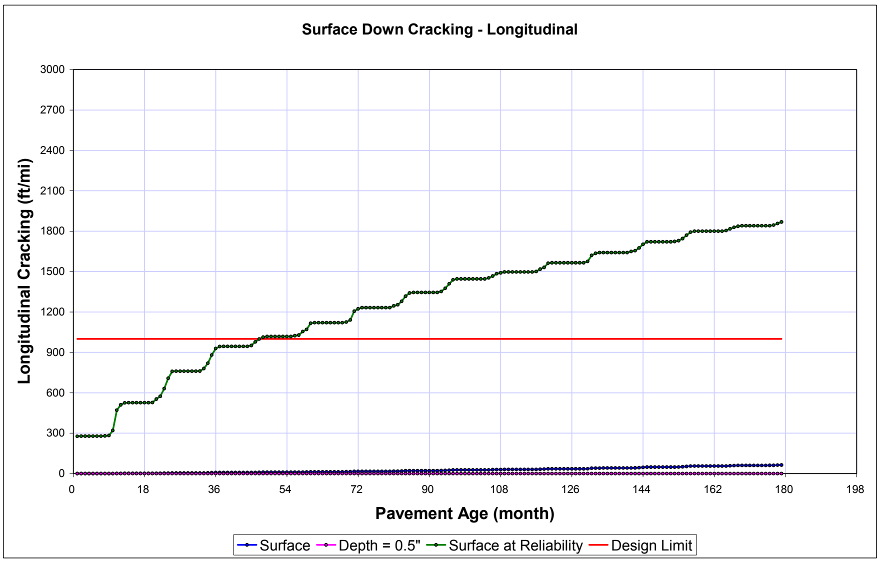
IRI Flexible Pavements with ATB	
C1 (ATB)	0.009995
C2 (ATB)	0.000518
C3 (ATB)	0.00235
C4 (ATB)	18.36
C5 (ATB)	0.9694
Std. Dev (ATB)	0.292

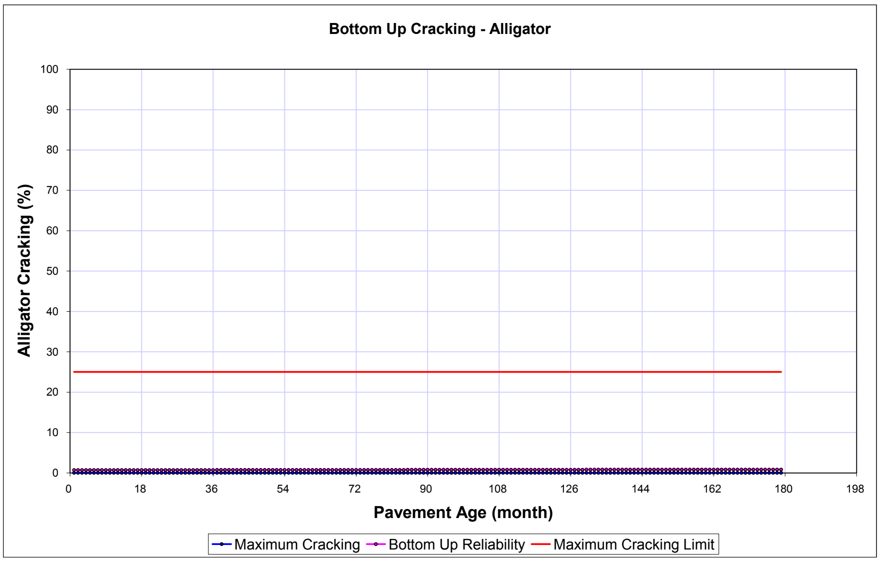
IRI Flexible Pavements with CSM	
C1 (CSM)	0.00732
C2 (CSM)	0.07647
C3 (CSM)	0.000145
C4 (CSM)	0.00842
C5 (CSM)	0.000212
Std. Dev (CSM)	0.229

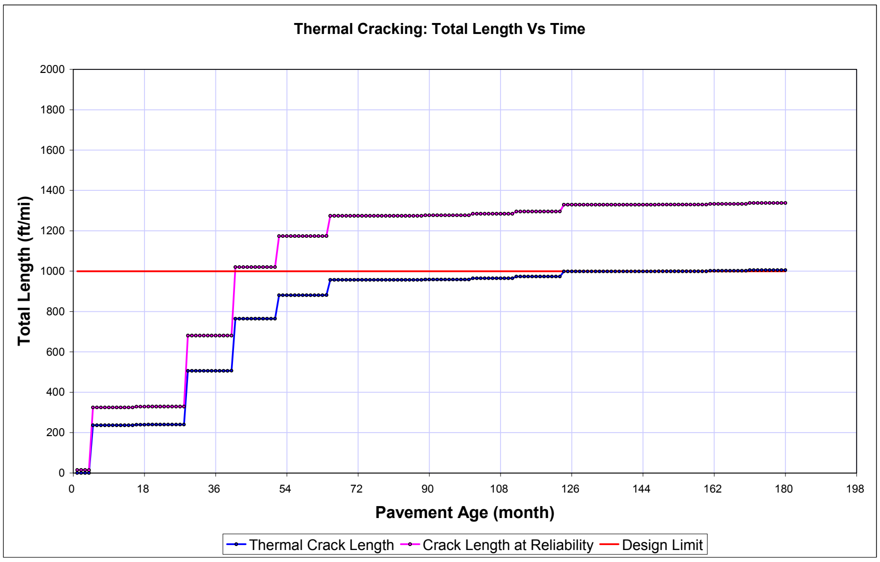
Project: SITE18-New
Design.dgp
Reliability Summary

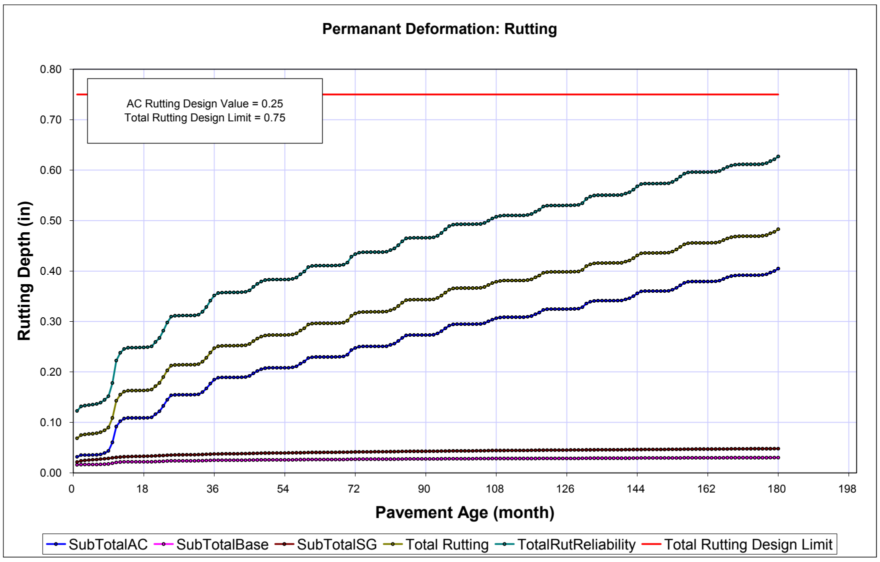
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	127.1	96.28	Pass
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	66.6	74.4	Fail
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1005	49.23	Fail
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.4	7.19	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.48	99.12	Pass

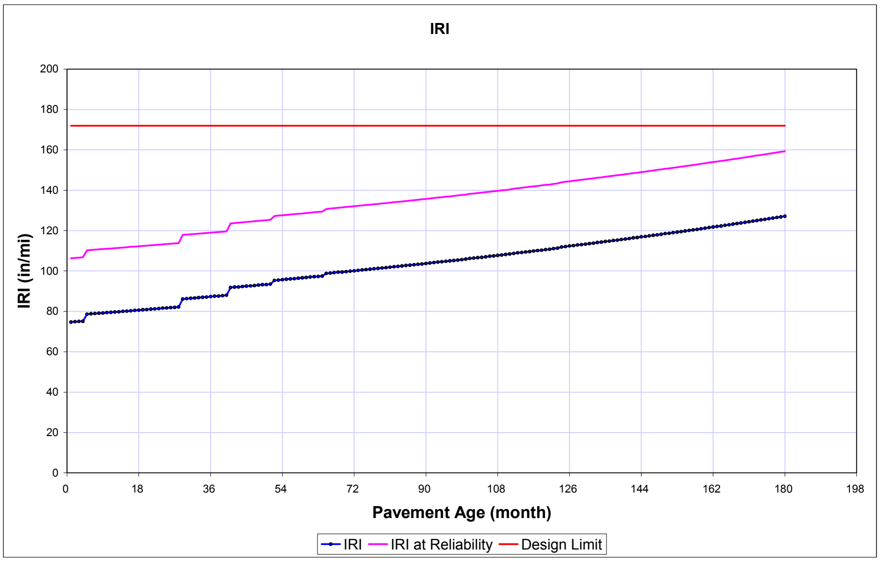





Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
200
180
160
140
120
100
80
60
40
20
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE18-Rehabilitation.dgp

Description:
o Route: 81 South o County: Washington (number 95) o Length: 2640 ft o Number of lanes in each direction: 3 o Pavement Category: Flexible, 0-5 years o Traffic: TT 5,940 & AADT 20,000 (one way traffic) o AC overlay: 2in HMA:13in; Asphalt OGDL: 3in Agg. Base: 21in o Subgrade: orange-brown to yellow-brown sandy silty clay

General Information

Design Life 20 years
Existing pavement construction: September, 1999
Pavement overlay construction: September, 2001
Traffic open: September, 2001
Type of design Flexible

Analysis Parameters

Analysis type Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location: Washington, VA
Project ID: SITE18
Section ID:
Principal Arterials - Interstate and Defense Routes
Date: 2/28/2005

Station/milepost format: Miles: 0.000
1.5
Station/milepost end: 1
Traffic direction: South bound

Default Input Level

Default input level Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	10561
Number of lanes in design direction:	3
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	70
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution
(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution
by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site18-02
Latitude (degrees.minutes)	36.7
Longitude (degrees.minutes)	-81.99
Elevation (ft)	2050
Depth of water table (ft)	15

Structure--Design Features

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	2

General Properties

General

Reference temperature (F°): 70

Volumetric Properties as Built

Effective binder content (%): 11
Air voids (%): 4.3
Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 12
Cumulative % Retained #4 sieve: 45
% Passing #200 sieve: 6

Asphalt Binder

Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 2 -- Asphalt concrete (existing)

Material type: Asphalt concrete (existing)
Layer thickness (in): 14.5

General Properties

General

Reference temperature (F°): 70

Volumetric Properties as Built

Effective binder content (%): 10
Air voids (%): 6
Total unit weight (pcf): 163

Poisson's ratio: 0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve: 21
Cumulative % Retained 3/8 inch sieve: 40
Cumulative % Retained #4 sieve: 57
% Passing #200 sieve: 4

Asphalt Binder

Option: Conventional viscosity grade
Viscosity Grade AC 20
A 10.7709 (correlated)
VTS: -3.6017 (correlated)

Layer 3 -- Crushed stone

Unbound Material: Crushed stone
Thickness(in): 21

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 90000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	1
Passing #200 sieve (%):	10
Passing #4 sieve (%):	54
D60 (mm):	9

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	122.3 (derived)
Specific gravity of solids, Gs:	2.67 (derived)
Saturated hydraulic conductivity (ft/hr):	285 (derived)
Optimum gravimetric water content (%):	11.2 (derived)
Calculated degree of saturation (%):	82.8 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11.4
b	1.72
c	0.518
Hr.	371

Layer 4 -- CL

Unbound Material:	CL
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.4
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	46000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Flexible

AC Fatigue

Level 3 (Nationally calibrated values)

k1	0.00432
k2	3.9492
k3	1.281

AC Rutting

Level 3 (Nationally calibrated values)

k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture

Level 3 (Nationally calibrated values)

k1	5
Std. Dev. (THERMAL):	0.2474 * THERMAL + 10.619

CSM Fatigue

Level 3 (Nationally calibrated values)

k1	1
k2	1

Subgrade Rutting

Level 3 (Nationally calibrated values)

Granular:

k1	1.673

Fine-grain:

k1	1.35

AC Cracking

AC Top Down Cracking

C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11

IRI

IRI Rehabilitation over Flexible

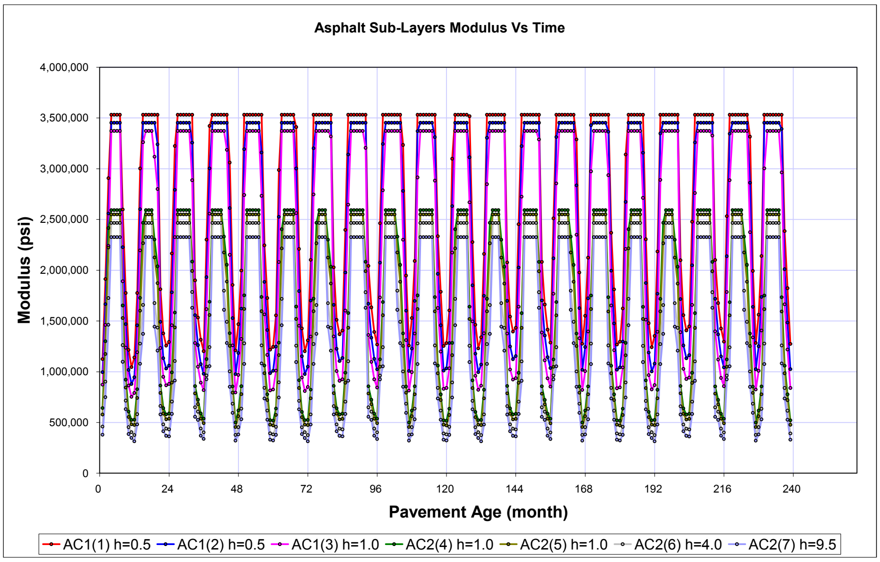
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723
C5 (Flexible)	0.011241
C6 (Flexible)	9.04244
Std. Dev (Flexible)	0.179

