2020

Evaluation of Test Specimen Geometry of Asphalt Mixes Tested with the Asphalt Mixture Performance Tester

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Evaluation of Test Specimen Geometry of Asphalt Mixes Tested with the Asphalt Mixture Performance Tester

Abha Dwivedy

**Dissertation submitted
to the Benjamin M. Statler College of Engineering and Mineral Resources
at West Virginia University**

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in

Civil and Environmental Engineering

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2020

**Keywords: AMPT, Sample Dimensions, Air Void Uniformity, Inscribed Circles,
FlexPAVE**

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Abstract

Evaluation of Test Specimen Geometry of Asphalt Mixes Tested with the Asphalt Mixture Performance Tester

Abha Dwivedy

Asphalt concrete, AC, is a heterogeneous material that is modeled as a homogeneous material. The disparity between material structure and theory presents issue with performance testing with test sample geometries, resulting in variability. To accommodate this issue, the concept of Representative Volume Element, RVE, was developed. RVE is a term that expresses a concept that can be implemented through testing sample dimensions such as aspect ratios, diameter to aggregate size ratio, and gauge length. The laboratory test exhibit variabilities and therefore specimen size should be large enough to enable results representative of AC mix. As RVE of asphalt mix depends on aggregate size, shape, and orientation, it should be unique for each mix due to aggregate effect within the particular AC mix. The purpose of this research is to develop appropriate sample geometry for dynamic modulus, fatigue, and rutting test for accurate characterization of asphalt mix and ease of testing of three different NMA mixes.

Four sample geometries were fabricated for three mix types. All specimens are fabricated at $7\% \pm 0.5\%$ air voids and tested for dynamic modulus, fatigue, and rutting in Asphalt Mixture Performance Tester, AMPT. The effect of sample geometry was statistically analyzed using laboratory test results and performance predictions using FlexPAVE. For ranking analysis all Sample Types, were compared to the full size AASHTO standard dimension used for up to 37.5 mm NMA mixes for dynamic modulus and rutting test and for up to 25 mm NMA mixes for fatigue test. Samples were also tested for air void uniformity using AASHTO R 83-17 for the three NMA mixes. The lateral air void distribution from six different inscribed circles are also statistically analyzed. The MANOVA showed there is a statistical difference for different temperatures and frequencies in dynamic modulus test. This confirms that specific sample types be selected based on the mix NMA for dynamic modulus test. More variability in air void distribution is observed axially than radially. The ST6, one 75X110 mm from one SGC pill, for 12.5 mm and 25 mm and ST4, three 50X110 mm from one SGC pill, for 19 mm NMA mixes have uniform air void distribution from statistical analysis and performed comparable to ST1, one 100X150 mm from one SGC pill, from ranking analysis. These results provide detailed insight on correct sample dimension testing for performance prediction of 12.5 mm, 19 mm, and 25 mm NMA asphalt mixes.

