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Mechanistic-empirical approach to evaluate new and rehabilitated flexible pavements

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**MECHANISTIC-EMPIRICAL APPROACH TO EVALUATE NEW AND
REHABILITATED FLEXIBLE PAVEMENTS**

by

**Wais Mehdawi
Bachelor of Engineering, Ryerson University, 2006**

**Master Project presented to Ryerson University
in partial fulfillment of the requirements for the degree of**

**Master of Engineering
in the Program of
Civil Engineering**

Toronto, Ontario, Canada, 2008

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Mechanistic-Empirical Approach to Evaluate New and Rehabilitated Flexible Pavements

Master of Engineering, 2008

Wais Mehdawi

Civil Engineering, Ryerson University

Abstract

The Mechanistic-Empirical Design provides more insight into pavement behaviour and performance than the 1993 AASHTO empirical method. The new Mechanistic-Empirical Pavement Design Guide (MEPDG) developed under the National Corporation Highway Research Program (NCHRP) 1-37A. A hierarchical approach is employed upon traffic, climate and materials input to produce pavement performance predictions of smoothness and number of distress types. One of the most significant changes offered in the Mechanistic Empirical Design Guide (ME PDG) is the difference in the method used to account for highway traffic loading. Traffic volume and traffic loads, the two most important aspects required to characterize traffic for pavement design are treated separately and independently and its use-oriented computational software implements an integrated analysis approach for predicting pavement condition over time that accounts for the interaction of traffic, climate, and pavement structures. The recently developed guide for mechanistic-empirical (M-E) design of new and rehabilitated pavement structures will change the way in which pavements are designed by replacing the traditional empirical design approach in

the AASHTO 1993 Guide. The M-E Pavement Design Guide will allow pavement designers to make better-informed decisions and take cost-effect advantage of new materials and features. However, the proposed design guide is substantially more complex than the 1993 AASHTO design guide. It requires more input values from the designer. There is limited availability of the data for many MEPDG inputs.

This project report presents the Mechanistic-Empirical approach of Pavement Design for New and Rehabilitated Flexible Pavements using the new ME PDG. The main objectives of this report are: (1) to demonstrate how the Mechanistic-Empirical design of pavement is more precise than the existing empirical method, (2) to explain the software input and output parameters, (3) to present a complete overview of the M-E design process and to gain a thorough understanding of the materials, traffic, climatic, and pavement design inputs required for M-E design.

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GLOSSARY OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing Materials
AVC	Automated Vehicle Classification
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
E	Elastic Modulus
E*	Dynamic Modulus
EICM	Enhanced Integrated Climate Module
ESAL	Equivalent Single Axle Load
FEA	Finite Element Analysis
FHWA	Federal Highway Administration
FWD	Falling Weight Deflectometer
HMA	Hot Mix Asphalt
IRI	International Roughness Index
JTFP	Joint Task Force for Pavements
LTPP	Long Term Pavement Performance
ME PDG	Mechanistic-Empirical Pavement Design Guide
MTO	Ministry of Transportation Ontario
NCHRP	National Cooperative Highway Research Program
PG	Performance Graded
SHRP	Strategic Highway Research Program
TAC	Transportation Association of Canada
USC	Unified Soils Classification
WIM	Weight in Motion

Chapter 1

1.0 INTRODUCTION

1.1 Mechanistic Empirical Design Approach

Mechanistic-empirical design is a technique of designing pavements. It combines empirical interactions obtained from the field records with theoretical predictions based on the mechanics of materials. This technique relates inputs such as traffic, soil strength, loadings and climate to the real pavement response. A mechanistic pavement design utilizes mechanical modeling to establish the stress, strain, and displacement under a load [1] and even importantly, a wheel load. With knowledge of the different layer properties of the pavement structure, these reactions can be determined and integrated into empirical transfer functions to determine the number of load applications to failure. Numerous transfer functions have been developed that center on the distresses of rutting and fatigue. Currently the AASHTO Guide for design of pavement structures is one of the most commonly used methods of pavement design in North America.

The 1972 version of the AASHTO Guide relied on performance equations based on the results of the AASHO Road Test, which was conducted near Ottawa, Illinois in the late 1950s early 1960s [2]. The original pavement design equations were developed for a quite restricted set of pavements, subgrade and traffic. Pavement rehabilitation design procedures were not originally considered. The AASHO Road Test was carried out in a single geographic location, making it difficult to readily address differences in climatic conditions. Vehicles have drastically changes and, as a result, the vehicles used during the AASHO Road Test are not representative of today's vehicles. Later versions of the Guide extrapolated considerably on the original AASHO Road Test results with revised Guides published in 1986 and 1993 with a addition to the 1993 Guide published in 1998 [3,4]. In this method, the pavement is designed based on the data

obtained from the field only. Mechanistic-empirical method is more precise than the empirical method since the empirical method only relies on the field performance, while the mechanistic-empirical method combines both the field performance and theoretical prediction models. Mechanistic models can easily adapt to changes in the vehicle configuration and load spectra. It should be noted that the mechanistic pavement design procedure does not drastically change the pavement cross-section from that of empirically based designs; however, it provides the ability to analyze changes in traffic and materials and employ them in the design [5].

Development in computer and modeling technologies tied with the significant pavement performance information now available from the Strategic Highway Research Program (SHRP) and the Long Term Pavement Performance Program (LTPP) initiatives has permitted the development of more precise pavement design procedures. The culmination of NCHRP Project 1-37a [6], the Guide for the Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures (ME PDG) incorporates a mechanistic-empirical design approach and will allow pavement designers to improve design reliability, predict specific failure modes, better characterize seasonal/drainage effects and reduce overall life-cycle costs.

The ME PDG contains procedures for the design and analysis of all types of new and rehabilitated pavement systems such as flexible, rigid and semi-rigid pavements. The mechanistic-empirical design procedure included in the ME PDG allows the designer to assess the effect of variations in materials both intrinsic and due to construction procedures on pavement performance. In this paper flexible pavement design is covered and explained.

To provide a smooth surface and reduce the stresses on the subgrade design of flexible pavements is required. High-quality materials are used at the top of the layered pavement system to decrease the vehicular induced stresses with depth. Typical flexible pavements are consisted of the following layers:

- The surface course (wearing surface) is the top layer in flexible pavement. It is typically constructed by dense graded hot mix asphalt. Large aggregates account for carrying capacity of the layer. The wearing surface thickness varies between 25 to 50mm.
- Since HMA is too thick to be compacted in one layer, the binder course is placed under the surface course. It is composed of larger size aggregates than used in the wearing surface. Asphalt base course thickness typically varies between 50 and 100 mm.
- The base course is a layer of aggregate constructed under the binder course. It is typically consisted of granular "A" or 19 mm crushed limestone that can be untreated or stabilized with small quantities of cement or asphalt binder. The base course thickness varies between 100 and 300 mm. The base should be compacted at the $\pm 2\%$ optimum moisture content and 100% of Standard Proctor to get a high density.
- The subbase is a layer of lower quality aggregates placed beneath the base course. It is typically consisted of granular "B" or 50 mm crushed limestone. The reason for using different materials is for economy. The subbase thickness varies between 100 and 300 mm. The subbase should be compacted at the $\pm 2\%$ optimum moisture content and 98% of Standard Proctor to get a high density.
- The subgrade is the bottom layer of compacted in-situ or selected material. The subgrade should be compacted at the $\pm 2\%$ optimum moisture content and 95% of Standard Proctor to get a high density.

The mechanistic-empirical design of flexible pavements is based on limiting the distresses in the pavement structures. Pavement distresses are caused by the different types of loadings mainly structural and environmental loadings. Environmental loading are mainly addressed in the selection of the asphalt binder. The structural loading distresses are mainly fatigue cracking and permanent deformation. Mechanistic-empirical method involves three major steps. The first step is consists of the development of input values for the

analysis. The second step is the structural/performance analysis and the third step consists of engineering analysis and life cycle analysis.

1.1.1. Step 1 – Development of input values

During this stage, potential strategies are identified for consideration in the analysis stage. A key step in this process is foundation analysis. For new pavements, the foundation analysis consists of stiffness determination and, where appropriate, an evaluation of volume change, frost heave, thaws weakening, and drainage concerns. As part of the foundation analysis, subgrade improvements such as strengthening and drainage are considered.

During this stage, pavement materials characterization and traffic input data are developed. The Enhanced Integrated Climate Model (EICM) is used to model temperature and moisture within each pavement layer and subgrade. The climatic models consider hourly climatic data from weather stations across the country. The pavement layer temperature and moisture predictions from EICM are calculated hourly over the design period and used in various ways to estimate material properties for the foundation and pavement layers throughout the design life.

The foundation analysis for rehabilitation projects also includes a subgrade analysis. The most important part of the foundation analysis for rehabilitation projects is the investigation of distress types occurring in the existing pavements and the underlying causes of those distresses.

1.1.2 Step 2 – Structural Analysis

The analysis approach is an iterative one that begins with selection of an initial trial design. The trial design requires initial estimates of layer thickness, geometric features, initial smoothness, required repairs to the existing

pavements, pavement materials characteristics. The trial selection is analyzed incrementally over time using the pavement response and distress models, and the outputs of the analysis are accumulated damage the expected amount of distress and smoothness over time. If the trial design does not meet the performance criteria, modifications are made and the analysis re-run until a satisfactory result is obtained.

1.1.3 Step 3 – Engineering Analysis

This process includes those activities required to evaluate the structurally viable alternatives. These activities include an engineering analysis and life cycle cost analysis of the alternatives. In summary, the design process for new and rehabilitated pavement structures include consideration of the following: foundation/subgrade, existing pavement condition, paving materials, construction factors, environmental factors, traffic loading, subdrainage, shoulder design, design reliability and life cycle costs.

1.2 Mechanistic Empirical Design Development

To understand the mechanisms of pavement failure, the critical location where the failure originates needed to be recognized. There are two major modes of failure for flexible pavement; permanent deformation and fatigue cracking. In 1953, Kerkhoven and Dormon [7] found that the critical location where rutting was believed to occur could be readily attributed to compressive strains at the surface of the subgrade. The interface of the other pavement layers should also be examined to ensure that higher compressive strains do not persist.

Several other researchers conducted studies between 1953 and 1982 on vertical and horizontal stresses and strains in a three-layer system at the bottom of the asphalt layer and at the surface of the subgrade. In 1982, Molenaar and Van

Gurp [8] presented a mechanistic-empirical model for the design of flexible pavements. In their study they examined 93 in-service pavement structures and used a computer program called BISAR to relate equivalent thicknesses to that of maximum radial strain in the asphalt layer and vertical strain in the surface of subgrade. The equation 1.2 shows the definition of equivalent layer thickness.

$$h_e = 0.9h_i \sqrt[3]{\frac{E_i}{E_3}}$$

where:

- h_e = equivalent layer thickness (m)
- h_i = thickness of layer i(m)
- E_i = elastic modulus of layer i (N/m^2)
- E_3 = elastic modulus of the subgrade (N/m^2)

The equivalent layer thickness can be used to determine the number of loads until failure occurred due to a 100-kN axle load. To have a better knowledge of the response of flexible pavements to loading, an explanation of the models used to describe the interaction of loading and the response of flexible pavement was identified by Lytton in 1993 [9]. His model presents in details the different models that are used to describe the elastic, plastic, viscoelastic, and viscoelastoplastic models as they apply to the different distresses and temperatures that a pavement endures throughout its life.

Figure 1-1 Viscoelastoplastic component model (Lytton et al, 1993)

In 2003, Collop [10] developed a finite element program named CAPA-3D which used the viscoelastoplastic model to determine the stresses throughout an element due to loading. The program allowed for the development of the pavement structure where each layer is characterized by its Young's Modulus, Poisson's ratio, and thickness. Collop ran a simulation with a load of 700 kPa at 20 °C to show the stress, accumulated strain and damage and equivalent viscosities throughout the element, due to a single load application. The simulations illustrated that the location of the maximum strain was reliant on the stress-dependence of the flexible pavement. Stress-dependent pavements showed the greatest stress at approximately one-half the thickness of the asphalt layer, whereas non-stress dependent pavements showed more of an even distribution of vertical strain.

In 2004, Uzan [11] presented a mechanistic-empirical pavement design method measured the ratio of the resilient to plastic strain as a function of traffic composition, temperature changes throughout the day, environmental conditions, and changes in material response with depth. This method allows the surface and the underlying layers to be broken down into sublayers so that permanent strains can be more effectively determined as opposed to the overall deformation of the entire layer. Uzan used the program JULEA to conduct the pavement analysis, examining numerous points within the pavement structure in response to the loading. This research concluded two important findings. The first one is that a design load can be used to reduce the number of axle configuration and the second one is the stiffness of the pavement can be improved by increasing the thickness of the asphalt pavement layer, which reduce permanent deformation.

1.3 Current Design Guide

The AASHTO Joint Task Force for Pavements (JTTF) is in charge of the development and implementation of pavement design processes. This

responsibility has led to the development of past Design Guides (1972, 1986, and 1993). The newest Design Guide was the 2002 edition, which was released in 2004. The ultimate goal of the Design was to utilize a primarily mechanistic design approach. This would involve establishing an ideal test that could be used to determine the fundamental engineering properties of the individual layers of the pavement structure. The current Design guide uses two different software packages to determine the stresses, strains, and deflections in the pavement structure due to loading. The first is JULEA, which is a multi-layer elastic theory program (AASHTO Design Guide 2004). By using this program some unbound materials like subbase and subgrade materials exhibit non-linear response to loading in that they exhibit stress dependent stiffness, which can vary in thickness. Another program was introduced to account for non-linear responses and is called DSC2D. Both programs calculate the location of the maximum damage based upon the given conditions and this calculation is used to determine the pavement's performance. One reservation for using the program DSC2D is that, unlike JULEA, it has not been calibrated based on field experience for use in the current Design Guide. The design procedure outlined in the current Design Guide is mechanistic-empirical in nature due to the fact that calibration factors must be used to relate the properties that predict permanent deformation, fatigue cracking, and the International Roughness Index (IRI). IRI measures the longitudinal profile of a pavement by means of a profilometer and is relevant to the comfort of the motorists utilizing the facility.

1.4 Project Objectives

The objective of this report is to understand the process and the steps of M-E design for flexible and rehabilitated pavements. The following are the main key points of this project paper:

- Obtain a complete overview of mechanistic-empirical design process.

- Gain a thorough understanding of the materials, traffic, climatic, and pavement design inputs required for M-E design.
- Learn how to calculate pavement structural responses using available software tools and how to use these in predicting pavement performance for new and rehabilitation design purposes.
- Obtain a first look at the new M-E PDG procedures.
- Understand how to back calculate pavement layer properties for rehabilitation design.
- Identify key points to be aware of when trying to implement the new M-E PDG procedures within a given agency

The process and steps are explained in Chapter 6 and 7 of this report.

Chapter 2

2.0 IMPLEMENTATION AND BENEFITS OF A MECHANISTIC-EMPIRICAL PROCEDURE

The majority of the U.S. State highway agencies have indicated that they will be implementing the ME PDG and in fact many of these already have programs underway. The expected benefits in adopting the ME PFG include:

- Due to the inherently empirical nature of the current design methods, pavement is inherently over designed for strength. Other performance measures, such as rutting, thermal cracking, and faulting are not addressed. The M-E Pavement Design Guide method will significantly reduce the degree of uncertainty in the design process, and provide realistic designs that are appropriate to the type of performance expected
- For the design life of pavement, the predicted occurrence of distresses will be much closer to the actual occurrence. Combined with realistic criteria for design levels of distress, this will lead to significantly less maintenance and rehabilitation. Currently, although pavements are designed for 20 years, it is common that major rehabilitation may be required as early as 12 years into the design life. The M-E Pavement Design Guide will help ensure that this type of major rehabilitation activity occurs closer to the actual life design.
- Cost responsibility studies will be enhanced by the improved ability to evaluate the consequences of new loading conditions and the damaging effects of increased loads, high tire pressure, and multiple axles.
- The designer will be better able to use and evolving materials and, in many cases, the expected benefits of those materials can be

modeled and evaluated without the expense of elaborate testing programs.

- Better diagnostic techniques will allow improved evaluation of premature failures. The M-E Pavement Design Guide software has an interesting and powerful capability as a forensic tool.
- Improved environmental inputs and analysis will permit better assessment of aging effects as well as that of freeze-thaw and of the provision of improved drainage.

2.1 Impact of Reduced Early Failures

The observed performance of existing pavements generally follows the frequency distribution in Figure 1. One of the main reasons for the early peak (significant number of premature failures) was the incapability to include variations in materials and construction into the design procedures. In the previous AASHTO flexible design procedure, the only material property included was the loosely defined layer coefficient "a". This limitation results from the fact that variation in material quality was not a primary experimental variable included in the AASHTO Road Test. In addition, the flexible pavement procedure cannot determine the required thickness of asphalt bound material to limit fatigue cracking; this value is chosen by the designer, which can lead to early failures. The mechanistic-empirical design procedure included in the Design Guide provides the tools for evaluating the effect of variations in materials on pavement performance. The Design Guide provides a rational relationship between construction and materials specification and the design of the pavement structure. Because of the mechanistic procedures are able to better account for climate, aging, present day materials, and present day vehicle loading, variation in performance in relation to design life should be reduced, as indicated by the desired frequency distribution shown in figure 2. This capability will reduce life cycle costs significantly over an entire highway network.

Figure 1-1 Pavement Performance Model

2.2 Impact of Increased Pavement Longevity

A late study by FHWA on the value of the LTPP program highlights the benefits of adopting the Design Guide in terms of increased pavement life [12]. The study considered the stream of costs for a given pavement design over many years into the future (initial construction, maintenance, rehabilitation, user delay costs due to lane closures for rehabilitation). These costs were found to vary widely depending on the design of the pavement, its materials, and its construction. The improved technology of pavement design and rehabilitation incorporated into the Design Guide is expected to increase pavement longevity, resulting in economic benefits to highway agencies.

2.3 Principles of Mechanistic Procedures

Mechanistic refers to the application of the principles of engineering mechanics, which leads to a balanced design process. Yolder and Witczak [13] showed that, for any pavement design procedure to be completed rational, three fundamentals must be considered completely; the theory used to predict the assumed failure or distress parameter, the assessment of the materials properties applicable to the selected theory, and the determination of the relationship between the magnitude of the parameter in question to the performance level desired.

Figure 2-2 illustrates the general concept of a multi-layered elastic system as defined by Yolder and Witczak.

Figure 2-2 Generalized multi-layered elastic system

In order to conduct analysis of a flexible pavement system (Figure 1.1) using a multi-layered theory, several assumptions must be made [14]:

- Each layer is homogeneous, isotropic, and linearly elastic and has an elastic modulus, E , and Poisson's ratio, ν , which is representative of that particular layer.
- The layer itself does not induce a load on the supporting layers due to its presence and the layer is infinite in the horizontal directions.
- Each layer has a specific layer thickness and the lowest layer is considered to be infinite in thickness.
- The load that is applied to the surface layer is uniform over the circular area with radius and is applied as pressure q .
- The interfaces of the layers are in constant contact with one another and act together; thus, the normal and shearing stresses and the horizontal and vertical displacements present at the interface are equal for each layer.

Chapter 3

3.0 MATERIAL CHARACTERISTICS

The major characteristics used to evaluate the performance of pavement materials under different loading and environmental conditions are the resilient modulus (E) and Poisson's ratio (μ). The mechanistic properties of the pavement materials and subgrade are used to calculate the stresses, strains and displacements within the pavement under vehicular loading. The pavement materials and subgrade have been divided into nine primary categories for the Design Guide. These include:

1. Hot mix asphalt materials (all layers bound with asphalt cement including stabilized bases, open graded drainage layers)
2. Portland Cement Concrete (used as a pavement surfacing)
3. Chemically or cement stabilized materials (cement, fly ash and lime stabilized materials)
4. Unbound materials (granular base/subbase and subgrade)
5. Recycled concrete (crack and seal)
6. Recycled hot mix asphalt (used in new asphalt concrete mixes)
7. Recycled cold mix asphalt concrete (plant or in-situ recycled)
8. Recycled asphalt pavement (used as a granular base/subbase)
9. Bedrock

The material characterization input parameters for each of the above categories are summarized in Appendix A.

In the mechanistic empirical method the following categories are required for material characterization:

1. Material properties for computing pavement responses
2. Additional materials inputs to the distress/transfer functions
3. Additional materials inputs required for climatic modeling

In the first category which is the material properties, in the M-E approach the properties include are elastic modulus (E) and Poisson's ratio (μ). These properties are mandatory inputs for each pavement layer in the system.

In the second category are all the materials-related inputs that enter the distress or smoothness models directly. The most significant distress type or performance measures considered in flexible pavement design include load-related fatigue fracture (top-down and bottom-up), permanent deformation, and transverse fracture. For each of these distresses, the critical structural response under a given wheel and climatic loading condition is affected by pavement material properties such as modulus and Poisson's ratio.

The third category is materials related that enter the climatic module to help determine the temperature and moisture profiles through the pavement cross-section. These include engineering index properties such as plasticity index, gradation parameters (porosity, effective grain sizes) and thermal properties.

3.1 Material Factors Consideration

3.1.1 Time-Dependent Properties

Since some materials' properties go through time-dependent changes, it is very important to be able to consider these changes in any M-E analysis. Pavement material properties are always changing over time due to chemical and physical forces, influence of climate, as well as the onset of fracture or deformation [15, pg 2.2.2]. The magnitude of the material properties either experience an enhancement or deterioration. These should be taken into consideration during the design and are discussed below.

3.1.2 Property Enhancement

Long-term, time dependent property development take place due to chemical and physical hardening of asphalt binders and due to short and long-term aging of AC binder, curing caused by the evaporation of moisture within asphalt emulsion systems, and pozzolanic reactions of cementitious materials.

3.1.3 Property Deterioration

Materials that are subjected to load-related fatigue distress may face an insensitive degradation of properties with time and load repetitions. Micro-cracks may occur, leading to a reduced stiffness or modulus. This reaction in modulus will, in turn, lead to an increase in stress states within the pavement and a greater possibility of permanent deformation. The Design Guide considers the impact of load-related damage on property degradation.

3.1.4 Time-Temperature Effects

Environment plays an important role in finding the properties of hot mix asphalt as a function of time, which in fact affects the performance of HMA pavements. Asphaltic materials are extremely responsive to temperature and the rate of loading. Because asphalt is a viscoelastic-plastic material, the modulus of an asphalt mix may approach that of an unbound granular material at high temperatures and long loading rates.

Strategic Highway Research Program (SHRP) conducted a research on the effect of temperature on the age hardening characteristics of asphalt binders. [16]. The research concluded that the higher mean annual air temperatures result in relatively higher rates of aging than the colder climates. The research also showed the effect of other parameters, such a volumetric properties and the

location of the HMA layer in the pavement system on asphalt mix aging. Higher air void contents result in greater oxidation and hence more stiffening of the HMA mix. HMA layers located deeper in the pavement are not in direct contact with air and therefore, the oxidation of the asphalt binder in these layers is reduced.

In the Design Guide, the methodology for asphaltic mixtures will take into account the range of temperature expected in the design period. In addition, the use of an asphalt master curve, based on time-temperature superposition principles, will allow the designer to account for the approximate speed of the vehicle under consideration.

3.1.5 Non-Linear Behavior

A material is considered non-linear if the value of the elastic modulus depends on the state of stress in the material. Base and subbase materials are considered to be non-linear in this guide. If a non-linear analysis is desired due to use of non-linear moduli for the unbound materials present in the system, a finite element must be used to compute the flexible pavement response.

3.2 Hierarchical Design Concept

Pavement design needs depends on the intended function of the pavement. Structural design of pavements on urban freeways requires higher design reliability and better input data than a preliminary design of pavements on secondary roads. In order to accommodate different pavement design needs and the differences in the availability of input data, the M-EPDG accommodates three progressively more reliable and accurate level of input data. These levels are called hierarchical input levels. The difference between the hierarchical input levels is in terms of data quality (reliability and accuracy), not in terms of the level of detail. The Design Guide uses a hierarchical approach which allows the

designer flexibility in selecting the design inputs based on the importance of the project and available information [15, pg 2.2.7]. Three levels of design are provided as follows:

Level 1 – Requires testing of specific materials to be used in a project, example complex modulus testing of an asphalt concrete mix. A Level 1 design would typically be used for a research test section or very high volume road. A Level 1 design typically has the highest confidence level of performance.

Level 2 – This level is intended for used for routine pavement designs. While still required as a key input, complex testing such as resilient modulus determination is not required. Rather, resilient modulus values are determined through correlations with other more standard testing procedures, such as, CBR, aggregated gradation, plasticity index and moisture content. Level 2 design have a moderate confidence level of performance.

Level 3 – This level has the lowest level of accuracy and would be typically be used for lower volume roadways. Level 3 designs are based on typical material default values derived from the LTPP database.

3.3 Asphalt Concrete Materials Characterization

The characterization for asphalt concrete materials is the most complex in the Design Guide. The primary input parameter is the dynamic modulus of the asphalt concrete mix. Dynamic modulus testing (NCHRP 1-28A), asphalt binder complex shear modulus and phase angle testing (AASHTO T315) are used to develop a master curve that represents time vs. temperature performance. The master curve is developed for a standard mix temperature 21°C and then shifted as necessary to represent other temperature conditions within the tested temperature range. The asphalt concrete materials characterization procedure used in the Design guide accounts for short term binder aging during asphalt

concrete mixing and placement at initial construction and due to age hardening as the asphalt concrete pavement gets older.

For a Level 1 rehabilitation project, the master curve for the asphalt concrete is developed by using the Falling Weight Deflectometer (FWD) and laboratory testing on extracted cores. For new projects at Level 1 actual laboratory test data are required to develop the master curve and shift factors. The FWD testing is used to measure pavement surface deflections with the asphalt modulus calculated through backcalculation. The Level 2 project eliminates the FWD testing and used some additional resilient modulus testing while the Level 3 analysis uses a typical asphalt concrete master curve and the results of a visual distress survey to determine the field master curve.

The asphalt concrete master curves are used as input to the distress prediction to determine the amount of fatigue cracking and rutting. Additional testing is necessary to predict the amount of thermal cracking that will occur for a particular pavement. The additional testing includes:

- Tensile strength (AASHTO T322)
- Creep compliance (AASHTO T322)
- Thermal conductivity and heat capacity (ASTM D2766)

3.4 Layer Modulus for New and Reconstruction Design

The primary stiffness property of interest for asphalt materials is the time-temperature dependent dynamic modulus (E). Table below (table 3.1) provides a brief summary of the procedures at various input hierarchical levels to derive E for new or reconstruction design.

Table 3-1 Hierarchical Input Levels

Material Group Category	Input Level	Description
Asphalt Material	1	<ul style="list-style-type: none"> • Conduct E (complex modulus) laboratory test (ASTM D 3496) at loading frequencies and temperatures of interest for the given mixture. • Conduct G^*-δ testing on the proposed asphalt binder (AASHTO MP1) at $\omega = 1.59$ Hz over a range of temperatures. • Develop master curve for AC mixtures that accurately defines the time-temperature dependency including aging.
	2	<ul style="list-style-type: none"> • No E laboratory test required • Use E predictive equation • Conduct G^*-δ testing on the proposed asphalt binder (AASHTO MP1) at $\omega = 1.59$ Hz over a range of temperatures. The binder viscosity or stiffness can also be estimated using conventional asphalt test data • Develop A_i-VTSi for mix-compaction temperature. • Develop master curve for AC mixtures that accurately defines the time-temperature dependency including aging.
	Input Level	Description
	3	<ul style="list-style-type: none"> • No E laboratory test required • Use E predictive equation • Use typical A_i-VTSi values provided in the Design Guide Software based on PG, viscosity, or penetration grade of the binder. • Develop master curve for AC mixtures that accurately defines the time-temperature dependency including aging.

3.4.1 Master Curve and Shift Factors

Master curve are constructed using the principle of time-temperature superposition. First, a standard reference temperature is selected, and then data at various temperatures are shifted with respect to time until the curve merge into

a single smooth function. The master curve of modulus as a function of time formed in this manner describes the time dependency of the material. The amount of shifting at each temperature required to form the master curve describes the temperature dependency of the material [15, pg 2.2.8]. Master curves and the corresponding shift factors can be developed experimentally by shifting laboratory frequency sweep data from either dynamic modulus tests, ASTM D3497, or shear test, AASHTO TP7. This method is used for Level 1 analysis. For Level 2 and Level 3 analysis, the master curves will be developed directly from the dynamic modulus.

3.4.2 Master Curves Background

Master curve are used as input parameters for fatigue cracking and rutting prediction. For linear viscoelastic materials such as HMA mixes, the stress-to-strain relationship under a continuous sinusoidal loading is defined by its complex dynamic modulus (E^*). This is a complex number that relates stress to strain for linear viscoelastic materials subjected continuously applied sinusoidal loading in the frequency domain. The small strain behaviour of asphalt mixes ($\epsilon < 100 \mu\epsilon$) is considered to be viscoelastic linear [17]. The complex E^* is the ratio between the stress and strain, as described by equation 1. The complex modulus is defined as the ratio of the amplitude of the sinusoidal stress (at any given time, t , and angular load frequency, ω), $\sigma = \sigma_0 \sin(\omega t)$ and the amplitude of the sinusoidal strain $\epsilon = \epsilon_0 \sin(\omega t - \Phi)$, at the same time and frequency, that results in a steady state response as shown in Figure 3-1. [18]

Figure 3-1 Dynamic (Complex) Modulus

The complex dynamic modulus (E^*) can be mathematically expressed as follows:

$$E^* = \frac{\sigma}{\varepsilon} = \frac{\sigma_0 \sin \omega t}{\varepsilon_0 \sin(\omega t - \phi)} \quad (1)$$

Where,

σ_0 = peak (maximum) stress

ε_0 = peak (minimum) strain

Φ = phase angle, degrees

ω = angular load frequency

t = time, seconds

Dynamic modulus is a measure of the relative stiffness of a mix. Mixes that tend to have good rut resistance at high temperatures likewise have high stiffness. Although the tradeoff is at intermediate temperatures, stiffer mixes tend to be more prone to cracking for thicker pavements [19]. Stiffness data of HMA mix as obtained from the E^* test provide very important information about the linear viscoelastic behavior of that particular mix over a wide range of temperature and loading frequency. The mechanistic-empirical design requires that for HMA materials a time-dependent Dynamic Modulus (E^*) and Poisson's ratio be determined. [20]. The procedure for the dynamic modulus testing is covered by the AASHTO TP62-03 standard [21]. The testing is run at five different temperatures (-10, 4.4, 21.1, 37.8 and 54.4°C) and six loading frequencies (0.1, 0.5, 1.0, 5.0, 10.0 and 25.0 Hz).