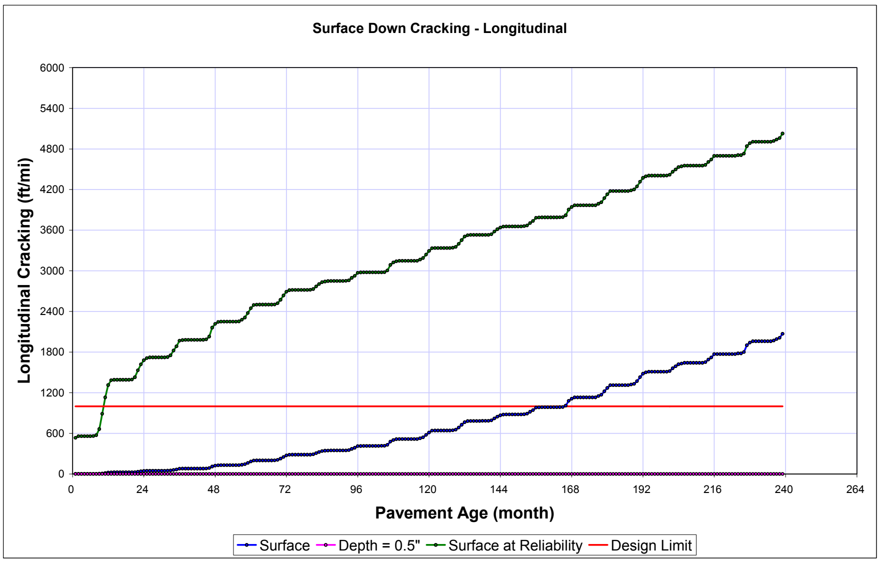
IRI Rehabilitation over Rigid

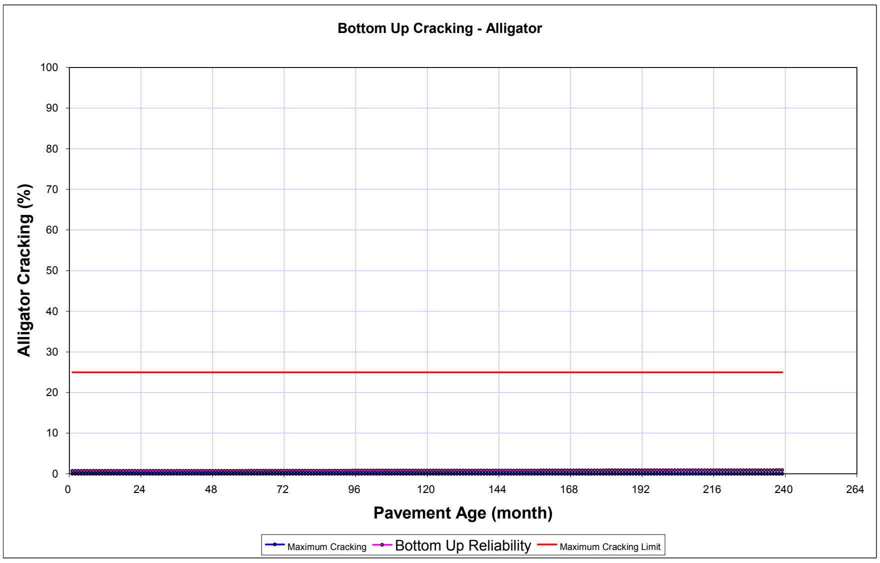
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

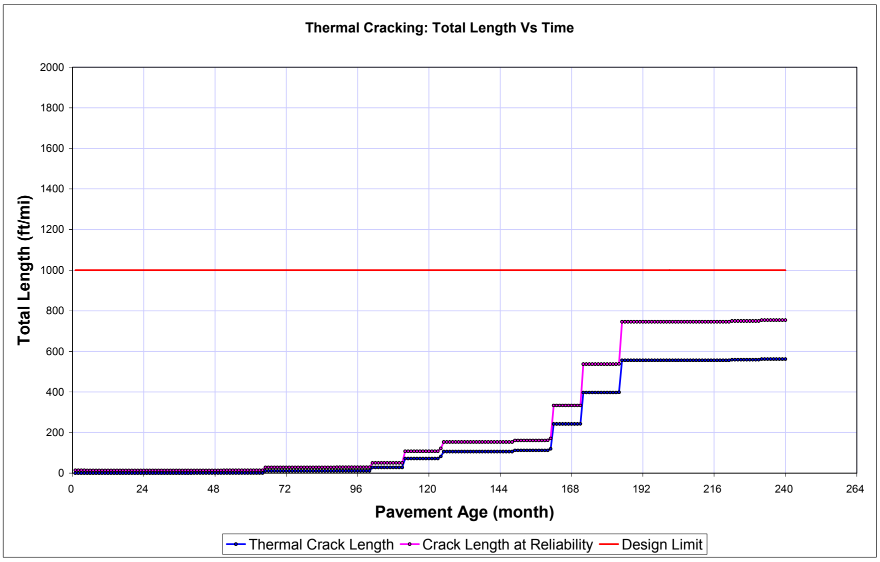
Project: SITE18-Rehabilitation.dgp
Reliability Summary

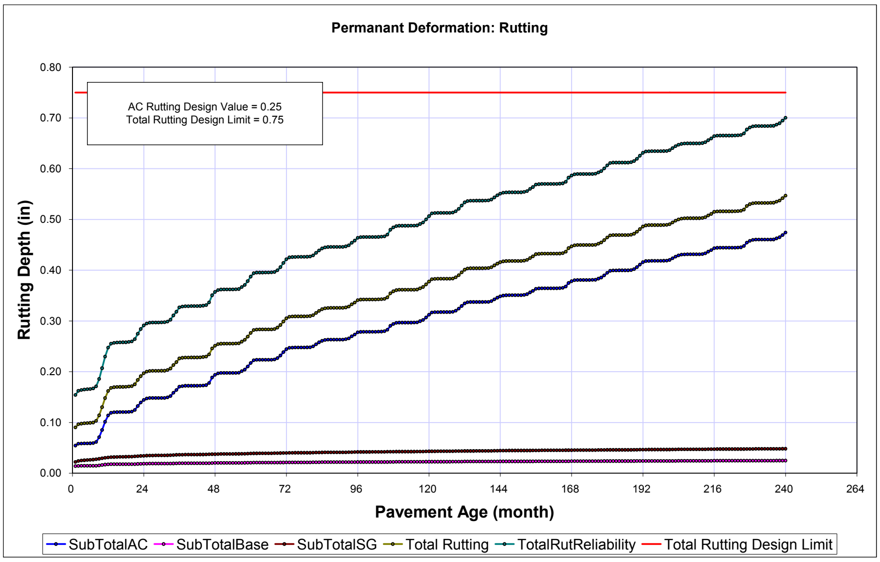
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	245.1	11.23	Fail
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	2140	31.09	Fail
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	562.2	99.83	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.47	2.44	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.55	95.51	Pass

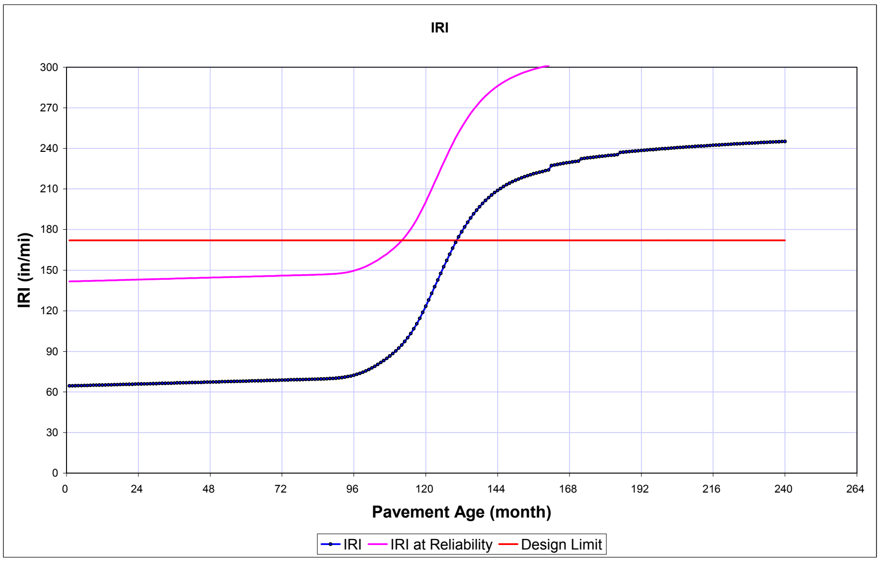





Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
300
270
240
210
180
150
120
90
60
30
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE02-New Design.dgp

Description:
(SITE02-01 Original Design) o Route: I64 East o County: Albemarle, Charlottesville (number 2) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Composite CRCP older than 20 years, w/surface older than 10 years o Traffic: TT 1,680, AADT 15,000 o AC Overlay: 4.5in CRCP:8.25in o Subgrade: reddish-brown sandy salt w/mica

General Information

Design Life	20 years
Pavement construction:	September, 1970
Traffic open:	October, 1970
Type of design	CRCP

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
CRCP Punchouts (per mi)	10	90

Location:	Albermarle, Charlottesville, VA	
Project ID:	SITE02	
Section ID:		
	Principal Arterials - Interstate and Defense Routes	
Date:	2/28/2005	
Station/milepost format:	Miles: 0.000	
Station/milepost begin:		12.99
Station/milepost end:		13.37
Traffic direction:	East bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	886
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution
(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%
Class 13	0.3%

Hourly truck traffic distribution
by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%
10:00 am	5.9%	10:00 pm	3.1%
11:00 am	5.9%	11:00 pm	3.1%

Traffic Growth Factor

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking): 18
Traffic wander standard deviation (in): 10
Design lane width (ft): 12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft): 8.5
Dual tire spacing (in): 12

Axle Configuration

Single Tire (psi): 120
Dual Tire (psi): 120

Average Axle Spacing

Tandem axle(psi): 51.6
Tridem axle(psi): 49.2
Quad axle(psi): 49.2

Wheelbase Truck Tractor

	Short	Medium	Long
Average Axle Spacing (ft)	12	15	18
Percent of trucks	33%	33%	34%

Climate

icm file: Site02-01
Latitude (degrees.minutes) 38.06
Longitude (degrees.minutes) -78.5
Elevation (ft) 640
Depth of water table (ft) 25

Structure--Design Features

Permanent curl/warp effective temperature difference (°F): -10
Shoulder type: Asphalt

Steel Reinforcement

Percent steel (%): 0.7
Bar diameter (in): 0.625
Steel depth (in): 4

Base Properties

Base type: Granular
Erodibility index: Fairly Erodable (4)
Base/slab friction coefficient: 4

Crack Spacing

Cracking Model Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity: 0.85

Drainage Parameters

Structure--Layers

Layer 1 -- CRCP

General Properties

PCC material CRCP
Layer thickness (in): 8.25
Unit weight (pcf): 150
Poisson's ratio 0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6): 5.5
Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Mix Properties

Cement type: Type II
Cementitious material content (lb/yd^3): 564
Water/cement ratio: 0.45
Aggregate type: Limestone
PCC zero-stress temperature (F°) Derived
Ultimate shrinkage at 40% R.H (microstrain) Derived
Reversible shrinkage (% of ultimate shrinkage): 50
Time to develop 50% of ultimate shrinkage (days): 35
Curing method: Curing compound

Strength Properties

Input level: Level 3
28-day PCC modulus of rupture (psi): n/a
28-day PCC compressive strength (psi): 4120

Layer 2 -- ML

Unbound Material: ML
Thickness(in): 12

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 38000

ICM Inputs

<u>Gradation and Plasticity Index</u>

Plasticity Index, PI: 10
Passing #200 sieve (%): 80
Passing #4 sieve (%): 95
D60 (mm): 0.05

<u>Calculated/Derived Parameters</u>

Maximum dry unit weight (pcf): 111.2 (derived)
Specific gravity of solids, Gs: 2.72 (derived)
Saturated hydraulic conductivity (ft/hr): 3.25e-005 (derived)
Optimum gravimetric water content (%): 16.9 (derived)
Calculated degree of saturation (%): 87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Distress Model Calibration Settings - Rigid (new)

Punchouts

Fatigue

C1	2
C2	1.22

Punchout

C3	105.2632
C4	4
C5	-0.38158

Crack Width

C6	1

Reliability (PO)

Std. Dev.	4.04*POWER(PO, 0.3825)

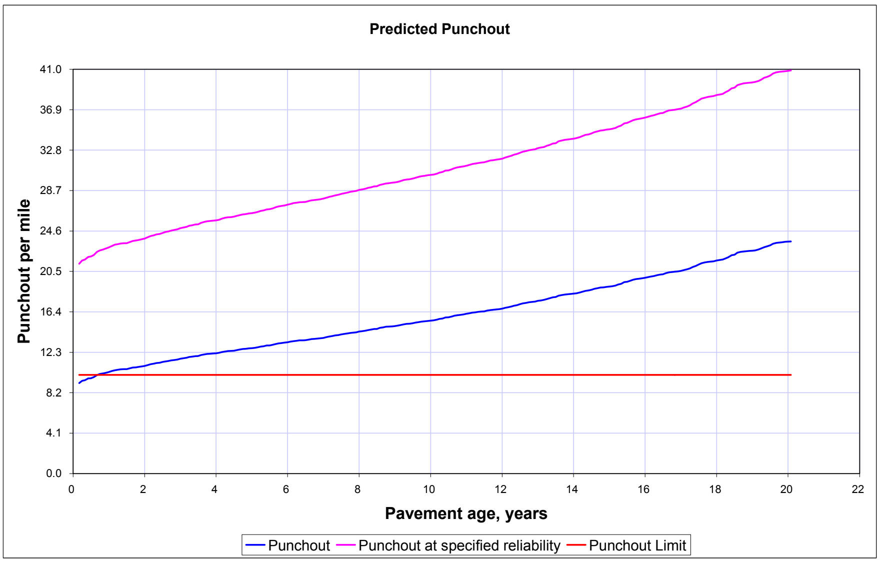
IRI(crcp)

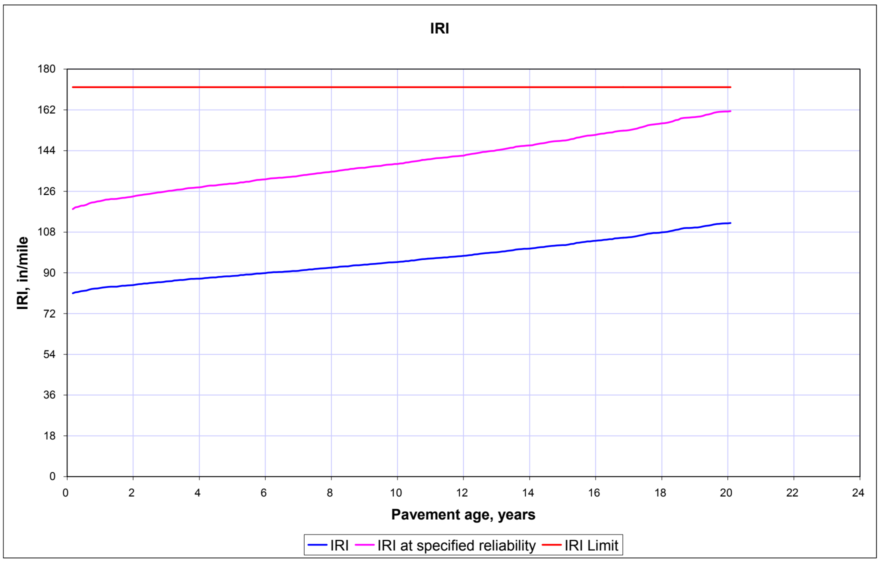
C1	1
C2	3.15
C3	28.35
C4	10.03
Standard deviation in initial IRI (in/mile):	5.4