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List of Abbreviations

AASHTO = American Association of State Highway and Transportation Officials

AC = Asphalt Concrete

ASTM = American Society for Testing and Materials

AMPT = Asphalt Mixer Performance Tester

CT = Computed Tomography

DTCF = Direct Tension Cyclic Fatigue Test

DM = Dynamic Modulus

DTT = Direct Tension Tensile test

ESAL = Equivalent Single Axle Load

FHWA = Federal Highway Administration

G_{mb} = Bulk specific gravity of compacted mix

G_{mm} = Theoretical maximum specific gravity of loose mixture

G_{sb} = Specific gravity of bulk aggregate

HMA = Hot Mix Asphalt

ITS = Indirect Tensile Strength

LVDT = Linear Variable Displacement Transducers

MAS = Maximum Aggregate Size

NMAS = Nominal Maximum Aggregate size

NCHRP = National Cooperative Highway Research Program

NCSU = North Carolina State University

P_s = Percentage of stone/aggregate in mix

RAP = Reclaimed Asphalt Pavement

RVE = Representative Volume Element

SSR = Stress sweep Rutting Test

SSD = Saturated Surface Dry

SGC = Superpave Gyrotory Compactor

SHARP = Strategic Highway Research Program

SPT = Simple Performance Tester

S-VECD = Simplified Viscoelastic Continuum Damage

USACE = U.S. Army Corps of Engineers

VTM = Voids in Total Mix

VMA = Voids in Mineral Aggregate

VFA = Voids Filled with Asphalt

WVDOH = West Virginia Department of Highway

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

The U.S. highway system encompasses over 4 million miles of public roads (FHWA, 2019). The West Virginia Department of Highways (WVDOH) is responsible for about 36,000 miles of highway network and despite the small size of the state, it is the 6th biggest network of state-maintained highways in the nation (WVDOH, 2016). Roads are a crucial part of transportation system and with limited resources the Department of Transportation must continue to deliver services and facilitate country's demand.

The WVDOH uses two asphalt mix design methods, Marshall and Superpave. The Superpave mixes are designated by Nominal Maximum Aggregate size (NMAS). The NMAS is one sieve size larger than the first sieve to retain at least 10% of the aggregate blend and Maximum Aggregate size (MAS) is one sieve size larger than NMAS (AASHTO R 35-17). The NMAS of asphalt mix ranges from 4.75 mm to 37.5 mm. The WVDOH designates Marshall Mixes as either wearing or base mix followed by a number that uniquely identifies the NMAS of the mix. The mix types used by the WVDOH are summarized in Table 1 (WVDOT, 2011).

Table 1: Mix Types Used by WVDOH (MP 401.02.22)

Marshall	Superpave	NMAS (mm)	MAS (mm)
Wearing III ¹	4.75	4.75	9.5
Wearing I	9.5	9.5	12.5
-	12.5	12.5	19
Base II Wearing IV ²	19	19	25
-	25	25	37.5
Base I	37.5	37.5	50

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¹ The WVDOH also has pavement preservation specialty mixes for both Marshall and Superpave with a NMAS of 4.75 mm

² The Wearing IV mix requires the gradation pass above the primary sieve control point as defined for a Superpave 19 mm mix

1.2 PROBLEM STATEMENT

Performance testing of asphalt mix is growing with an expectation of accurately measuring engineering properties of pavement materials. Performance testing is important because it ensures the quality of Hot Mix Asphalt (HMA). The measured engineering properties of material can then be used for structural design of pavement. It also provides potential method for evaluating performance expectation in mix design process.

The Asphalt Mixture Performance Tester (AMPT) is a servo-hydraulic test device. FHWA in partnership with state highway agencies uses AMPT for asphalt mix performance testing. AMPT test methods were developed by Witczak under National Cooperative Highway Research Program (NCHRP Report 513, 2003) to test dynamic modulus and permanent deformation of asphalt concrete. Witczak (2000) analyzed multiple sample dimensions and concluded that 100X150 mm was a good geometry to test dynamic modulus and permanent deformation of asphalt mix. In 2009, AASHTO published 100X150 mm geometry for dynamic modulus and flow number testing under AASHTO TP 79. As per FHWA (2013), fatigue testing in AMPT was developed by Christensen and Bonaquist (2009) and Hou et al. (2010). In 2014, AASHTO TP107-14 required 100X130 mm sample for Direct Tension Cyclic (DTC) fatigue testing.

In 2019, AASHTO published three testing procedures based on the work of Kim at NC State University (NCHRP IDEA Project 181, 2017):

- AASHTO TP 132-19- 38X110 mm samples for dynamic modulus tests
- AASHTO TP 133-19- 38X110mm samples for DTC fatigue tests
- AASHTO TP 134-19- 100X150 mm samples for Stress Sweep Rutting (SSR) tests

In addition to the research that produced test methods, several researches have investigated the issue of sample dimensions relative to the aggregate size in the mix (Kutay et al., 2009, Li and Gibson, 2012, Bower et al., 2015, Lee et al., 2017a, and Lee et al., 2017b). Each research recommended different sample geometries. The lack of uniformity in sample size recommendations demonstrates that sample size is an unresolved issue for AMPT testing to evaluate the performance characteristics of asphalt mix.