3.4.3 Time-Temperature Superposition of E^*

In the M-E PDG the stiffness of HMA, at all levels of temperature and time rate of load, is determined from a master curve constructed at a reference temperature (generally taken as 70°F or 21°C). Master curve are constructed using the principle of time-temperature superposition. The data at various temperatures are shifted with respect to time until the curves merge into single smooth function.

The master curve of the modulus, as a function of time, formed in this manner describes the time dependency of the material. The amount of shifting at each temperature required to form the master curve describes the temperature dependency of the material. In general, the master modulus curve can be mathematically modeled by a sigmoidal function described as:

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma (\log t_r)}} \quad (2)$$

Where,

- E^* = dynamic modulus
- t_r = reduced time of loading at the reference temperature
- δ = minimum value of E^*
- $\delta + \alpha$ = maximum value of E^*
- $\beta + \gamma$ = parameters describing the shape of sigmoidal function

The shift factor can be shown in the following form:

$$a(T) = t/t_r$$

Where,

- $a(T)$ = shift factor as a function of temperature
- t = time of loading at desired temperature
- t_r = reduced time of loading at reference temperature
- T = temperature of interest

For precision, a second order polynomial relationship between the logarithm of the shift factor i.e. $\log a(T_i)$ and the temperature in ($^{\circ}\text{F}$) is used. The relationship can be expressed as follows:

$$\text{Log } a(T_i) = aT_i^2 + bT_i + c \quad (3)$$

Where,

$\text{Log } a(T_i)$ = shift factor as a function of temperature T_i
 T_i = temperature of interest, °F
 $a, b \text{ and } c$ = coefficient of the second order polynomial

3.4.4 Input Levels for the M-E PDG

In the new M-E PDG, the stiffness of the hot mix asphalt is determined from a master curve using one of the three input levels, depending on the availability and type of related data. The master curve for Level 1 is developed using numerical optimization to shift the laboratory mixture test data into a smooth master curve. Prior to shifting the mix data, the relationship between binder viscosity and temperature must be established. This is done by first converting the asphalt stiffness data at each temperature to viscosity using equation (4). The parameters of the ASTM $A_i\text{-VTS}_i$ equation are then found by linear regression of equation (5) after log-log transformation of the viscosity data and log transformation of the temperature data.

$$\eta = G^* / 10 \left[1 / \sin \delta \right]^{4.8628} \quad (4)$$

$$\log \log \eta = A + \text{VTS} \text{ Log } T_R \quad (5)$$

Where,

G^* = binder complex shear modulus
 δ = binder phase angle
 η = viscosity
 T_R = temperature in Rankine at which the viscosity was estimated
 A, VTS = regression parameters

The resulting regression parameters from equation (5) can then be used to calculate the viscosity for any temperature. After the viscosity-temperature relationship is established, the laboratory test data can be shifted into a smooth master curve using equation (6):

$$\log |E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \left[\log(t) - c(\log(\eta) - \log(\eta_{Tr})) \right]}} \quad (6)$$

Where

- E^* = dynamic modulus
- t = time of loading
- η = viscosity at temperature of interest
- η_{Tr} = viscosity at reference temperature
- $\delta + \alpha$ = maximum value of E^*
- $\alpha, \beta, \delta, \gamma, c$ = mixture specific fitting parameters

The master curve for the Level 2 input is developed using the Witczak E^* Predictive Model (shown in equation 7) from specific laboratory test data. [22]. The level 3 input requires no laboratory test data for the asphalt binder but requires volumetric properties of the mix.

3.4.5 E^* Predictive Equation

In the M-E PDG uses the laboratory E^* data for input Level 1, while it uses E^* values from Witczak predictive equation for input Levels 2 and 3. The Witczak E^* predictive model was based on 2750 test points and 205 different HMA mixtures. [22]. Most of the 205 HMA mixtures were dense graded and unmodified. From an analysis of the mix designs, it was determined that mixture temperature was the most significant variable in a dynamic modulus predictive equation. The current version of the E^* predictive equation, updated in 2002, is:

$$\log |E^*| = -1.249937 + 0.029232(\rho_{200}) - 0.001767(\rho_{200})^2 - 0.002841(\rho_4) - 0.058097(V_a) - 0.82208 \frac{V_{beff}}{V_{beff} + V_a} + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{3/8} - 0.000017(\rho_{3/8})^2 + 0.005470\rho_{3/4}}{1 + e^{(-0.603313 - 0.313351X \log(f) - 0.393532X \log(\eta))}} \quad (7)$$

Where,

- E^* = dynamic modulus (10^5 psi)
- η = bitumen viscosity (10^6 psi)
- f = loading frequency (Hz)
- V_a = air void content (%)
- V_{beff} = effective bitumen content (% by volume)
- $P_{3/4}$ = cumulative percent retained on 19 mm sieve
- $P_{3/8}$ = cumulative percent retained on 9.5 mm sieve
- P_4 = cumulative percent retained on 4.75 mm sieve
- P_{200} = percent passing 0.075 mm sieve

Witczak's E^* predictive equation can be presented in the same form as equation (6) for a mixture-specific master curve as follows:

$$\text{Log}|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma(\log t_r)}} \quad (8)$$

Where,

$|E^*|$ = dynamic modulus, 10^5 psi

$$\delta = -1.249937 + 0.02923 P_{200} - 0.001767 (P_{200})^2 - 0.002841 P_4 - 0.058097 V_a - 0.82208 \left(\frac{V_{beff}}{V_{beff} + V_a} \right)$$

$$\alpha = 3.871977 - 0.0021 P_4 + 0.003958 P_{3/8} - 0.000017 (P_{3/8})^2 + 0.00547 P_{3/4}$$

$$\beta = -0.603313 - 0.313532 \log(\eta_{Tr})$$

$$\gamma = 0.313351$$

t_r = reduced time of loading at reference temperature

η_{Tr} = asphalt RTFOT viscosity at reference temperature, 10^6 Poise

3.4.5 Research Example of Master Curve and Shift Curve Development from Laboratory Test Results

A study was conducted between Golder Associates from Whitby, Ontario and University of Waterloo to conduct dynamic modulus testing on four different mixes to produce master curve and shift curve for analysis on rutting resistance [23].

The mixes were consisted of three surface course asphalt and one binder course mix. The surface course mixes were Stone Mastic Asphalt (SMA), and a conventional Surface Course (CSC) Marshall mix. The mixes incorporate different types of asphalt cements ranging from PG58-28 to PG70-28. Table 3-2 shows the gradation for each mix.

Table 3-2 Mix Properties

Properties	Mix Type			
	SMA	CSC	SP 19D	SP 19E
	Stone mastic asphalt	Conventional surface course	Superpave 19mm Course Mix	Superpave 19mm Fine Mix
Gradation				
Sieve Sizes (mm)	Percentage Passing			
25.0	100.0	100.0	100.0	100.0
19.0	100.0	100.0	97.2	97.0
12.5	98.8	98.0	77.9	80.2
9.5	71.1	86.0	68.2	63.2
4.75	25.4	60.0	60.2	38.0
2.36	21.3	50.7	44.6	33.4
1.18	17.5	40.9	29.7	22.5
0.600	14.8	28.8	18.8	14.4
0.300	13.0	13.3	9.9	8.7
0.15	10.8	5.7	5.3	5.2
0.075	9.1	3.7	5.2	3.8
Asphalt Cement Content (%)	5.70	5.30	4.35	4.60
Asphalt Cement Grade (PG)	70-28	58-28	64-28	70-28
Theoretical Maximum Specific Gravity	2.599	2.496	2.582	2.570

Air void analyses were conducted on all four mixes and a summary of the results are shown the table below:

Table 3-3 Summary of Superpave Gyrotory Compactor (SGC)

Mix Type	Specimen No.	Air Voids (%)
SMA	5	6.9
	6	6.8
	20	5.6
	Mean	6.4
	SD	0.7
CSC	34	6.6
	35	6.3
	36	6.5
	Mean	6.5
	SD	0.2
SP 19 D	3	7.4
	4	7.3
	51	7.6
	Mean	7.4
	SD	0.2
SP 19 E	8	6.7
	22	7.0
	25	6.8
	Mean	6.8
	SD	0.2

The Rolling Thin Film Oven (RTFO) was included in the asphalt cement testing, residue Complex Modulus (G^*) and Phase Angel (δ) [24] determination for each type of asphalt cement used. The results are shown in table 3-4.

Table 3-4 Summary of Asphalt Cement Testing Results

Mix Type	Marshall Stability (Newton)	Flow (0.25 mm)	Asphalt Cement Grade	RTFO Residue $G^*/\sin \delta$ (kPa)	
				Determined	Specified Minimum
SMA	8,679	12.2	70-28	2.6	2.2 @ 70°C
CSC	15,400	8.5	58-28	3.4	2.2 @ 58°C
SP 19 D	19,300	11.5	64-28	4.3	2.2 @ 58°C
SP 19E	19,400	11.9	70-28	7.6	2.2 @ 70°C

The Interlaken asphalt and soil testing apparatus was used for the dynamic testing. Linear Variable Differential Transducers (LVDT's) were used on each sample to determine the deformation. The dynamic modulus and phase angle were determined for a minimum of three specimens of each mix. Table 3-5 shows a summary of dynamic modulus testing results for SP 19 D mix at different frequencies and different temperatures.

Figure 3-2 Dynamic Modulus Testing Set-up [23, pg 7]

Table 3-5 Summary of SP19 D (Superpave 19 mm) Dynamic Modulus Results

Specimen Mix	Frequency (Hz)	Dynamic Modulus (GPa)				
		-10°C 14°F	4.4°C 40°F	21.1°C 70°F	37.8°C 100°F	54.4°C 130°F
3 SP 19D	25	29.7	21.7	10.7	5.7	2.7
	10	26.6	19.4	8.9	4.5	1.9
	5	24.5	17.9	7.8	3.7	1.6
	1	20.6	14.6	5.4	2.4	1.2
	0.5	18.5	13.2	4.6	2.0	1.1
	0.1	14.2	10.3	3.1	1.4	0.9
4 SP 19D	25	30.0	21.8	11.4	6.5	3.3
	10	26.9	19.3	9.6	5.1	2.4
	5	24.6	17.8	8.4	4.3	2.0
	1	20.6	14.3	6.0	2.9	1.5
	0.5	18.5	12.9	5.1	2.5	1.4
	0.1	14.1	9.8	3.6	1.8	1.2
5 SP 19D	25	31.6	20.1	11.1	5.5	2.9
	10	28.4	17.9	9.1	4.0	2.1
	5	26.3	16.5	8.0	3.3	1.8
	1	22.2	13.2	5.5	2.2	1.3
	0.5	19.9	11.8	4.6	1.9	1.2
	0.1	15.4	8.8	3.2	1.4	1.0
Average	25	30.4	21.2	11.1	5.9	3.0
	10	27.3	18.9	9.2	4.5	2.2
	5	25.1	17.4	8.1	3.8	1.8
	1	21.1	14.1	5.7	2.5	1.3
	0.5	18.9	12.6	4.8	2.1	1.2
	0.1	14.5	9.6	3.3	1.5	1.0

In order to compare all four mixes, a single master curve is formed for each mix. A master curve of SP 19 D mix is shown in Figure 3-3. The data collected at different temperatures was shifted relative to the time of loading to form a single curve. The shift factor is shown in Figure 3-4. Figure 3-5 shows the master curve for all four mixes.

Figure 3-3 Master Curve for SP 19 D Mix [23, pg 8]

Figure 3-4 Shift Factor for SP 19 D Mix [23, pg 8]

Figure 3-5 Master Curves for SMA, CSC, SP 19 D, and SP 19 E [23, pg 9]

3.5 Unbound Granular and Subgrade Materials Characterization

The Design Guides uses the AASHTO M 145 soils classification. Unbound materials are categorized by grain size distribution, liquid limit and plasticity index value. The designer select the primary unbound material type using one of the classification systems and then provides further input to determine appropriate properties to be used for design. The primary input parameter used for the design is the resilient modulus. For Level 1 designs, the resilient modulus values of unbound granular materials, subgrade, and bedrock are determined from triaxial tests.

Unbound materials can be either stress hardening or stress softening and therefore, the nonlinear behaviour of the material must be established for design [25]. Resilient modulus for rehabilitation projects is determined using the procedures outlined in ASTM D5858, Standard Guide for calculating in situ equivalent elastic moduli of pavement materials using layered elastic theory.

For Level 2 designs, correlation equations have been developed with more commonly used testing protocols to estimate the resilient modulus of the unbound materials. These correlations are summarized in Table (3-6)

Table 3-6 Correlation Equations

Test	Correlation Equation	Test Procedure
California Bearing Ratio (CBR)	$M_r = 2555 (\text{CBR})^{0.64}$ M_r , psi	AASHTO T193, "The California Bearing Ratio"
R-Value	$M_r = 2555 + 555R (20)$ M_r , psi	AASHTO T190, "Resistance R-value and Expansion Pressure of Compacted Soils"
AASHTO layer coefficient	$M_r = 2555 (a_i / 0.14)$ M_r , psi	AASHTO Guide for the Design of Pavement Structures
Plasticity Index (PI) & percentage of material passing 75µm sieve (w)	$\text{CBR} = 75 / 1 + 0.728(wPI)$	AASHTO T27, "Sieve Analysis of Coarse and Fine Aggregates" AASHTO T90, "Determining the Plastic Limit and Plasticity Index of Soils"
Dynamic Cone Penetrometer (DCP) value	$\text{CBR} = 292 / \text{DCP}^{1.12}$	ASTM D6951, "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications"

For Level 3 designs, the resilient modulus of unbound materials is selected based on the unbound material classification. The Design Guide provides a general range of typical modulus values (based on LTPP averages) for each unbound material classification at their optimum moisture content.

Other important parameters of unbound materials considered by the Design Guide include:

- Atterberg Limits (AASHTO 89/90)
- Grain Size Analysis (AASHTO T27)
- Moisture/Density Relationship (AASHTO T99)

3.6 Bedrock Materials Characterization

As with other data input requirements for the Design Guide, the resilient modulus of the bedrock is the most important parameter to be selected. As actual resilient modulus testing of bedrock is very rare for pavement design, the Design Guide provides the following default resilient modulus values for bedrock:

- Uniform, solid bedrock, 1000 ksi (approx. 7,000 MPa)
- Highly fractured, weathered bedrock, 500 ksi (3,500 MPa)

The Poisson's ratio for bedrock is selected as 0.15 for uniform, solid bedrock and 0.3 for highly fractured and weathered rock.

Chapter 4

4.0 ENVIRONMENTAL EFFECTS

Climatic information is one of the most critical mechanisms of the new design procedure. Environmental conditions have a significant effect on the performance of both flexible and rigid pavements. External factors such as precipitation, temperature, freeze-thaw cycles, and depth to water table play an important role in defining the bounds of the impact the environment can have on the pavement performance. Internal factors such as the susceptibility of the pavement materials to moisture and freeze-thaw damage, drainability of the paving layers, infiltration potential of the pavement, and so on define the extent to which the pavement will react to applied external environmental conditions.

4.1 Consideration of Climatic Effects in Design

Enhanced Integrated Climatic Model (EICM) is used in the Design Guide when changing temperature and moisture profiles in the pavement structure and subgrade over the design life of a pavement. The EICM is a one-dimensional coupled heat and moisture flow program that simulated changes in the behavior and characteristics of pavement and subgrade materials in conjunction with climatic conditions overall several years of operation.

The hourly climate information is fed into the Enhanced Integrated Climatic Model (EICM) to calculate the conditions of all of the pavement layers at the time of the various loading. The inputs data required for the EICM consists of typical climate that is generally available from weather station data bases.

4.1.1 Climatic and Material Inputs Required to Model Thermal & Moisture Conditions

A relatively large number of input parameters are needed to produce the desired outputs from the EICM for pavement design. The inputs required by climatic model fall under the following broad categories:

- General information
- Weather-related information
- Ground water related information
- Drainage and surface properties
- Pavement structure and materials

4.1.2 General Information

- Base/Subbase Construction Completion Month and Year – This input is necessary for new flexible pavement design only. It is required to initialize the moisture model in the EICM. The moisture calculations in the unbound materials start from this point in time and as the moisture contents in these layers change from the optimum values input by the user to an equilibrium value, the layer moduli are adjusted accordingly.
- Existing Pavement Construction Month and Year - This input is required only for rehabilitation design using both AC and PCC overlays. If the underlying pavement is a flexible pavement, this parameter helps identify the extent to which the pavement is aged at the time of rehabilitation.
- Pavement Construction Month and Year – This parameter is required for both new and rehabilitation design. For flexible pavement design, this parameter helps determine the stiffness and strength characteristics of the asphalt layer.
- Traffic Opening Month and Year – The expected month in which the pavement will be opened to traffic after construction. This value defines the climatic conditions at the time of opening to traffic, which relates to the

temperature gradients and the layer moduli, including that of the subgrade. If completely unknown, the designer should use the most likely month after the estimated construction month.

- Type of Design – New or Rehabilitation and AC or PCC. This input determines the types of climatic user inputs required for the analysis, climatic model initialization parameters, pavement sublayering schemes, types of inputs required from climatic analysis, and so on.

4.1.3 Weather-Related Data

To achieve the climatic analysis required for incremental damage buildup, the Design Guide requires information on the following five weather-related parameters on an hourly basis over the entire design life for the project being designed:

- Hourly air temperature
- Hourly precipitation
- Hourly wind speed
- Hourly percentage sunshine
- Hourly relative humidity

The air temperature is required by the heat balance equation in the EICM for calculations of long wave radiation emitted by the air and for the convective heat transfer from surface to air. Heat fluxes resulting from precipitation and infiltration into the pavement structure have not been considered in formulating the surface heat flux boundary conditions.

Wind speed is needed in the computations of the convection heat transfer coefficient at the pavement surface. The percentage sunshine is needed for the calculations of heat balance at the surface of the pavement.

In the Design Guide approach, the weather-related information is mainly obtained from weather stations located close to the project site. The software accompanying the Design Guide has an available database from nearly 800 weather stations throughout the United States. Several of the major weather stations have approximately 60 to 66 months of climatic data at each time step (1 hour) needed by the EICM.

4.1.4 Groundwater Table Depth

The groundwater table depth is proposed to be either the best approximation of the annual average depth or the seasonal average depth (a value for each of the four seasons of the year). At input Level 1, it could be determined from profile characterization boring prior the design. At input Level 3, an estimate of the annual average value or the seasonal averages can be provided.

4.1.5 Drainage and Surface Properties

Surface Shortwave Absorptivity- This input pertains to the AC and PCC surface layers. The surface short wave absorptivity of a given layer depends on its structure, color, and texture. This quantity directly correlates with the amount of available solar energy that is absorbed by the pavement surface. The following are the recommended ways to estimate this parameter at each of the hierarchical input levels [15, pg 2.3.11]:

- Level 1 – At this level it is recommended that this parameter be estimated through laboratory testing. However, although there are procedures in existence to measure shortwave absorptivity, there are no current AASHTO certified standards for paving materials.
- Level 2 – Not applicable
- Level 3 – At Level 3, default values can be assumed for various pavement materials as follows:

- Weathered asphalt (gray) 0.8-0.90
- Fresh asphalt (black) 0.90-0.98
- Aged PCC layer 0.70-0.90

Infiltration – This parameter explains the net infiltration potential of the pavement over its design life. In the Design Guide approach, infiltration can assume four values – none, minor (10% of the precipitation enters the pavement, moderate (50% of the precipitation enters the pavement), and extreme (100% of the precipitation enters the pavement). Based on this input, the EICM determines the amount of water available on to of the first unbound layer.

Drainage Path Length – The drainage path length is the resultant length of the drainage path, i.e., the distance measured along the resultant of the cross and longitudinal slopes of the pavement. It is measured from highest point in the pavement cross-section to the point where drainage occurs. This input is used in the EICM's infiltration and drainage model to compute the time required to drain an unbound or subbase layer from an initially wet condition.

4.1.6 Pavement Structure Materials Inputs

The layer thickness of each material in the pavement structure should match to layers that are more or less homogeneous. EICM subdivides these layers for more accurate calculations of moisture and temperature profiles. The procedure always requires two unbound layers under the last stabilized layer for computational purposes.

Asphalt Material Properties – Several asphalt properties are required for the design of flexible pavements and AC overlays. Among these properties are those that control the heat flow through the pavement system and thereby influence the temperature and moisture regimes within it. Asphalt material properties that enter the EICM calculations include:

- Surface shortwave absorptivity
- Thermal conductivity, K
- Heat or thermal capacity, Q

Thermal conductivity, K, is the quantity of heat that flows normally across a surface of unit area per unit of time and per unit of temperature gradient. The moisture content has an influence upon the thermal conductivity of asphalt concrete. If the moisture content is small, the differences between the unfrozen, freezing and frozen thermal conductivity are small. Only when the moisture content is high (e.g. greater than 10%) does the thermal conductivity vary substantially. The EICM does not vary the thermal conductivity with varying moisture content of the asphalt layers as it does with the unbound layers.

The heat or thermal capacity is the actual amount of Q necessary to change the temperature of a unit mass by one degree. Table 4-1 outlines the recommended approaches to characterizing K and Q at the various input levels.

Table 4-1 K and Q values at Different Input Levels

Material Property	Input Level	Description
Thermal Conductivity, K	1	A direct measurement is recommended at this level (AST M1952)
	2	Not applicable
	3	User select design values based upon agency historical data or from typical values shown below: Typical values for asphalt concrete range from 0.44 to 0.81 Btu/(ft)(hr)(°F)
Heat Capacity, Q	1	A direct measurement is recommended at this level (ASTM D2766)
	2	Not applicable.
	3	User selects design values based upon agency historical data or from values shown below: Typical values for asphalt concrete range from 0.22 to 0.40 Btu/(ft)(lb)(°F)

Chapter 5

5.0 TRAFFIC EFFECT

Traffic data is one of the important data elements required for the structural design/analysis of pavement structures. It is needed for estimating the loads that are applied to a pavement and the frequency with which those given loads are applied throughout the pavement's design life. In the Design Guide the following lists are the typical traffic data required [15, pg 2.4.11]:

- Base year truck-traffic volume
- Vehicle operational speed
- Truck-traffic directional and lane distribution factors
- Truck type and axle load distribution factors
- Axle and wheel base configurations
- Tire characteristics and inflation pressure
- Truck growth factors

The equivalent single axle load (ESAL) approach used for traffic characterization in previous versions of the AASHTO Guide for pavement Design is no longer applicable. The Design guide software outputs on a monthly basis the cumulated number of heavy trucks in the design lane as an overall indicator of the magnitude of truck traffic loadings (FHWA class 4 and above) [26]. The table below shows the standard vehicle classes that have been used to summarize and vehicle classification data for FHWA.

CLASS. GROUP		DESCRIPTION	NO. OF AXLES
1		MOTORCYCLES	2
2		ALL CARS	2
		CARS W/ 1-AXLE TRLR	3
		CARS W/2-AXLE TRLR	4
3		PICK-UPS & VANS	2, 3, & 4
4		BUSES	2 & 3
5		2-AXLE, SINGLE UNIT	2
6		3-AXLE, SINGLE UNIT	3
7		4-AXLE, SINGLE UNIT	4
8		2-AXLE TRACTOR, 1-AXLE TRLR(2S1)	3
		2-AXLE TRACTOR, 2-AXLE TRLR(2S2)	4
		3-AXLE TRACTOR, 1-AXLE TRLR(3S1)	4
9		3-AXLE TRACTOR, 2-AXLE TRLR(3S2)	5
		3-AXLE TRUCK, W/2-AXLE TRLR	5
10		TRACTOR W/ SINGLE TRLR	6 & 7
11		5-AXLE MULTI- TRLR	5
12		6-AXLE MULTI- TRLR	6
13	ANY 7 OR MORE AXLE		7 or more

Figure 5-1 Vehicle Classes

5.1 Description of the Hierarchical Approach used in Traffic Characterization

The full axle-load spectrum data for each axle type are needed for the Design Guide for both new pavement and rehabilitation design procedures. The Design Guide defines three wide levels of traffic data inputs (Levels 1 through 3) based on the amount of existing traffic data. These levels correspond to how well the

pavement designer can estimate future truck traffic characteristics for the roadway being designed. The three levels can be explained as follows [15, pg 2.4.2]:

- Level 1 – Very good knowledge of past and future traffic characteristics.
- Level 2 – Modest knowledge of past and future traffic characteristics.
- Level 3 – Poor knowledge of past and future traffic characteristics.

Truck volumes and weights can differ significantly from road to road and even from location to location along a road. A very good knowledge of traffic loads can only be obtained where past traffic volume and weight data have been collected along or near the roadway segment to be designed. Where only regional truck volume and weights data are available for the roadway in question, the design process assumes a modest knowledge of past and thus future traffic characteristics exists. Where the designer must rely on default values computed from a national database and weight information are available, the design process assumes a poor knowledge of past and thus future traffic characteristics.

5.1.1 Level 1 inputs – A Very Good Knowledge of Traffic Characteristics

Level 1 requires collecting and analysis of historical site-specific traffic volume and load data. The traffic data collected at or near a site must include counting and classifying the number of trucks traveling over the roadway, along with breakdown by lane and direction, and measuring the axle loads for each truck class to determine the truck traffic for the first year after construction. Level 1 is considered the most accurate because it uses the actual axle weights and truck traffic volumes distributions measured over or near the project site.

5.1.2 Level 2 Inputs – A Modest Knowledge of Traffic Characteristics

Level 2 requires the designer to collect sufficient truck volume information at a site to measure truck volumes precisely. This includes being able to account for any weekday/weekend volume variation, and any major seasonal trends in truck loads (e.g., in areas affected by heavy, seasonal, agricultural hauls).

5.1.3 Level 3 Inputs – A Poor Knowledge of Traffic Characteristics

Level 3 is used when the designer has little truck volume information for the roadway in question (for example, if all that is available is a value for Average Annual Daily Traffic [AADT] and a truck percentage). This level starts from AADT and percent trucks or from simple truck volume counts with no site-specific (or segment-specific) knowledge on the size of the loads those trucks are carrying. This lack of load knowledge means that a regional or statewide average load distribution (or other default load distribution table) must be used. An estimate of traffic inputs based on local experience is also considered Level 3.

5.2 Inputs Required For Traffic Characterization

Four basic types of traffic data are required for pavement structural design:

- Traffic volume – base year information
- Traffic volume adjustment factors
 - Monthly adjustment
 - Vehicle class distribution
 - Hourly truck distribution
 - Traffic growth factors
- Axle load distribution factors
- General traffic inputs
 - Number axles/trucks
 - Axle configuration
 - Wheel base

5.2.1 Traffic Volume – Base Year Information

The base year for the traffic inputs is defined as the first calendar year that the roadway segment under design is opened to traffic. The following base year information is required:

- Two-way annual average daily truck traffic (AADTT)
- Number of lanes in the design direction
- Percent trucks in design direction
- Percent trucks in design lane
- Vehicle (truck) operational speed

Two-Way Annual Average Daily Truck Traffic

Two-way AADT is the total volume of truck traffic (the total number of heavy vehicles [classes 4 to 13] in the traffic stream) passing a point or segment of a road facility to be designed in both directions during a 24-hour period. AADT is just the total number of truck traffic of the given time period divided by the number of days in that time period. Base year AADTT is defined as follows:

- Level 1 – AADTT determined from site –specific WIM (weigh in motion), AVC (automatic vehicle classification), vehicle count data or site calibrated traffic forecasting and trip generation models. It is recommended that the average of the three most recent years with adequate data be used as the base year AADTT. This average value may need to be adjusted to account for truck-traffic growth depending on the amount of time between the three historical years and the base year.
- Level 2 – AADTT determined regional/statewide WIM, AVC, or vehicle count data or from regionally calibrated traffic forecasting and trip generation models. It is recommended that the average of the last three years prior to the base year be used as the base year AADTT.

- Level 3 – AADTT is estimated from AADT obtained mostly from traffic counts and an estimate of the percentage of trucks expected in the traffic stream. The AADT and percentage of trucks (vehicle class 4-13) should be averaged over the three most recent years with data. Estimates based on local experience are also considered Level 3.

Number of Lanes in the Design Direction

The number of lanes in the design direction is determined from design specifications and represents the total number of lanes in one direction.

Percent Trucks in Design Direction

Percent trucks in the design direction, or the directional distribution factor (DDF), is used to quantify any differences in the overall volume of trucks in two directions. It is usually assumed to be 50 percent when the AADT and AADTT are given in two directions. The levels of input or percent trucks in design direction are described as follows:

- Level 1 – a site-specific directional distribution factor determined from WIM, AVC, and vehicle count data.
- Level 2 – a regional/statewide directional distribution factor determined from WIM, AVC, and vehicle count data. Estimates from trip generation models may also be used.
- Level 3 – a national average value or an estimate based on local experience.

The Design Guide software provides a default value (Level 3) of 55 percent for Interstate type facilities computed using traffic data from LTPP database [27]. Those values computed using data from the LTPP traffic database are listed below:

- Vehicle Class 4, Buses – 0.5, except for local or municipal bus routes. For local routes, the DDF for buses varies from 0.8 to 1.0
- Vehicle Classes 5-7, Single Unit Trucks – 0.62. These types of trucks consistently have the greatest directional distribution factors.
- Vehicle Classes 8-10, Tractor Trailer Trucks – 0.55.
- Vehicle Classes 11-13, Multi-Trailer Trucks -0.50.

Percent Trucks in Design Lane

Percent trucks in the design lane, or truck lane distribution factor (LDF), accounts for the distribution of truck traffic between the lanes in one direction. For two-lane, two-way highways (one lane in one direction), this factor is 1.0 because all truck traffic in any one direction must use the same lane. For multiple lanes in one direction, it depends on the AADTT and other geometric and site-specific conditions. The level of input for LDF is described as follows:

- Level 1 – a site-specific lane distribution factor determined from WIM, AVC, or vehicle count data.
- Level 2 – a regional/statewide lane distribution factor determined from WIM, AVC, or vehicle count data.
- Level 3 – a national average value or an estimate obtained from traffic forecasting and trip generation models. An estimate based on local experience is also considered Level 3.

Vehicle Operation Speed

The vehicle operational speed of trucks or the average travel speed generally depends on many factors, including the roadway facility type, terrain, percentage of trucks, in the traffic stream, and so on. The Design Guide software uses 60 mph as the default operational speed value, but this speed can be modified to reflect local/site conditions [28].

5.2.2 Traffic Volume Adjustments

The following truck-traffic volume adjustment factors are required for traffic characterization, and each described in the following sections:

- Monthly adjustment factors
- Vehicle class distribution factors
- Traffic growth factors

Monthly Adjustment Factors

Truck traffic monthly adjustment factors simply represent the percentage of the annual truck traffic for a given truck class that occurs in a specific month. In other words, the monthly distribution factor for a specific month is equal to the monthly truck traffic for the given class for the month divided by the total truck traffic for that truck class for the entire year. Truck traffic monthly adjustment factors (MAF) depends on factors such as adjacent land use, the location of industries in the area, and roadway location. Monthly distribution of truck traffic is assumed to be constant over the entire design period. Pavement designs can be sensitivity to MAF. If not information is available, it is recommended that designers assume an even or equal distribution (i.e., 1.0 for all months for all vehicle classes).