Project: SITE02-New Design.dgp

Reliability Summary

Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	112	94	Pass
CRCP Punchouts (per mi)	10	90	23.5	15.82	Fail




IRI
IRI, in/mile
180
162
144
126
108
90
72
54
36
18
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Pavement age, years
IRI
IRI at specified reliability
IRI Limit

Project: SITE02-Rehabilitation.dgp

Description:
(SITE02-01 Overlay Design) o Route: I64 East o County: Albemarle, Charlottesville (number 2) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Composite CRCP older than 20 years, w/surface older than 10 years o Traffic: TT 1,680, AADT 15,000 o AC Overlay: 4.5in CRCP:8.25in o Subgrade: reddish-brown sandy salt w/mica

General Information

Design Life	20 years
Existing pavement construction:	September, 1970
Pavement overlay construction:	September, 1992
Traffic open:	October, 1992
Type of design	Flexible

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location:	Albermarle, Charlottesville, VA	
Project ID:	SITE02	
Section ID:		
	Principal Arterials - Interstate and Defense Routes	
Date:	2/28/2005	
Station/milepost format:	Miles: 0.000	
Station/milepost begin:		12.99
Station/milepost end:		13.37
Traffic direction:	East bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	2099
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution
(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution
by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site02-02B
Latitude (degrees.minutes)	38.06
Longitude (degrees.minutes)	-78.5
Elevation (ft)	640
Depth of water table (ft)	25

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7
Bar diameter (in):	0.625
Steel depth (in):	4

Base Properties

Base type:	Granular
Erodibility index:	Fairly Erodable (4)
Base/slab friction coefficient:	4

Crack Spacing

Cracking Model	Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity:	0.85

Drainage Parameters

Infiltration:	Minor (10%)
Drainage path length (ft):	12
Pavement cross slope (%):	2

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	4.5

General Properties

General

Reference temperature (F°):	70

Volumetric Properties as Built

Effective binder content (%):	11
Air voids (%):	4.3
Total unit weight (pcf):	148

Poisson's ratio:	0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°):	0.67
Heat capacity asphalt (BTU/lb-F°):	0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve:	0
Cumulative % Retained 3/8 inch sieve:	12
Cumulative % Retained #4 sieve:	45
% Passing #200 sieve:	5

Asphalt Binder

Option:	Conventional viscosity grade
Viscosity Grade	AC 30
A	10.6316 (correlated)
VTS:	-3.548 (correlated)

Layer 2 -- CRCP (existing)

General Properties

PCC material	CRCP (existing)
Layer thickness (in):	8.25
Unit weight (pcf):	150
Poisson's ratio	0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6):	5.5
Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Mix Properties

Cement type:	Type II
Cementitious material content (lb/yd^3):	564
Water/cement ratio:	0.45
Aggregate type:	Limestone
PCC zero-stress temperature (F°)	Derived
Ultimate shrinkage at 40% R.H (microstrain)	Derived
Reversible shrinkage (% of ultimate shrinkage):	50
Time to develop 50% of ultimate shrinkage (days):	35
Curing method:	Curing compound

Strength Properties

Input level:	Level 3
28-day PCC modulus of rupture (psi):	n/a
28-day PCC compressive strength (psi):	4120

Layer 3 -- ML

Unbound Material:	ML
Thickness(in):	12

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	38000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Layer 4 -- ML

Unbound Material:	ML
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	38000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Distress Model Calibration Settings - Flexible

AC Fatigue

Level 3 (Nationally calibrated values)

k1	0.00432
k2	3.9492
k3	1.281

AC Rutting

Level 3 (Nationally calibrated values)

k1	-3.4488
k2	1.5606
k3	0.4791

Standard Deviation Total Rutting (RUT): 0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture

Level 3 (Nationally calibrated values)

k1	5

Subgrade Rutting

Level 3 (Nationally calibrated values)

Granular:

k1	1.673

Fine-grain:

k1	1.35

AC Cracking

AC Top Down Cracking

C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11

IRI

IRI Rehabilitation over Flexible

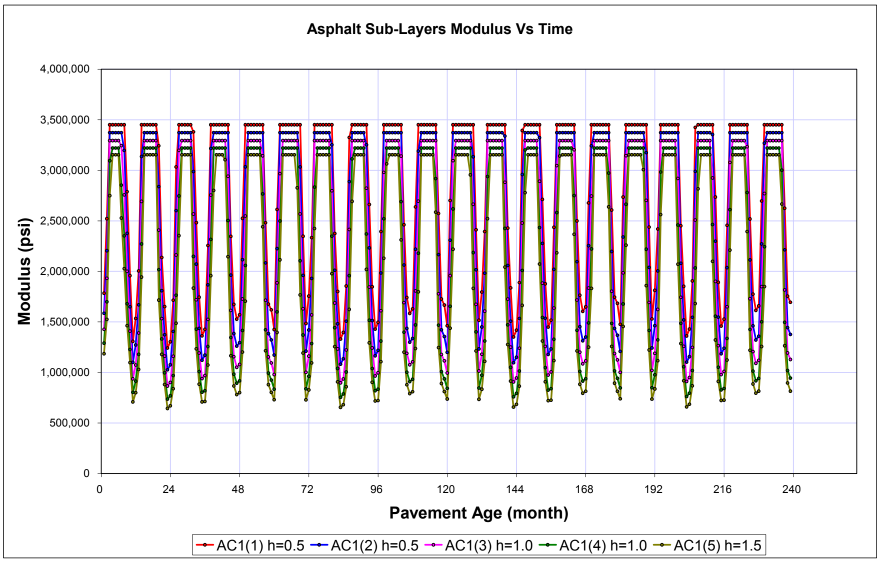
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723
C5 (Flexible)	0.011241
C6 (Flexible)	9.04244
Std. Dev (Flexible)	0.179

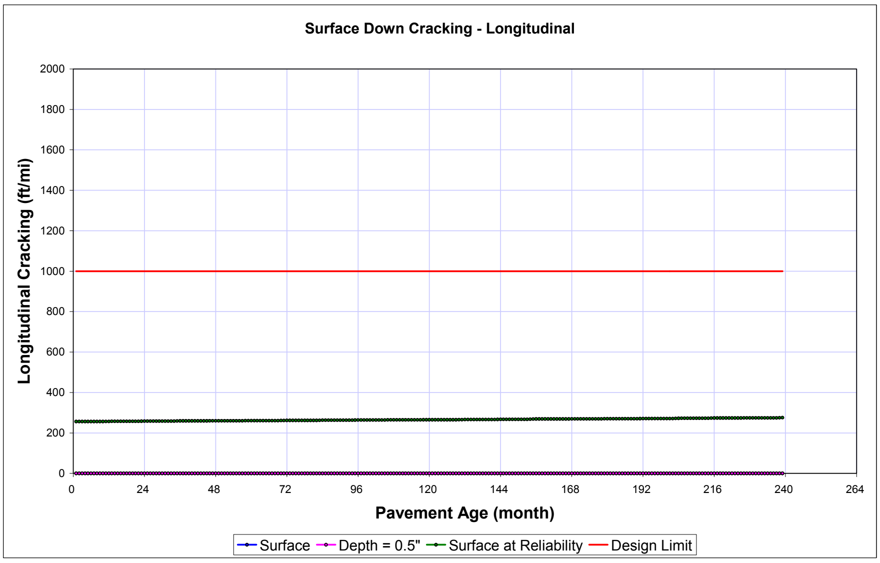
IRI Rehabilitation over Rigid

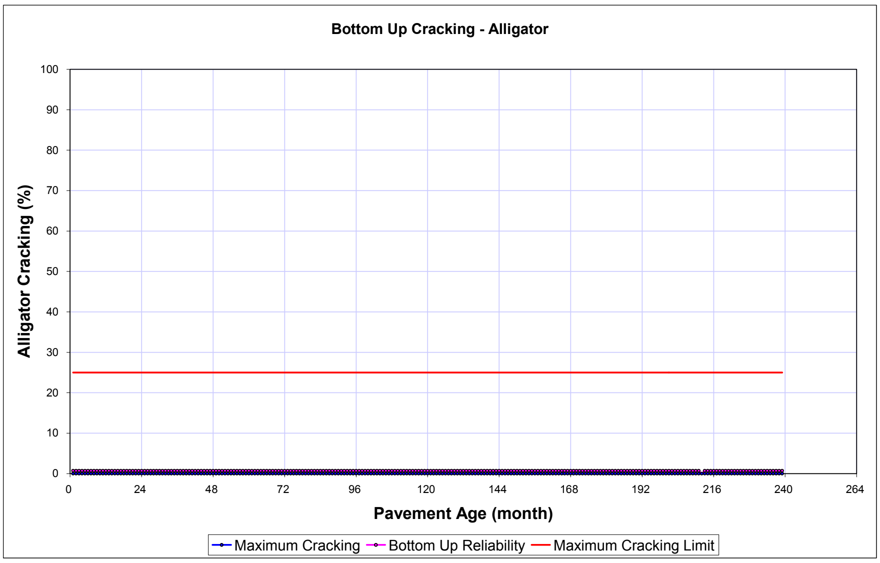
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

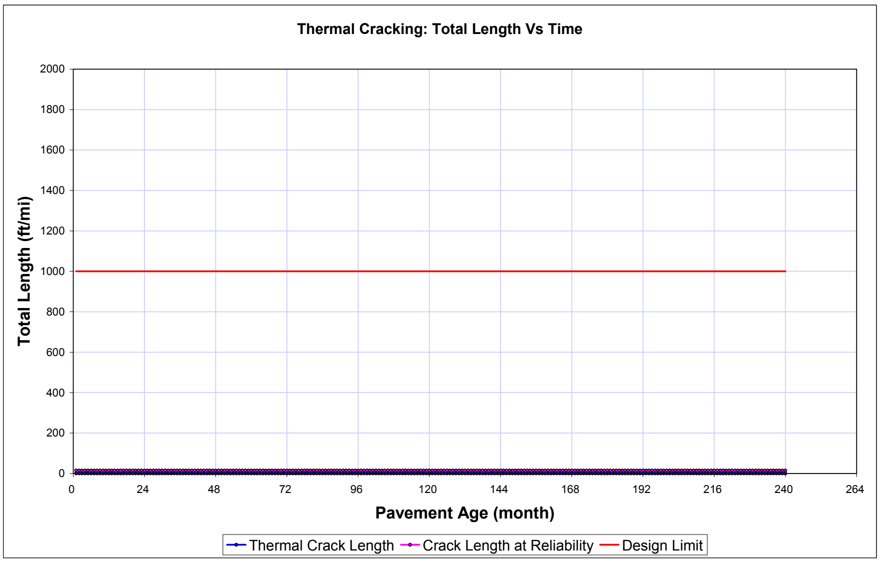
Project: SITE02-Rehabilitation.dgp
Reliability Summary

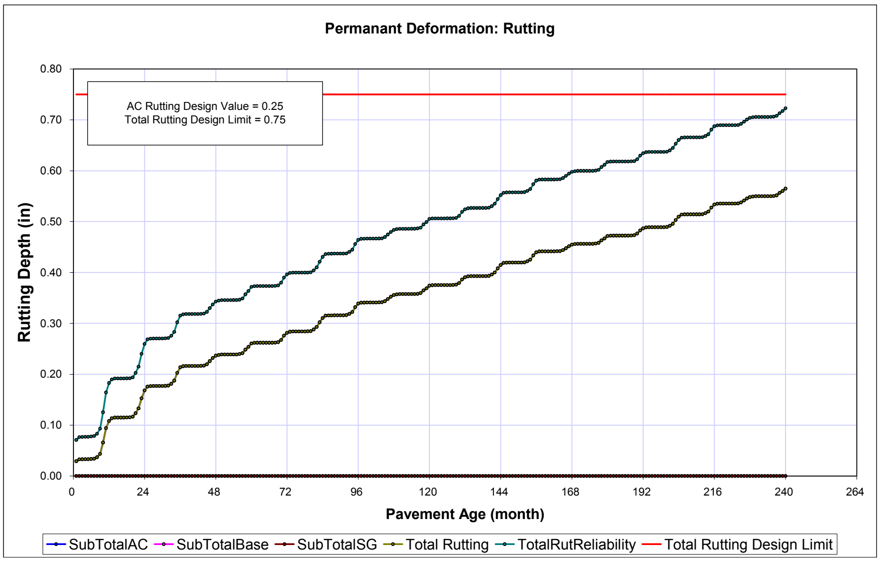
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	94	99.999	Pass
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	0	99.999	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.56	0.53	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.56	93.36	Pass

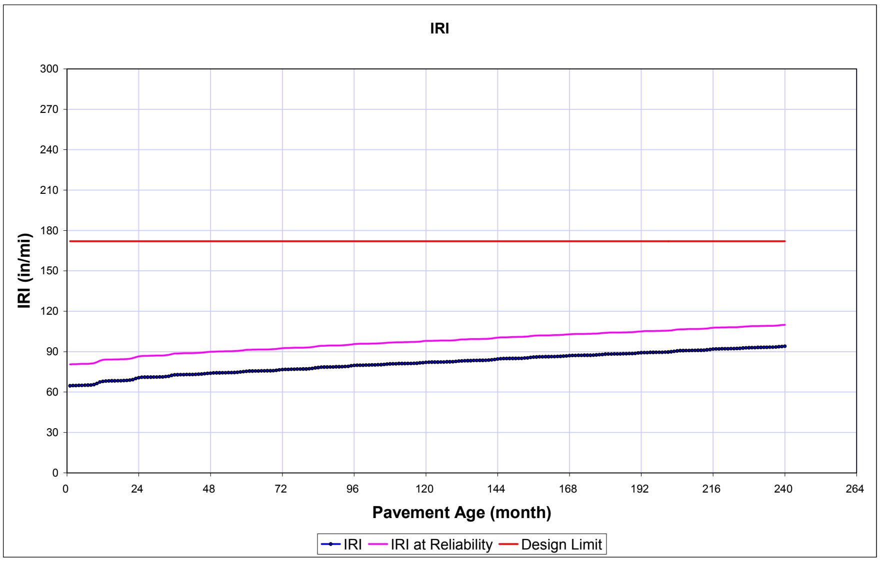





Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
300
270
240
210
180
150
120
90
60
30
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE05-New Design.dgp

General Information

Design Life	20 years
Pavement construction:	August, 1972
Traffic open:	September, 1972
Type of design	CRCP

Description:
o Route: I64 East o County: New Kent (number 63) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Composite CRCP older than 20 years w/surface older than 10 years o Traffic: TT 880 & 800 AADT 21,000 o AC Overlay: 4.25in CRCP:8in Agg Base: 6in o Subgrade: dry silt to fine sand