An issue associated with the NMAS of asphalt mix versus sample dimensions is the distribution of air voids within the sample. Air voids distribution within the sample can impact the evaluation of performance of asphalt mix. Kassem et al. (2011) found air void variability within a sample affected the variability of fatigue test results. Additionally, Lee et al. (2017b) investigated the possibility of end failure in DTC fatigue specimens as a result of air void gradient in the test specimen. To test the air void uniformity within the specimen, AASHTO R 83-17 recommends slicing 100X150 mm test samples into 3

disks, top, middle, and bottom, and using a Student's t test to check for statistically significant difference in the vertical air void distribution. The AASHTO PP 99-19 for 38X110 mm does not require checking air void uniformity. Therefore, there is a need for research to investigate if the air void distribution within 38X110 mm (4 cored from a single Superpave Gyrotory Compacted (SGC) pill and 1 cored from the center of a single SGC pill), 50X110 mm (4 cored from a single SGC pill and 1 cored from the center of a single SGC pill), 75X110 mm, and 100X150 mm is statistically same or not.

AASHTO R 83-17 requires coring 100X150 mm and 100X130 mm specimens from the center of 150X180 mm SGC pills and AASHTO PP 99-19 requires coring four 38X110 mm specimens within a 100 mm diameter of 150X180 mm SGC pill. No research was reported on obtaining the small size specimens outside the 100 mm diameter of SGC pill. By fabricating three 50X110 mm samples within 120 mm diameter of SGC pill and four 38X110 mm samples within 104 mm diameter of SGC pill, total air void distribution within the sample can be compared to 100X150 mm and 75X110 mm specimen, which is obtained from the center of SGC pill. This would help find if total air void in specimen geometry obtained from 120 mm, 104 mm, 100 mm or the center is statistically same or not.

For ease of sample fabrication and testing, small samples are preferred. However, for a composite material that are a blend of aggregates and binder, the minimum sample dimension is constrained by the size of the aggregates. ASTM D-3497³ recommends two sample dimension requirements:

- The minimum ratio of specimen height to diameter should be 2:1
- The minimum ratio of specimen diameter to MAS should be 4:1

In the development of AASHTO TP 79, Witczak (2000) followed the recommendation for the minimum ratio of specimen diameter to MAS but not for minimum ratio of specimen height to diameter (aspect ratio). Contrarily, Park and Kim (2013), and Lee et al., (2017b) followed the recommendation for the minimum aspect ratio but not for minimum ratio of specimen diameter to MAS for the development AASHTO TP 132-19 and TP 133-19.

Some researches referred to these minimum specimen dimensions and minimum gauge length to measure sample deformation as Representative Volume Element, RVE. Several researches (Witczak et al., 2000, Chehab et al., 2000, and Weissman et al., 1999) have investigate RVE from laboratory performance test and concluded different results for specimen dimension: aspect ratio and diameter to MAS ratio. This indicates sample dimension is an unresolved issue for AMPT testing and more research is needed to examine sample geometry by analyzing dynamic modulus, fatigue, and rutting of different

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³ Although ASTM D-3497 was withdrawn, it is a referenced cited by some researchers.

asphalt mixes. This research can help define RVE requirements and sample dimensions for reliable performance testing with the AMPT.

1.3 OBJECTIVE

The objective of this research is to determine appropriate sample geometry for dynamic modulus, fatigue, and rutting test for accurate characterization of asphalt mix and ease of testing.

1.4 SCOPE AND LIMITATIONS

The scope of this research is divided into three parts:

1. Effect of new specimen geometries (50X110 mm and 75X110 mm) yielding different aspect and diameter to MAS ratio for dynamic modulus, DTC fatigue, and SSR test.
2. Effect of vertical coring three 50X110 mm specimens from 120 mm and four 38X110 mm specimens from 104 mm diameter within the SGC pill. Additionally, effect of vertical coring one 75X110 mm specimen from the center of SGC pill.
3. Investigate air void variability within sample.