Vehicle Class Distribution

Vehicle class distribution is computed from data obtained from vehicle classification counting programs such as AVC, WIM, and vehicle counts. Vehicle classification counting programs can be short or continuous duration. Normalized vehicle class distribution represents the percentage of each truck class (classes 4 through 13) within the AADTT for the base year. The sum of the percent AADTT of all truck classes should equal 100. The inputs at different levels are as follows:

- Level 1 – data obtained from site or segment, specific WIM, AVC, or vehicle counts.
- Level 2- data obtained from regional/statewide WIM, AVC, or vehicle counts.
- Level 3- data obtained from national WIM, AVC, or vehicle counts or local experience

Default vehicle class distribution factors (Level 3) determined using LTPP traffic data are provided as part of the Design Guide software. The default vehicle class distribution factors are chosen based on the roadway function class and the best combination of Truck Traffic Classification (TTC) groups that describes the traffic stream expected on the given roadway. An example of the default vehicle class distribution is shown in Appendix B.

Truck Hourly Distribution Factors

The hourly distribution factors (HDF) represent the percentage of the AADTT within each hour of the day. The inputs at different levels are as follows:

- Level 1 – a site or segment-specific distribution determined from AVC, WIM, or vehicle count data.
- Level 2 – a regional/statewide distribution determined from AVC, WIM, or vehicle count data.
- Level 3 – the factors determined from a national data or local experience.

For Level 1 through 3 inputs, HDF may be computed using truck traffic data measured continuously over a 24-hour period of time. The hourly data are used to determine the percentage of total trucks within each hour as follows:

1. Review the AVC data and exclude all traffic samples with more than or less than 24 hours of data.

2. Determine the total number of trucks counted within each hour of each 24-hour traffic sample.
3. Divide the total number of trucks counted within each hour by the total number of trucks counted for the entire 24-hour sample and multiply by 100.

The sum of the percent of daily truck per time increment must add up to 100 percent.

Traffic Growth Factors

Traffic growth factors at a particular site or segment are best estimated when a continuous traffic count data is available (assuming that the data is reliable and that the differences found from year to year can be attributed to growth), since it is well known that traffic volumes at a single site can be affected by a variety of extraneous factors, and does growth factors computed from limited data collected from a limited number of locations can be biased.

The Design Guide software allows users to use three different traffic growth functions to compute the growth or decay in truck over time (forecasting truck traffic). The three functions provided to estimate future truck traffic volumes are presented below [15, pg 2.4.19]:

Function Description	Model
No Growth	$AADTT_x = 1.0 * AADT_{BY}$
Linear Growth	$AADTT_x = GR * AGE + AADT_{BY}$
Compound Growth	$AADTT_x = 1.0 * AADT_{BY} * (GR)^{AGE}$

Where $AADTT_x$ is the annual average daily truck traffic at age X, GR is the traffic growth rate and $AADT_{BY}$ is the base year annual average daily truck traffic.

The Design Guide software allows user to input both a growth rate and the growth function. A common growth function may be chosen for all truck classes,

or different functions may be chosen for the different truck classes. Based on the function chosen, the opening date of the roadway to traffic (excluding construction traffic) and the pavement design life, AADTT is forecast for the entire design of the pavement.

5.2.3 Axle Load Distribution Factors

The axle load factors simply represent the percentage of the total axle applications within each load interval for a specific axle type (single, tandem, tridem, and quad) and vehicle class (classes 4 through 13). A definition of load intervals for each axle type is provided below:

- Single axles – 3,000 lb to 40,000 lb at 1,000 lb intervals
- Tandem axles – 6,000 lb to 80,000 lb at 2,000 lb intervals
- Tridem and quad axles – 12,000 lb to 102,000 lb at 3,000 lb intervals

The normalized axle load distribution or spectra can only be determined from WIM data. Therefore, the level of input depends on the data source (site, regional, or national). For this design procedure, load spectra are normalized on an annual basis because no systematic or significant year-to-year or month-to-month differences were found in the analysis of the LTPP WIM data [29].

5.3 General Traffic Inputs

Most of the inputs under this category define the axle load configuration and loading details used for calculating pavement responses. The exceptions are “Number of Axle Types per Truck Class” and “Wheelbase” inputs, which are used in the traffic volume calculations.

5.3.1 Mean Wheel Locations

Distance from the outer edge of the wheel to the pavement marking. The inputs at different levels are as follows:

- Level 1 – the value determined through direct measurements on site-specific segments (not applicable to new alignments).
- Level 2 – a regional/statewide average value determined from measurements on roadway with similar traffic characteristics and site conditions (e.g., functional class, pavement type, level of service).
- Level 3 – national average value or estimates based on local experience.

A default (Level 3) mean wheel location of 18 inches is provided in the Design Guide software. This is recommended if more accurate information is not available.

5.3.2 Traffic Wander Standard Deviation

This is the standard deviation of the lateral traffic wander. The wander is used to determine the number of axle load applications over a point for predicting distress and performance. The different levels for traffic wander are the same as the mean wheel location. A default (Level 3) mean truck traffic wander standard deviation of 10 inches is provided in the Design Guide software.

5.3.3 Design Lane Width

This parameter refers to the actual traffic lane width, as defined by the lane marking on either side of the design lane. It is a design factor and may or may not equal the slab width. The default value for standard-width lanes is 12 ft.

5.3.4 Number of Axle Types per Truck

This input represents the average number of axles for each truck class (class 4 to 13) for each axle type (single, tandem, tridem, and quad). The inputs at different levels are as follows:

- Level 1 – the values determined through direct analysis of site-specific traffic data (AVC, WIM, or traffic counts).
- Level 2 – the values determined through direct analysis of regional/statewide traffic data (AVC, WIM, or traffic counts).
- Level 3 – the default values based on analysis of national databases such as the LTPP databases.

Default (Level 3) estimated of the number of axle types per truck class provided in the Design software and estimating using LTPP data are presented in table 5-1:

Table 5-1 Axles per Trucks

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

The number of quad per truck class is 0.00, because there were too few counted in the LTPP traffic database.

5.3.5 Axle Configuration

A series of data elements are needed to describe the configuration of the typical tire and axle loads that would be applied to the roadway because computed pavement responses are generally sensitive to both wheel locations and the intersection between the various wheels on a given axle. These data elements can be obtained directly from manufacturers databases or measured directly in the field. Typical values are provided for each of the following elements; however, site-specific values may be used, if available [15, pg 2.4.27].

- Average axle-width – the distance between two outside edges of an axle. For typical trucks, 8.5 ft may be assumed for axle width.
- Dual tire spacing – the distance between centers of a dual tire. Typical dual tire spacing for trucks is 12 in.
- Axle spacing – the distance between the two consecutive axles of a tandem, tridem, or quad. The average axle spacing is 51.6 inches for tandem and 49.2 inches for tridem and quad axles.

5.3.6 Wheelbase

A series of data elements are needed to describe the details of the vehicles wheelbase for use in computing pavement responses. These data elements can be obtained directly from manufacturer's database or measured directly in the field. Typical values are providing for each of the following elements; however, site-specific values may be used, if available.

- Average axle spacing (ft) – short, medium or long. The recommended values are 12, 15, and 18 ft for short, medium and long axle spacing, respectively.
- Percent of trucks in class 8 through 13 with the short, medium, and long axle spacing – use even distribution (e.g., 33, 33 and 34 percent for short,

medium, and long axles, respectively), unless more accurate information is available.

The axle spacing distribution is applicable to only truck tractors (Class 8 and above). If other vehicles in the traffic stream also have the axle spacing in the range of the short, medium and long axles defined above, the frequency of those vehicles should be added to the axle-spacing distribution of truck tractors.

Chapter 6

6.0 DESIGN ANALYSIS

The mechanistic-empirical design of new and reconstructed flexible pavements requires an iterative hands-on by the designer. The designer must choose a trial design and then examine the design in detail to find out if it meets the performance criteria established by the designer. The flexible pavement performance measures considered in this guide include ***permanent deformation, fatigue cracking, thermal cracking and smoothness (International Roughness Index or IRI)***. If the trial design does not satisfy the performance criteria, the design is modified and reanalyzed until the design does suit all criteria.

6.1 Overview of Flexible Pavement Design Process

The main steps in the design process are the following:

1. Put together a trial design for specific site conditions, describe subgrade support, asphalt concrete and other paving material properties, traffic loads, climate, pavement type and design and construction features.
2. Create criteria for acceptable pavement performance at the end of the design period.
3. Choose the desired level of reliability for each of the applicable performance indicators.
4. Process input to obtain monthly values of traffic inputs and seasonal variation of material and climatic inputs needed in the design evaluations for the entire design period.
5. Compute structural responses (stresses and strains) using multilayer elastic theory of finite element based pavement response models for each axle type and load and for each damage-calculation increment throughout the design period.

6. Calculate accumulated distress and/or damage at the end of each analysis period for the entire design period.
7. Predict key distresses (rutting, bottom-up/top-down fatigue cracking, thermal cracking) at the end of each analysis period throughout the design life using calibrated mechanistic-empirical performance models provided in the Guide.
8. Predict smoothness (IRS) as a function of initial IRI, distresses that accumulate over time, and site factors at the end of each analysis increment.
9. Evaluate the expected performance of the trial design at the given reliability level.
10. If the trial design does not meet the performance criteria, modify the design and repeat the steps 4 through 9 above until the design meets the criteria.

6.1.1 Design Input Levels

For the design inputs, the designer can choose from multiple levels of data quality. The levels are described below:

1. **Level 1** – site or material specific inputs for the project obtained through direct testing or measurements. Level 1 data include material properties obtained through laboratory testing and measured traffic volumes and weights at the project site.
2. **Level 2** – the use of the correlations to establish or determine the required inputs. Level 2 data include the resilient modulus of the subgrade or unbound base materials estimated from CBR using empirical correlations.
3. **Level 3** – the use of the national or regional default values to define the inputs. Level 3 input includes the use of AASHTO soil classifications to determine a typical resilient modulus value or the use of roadway type or

truck type classifications to determine normalized axle weight and truck type distribution.

The input levels can be different from one input parameter to another. For instance, subgrade resilient modulus can be obtained from laboratory test (Level 1) and the traffic axle load distribution from regional data (Level 3). The input level selection for a specific parameter depends on several factors such as sensitivity of the pavement performance to a given input, the criticality of the project, the information available at the time of the design and the resources and time available to the designer to obtain the inputs.

6.1.2 Pavement Response Models

The reason of the flexible pavement model is to determine the structural response of the pavement system due to traffic loads and environmental influences. Environmental influences may be direct (e.g. strains due to thermal expansion or contraction) or indirect via effects on material properties (e.g. changes in stiffness due to temperature or moisture effects). Pavement responses include stresses, strains and deflections. In theory, only those responses that contribute to each distress should be evaluated by the structural models and used in the distress models. The response models include the heat transfer model, the moisture equilibrium element structural model, the infiltration and drainage model and the structural model.

Heat Transfer Model

This model is for examining frost action and temperature system in multilayered pavement systems. This model applies the finite difference method to answer the following Fourier equation for one-dimensional heat flow:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial Z^2}$$

Where,

- T = temperature
- t = time
- Z = the depth below surface
- α = thermal diffusivity

The above model is developed at the University of Illinois. [30]

For the above model the inputs to the heat transfer are the climatic data and the thermal properties of paving materials and soils. The climatic data contain maximum and minimum daily air temperatures, percent sunshine and wind speed.

Moisture Equilibrium Model

This model is based on an assumption in the climatic materials structural model (Dempsey et al. 1986) that the subgrade will not collect moisture by infiltration through the pavement. Usually surface rainwater drains out through the base and subbase layers to the side ditches or longitudinal drain, therefore the only water in the subgrade layer is the capillary water caused by the water table. Because of the thermodynamics relationship between suction and moisture content, an easy way to figure out the moisture content in a soil is to determine its suction, which is related to the pore water pressure. The relationship between suction and pore pressure can be expressed as [31].

$$u = S + \alpha p$$

- Where U = pore pressure
- S = soil suction, which is negative pressure
- P = applied pressure, which is always positive
- α = is the compressibility factor

For unsaturated cohesive soils, α is related to the plasticity index PI (Black and Croney, 1957) [32]. $\alpha = 0.03 \times \text{PI}$

The pore pressure in a soil depends solely on its distance above groundwater table.

Infiltration and Drainage Model

In 1984, Liu and Lytton from Texas A & M University developed this model to assess the effects of rainfall on the amount of saturation and the resilient moduli of the base and subgrade [33]. Probability distribution was considered for rainfall, wet and dry days, infiltration of water into pavements through joints, the drainage of base course to find the degree of saturation for base and subgrade in a daily basis.

Distress Models

Distress models relate structural responses to a variety of types of distress such as fatigue cracking, rutting and thermal cracking. Asphalt pavement ruttings is one of the most common and destructive pavement distresses observed on roads, particularly at intersections in the urban environment. Asphalt pavement rutting can be caused by insufficient pavement structural support allowing excessive stress to be transferred to the subgrade.

Figure 6-1 Asphalt Pavement Rutting due to Plastic Movement of the Asphalt Mix under Heavy Loads

Fatigue Cracking Models

To predict fatigue cracking Miner's (1945) cumulative damage idea has been extensively used [34]. It is understood that the allowable number of load repetition is related to the tensile strain at the bottom of the asphalt layer. Damage occurs when the sum of damage ratios reaches the value 1. There are different design methods to calculate fatigue cracking and the difference in methods is the transfer functions that relate the HMA tensile strains to the allowable number of load repetitions.

Rutting Models

There are two steps to limit rutting; one is the vertical compressive strain on top of the subgrade on the other one is the accumulated total permanent deformation on the pavement surface based on the permanent deformation properties of each layer. In the Asphalt Institute in order to limit rutting the allowable number of load repetitions N_d is related to the vertical compressive strain ϵ_c on top of the subgrade by

$$N_d = f_4 (\epsilon_c)^{-f_5}$$

f_4 & f_5 are calibrated values from the field

In the subgrade strain method, it is assumed that, if the subgrade compressive strain is controlled, reasonable surface rut depth will not be exceeded.

With thicker hot mix asphalt and heavy traffic, most of the rutting occurs in the hot mix asphalt rather than the subgrade. Since rutting is caused by the buildup of permanent deformation over all layers, it is more practical to determine the permanent deformation in each layer and sum up the results.

Thermal Cracking Models

In asphalt pavement there are two different kind of thermal cracking, low-temperature and thermal fatigue cracking. The system of low temperature cracking is shown in Figure 8. The graph indicates that when the temperature decreases, tensile stress increases always and the tensile strength increase only to a maximum and then decreases. When the thermal tensile stress exceeds its tensile strength then the low-temperature cracking will occur.

Figure 6-2 Mechanism of low-temperature cracking (After McLeod, 1970)

Thermal fatigue cracking will occur when tensile strength is larger than tensile stress, the pavement may not crack under a single daily temperature cycle but it could crack under a large number of cycles.

Two flexible pavement analysis methods have been implemented in the 2002 Design Guide. For cases in which all materials in the pavement structure can realistically be treated as linearly elastic, multilayer elastic theory is used to determine the pavement response, the JULEA multilayer elastic theory program is used to determine the pavement response. Multilayer elastic theory provides

an excellent combination of analysis features, theoretical rigor, and computation speed for linear pavement analysis. In cases where the unbound material nonlinearity is also considered, a nonlinear finite element (DSC2D) procedure is used instead for determining the pavement stresses, strains, and displacements.

The outputs from the pavement response model are the strains, stresses, and displacements within the pavement layers, of particular interest are the critical response variables required as inputs to the pavement distress models in the mechanistic-empirical design procedures. Examples of critical response variables include:

- Tensile horizontal strain at the bottom/top of the HMA layer (for HMA fatigue cracking)
- Compressive vertical stresses/strains within the HMA layer (for HMA rutting)
- Compressive vertical stresses/strains within the base/subbase layers (for rutting of unbound layers)
- Compressive vertical stresses/strains at the top of the subgrade (for subgrade rutting).

Each pavement response variable must be evaluated at the critical location within the pavement layer where the parameter is at its most extreme value. For a single wheel loading, the critical location can usually be determined by inspection. For multiple wheels and/or axles, the critical location will be a function of the wheel load configuration and the pavement structure. The stresses and strains are always computed at the mid depth location of each layer/sublayer of the pavement structure, except for the subgrade. Subgrade response is estimated at 150 mm from the interface.

6.1.3 Stress Analysis

The pavement response model should be used for pavement structure to calculate stresses (strains) for all cases that needs to be analyzed. The number of cases depends on the damage increment. The following increments are considered:

Pavement age – by year

Season – by month or semi-month

Load configuration – axle type

Load level – discrete load levels in 1,000 to 3,000 lb increments, depending on axle type.

Temperature- pavement temperature for the HMA dynamic modulus

6.1.4 Incremental Distress and Damage Accumulation

The trial design is analyzed for adequacy by dividing the target design life into shorter design analysis periods or increments beginning with the traffic opening month. Within each increment (each analysis period), all factors that affect pavement responses and damage are held constant. These include the following:

- Traffic levels
- Asphalt concrete modulus
- Base and subbase moduli
- Subgrade modulus

Critical stress or strain values for each distress type are determined for each analysis increment. These critical stress or strain values are converted to incremental distresses, either in absolute terms (e.g. incremental rut depth) for in terms of a damage index (e.g. fatigue cracking). Incremental distresses or damage are summed over all increments and output at the end of each analysis period by the Design Guide software.

6.1.5 Distress Prediction

A variety of structural distresses are considered in flexible pavement design and analysis. These include the following:

- Bottom-up fatigue (or alligator) cracking
- Surface-down fatigue (or longitudinal) cracking
- Fatigue in chemically stabilized layers (only considered in semi-rigid pavements)
- Permanent deformation (or rutting)
- Thermal cracking

Rutting distress is predicted in absolute terms. Therefore the incremental distress computed for each analysis period can be directly accumulated over the entire target design life for the pavement. Cracking distress (bottom-up/surface-down fatigue cracking, thermal cracking) is predicted in terms of a damage index, which is a mechanistic parameter representing the load associated damage within the pavement structure. When "damage" is very small (e.g., 0.0001) the pavement structure would not be expected to exhibit significant cracking.

Bottom-up Fatigue Cracking or Alligator Cracking

This type of fatigue cracking first shows up as short longitudinal cracks in the wheel path that quickly spread and become interconnected to form a chicken wire/alligator cracking pattern. These cracks initiate at the bottom of the HMA layer and propagate to the surface under repeated load applications.

Figure 6-3 Top-down cracking

This type of fatigue cracking is a result of the repeated bending of the HMA layer under traffic. Basically, the pavement and HMA layer deflects under wheel loads that result in tensile strains and stresses at the bottom of the layer. With continue bending, the tensile stresses and strains cause cracks to initiate at the bottom of the layer and then propagate to the surface. The following are some of the reasons for higher tensile strains and stresses to occur at the bottom of the HMA layer:

- Relatively thin weak HMA layers for the magnitude and repetitions of the wheel loads.
- Higher wheel loads and higher tire pressures.
- Soft spots or areas in unbound aggregate base materials or in the subgrade soil.
- Weak aggregate base/subbase layers caused by inadequate compaction or increases in moisture contents or extremely high ground water table.

Surface-down Fatigue Cracking or Longitudinal Cracking

The majority of fatigue cracking occurs at the bottom of the HMA layer and spread upward to the surface of the pavement. However, there is increasing evidence that suggests load-related cracks do initiate at the surface and propagate downward. There are various opinions on the mechanisms that cause these types of cracks, but there are no conclusive data to suggest that one is more applicable than the other. Some of the suggested mechanisms are:

- Wheel load induced tensile stresses and strains that occur at the surface and cause cracks to initiate and propagate in tension. Aging of the HMA surface mixture accelerates this crack initiation-propagation process.
- Shearing of the HMA surface mixture caused from radial tires with high contact pressures near the edge of the tire. This leads to cracks to initiates and propagate both in shear and tension.

- Severe aging of the HMA mixture near the surface resulting in high stiffness and when combined with high contact pressures, adjacent to the tire loads, cause the cracks to initiate and propagate.

Figure 6-4 Longitudinal cracking

Permanent Deformation or Rutting

Rutting is a surface depression in the wheel paths caused by inelastic or plastic deformations in any or all of the pavement layers and subgrade. These plastic deformations are usually the results of densification or one-dimensional compression and consolidation, lateral movements or plastic flow of materials from wheel loads. The more severe premature distortion and rutting failures are related to lateral flow and inadequate shear strength any pavement layer, rather than one-dimensional densification.

Thermal Cracking

Cracking in flexible pavements due to cold temperatures or temperature cycling is commonly referred to as thermal cracks. Thermal cracks usually show as transverse cracks on the pavement surface roughly perpendicular to the pavement centerline. These cracks can be caused by shrinkage of the HMA

surface due to low temperature, hardening of the asphalt daily temperature cycles.

Cracks that result from the coldest in temperature are referred to as low temperature cracking. Cracking that result from thermal cracking is commonly referred to as thermal fatigue cracking. Low temperature cracking is associated with regions of extreme cold whereas thermal fatigue cracking is associated with regions that experience large extremes in daily and seasonal temperatures.

6.1.6 Smoothness (IRI) Prediction

The IRI over the design period depends upon the initial as constructed profile of the pavement from which the initial IRI is computed and upon the subsequent development of distress over time. These distresses include rutting, bottom-up/top-down fatigue cracking, and thermal cracking for flexible pavements. The IRI model uses the distresses predicted using the models included in the Guide, initial IRI, and site factors to predict smoothness over time. The site factors include subgrade and climatic factors to account for the roughness caused by the shrinking or swelling soils and frost heave conditions, IRI is estimated incrementally over the entire design period.

6.1.7 Design Reliability

A large amount of vagueness and inconsistency exists in pavement design and construction, as well as in the application of traffic loads and climatic factors over the design life. In M-E design, the key outputs of interest are the individual distress quantities (e.g., rutting, fatigue cracking, and thermal cracking for flexible pavements). Therefore, the predicted distress is the random variable of interest in reliability design.

Design reliability for the individual pavement distress models (i.e., rutting, bottom-up cracking, top-down cracking, and thermal cracking) are based on the standard

error of the estimates of error include a combined input variability, variability in the construction process, and model or pure error. The desired level of reliability is specified along with the acceptable level of distress at the end of design life in defining the performance requirements for a pavement design in the Guide.

Chapter 7

7.0 DESIGN INPUTS FOR NEW FLEXIBLE PAVEMENT DESIGN

Input data used for the design of new flexible pavements are as follows:

- **General information**
- **Site/Project identification**
- **Analysis parameters**
- **Traffic**
- **Climate**
- **Drainage and surface properties**
- **Pavement structure**

7.1 Site and Project Identification

This group of inputs includes the following:

- Project location
- Project identification –Project ID, Section ID, begin and end mile posts and traffic direction
- Functional class of the pavement being designed. The choices under this option include the following: principal arterial, minor arterial, major collectors, minor collectors and local routes and streets.

7.2 Analysis Parameters

7.2.1 Initial IRI

The initial IRI defines the as-constructed smoothness of the pavement. This parameter is highly dependent on the project smoothness specifications and has a significant impact on the long-term ride quality of the pavement. Typical values range from **50 to 100 in/mi**.

7.2.2 Performance Criteria

The flexible design is based on surface-down and bottom-up fatigue cracking of the asphalt surface, HMA thermal cracking, fatigue cracking in chemically stabilized layers, permanent deformation for both the asphalt layers and the total pavement, and pavement smoothness (IRI). The designer may select some or all of these performance indicators and establish criteria to evaluate a design and make modifications if necessary. The performance criteria for each distress will depend on the individual highway agency's tolerance for the amount of cracking over the design period. The performance criteria will also depend upon the design reliability level, which in turn will be dependent upon the functional class of the roadway.

The performance criterion for surface-down fatigue cracking is defined as the maximum allowable length of longitudinal cracking per mile of pavement that is permitted to occur over the design period. Typical values of allowable surface-down fatigue cracking are on the order of **1000 ft per mile** of pavement. Surface-down fatigue cracking is manifested as longitudinal cracking at the edge of the wheel path. Surface-down cracking permits water infiltration into the underlying pavement layers that can cause structural failure of the pavement.

The performance criterion for bottom-up fatigue cracking is defined as the maximum area of alligator cracking expressed as a percentage of the total lane area that is permitted to occur over the design period. Typical values of allowable bottom-up fatigue cracking are on the order of **25 to 50 percent** of the total lane area. Bottom-up fatigue cracking is manifested as alligator cracking within the wheel paths. Bottom-up cracking permits water infiltration into the underlying pavement layers that can cause structural failure of the pavement. It also contributes directly to a loss of smoothness.

The performance criterion for thermal cracking is defined as the maximum length of transverse cracking per mile of pavement that is permitted to occur over the design period. Typical values of allowable thermal cracking are on the order of **1000 ft per mile** of pavement. Thermal cracking appears as regularly spaced transverse cracks across the complete pavement surface. Thermal cracking is environmentally induced by sharp and rapid drops in pavement temperature that cause extreme thermal contraction and fracture of the asphalt surface. Thermal cracking permits water infiltration into the underlying pavement layers that can cause structural failure of the pavement.

The performance criterion for fatigue cracking in chemically stabilized is defined in terms of a damage index. Typical design damage index values for fatigue cracking in chemically stabilized layers are on the order of **25%**. Fatigue cracking in underlying chemically stabilized layers reduces the support provided to the upper pavement layers. This will accelerate the manifestation of surface distress, especially surface-down and bottom-up fatigue fracture in the asphalt surface layers. This will lead to a loss of smoothness and can lead to premature failure of the pavement system.

7.2.3 Total Permanent Deformation

Permanent deformation most typically is manifested as ruts within the wheel paths. Total permanent deformation at the surface is the accumulation of the permanent deformation in all of the asphalt and unbound layers in the pavement system. Rutting is a major contributor to loss of pavement smoothness. It can also create functional problems such as water ponding and consequent vehicle hydroplaning and handling problems for vehicles during lane changes.

The performance criterion for total permanent deformation is defined in terms of the maximum rut depth in the wheel path. Typical maximum rut depths for total

permanent deformation are on the order of **0.3 to 0.5 inches**. This limiting value is a direct function of the specific policy used by each design agency.

7.2.4 Smoothness

Functional adequacy is quantified most often by pavement smoothness. Rough roads not only lead to used discomfort but also to increased travel times and higher vehicle operating costs. Although the structural performance of a pavement in terms of pavement distress is important the public complaints generated by rough roads often contribute to a large part of the rehabilitation decisions that are made by State highway agencies. The international roughness index (IRI) is one of the most common ways of measuring smoothness in managing pavement.

As with structural distresses, the performance criterion for smoothness is defined by the acceptable IRI at the end of design life. Terminal IRI values are chose by the designer and should not be exceeded at the design level of reliability. Typically values in the range of **150 to 250 in/mile** are used for terminal IRI, depending on the functional class of the roadway and design reliability.

7.3 Traffic Input

Traffic data is one of the key data elements required for the analysis and design of pavement structures. The standard traffic option for flexible pavement design is to specify the actual load spectra for single, tandem, tridem and quad axles. The second traffic option for flexible pavement is the special axle configuration. This option enables the analysis of pavement performance due to special, heavy, non-conventional off-road vehicle systems that are often subject to special permitting requirements. The following are the basic information required:

- Annual Average Daily Truck Traffic (AADTT) for base year
- Percent trucks in the design direction (directional distribution factor)

- Percent trucks in the design lane (lane distribution factor)
- Operational speed of vehicles – this input is used in the calculation of moduli of asphalt bound layers.

7.3.1 Traffic Volume Adjustment

The truck monthly distribution factors are used to determine the monthly variation in truck traffic within the base year. These values are simply the ratio of the monthly truck traffic to the AADTT. Naturally, the average of the ratios for the 12-months of the base must be equal **1.0**.

7.3.2 Vehicle Class Distribution

The normalized vehicle distribution represents the percentage of each truck class (class 4 through 13) within the AADTT for the base year. The sum of the percent AADTT of all truck classes should equal 100. It is important to note that if site specific (level 1) or regional data (level 2) data are not available, truck traffic classification (TTC) can be used in conjunction with the functional class of the roadway to estimate the vehicle class distribution. Each TTC represents a traffic stream with unique truck traffic characteristics, and a default vehicle class distribution was established for each TTC using a national traffic database for use at level 3.

Traffic Growth Factors

The traffic growth function allows the growth or decay in truck traffic over time (forecasting or backcasting truck traffic). Three functions are available to estimate future truck traffic volumes such as no growth, linear growth, compound growth. Different growth functions may be used for different functional classes. Based on the function chosen, the opening date of the roadway to traffic (excluding construction traffic), and the design life, the traffic is projected into the future.

Axle Load Distribution Factors

The axle load distribution factors simply represent the percentage of the total axle applications within each load interval for a specific axle type and vehicle class (class 4 through 13). This data needs to be provided for each month for each vehicle class. A definition of load intervals for each axle type is provided below:

- Single axles – 3,000 lb to 41,000 lb at 1,000 lb intervals
- Tandem axles – 6,000 lb to 82,000 lb at 2,000 lb intervals.
- Tridem and Quad axles – 12,000 lb to 102,000 lb at 3,000 lb intervals.

General Traffic Inputs

Most of the inputs under this category define the axle load configuration and loading details for calculating pavement responses. The exceptions are “Number of Axle Types per Truck Class” and “Wheelbase” inputs, which are used in the traffic calculations.

Mean Wheel Location

Distance from the outer edge of the wheel to the pavement marking. This input is very important in computing fatigue damage for both JPCP cracking and CRCP punchout prediction but is not used for flexible pavement analyses.

Traffic Wander Standard Deviation

Lateral wander of traffic influences the number of axle load application over a point for predicting distress and performances. The parameter affects prediction of fatigue and permanent deformation within the pavement system. An increase

in wander will result in more fatigue life and less permanent deformation within the pavement system.

Although wander directly affect the progression of damage for both fatigue and rutting, a slightly different approach is used for each distress. Estimation of fatigue damage is based upon Miner's law, which states that damage is given by the following relationship.

$$D = \sum_{i=1}^T n_i / N_i$$

Where:

D = damage

T = total number of periods

n_i = actual traffic for period i

N_i = traffic allowed under conditions prevailing in i

Because Miner's law is linear with traffic, damage distribution with wander is computed from the fatigue damage profile obtained that has no wander (wander = 0 inch). This cannot be done when dealing with permanent deformation, because rutting in the pavement is not linearly related to traffic and wander is applied to the response, not the distress.

Axle Configuration

A series of data elements are needed to describe the details of the tire and axle loads for used in the pavement response module. Typical values are provided for each of the following elements; however, site-specific values may be used, if available.