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
CRCP Punchouts (per mi)	10	90

Location:	New Kent, VA	
Project ID:	SITE05	
Section ID:		
	Principal Arterials - Interstate and Defense Routes	
Date:	3/1/2005	
Station/milepost format:	Miles: 0.000	
Station/milepost begin:		14.69
Station/milepost end:		15.19
Traffic direction:	East bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	502
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors

(Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%
Class 13	0.3%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%
10:00 am	5.9%	10:00 pm	3.1%
11:00 am	5.9%	11:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Wheelbase Truck Tractor

	Short	Medium	Long
Average Axle Spacing (ft)	12	15	18
Percent of trucks	33%	33%	34%

Climate

icm file:	site05-01
Latitude (degrees.minutes)	37.54
Longitude (degrees.minutes)	-77.03
Elevation (ft)	123
Depth of water table (ft)	40

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7

Structure--ICM Properties

Surface shortwave absorptivity: 0.85

Drainage Parameters

Infiltration: Minor (10%)
Drainage path length (ft): 12
Pavement cross slope (%): 2

Structure--Layers

Layer 1 -- CRCP

General Properties

PCC material CRCP
Layer thickness (in): 8
Unit weight (pcf): 150
Poisson's ratio 0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6): 5.5
Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Mix Properties

Cement type: Type II
Cementitious material content (lb/yd^3): 564
Water/cement ratio: 0.45
Aggregate type: Limestone
PCC zero-stress temperature (F°) Derived
Ultimate shrinkage at 40% R.H (microstrain) Derived
Reversible shrinkage (% of ultimate shrinkage): 50
Time to develop 50% of ultimate shrinkage (days): 35
Curing method: Curing compound

Strength Properties

Input level: Level 3
28-day PCC modulus of rupture (psi): n/a
28-day PCC compressive strength (psi): 4850

Layer 2 -- Crushed stone

Unbound Material: Crushed stone
Thickness(in): 6

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 68000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI: 1
Passing #200 sieve (%): 10
Passing #4 sieve (%): 54
D60 (mm): 9.5

Calculated/Derived Parameters

Maximum dry unit weight (pcf): 122.3 (derived)
Specific gravity of solids, Gs: 2.67 (derived)
Saturated hydraulic conductivity (ft/hr): 294 (derived)
Optimum gravimetric water content (%): 11.2 (derived)
Calculated degree of saturation (%): 82.8 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11.4
b	1.72
c	0.518
Hr.	371

Layer 3 -- ML

Unbound Material: ML

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Distress Model Calibration Settings - Rigid (new)

Punchouts

Fatigue

C1	2
C2	1.22

Punchout

C3	105.2632
C4	4
C5	-0.38158

Crack Width

C6	1

Reliability (PO)

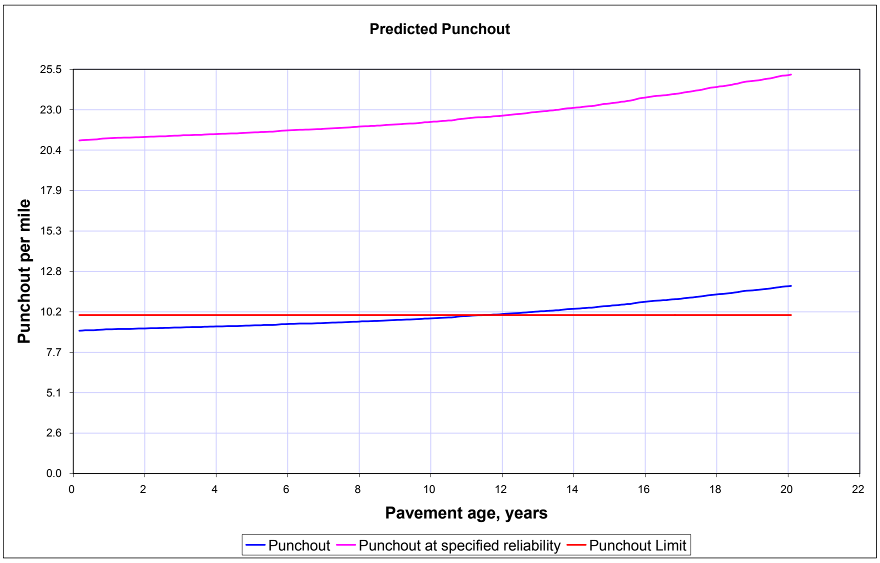
Std. Dev.	4.04*POWER(PO, 0.3825)

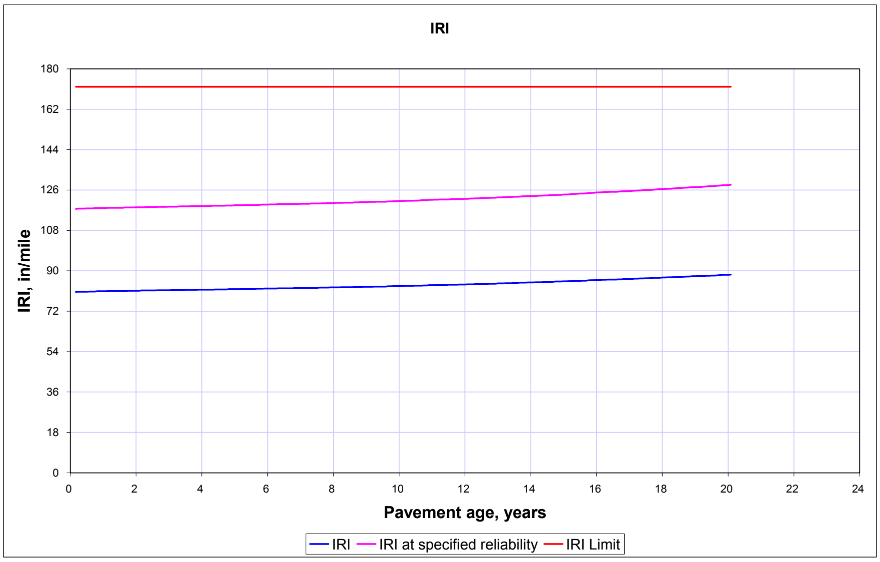
IRI(crcp)

C1	1
C2	3.15
C3	28.35
C4	10.03
Standard deviation in initial IRI (in/mile):	5.4

Project: SITE05-New Design.dgp
Reliability Summary

Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	88.3	99.64	Pass
CRCP Punchouts (per mi)	10	90	11.8	42.99	Fail





Project: SITE05-Rehabilitation.dgp

General Information

Design Life	20 years
Existing pavement construction:	September, 1972
Pavement overlay construction:	September, 1991
Traffic open:	October, 1991
Type of design	Flexible

Description:
o Route: I64 East o County: New Kent (number 63) o Length: 2640 ft o Number of lanes in each direction: 2 o Pavement Category: Composite CRCP older than 20 years w/surface older than 10 years o Traffic: TT 880 & 800 AADT 21,000 o AC Overlay: 4.25in CRCP:8in Agg Base: 6in o Subgrade: dry silt to fine sand

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location: New Kent, VA
Project ID: SITE05
Section ID:
Principal Arterials - Interstate and Defense Routes
Date: 3/1/2005

Station/milepost format: Miles: 0.000
Station/milepost begin: 14.69
Station/milepost end: 15.19
Traffic direction: East bound

Default Input Level

Default input level: Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	1057
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	80
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors

(Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site05-02
Latitude (degrees.minutes)	37.54
Longitude (degrees.minutes)	-77.03
Elevation (ft)	123
Depth of water table (ft)	40

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7
Bar diameter (in):	0.625
Steel depth (in):	4

Base Properties

Base type:	Granular

Structure--ICM Properties

Surface shortwave absorptivity: 0.85

Drainage Parameters

Infiltration: Minor (10%)
Drainage path length (ft): 12
Pavement cross slope (%): 2

Structure--Layers

Layer 1 -- Asphalt concrete

Material type: Asphalt concrete
Layer thickness (in): 4.25

General Properties

General
Reference temperature (F°): 70

Volumetric Properties as Built
Effective binder content (%): 11
Air voids (%): 4.3
Total unit weight (pcf): 148

Poisson's ratio: 0.35 (user entered)

Thermal Properties
Thermal conductivity asphalt (BTU/hr-ft-F°): 0.67
Heat capacity asphalt (BTU/lb-F°): 0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve: 0
Cumulative % Retained 3/8 inch sieve: 12
Cumulative % Retained #4 sieve: 45
% Passing #200 sieve: 5

Asphalt Binder

Option: Conventional viscosity grade
Viscosity Grade AC 30
A 10.6316 (correlated)
VTS: -3.548 (correlated)

Layer 2 -- CRCP (existing)

General Properties

PCC material CRCP (existing)
Layer thickness (in): 8
Unit weight (pcf): 150
Poisson's ratio 0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6): 5.5
Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Mix Properties

Cement type: Type II
Cementitious material content (lb/yd^3): 564
Water/cement ratio: 0.45
Aggregate type: Limestone
PCC zero-stress temperature (F°) Derived
Ultimate shrinkage at 40% R.H (microstrain) Derived
Reversible shrinkage (% of ultimate shrinkage): 50
Time to develop 50% of ultimate shrinkage (days): 35
Curing method: Curing compound

Strength Properties

Input level: Level 3
28-day PCC modulus of rupture (psi): n/a
28-day PCC compressive strength (psi): 4850

Layer 3 -- Crushed stone

Unbound Material: Crushed stone
Thickness(in): 6

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	1
Passing #200 sieve (%):	10
Passing #4 sieve (%):	54
D60 (mm):	9.5

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	122.3 (derived)
Specific gravity of solids, Gs:	2.67 (derived)
Saturated hydraulic conductivity (ft/hr):	294 (derived)
Optimum gravimetric water content (%):	11.2 (derived)
Calculated degree of saturation (%):	82.8 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	11.4
b	1.72
c	0.518
Hr.	371

Layer 4 -- ML

Unbound Material:	ML
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	35000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	10
Passing #200 sieve (%):	80
Passing #4 sieve (%):	95
D60 (mm):	0.05

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	111.2 (derived)
Specific gravity of solids, Gs:	2.72 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	16.9 (derived)
Calculated degree of saturation (%):	87.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	46.9
b	1.21
c	0.635
Hr.	1760

Distress Model Calibration Settings - Flexible

AC Fatigue	Level 3 (Nationally calibrated values)
k1	0.00432
k2	3.9492
k3	1.281

AC Rutting	Level 3 (Nationally calibrated values)
k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture	Level 3 (Nationally calibrated values)
k1	5

Subgrade Rutting

Level 3 (Nationally calibrated values)

Granular:

k1	1.673

Fine-grain:

k1	1.35

AC Cracking

AC Top Down Cracking

C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11

IRI

IRI Rehabilitation over Flexible

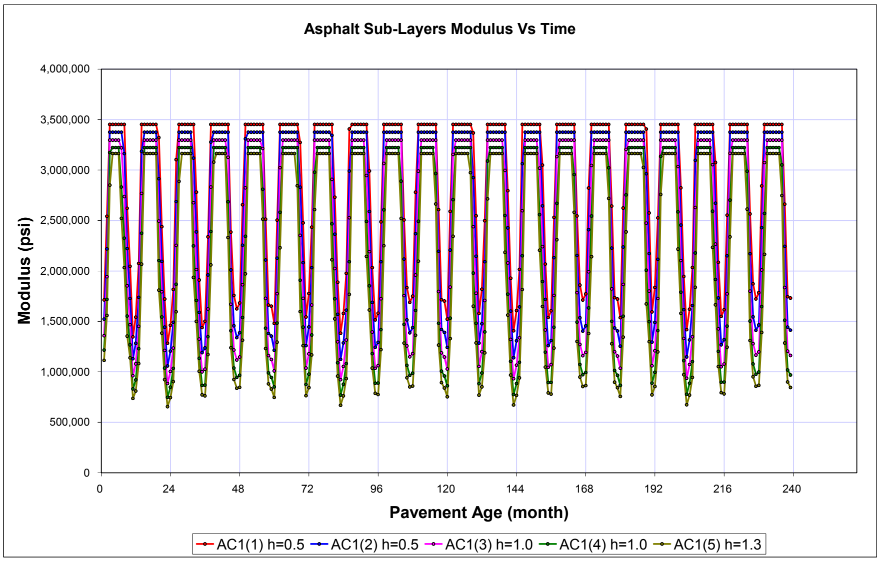
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723
C5 (Flexible)	0.011241
C6 (Flexible)	9.04244
Std. Dev (Flexible)	0.179

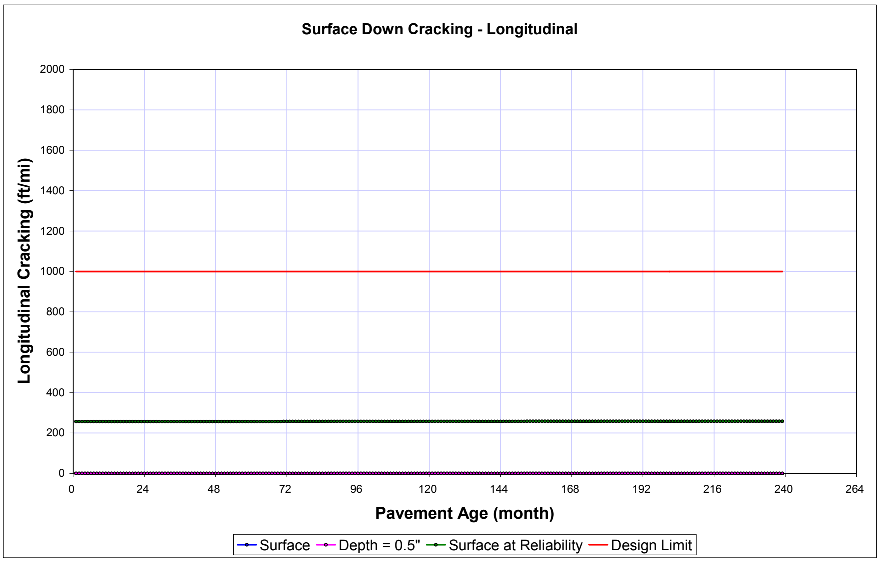
IRI Rehabilitation over Rigid

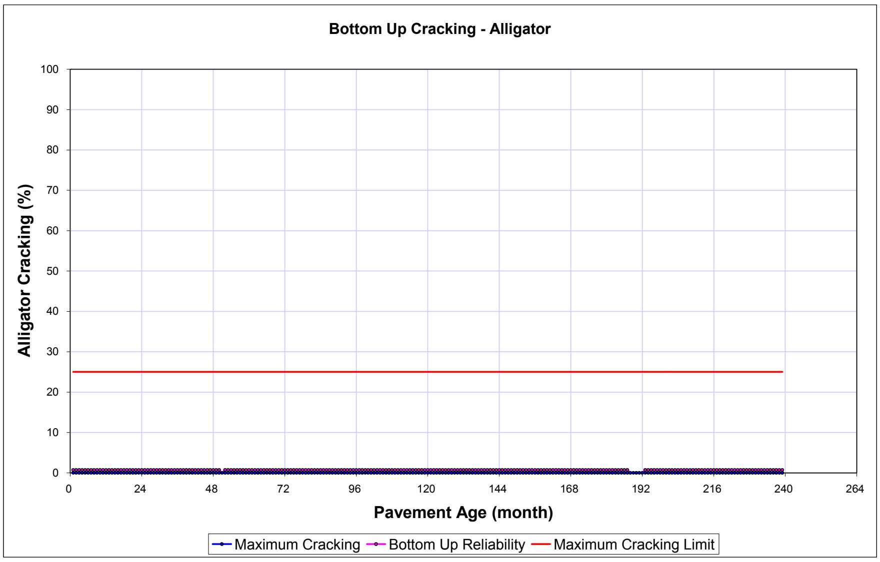
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