Most researches have evaluated 100X150 mm, 100X130 mm and 38X110 mm specimens therefore, the purpose of this research is to analyze another small scale specimen of 50X110 mm as this dimension would provide better Representative Volume Element (RVE) for higher NMAS mixes such as 19 and 25 mm, yet yield three specimens per a single SGC pill. Additionally, 75X110 mm specimens are researched as this may provide better air void uniformity compared to 100X150 mm and 100X130 mm specimens. This research also fabricates three 50X110 mm specimens from a single SGC pill and compare the permanent strain results to 100X150 mm specimens.

The air void uniformity is tested and compared between different geometries obtained from a single SGC pill to investigate the reduction in air void from coring within 120- and 104-mm diameter of SGC pill.

The air void uniformity within each specimen is tested by sawing the specimens in three equal sections.

Due to extensive geometry testing, only three different plant produced asphalt mixes with different NMAS is tested. The three plant produced asphalt mixes are: 12.5 mm, Marshall Wearing 4 (19 mm), and 25 mm. Additionally, only the equipment available in WVU asphalt lab are used for this research with a single operator.

CHAPTER 2. LITERATURE REVIEW

This chapter discusses AMPT testing and data analysis. For AMPT test, SGC is used to compact asphalt mix into cylindrical test pills of 150 mm in diameter and 180 mm in height, called SGC pill⁴. The pills are then trimmed to specific dimensions required for the different tests. Table 2 summarizes AASHTO sample dimensions for the dynamic modulus, Direct Tension Cyclic (DTC) fatigue, and Stress Sweep Rutting (SSR) AMPT tests.

Table 2: Sample Dimensions and Maximum NMAS for asphalt mixes used in AMPT Testing per AASHTO Standards

Test	AASHTO Method	Max. NMAS, mm	Diameter, mm	Height, mm
Dynamic Modulus	T 378-17*	37.5	100	150
	TP 132-19**	19	38	110
DTC Fatigue	TP 107-18	25	100	130
	TP 133-19**	19	38	110
SSR	TP 134-19	37.5	100	150

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*This standard replaced TP 79 that was commonly cited by researchers.

**Four samples are obtained from a single SGC pill.

Meaningful use of the AMPT necessitates analysis to estimate material parameters for pavement performance. For the analysis of the dynamic modulus tests, the Excel template developed by Bonaquist (2011) was used to compute master curve parameters. The analysis of the dynamic modulus can also be performed with DTC fatigue and SSR tests in FlexMAT Cracking and Rutting templates developed by Kim (2018) at North Carolina State University (NCSU). The output of these templates is used for the material inputs to the NCSU FlexPAVE program for mechanistic analysis and pavement deterioration predictions (FlexPAVE 1.1 Alpha., 2018).

This chapter also discusses volumetric properties of asphalt mix in dynamic modulus, fatigue, and rutting. The literature on air void distribution within the SGC pill is discussed in addition to specimen geometries and different asphalt mix NMAS used by different researches to test the outcome of performance test.

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⁴ In some cases, the samples are obtained using 6-inch diameter core of the pavements. Test results from field core are not discussed here in.

The AASHTO standards provide protocols for AMPT testing for dynamic modulus, DTC fatigue, and SSR test. However, some researchers used testing methods that were not performed with current AASHTO protocol. These include:

- Push-Pull fatigue test- uniaxial tension compression test performed in controlled stress and strain loading mode. The stress control is set at ± 610 kPa and strain control is ± 300 microstrain. The strain level is controlled using LVDT actuator with an initial specimen strain of 300 microstrain (Kutay et al., 2009).
- Uniaxial compressive test- stiffness test conducted per ASTM D 3497 by applying haversine loading between 0 to 35 psi. This test is conducted either unconfined or with a confining pressure 30 psi. The test temperatures and frequencies are:

Temperature, °C	Frequency, Hz
5	1
	4
	16
25	1
	4
	16
40	1
	4
	16

- Crosshead rate monotonic test until failure- conducted in uniaxial tension with crosshead rate of 0.0004 strains/sec and temperature between -30°C to 40°C (Chehab et al., 2000).