- Average Axle Width – the distance between two outside edges of an axle. For typical trucks, 8.5 ft may be assumed for axle width.

- Dual Tire Spacing – the distance between centers of a dual tire. Typical dual tire spacing for trucks is 12 in.
- Tire Pressure – the hot inflation pressure or the contract pressure of a single tire or a dual tire. For heavy trucks, typical hot inflation pressure is 120 psi.
- Axle Spacing – the distance between the two consecutive axles of a tandem, tridem, or quad. The average axle spacing is 51.6 in for tandem and 49.2 in for tridem axles.

7.4 Climate

Environmental conditions have a significant effect on the performance of flexible pavements. The interaction of the climatic factors with pavement materials and loading is complex. Factors such as precipitation, temperature, freeze-thaw cycles, and depth to water table affect pavement and subgrade temperature and moisture content, which, in turn, directly affects the load-carrying capacity of the pavement layers and ultimately pavement performance.

7.4.1 Climatic Inputs

The following weather related information is required to perform flexible pavement design:

- Hourly air temperature over the design period
- Hourly precipitation over the design period
- Hourly wind speed over the design period
- Hourly percentage sunshine over the design period
- Hourly ambient relative humidity values
- Seasonal or constant water table depth at the project site

The first five inputs above can be obtained from weather station data for a give site, if available. For locations within the Unites States, they can be obtained from the National Climatic Data Center database. The software includes an extensive climatic database for over 800 locations in the U.S.

All of the necessary climatic information at any given location within the U.S., with the exception of the seasonal water table depth, can be generated by simply providing the following inputs:

- Pavement location – latitude and longitude
- Elevation

Designers may use data from the closest weather station or data interpolated from up to six closest weather stations.

7.4.2 Input Processing

The climatic inputs are combined with the pavement material properties, layer thicknesses, and drainage-related inputs by the EICM to yield the following information for use in the flexible pavement design analysis:

- Hourly profiles of temperature distribution through the asphalt layers
- Hourly temperature and moisture profiles (including frost depth calculations) through other pavement layers.
- Monthly or semi-monthly (during frozen or recently frozen periods) predictions of layer moduli for asphalt, unbound base/subbase, and subgrade layers.
- Annual freezing index values.
- Mean annual number of wet days.
- Number of freeze-thaw cycles.

7.5 Pavement Structure

Input values for pavement structure properties are organized into the following categories:

- Drainage and surface characteristics
- Layer properties
- Distress potential

7.5.1 Drainage and Surface Properties

These are general pavement structure properties required for the design analysis.

- Pavement surface layer shortwave absorptivity
- Potential for infiltration
- Pavement cross slope
- Length of drainage path

The first in the list above is essentially a material property that interacts with the climatic inputs in defining the temperature regime in pavement layers. The remaining three inputs are related to infiltration and drainage.

Pavement Shortwave Absorptivity

The short wave absorptivity of a pavement surface depends on pavement composition, color, and texture. The short wave absorptivity is the ratio of the amount of solar energy absorbed by the pavement surface to the total energy the surface was exposed to, which naturally affects the temperature regime within the pavement structure and the associated structural response. The input

arranges from **0 to 1**. Generally the lighter and more reflective the surface is, the lower the short wave absorptivity will be. For level 1 input, this value should be determined through direct testing. The typical values range from **0.8 to 0.9** for fresh asphalt and **0.9 to 0.98** for weathered asphalt. The recommended default value is **0.85** for new pavement design.

Infiltration

This input quantifies the amount of water infiltrating the pavement structure. The calibration of the flexible pavement distress models assumed that no infiltration of moisture occurred throughout the design period. Thus, this input screen is grayed out and does not allow the designer to choose any level of infiltration.

7.5.2 Layer Properties

The flexible pavement design procedure allows a wide variety of asphalt, base, and subbase material properties and layer thicknesses. A flexible pavement structure could consist of one or more asphalt concrete surface layers, an asphalt treated base, an aggregate subbase, compacted subgrade, natural subgrade and bedrock.

The original pavement structure defined by the user usually has 4 to 6 layers. However, the Design Guide software may subdivide the pavement structure into 12 to 15 sublayers for the modeling of temperature and moisture variations. The Design Guide software performs the sublayering internally based on the material type, layer thickness and the location of the layer within the pavement structure.

Asphalt Concrete and Asphalt Stabilized Layers

The surface asphalt concrete layer is divided into sublayers to account for temperature and aging gradients. Within the program, the user can specify a

maximum of three layers (surface, binder, and base) for new construction. This requires material properties for each individual asphalt layer. Asphalt aging is modeled only for the top sublayer. The largest change in stiffness due to aging occurs only in the top half inch, and the aging gradient for layers other than the top layer is not significant. The top layer is more susceptible to aging since long-term aging is strongly affected by the oxidation process, and the top layer is in direct contact with sunlight and air.

The material inputs required for asphalt concrete layers are grouped under three broad categories – general materials inputs, inputs required to construct the dynamic modulus (E^*) master curve, and inputs required for thermal cracking prediction.

General Layer Property Inputs

- Layer thickness
- Poisson's ratio
- Thermal conductivity – the quantity of heat that flows normally across a surface of unit area per unit of temperature gradient normal to the surface. The typical value for asphalt-stabilized base material is 0.67 BTU/hr-ft-°F.
- Heat capacity – the heat required to raise the temperature of a unit mass of material by a unit temperature. A typical value for asphalt-stabilized base is 0.23 BTU/hr-ft-°F.
- Total unit weight – typical range for dense-graded hot-mix asphalt is 134 to 148 lb/ft³.

Inputs Required to Construct E^* Master Curve

The primary material property of interest for asphalt stabilized layers is its dynamic modulus, E^* . For Level 1 input, E^* , is determined in the laboratory using

standard test protocols for various frequencies and rates of loading. A master curve of E^* versus reduced time is then derived from this data that defines the behavior of this layer under loading and at various climatic conditions.

- Asphalt mixture properties
 - For Level 1 input – specify the laboratory measured dynamic modulus values at various temperatures and loading rates.
 - For Level 2 and 3 inputs – specify the mix properties required for the Witczak dynamic modulus predictive equation:
 - Percent retained on $\frac{3}{4}$ in sieve- a typical value is 5 to 16% for dense graded and 30% for permeable.
 - Percent retained on $\frac{3}{8}$ in sieve – a typical value is 27 to 49% for dense graded and 70% for permeable.
 - Percent retained on #4 sieve – a typical value is 38 to 61% for dense graded and 95% for permeable.
 - Percent passing the #200 sieve- a typical value is 3 to 8% for dense graded and 1% for permeable.
- Asphalt binder
 - For Level 1 input – specify either Superpave or conventional laboratory binder test data.
 - For Level 2 input – specify PG grade or Viscosity grade.
 - For Level 3 input – specify PG grade, Viscosity grade, or Penetration Grade.

Inputs Required for Thermal Cracking Prediction

The properties of the asphalt layer specific to the prediction of thermal cracking distress must be specified. These include the following:

- Average tensile strength at -10°C .
- Creep compliance data. For Level 1 input, these are mix-specific values measured at three different temperatures (-16° , -10° , 0°C). For Level 2

input, these are mix-specific values measured at a single temperature (-10°C). For Level 3 input, these are default material properties based on the binder performance grade.

- The mix coefficient of thermal contraction. This may be specified directly, or the Guide software can estimate it based upon input values for mix VMA and the thermal contraction coefficient for the aggregates.

Chemically Stabilized Layers

No sub-layering is done for any chemically stabilized base or subbase layers. The following inputs are required to define a chemically stabilized layer:

- Maximum design resilient modulus.
- Minimum resilient modulus (after fatigue damage completely propagates the layer).
- Modulus of rupture.
- Unit weight of the material.
- Poisson's ratio.
- Thermal conductivity – the quantity of heat that flows normally across a surface of unit area per unit of time of temperature gradient normal to the surface. A typical unit value for chemically or cementitiously stabilized base is 1.0 BTU/hr-ft-°F.
- Heat capacity – the heat required to raise the temperature of a unit mass of material by a unit temperature. A typical value for chemically or cementitiously stabilized base is 0.28 BTU/lb-°F.

Unbound Base/Subbase/Subgrade

Unbound base layers thicker than six inches and unbound subbase layer thicker than eight inches are sublayered internally within the Guide software for analysis purposes. For the base layer (first unbound layer), the first sub-layer is always

two inches. The remaining thickness of the base layer and any subbase layers that are sub-layered are divided into sublayers with a minimum thickness of four inches. For compacted and natural subgrades, the minimum sub-layer thickness is 12 in. A pavement structure is sub-layered only to a depth of eight feet. Any remaining subgrade is treated as an infinite layer. If bedrock is present, the remaining subgrade is treated as one layer beyond eight feet.

The major inputs required for unbound/subbase and subgrade layers are:

- Layer thickness (only for base and subbase layers) – for subgrade layers if the lime modified or compacted subgrades need to be considered separately from the natural subgrade, they can be defined as a structural layer.
- Layer resilient modulus
 - For Level 1 input – specify the nonlinear stress-dependent resilient modulus parameters, k_1 , k_2 , and k_3 . It should be noted that level 1 inputs require the use of the nonlinear finite element code for performance prediction which is currently only recommended to be used for research and analysis purposes.
 - For Level 2 input – specify the linearly elastic resilient modulus value directly; alternatively, the resilient modulus value can be determined from empirical relations in terms of other index properties.
 - For Level 3 input – specify a default resilient modulus as a function of the AASHTO or Unified soil classification.
- Poisson's ratio.
- Coefficient of lateral earth pressure, K_0 – a typical value for this input is 0.5 for natural or uncompacted materials.

Chapter 8

8.0 DESIGN EXAMPLE

In this example a typical flexible pavement is designed for a municipal road in the Province of Ontario by using the software from mechanistic empirical pavement design guide developed by NCHRP 1-37A. The software program is designed for United States, therefore the units are all in imperial units. The software does not have the capability to change the units. In this example the units are all imperial. Level 3 input is also used in this example since no actual values from the field and laboratory were available. Some modification has been made in the default values to satisfy the pavement design. It should be noted that the default values are developed for the conditions and mixes in the United States. An extensive calibration is required for Canadian conditions and asphalt mixes.

8.1 General Input Information

Project location such as principal arterial, minor arterial, major collectors, minor collectors and local routes and streets must be identified. The design life of the pavement is required depending on the project specification. In this example the design life of road is 20 years. It is important to indicate the start of construction and also the start of paving construction.

8.2 Analysis Parameters

The desired level of reliability is specified along with the acceptable level of distress at the end of design life in defining the performance requirements for a pavement design in the Guide. The following parameters are required to calculate AC surface down cracking, AC bottom up cracking, thermal fracture, and pavement deformation for entire design length of the pavement (shown in table 8-1). For flexible pavement the initial IRI should designed. The initial IRI

defines the as-constructed smoothness of the pavement. Typical values range from 50 to 100 in/mi. IRI expected at end of design life for the AC pavement. In this example IRI is selected to 63 (in/mile). The flexible pavement also based on surface down and bottom up fatigue cracking, permanent deformation for asphalt layer and total pavement structure. The default values for level 3 are provided in Chapter 7.

Table 8-1 Input Parameters

Parameters	Limit	Reliability
Terminal IRI (in/mile)	172	90
AC Surface Down Cracking (ft/mile)	2000	90
AC Bottom Up Cracking, Alligator Cracking (%)	25	90
AC Thermal Fracture (ft/mile)	1000	90
Chemically Stabilized Layer Fatigue Fracture (%)	25	90
Permanent Deformation – Total Pavement (in)	0.75	90
Permanent Deformation – AC Only (in)	0.4	90

8.3 Design Input Parameters

In this section traffic information, environmental data and structural data such as AC, base, subbase and subgrade information is required.

8.3.1 Traffic Information

The following parameters are designed in this example:

Initial two way AADTT	400
Number of lanes in design direction	2
Percent of trucks in design direction	50
Percent of trucks in design lane	50
Operation speed (mph)	50
Traffic growth (compound %)	2

The normalized vehicle distribution is required and it represents the percentage of each truck class (class 4 through 13) within the AADTT for the base year. The

sum of the percent AADTT of all truck classes should equal 100. Approximate percentage of different class of vehicles has been selected and they are as follows:

Table 8-2 Percentage of Truck

Classes	Percentage
4	1.8
5	34.6
6	14.6
7	10.0
8	10.5
9	9.3
10	9.8
11	0.8
12	3.3
13	5.5
Total	100

Hourly distribution and monthly adjustments are also required. They are presented in full details in Appendix C.

General Traffic Input

For traffic input parameters such as axle load distribution factors for each vehicle class, design, lane width, average axle width, dual tire spacing, tire pressure and axle spacing are required. The default values are provided in Chapter 7.

In this project some of the default values were changed to satisfy the design of this project and the following values are selected:

- Lane width 12 ft
- Tire Pressure 120 psi
- Avg. axle width 8.5 ft
- Dual tire spacing 12 in

8.3.2 Climate Information

Environmental conditions have a significant effect on the performance of flexible pavements. Since there are no climate information data for the Canadian cities

in the software guide, therefore the climate information from Chicago was selected for this project, since the weather condition is similar to Ontario's climate. The following parameters are included in the Climate data base for Chicago.

- Hourly air temperature over the design period
- Hourly sunshine, humidity, wind speed, precipitation over the design period
- Seasonal or constant water table depth at the project site.

The tabulated results are listed in Appendix C.

After selecting climate data from the data base the final step is to input the pavement structure.

8.3.3 Pavement Structure Input

For designing the flexible pavement the following pavement structure was selected in this project.

- A total asphalt concrete thickness of 6 in (150 mm)
- A total of 24 in (600 mm) granular base and subbase
- The subgrade consisted of native silty clay (CL)

The asphalt selected in this project has the following properties:

• Superpave 19	(PG58-28)
• Air Void (%)	4.5
• VMA (%)	14.5
• Effective volumetric binder content (%)	5.2

Asphalt mix gradation is provided in Appendix C.

Granular base and subbase consisted on well graded Sand and Gravel, trace silt. Gradation for granular base and subbase and also the gradation of subgrade material including plasticity index and liquid limit values were selected for this project and the results are presented in Appendix C under the input properties. For the remaining asphalt, granular and soil parameters such as Poisson's ratio, specific gravity, and other parameters the default values were used.

8.4 Output Results

After entering all the required parameters then it is safe to run the analysis which will take the software between 45 to 60 minutes to complete the analysis. After the analysis is completed the output results are available in Excel format. To see the entire output graphs and tables refer to Appendix C. Important tables and graphs are presented below:

Figure 8-1 shows the required input steps in order to come out with output results.

Figure 8-1 Input and Output Diagram

The following tables and graphs are available from the output.

- Reliability Summary, Performance Criteria
- Master Curve
- Shift Factor Curve
- Distress Summary
- Surface Down Cracking – Longitudinal
- Bottom Up Cracking - Alligator
- Thermal Cracking
- Total Rutting
- IRI

Reliability Summary

In case if the parameters chosen are not adequate for the designed pavement, then the performance criteria table will show a FAIL in the acceptable column. In this example all the performance criteria parameters passed.

Table 8-3 Performance Criteria

Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	113	97.11	Pass
AC Surface Down Cracking (Long. Cracking) (ft/mile):	2000	90	15.5	98.4	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0.2	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	0	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture) (%)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.4	90	0.12	99.999	Pass
Permanent Deformation (Total Pavement) (in):	0.75	90	0.42	99.999	Pass

Distress Summary

The distress results are the prediction for the entire design life of the pavement. The results provide predicted monthly longitudinal, transverse and alligator cracking and total rutting and IRI for the entire design life of the pavement. Two year results are listed below. The full results for 20 year design are available in appendix C.

Table 8-4 Predicted Distresses

Pavement age		Month	Longit. Crack. (ft/mi)	Allig. Crack. (%)	Trans. Crack. (ft/mi)	Subtotal AC Rutting (in)	Total Rutting (in)	IRI (in/mi)	Heavy Trucks (cumulative)	IRI at Reliability (in/mi)
Mo	Yr									
1	0.08	December	0	0.0001	0	0	0.085	66.4	5783	90.01
2	0.17	January	0	0.0001	0	0.001	0.101	67.1	11566	90.96
3	0.25	February	0	0.0002	0	0.001	0.114	67.6	17349	91.74
4	0.33	March	0.01	0.0004	0	0.002	0.128	68.2	23133	92.55
5	0.42	April	0.02	0.0007	0	0.003	0.139	68.7	28916	93.24
6	0.5	May	0.05	0.0016	0	0.011	0.162	69.6	34699	94.55
7	0.58	June	0.09	0.0026	0	0.017	0.18	70.4	40482	95.61
8	0.67	July	0.13	0.0037	0	0.024	0.194	71	46265	96.46
9	0.75	August	0.16	0.0047	0	0.028	0.203	71.4	52048	97.04
10	0.83	September	0.2	0.0056	0	0.03	0.209	71.7	57831	97.43
11	0.92	October	0.21	0.0059	0	0.03	0.211	71.8	63614	97.61
12	1	November	0.22	0.006	0	0.03	0.213	71.9	69398	97.75
13	1.08	December	0.22	0.0061	0	0.03	0.214	72	75296	97.88
14	1.17	January	0.22	0.0062	0	0.03	0.215	72.1	81195	98.03
15	1.25	February	0.22	0.0063	0	0.03	0.218	72.2	87094	98.23
16	1.33	March	0.23	0.0065	0	0.03	0.22	72.4	92993	98.41
17	1.42	April	0.25	0.0068	0	0.03	0.221	72.5	98891	98.59
18	1.5	May	0.29	0.0076	0	0.031	0.225	72.7	104790	98.88
19	1.58	June	0.35	0.0086	0	0.034	0.232	73	110689	99.32
20	1.67	July	0.4	0.01	0	0.041	0.242	73.5	116588	100.01
21	1.75	August	0.45	0.011	0	0.042	0.246	73.7	122487	100.32
22	1.83	September	0.48	0.0117	0	0.043	0.249	73.9	128385	100.55
23	1.92	October	0.5	0.012	0	0.043	0.25	74	134284	100.69
24	2	November	0.51	0.0121	0	0.043	0.251	74.1	140183	100.82

Master curve and shift factor plots are presented below. For more details in master curve and shift factor refer to Chapter 3.

Master Curve

Figure 8-2 Master Curve Plot

Shift Factor

Figure 8-4 Shift Curve Plot

Fatigue Cracking

The software predicts the surface down cracking, bottom up cracking for the entire life of the pavement. The tabulated monthly results are in Appendix C. The graphs below are showing surface down and bottom up cracking, thermal cracking, total rutting and IRI.

Figure 8-4 Surface Down Cracking – Longitudinal

Figure 8-5 Bottom Up Cracking - Alligator

Thermal Cracking:

Thermal Cracking: Total Length Vs Time

Figure 8-6 Thermal Cracking: Total Length Vs Time

Total Rutting:

Figure 8-7 Permanent Deformation for Asphalt, Base/Subbae/Subgrade

IRI

Figure 8-8 IRI Results

The output results indicate that the selected designed parameters and the selected default parameters for this project met the required specified limits. None of the distress parameters did exceed the 20 years design life. Therefore, it is safe to say that the pavement design is satisfactory and the pavement can last its 20 year design life. From the results we can also say that different loading and different pavement structure will give us different results for distresses. It is really critical to consider all the necessary parameters such as traffic loading, climate condition, and pavement structure materials when designing flexible pavements. If any data missing or selected incorrectly the software program will not run. The mechanistic-empirical design approach will allow pavement designers to improve design reliability, predict specific failure modes, which can minimize premature failures.

Chapter 9

9.0 IMPLEMENTING THE MECHANISTIC-EMPIRICAL DESIGN GUIDE IN TORONTO, ONTARIO

The City of Toronto maintains a network of about 5,200 centreline-kilometres of roads and over 250 centreline-kilometres of laneways. This pavement infrastructure has been constructed, maintained, and enhanced over more than 100 years. Over the past several decades, fuelled by research and other technological advancements in the pavement engineering field, a gradual shift is being observed in terms of how pavements and pavement materials are designed, tested, evaluated, constructed, and managed. The U.S. National Corporative Highway Research Program (NCHRP) Project 1-37A was awarded to a team led by Applied Research Associates Inc. (ARA) from US and from Toronto, Ontario to develop a new pavement design guide on mechanistic-empirical principals. The implementation of the new design methodology will bring the City of Toronto to the forefront of pavement design technology. The ME PDG will allow the City to effectively evaluate the various design standards used across the City and to consolidate their standards based on mechanistic-empirical design principals and the experience of the City of Toronto.

9.1 Design Guide Inputs

The ME PDG has a number of new inputs that have not been used widely in pavement structural design. The mechanistic element of the analysis requires a series of input values in order to calculate the expected stresses and strains that the pavement is to experience.

9.1.1 Climate

A number of climate files for stations spotted across the US were made available with the software. Unfortunately no climate data information is provided for Canadian cities. Although information is available for locations in New York state, Detroit, Michigan that are similar to those of the City of Toronto.

The hourly climate information is fed into the Enhanced Integrated Climatic Model (EICM) to calculate the conditions of all of the pavement layers at the time of various loading. This information can be obtained through Environment Canada. Weather station data can be used from Pearson International Airport, Buttonville Airport and, Toronto Island Airport and Toronto City Centre. In total, over 40 years of complete climate data is available from these four stations. Not all stations, however, collected all of the required climate parameters.

9.1.2 Traffic Data Inputs

The traffic information used for the Toronto roads was split into four main categories based on functional classification including major arterial, minor arterial, collector, and local roadways. Vehicular volumes were based on functional classification and traffic data count data. City records indicate volumes based on cars, trucks and buses. Commercial vehicle distributions were assumed for various land-use and truck restriction criteria and based on vehicle observed.

9.1.3 Pavement Material Characteristics

The ME PDG uses a far more advanced methodology for predicting the performance and behavior of the pavement structure than any of its predecessors. Material test data collected by the City, supplemented with engineering assumptions and mechanistic properties, such as, modulus values, etc, were used to develop the necessary design inputs for the ME PDG.

9.1.4 Field Performance Data Collection Procedure

The key component of the local calibration is the collection of representative field data that can be used to describe typical pavement performance. The condition survey data collection in the field was designed such that collection of current conditions of flexible pavements for a variety of functional classes and ages would yield a view of the historic performance of the entire network. This was accomplished through the use of 64 field test locations.

The field survey was conducted to collect the key distresses that are used on the ME PDG to measure the service life of a pavement. These surface condition parameters were collected on the form in which they are predicted in ME PDG. The performance parameters that were examined are:

- Alligator Cracking (% of Area)
- Longitudinal Wheel Path Cracking (m/km)
- Transverse Cracking (m/km)
- Rutting (mm)
- International Roughness Index (m/km)

In addition of to the field calibration data collected as part of the research, historic data available from the Toronto Municipal Pavement Management Application (MPMA) system was reviewed. The MPMA distress data collected was based on the qualitative severity and extent ranges of individual distresses rather than specific quantities for each severity level.

9.2 Recommendations for the Implementation of the ME PDG by Canadian Roadway Agencies

Based on the review of current practices of Canadian roadway agencies and requirements to implement the ME PDG, the following tasks/agency requirements will be needed.

1. Canadian cities and agencies implementing the ME PDG will require participation by many agency staff, not just pavement designers. These will likely include staff from various central office and district/region groups associated with the pavement design, traffic, materials, construction, and pavement management.
2. Activities necessary for successful implementation include the following:
 - a. Development of a well-articulated and effective agency implementation plan that unifies units within the agency for the successful use of the new design procedure.
 - b. Training of agency staff in ME concepts and principles.
3. Criteria for judging the progress and consequences of implementation are as follows:
 - a. Establishment of a local agency Steering Committee to guide the implementation of the new design procedure.
 - b. Allocation of resources sufficient to implement the new design procedure.
 - c. Making the necessary time available by key individuals in the agency to spend on the implementation.
4. Costs on implementation of the new design procedure will include the following:
 - a. Purchase of new laboratory and field equipment.
 - b. Training for staff in the new design procedure.
 - c. Computer hardware and software costs.
 - d. Sponsorship of research/expertise projects to be completed by university/private sector groups for development of specific procedures and appropriate input data and calibration/validation of the ME PDG models.
 - e. Additional time required by various key agency staff for the implementation process.
5. Specific focus areas for Canadian roadway agencies include:
 - a. Local calibration and validation of the distress models:

1. Establishing a database of projects.
 2. Input guidelines for local conditions, materials and traffic.
 3. Adjusting distress and IRI models to fit the agency observed performance.
- b. Collection of traffic information including:
1. Axle load spectra.
 2. Vehicle lane distribution.
 3. Monthly and hourly vehicle volume variations.
 4. Tire pressures.
- c. Collection of pavement and subgrade material properties including:
1. Asphalt concrete dynamic modulus.
 2. Portland cement concrete modulus of elasticity, heat capacity and thermal conductivity.
 3. Unbound material and subgrade resilient modulus.
 4. Backcalculated subgrade and pavement layer modulus values for rehabilitation design.
- d. Establishment of the environmental data necessary to run the Enhanced Integrated Climate Model for Canadian locations.

Chapter 10

10.0 CONCLUSIONS

The Guide for the Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures incorporated a mechanistic-empirical design approach that will allow pavement engineers to improve design reliability, predict specific failures modes (which minimize premature failures), better characterize seasonal/drainage effects and reduce overall life cycle costs.

There are many other specific input parameters and the Design Guide calculated values that are used to characterize pavement materials for design. The mechanistic-empirical design procedures will allow the designer to evaluate the effect of variation in materials (both inherent and due to construction procedures) on pavement performances. However, as presented in this paper, the mechanistic principles will require more comprehensive input data which, in turn will require more comprehensive test data.

There are still a few challenges in adopting the mechanistic-base approach. Distress models are the weak point in the M-E design. Extensive field calibration and verification are required to establish reliable distress prediction models, something that is not easy to achieve. A major credibility gap in M-E design procedures is the magnitude of the sift factors between predicted and observed pavement distress and performance. Another complicating factor is the sufficiency and correctness of the input traffic data. The procedures used to estimate traffic data do not reflect a reliable methodology or procedure. Another main issue is the need for financial funds to fully implement the M-E design procedure. Most state highway authorities and Canadian highway authorities at this time do not have the necessary personnel, time, and financial resources to support a large-scale M-E implementation program. Both he state highway authorities and Canadian highway authorities, at the same time, do not have

adequate available flexible pavement data and information to support M-E verification and calibration activities

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Appendix A

Material Property Input Requirements

Primary Material Property Input Requirements

Material	Required Information
Hot Mix Asphalt	<ul style="list-style-type: none"> • Dynamic modulus • Poisson's ratio • Tensile strength • Coefficient of thermal expansion • Creep compliance • Thermal conductivity • Asphalt binder stiffness • Aggregate properties
Portland Cement Concrete	<ul style="list-style-type: none"> • Modulus of elasticity • Poisson's ratio • Unit weight • Coefficient of thermal expansion • Mix properties (aggregate blend, w/c ratio, compressive strength, etc.) • Aggregate type • Thermal conductivity • Heat capacity
Chemically Stabilized Material	<ul style="list-style-type: none"> • Elastic Modulus • Poisson's ratio • Unit weight • Modulus of rupture • Thermal conductivity • Heat capacity
Unbound Material	<ul style="list-style-type: none"> • Resilient modulus • Poisson's ratio • Unit weight • Gradation • Hydraulic conductivity • Optimum moisture content • Plasticity index
Recycled Concrete	<ul style="list-style-type: none"> • Resilient modulus • Poisson's ratio • Thermal conductivity • Heat capacity
Recycled Hot Mix	<ul style="list-style-type: none"> • Dynamic modulus • Poisson's ratio • Tensile strength • Coefficient of thermal expansion • Creep compliance • Thermal conductivity • Asphalt binder stiffness • Aggregate properties

Material	Required Information
Recycled Cold Mix Asphalt	<ul style="list-style-type: none"> • Dynamic Modulus • Poisson's ratio • Tensile strength • Coefficient of thermal expansion • Creep compliance • Thermal conductivity • Asphalt binder stiffness • Aggregate properties
Recycled Asphalt pavement	<ul style="list-style-type: none"> • Resilient modulus • Poisson's ratio • Unit weight • Gradation • Hydraulic conductivity • Optimum moisture content • Plasticity index
Bedrock	<ul style="list-style-type: none"> • Elastic modulus • Poisson's ratio • Unit weight

Appendix B

Vehicle/Truck Class Distribution Table

TTC Group	TTC Description	Vehicle/Truck Class Distribution (percent)										
		4	5	6	7	8	9	10	11	12	13	
1	Major Single-trailer truck route (type I)	1.3	8.5	2.8	0.3	7.6	74.0	1.2	3.4	0.6	0.3	
2	Major Single-trailer truck route (type II)	2.4	14.1	4.5	0.7	7.9	66.3	1.4	2.2	0.3	0.2	
3	Major single-and multi-trailer truck route (type I)	0.9	11.6	3.6	0.2	6.7	62.0	4.8	2.6	1.4	6.2	
4	Major single-trailer truck route (type III)	2.4	22.7	5.7	1.4	8.1	55.5	1.7	2.2	0.2	0.4	
5	Major single-and multi-trailer truck route (I)	0.9	14.2	3.5	0.6	6.9	54.0	5.0	2.7	1.2	11.0	
6	Intermediate light and single-trailer truck route (I)	2.8	31.0	7.3	0.8	9.3	44.8	2.3	1.0	0.4	0.3	
7	Major mixed truck route (Type I)	1.0	23.8	4.2	0.5	10.2	42.2	5.8	2.6	1.3	8.4	
8	Major multi-trailer truck route (Type I)	1.7	19.3	4.6	0.9	6.7	44.8	6.0	2.6	1.6	11.8	
9	Intermediate light and single-trailer truck route (II)	3.3	34.0	11.7	1.6	9.9	36.2	1.0	1.8	0.2	0.3	
10	Major mixed truck route (Type II)	0.8	30.8	6.9	0.1	7.8	37.5	3.7	1.2	4.5	6.7	
11	Major multi-trailer truck route (Type II)	1.8	24.6	7.6	0.5	5.0	31.3	9.8	0.8	3.3	15.3	
12	Intermediate light and single-trailer truck route (III)	3.9	40.8	11.7	1.5	12.2	25.0	2.7	0.6	0.3	1.3	
13	Major mixed truck route (Type III)	0.8	33.6	6.2	0.1	7.9	26.0	10.5	1.4	3.2	10.3	
14	Major light truck route (Type I)	2.9	56.9	10.4	3.7	9.2	15.3	0.6	0.3	0.4	0.3	
15	Major light truck route (Type II)	1.8	56.5	8.5	1.8	6.2	14.1	5.4	0.0	0.0	5.7	
16	Major light and multi-trailer truck route	1.3	48.4	10.8	1.9	6.7	13.4	4.3	0.5	0.1	12.6	
17	Major bus route	36.2	14.6	13.4	0.5	14.6	17.8	0.5	0.8	0.1	1.5	

Appendix C

Input Information

Climate Summary

Reliability Summary

Subseason Layer Modulus

Predicted Distress

Fatigue Cracking

Asphalt Sub-layers Modulus Vs Time

Surface Down Cracking, Bottom Up Damage for Alligator Cracking

Bottom Up Cracking, Thermal Cracking, Transverse Crack Spacing

Thermal Cracking

Predicted Rutting

Permanent Deformation: Rutting

IRI

Master Curve Tables and Graphs

Shift Curve Tables and Graphs

Viscosity Tables and Graphs

Project: Ryerson.dgp

General Information

Design Life	20 years
Base/Subgrade construction:	June, 2008
Pavement construction:	September, 2008
Traffic open:	December, 2008
Type of design	Flexible

Description:

Analysis Parameters

Performance Criteria

	Limit	bility
Initial IRI (in/mi)	63	
Terminal IRI (in/mi)	172	90
AC Surface Down Cracking (Long. Cracking) (ft/mile):	2000	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):	0.4	90
Permanent Deformation (Total Pavement) (in):	0.75	90
Reflective cracking (%):	100	

Location:	Sheldon Drive
Project ID:	10-10
Section ID:	15+100

Date:	2/3/2008
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Station/milepost format:	Feet: 00 + 00
Station/milepost begin:	1+000
Station/milepost end:	4+000
Traffic direction:	East bound

Default Input Level

Default input level	Level 3, Default and selected values for this project.
---------------------	--

Traffic

Designed for this project	
Initial two-way AADTT:	400
Number of lanes in design direction:	2
Percent of trucks in design direction (%):	50
Percent of trucks in design lane (%):	95
Operational speed (mph):	50

Traffic -- Volume Adjustment Factors

Monthly Adjustment Factors (Level 3, Default MAF)

Month	Vehicle Class									
	4	5	6	7	8	9	10	11	12	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

Designed for this Project.