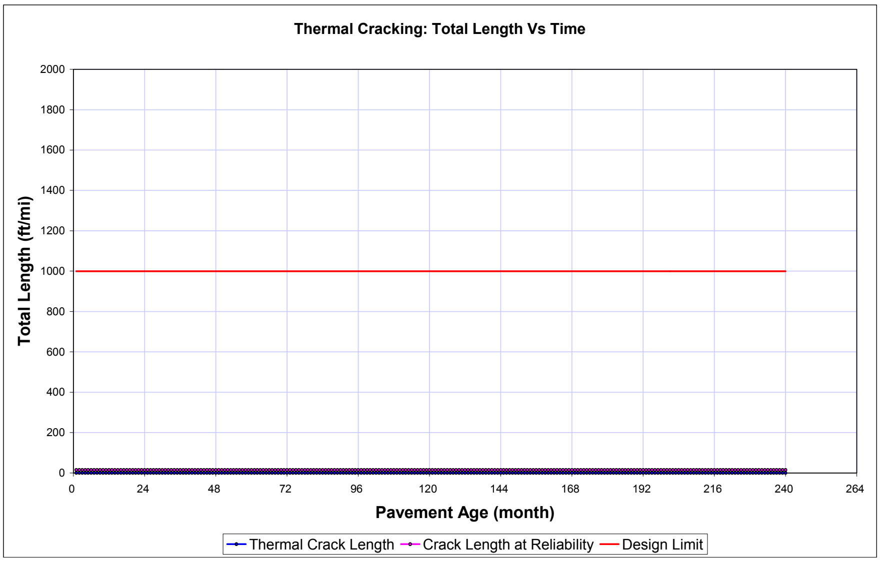
Project: SITE05-Rehabilitation.dgp
Reliability Summary

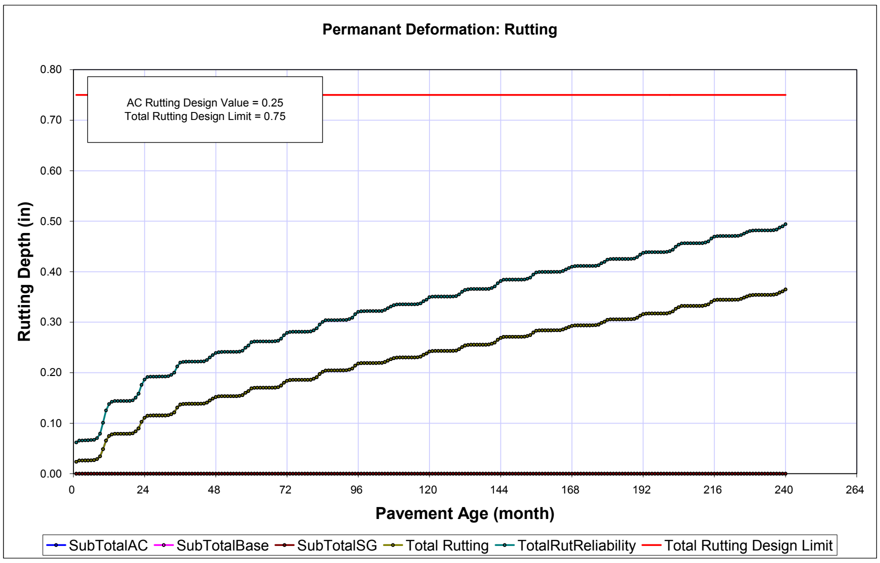
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	86.9	99.999	Pass
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	0	99.999	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.36	12.8	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.36	99.99	Pass



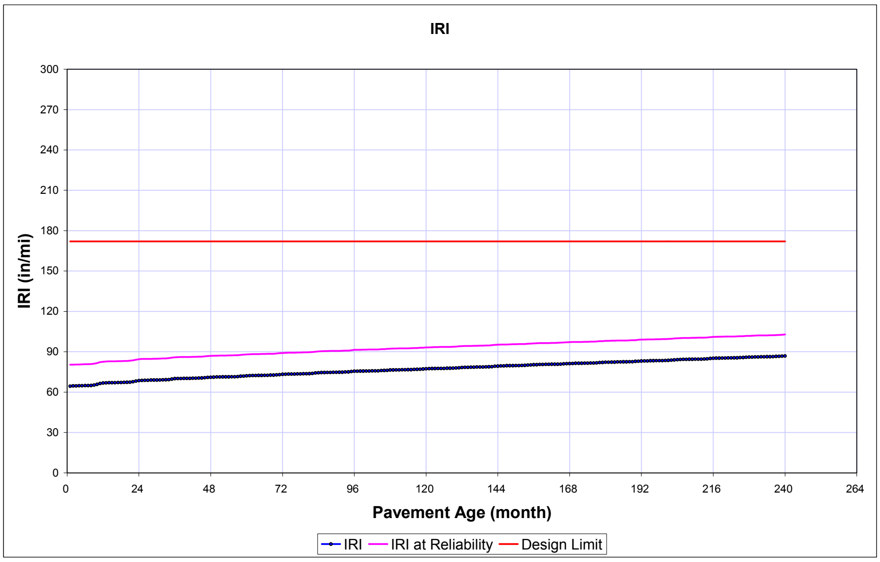

Surface Down Cracking - Longitudinal
Longitudinal Cracking (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Surface
Depth = 0.5"
Surface at Reliability
Design Limit


Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time


Permanant Deformation: Rutting

AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75


IRI
IRI (in/mi)
0
30
60
90
120
150
180
210
240
270
300
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE09-New Design.dgp

Description:
o Route: 295 South o County: Henrico, Richmond (number 43) o Length: 2640 ft o Number of lanes in each direction: 3 o Pavement Category: Composite CRCP older than 20 years with a surface less than 10 years old o Traffic: TT 1,100, AADT N/A (see traffic calculation I did for Mus) o AC overlay:3.75in CRCP:8.5in; CTA:6in o Subgrade: BR1: yellow-brown and yellow-red 50/50 silt/clay; B2: same thing & conglom sand/grav/silt/clay

General Information

Design Life	20 years
Pavement construction:	September, 1980
Traffic open:	October, 1980
Type of design	CRCP

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
CRCP Punchouts (per mi)	10	90

Location:	Henrico, Richmond, VA
Project ID:	SITE09
Section ID:	
	Principal Arterials - Interstate and Defense Routes
Date:	3/1/2005
Station/milepost format:	Miles: 0.000
Station/milepost begin:	5.29
Station/milepost end:	5.79
Traffic direction:	South bound

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	780
Number of lanes in design direction:	3
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	75
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%
Class 13	0.3%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%
10:00 am	5.9%	10:00 pm	3.1%
11:00 am	5.9%	11:00 pm	3.1%

Traffic Growth Factor

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Wheelbase Truck Tractor

	Short	Medium	Long
Average Axle Spacing (ft)	12	15	18
Percent of trucks	33%	33%	34%

Climate

icm file:	site09-01
Latitude (degrees.minutes)	37.7
Longitude (degrees.minutes)	-77.5
Elevation (ft)	190
Depth of water table (ft)	15

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7
Bar diameter (in):	0.625
Steel depth (in):	4

Base Properties

Base type:	Cement treated
Erodibility index:	Erosion Resistant (3)
Base/slab friction coefficient:	4

Crack Spacing

Cracking Model	Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity:	0.85

Drainage Parameters

Infiltration:	Minor (10%)
Drainage path length (ft):	12
Pavement cross slope (%):	2

Structure--Layers

Layer 1 -- CRCP

General Properties

PCC material	CRCP
Layer thickness (in):	8.5
Unit weight (pcf):	150
Poisson's ratio	0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6):	5.5
Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Mix Properties

Cement type:	Type II
Cementitious material content (lb/yd^3):	564
Water/cement ratio:	0.45
Aggregate type:	Limestone
PCC zero-stress temperature (F°)	Derived
Ultimate shrinkage at 40% R.H (microstrain)	Derived

Layer 2 -- Cement Stabilized

General Properties

Material type:	Cement Stabilized
Layer thickness (in):	6
Unit weight (pcf):	150
Poisson's ratio:	0.2

Strength Properties

Elastic/resilient modulus (psi):	331000

Thermal Properties

Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Layer 3 -- CL

Unbound Material:	CL
Thickness(in):	12

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.4
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	43000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Layer 4 -- CL

Unbound Material:	CL
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.4
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	43000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Rigid (new)

Punchouts

Fatigue

C1	2
C2	1.22

Punchout

C3	105.2632
C4	4
C5	-0.38158

Crack Width

C6	1

Reliability (PO)

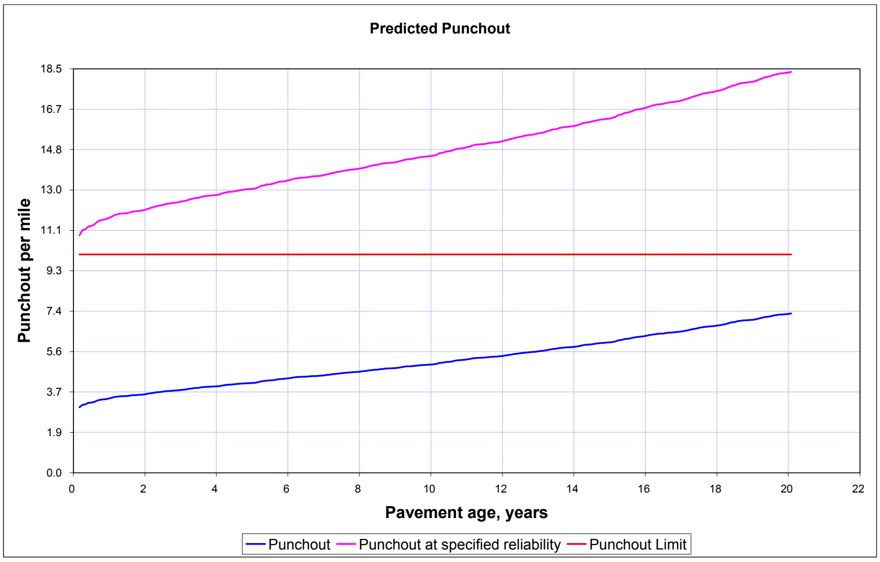
Std. Dev.	4.04*POWER(PO, 0.3825)

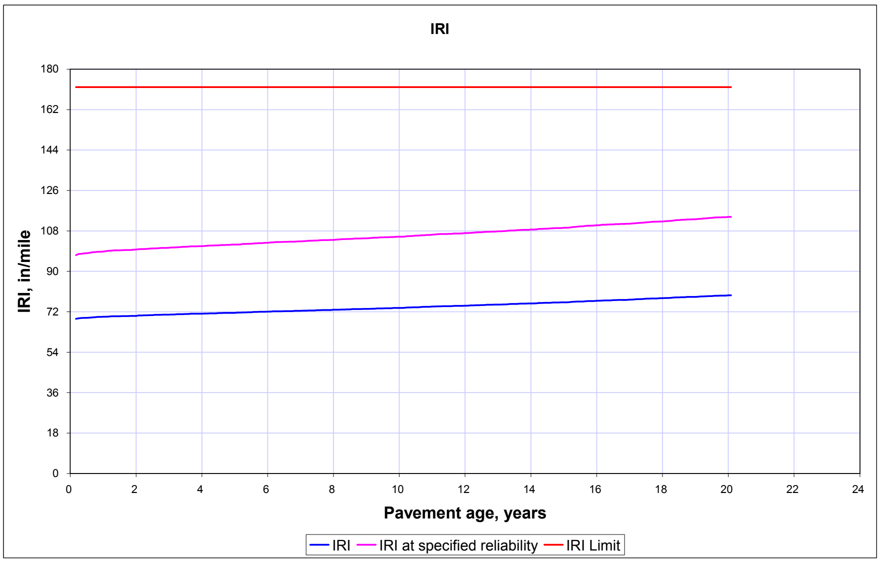
IRI(crcp)

C1	1
C2	3.15
C3	28.35
C4	10.03
Standard deviation in initial IRI (in/mile):	5.4

Project: SITE09-New Design.dgp
Reliability Summary

Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	79.3	99.97	Pass
CRCP Punchouts (per mi)	10	90	7.3	62.3	Fail


Predicted Punchout
Punchout per mile
18.5
16.7
14.8
13.0
11.1
9.3
7.4
5.6
3.7
1.9
0.0
0
2
4
6
8
10
12
14
16
18
20
22
Pavement age, years
Punchout
Punchout at specified reliability
Punchout Limit


IRI
IRI, in/mile
180
162
144
126
108
90
72
54
36
18
0
0
2
4
6
8
10
12
14
16
18
20
22
24
Pavement age, years
IRI
IRI at specified reliability
IRI Limit

Project: SITE09-Rehabilitation.dgp

Description:
o Route: 295 South o County: Henrico, Richmond (number 43) o Length: 2640 ft o Number of lanes in each direction: 3 o Pavement Category: Composite CRCP older than 20 years with a surface less than 10 years old o Traffic: TT 1,100, AADT N/A (see traffic calculation I did for Mus) o AC overlay:3.75in CRCP:8.5in; CTA:6in o Subgrade: BR1: yellow-brown and yellow-red 50/50 silt/clay; B2: same thing & conglom sand/grav/silt/clay

General Information

Design Life	15 years
Existing pavement construction:	September, 1980
Pavement overlay construction:	September, 1998
Traffic open:	October, 1998
Type of design	Flexible

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location:	Henrico, Richmond, VA	
Project ID:	SITE09	
Section ID:		
	Principal Arterials - Interstate and Defense Routes	
Date:	3/1/2005	
Station/milepost format:	Miles: 0.000	
Station/milepost begin:		5.29
Station/milepost end:		5.79
Traffic direction:	South bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	1581
Number of lanes in design direction:	3
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	75
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site09-02
Latitude (degrees.minutes)	37.7
Longitude (degrees.minutes)	-77.5
Elevation (ft)	190
Depth of water table (ft)	15