2.1 VOLUMETRIC PROPERTIES

The volumetric properties used in this research are:

- Bulk Specific Gravity of asphalt mix (G_{mb}) is determined per AASHTO T 166.
- Maximum Specific Gravity of AC mix (G_{mm}) is determined per AASHTO T 209.
- Bulk Specific Gravity of Aggregate (G_{sb}) is determined per AASHTO T 84-13 (2017)).
- Voids in Total Mix (VTM) is determined per AASHTO T 269-14.
- Voids in Mineral Aggregate (VMA) is determined per AASHTO R 35-17
- Voids Filled with Asphalt (VFA) is determined per AASHTO R 35-17

2.2 ASPHALT MIXTURE PERFORMANCE TESTER TEST METHODS

Asphalt Mixture Performance Testing (AMPT) machine can perform multiple tests such as dynamic modulus, cyclic fatigue, Stress Sweep Rutting (SSR), and flow number. The SSR test was developed as an alternative to the flow number test (Kim and Kim, 2017).

2.2.1 Dynamic Modulus and Phase Angle

Dynamic Modulus Test Protocol

AMPT subjects specimens to controlled sinusoidal (haversine) compressive⁵ stress and the stress values are calculated by setting peak to peak microstrain between 75 and 125 for unconfined 100X150 mm specimen (per AASHTO T 378) and 50 to 75 microstrain for unconfined 38X110 mm specimen (per AASHTO TP 132). At least two replicate specimens are required for dynamic modulus testing (per AASHTO T 378 and AASHTO TP 132). The test specimen air void uniformity is performed on 100X150 mm dynamic modulus specimen (per AASHTO R-83 17) for which three replicate specimens are required.

The test temperature and frequencies in AMPT relate to traffic conditions and road temperature for example low frequency refers to long duration of load. The recommended test temperature and loading frequency for 100X150 mm specimen per AASHTO R 84-17 and for 38X110 mm specimen per AASHTO TP 132 are shown in Tables 3 and 4.

The data quality statistics requirements as per AASHTO T 378-17 and AASHTO TP 132-19 are shown in Table 5. If the data quality does not fall within the range, sample should be discarded, and test should be repeated with a new sample. The possible causes and solution to obtain data quality statistics are provided in the test standard (AASHTO T 378 and AASHTO TP 132).

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⁵ The AASHTO T-378-17 specifications uses sinusoidal to describe the load pulses. The AMPT actually uses a haversine load pulse for compressive tests.

Table 3: Recommended Test Temperatures and Frequencies for 100X150 mm Dynamic Modulus Specimen (AASHTO T 378-17)

PG 58-XX and Softer		PG 64-XX and PG 70-XX		PG 76-XX and Stiffer	
Temperature, °C	Loading Frequencies, Hz	Temperature, °C	Loading Frequencies, Hz	Temperature, °C	Loading Frequencies, Hz
4	10, 1, 0.1	4	10, 1, 0.1	4	10, 1, 0.1
20	10, 1, 0.1	20	10, 1, 0.1	20	10, 1, 0.1
35	10, 1, 0.1, and 0.01	40	10, 1, 0.1, and 0.01	45	10, 1, 0.1, and 0.01

Table 4: Recommended Test Temperatures and Frequencies for 38X110 mm Dynamic Modulus Specimen (AASHTO TP 132-19)

PG 58-XX and Softer		PG 64-XX and Stiffer	
Temperature, °C	Loading Frequencies, Hz	Temperature, °C	Loading Frequencies, Hz
4	10, 1, 0.1	4	10, 1, 0.1
20	10, 1, 0.1	20	10, 1, 0.1
35	10, 1, 0.1	40	10, 1, 0.1