AADTT distribution by vehicle class

Class 4	1.8%
Class 5	34.6%
Class 6	14.6%
Class 7	10.0%
Class 8	10.5%
Class 9	9.3%
Class 10	9.8%
Class 11	0.8%
Class 12	3.3%
Class 13	5.3%

Hourly truck traffic

by period beginning:

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

Traffic Growth Factor

Designed for this Project.

Vehicle Class	Growth Rate	Growth Function
Class 4	2.0%	Compound
Class 5	2.0%	Compound
Class 6	2.0%	Compound
Class 7	2.0%	Compound
Class 8	2.0%	Compound
Class 9	2.0%	Compound
Class 10	2.0%	Compound
Class 11	2.0%	Compound
Class 12	2.0%	Compound
Class 13	2.0%	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	Tridem	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

Tire Pressure (psi) : 120

Average Axle Spacing

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

Climate

icm file:

C:\DG2002\Projects\ChicagoEdens.icm

Latitude (degrees.minutes) 41.47
Longitude (degrees.minutes) -87.45
Elevation (ft) 616
Depth of water table (ft) 10

Structure--Design Features

HMA E* Predictive Model: NCHRP 1-37A viscosity based

HMA Rutting Model
Endurance Limit (microstrain):

NCHRP 1-37A coefficients
None (0 microstrain)

Structure--Layers

Layer 1 -- Asphalt concrete

Designed for this Project:

Material type: Asphalt concrete
Layer thickness (in): 6

General Properties

General

Reference temperature (F°): 70

Volumetric Properties as Built

Effective binder content (%): 5.2
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 5
Cumulative % Retained 3/8 inch 15
Cumulative % Retained #4 sieve: 50
% Passing #200 sieve: 5

Asphalt Binder

Option: Superpave binder grading
A 11.0100 (correlated)
VTS: -3.7010 (correlated)

High temp. °C	Low temperature, °C						
	-10	-16	-22	-28	-34	-40	-46
46							
52							
58							
64							
70							
76							
82							

Thermal Cracking Properties

Average Tensile Strength at 14°F:	456.16
Mixture VMA (%)	14.5
Aggreagate coeff. thermal contraction (in./in.)	0.000005
Mix coeff. thermal contraction (in./in./°F):	0.000013

Load Time (sec)	Low Temp. -4°F (1/psi)	Mid. Temp. 14°F (1/psi)	High Temp. 32°F (1/psi)
1	2.3E-07	3E-07	5E-07
2	2.6E-07	4E-07	6E-07
5	3E-07	5E-07	9E-07
10	3.3E-07	6E-07	1E-06
20	3.6E-07	7E-07	2E-06
50	4.2E-07	9E-07	2E-06
100	4.6E-07	1E-06	3E-06

Layer 2 -- Crushed stone

Unbound Material:	Crushed stone
Thickness(in):	24

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):	30000

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	1
Liquid Limit (LL)	6
Compacted Layer	No
Passing #200 sieve (%):	8.7
Passing #4 sieve (%):	44.7
D10(mm)	0.1035
D20(mm)	0.425
D30(mm)	1.306
D60(mm)	10.82
D90(mm)	46.19

Sieve	Percent
0.001mm	
0.002mm	
0.020mm	
#200	8.7
#100	
#80	12.9
#60	
#50	
#40	20
#30	
#20	
#16	
#10	33.8
#8	
#4	44.7
3/8"	57.2
1/2"	63.1
3/4"	72.7
1"	78.8
1 1/2"	85.8
2"	91.6
2 1/2"	
3"	
3 1/2"	97.6
4"	97.6

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	127.2 (derived)
Specific gravity of solids, Gs:	2.70 (derived)
Saturated hydraulic conductivity (ft/hr):	0.05054 (derived)
Optimum gravimetric water content (%):	7.4 (derived)
Calculated degree of saturation (%):	61.2 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	7.2555
b	1.3328
c	0.8242
Hr.	117.4

Layer 3 -- 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

ICM Inputs

Gradation and Plasticity Index

Plasticity Index, PI:	19
Liquid Limit (LL)	37
Compacted Layer	No
Passing #200 sieve (%):	50
Passing #40	83.3
Passing #4 sieve (%):	94
D10(mm)	0.0003758
D20(mm)	0.001413
D30(mm)	0.005309
D60(mm)	0.1091
D90(mm)	1.695

Sieve	Percent
0.001mm	
0.002mm	
0.020mm	
#200	50
#100	
#80	77.7
#60	
#50	
#40	83.3
#30	
#20	
#16	
#10	90.8
#8	
#4	94
3/8"	95.7
1/2"	96.3
3/4"	97.3
1"	97.9
1 1/2"	98.4
2"	98.8
2 1/2"	
3"	
3 1/2"	99.3
4"	99.3

Calculated/Derived Parameters

Maximum dry unit weight (pcf):	110.8 (derived)
Specific gravity of solids, Gs:	2.70 (derived)
Saturated hydraulic conductivity (ft/hr):	1.374e-005 (derived)
Optimum gravimetric water content (%):	15.6 (derived)
Calculated degree of saturation (%):	81.0 (calculated)

Soil water characteristic curve parameters: Default values

Parameters	Value
a	106.36
b	0.6937
c	0.2296
Hr.	500

Distress Model Calibration Settings - Flexible

AC Fatigue

Level 3: NCHRP 1-37A coefficients
(nationally calibrated values)

k1	0.0076
k2	3.9492
k3	1.281

AC Rutting

Level 3: NCHRP 1-37A coefficients
(nationally calibrated values)

k1	-3.354
k2	1.5606
k3	0.4791

Standard Deviation Total
Rutting (RUT): $0.24 * \text{POWER}(\text{RUT}, 0.8026) + 0.001$

Thermal Fracture

Level 3: NCHRP 1-37A coefficients
(nationally calibrated values)

k1	1.5
----	-----

Std. Dev. (THERMAL): $0.1468 * \text{THERMAL} + 65.027$

CSM Fatigue

Level 3: NCHRP 1-37A coefficients
(nationally calibrated values)

k1	1
k2	1

Subgrade Rutting Granular:

Level 3: NCHRP 1-37A coefficients
(nationally calibrated values)

k1	2.03
----	------

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) $200 + 2300 / (1 + \exp(1.072 - 2.1654 * \log(\text{TOP} + 0.0001)))$

AC Bottom Up Cracking

C1 (bottom)	1
C2 (bottom)	1
C3 (bottom)	0
C4 (bottom)	6000

Standard Deviation (TOP) $1.13 + 13 / (1 + \exp(7.57 - 15.5 * \log(\text{BOTTOM} + 0.0001)))$

CSM Cracking

C1 (CSM)	1
C2 (CSM)	1
C3 (CSM)	0
C4 (CSM)	1000

Standard Deviation (CSM) CTB*1

IRI

IRI HMA Pavements New

C1(HMA)	40
C2(HMA)	0.4
C3(HMA)	0.008
C4(HMA)	0.015

IRI HMA/PCC Pavements

C1(HMA/PCC)	40.8
C2(HMA/PCC)	0.575
C3(HMA/PCC)	0.0014
C4(HMA/PCC)	0.0083

Climate Summary

Climate Station File:

C:\DG2002\Projects\ChicagoEdens.icm

Climate station(s) used in analysis:

0.0 miles CHICAGO, IL - CHICAGO MIDWAY INTL ARPT Lat. 41.47 Lon. -87.45 Ele. 619 Months: 106 (C)

16.3 miles CHICAGO, IL - O'HARE INTERNATIONAL ARPT Lat. 41.59 Lon. -87.55 Ele. 658 Months: 116 (C)

24.3 miles CHICAGO/PROSPECT HGTS/WHEELING, IL - PALWAUKEE MUNICIPAL ARPT Lat. 42.07 Lon. -87.54 Ele. 644

27.3 miles CHICAGO/WEST CHICAGO, IL - DUPAGE AIRPORT Lat. 41.55 Lon. -88.15 Ele. 758 Months: 105 (C)

37.8 miles CHICAGO/AURORA, IL - AURORA MUNICIPAL AIRPORT Lat. 41.46 Lon. -88.29 Ele. 709 Months: 89 (C)

44.1 miles CHICAGO/WAUKEGAN, IL - WAUKEGAN REGIONAL AIRPORT Lat. 42.25 Lon. -87.52 Ele. 735 Months: 78 (C)

Average Monthly Quintile Temperatures - Surface

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	15.8	24.7	29.5	33.9	41.1	29	9
February	23.4	31.1	36.1	41	49.9	36.3	9.5
March	28.1	36.3	42.2	49.3	61.5	43.5	12
April	40.6	49.1	55.6	64.1	79.1	57.7	13.8
May	51.7	60.7	67.9	76.2	89.8	69.3	13.6
June	60	69.9	77	86.4	99.4	78.5	14.1
July	68.3	75.4	82.2	91.6	103	84.1	12.6
August	66.1	72.5	78.4	87.1	99	80.6	11.9
September	56	64.6	71.3	79.5	94.4	73.1	13.8
October	43.2	51.7	58	65	77.6	59.1	12.3
November	33.3	40.6	45.9	51.5	60.6	46.4	9.8
December	20.3	28.1	33.5	38.5	46.6	33.4	9.4

Average Monthly Quintile Temperatures - Sublayer 1

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	16.2	24.9	29.6	33.8	40.8	29.1	8.7
February	23.7	31.2	36.1	40.9	49.3	36.3	9.2
March	28.5	36.5	42.3	49.1	60.8	43.4	11.6
April	41.1	49.5	55.7	63.9	78.2	57.7	13.3
May	52.3	61	68	75.9	88.9	69.2	13.1
June	60.5	70.2	77.2	86	98.5	78.5	13.5
July	68.9	75.9	82.3	91.1	102.1	84.1	12
August	66.7	72.9	78.6	86.7	98.1	80.6	11.4
September	56.6	65.1	71.6	79.3	93.4	73.2	13.2
October	43.7	52	58.1	64.9	76.9	59.1	11.9
November	33.7	40.8	46	51.5	60.2	46.4	9.5
December	20.8	28.3	33.6	38.4	46.3	33.5	9.1

Average Monthly Quintile Temperatures - Sublayer 2

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	17.1	25.1	29.6	33.6	40.1	29.1	8.2
February	24.5	31.5	36.1	40.5	48.3	36.2	8.5
March	29.3	36.9	42.3	48.7	59.5	43.4	10.9
April	41.9	50.1	55.9	63.4	76.6	57.6	12.4
May	53.2	61.6	68.1	75.3	87.2	69.1	12.1
June	61.3	70.7	77.4	85.3	96.8	78.3	12.6
July	70	76.7	82.5	90.3	100.3	84	11
August	67.7	73.7	78.9	86	96.4	80.6	10.3
September	57.6	65.8	71.9	78.9	91.7	73.2	12.2
October	44.6	52.6	58.3	64.7	75.7	59.2	11.2
November	34.5	41.3	46.1	51.4	59.4	46.5	8.9
December	21.7	28.7	33.6	38.3	45.7	33.6	8.6

Average Monthly Quintile Temperatures - Sublayer 3

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	18.2	25.5	29.7	33.4	39.2	29.2	7.5
February	25.4	31.8	36.1	40.1	46.8	36.1	7.7
March	30.2	37.2	42.3	48.2	57.8	43.2	9.9
April	42.9	50.8	56.1	62.9	74.5	57.4	11.3
May	54.5	62.3	68.3	74.6	85	68.9	10.9
June	62.5	71.3	77.6	84.5	94.6	78.1	11.4
July	71.4	77.7	82.8	89.2	98	83.8	9.5
August	69.1	74.7	79.3	85.1	94.2	80.5	9
September	59	66.7	72.4	78.5	89.5	73.2	10.9
October	45.8	53.2	58.6	64.5	74.2	59.3	10.2
November	35.5	41.8	46.4	51.3	58.5	46.7	8.3
December	22.8	29.2	33.7	38.1	45	33.8	7.9

Average Monthly Quintile Temperatures - Sublayer 4

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	19.5	25.9	29.7	33.1	38.4	29.3	6.7
February	26.5	32.2	36	39.5	45.3	35.9	6.8
March	31.3	37.6	42.3	47.7	56	43	8.9
April	44.1	51.5	56.3	62.2	72.2	57.3	10
May	55.8	63	68.4	73.8	82.6	68.7	9.5
June	63.7	71.8	77.8	83.6	92.1	77.8	10.1
July	73	78.7	82.9	88	95.4	83.6	8
August	70.6	75.7	79.7	84.3	91.8	80.4	7.6
September	60.5	67.8	72.9	78	87.2	73.3	9.5
October	47.1	53.9	58.9	64.3	72.7	59.4	9.2
November	36.7	42.4	46.7	51.2	57.6	46.9	7.5
December	24.2	29.8	33.9	38	44.3	34	7.2

Average Monthly Quintile Temperatures - Sublayer 5

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	20.7	26.2	29.7	32.9	37.7	29.5	6.1
February	27.4	32.4	35.9	39	44	35.7	6
March	32.2	37.7	42.2	47.2	54.7	42.8	8.2
April	44.9	51.9	56.4	61.7	70.5	57.1	9.1
May	56.8	63.4	68.3	73.1	80.7	68.5	8.5
June	64.5	72.2	77.9	82.9	90.2	77.5	9.2
July	74.1	79.4	83	87.1	93.4	83.4	6.8
August	71.8	76.4	79.8	83.6	90	80.3	6.5
September	61.8	68.5	73.1	77.7	85.4	73.3	8.4
October	48.2	54.5	59.2	64.2	71.7	59.6	8.4
November	37.6	42.9	46.9	51.2	57	47.1	7
December	25.4	30.3	34	37.9	43.9	34.3	6.6

Average Monthly Quintile Temperatures - Sublayer 6

Month	1st Quintile (°F)	2nd Quintile (°F)	3rd Quintile (°F)	4th Quintile (°F)	5th Quintile (°F)	Mean Temp. (°F)	Std. Dev. (°F)
January	22.2	26.6	29.6	32.8	37.1	29.7	5.4
February	28.3	32.5	35.7	38.3	42.7	35.5	5.3
March	33	37.7	42	46.7	53.2	42.5	7.4
April	45.8	52.3	56.4	61	68.7	56.8	8.1
May	57.8	63.7	68	72.4	78.8	68.2	7.5
June	65.3	72.3	77.7	82.2	88.3	77.1	8.3
July	75.3	79.9	82.9	86.2	91.2	83.1	5.7
August	73	77	79.9	83	88.1	80.2	5.4
September	63	69.2	73.3	77.4	83.9	73.4	7.4
October	49.4	55.1	59.3	64.1	70.7	59.7	7.7
November	38.7	43.4	47.2	51.2	56.5	47.4	6.4
December	27	31	34.1	37.8	43.4	34.7	5.9

Annual Climate Statistics

Mean annual air temperature (°F):	52.42
Mean annual rainfall (in):	30.55
Freezing index (°F-days):	564.09
Average Annual Number of Freeze/Thaw Cycles:	48

Monthly Rainfall Statistics

Month	Mean Rainfall (in)	Std. Dev. (in)
January	1.26	0.9
February	1.83	1.12
March	3.16	1.48
April	4.07	1.71
May	3.56	1.2
June	3.19	1.82
July	3.77	1.25
August	2.1	1
September	2.44	1.4
October	2.24	1.6
November	1.55	0.47

Project: Ryerson.dgp

Reliability Summary

Performance Criteria	Distress Target	Reliability Target	Distress Predicted	Reliability Predicted	Acceptable
Terminal IRI (in/mi)	172	90	113	97.11	Pass
AC Surface Down Cracking (Long. Cracking) (ft/mile):	2000	90	15.5	98.4	Pass
AC Bottom Up Cracking (Alligator Cracking) (%):	25	90	0.2	99.999	Pass
AC Thermal Fracture (Transverse Cracking) (ft/mi):	1000	90	0	99.999	Pass
Chemically Stabilized Layer (Fatigue Fracture)	25	90			N/A
Permanent Deformation (AC Only) (in):	0.4	90	0.12	99.999	Pass
Permanent Deformation (Total Pavement) (in):	0.75	90	0.42	99.999	Pass

Subseason Layer Modulus: Project Ryerson.dgp

Pavement age		Modulus (psi)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
		ACI (1) h=0.5					ACI (2) h=0.5					ACI (3) h=1.0					GB2 (7) h=2.0		GB2 (8) h=4.0		GB2 (9) h=4.0		GB2 (10) h=4.0																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
mo	yr	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														</

128	10.7	July	2E+06	2E+06	2E+06	1E+06	893585	637104	1E+06	1E+06	1E+06	732825	532477	1E+06	835970	636094	474784	42360	42090	41700	41310
129	10.8	August	2E+06	2E+06	1E+06	1E+06	863040	566873	2E+06	1E+06	1E+06	706732	472030	1E+06	808943	610348	427990	42060	41820	41490	41130
130	10.8	September	4E+06	3E+06	2E+06	2E+06	1E+06	706907	3E+06	2E+06	2E+06	1E+06	594239	3E+06	2E+06	853303	536273	42060	41820	41460	41070
131	10.9	October	4E+06	4E+06	3E+06	3E+06	2E+06	1E+06	2E+06	3E+06	3E+06	2E+06	1E+06	3E+06	3E+06	2E+06	992566	42390	42120	41730	41340
132	11	November	4E+06	4E+06	4E+06	4E+06	4E+06	2E+06	3E+06	3E+06	3E+06	3E+06	2E+06	3E+06	3E+06	3E+06	2E+06	42210	41970	41670	41310
133	11.1	December	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	46380	45420	47460	42120
134	11.2	January	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	87690	118860	190740	106680
135	11.3	February	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	57720	36660	22620	22140
136	11.3	March	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	20850	19320	22500	27300
137	11.4	April	4E+06	4E+06	3E+06	3E+06	2E+06	1E+06	3E+06	3E+06	3E+06	2E+06	949057	3E+06	3E+06	3E+06	2E+06	22560	26010	29880	34440
138	11.5	May	4E+06	3E+06	2E+06	2E+06	1E+06	832838	3E+06	2E+06	2E+06	1E+06	700486	3E+06	2E+06	1E+06	633512	29160	32490	36120	39660
139	11.6	June	3E+06	2E+06	1E+06	1E+06	889638	532901	3E+06	2E+06	2E+06	1E+06	723088	441575	3E+06	1E+06	896645	616584	398635	36150	40860
140	11.7	July	2E+06	1E+06	1E+06	1E+06	748166	509570	2E+06	1E+06	8E+05	608900	422262	1E+06	870322	693111	526182	37548	41520	42300	41490
141	11.8	August	2E+06	2E+06	1E+06	1E+06	862850	548141	2E+06	1E+06	9E+05	706237	453478	1E+06	980454	767954	601932	402689	42720	42450	41760
142	11.8	September	4E+06	3E+06	2E+06	2E+06	1E+06	773609	3E+06	2E+06	2E+06	1E+06	650601	3E+06	2E+06	1E+06	586550	42060	41880	41580	41280
143	11.9	October	4E+06	4E+06	3E+06	3E+06	3E+06	2E+06	3E+06	3E+06	3E+06	2E+06	1E+06	3E+06	3E+06	3E+06	2E+06	41280	41100	40800	40470
144	12	November	4E+06	4E+06	4E+06	4E+06	4E+06	2E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	40290	40110	39810	39450
145	12.1	December	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	40620	40260	39780	39270
146	12.2	January	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	39900	32850	28650	41640
147	12.3	February	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	24570	21750	27150	40170
148	12.3	March	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	25680	24000	26070	40380
149	12.4	April	4E+06	4E+06	4E+06	4E+06	3E+06	1E+06	3E+06	3E+06	3E+06	2E+06	982583	3E+06	3E+06	2E+06	876708	22830	24270	28080	40170
150	12.5	May	4E+06	4E+06	3E+06	3E+06	2E+06	990160	3E+06	3E+06	3E+06	2E+06	840714	3E+06	3E+06	2E+06	1E+06	30540	33270	40110	40110
151	12.6	June	3E+06	2E+06	1E+06	1E+06	858476	514252	2E+06	1E+06	1E+06	699392	426087	2E+06	1E+06	829560	600853	382214	35460	36750	40080
152	12.7	July	2E+06	1E+06	1E+06	1E+06	691645	459706	1E+06	999963	8E+05	560818	377626	1E+06	786824	632885	481613	337359	40140	40500	39780
153	12.8	August	2E+06	2E+06	1E+06	1E+06	826683	555098	2E+06	1E+06	9E+05	672445	459260	1E+06	968904	749424	579650	410716	41400	41070	40140
154	12.8	September	3E+06	2E+06	2E+06	2E+06	1E+06	589490	3E+06	2E+06	1E+06	870627	496476	2E+06	1E+06	995120	741038	450632	41730	41010	40560
155	12.9	October	4E+06	4E+06	4E+06	4E+06	4E+06	1E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	2E+06	42360	42060	41640	41190
156	13	November	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	43140	42720	42240	41790
157	13.1	December	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	31410	29010	43920	43140
158	13.2	January	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	28500	33210	42300	42660
159	13.3	February	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	167490	233250	554160	267690
160	13.3	March	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	76710	90420	62760	29730
161	13.4	April	4E+06	4E+06	4E+06	4E+06	3E+06	1E+06	3E+06	3E+06	3E+06	2E+06	1E+06	3E+06	3E+06	3E+06	2E+06	24840	24540	24120	24000
162	13.5	May	4E+06	4E+06	3E+06	3E+06	2E+06	1E+06	3E+06	3E+06	3E+06	2E+06	946500	3E+06	3E+06	2E+06	1E+06	31140	30720	30570	30570
163	13.6	June	3E+06	2E+06	2E+06	2E+06	1E+06	658583	3E+06	2E+06	1E+06	924619	554513	3E+06	2E+06	1E+06	795359	502070	37080	36720	36570
164	13.7	July	2E+06	2E+06	1E+06	1E+06	847916	574236	2E+06	1E+06	1E+06	695838	475863	1E+06	1E+06	792720	599986	429208	42180	41760	41430
165	13.8	August	2E+06	2E+06	1E+06	1E+06	854627	570763	2E+06	1E+06	1E+06	695844	474397	1E+06	991910	790004	597490	424683	41250	41130	40650
166	13.8	September	4E+06	3E+06	2E+06	2E+06	1E+06	758405	3E+06	2E+06	2E+06	1E+06	636524	3E+06	2E+06	1E+06	949976	577606	41670	40950	40500
167	13.9	October	4E+06	4E+06	4E+06	4E+06	4E+06	1E+06	3E+06	3E+06	3E+06	3E+06	1E+06	3E+06	3E+06	3E+06	2E+06	41340	41100	40740	40380
168	14	November	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	41400	41100	40710	40290
169	14.1	December	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	37680	38160	40200	39840
170	14.2	January	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	45540	39300	31680	40200
171	14.3	February	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	999990	999990	999990	999990

Predicted distress: Project Ryerson.dgp

Pavement age		Month	Longit. Crack. (ft/mi)	Allig. Crack. (%)	Trans. Crack. (ft/mi)	Subtotal AC Rutting (in)	Total Rutting (in)	IRI (in/mi)	Heavy Trucks (cumulative)	IRI at Reliability (in/mi)
mo	yr									
1	0.08	December	0	0.0001	0	0	0.085	66.4	5783	90.01
2	0.17	January	0	0.0001	0	0.001	0.101	67.1	11566	90.96
3	0.25	February	0	0.0002	0	0.001	0.114	67.6	17349	91.74
4	0.33	March	0.01	0.0004	0	0.002	0.128	68.2	23133	92.55
5	0.42	April	0.02	0.0007	0	0.003	0.139	68.7	28916	93.24
6	0.5	May	0.05	0.0016	0	0.011	0.162	69.6	34699	94.55
7	0.58	June	0.09	0.0026	0	0.017	0.18	70.4	40482	95.61
8	0.67	July	0.13	0.0037	0	0.024	0.194	71	46265	96.46
9	0.75	August	0.16	0.0047	0	0.028	0.203	71.4	52048	97.04
10	0.83	September	0.2	0.0056	0	0.03	0.209	71.7	57831	97.43
11	0.92	October	0.21	0.0059	0	0.03	0.211	71.8	63614	97.61
12	1	November	0.22	0.006	0	0.03	0.213	71.9	69398	97.75
13	1.08	December	0.22	0.0061	0	0.03	0.214	72	75296	97.88
14	1.17	January	0.22	0.0062	0	0.03	0.215	72.1	81195	98.03
15	1.25	February	0.22	0.0063	0	0.03	0.218	72.2	87094	98.23
16	1.33	March	0.23	0.0065	0	0.03	0.22	72.4	92993	98.41
17	1.42	April	0.25	0.0068	0	0.03	0.221	72.5	98891	98.59
18	1.5	May	0.29	0.0076	0	0.031	0.225	72.7	104790	98.88
19	1.58	June	0.35	0.0086	0	0.034	0.232	73	110689	99.32
20	1.67	July	0.4	0.01	0	0.041	0.242	73.5	116588	100.01
21	1.75	August	0.45	0.011	0	0.042	0.246	73.7	122487	100.32
22	1.83	September	0.48	0.0117	0	0.043	0.249	73.9	128385	100.55
23	1.92	October	0.5	0.012	0	0.043	0.25	74	134284	100.69
24	2	November	0.51	0.0121	0	0.043	0.251	74.1	140183	100.82
25	2.08	December	0.51	0.0122	0	0.043	0.251	74.2	146200	100.95
26	2.17	January	0.51	0.0123	0	0.043	0.252	74.3	152216	101.08
27	2.25	February	0.52	0.0124	0	0.043	0.253	74.4	158233	101.23
28	2.33	March	0.54	0.0127	0	0.043	0.254	74.5	164250	101.39
29	2.42	April	0.56	0.013	0	0.043	0.255	74.6	170267	101.55
30	2.5	May	0.62	0.0137	0	0.044	0.257	74.7	176284	101.75
31	2.58	June	0.67	0.0145	0	0.045	0.259	74.9	182300	102
32	2.67	July	0.72	0.0155	0	0.047	0.262	75.1	188317	102.28
33	2.75	August	0.78	0.0165	0	0.048	0.266	75.3	194334	102.58
34	2.83	September	0.83	0.0172	0	0.049	0.268	75.5	200351	102.79
35	2.92	October	0.85	0.0176	0	0.049	0.268	75.6	206367	102.94
36	3	November	0.86	0.0177	0	0.049	0.269	75.7	212384	103.07
37	3.08	December	0.86	0.0177	0	0.049	0.269	75.8	218521	103.19
38	3.17	January	0.86	0.0178	0	0.049	0.269	75.9	224658	103.34
39	3.25	February	0.86	0.0179	0	0.049	0.27	76	230795	103.51
40	3.33	March	0.86	0.0181	0	0.049	0.271	76.1	236933	103.66
41	3.42	April	0.92	0.0186	0	0.049	0.272	76.2	243070	103.84
42	3.5	May	1	0.0194	0	0.05	0.273	76.4	249207	104.05
43	3.58	June	1.09	0.0207	0	0.052	0.277	76.6	255344	104.39
44	3.67	July	1.16	0.0219	0	0.054	0.281	76.9	261481	104.74
45	3.75	August	1.22	0.023	0	0.056	0.285	77.1	267618	105.06
46	3.83	September	1.27	0.0237	0	0.057	0.286	77.2	273755	105.25
47	3.92	October	1.29	0.024	0	0.057	0.286	77.4	279892	105.4
48	4	November	1.3	0.0241	0	0.057	0.287	77.5	286029	105.55
49	4.08	December	1.3	0.0242	0	0.057	0.287	77.6	292289	105.69
50	4.17	January	1.31	0.0244	0	0.057	0.287	77.7	298549	105.85
51	4.25	February	1.31	0.0245	0	0.057	0.288	77.8	304809	106
52	4.33	March	1.32	0.0247	0	0.057	0.288	77.9	311069	106.16
53	4.42	April	1.38	0.0251	0	0.057	0.289	78	317328	106.34
54	4.5	May	1.44	0.0256	0	0.057	0.29	78.2	323588	106.53
55	4.58	June	1.57	0.027	0	0.059	0.294	78.4	329848	106.86
56	4.67	July	1.66	0.0285	0	0.062	0.298	78.7	336108	107.26
57	4.75	August	1.74	0.0297	0	0.064	0.301	78.9	342368	107.55
58	4.83	September	1.81	0.0307	0	0.065	0.303	79.1	348628	107.79
59	4.92	October	1.83	0.0309	0	0.065	0.303	79.2	354888	107.96
60	5	November	1.83	0.0311	0	0.065	0.303	79.3	361147	108.11
61	5.08	December	1.83	0.0312	0	0.065	0.304	79.4	367532	108.27
62	5.17	January	1.84	0.0312	0	0.065	0.304	79.5	373917	108.42
63	5.25	February	1.84	0.0313	0	0.065	0.304	79.6	380302	108.58