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7
Bar diameter (in):	0.625
Steel depth (in):	3

Base Properties

Base type:	Cement treated

Crack Spacing

Cracking Model	Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity:	0.85

Drainage Parameters

Infiltration:	Minor (10%)
Drainage path length (ft):	12
Pavement cross slope (%):	2

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	3.75

General Properties

General

Reference temperature (F°):	70

Volumetric Properties as Built

Effective binder content (%):	11
Air voids (%):	4.3
Total unit weight (pcf):	148
Poisson's ratio:	0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°):	0.67
Heat capacity asphalt (BTU/lb-F°):	0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve:	0
Cumulative % Retained 3/8 inch sieve:	12
Cumulative % Retained #4 sieve:	45
% Passing #200 sieve:	5

Asphalt Binder

Option:	Conventional viscosity grade
Viscosity Grade	AC 30
A	10.6316 (correlated)
VTS:	-3.548 (correlated)

Layer 2 -- CRCP (existing)

General Properties

PCC material	CRCP (existing)
Layer thickness (in):	8.5
Unit weight (pcf):	150
Poisson's ratio	0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6):	5.5
Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Mix Properties

Cement type:	Type II
Cementitious material content (lb/yd^3):	564
Water/cement ratio:	0.45
Aggregate type:	Limestone
PCC zero-stress temperature (F°)	Derived
Ultimate shrinkage at 40% R.H (microstrain)	Derived
Reversible shrinkage (% of ultimate shrinkage):	50
Time to develop 50% of ultimate shrinkage (days):	35
Curing method:	Curing compound

Strength Properties

Input level:	Level 3
28-day PCC modulus of rupture (psi):	n/a
28-day PCC compressive strength (psi):	5775

Layer 3 -- Cement Stabilized

General Properties

Material type: Cement Stabilized
Layer thickness (in): 6
Unit weight (pcf): 150
Poisson's ratio: 0.2

Strength Properties

Elastic/resilient modulus (psi): 331000

Thermal Properties

Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Layer 4 -- CL

Unbound Material: CL
Thickness(in): 12

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.4
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 43000

ICM Inputs

Gradation and Plasticity Index
Plasticity Index, PI: 15
Passing #200 sieve (%): 75
Passing #4 sieve (%): 95
D60 (mm): 0.1

Calculated/Derived Parameters
Maximum dry unit weight (pcf): 107.9 (derived)
Specific gravity of solids, Gs: 2.73 (derived)
Saturated hydraulic conductivity (ft/hr): 3.25e-005 (derived)
Optimum gravimetric water content (%): 18.6 (derived)
Calculated degree of saturation (%): 87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Layer 5 -- CL

Unbound Material: CL
Thickness(in): Semi-infinite

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.4
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 43000

ICM Inputs

Gradation and Plasticity Index
Plasticity Index, PI: 15
Passing #200 sieve (%): 75
Passing #4 sieve (%): 95
D60 (mm): 0.1

Calculated/Derived Parameters
Maximum dry unit weight (pcf): 107.9 (derived)
Specific gravity of solids, Gs: 2.73 (derived)
Saturated hydraulic conductivity (ft/hr): 3.25e-005 (derived)
Optimum gravimetric water content (%): 18.6 (derived)
Calculated degree of saturation (%): 87.6 (calculated)

Soil water characteristic curve parameters:	Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Flexible

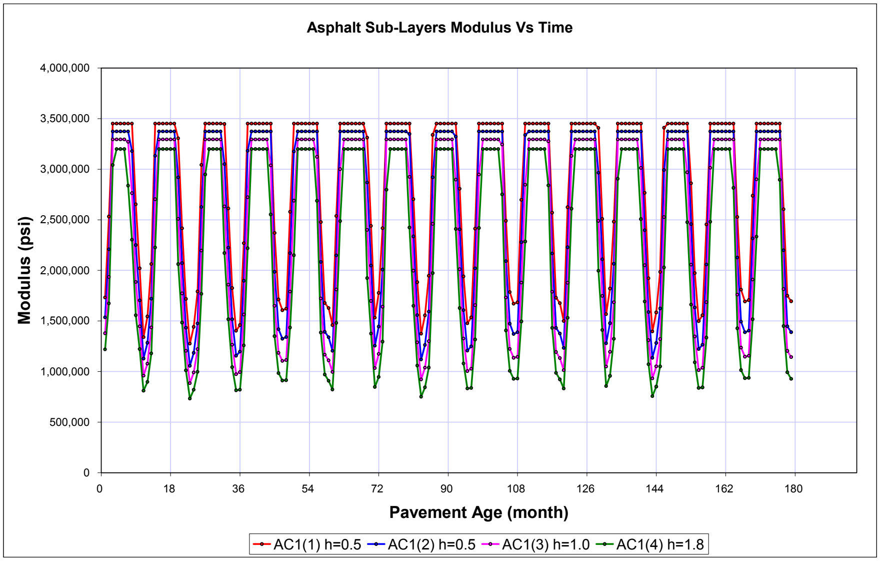
AC Fatigue	Level 3 (Nationally calibrated values)
k1	0.00432
k2	3.9492
k3	1.281
AC Rutting	Level 3 (Nationally calibrated values)
k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001
Thermal Fracture	Level 3 (Nationally calibrated values)
k1	5
Std. Dev. (THERMAL):	0.2474 * THERMAL + 10.619
CSM Fatigue	Level 3 (Nationally calibrated values)
k1	1
k2	1
Subgrade Rutting	Level 3 (Nationally calibrated values)
Granular:	
k1	1.673
Fine-grain:	
k1	1.35
AC Cracking	
AC Top Down Cracking	
C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))
AC Bottom Up Cracking	
C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))
CSM Cracking	
C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11
IRI	
IRI Rehabilitation over Flexible	
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723

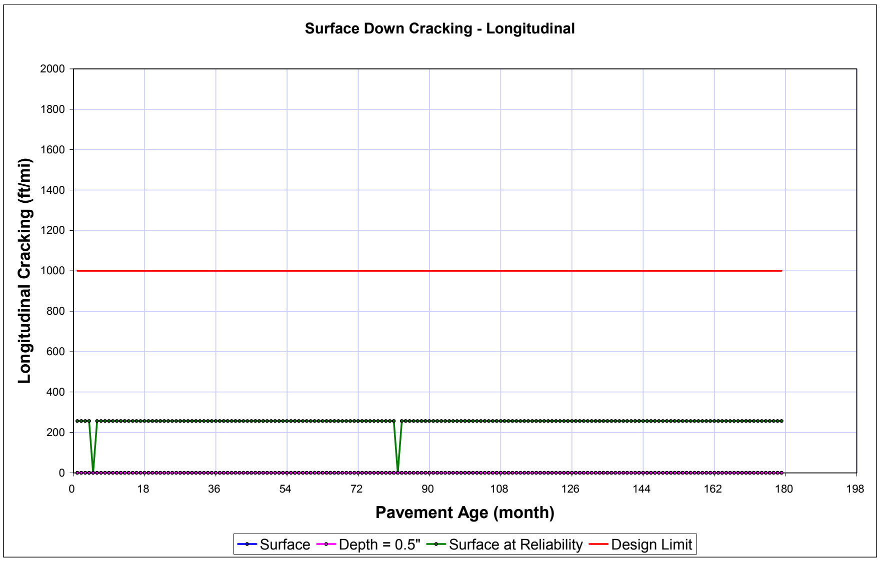
IRI Rehabilitation over Rigid

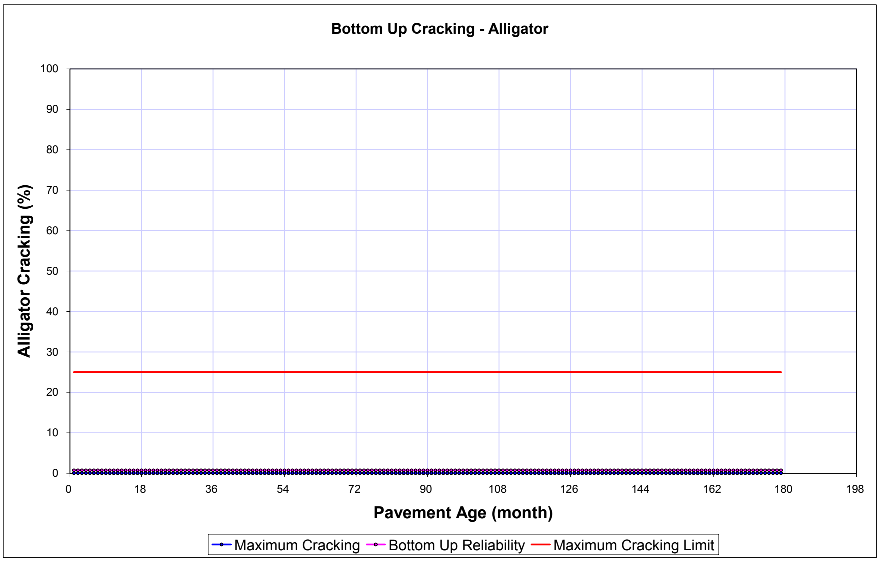
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

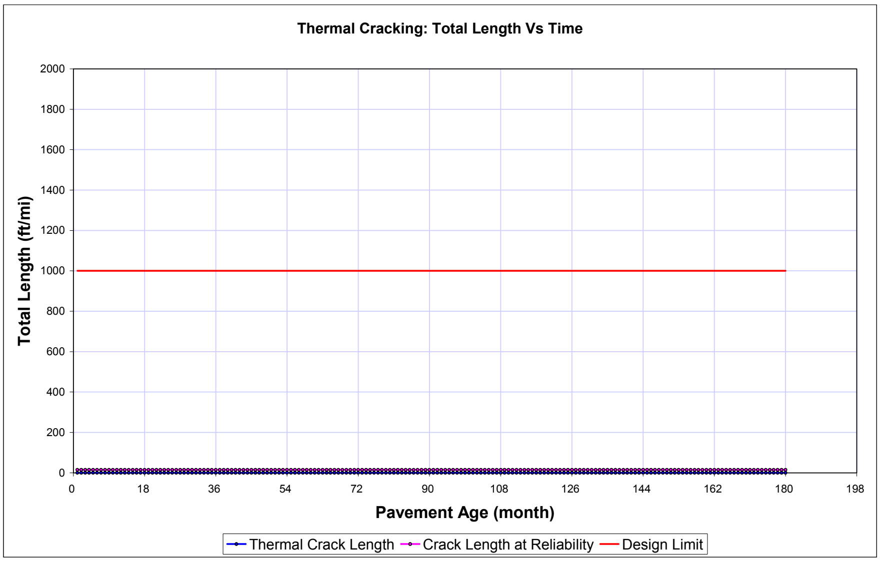
Project: SITE09-Rehabilitation.dgp Reliability Summary

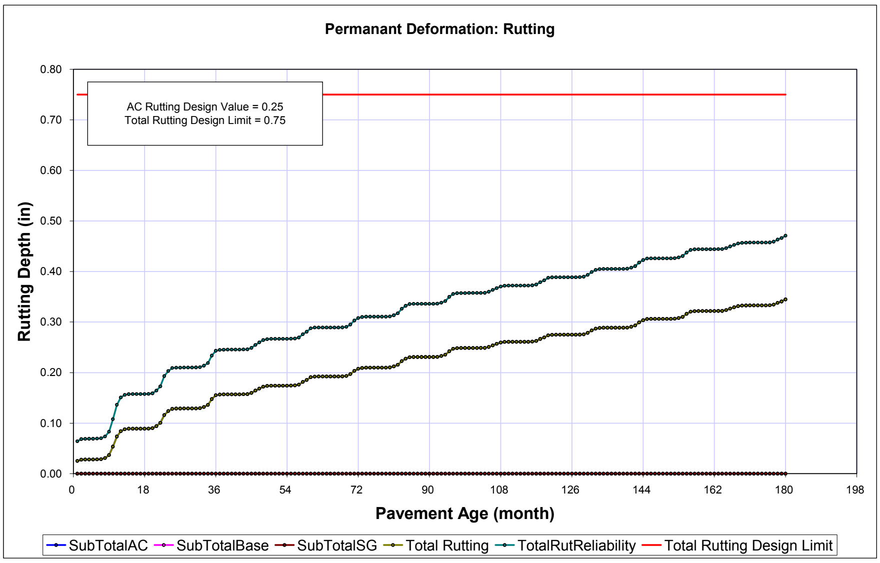
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	83.6	99.999	Pass
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	0	99.999	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.34	16.8	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.34	99.999	Pass

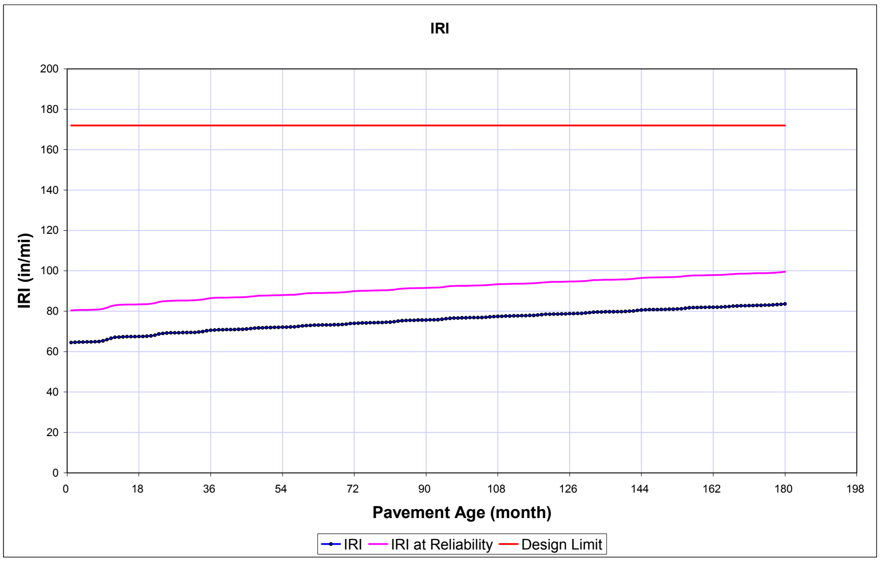



Surface Down Cracking - Longitudinal
Longitudinal Cracking (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Surface
Depth = 0.5"
Surface at Reliability
Design Limit


Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
200
180
160
140
120
100
80
60
40
20
0
IRI (in/mi)
0
18
36
54
72
90
108
126
144
162
180
198
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

Project: SITE10-New Design.dgp

General Information

Design Life	20 years
Pavement construction:	September, 1980
Traffic open:	October, 1980
Type of design	CRCP