Table 5: Data Quality Statistics for 100X150 mm and 38X110 mm Dynamic Modulus Specimen (AASHTO T 378-17 and AASHTO TP 132-19)

Data Statistics	Limit
Load Standard Error	>10%
Deformation Standard Error	>10%
Deformation Uniformity	>30%
Phase Uniformity	>3 degrees

|*Dynamic Modulus and Phase Angle Analysis*

The stresses and strains measured during the AMPT dynamic modulus are used to compute dynamic modulus and phase angle (Witczak et al., 2000). The dynamic modulus is computed as:

$$|E^*| = \frac{\sigma_0}{\varepsilon_0} \quad (1)$$

Where,

$|E^*|$ = Dynamic modulus, N/m² or psi;

σ_0 = Peak stress amplitude, N/m² or psi;
 ϵ_0 = Peak amplitude of axial strain

The peak stress amplitude, σ_0 , is the peak load applied over sample cross section area. The peak axial strain amplitude, ϵ_0 , is the maximum change in length divided by initial gauge length of 70 mm (Faridmehr et al., 2014).

Phase angle (δ) represents viscous and elastic property of asphalt mix and ranges from 0° to 90°. The phase angle of 0° represents an elastic material and 90° represents a viscous material (Witczak et al., 2000). The phase angle is computed as:

$$\delta = \frac{t_i}{t_p} \times 360 \quad (2)$$

Where,

δ = Phase angle, degrees;

t_i = Average time lag between stress and strain cycles, seconds;

t_p = Average time for stress cycles, seconds

Following the test at each temperature, AMPT creates a summary file with the dynamic modulus and phase angle, and other results about the test as shown in Table 6.

Table 6: Example Dynamic Modulus Test Summary (AASHTO T 378-17 and AASHTO TP 132-19)

Test results summary	10 Hz	1 Hz	0.1 Hz
Dynamic modulus (MPa)	13043	9879	6825
Phase angle (Degrees)	10.13	13.44	18.33
Average temperature (°C)	4.1	4.1	4.1
Average confining pressure (kPa)	0.6	0.7	0.6
Average micro-strain	97	97	100
Load drift (%)	0	0	0
Load standard error (%)	0.7	0.4	0.5
Average deformation drift (%)	-42.5	-70.4	-134.6
Average deformation standard error (%)	2.9	2.6	2.8
Deformation uniformity (%)	28.5	26.2	24.3
Phase uniformity (Degrees)	0.5	0.8	0.9

The dynamic modulus test results from each temperature-frequency pair and from replicate samples are then used to determine a master curve which defines the modulus versus frequency

relationship for the asphalt concrete relative to a reference temperature. The concept for transforming the dynamic modulus test results to a master curve is shown in Figure 1.

Note: the reference temperature is for the master curve. The test results points are plotted versus actual frequency

Figure 1: Asphalt Concrete Master Curve (Lee, 2013).

Figure 1 shows data points obtained from AMPT above and below the fitted line, and points on the fitted line were for tests performed at the reference temperature of the master curve. The master curve is constructed as per time temperature superposition principle which relates frequency to temperature for viscoelastic materials. Master curve is developed by shifting dynamic modulus data for various temperatures with respect to reduced frequency to merge into a smooth curve. The amount of horizontal shift for a given temperature and shift frequency is referred as reduced frequency. The shift factor is the amount of shift that occurs at each temperature to the reference temperature, to form master curve. The dynamic modulus of asphalt mix is determined from master curve at a particular temperature and frequency (Lee, 2013).