64	5.33	March	1.85	0.0315	0	0.065	0.304	79.8	386688	108.76
65	5.42	April	1.91	0.0319	0	0.065	0.305	79.9	393073	108.95
66	5.5	May	1.98	0.0325	0	0.065	0.306	80.1	399458	109.14
67	5.58	June	2.07	0.0334	0	0.065	0.307	80.2	405843	109.37
68	5.67	July	2.16	0.0345	0	0.067	0.309	80.4	412228	109.64
69	5.75	August	2.25	0.0358	0	0.068	0.312	80.6	418613	109.92
70	5.83	September	2.31	0.0366	0	0.069	0.313	80.8	424998	110.12
71	5.92	October	2.33	0.0368	0	0.069	0.313	80.9	431383	110.3
72	6	November	2.34	0.037	0	0.069	0.313	81	437768	110.47
73	6.08	December	2.34	0.0371	0	0.069	0.313	81.1	444281	110.64
74	6.17	January	2.34	0.0372	0	0.069	0.314	81.3	450793	110.81
75	6.25	February	2.34	0.0372	0	0.069	0.314	81.4	457306	110.98
76	6.33	March	2.35	0.0375	0	0.069	0.315	81.5	463819	111.19
77	6.42	April	2.41	0.0379	0	0.069	0.316	81.7	470332	111.41
78	6.5	May	2.51	0.0387	0	0.069	0.317	81.9	476844	111.63
79	6.58	June	2.63	0.0398	0	0.069	0.318	82	483357	111.87
80	6.67	July	2.74	0.0411	0	0.07	0.32	82.2	489870	112.13
81	6.75	August	2.83	0.042	0	0.071	0.321	82.4	496382	112.36
82	6.83	September	2.92	0.043	0	0.071	0.322	82.5	502895	112.59
83	6.92	October	2.95	0.0433	0	0.072	0.323	82.7	509408	112.77
84	7	November	2.96	0.0434	0	0.072	0.323	82.8	515921	112.95
85	7.08	December	2.96	0.0436	0	0.072	0.323	82.9	522564	113.13
86	7.17	January	2.96	0.0436	0	0.072	0.323	83.1	529207	113.31
87	7.25	February	2.97	0.0438	0	0.072	0.323	83.2	535850	113.5
88	7.33	March	2.97	0.044	0	0.072	0.324	83.3	542493	113.68
89	7.42	April	3.04	0.0444	0	0.072	0.324	83.5	549136	113.88
90	7.5	May	3.13	0.0451	0	0.072	0.325	83.6	555779	114.09
91	7.58	June	3.28	0.0464	0	0.073	0.327	83.9	562422	114.37
92	7.67	July	3.39	0.0477	0	0.074	0.329	84.1	569065	114.67
93	7.75	August	3.47	0.0488	0	0.075	0.33	84.2	575708	114.91
94	7.83	September	3.54	0.0495	0	0.075	0.331	84.4	582351	115.12
95	7.92	October	3.58	0.0498	0	0.075	0.331	84.5	588994	115.32
96	8	November	3.58	0.05	0	0.075	0.331	84.7	595637	115.51
97	8.08	December	3.59	0.0501	0	0.075	0.331	84.8	602412	115.69
98	8.17	January	3.59	0.0502	0	0.075	0.332	85	609188	115.89
99	8.25	February	3.6	0.0504	0	0.075	0.332	85.1	615964	116.08
100	8.33	March	3.63	0.0507	0	0.075	0.332	85.2	622740	116.28
101	8.42	April	3.66	0.0509	0	0.075	0.332	85.4	629516	116.47
102	8.5	May	3.8	0.052	0	0.076	0.333	85.6	636292	116.72
103	8.58	June	3.96	0.0534	0	0.077	0.335	85.8	643068	117
104	8.67	July	4.09	0.0549	0	0.078	0.337	86	649843	117.31
105	8.75	August	4.22	0.0564	0	0.079	0.339	86.2	656619	117.59
106	8.83	September	4.32	0.0574	0	0.08	0.34	86.4	663395	117.83
107	8.92	October	4.35	0.0577	0	0.08	0.34	86.5	670171	118.03
108	9	November	4.36	0.0578	0	0.08	0.341	86.7	676947	118.23
109	9.08	December	4.36	0.058	0	0.08	0.341	86.8	683858	118.43
110	9.17	January	4.37	0.058	0	0.08	0.341	87	690770	118.63
111	9.25	February	4.37	0.0582	0	0.08	0.341	87.1	697681	118.85
112	9.33	March	4.38	0.0585	0	0.08	0.342	87.3	704592	119.05
113	9.42	April	4.42	0.0588	0	0.08	0.342	87.4	711504	119.26
114	9.5	May	4.53	0.0596	0	0.08	0.343	87.6	718415	119.49
115	9.58	June	4.68	0.0612	0	0.081	0.344	87.8	725326	119.79
116	9.67	July	4.82	0.0631	0	0.084	0.348	88.1	732238	120.2
117	9.75	August	4.94	0.0644	0	0.085	0.35	88.3	739149	120.47
118	9.83	September	5.04	0.0652	0	0.085	0.35	88.5	746061	120.71
119	9.92	October	5.07	0.0655	0	0.086	0.351	88.7	752972	120.91
120	10	November	5.08	0.0657	0	0.086	0.351	88.8	759883	121.12
121	10.08	December	5.08	0.0658	0	0.086	0.351	89	766933	121.33
122	10.17	January	5.09	0.0659	0	0.086	0.351	89.1	773982	121.53
123	10.25	February	5.1	0.0661	0	0.086	0.351	89.3	781032	121.75
124	10.33	March	5.13	0.0664	0	0.086	0.352	89.4	788082	121.96
125	10.42	April	5.17	0.0667	0	0.086	0.352	89.6	795131	122.18
126	10.5	May	5.29	0.0676	0	0.086	0.352	89.8	802181	122.41
127	10.58	June	5.41	0.0686	0	0.086	0.353	90	809230	122.67
128	10.67	July	5.53	0.0699	0	0.087	0.355	90.2	816280	122.94
129	10.75	August	5.66	0.0713	0	0.088	0.356	90.4	823330	123.23

130	10.83	September	5.75	0.0723	0	0.089	0.357	90.6	830379	123.47
131	10.92	October	5.8	0.0727	0	0.089	0.357	90.7	837429	123.69
132	11	November	5.81	0.0729	0	0.089	0.357	90.9	844478	123.9
133	11.08	December	5.81	0.0729	0	0.089	0.357	91	851669	124.11
134	11.17	January	5.81	0.073	0	0.089	0.358	91.2	858860	124.32
135	11.25	February	5.82	0.0732	0	0.089	0.358	91.3	866050	124.54
136	11.33	March	5.83	0.0734	0	0.089	0.358	91.5	873241	124.77
137	11.42	April	5.93	0.074	0	0.089	0.358	91.7	880431	125
138	11.5	May	6.09	0.0749	0	0.089	0.359	91.9	887622	125.24
139	11.58	June	6.28	0.0765	0	0.09	0.361	92.1	894813	125.55
140	11.67	July	6.42	0.0782	0	0.092	0.363	92.4	902003	125.89
141	11.75	August	6.54	0.0796	0	0.093	0.365	92.6	909194	126.19
142	11.83	September	6.64	0.0805	0	0.093	0.365	92.8	916384	126.44
143	11.92	October	6.67	0.0808	0	0.093	0.366	92.9	923575	126.66
144	12	November	6.68	0.0809	0	0.093	0.366	93.1	930765	126.88
145	12.08	December	6.69	0.0811	0	0.093	0.366	93.3	938100	127.1
146	12.17	January	6.69	0.0813	0	0.093	0.366	93.4	945434	127.33
147	12.25	February	6.7	0.0814	0	0.093	0.366	93.6	952769	127.56
148	12.33	March	6.71	0.0816	0	0.093	0.366	93.8	960103	127.78
149	12.42	April	6.82	0.0821	0	0.093	0.367	93.9	967438	128.02
150	12.5	May	6.94	0.0827	0	0.093	0.367	94.1	974772	128.26
151	12.58	June	7.17	0.0846	0	0.095	0.369	94.4	982106	128.59
152	12.67	July	7.34	0.0867	0	0.097	0.373	94.7	989441	128.98
153	12.75	August	7.49	0.0884	0	0.098	0.374	94.9	996775	129.3
154	12.83	September	7.61	0.0896	0	0.099	0.375	95.1	1004110	129.57
155	12.92	October	7.65	0.0899	0	0.099	0.376	95.3	1011440	129.8
156	13	November	7.65	0.0901	0	0.099	0.376	95.5	1018780	130.03
157	13.08	December	7.66	0.0902	0	0.099	0.376	95.6	1026260	130.26
158	13.17	January	7.66	0.0903	0	0.099	0.376	95.8	1033740	130.49
159	13.25	February	7.66	0.0903	0	0.099	0.376	96	1041220	130.71
160	13.33	March	7.68	0.0906	0	0.099	0.376	96.1	1048700	130.95
161	13.42	April	7.77	0.0911	0	0.099	0.377	96.3	1056180	131.19
162	13.5	May	7.89	0.0918	0	0.099	0.377	96.5	1063660	131.44
163	13.58	June	8.07	0.093	0	0.1	0.378	96.7	1071150	131.71
164	13.67	July	8.22	0.0943	0	0.1	0.379	96.9	1078630	132
165	13.75	August	8.38	0.096	0	0.102	0.38	97.2	1086110	132.31
166	13.83	September	8.49	0.097	0	0.102	0.381	97.4	1093590	132.57
167	13.92	October	8.53	0.0972	0	0.102	0.381	97.6	1101070	132.81
168	14	November	8.54	0.0974	0	0.102	0.381	97.7	1108550	133.04
169	14.08	December	8.54	0.0976	0	0.102	0.381	97.9	1116180	133.27
170	14.17	January	8.55	0.0976	0	0.102	0.381	98.1	1123810	133.51
171	14.25	February	8.55	0.0977	0	0.102	0.382	98.3	1131440	133.75
172	14.33	March	8.56	0.0981	0	0.102	0.382	98.5	1139070	134.01
173	14.42	April	8.65	0.0986	0	0.102	0.383	98.7	1146700	134.27
174	14.5	May	8.83	0.0996	0	0.102	0.383	98.9	1154340	134.53
175	14.58	June	9.04	0.101	0	0.102	0.384	99.1	1161970	134.82
176	14.67	July	9.22	0.103	0	0.103	0.385	99.3	1169600	135.12
177	14.75	August	9.38	0.104	0	0.104	0.386	99.5	1177230	135.39
178	14.83	September	9.53	0.105	0	0.104	0.387	99.7	1184860	135.65
179	14.92	October	9.58	0.105	0	0.104	0.387	99.9	1192490	135.9
180	15	November	9.59	0.106	0	0.104	0.387	100.1	1200120	136.14
181	15.08	December	9.59	0.106	0	0.104	0.387	100.3	1207900	136.38
182	15.17	January	9.6	0.106	0	0.104	0.387	100.4	1215690	136.63
183	15.25	February	9.6	0.106	0	0.104	0.387	100.6	1223470	136.87
184	15.33	March	9.62	0.106	0	0.104	0.388	100.8	1231250	137.12
185	15.42	April	9.72	0.107	0	0.104	0.388	101	1239040	137.37
186	15.5	May	9.88	0.108	0	0.104	0.388	101.2	1246820	137.63
187	15.58	June	10.1	0.109	0	0.105	0.389	101.4	1254600	137.94
188	15.67	July	10.3	0.111	0	0.106	0.391	101.7	1262390	138.25
189	15.75	August	10.5	0.112	0	0.106	0.392	101.9	1270170	138.54
190	15.83	September	10.6	0.113	0	0.107	0.392	102.1	1277950	138.8
191	15.92	October	10.6	0.113	0	0.107	0.392	102.3	1285740	139.05
192	16	November	10.6	0.114	0	0.107	0.392	102.5	1293520	139.3
193	16.08	December	10.6	0.114	0	0.107	0.393	102.7	1301460	139.55
194	16.17	January	10.6	0.114	0	0.107	0.393	102.9	1309400	139.8
195	16.25	February	10.7	0.114	0	0.107	0.393	103.1	1317340	140.05

196	16.33	March	10.7	0.114	0	0.107	0.393	103.3	1325280	140.3
197	16.42	April	10.7	0.115	0	0.107	0.393	103.4	1333210	140.55
198	16.5	May	11	0.116	0	0.107	0.394	103.7	1341150	140.83
199	16.58	June	11.2	0.118	0	0.108	0.395	103.9	1349090	141.14
200	16.67	July	11.5	0.12	0	0.109	0.397	104.2	1357030	141.48
201	16.75	August	11.7	0.121	0	0.11	0.398	104.4	1364970	141.79
202	16.83	September	11.8	0.123	0	0.11	0.399	104.6	1372910	142.07
203	16.92	October	11.9	0.123	0	0.11	0.399	104.8	1380850	142.33
204	17	November	11.9	0.123	0	0.11	0.399	105	1388790	142.58
205	17.08	December	11.9	0.123	0	0.11	0.399	105.2	1396890	142.84
206	17.17	January	11.9	0.123	0	0.11	0.399	105.4	1404980	143.09
207	17.25	February	11.9	0.124	0	0.11	0.399	105.6	1413080	143.35
208	17.33	March	11.9	0.124	0	0.11	0.399	105.8	1421180	143.61
209	17.42	April	12	0.124	0	0.11	0.4	106	1429280	143.87
210	17.5	May	12.1	0.125	0	0.11	0.4	106.2	1437370	144.15
211	17.58	June	12.4	0.127	0	0.111	0.401	106.5	1445470	144.47
212	17.67	July	12.6	0.13	0	0.114	0.404	106.8	1453570	144.88
213	17.75	August	12.8	0.131	0	0.114	0.405	107	1461670	145.19
214	17.83	September	13	0.132	0	0.115	0.406	107.2	1469770	145.47
215	17.92	October	13	0.133	0	0.115	0.406	107.4	1477860	145.74
216	18	November	13	0.133	0	0.115	0.406	107.6	1485960	146
217	18.08	December	13	0.133	0	0.115	0.406	107.8	1494220	146.25
218	18.17	January	13	0.133	0	0.115	0.406	108	1502480	146.51
219	18.25	February	13.1	0.133	0	0.115	0.407	108.2	1510740	146.78
220	18.33	March	13.1	0.134	0	0.115	0.407	108.4	1519000	147.04
221	18.42	April	13.2	0.134	0	0.115	0.407	108.7	1527260	147.31
222	18.5	May	13.4	0.135	0	0.115	0.407	108.9	1535520	147.59
223	18.58	June	13.5	0.137	0	0.116	0.408	109.1	1543780	147.88
224	18.67	July	13.7	0.138	0	0.116	0.409	109.3	1552040	148.2
225	18.75	August	13.9	0.14	0	0.117	0.41	109.6	1560300	148.51
226	18.83	September	14.1	0.141	0	0.117	0.411	109.8	1568560	148.8
227	18.92	October	14.2	0.142	0	0.117	0.411	110	1576820	149.07
228	19	November	14.2	0.142	0	0.117	0.411	110.2	1585080	149.33
229	19.08	December	14.2	0.142	0	0.117	0.411	110.4	1593500	149.59
230	19.17	January	14.2	0.142	0	0.117	0.411	110.6	1601930	149.86
231	19.25	February	14.2	0.142	0	0.117	0.411	110.8	1610350	150.13
232	19.33	March	14.2	0.142	0	0.117	0.411	111.1	1618780	150.4
233	19.42	April	14.4	0.143	0	0.117	0.412	111.3	1627200	150.68
234	19.5	May	14.6	0.144	0	0.118	0.412	111.5	1635630	150.96
235	19.58	June	14.9	0.146	0	0.119	0.414	111.8	1644050	151.3
236	19.67	July	15.1	0.148	0	0.12	0.416	112	1652480	151.67
237	19.75	August	15.3	0.15	0	0.121	0.417	112.3	1660900	152.01
238	19.83	September	15.4	0.151	0	0.121	0.417	112.5	1669330	152.29
239	19.92	October	15.5	0.152	0	0.121	0.418	112.7	1677750	152.56
240	20	November	15.5	0.152	0	0.121	0.418	113	1686180	152.83

Fatigue Cracking: Project Ryerson.dgp

Pavement age		Month	Top Down at Surface			Top Down at 0.5"			Bottom Up at h _{ac}			Reliability	
			Max. Damage (%)	Max. Cracking (ft/mi)	Location (in)	Max. Damage (%)	Max. Cracking (ft/mi)	Location (in)	Max. Damage (%)	Max. Cracking (%)	Location (in)	Top Down Cracking (ft/mi)	Bottom Up Cracking (%)
1	0.08	December	0.000487	0	0	0.000173	0	0	0.000221	0	0	257.23	1.45
2	0.17	January	0.00109	0	0	0.000389	0	0	0.000454	0	0	258.1	1.45
3	0.25	February	0.00227	0	0	0.000832	0	0	0.000771	0	0	259.74	1.45
4	0.33	March	0.00695	0.01	0	0.00261	0	0	0.00133	0	0	265.84	1.45
5	0.42	April	0.0147	0.02	0	0.00545	0	0	0.00232	0	0	275.4	1.45
6	0.5	May	0.0296	0.05	0	0.0106	0.01	0	0.00486	0	0	292.85	1.45
7	0.58	June	0.0459	0.09	0	0.0162	0.02	0	0.00751	0	0	311.13	1.45
8	0.67	July	0.0573	0.13	0	0.0198	0.02	0	0.0104	0	0	323.54	1.45
9	0.75	August	0.0679	0.16	0	0.0231	0.03	0	0.013	0	0	334.86	1.45
10	0.83	September	0.0773	0.2	0	0.0261	0.04	0	0.015	0.01	0	344.74	1.45
11	0.92	October	0.0818	0.21	0	0.0276	0.04	0	0.0158	0.01	0	349.43	1.45
12	1	November	0.0828	0.22	0	0.0279	0.04	0	0.0161	0.01	0	350.46	1.45
13	1.08	December	0.0836	0.22	0	0.0282	0.04	0	0.0164	0.01	0	351.29	1.45
14	1.17	January	0.0838	0.22	0	0.0283	0.04	0	0.0165	0.01	0	351.5	1.45
15	1.25	February	0.0842	0.22	0	0.0285	0.04	0	0.0169	0.01	0	351.91	1.45
16	1.33	March	0.0857	0.23	0	0.029	0.04	0	0.0173	0.01	0	353.46	1.45
17	1.42	April	0.0907	0.25	0	0.0309	0.05	0	0.0181	0.01	0	358.6	1.45
18	1.5	May	0.1	0.29	0	0.0341	0.06	0	0.0198	0.01	0	368.07	1.46
19	1.58	June	0.112	0.35	0	0.0379	0.07	0	0.0223	0.01	0	380.12	1.46
20	1.67	July	0.123	0.4	0	0.041	0.07	0	0.0255	0.01	0	391.01	1.46
21	1.75	August	0.133	0.45	0	0.0442	0.08	0	0.0276	0.01	0	400.8	1.46
22	1.83	September	0.14	0.48	0	0.0466	0.09	0	0.0292	0.01	0	407.59	1.46
23	1.92	October	0.143	0.5	0	0.0477	0.09	0	0.0299	0.01	0	410.48	1.46
24	2	November	0.145	0.51	0	0.0481	0.1	0	0.0302	0.01	0	412.4	1.46
25	2.08	December	0.145	0.51	0	0.0482	0.1	0	0.0304	0.01	0	412.4	1.46
26	2.17	January	0.145	0.51	0	0.0483	0.1	0	0.0306	0.01	0	412.41	1.46
27	2.25	February	0.146	0.52	0	0.0487	0.1	0	0.0309	0.01	0	413.37	1.46
28	2.33	March	0.15	0.54	0	0.0501	0.1	0	0.0314	0.01	0	417.19	1.46
29	2.42	April	0.154	0.56	0	0.0517	0.11	0	0.0321	0.01	0	421.01	1.46
30	2.5	May	0.164	0.62	0	0.0552	0.12	0	0.0336	0.01	0	430.47	1.46
31	2.58	June	0.173	0.67	0	0.0581	0.13	0	0.0355	0.01	0	438.91	1.46
32	2.67	July	0.182	0.72	0	0.0609	0.14	0	0.0376	0.02	0	447.27	1.46
33	2.75	August	0.192	0.78	0	0.0638	0.15	0	0.0399	0.02	0	456.48	1.46
34	2.83	September	0.199	0.83	0	0.0661	0.16	0	0.0414	0.02	0	462.87	1.47
35	2.92	October	0.203	0.85	0	0.0674	0.16	0	0.0422	0.02	0	466.51	1.47
36	3	November	0.203	0.86	0	0.0677	0.16	0	0.0424	0.02	0	466.51	1.47
37	3.08	December	0.204	0.86	0	0.0677	0.16	0	0.0425	0.02	0	467.41	1.47
38	3.17	January	0.204	0.86	0	0.0678	0.16	0	0.0427	0.02	0	467.41	1.47
39	3.25	February	0.204	0.86	0	0.0679	0.16	0	0.043	0.02	0	467.42	1.47
40	3.33	March	0.205	0.86	0	0.0681	0.16	0	0.0433	0.02	0	468.32	1.47
41	3.42	April	0.214	0.92	0	0.0715	0.17	0	0.0444	0.02	0	476.43	1.47
42	3.5	May	0.226	1	0	0.0756	0.19	0	0.0461	0.02	0	487.14	1.47
43	3.58	June	0.239	1.09	0	0.08	0.21	0	0.0488	0.02	0	498.63	1.47
44	3.67	July	0.249	1.16	0	0.083	0.22	0	0.0514	0.02	0	507.37	1.47
45	3.75	August	0.258	1.22	0	0.0856	0.23	0	0.0538	0.02	0	515.17	1.47
46	3.83	September	0.264	1.27	0	0.0877	0.24	0	0.0553	0.02	0	520.35	1.47
47	3.92	October	0.267	1.29	0	0.0886	0.24	0	0.0558	0.02	0	522.92	1.47
48	4	November	0.268	1.3	0	0.0891	0.24	0	0.0561	0.02	0	523.78	1.47
49	4.08	December	0.268	1.3	0	0.0892	0.24	0	0.0563	0.02	0	523.78	1.47
50	4.17	January	0.269	1.31	0	0.0893	0.25	0	0.0566	0.02	0	524.64	1.47
51	4.25	February	0.27	1.31	0	0.0895	0.25	0	0.0569	0.02	0	525.49	1.47
52	4.33	March	0.27	1.32	0	0.0898	0.25	0	0.0572	0.02	0	525.5	1.47
53	4.42	April	0.278	1.38	0	0.0927	0.26	0	0.0581	0.03	0	532.32	1.47
54	4.5	May	0.287	1.44	0	0.096	0.27	0	0.0592	0.03	0	539.93	1.47
55	4.58	June	0.303	1.57	0	0.101	0.3	0	0.0621	0.03	0	553.34	1.48

56	4.67	July	0.314	1.66	0	0.105	0.31	0	0.0652	0.03	0	562.46	1.48
57	4.75	August	0.324	1.74	0	0.108	0.33	0	0.0677	0.03	0	570.69	1.48
58	4.83	September	0.333	1.81	0	0.11	0.34	0	0.0697	0.03	0	578.03	1.48
59	4.92	October	0.335	1.83	0	0.111	0.34	0	0.0702	0.03	0	579.66	1.48
60	5	November	0.335	1.83	0	0.111	0.34	0	0.0704	0.03	0	579.66	1.48
61	5.08	December	0.336	1.83	0	0.111	0.34	0	0.0707	0.03	0	580.46	1.48
62	5.17	January	0.336	1.84	0	0.112	0.34	0	0.0708	0.03	0	580.47	1.48
63	5.25	February	0.336	1.84	0	0.112	0.34	0	0.0709	0.03	0	580.47	1.48
64	5.33	March	0.338	1.85	0	0.112	0.35	0	0.0713	0.03	0	582.09	1.48
65	5.42	April	0.345	1.91	0	0.115	0.36	0	0.0721	0.03	0	587.74	1.48
66	5.5	May	0.353	1.98	0	0.118	0.37	0	0.0733	0.03	0	594.17	1.48
67	5.58	June	0.364	2.07	0	0.122	0.39	0	0.0752	0.03	0	602.95	1.48
68	5.67	July	0.374	2.16	0	0.125	0.41	0	0.0775	0.03	0	610.87	1.48
69	5.75	August	0.384	2.25	0	0.128	0.42	0	0.0801	0.04	0	618.73	1.48
70	5.83	September	0.391	2.31	0	0.13	0.43	0	0.0816	0.04	0	624.19	1.48
71	5.92	October	0.393	2.33	0	0.131	0.44	0	0.0821	0.04	0	625.75	1.48
72	6	November	0.394	2.34	0	0.131	0.44	0	0.0823	0.04	0	626.53	1.49
73	6.08	December	0.394	2.34	0	0.131	0.44	0	0.0826	0.04	0	626.53	1.49
74	6.17	January	0.395	2.34	0	0.131	0.44	0	0.0827	0.04	0	627.3	1.49
75	6.25	February	0.395	2.34	0	0.131	0.44	0	0.0829	0.04	0	627.3	1.49
76	6.33	March	0.396	2.35	0	0.132	0.44	0	0.0834	0.04	0	628.07	1.49
77	6.42	April	0.402	2.41	0	0.134	0.45	0	0.0842	0.04	0	632.73	1.49
78	6.5	May	0.413	2.51	0	0.138	0.47	0	0.0859	0.04	0	641.19	1.49
79	6.58	June	0.426	2.63	0	0.142	0.5	0	0.088	0.04	0	651.12	1.49
80	6.67	July	0.438	2.74	0	0.146	0.52	0	0.0905	0.04	0	660.19	1.49
81	6.75	August	0.447	2.83	0	0.149	0.53	0	0.0924	0.04	0	666.95	1.49
82	6.83	September	0.456	2.92	0	0.152	0.55	0	0.0944	0.04	0	673.67	1.49
83	6.92	October	0.459	2.95	0	0.153	0.55	0	0.095	0.04	0	675.9	1.49
84	7	November	0.46	2.96	0	0.153	0.56	0	0.0952	0.04	0	676.65	1.49
85	7.08	December	0.46	2.96	0	0.153	0.56	0	0.0954	0.04	0	676.65	1.49
86	7.17	January	0.46	2.96	0	0.153	0.56	0	0.0956	0.04	0	676.65	1.49
87	7.25	February	0.461	2.97	0	0.153	0.56	0	0.0959	0.04	0	677.39	1.49
88	7.33	March	0.462	2.97	0	0.154	0.56	0	0.0963	0.04	0	678.12	1.49
89	7.42	April	0.468	3.04	0	0.156	0.57	0	0.0971	0.04	0	682.57	1.49
90	7.5	May	0.478	3.13	0	0.16	0.59	0	0.0985	0.05	0	689.92	1.49
91	7.58	June	0.492	3.28	0	0.165	0.62	0	0.101	0.05	0	700.14	1.49
92	7.67	July	0.503	3.39	0	0.168	0.64	0	0.104	0.05	0	708.1	1.5
93	7.75	August	0.511	3.47	0	0.17	0.65	0	0.106	0.05	0	713.85	1.5
94	7.83	September	0.518	3.54	0	0.172	0.67	0	0.107	0.05	0	718.85	1.5
95	7.92	October	0.522	3.58	0	0.174	0.67	0	0.108	0.05	0	721.7	1.5
96	8	November	0.522	3.58	0	0.174	0.67	0	0.108	0.05	0	721.7	1.5
97	8.08	December	0.522	3.59	0	0.174	0.67	0	0.108	0.05	0	721.71	1.5
98	8.17	January	0.523	3.59	0	0.174	0.68	0	0.109	0.05	0	722.41	1.5
99	8.25	February	0.523	3.6	0	0.174	0.68	0	0.109	0.05	0	722.42	1.5
100	8.33	March	0.526	3.63	0	0.175	0.68	0	0.109	0.05	0	724.55	1.5
101	8.42	April	0.529	3.66	0	0.176	0.69	0	0.11	0.05	0	726.68	1.5
102	8.5	May	0.542	3.8	0	0.181	0.71	0	0.112	0.05	0	735.86	1.5
103	8.58	June	0.558	3.96	0	0.186	0.75	0	0.115	0.05	0	747.03	1.5
104	8.67	July	0.57	4.09	0	0.19	0.77	0	0.118	0.05	0	755.35	1.5
105	8.75	August	0.581	4.22	0	0.193	0.79	0	0.12	0.06	0	762.92	1.5
106	8.83	September	0.59	4.32	0	0.196	0.81	0	0.122	0.06	0	769.08	1.51
107	8.92	October	0.593	4.35	0	0.197	0.82	0	0.123	0.06	0	771.12	1.51
108	9	November	0.594	4.36	0	0.197	0.82	0	0.123	0.06	0	771.79	1.51
109	9.08	December	0.594	4.36	0	0.197	0.82	0	0.123	0.06	0	771.79	1.51
110	9.17	January	0.595	4.37	0	0.198	0.82	0	0.124	0.06	0	772.47	1.51
111	9.25	February	0.595	4.37	0	0.198	0.82	0	0.124	0.06	0	772.47	1.51
112	9.33	March	0.596	4.38	0	0.198	0.82	0	0.124	0.06	0	773.15	1.51
113	9.42	April	0.599	4.42	0	0.199	0.83	0	0.125	0.06	0	775.19	1.51
114	9.5	May	0.609	4.53	0	0.203	0.85	0	0.127	0.06	0	781.95	1.51
115	9.58	June	0.622	4.68	0	0.207	0.88	0	0.13	0.06	0	790.67	1.51
116	9.67	July	0.634	4.82	0	0.21	0.9	0	0.133	0.06	0	798.66	1.51
117	9.75	August	0.645	4.94	0	0.214	0.92	0	0.136	0.06	0	805.93	1.51