Description:
o Route: 295 South o County: Hanover (number 42) o Length: 2640 ft o Number of lanes in each direction: 4 o Pavement Category: Composite CRCP older than 20 years w/ surface less than 10 years old o Traffic: TT 3,300 & 3,060, AADT 37,000 & 34,000 o AC Overlay:4in CRCP:8in CTA:6in o Subgrade: silty clay w/fine gravel

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
CRCP Punchouts (per mi)	10	90

Location:	Hanover, VA
Project ID:	SITE10
Section ID:	
	Principal Arterials - Interstate and Defense Routes
Date:	3/1/2005
Station/milepost format:	Miles: 0.000
Station/milepost begin:	9.52
Station/milepost end:	10.02
Traffic direction:	South bound

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	2575
Number of lanes in design direction:	4
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	70
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

	Vehicle Class									
Month	**Class 4**	**Class 5**	**Class 6**	**Class 7**	**Class 8**	**Class 9**	**Class 10**	**Class 11**	**Class 12**	**Class 13**
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%
Class 13	0.3%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%
10:00 am	5.9%	10:00 pm	3.1%
11:00 am	5.9%	11:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3: Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Wheelbase Truck Tractor

	Short	Medium	Long
Average Axle Spacing (ft)	12	15	18
Percent of trucks	33%	33%	34%

Climate

icm file:	site10-01
Latitude (degrees.minutes)	37.77
Longitude (degrees.minutes)	-77.37
Elevation (ft)	2069
Depth of water table (ft)	17

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7

Base Properties

Base type:	Cement treated
Erodibility index:	Fairly Erodable (4)
Base/slab friction coefficient:	4

Crack Spacing

Cracking Model	Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity:	0.85

Drainage Parameters

Infiltration:	Minor (10%)
Drainage path length (ft):	12
Pavement cross slope (%):	2

Structure--Layers

Layer 1 -- CRCP

General Properties

PCC material	CRCP
Layer thickness (in):	8
Unit weight (pcf):	150
Poisson's ratio	0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6):	5.5
Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Mix Properties

Cement type:	Type II
Cementitious material content (lb/yd^3):	564
Water/cement ratio:	0.42
Aggregate type:	Limestone
PCC zero-stress temperature (F°)	Derived
Ultimate shrinkage at 40% R.H (microstrain)	Derived
Reversible shrinkage (% of ultimate shrinkage):	50
Time to develop 50% of ultimate shrinkage (days):	35
Curing method:	Curing compound

Strength Properties

Input level:	Level 3
28-day PCC modulus of rupture (psi):	n/a
28-day PCC compressive strength (psi):	3632

Layer 2 -- Cement Stabilized

General Properties

Material type:	Cement Stabilized
Layer thickness (in):	6
Unit weight (pcf):	150
Poisson's ratio:	0.2

Strength Properties

Elastic/resilient modulus (psi):	540000

Thermal Properties

Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Layer 3 -- CL

Unbound Material:	CL
Thickness(in):	12

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	50000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.25e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Layer 4 -- CL

Unbound Material:	CL
Thickness(in):	Semi-infinite

Strength Properties

Input Level:	Level 3
Analysis Type:	ICM inputs (ICM Calculated Modulus)
Poisson's ratio:	0.35
Coefficient of lateral pressure,Ko:	0.5
Modulus (input) (psi):	50000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	15
Passing #200 sieve (%):	75
Passing #4 sieve (%):	95
D60 (mm):	0.1

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	107.9 (derived)
Specific gravity of solids, Gs:	2.73 (derived)
Saturated hydraulic conductivity (ft/hr):	3.2175e-005 (derived)
Optimum gravimetric water content (%):	18.6 (derived)
Calculated degree of saturation (%):	87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Rigid (new)

Punchouts

Fatigue

C1	2
C2	1.22

Punchout

C3	105.2632
C4	4
C5	-0.38158

Crack Width

C6	1

Reliability (PO)

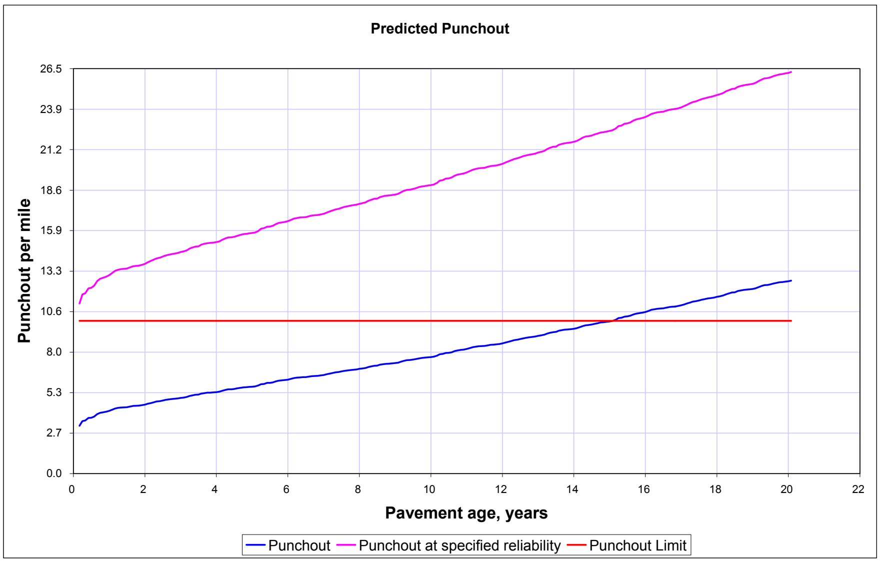
Std. Dev.	4.04*POWER(PO, 0.3825)

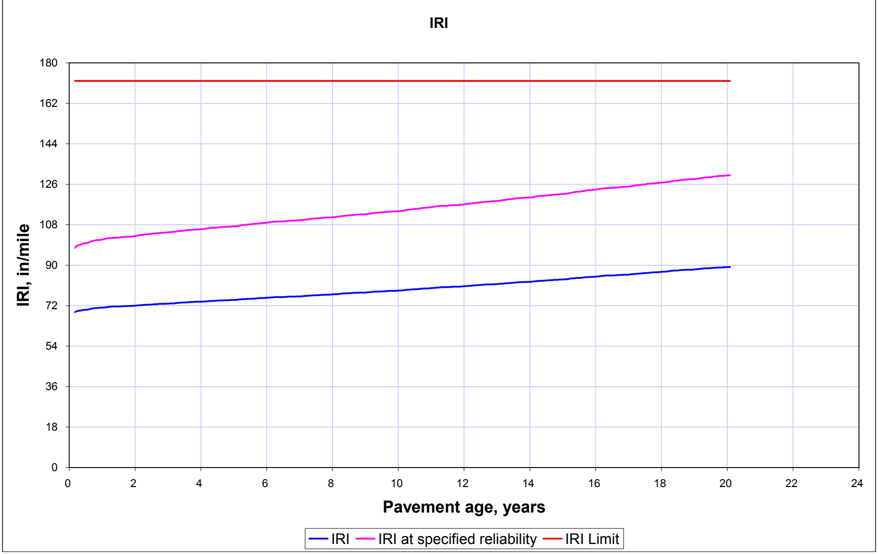
IRI(crcp)

C1	1
C2	3.15
C3	28.35
C4	10.03
Standard deviation in initial IRI (in/mile):	5.4

Project: SITE10-New Design.dgp
Reliability Summary

Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	89.2	99.54	Pass
CRCP Punchouts (per mi)	10	90	12.6	40.28	Fail




IRI
180
162
144
126
108
90
72
54
36
18
0
IRI, in/mile
0
2
4
6
8
10
12
14
16
18
20
22
24
Pavement age, years
IRI
IRI at specified reliability
IRI Limit

Project: SITE10-Rehabilitation.dgp

General Information

Design Life	20 years
Existing pavement construction:	September, 1980
Pavement overlay construction:	September, 1996
Traffic open:	October, 1996
Type of design	Flexible

Description:
o Route: 295 South o County: Hanover (number 42) o Length: 2640 ft o Number of lanes in each direction: 4 o Pavement Category: Composite CRCP older than 20 years w/ surface less than 10 years old o Traffic: TT 3,300 & 3,060, AADT 37,000 & 34,000 o AC Overlay:4in CRCP:8in CTA:6in o Subgrade: silty clay w/fine gravel

Analysis Parameters

Analysis type	Probabilistic

Performance Criteria

	Limit	Reliability
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90
Chemically Stabilized Layer (Fatigue Fracture)	25	90
Permanent Deformation (AC Only) (in):	0.25	90
Permanent Deformation (Total Pavement) (in):	0.75	90

Location:	Hanover, VA	
Project ID:	SITE10	
Section ID:		
	Principal Arterials - Interstate and Defense Routes	
Date:	3/1/2005	
Station/milepost format:	Miles: 0.000	
Station/milepost begin:		9.52
Station/milepost end:		10.02
Traffic direction:	South bound	

Default Input Level

Default input level	Level 3, Default and historical agency values.

Traffic

Initial two-way aadtt:	4823
Number of lanes in design direction:	4
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	70
Operational speed (mph):	60

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors

(Level 3, Default MAF)

	Vehicle Class									
Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
February	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
March	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
April	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
June	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
July	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
August	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
September	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
October	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
November	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
December	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Vehicle Class Distribution

(Level 3, Default Distribution)

AADTT distribution by vehicle class

Class 4	1.3%
Class 5	8.5%
Class 6	2.8%
Class 7	0.3%
Class 8	7.6%
Class 9	74.0%
Class 10	1.2%
Class 11	3.4%
Class 12	0.6%

Hourly truck traffic distribution

by period beginning:

Midnight	2.3%	Noon	5.9%
1:00 am	2.3%	1:00 pm	5.9%
2:00 am	2.3%	2:00 pm	5.9%
3:00 am	2.3%	3:00 pm	5.9%
4:00 am	2.3%	4:00 pm	4.6%
5:00 am	2.3%	5:00 pm	4.6%
6:00 am	5.0%	6:00 pm	4.6%
7:00 am	5.0%	7:00 pm	4.6%
8:00 am	5.0%	8:00 pm	3.1%
9:00 am	5.0%	9:00 pm	3.1%

Traffic Growth Factor

Vehicle Class	Growth Rate	Growth Function
Class 4	4.0%	Compound
Class 5	4.0%	Compound
Class 6	4.0%	Compound
Class 7	4.0%	Compound
Class 8	4.0%	Compound
Class 9	4.0%	Compound
Class 10	4.0%	Compound
Class 11	4.0%	Compound
Class 12	4.0%	Compound
Class 13	4.0%	Compound

Traffic -- Axle Load Distribution Factors

Level 3:	Default

Traffic -- General Traffic Inputs

Mean wheel location (inches from the lane marking):	18
Traffic wander standard deviation (in):	10
Design lane width (ft):	12

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.62	0.39	0.00	0.00
Class 5	2.00	0.00	0.00	0.00
Class 6	1.02	0.99	0.00	0.00
Class 7	1.00	0.26	0.83	0.00
Class 8	2.38	0.67	0.00	0.00
Class 9	1.13	1.93	0.00	0.00
Class 10	1.19	1.09	0.89	0.00
Class 11	4.29	0.26	0.06	0.00
Class 12	3.52	1.14	0.06	0.00
Class 13	2.15	2.13	0.35	0.00

Axle Configuration

Average axle width (edge-to-edge) outside dimensions,ft):	8.5
Dual tire spacing (in):	12

Axle Configuration

Single Tire (psi):	120
Dual Tire (psi):	120

Average Axle Spacing

Tandem axle(psi):	51.6
Tridem axle(psi):	49.2
Quad axle(psi):	49.2

Climate

icm file:	site10-02
Latitude (degrees.minutes)	37.77
Longitude (degrees.minutes)	-77.37
Elevation (ft)	2069
Depth of water table (ft)	17

Structure--Design Features

Permanent curl/warp effective temperature difference (°F):	-10
Shoulder type:	Asphalt

Steel Reinforcement

Percent steel (%):	0.7
Bar diameter (in):	0.625
Steel depth (in):	4

Base Properties

Base type:	Cement treated

Crack Spacing

Cracking Model	Generate using model.

Structure--ICM Properties

Surface shortwave absorptivity:	0.85

Drainage Parameters

Infiltration:	Minor (10%)
Drainage path length (ft):	12
Pavement cross slope (%):	2

Structure--Layers

Layer 1 -- Asphalt concrete

Material type:	Asphalt concrete
Layer thickness (in):	4

General Properties

General

Reference temperature (F°):	70

Volumetric Properties as Built

Effective binder content (%):	6
Air voids (%):	4
Total unit weight (pcf):	148
Poisson's ratio:	0.35 (user entered)

Thermal Properties

Thermal conductivity asphalt (BTU/hr-ft-F°):	0.67
Heat capacity asphalt (BTU/lb-F°):	0.23

Asphalt Mix

Cumulative % Retained 3/4 inch sieve:	0
Cumulative % Retained 3/8 inch sieve:	38
Cumulative % Retained #4 sieve:	75
% Passing #200 sieve:	10

Asphalt Binder

Option:	Conventional viscosity grade
Viscosity Grade	AC 20
A	10.7709 (correlated)
VTS:	-3.6017 (correlated)

Layer 2 -- CRCP (existing)

General Properties

PCC material	CRCP (existing)
Layer thickness (in):	8
Unit weight (pcf):	150
Poisson's ratio	0.2

Thermal Properties

Coefficient of thermal expansion (per F° x 10- 6):	5.5
Thermal conductivity (BTU/hr-ft-F°) :	1.25
Heat capacity (BTU/lb-F°):	0.28

Mix Properties

Cement type:	Type II
Cementitious material content (lb/yd^3):	564
Water/cement ratio:	0.45
Aggregate type:	Limestone
PCC zero-stress temperature (F°)	Derived
Ultimate shrinkage at 40% R.H (microstrain)	Derived
Reversible shrinkage (% of ultimate shrinkage):	50
Time to develop 50% of ultimate shrinkage (days):	35
Curing method:	Curing compound

Strength Properties

Input level:	Level 3
28-day PCC modulus of rupture (psi):	n/a
28-day PCC compressive strength (psi):	3632

Layer 3 -- Cement Stabilized

General Properties

Material type: Cement Stabilized
Layer thickness (in): 6
Unit weight (pcf): 150
Poisson's ratio: 0.2

Strength Properties

Elastic/resilient modulus (psi): 540000

Thermal Properties

Thermal conductivity (BTU/hr-ft-F°) : 1.25
Heat capacity (BTU/lb-F°): 0.28

Layer 4 -- CL

Unbound Material: CL
Thickness(in): 12

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 50000

ICM Inputs

Gradation and Plasticity Index
Plasticity Index, PI: 15
Passing #200 sieve (%): 75
Passing #4 sieve (%): 95
D60 (mm): 0.1

Calculated/Derived Parameters
Maximum dry unit weight (pcf): 107.9 (derived)
Specific gravity of solids, Gs: 2.73 (derived)
Saturated hydraulic conductivity (ft/hr): 3.25e-005 (derived)
Optimum gravimetric water content (%): 18.6 (derived)
Calculated degree of saturation (%): 87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Layer 5 -- CL