The master curve equation from AASHTO R 84 is:

$$\log|E^*| = \delta + \frac{(|E^*|_{\max} - \delta)}{1 + e^{\beta + \gamma\{\log[f_r]\}}} \quad (3)$$

Where,

$|E^*|$ = Dynamic modulus, psi;

δ , β , and γ = Fitting parameters;

$|E^*|_{max}$ = Limiting maximum asphalt mixture dynamic modulus, psi;

f_r = Reduced frequency, Hz

Bonaquist (2011) developed the MasterSolver Excel template for computing the master curve fitting parameters from the AMPT dynamic modulus test. An examination of the equation used by Bonaquist⁶ is:

$$\log|E^*| = \log(\text{Min}) + \frac{\log(\text{Max}) - \log(\text{Min})}{1 + e^{\beta + \gamma \{\log[f_r]\}}} \quad (4)$$

Where,

$|E^*|$ = Dynamic modulus, psi;

Min = Limiting minimum modulus (δ in Equation 3), ksi;

Max = Limiting maximum modulus ($|E^*|_{max}$ in Equation 3), ksi;

β , and γ = Fitting parameters;

f_r = Reduced frequency, Hz

$$\log(f_r) = \log(f) + \log[\alpha(T)] \quad (5)$$

Where,

f_r = Reduced frequency, Hz;

f = Frequency, Hz;

$\alpha(T)$ = Temperature shift factor function

$$\log[\alpha(T)] = \frac{\Delta E_a}{19.14714} \left(\frac{1}{T} - \frac{1}{T_r} \right) \quad (6)$$

Where,

$\alpha(T)$ = Temperature shift factor function

ΔE_a = Activation energy (fitting parameter), (J/mol);

T = Test temperature, (°K);

T_r = Reference temperature, (°K)

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⁶ Dr. Bonaquist verified equation 3 is correct in an email to Dr. Zaniewski, February 17, 2020.

Combining equations 5 and 6, reduced frequency is computed using Arrhenius equation:

$$\log(f_r) = \log(f) + \frac{\Delta E_a}{19.14714} \left(\frac{1}{T} - \frac{1}{T_r} \right) \quad (7)$$

$$|E^*|_{\max} = P_c \left[4,200,000 \left(1 - \frac{VMA}{100} \right) + 435,000 \left(\frac{VFA \times VMA}{10,000} \right) + \frac{1 - P_c}{\frac{\left(1 - \frac{VMA}{100} \right)}{4,200,000} + \frac{VMA}{435,000(VFA)}} \right] \quad (8)$$

Where,

$$P_c = \frac{\left(20 + \frac{435,000(VFA)}{VMA} \right)^{0.58}}{650 + \left(\frac{435,000(VFA)}{VMA} \right)^{0.58}} \quad (9)$$

Where,

$|E^*|_{\max}$ = Limiting maximum asphalt mixture dynamic modulus, psi;

VMA = Voids in mineral aggregate, %;

VFA = Voids filled with asphalt, %

Note that equations 9 and 10 use the volumetric parameters VMA and VFA. These are determined using standard mix design tests (AASHTO R 35-17).

The AMPT dynamic modulus data are analyzed by FlexMAT Cracking Excel template, which generates Prony series and linear viscoelastic properties of asphalt mix (Kim, 2018).

The Prony series was developed to represent long term complex viscoelastic behavior of asphalt mix (Zhang et al.,2018). The Wiechert model is used to obtain Prony series expression of the relaxation modulus. The Wiechert model consist of m Maxwell Models and a parallel spring, to describe the mechanical behavior of asphalt mix. The Prony series is determined as:

$$E^* = E_e + \sum_{i=1}^m \frac{i\omega\rho_i E_i}{i\omega\rho_i + 1} \quad (10)$$

Where,

E^* = Prony series representation of complex modulus (E^*), MPa;

E_e = Equilibrium Modulus or Infinite modulus, $E_e = \frac{\sigma_\infty}{\varepsilon}$, MPa;

σ_∞ = Stress in the i^{th} term, MPa;

ε = Strain;

i = Complex number, $i = \sqrt{-1}$;

ω = Angular frequency, rad/ seconds;

E_i = Relaxation in the i^{th} term or Prony coefficient, MPa;