118	9.83	September	0.653	5.04	0	0.216	0.94	0	0.137	0.07	0	811.19	1.51
119	9.92	October	0.656	5.07	0	0.217	0.94	0	0.138	0.07	0	813.15	1.51
120	10	November	0.657	5.08	0	0.217	0.95	0	0.138	0.07	0	813.81	1.51
121	10.08	December	0.657	5.08	0	0.218	0.95	0	0.138	0.07	0	813.81	1.51
122	10.17	January	0.657	5.09	0	0.218	0.95	0	0.138	0.07	0	813.82	1.51
123	10.25	February	0.658	5.1	0	0.218	0.95	0	0.139	0.07	0	814.47	1.51
124	10.33	March	0.661	5.13	0	0.219	0.96	0	0.139	0.07	0	816.42	1.51
125	10.42	April	0.664	5.17	0	0.22	0.97	0	0.14	0.07	0	818.38	1.51
126	10.5	May	0.675	5.29	0	0.224	0.99	0	0.142	0.07	0	825.51	1.52
127	10.58	June	0.685	5.41	0	0.227	1.01	0	0.144	0.07	0	831.97	1.52
128	10.67	July	0.695	5.53	0	0.23	1.03	0	0.146	0.07	0	838.38	1.52
129	10.75	August	0.705	5.66	0	0.233	1.05	0	0.149	0.07	0	844.77	1.52
130	10.83	September	0.713	5.75	0	0.236	1.07	0	0.15	0.07	0	849.83	1.52
131	10.92	October	0.717	5.8	0	0.237	1.08	0	0.151	0.07	0	852.36	1.52
132	11	November	0.718	5.81	0	0.237	1.08	0	0.152	0.07	0	852.99	1.52
133	11.08	December	0.718	5.81	0	0.237	1.08	0	0.152	0.07	0	852.99	1.52
134	11.17	January	0.718	5.81	0	0.237	1.08	0	0.152	0.07	0	852.99	1.52
135	11.25	February	0.718	5.82	0	0.238	1.08	0	0.152	0.07	0	853	1.52
136	11.33	March	0.719	5.83	0	0.238	1.08	0	0.153	0.07	0	853.63	1.52
137	11.42	April	0.727	5.93	0	0.241	1.11	0	0.154	0.07	0	858.66	1.52
138	11.5	May	0.74	6.09	0	0.246	1.14	0	0.155	0.07	0	866.79	1.52
139	11.58	June	0.755	6.28	0	0.25	1.17	0	0.158	0.08	0	876.1	1.52
140	11.67	July	0.766	6.42	0	0.254	1.2	0	0.161	0.08	0	882.87	1.53
141	11.75	August	0.776	6.54	0	0.257	1.22	0	0.164	0.08	0	888.99	1.53
142	11.83	September	0.783	6.64	0	0.259	1.23	0	0.166	0.08	0	893.26	1.53
143	11.92	October	0.786	6.67	0	0.26	1.24	0	0.166	0.08	0	895.07	1.53
144	12	November	0.787	6.68	0	0.26	1.24	0	0.167	0.08	0	895.68	1.53
145	12.08	December	0.787	6.69	0	0.26	1.24	0	0.167	0.08	0	895.69	1.53
146	12.17	January	0.787	6.69	0	0.26	1.25	0	0.167	0.08	0	895.69	1.53
147	12.25	February	0.788	6.7	0	0.261	1.25	0	0.168	0.08	0	896.29	1.53
148	12.33	March	0.789	6.71	0	0.261	1.25	0	0.168	0.08	0	896.89	1.53
149	12.42	April	0.797	6.82	0	0.264	1.27	0	0.169	0.08	0	901.74	1.53
150	12.5	May	0.806	6.94	0	0.267	1.3	0	0.17	0.08	0	907.15	1.53
151	12.58	June	0.824	7.17	0	0.273	1.34	0	0.173	0.08	0	917.9	1.53
152	12.67	July	0.836	7.34	0	0.277	1.37	0	0.177	0.09	0	925.01	1.53
153	12.75	August	0.848	7.49	0	0.28	1.39	0	0.18	0.09	0	932.07	1.54
154	12.83	September	0.857	7.61	0	0.283	1.41	0	0.183	0.09	0	937.33	1.54
155	12.92	October	0.86	7.65	0	0.284	1.42	0	0.183	0.09	0	939.08	1.54
156	13	November	0.86	7.65	0	0.284	1.42	0	0.183	0.09	0	939.08	1.54
157	13.08	December	0.861	7.66	0	0.284	1.42	0	0.184	0.09	0	939.66	1.54
158	13.17	January	0.861	7.66	0	0.284	1.42	0	0.184	0.09	0	939.66	1.54
159	13.25	February	0.861	7.66	0	0.284	1.42	0	0.184	0.09	0	939.66	1.54
160	13.33	March	0.862	7.68	0	0.285	1.43	0	0.184	0.09	0	940.25	1.54
161	13.42	April	0.869	7.77	0	0.287	1.45	0	0.185	0.09	0	944.31	1.54
162	13.5	May	0.878	7.89	0	0.291	1.47	0	0.187	0.09	0	949.51	1.54
163	13.58	June	0.891	8.07	0	0.295	1.51	0	0.189	0.09	0	956.99	1.54
164	13.67	July	0.902	8.22	0	0.298	1.53	0	0.191	0.09	0	963.27	1.54
165	13.75	August	0.913	8.38	0	0.302	1.56	0	0.194	0.1	0	969.52	1.54
166	13.83	September	0.921	8.49	0	0.304	1.58	0	0.196	0.1	0	974.04	1.55
167	13.92	October	0.924	8.53	0	0.305	1.59	0	0.197	0.1	0	975.73	1.55
168	14	November	0.924	8.54	0	0.305	1.59	0	0.197	0.1	0	975.74	1.55
169	14.08	December	0.925	8.54	0	0.306	1.59	0	0.197	0.1	0	976.29	1.55
170	14.17	January	0.925	8.55	0	0.306	1.59	0	0.197	0.1	0	976.3	1.55
171	14.25	February	0.925	8.55	0	0.306	1.59	0	0.197	0.1	0	976.3	1.55
172	14.33	March	0.926	8.56	0	0.306	1.59	0	0.198	0.1	0	976.86	1.55
173	14.42	April	0.933	8.65	0	0.309	1.61	0	0.199	0.1	0	980.78	1.55
174	14.5	May	0.945	8.83	0	0.313	1.65	0	0.201	0.1	0	987.49	1.55
175	14.58	June	0.96	9.04	0	0.318	1.69	0	0.203	0.1	0	995.81	1.55
176	14.67	July	0.973	9.22	0	0.322	1.72	0	0.206	0.1	0	1002.96	1.55
177	14.75	August	0.983	9.38	0	0.325	1.75	0	0.208	0.1	0	1008.45	1.55
178	14.83	September	0.994	9.53	0	0.329	1.78	0	0.211	0.11	0	1014.43	1.55
179	14.92	October	0.997	9.58	0	0.33	1.78	0	0.211	0.11	0	1016.06	1.55

180	15	November	0.998	9.59	0	0.33	1.79	0	0.212	0.11	0	1016.6	1.55
181	15.08	December	0.998	9.59	0	0.33	1.79	0	0.212	0.11	0	1016.6	1.55
182	15.17	January	0.998	9.6	0	0.33	1.79	0	0.212	0.11	0	1016.61	1.55
183	15.25	February	0.999	9.6	0	0.331	1.79	0	0.212	0.11	0	1017.13	1.55
184	15.33	March	1	9.62	0	0.331	1.79	0	0.213	0.11	0	1017.68	1.55
185	15.42	April	1.01	9.72	0	0.334	1.81	0	0.214	0.11	0	1023.03	1.56
186	15.5	May	1.02	9.88	0	0.337	1.85	0	0.215	0.11	0	1028.42	1.56
187	15.58	June	1.03	10.1	0	0.343	1.89	0	0.218	0.11	0	1033.83	1.56
188	15.67	July	1.05	10.3	0	0.347	1.92	0	0.221	0.11	0	1044.34	1.56
189	15.75	August	1.06	10.5	0	0.349	1.95	0	0.223	0.11	0	1049.65	1.56
190	15.83	September	1.06	10.6	0	0.352	1.97	0	0.225	0.11	0	1049.75	1.56
191	15.92	October	1.07	10.6	0	0.353	1.98	0	0.226	0.11	0	1054.84	1.56
192	16	November	1.07	10.6	0	0.353	1.98	0	0.226	0.11	0	1054.84	1.56
193	16.08	December	1.07	10.6	0	0.354	1.98	0	0.226	0.11	0	1054.84	1.56
194	16.17	January	1.07	10.6	0	0.354	1.98	0	0.227	0.11	0	1054.84	1.56
195	16.25	February	1.07	10.7	0	0.354	1.99	0	0.227	0.11	0	1054.94	1.56
196	16.33	March	1.07	10.7	0	0.355	1.99	0	0.227	0.11	0	1054.94	1.56
197	16.42	April	1.08	10.7	0	0.356	2	0	0.228	0.12	0	1060	1.56
198	16.5	May	1.09	11	0	0.361	2.05	0	0.23	0.12	0	1065.34	1.56
199	16.58	June	1.11	11.2	0	0.367	2.1	0	0.233	0.12	0	1075.52	1.57
200	16.67	July	1.12	11.5	0	0.371	2.14	0	0.237	0.12	0	1080.78	1.57
201	16.75	August	1.14	11.7	0	0.375	2.17	0	0.24	0.12	0	1090.82	1.57
202	16.83	September	1.15	11.8	0	0.379	2.2	0	0.242	0.12	0	1095.8	1.57
203	16.92	October	1.15	11.9	0	0.38	2.21	0	0.243	0.12	0	1095.9	1.57
204	17	November	1.15	11.9	0	0.38	2.21	0	0.243	0.12	0	1095.9	1.57
205	17.08	December	1.15	11.9	0	0.38	2.21	0	0.243	0.12	0	1095.9	1.57
206	17.17	January	1.15	11.9	0	0.38	2.21	0	0.244	0.12	0	1095.9	1.57
207	17.25	February	1.15	11.9	0	0.381	2.22	0	0.244	0.12	0	1095.9	1.57
208	17.33	March	1.15	11.9	0	0.381	2.22	0	0.245	0.12	0	1095.9	1.57
209	17.42	April	1.16	12	0	0.382	2.23	0	0.245	0.12	0	1100.85	1.57
210	17.5	May	1.17	12.1	0	0.386	2.27	0	0.247	0.13	0	1105.78	1.57
211	17.58	June	1.18	12.4	0	0.391	2.31	0	0.25	0.13	0	1110.89	1.58
212	17.67	July	1.2	12.6	0	0.395	2.35	0	0.255	0.13	0	1120.63	1.58
213	17.75	August	1.21	12.8	0	0.399	2.38	0	0.257	0.13	0	1125.56	1.58
214	17.83	September	1.22	13	0	0.402	2.41	0	0.259	0.13	0	1130.47	1.58
215	17.92	October	1.22	13	0	0.403	2.42	0	0.26	0.13	0	1130.47	1.58
216	18	November	1.22	13	0	0.403	2.42	0	0.26	0.13	0	1130.47	1.58
217	18.08	December	1.22	13	0	0.403	2.42	0	0.261	0.13	0	1130.47	1.58
218	18.17	January	1.22	13	0	0.403	2.42	0	0.261	0.13	0	1130.47	1.58
219	18.25	February	1.22	13.1	0	0.404	2.43	0	0.261	0.13	0	1130.57	1.58
220	18.33	March	1.23	13.1	0	0.405	2.44	0	0.262	0.13	0	1135.26	1.58
221	18.42	April	1.23	13.2	0	0.407	2.45	0	0.263	0.13	0	1135.36	1.58
222	18.5	May	1.24	13.4	0	0.411	2.49	0	0.264	0.14	0	1140.22	1.58
223	18.58	June	1.25	13.5	0	0.414	2.52	0	0.267	0.14	0	1144.96	1.59
224	18.67	July	1.26	13.7	0	0.418	2.55	0	0.27	0.14	0	1149.78	1.59
225	18.75	August	1.28	13.9	0	0.421	2.59	0	0.273	0.14	0	1159.15	1.59
226	18.83	September	1.29	14.1	0	0.424	2.61	0	0.275	0.14	0	1163.89	1.59
227	18.92	October	1.29	14.2	0	0.426	2.63	0	0.276	0.14	0	1163.99	1.59
228	19	November	1.29	14.2	0	0.426	2.63	0	0.276	0.14	0	1163.99	1.59
229	19.08	December	1.29	14.2	0	0.426	2.63	0	0.276	0.14	0	1163.99	1.59
230	19.17	January	1.29	14.2	0	0.426	2.63	0	0.276	0.14	0	1163.99	1.59
231	19.25	February	1.29	14.2	0	0.426	2.63	0	0.277	0.14	0	1163.99	1.59
232	19.33	March	1.29	14.2	0	0.426	2.64	0	0.277	0.14	0	1163.99	1.59
233	19.42	April	1.3	14.4	0	0.43	2.67	0	0.278	0.14	0	1168.72	1.59
234	19.5	May	1.32	14.6	0	0.435	2.72	0	0.28	0.14	0	1177.91	1.59
235	19.58	June	1.33	14.9	0	0.441	2.77	0	0.284	0.15	0	1182.67	1.59
236	19.67	July	1.35	15.1	0	0.445	2.81	0	0.287	0.15	0	1191.74	1.6
237	19.75	August	1.36	15.3	0	0.448	2.84	0	0.291	0.15	0	1196.33	1.6
238	19.83	September	1.37	15.4	0	0.45	2.86	0	0.292	0.15	0	1200.81	1.6
239	19.92	October	1.37	15.5	0	0.451	2.87	0	0.293	0.15	0	1200.91	1.6
240	20	November	1.37	15.5	0	0.452	2.88	0	0.293	0.15	0	1200.91	1.6

Asphalt Sub-Layers Modulus Vs Time

Surface Down Cracking - Longitudinal

—●— Surface
—○— Depth = 0.5"

Surface Down Cracking - Longitudinal

Bottom Up Damage for Alligator Cracking

Bottom Up Cracking - Alligator

Maximum Cracking
Bottom Up Reliability
Maximum Cracking Limit

Thermal Cracking: Crack Depth Vs Time

Thermal Cracking: Total Length Vs Time

Transverse Crack Spacing

Thermal Cracking: Project Ryerson.dgp

Pavement age		Month	Crack Depth C_{ave} (in)	Depth Ratio C/h_{ac}	Crack Length (ft/mi)	Crack Spacing (ft)	Crack Length at Reliability (ft/mi)
mo	yr						
1	0.08	December	0	0	0		84.3
2	0.17	January	0.00000261	0.000000434	0		84.3
3	0.25	February	0.00000261	0.000000434	0		84.3
4	0.33	March	0.00000261	0.000000434	0		84.3
5	0.42	April	0.00000261	0.000000434	0		84.3
6	0.5	May	0.00000261	0.000000434	0		84.3
7	0.58	June	0.00000261	0.000000434	0		84.3
8	0.67	July	0.00000261	0.000000434	0		84.3
9	0.75	August	0.00000261	0.000000434	0		84.3
10	0.83	September	0.00000261	0.000000434	0		84.3
11	0.92	October	0.00000261	0.000000434	0		84.3
12	1	November	0.00000261	0.000000434	0		84.3
13	1.08	December	0.00000477	0.000000794	0		84.3
14	1.17	January	0.000355	0.0000591	0		84.3
15	1.25	February	0.000355	0.0000591	0		84.3
16	1.33	March	0.000355	0.0000591	0		84.3
17	1.42	April	0.000355	0.0000591	0		84.3
18	1.5	May	0.000355	0.0000591	0		84.3
19	1.58	June	0.000355	0.0000591	0		84.3
20	1.67	July	0.000355	0.0000591	0		84.3
21	1.75	August	0.000355	0.0000591	0		84.3
22	1.83	September	0.000355	0.0000591	0		84.3
23	1.92	October	0.000355	0.0000591	0		84.3
24	2	November	0.000355	0.0000591	0		84.3
25	2.08	December	0.000358	0.0000596	0		84.3
26	2.17	January	0.000384	0.000064	0		84.3
27	2.25	February	0.000384	0.000064	0		84.3
28	2.33	March	0.000384	0.000064	0		84.3
29	2.42	April	0.000384	0.000064	0		84.3
30	2.5	May	0.000384	0.000064	0		84.3
31	2.58	June	0.000384	0.000064	0		84.3
32	2.67	July	0.000384	0.000064	0		84.3
33	2.75	August	0.000384	0.000064	0		84.3
34	2.83	September	0.000384	0.000064	0		84.3
35	2.92	October	0.000384	0.000064	0		84.3
36	3	November	0.000384	0.000064	0		84.3
37	3.08	December	0.000561	0.0000935	0		84.3
38	3.17	January	0.000562	0.0000937	0		84.3
39	3.25	February	0.00057	0.000095	0		84.3
40	3.33	March	0.00057	0.000095	0		84.3
41	3.42	April	0.00057	0.000095	0		84.3
42	3.5	May	0.00057	0.000095	0		84.3
43	3.58	June	0.00057	0.000095	0		84.3
44	3.67	July	0.00057	0.000095	0		84.3
45	3.75	August	0.00057	0.000095	0		84.3
46	3.83	September	0.00057	0.000095	0		84.3
47	3.92	October	0.00057	0.000095	0		84.3
48	4	November	0.00057	0.000095	0		84.3
49	4.08	December	0.00057	0.000095	0		84.3
50	4.17	January	0.00057	0.000095	0		84.3
51	4.25	February	0.00057	0.000095	0		84.3
52	4.33	March	0.000586	0.0000977	0		84.3
53	4.42	April	0.000586	0.0000977	0		84.3
54	4.5	May	0.000586	0.0000977	0		84.3
55	4.58	June	0.000586	0.0000977	0		84.3
56	4.67	July	0.000586	0.0000977	0		84.3
57	4.75	August	0.000586	0.0000977	0		84.3
58	4.83	September	0.000586	0.0000977	0		84.3

59	4.92	October	0.000586	0.0000977	0	84.3
60	5	November	0.000586	0.0000977	0	84.3
61	5.08	December	0.000586	0.0000977	0	84.3
62	5.17	January	0.000618	0.000103	0	84.3
63	5.25	February	0.000624	0.000104	0	84.3
64	5.33	March	0.000626	0.000104	0	84.3
65	5.42	April	0.000626	0.000104	0	84.3
66	5.5	May	0.000626	0.000104	0	84.3
67	5.58	June	0.000626	0.000104	0	84.3
68	5.67	July	0.000626	0.000104	0	84.3
69	5.75	August	0.000626	0.000104	0	84.3
70	5.83	September	0.000626	0.000104	0	84.3
71	5.92	October	0.000626	0.000104	0	84.3
72	6	November	0.000626	0.000104	0	84.3
73	6.08	December	0.000626	0.000104	0	84.3
74	6.17	January	0.000745	0.000124	0	84.3
75	6.25	February	0.000787	0.000131	0	84.3
76	6.33	March	0.000787	0.000131	0	84.3
77	6.42	April	0.000787	0.000131	0	84.3
78	6.5	May	0.000787	0.000131	0	84.3
79	6.58	June	0.000787	0.000131	0	84.3
80	6.67	July	0.000787	0.000131	0	84.3
81	6.75	August	0.000787	0.000131	0	84.3
82	6.83	September	0.000787	0.000131	0	84.3
83	6.92	October	0.000787	0.000131	0	84.3
84	7	November	0.000787	0.000131	0	84.3
85	7.08	December	0.000803	0.000134	0	84.3
86	7.17	January	0.000807	0.000135	0	84.3
87	7.25	February	0.000807	0.000135	0	84.3
88	7.33	March	0.000807	0.000135	0	84.3
89	7.42	April	0.000807	0.000135	0	84.3
90	7.5	May	0.000807	0.000135	0	84.3
91	7.58	June	0.000807	0.000135	0	84.3
92	7.67	July	0.000807	0.000135	0	84.3
93	7.75	August	0.000807	0.000135	0	84.3
94	7.83	September	0.000807	0.000135	0	84.3
95	7.92	October	0.000807	0.000135	0	84.3
96	8	November	0.000807	0.000135	0	84.3
97	8.08	December	0.000807	0.000135	0	84.3
98	8.17	January	0.00081	0.000135	0	84.3
99	8.25	February	0.00081	0.000135	0	84.3
100	8.33	March	0.00081	0.000135	0	84.3
101	8.42	April	0.00081	0.000135	0	84.3
102	8.5	May	0.00081	0.000135	0	84.3
103	8.58	June	0.00081	0.000135	0	84.3
104	8.67	July	0.00081	0.000135	0	84.3
105	8.75	August	0.00081	0.000135	0	84.3
106	8.83	September	0.00081	0.000135	0	84.3
107	8.92	October	0.00081	0.000135	0	84.3
108	9	November	0.00081	0.000135	0	84.3
109	9.08	December	0.000813	0.000135	0	84.3
110	9.17	January	0.00122	0.000204	0	84.3
111	9.25	February	0.00122	0.000204	0	84.3
112	9.33	March	0.00122	0.000204	0	84.3
113	9.42	April	0.00122	0.000204	0	84.3
114	9.5	May	0.00122	0.000204	0	84.3
115	9.58	June	0.00122	0.000204	0	84.3
116	9.67	July	0.00122	0.000204	0	84.3
117	9.75	August	0.00122	0.000204	0	84.3
118	9.83	September	0.00122	0.000204	0	84.3
119	9.92	October	0.00122	0.000204	0	84.3
120	10	November	0.00122	0.000204	0	84.3

121	10.1	December	0.00123	0.000205	0		84.3
122	10.2	January	0.00126	0.00021	0		84.3
123	10.3	February	0.00126	0.00021	0		84.3
124	10.3	March	0.00126	0.00021	0		84.3
125	10.4	April	0.00126	0.00021	0		84.3
126	10.5	May	0.00126	0.00021	0		84.3
127	10.6	June	0.00126	0.00021	0		84.3
128	10.7	July	0.00126	0.00021	0		84.3
129	10.8	August	0.00126	0.00021	0		84.3
130	10.8	September	0.00126	0.00021	0		84.3
131	10.9	October	0.00126	0.00021	0		84.3
132	11	November	0.00126	0.00021	0		84.3
133	11.1	December	0.00145	0.000242	0		83.3
134	11.2	January	0.00146	0.000243	0		83.3
135	11.3	February	0.00147	0.000244	0		83.3
136	11.3	March	0.00147	0.000244	0		83.3
137	11.4	April	0.00147	0.000244	0		83.3
138	11.5	May	0.00147	0.000244	0		83.3
139	11.6	June	0.00147	0.000244	0		83.3
140	11.7	July	0.00147	0.000244	0		83.3
141	11.8	August	0.00147	0.000244	0		83.3
142	11.8	September	0.00147	0.000244	0		83.3
143	11.9	October	0.00147	0.000244	0		83.3
144	12	November	0.00147	0.000244	0		83.3
145	12.1	December	0.00147	0.000244	0		83.3
146	12.2	January	0.00147	0.000244	0		83.3
147	12.3	February	0.00147	0.000244	0		83.3
148	12.3	March	0.00148	0.000247	0		83.3
149	12.4	April	0.00148	0.000247	0		83.3
150	12.5	May	0.00148	0.000247	0		83.3
151	12.6	June	0.00148	0.000247	0		83.3
152	12.7	July	0.00148	0.000247	0		83.3
153	12.8	August	0.00148	0.000247	0		83.3
154	12.8	September	0.00148	0.000247	0		83.3
155	12.9	October	0.00148	0.000247	0		83.3
156	13	November	0.00148	0.000247	0		83.3
157	13.1	December	0.00148	0.000247	0		83.3
158	13.2	January	0.00152	0.000253	0		83.3
159	13.3	February	0.00153	0.000254	0		83.3
160	13.3	March	0.00153	0.000255	0		83.3
161	13.4	April	0.00153	0.000255	0		83.3
162	13.5	May	0.00153	0.000255	0		83.3
163	13.6	June	0.00153	0.000255	0		83.3
164	13.7	July	0.00153	0.000255	0		83.3
165	13.8	August	0.00153	0.000255	0		83.3
166	13.8	September	0.00153	0.000255	0		83.3
167	13.9	October	0.00153	0.000255	0		83.3
168	14	November	0.00153	0.000255	0		83.3
169	14.1	December	0.00153	0.000255	0		83.3
170	14.2	January	0.00156	0.000261	0		83.3
171	14.3	February	0.00171	0.000285	0		83.3
172	14.3	March	0.00171	0.000285	0		83.3
173	14.4	April	0.00171	0.000285	0		83.3
174	14.5	May	0.00171	0.000285	0		83.3
175	14.6	June	0.00171	0.000285	0		83.3
176	14.7	July	0.00171	0.000285	0		83.3
177	14.8	August	0.00171	0.000285	0		83.3
178	14.8	September	0.00171	0.000285	0		83.3
179	14.9	October	0.00171	0.000285	0		83.3
180	15	November	0.00171	0.000285	0		83.3
181	15.1	December	0.00173	0.000288	0		83.3
182	15.2	January	0.00173	0.000288	0		83.3

183	15.3	February	0.00173	0.000288	0		83.3
184	15.3	March	0.00173	0.000288	0		83.3
185	15.4	April	0.00173	0.000288	0		83.3
186	15.5	May	0.00173	0.000288	0		83.3
187	15.6	June	0.00173	0.000288	0		83.3
188	15.7	July	0.00174	0.000289	0		83.3
189	15.8	August	0.00174	0.000289	0		83.3
190	15.8	September	0.00174	0.000289	0		83.3
191	15.9	October	0.00174	0.000289	0		83.3
192	16	November	0.00174	0.000289	0		83.3
193	16.1	December	0.00174	0.000289	0		83.3
194	16.2	January	0.00174	0.000289	0		83.3
195	16.3	February	0.00174	0.000289	0		83.3
196	16.3	March	0.00174	0.000289	0		83.3
197	16.4	April	0.00174	0.000289	0		83.3
198	16.5	May	0.00174	0.000289	0		83.3
199	16.6	June	0.00174	0.000289	0		83.3
200	16.7	July	0.00219	0.000365	0		83.4
201	16.8	August	0.00219	0.000365	0		83.4
202	16.8	September	0.00219	0.000365	0		83.4
203	16.9	October	0.00219	0.000365	0		83.4
204	17	November	0.00219	0.000365	0		83.4
205	17.1	December	0.00219	0.000365	0		83.4
206	17.2	January	0.00219	0.000365	0		83.4
207	17.3	February	0.00219	0.000365	0		83.4
208	17.3	March	0.00219	0.000365	0		83.4
209	17.4	April	0.00219	0.000365	0		83.4
210	17.5	May	0.00219	0.000365	0		83.4
211	17.6	June	0.00219	0.000366	0		83.4
212	17.7	July	0.00222	0.000371	0		83.4
213	17.8	August	0.00222	0.000371	0		83.4
214	17.8	September	0.00222	0.000371	0		83.4
215	17.9	October	0.00222	0.000371	0		83.4
216	18	November	0.00222	0.000371	0		83.4
217	18.1	December	0.00222	0.000371	0		83.4
218	18.2	January	0.00222	0.000371	0		83.4
219	18.3	February	0.00222	0.000371	0		83.4
220	18.3	March	0.00222	0.000371	0		83.4
221	18.4	April	0.00222	0.000371	0		83.4
222	18.5	May	0.00222	0.000371	0		83.4
223	18.6	June	0.00244	0.000406	0		83.4
224	18.7	July	0.00244	0.000407	0		83.4
225	18.8	August	0.00245	0.000408	0		83.4
226	18.8	September	0.00245	0.000408	0		83.4
227	18.9	October	0.00245	0.000408	0		83.4
228	19	November	0.00245	0.000408	0		83.4
229	19.1	December	0.00245	0.000408	0		83.4
230	19.2	January	0.00245	0.000408	0		83.4
231	19.3	February	0.00245	0.000408	0		83.4
232	19.3	March	0.00245	0.000408	0		83.4
233	19.4	April	0.00245	0.000408	0		83.4
234	19.5	May	0.00245	0.000408	0		83.4
235	19.6	June	0.00245	0.000408	0		83.4
236	19.7	July	0.00245	0.000408	0		83.4
237	19.8	August	0.00245	0.000408	0		83.4
238	19.8	September	0.00247	0.000412	0		83.4
239	19.9	October	0.00247	0.000412	0		83.4
240	20	November	0.00247	0.000412	0		83.4