Unbound Material: CL
Thickness(in): Semi-infinite

Strength Properties

Input Level: Level 3
Analysis Type: ICM inputs (ICM Calculated Modulus)
Poisson's ratio: 0.35
Coefficient of lateral pressure,Ko: 0.5
Modulus (input) (psi): 50000

ICM Inputs

Gradation and Plasticity Index
Plasticity Index, PI: 15
Passing #200 sieve (%): 75
Passing #4 sieve (%): 95
D60 (mm): 0.1

Calculated/Derived Parameters
Maximum dry unit weight (pcf): 107.9 (derived)
Specific gravity of solids, Gs: 2.73 (derived)
Saturated hydraulic conductivity (ft/hr): 3.2175e-005 (derived)
Optimum gravimetric water content (%): 18.6 (derived)
Calculated degree of saturation (%): 87.6 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	68.1
b	1.15
c	0.658
Hr.	2720

Distress Model Calibration Settings - Flexible

AC Fatigue	Level 3 (Nationally calibrated values)
k1	0.00432
k2	3.9492
k3	1.281

AC Rutting	Level 3 (Nationally calibrated values)
k1	-3.4488
k2	1.5606
k3	0.4791
Standard Deviation Total Rutting (RUT):	0.1587*POWER(RUT,0.4579)+0.001

Thermal Fracture	Level 3 (Nationally calibrated values)
k1	5
Std. Dev. (THERMAL):	0.2474 * THERMAL + 10.619

CSM Fatigue	Level 3 (Nationally calibrated values)
k1	1
k2	1

Subgrade Rutting	Level 3 (Nationally calibrated values)
Granular:	
k1	1.673
Fine-grain:	
k1	1.35

AC Cracking

AC Top Down Cracking	
C1 (top)	7
C2 (top)	3.5
C3 (top)	0
C4 (top)	1000
Standard Deviation (TOP)	200 + 2300/(1+exp(1.072-2.1654*log(TOP+0.0001)))

AC Bottom Up Cracking	
C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000
Standard Deviation (TOP)	32.7 + 995.1 /(1+exp(2-2*log(BOTTOM+0.001)))

CSM Cracking	
C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000
Standard Deviation (CSM)	CTB*11

IRI

IRI Rehabilitation over Flexible

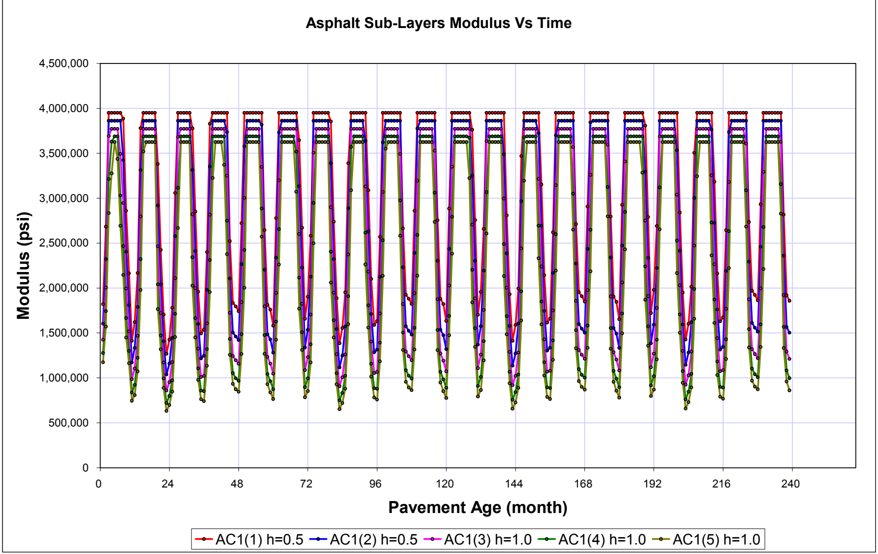
C1 (Flexible)	0.011505
C2 (Flexible)	0.003599
C3 (Flexible)	3.430057
C4 (Flexible)	0.000723
C5 (Flexible)	0.011241
C6 (Flexible)	9.04244
Std. Dev (Flexible)	0.179

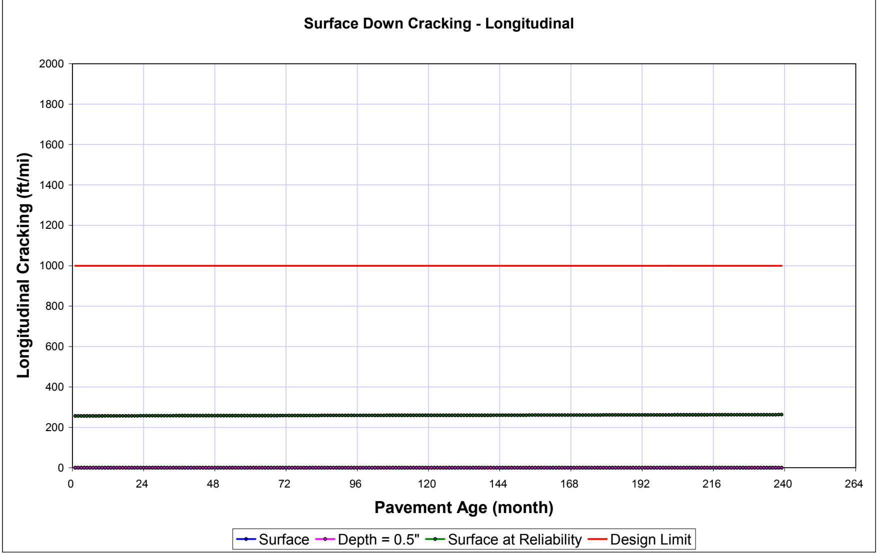
IRI Rehabilitation over Rigid

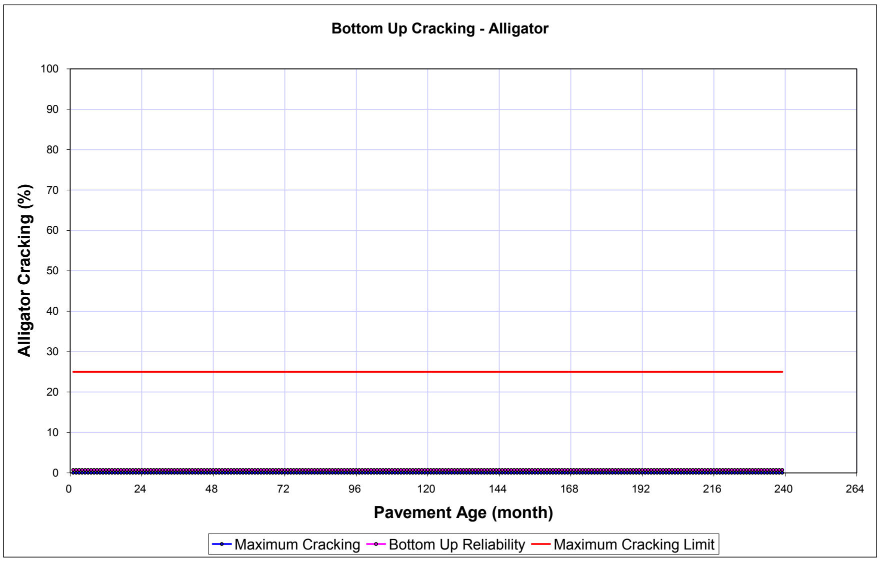
C1 (Rigid)	0.008263
C2 (Rigid)	0.022183
C3 (Rigid)	1.33041
Std. Dev (Rigid)	0.197

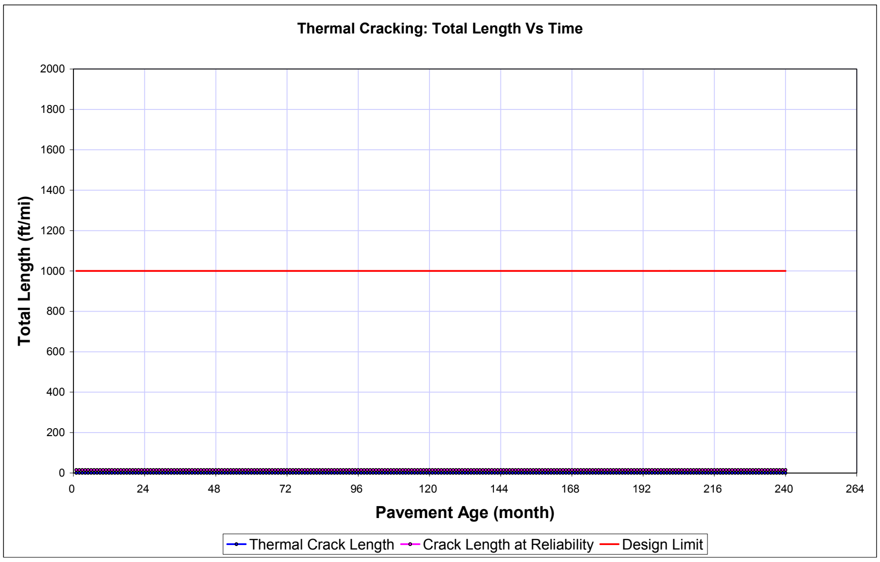
Project: SITE10-Rehabilitation.dgp
Reliability Summary

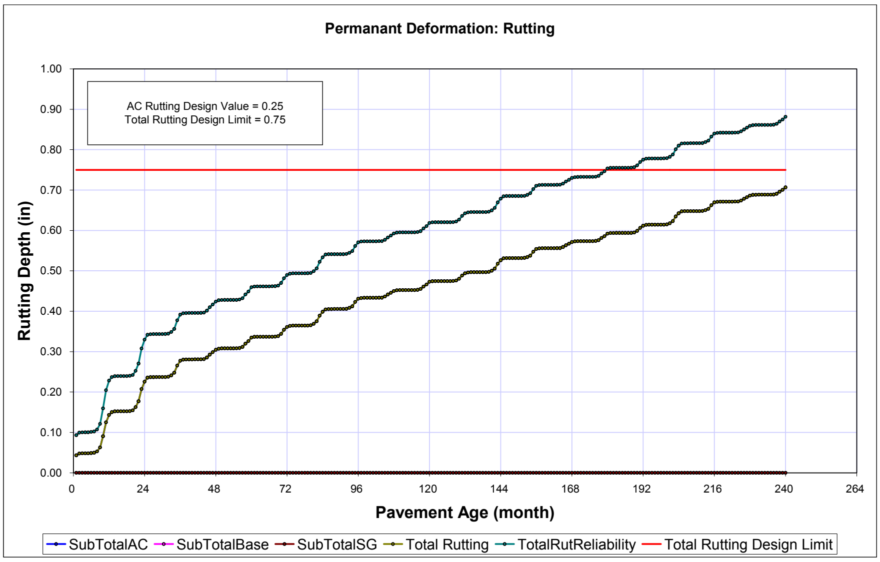
Performance Criteria	Distress Target	Reliablity Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	99	99.999	Pass
AC Surface Down Cracking (Long. Cracking) (ft/500):	1000	90	0	99.999	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	1	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.25	90	0.71	0.04	Fail
Permanent Deformation (Total Pavement) (in):	0.75	90	0.71	62.48	Fail

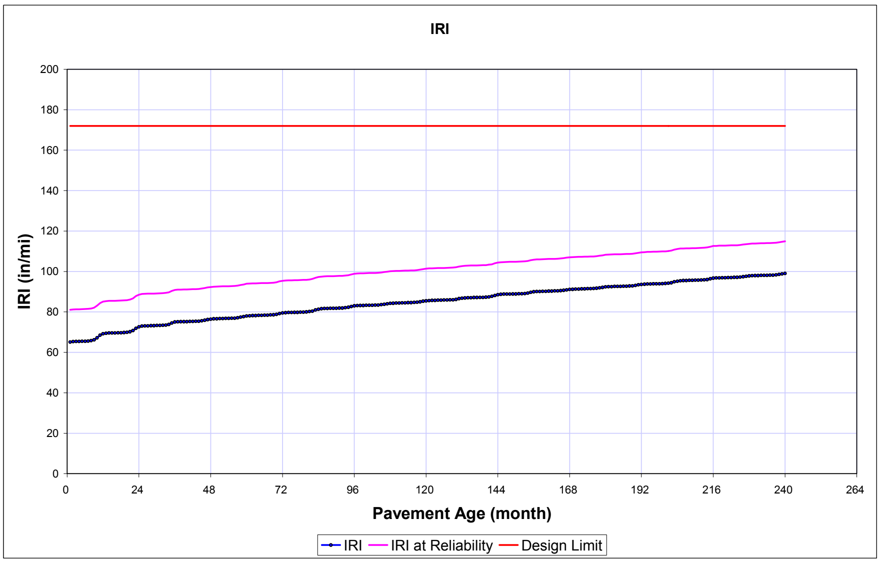

Asphalt Sub-Layers Modulus Vs Time
Modulus (psi)
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
0
24
48
72
96
120
144
168
192
216
240
Pavement Age (month)
AC1(1) h=0.5
AC1(2) h=0.5
AC1(3) h=1.0
AC1(4) h=1.0
AC1(5) h=1.0


Surface Down Cracking - Longitudinal
Longitudinal Cracking (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Surface
Depth = 0.5"
Surface at Reliability
Design Limit


Bottom Up Cracking - Alligator
Alligator Cracking (%)
100
90
80
70
60
50
40
30
20
10
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit


Thermal Cracking: Total Length Vs Time
Total Length (ft/mi)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
Thermal Crack Length
Crack Length at Reliability
Design Limit


Permanant Deformation: Rutting
AC Rutting Design Value = 0.25
Total Rutting Design Limit = 0.75
Rutting Depth (in)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
SubTotalAC
SubTotalBase
SubTotalSG
Total Rutting
TotalRutReliability
Total Rutting Design Limit


IRI
IRI (in/mi)
200
180
160
140
120
100
80
60
40
20
0
0
24
48
72
96
120
144
168
192
216
240
264
Pavement Age (month)
IRI
IRI at Reliability
Design Limit

VITA

Carlos Gramajo was born in Guatemala City, Guatemala. In July 2002 he received his degree of Bachelor of Science in Civil Engineering at Universidad del Valle, Guatemala. He started working as a design engineer in a consulting company called CM Ingenieros in Guatemala, from July 2002 to August 2003. During this time, his work involved basically the analysis of Non-Destructive Evaluation measurements performed with Falling Weight Deflectometer and Surface Profilemeter; he was also involved in the structural design of different new and rehabilitated highways in his country. In August 2003, he started his M.S. program at Virginia Tech Polytechnic Institute and State University, Blacksburg, Virginia, joining the Transportation Infrastructure and Systems Engineering program under the supervision of Dr. Gerardo Flintsch.