Predicted Rutting: Project Ryerson.dgp

Pavement age		Month	Maximum Rutting (inch)											Total Rut Reliability
			AC1	Locat ion (in)	GB2	Locat ion (in)	SG3	Locat ion (in)	Sub Total AC	Sub Total Base	Sub Total SG	Total	Locat ion (in)	
1	0.08	December	0.0004	0	0.0338	0	0.0504	0	0.0004	0.0338	0.0504	0.0846	0	0.1287
2	0.17	January	0.0006	0	0.0406	0	0.0598	0	0.0006	0.0406	0.0598	0.101	0	0.1489
3	0.25	February	0.0009	0	0.0464	0	0.0669	0	0.0009	0.0464	0.0669	0.1142	0	0.165
4	0.33	March	0.0022	0	0.0536	0	0.0721	0	0.0022	0.0536	0.0721	0.1279	0	0.1812
5	0.42	April	0.0035	0	0.0592	0	0.0767	0	0.0035	0.0592	0.0767	0.1393	0	0.1947
6	0.5	May	0.0113	0	0.0696	0	0.081	0	0.0113	0.0696	0.081	0.1619	0	0.2201
7	0.58	June	0.0171	0	0.0778	0	0.0849	0	0.0171	0.0778	0.0849	0.1799	0	0.2404
8	0.67	July	0.0238	0	0.0823	0	0.0881	0	0.0238	0.0823	0.0881	0.1941	0	0.2569
9	0.75	August	0.0277	0	0.0851	0	0.0907	0	0.0277	0.0851	0.0907	0.2035	0	0.2678
10	0.83	September	0.0297	0	0.0867	0	0.093	0	0.0297	0.0867	0.093	0.2094	0	0.2747
11	0.92	October	0.0299	0	0.0871	0	0.0946	0	0.0299	0.0871	0.0946	0.2115	0	0.2772
12	1	November	0.0299	0	0.0871	0	0.0958	0	0.0299	0.0871	0.0958	0.2128	0	0.2788
13	1.08	December	0.0299	0	0.0872	0	0.0969	0	0.0299	0.0872	0.0969	0.214	0	0.2802
14	1.17	January	0.0299	0	0.0876	0	0.0978	0	0.0299	0.0876	0.0978	0.2153	0	0.2817
15	1.25	February	0.0299	0	0.0884	0	0.0995	0	0.0299	0.0884	0.0995	0.2177	0	0.2846
16	1.33	March	0.0299	0	0.0887	0	0.1009	0	0.0299	0.0887	0.1009	0.2195	0	0.2867
17	1.42	April	0.03	0	0.0892	0	0.1023	0	0.03	0.0892	0.1023	0.2214	0	0.289
18	1.5	May	0.0311	0	0.0903	0	0.1038	0	0.0311	0.0903	0.1038	0.2251	0	0.2933
19	1.58	June	0.0339	0	0.0923	0	0.1053	0	0.0339	0.0923	0.1053	0.2315	0	0.3007
20	1.67	July	0.0406	0	0.0948	0	0.1069	0	0.0406	0.0948	0.1069	0.2424	0	0.3133
21	1.75	August	0.0422	0	0.0958	0	0.1082	0	0.0422	0.0958	0.1082	0.2463	0	0.3179
22	1.83	September	0.0431	0	0.0964	0	0.1093	0	0.0431	0.0964	0.1093	0.2488	0	0.3208
23	1.92	October	0.0432	0	0.0965	0	0.1101	0	0.0432	0.0965	0.1101	0.2498	0	0.322
24	2	November	0.0432	0	0.0966	0	0.1107	0	0.0432	0.0966	0.1107	0.2505	0	0.3228
25	2.08	December	0.0432	0	0.0966	0	0.1113	0	0.0432	0.0966	0.1113	0.2511	0	0.3235
26	2.17	January	0.0432	0	0.0966	0	0.1119	0	0.0432	0.0966	0.1119	0.2517	0	0.3242
27	2.25	February	0.0432	0	0.0968	0	0.1127	0	0.0432	0.0968	0.1127	0.2527	0	0.3254
28	2.33	March	0.0433	0	0.097	0	0.1134	0	0.0433	0.097	0.1134	0.2537	0	0.3266
29	2.42	April	0.0433	0	0.0973	0	0.1141	0	0.0433	0.0973	0.1141	0.2547	0	0.3277
30	2.5	May	0.0437	0	0.0979	0	0.1149	0	0.0437	0.0979	0.1149	0.2566	0	0.3299
31	2.58	June	0.045	0	0.0986	0	0.1156	0	0.045	0.0986	0.1156	0.2592	0	0.333
32	2.67	July	0.0465	0	0.0993	0	0.1164	0	0.0465	0.0993	0.1164	0.2622	0	0.3365
33	2.75	August	0.0484	0	0.1001	0	0.1171	0	0.0484	0.1001	0.1171	0.2657	0	0.3405
34	2.83	September	0.0492	0	0.1005	0	0.1177	0	0.0492	0.1005	0.1177	0.2675	0	0.3426
35	2.92	October	0.0493	0	0.1006	0	0.1182	0	0.0493	0.1006	0.1182	0.2681	0	0.3433
36	3	November	0.0493	0	0.1007	0	0.1186	0	0.0493	0.1007	0.1186	0.2685	0	0.3438
37	3.08	December	0.0493	0	0.1007	0	0.1188	0	0.0493	0.1007	0.1188	0.2687	0	0.3441
38	3.17	January	0.0493	0	0.1009	0	0.1191	0	0.0493	0.1009	0.1191	0.2693	0	0.3447
39	3.25	February	0.0493	0	0.1011	0	0.1197	0	0.0493	0.1011	0.1197	0.2701	0	0.3457
40	3.33	March	0.0493	0	0.1012	0	0.1202	0	0.0493	0.1012	0.1202	0.2707	0	0.3464
41	3.42	April	0.0494	0	0.1016	0	0.1208	0	0.0494	0.1016	0.1208	0.2718	0	0.3476
42	3.5	May	0.0498	0	0.1022	0	0.1215	0	0.0498	0.1022	0.1215	0.2734	0	0.3495
43	3.58	June	0.0516	0	0.1035	0	0.1222	0	0.0516	0.1035	0.1222	0.2773	0	0.354
44	3.67	July	0.0542	0	0.1044	0	0.1228	0	0.0542	0.1044	0.1228	0.2814	0	0.3588
45	3.75	August	0.0564	0	0.1051	0	0.1233	0	0.0564	0.1051	0.1233	0.2849	0	0.3629
46	3.83	September	0.0569	0	0.1053	0	0.1238	0	0.0569	0.1053	0.1238	0.286	0	0.3642
47	3.92	October	0.0569	0	0.1054	0	0.1242	0	0.0569	0.1054	0.1242	0.2864	0	0.3647
48	4	November	0.0569	0	0.1054	0	0.1245	0	0.0569	0.1054	0.1245	0.2868	0	0.3651
49	4.08	December	0.0569	0	0.1054	0	0.1248	0	0.0569	0.1054	0.1248	0.2871	0	0.3655
50	4.17	January	0.0569	0	0.1054	0	0.1251	0	0.0569	0.1054	0.1251	0.2875	0	0.3659
51	4.25	February	0.0569	0	0.1054	0	0.1255	0	0.0569	0.1054	0.1255	0.2878	0	0.3663
52	4.33	March	0.0569	0	0.1054	0	0.1259	0	0.0569	0.1054	0.1259	0.2882	0	0.3668
53	4.42	April	0.057	0	0.1058	0	0.1263	0	0.057	0.1058	0.1263	0.2891	0	0.3678
54	4.5	May	0.0571	0	0.106	0	0.1268	0	0.0571	0.106	0.1268	0.29	0	0.3688
55	4.58	June	0.0589	0	0.1073	0	0.1274	0	0.0589	0.1073	0.1274	0.2936	0	0.373
56	4.67	July	0.0621	0	0.1082	0	0.128	0	0.0621	0.1082	0.128	0.2983	0	0.3785
57	4.75	August	0.0637	0	0.1088	0	0.1285	0	0.0637	0.1088	0.1285	0.301	0	0.3817
58	4.83	September	0.0647	0	0.1091	0	0.1289	0	0.0647	0.1091	0.1289	0.3027	0	0.3837
59	4.92	October	0.0648	0	0.1092	0	0.1292	0	0.0648	0.1092	0.1292	0.3031	0	0.3842
60	5	November	0.0648	0	0.1092	0	0.1294	0	0.0648	0.1092	0.1294	0.3034	0	0.3845

61	5.08	December	0.0648	0	0.1092	0	0.1297	0	0.0648	0.1092	0.1297	0.3036	0	0.3847
62	5.17	January	0.0648	0	0.1092	0	0.1298	0	0.0648	0.1092	0.1298	0.3037	0	0.3849
63	5.25	February	0.0648	0	0.1092	0	0.1299	0	0.0648	0.1092	0.1299	0.3039	0	0.3851
64	5.33	March	0.0648	0	0.1094	0	0.1302	0	0.0648	0.1094	0.1302	0.3044	0	0.3857
65	5.42	April	0.0648	0	0.1097	0	0.1307	0	0.0648	0.1097	0.1307	0.3052	0	0.3866
66	5.5	May	0.0649	0	0.11	0	0.131	0	0.0649	0.11	0.131	0.3059	0	0.3874
67	5.58	June	0.0655	0	0.1104	0	0.1314	0	0.0655	0.1104	0.1314	0.3073	0	0.389
68	5.67	July	0.0668	0	0.1108	0	0.1318	0	0.0668	0.1108	0.1318	0.3094	0	0.3915
69	5.75	August	0.0682	0	0.1113	0	0.1322	0	0.0682	0.1113	0.1322	0.3117	0	0.3942
70	5.83	September	0.0686	0	0.1114	0	0.1326	0	0.0686	0.1114	0.1326	0.3126	0	0.3952
71	5.92	October	0.0686	0	0.1115	0	0.1328	0	0.0686	0.1115	0.1328	0.3129	0	0.3956
72	6	November	0.0686	0	0.1115	0	0.1331	0	0.0686	0.1115	0.1331	0.3132	0	0.3959
73	6.08	December	0.0686	0	0.1115	0	0.1333	0	0.0686	0.1115	0.1333	0.3134	0	0.3961
74	6.17	January	0.0686	0	0.1115	0	0.1335	0	0.0686	0.1115	0.1335	0.3136	0	0.3964
75	6.25	February	0.0686	0	0.1116	0	0.1337	0	0.0686	0.1116	0.1337	0.3139	0	0.3967
76	6.33	March	0.0686	0	0.1118	0	0.1344	0	0.0686	0.1118	0.1344	0.3148	0	0.3978
77	6.42	April	0.0687	0	0.1121	0	0.135	0	0.0687	0.1121	0.135	0.3158	0	0.3989
78	6.5	May	0.0688	0	0.1125	0	0.1356	0	0.0688	0.1125	0.1356	0.3169	0	0.4002
79	6.58	June	0.0694	0	0.1129	0	0.136	0	0.0694	0.1129	0.136	0.3183	0	0.4018
80	6.67	July	0.0704	0	0.1132	0	0.1364	0	0.0704	0.1132	0.1364	0.32	0	0.4038
81	6.75	August	0.0709	0	0.1135	0	0.1367	0	0.0709	0.1135	0.1367	0.3211	0	0.4051
82	6.83	September	0.0715	0	0.1137	0	0.1371	0	0.0715	0.1137	0.1371	0.3222	0	0.4064
83	6.92	October	0.0715	0	0.1137	0	0.1373	0	0.0715	0.1137	0.1373	0.3225	0	0.4067
84	7	November	0.0715	0	0.1137	0	0.1375	0	0.0715	0.1137	0.1375	0.3227	0	0.4069
85	7.08	December	0.0715	0	0.1137	0	0.1377	0	0.0715	0.1137	0.1377	0.3229	0	0.4072
86	7.17	January	0.0715	0	0.1137	0	0.1378	0	0.0715	0.1137	0.1378	0.3231	0	0.4074
87	7.25	February	0.0715	0	0.1137	0	0.1381	0	0.0715	0.1137	0.1381	0.3234	0	0.4077
88	7.33	March	0.0715	0	0.1137	0	0.1384	0	0.0715	0.1137	0.1384	0.3236	0	0.408
89	7.42	April	0.0716	0	0.1139	0	0.1387	0	0.0716	0.1139	0.1387	0.3241	0	0.4086
90	7.5	May	0.0717	0	0.114	0	0.139	0	0.0717	0.114	0.139	0.3247	0	0.4092
91	7.58	June	0.0726	0	0.1146	0	0.1394	0	0.0726	0.1146	0.1394	0.3267	0	0.4116
92	7.67	July	0.0741	0	0.115	0	0.1397	0	0.0741	0.115	0.1397	0.3289	0	0.4141
93	7.75	August	0.0749	0	0.1152	0	0.14	0	0.0749	0.1152	0.14	0.3301	0	0.4156
94	7.83	September	0.0751	0	0.1153	0	0.1403	0	0.0751	0.1153	0.1403	0.3307	0	0.4163
95	7.92	October	0.0752	0	0.1154	0	0.1405	0	0.0752	0.1154	0.1405	0.331	0	0.4166
96	8	November	0.0752	0	0.1154	0	0.1406	0	0.0752	0.1154	0.1406	0.3312	0	0.4168
97	8.08	December	0.0752	0	0.1154	0	0.1408	0	0.0752	0.1154	0.1408	0.3313	0	0.417
98	8.17	January	0.0752	0	0.1154	0	0.1409	0	0.0752	0.1154	0.1409	0.3315	0	0.4172
99	8.25	February	0.0752	0	0.1154	0	0.1412	0	0.0752	0.1154	0.1412	0.3317	0	0.4174
100	8.33	March	0.0752	0	0.1154	0	0.1414	0	0.0752	0.1154	0.1414	0.332	0	0.4178
101	8.42	April	0.0752	0	0.1154	0	0.1416	0	0.0752	0.1154	0.1416	0.3322	0	0.418
102	8.5	May	0.0757	0	0.1158	0	0.1419	0	0.0757	0.1158	0.1419	0.3333	0	0.4193
103	8.58	June	0.0766	0	0.1164	0	0.1422	0	0.0766	0.1164	0.1422	0.3351	0	0.4214
104	8.67	July	0.0781	0	0.1168	0	0.1425	0	0.0781	0.1168	0.1425	0.3374	0	0.4241
105	8.75	August	0.0792	0	0.1171	0	0.1428	0	0.0792	0.1171	0.1428	0.3391	0	0.4261
106	8.83	September	0.0797	0	0.1173	0	0.1431	0	0.0797	0.1173	0.1431	0.3401	0	0.4272
107	8.92	October	0.0798	0	0.1173	0	0.1433	0	0.0798	0.1173	0.1433	0.3403	0	0.4275
108	9	November	0.0798	0	0.1173	0	0.1435	0	0.0798	0.1173	0.1435	0.3405	0	0.4277
109	9.08	December	0.0798	0	0.1173	0	0.1436	0	0.0798	0.1173	0.1436	0.3407	0	0.4279
110	9.17	January	0.0798	0	0.1174	0	0.1437	0	0.0798	0.1174	0.1437	0.3408	0	0.4281
111	9.25	February	0.0798	0	0.1175	0	0.144	0	0.0798	0.1175	0.144	0.3413	0	0.4286
112	9.33	March	0.0798	0	0.1175	0	0.1443	0	0.0798	0.1175	0.1443	0.3415	0	0.4289
113	9.42	April	0.0798	0	0.1176	0	0.1445	0	0.0798	0.1176	0.1445	0.3418	0	0.4292
114	9.5	May	0.0801	0	0.1177	0	0.1448	0	0.0801	0.1177	0.1448	0.3425	0	0.43
115	9.58	June	0.0813	0	0.1181	0	0.1451	0	0.0813	0.1181	0.1451	0.3445	0	0.4324
116	9.67	July	0.0843	0	0.1188	0	0.1454	0	0.0843	0.1188	0.1454	0.3484	0	0.437
117	9.75	August	0.0851	0	0.119	0	0.1457	0	0.0851	0.119	0.1457	0.3498	0	0.4386
118	9.83	September	0.0855	0	0.1191	0	0.1459	0	0.0855	0.1191	0.1459	0.3505	0	0.4394
119	9.92	October	0.0855	0	0.1191	0	0.1461	0	0.0855	0.1191	0.1461	0.3507	0	0.4397
120	10	November	0.0855	0	0.1191	0	0.1462	0	0.0855	0.1191	0.1462	0.3509	0	0.4399
121	10.08	December	0.0855	0	0.1191	0	0.1464	0	0.0855	0.1191	0.1464	0.351	0	0.44
122	10.17	January	0.0855	0	0.1191	0	0.1465	0	0.0855	0.1191	0.1465	0.3511	0	0.4401
123	10.25	February	0.0855	0	0.1192	0	0.1467	0	0.0855	0.1192	0.1467	0.3514	0	0.4405
124	10.33	March	0.0855	0	0.1192	0	0.1469	0	0.0855	0.1192	0.1469	0.3516	0	0.4407
125	10.42	April	0.0855	0	0.1192	0	0.1471	0	0.0855	0.1192	0.1471	0.3519	0	0.441
126	10.5	May	0.0857	0	0.1194	0	0.1474	0	0.0857	0.1194	0.1474	0.3525	0	0.4417
127	10.58	June	0.0863	0	0.1196	0	0.1476	0	0.0863	0.1196	0.1476	0.3534	0	0.4428

128	10.67	July	0.0872	0	0.1198	0	0.1478	0	0.0872	0.1198	0.1478	0.3547	0	0.4443
129	10.75	August	0.0882	0	0.12	0	0.1481	0	0.0882	0.12	0.1481	0.3563	0	0.4462
130	10.83	September	0.0886	0	0.1201	0	0.1483	0	0.0886	0.1201	0.1483	0.357	0	0.447
131	10.92	October	0.0886	0	0.1202	0	0.1484	0	0.0886	0.1202	0.1484	0.3572	0	0.4473
132	11	November	0.0886	0	0.1202	0	0.1486	0	0.0886	0.1202	0.1486	0.3573	0	0.4474
133	11.08	December	0.0886	0	0.1202	0	0.1486	0	0.0886	0.1202	0.1486	0.3574	0	0.4475
134	11.17	January	0.0886	0	0.1202	0	0.1487	0	0.0886	0.1202	0.1487	0.3576	0	0.4477
135	11.25	February	0.0886	0	0.1203	0	0.1489	0	0.0886	0.1203	0.1489	0.3578	0	0.4479
136	11.33	March	0.0886	0	0.1203	0	0.1491	0	0.0886	0.1203	0.1491	0.3581	0	0.4483
137	11.42	April	0.0887	0	0.1204	0	0.1494	0	0.0887	0.1204	0.1494	0.3585	0	0.4487
138	11.5	May	0.0888	0	0.1206	0	0.1496	0	0.0888	0.1206	0.1496	0.3591	0	0.4494
139	11.58	June	0.0898	0	0.1211	0	0.1499	0	0.0898	0.1211	0.1499	0.3608	0	0.4514
140	11.67	July	0.0916	0	0.1215	0	0.1501	0	0.0916	0.1215	0.1501	0.3632	0	0.4543
141	11.75	August	0.0929	0	0.1218	0	0.1503	0	0.0929	0.1218	0.1503	0.365	0	0.4564
142	11.83	September	0.0931	0	0.1218	0	0.1505	0	0.0931	0.1218	0.1505	0.3655	0	0.457
143	11.92	October	0.0932	0	0.1218	0	0.1507	0	0.0932	0.1218	0.1507	0.3657	0	0.4572
144	12	November	0.0932	0	0.1218	0	0.1508	0	0.0932	0.1218	0.1508	0.3658	0	0.4573
145	12.08	December	0.0932	0	0.1218	0	0.1509	0	0.0932	0.1218	0.1509	0.3659	0	0.4574
146	12.17	January	0.0932	0	0.1218	0	0.1511	0	0.0932	0.1218	0.1511	0.3661	0	0.4577
147	12.25	February	0.0932	0	0.1218	0	0.1512	0	0.0932	0.1218	0.1512	0.3663	0	0.4579
148	12.33	March	0.0932	0	0.1219	0	0.1514	0	0.0932	0.1219	0.1514	0.3664	0	0.458
149	12.42	April	0.0932	0	0.122	0	0.1516	0	0.0932	0.122	0.1516	0.3668	0	0.4585
150	12.5	May	0.0933	0	0.1221	0	0.1518	0	0.0933	0.1221	0.1518	0.3672	0	0.4589
151	12.58	June	0.0946	0	0.1227	0	0.1521	0	0.0946	0.1227	0.1521	0.3694	0	0.4615
152	12.67	July	0.0971	0	0.1232	0	0.1523	0	0.0971	0.1232	0.1523	0.3726	0	0.4653
153	12.75	August	0.0984	0	0.1235	0	0.1526	0	0.0984	0.1235	0.1526	0.3744	0	0.4675
154	12.83	September	0.099	0	0.1236	0	0.1528	0	0.099	0.1236	0.1528	0.3754	0	0.4686
155	12.92	October	0.099	0	0.1236	0	0.1529	0	0.099	0.1236	0.1529	0.3755	0	0.4687
156	13	November	0.099	0	0.1236	0	0.153	0	0.099	0.1236	0.153	0.3756	0	0.4689
157	13.08	December	0.099	0	0.1236	0	0.1531	0	0.099	0.1236	0.1531	0.3758	0	0.4691
158	13.17	January	0.099	0	0.1236	0	0.1532	0	0.099	0.1236	0.1532	0.3758	0	0.4691
159	13.25	February	0.099	0	0.1236	0	0.1532	0	0.099	0.1236	0.1532	0.3759	0	0.4692
160	13.33	March	0.099	0	0.1237	0	0.1534	0	0.099	0.1237	0.1534	0.3761	0	0.4694
161	13.42	April	0.099	0	0.1238	0	0.1536	0	0.099	0.1238	0.1536	0.3765	0	0.4699
162	13.5	May	0.0991	0	0.1239	0	0.1538	0	0.0991	0.1239	0.1538	0.3768	0	0.4702
163	13.58	June	0.0995	0	0.1241	0	0.154	0	0.0995	0.1241	0.154	0.3776	0	0.4712
164	13.67	July	0.1004	0	0.1243	0	0.1542	0	0.1004	0.1243	0.1542	0.3789	0	0.4727
165	13.75	August	0.1015	0	0.1246	0	0.1544	0	0.1015	0.1246	0.1544	0.3804	0	0.4745
166	13.83	September	0.1018	0	0.1246	0	0.1545	0	0.1018	0.1246	0.1545	0.381	0	0.4752
167	13.92	October	0.1018	0	0.1247	0	0.1547	0	0.1018	0.1247	0.1547	0.3811	0	0.4753
168	14	November	0.1018	0	0.1247	0	0.1548	0	0.1018	0.1247	0.1548	0.3812	0	0.4754
169	14.08	December	0.1018	0	0.1247	0	0.1549	0	0.1018	0.1247	0.1549	0.3813	0	0.4755
170	14.17	January	0.1018	0	0.1247	0	0.155	0	0.1018	0.1247	0.155	0.3814	0	0.4757
171	14.25	February	0.1018	0	0.1247	0	0.1551	0	0.1018	0.1247	0.1551	0.3816	0	0.4759
172	14.33	March	0.1018	0	0.1248	0	0.1555	0	0.1018	0.1248	0.1555	0.3821	0	0.4764
173	14.42	April	0.1018	0	0.125	0	0.1558	0	0.1018	0.125	0.1558	0.3826	0	0.477
174	14.5	May	0.1019	0	0.1252	0	0.1561	0	0.1019	0.1252	0.1561	0.3832	0	0.4777
175	14.58	June	0.1024	0	0.1254	0	0.1564	0	0.1024	0.1254	0.1564	0.3842	0	0.4789
176	14.67	July	0.1032	0	0.1256	0	0.1566	0	0.1032	0.1256	0.1566	0.3854	0	0.4803
177	14.75	August	0.1036	0	0.1257	0	0.1568	0	0.1036	0.1257	0.1568	0.3861	0	0.4811
178	14.83	September	0.104	0	0.1258	0	0.157	0	0.104	0.1258	0.157	0.3867	0	0.4818
179	14.92	October	0.104	0	0.1258	0	0.1571	0	0.104	0.1258	0.1571	0.3869	0	0.482
180	15	November	0.104	0	0.1258	0	0.1572	0	0.104	0.1258	0.1572	0.387	0	0.4821
181	15.08	December	0.104	0	0.1258	0	0.1573	0	0.104	0.1258	0.1573	0.3871	0	0.4823
182	15.17	January	0.104	0	0.1258	0	0.1574	0	0.104	0.1258	0.1574	0.3872	0	0.4824
183	15.25	February	0.104	0	0.1258	0	0.1575	0	0.104	0.1258	0.1575	0.3873	0	0.4825
184	15.33	March	0.104	0	0.1258	0	0.1577	0	0.104	0.1258	0.1577	0.3875	0	0.4827
185	15.42	April	0.104	0	0.1259	0	0.1579	0	0.104	0.1259	0.1579	0.3878	0	0.4831
186	15.5	May	0.1041	0	0.126	0	0.1581	0	0.1041	0.126	0.1581	0.3881	0	0.4834
187	15.58	June	0.1048	0	0.1263	0	0.1583	0	0.1048	0.1263	0.1583	0.3894	0	0.4849
188	15.67	July	0.1059	0	0.1265	0	0.1585	0	0.1059	0.1265	0.1585	0.3909	0	0.4867
189	15.75	August	0.1064	0	0.1266	0	0.1586	0	0.1064	0.1266	0.1586	0.3917	0	0.4876
190	15.83	September	0.1066	0	0.1267	0	0.1588	0	0.1066	0.1267	0.1588	0.3921	0	0.4881
191	15.92	October	0.1067	0	0.1267	0	0.1589	0	0.1067	0.1267	0.1589	0.3923	0	0.4883
192	16	November	0.1067	0	0.1267	0	0.159	0	0.1067	0.1267	0.159	0.3924	0	0.4885
193	16.08	December	0.1067	0	0.1267	0	0.1591	0	0.1067	0.1267	0.1591	0.3925	0	0.4886
194	16.17	January	0.1067	0	0.1267	0	0.1592	0	0.1067	0.1267	0.1592	0.3926	0	0.4887

195	16.25	February	0.1067	0	0.1267	0	0.1593	0	0.1067	0.1267	0.1593	0.3927	0	0.4888
196	16.33	March	0.1067	0	0.1267	0	0.1594	0	0.1067	0.1267	0.1594	0.3928	0	0.4889
197	16.42	April	0.1067	0	0.1267	0	0.1595	0	0.1067	0.1267	0.1595	0.393	0	0.4891
198	16.5	May	0.107	0	0.1269	0	0.1597	0	0.107	0.1269	0.1597	0.3937	0	0.4899
199	16.58	June	0.1077	0	0.1273	0	0.1599	0	0.1077	0.1273	0.1599	0.3949	0	0.4914
200	16.67	July	0.1089	0	0.1275	0	0.1601	0	0.1089	0.1275	0.1601	0.3966	0	0.4934
201	16.75	August	0.1097	0	0.1277	0	0.1603	0	0.1097	0.1277	0.1603	0.3978	0	0.4948
202	16.83	September	0.1102	0	0.1278	0	0.1605	0	0.1102	0.1278	0.1605	0.3985	0	0.4956
203	16.92	October	0.1102	0	0.1278	0	0.1606	0	0.1102	0.1278	0.1606	0.3986	0	0.4957
204	17	November	0.1102	0	0.1278	0	0.1607	0	0.1102	0.1278	0.1607	0.3987	0	0.4959
205	17.08	December	0.1102	0	0.1278	0	0.1608	0	0.1102	0.1278	0.1608	0.3988	0	0.496
206	17.17	January	0.1102	0	0.1279	0	0.1609	0	0.1102	0.1279	0.1609	0.3989	0	0.4961
207	17.25	February	0.1102	0	0.1279	0	0.1611	0	0.1102	0.1279	0.1611	0.3992	0	0.4964
208	17.33	March	0.1102	0	0.128	0	0.1612	0	0.1102	0.128	0.1612	0.3993	0	0.4966
209	17.42	April	0.1102	0	0.128	0	0.1614	0	0.1102	0.128	0.1614	0.3995	0	0.4968
210	17.5	May	0.1104	0	0.1281	0	0.1615	0	0.1104	0.1281	0.1615	0.4	0	0.4973
211	17.58	June	0.1114	0	0.1283	0	0.1617	0	0.1114	0.1283	0.1617	0.4014	0	0.499
212	17.67	July	0.1138	0	0.1287	0	0.1619	0	0.1138	0.1287	0.1619	0.4044	0	0.5026
213	17.75	August	0.1144	0	0.1289	0	0.1621	0	0.1144	0.1289	0.1621	0.4054	0	0.5038
214	17.83	September	0.1148	0	0.129	0	0.1623	0	0.1148	0.129	0.1623	0.406	0	0.5045
215	17.92	October	0.1148	0	0.129	0	0.1624	0	0.1148	0.129	0.1624	0.4062	0	0.5047
216	18	November	0.1148	0	0.129	0	0.1625	0	0.1148	0.129	0.1625	0.4063	0	0.5048
217	18.08	December	0.1148	0	0.129	0	0.1625	0	0.1148	0.129	0.1625	0.4063	0	0.5048
218	18.17	January	0.1148	0	0.129	0	0.1626	0	0.1148	0.129	0.1626	0.4064	0	0.5049
219	18.25	February	0.1148	0	0.129	0	0.1628	0	0.1148	0.129	0.1628	0.4066	0	0.5052
220	18.33	March	0.1148	0	0.129	0	0.1629	0	0.1148	0.129	0.1629	0.4067	0	0.5053
221	18.42	April	0.1148	0	0.129	0	0.163	0	0.1148	0.129	0.163	0.4069	0	0.5055
222	18.5	May	0.115	0	0.1291	0	0.1632	0	0.115	0.1291	0.1632	0.4073	0	0.506
223	18.58	June	0.1155	0	0.1292	0	0.1633	0	0.1155	0.1292	0.1633	0.4081	0	0.5069
224	18.67	July	0.1162	0	0.1294	0	0.1635	0	0.1162	0.1294	0.1635	0.4091	0	0.5081
225	18.75	August	0.1171	0	0.1295	0	0.1637	0	0.1171	0.1295	0.1637	0.4102	0	0.5094
226	18.83	September	0.1174	0	0.1296	0	0.1638	0	0.1174	0.1296	0.1638	0.4108	0	0.5101
227	18.92	October	0.1174	0	0.1296	0	0.1639	0	0.1174	0.1296	0.1639	0.4109	0	0.5102
228	19	November	0.1174	0	0.1296	0	0.164	0	0.1174	0.1296	0.164	0.411	0	0.5103
229	19.08	December	0.1174	0	0.1296	0	0.164	0	0.1174	0.1296	0.164	0.411	0	0.5103
230	19.17	January	0.1174	0	0.1297	0	0.1641	0	0.1174	0.1297	0.1641	0.4112	0	0.5106
231	19.25	February	0.1174	0	0.1297	0	0.1642	0	0.1174	0.1297	0.1642	0.4113	0	0.5107
232	19.33	March	0.1174	0	0.1297	0	0.1644	0	0.1174	0.1297	0.1644	0.4115	0	0.5109
233	19.42	April	0.1174	0	0.1298	0	0.1645	0	0.1174	0.1298	0.1645	0.4118	0	0.5112
234	19.5	May	0.1176	0	0.1299	0	0.1647	0	0.1176	0.1299	0.1647	0.4122	0	0.5117
235	19.58	June	0.1186	0	0.1303	0	0.1649	0	0.1186	0.1303	0.1649	0.4137	0	0.5135
236	19.67	July	0.12	0	0.1305	0	0.165	0	0.12	0.1305	0.165	0.4156	0	0.5157
237	19.75	August	0.1212	0	0.1307	0	0.1652	0	0.1212	0.1307	0.1652	0.4171	0	0.5175
238	19.83	September	0.1214	0	0.1308	0	0.1653	0	0.1214	0.1308	0.1653	0.4175	0	0.518
239	19.92	October	0.1214	0	0.1308	0	0.1654	0	0.1214	0.1308	0.1654	0.4176	0	0.5181
240	20	November	0.1214	0	0.1308	0	0.1655	0	0.1214	0.1308	0.1655	0.4177	0	0.5182

Permanent Deformation: Rutting

IRI

Master Curve Table: HMA Layer 1

Delta	3.24915
Alpha	3.40701
Beta	-0.736571
Gamma	0.355792
a	0.000254751
b	-0.108938
c	6.37735
R2	0.999743
Se/Sy	0.0186685

log(Reduced Time(sec))	E* (psi)	14 oF	40 oF	70 oF	100 oF	130 oF
-5.20319	2617730	2617730				
-4.90216	2472130	2472130				
-3.90216	1961750	1961750				
-3.50422	1754050	1754050				
-2.72848	1358810		1358810			
-2.42745	1213280		1213280			
-1.42745	783685		783685			
-1.02951	641391		641391			
-0.30103	428022			428022		
0	357379			357379		
1	187553			187553		
1.39794	143030			143030		
1.66787	118682				118682	
1.9689	96241.6				96241.6	
2.9689	48152.2				48152.2	
3.36684	36859.4				36859.4	
3.17821	41799.3					41799.3
3.47924	34228.2					34228.2
4.47924	18376					18376
4.87718	14666.1					14666.1

Master Curve HMA Layer 1

Shift Curve Table: HMA Layer 1

a 0.000254751
b -0.108938
c 6.37735

Temp (F)	Shift	14 oF	40 oF	70 oF	100 oF	130 oF
14	4.90216	4.90216				
40	2.42745		2.42745			
70	0			0		
100	-1.9689				-1.9689	
130	-3.47924					-3.47924

Shift Curve HMA Layer 1

- 14°F
- 40°F
- ▲ 70°F
- + 100°F
- * 130°F
- Shift Curve Layer 1

Viscosity Curve Table Short Term and/or RTFO Condition: HMA Layer 1

Ao 11.01
VTS_o -3.701

Log Temp (Rankine)	Log(Viscosity (cp))
2.69871	10.5215
2.72403	8.4794
2.74796	6.9154
2.77063	5.70025

2.68 12.43
2.78 12.43

Temperature Viscosity Relationship at Short Term Aging and/or RTFO Condition - Layer 1