ρ_i = Relaxation time, $\rho_i = \frac{\eta_i}{E_i}$, seconds;

η_i = Viscosity of dashpot in Maxwell element

Viscoelastic properties in FlexMAT Cracking Excel template include relaxation modulus, Poisson's ratio, and shift factors. Relaxation modulus is the ratio of stress at any time divided by instantaneous strain. When instant strain is fixed and remains constant, the applied stress is relaxed over time. The reduction in stress is called stress relaxation (Sun et al., 2018). The relaxation modulus is computed as:

$$E(t) = E_e + \sum_{i=1}^m E_i \exp(-t/\rho_i) \quad (11)$$

Where,

$E(t)$ = Relaxation modulus, MPa;

E_e = Equilibrium modulus or Infinite modulus, $E_e = \frac{\sigma_\infty}{\varepsilon}$, MPa;

σ_∞ = Stress in the i^{th} term, MPa;

ε = Strain;

E_i = Relaxation modulus in the i^{th} term or Prony coefficient, MPa;

t = Total time, seconds;

ρ_i = Relaxation time, $\rho_i = \frac{\eta_i}{E_i}$, seconds;

η_i = Viscosity of dashpot in a Maxwell element, Pa.sec

The derivation of Prony series is well described by Sun et al. (2018), and Zhang et al (2018).

FlexMAT Cracking is also used to analyze DTC fatigue data from the AMPT. FlexMAT Cracking generates output files for dynamic modulus and DTC fatigue separately for input into FlexPAVE, a 3-D finite element program for analyzing pavement structures (FlexPAVE 1.1 Alpha., 2018).

2.2.2 Direct Tension Cyclic Fatigue

Direct Tension Cyclic Fatigue Test Protocol

The cyclic fatigue test in AMPT is performed per AASHTO TP 107-18 and ASHTO TP 133-19. The cyclic fatigue test is a pull-pull (tension-tension) actuator displacement test. It begins by determining a linear viscoelastic fingerprint. This test is performed at a frequency of 10 Hz and target microstrain of 50 to 75. The fingerprint test determines mix's sensitivity to fatigue damage and records time history, applied load, and axial deformation (AASHTO TP 107-18 and ASHTO TP 133-19). It is used to calculate Dynamic Modulus Ratio (DMR) to ensure linear viscoelastic behavior for Simplified-Viscoelastic Continuum Damage (S-VECD) analysis (Sabouri and Kim, 2014). The S-VECD model characterizes cumulative fatigue damage under external loading in asphalt mix from different loading histories and model parameters (Wang, 2019). The AASHTO TP 107-18 for 100X130 mm does not specify the DMR range however, AASHTO TP 133 for 38X10 mm requires three replicate samples to be in the range of 0.9 to 1.1.

The master curve from MasterSolver is used to calculate the initial dynamic modulus value at a particular temperature and frequency for DTC fatigue test. DMR is computed as:

$$DMR = \frac{|E^*|_{fingerprint}}{|E^*|_{LVE}} \quad (12)$$

Where,

$|E^*|_{fingerprint}$ = Fingerprint dynamic modulus;

$|E^*|_{LVE}$ = Computed from master curve at test temperature and 10 Hz frequency

DTC fatigue test is performed at 10 Hz and temperature for binder grade selected for 98 percent reliability level using LTPP Bind Version 3.0. The test temperature is calculated as:

$$T^{\circ}\text{C} = \frac{\text{High Temperature PG Grade Binder} - \text{Low Temperature PG Grade Binder}}{2} - 3 \quad (13)$$

Three replicate specimens are tested. The seating load and the minimum number of cycle requirements before failure are:

AASHTO	Dimension, mm	Seating Load	Minimum Number of Load Cycles
TP 107-18	100X130	0.09 kN (20 lbs.)	500
TP 133-19	38X110	0.01 kN (2.2 lbs.)	2,000 – 80,000

If the minimum cycles are not achieved, the data and specimen must be discarded, and test must be repeated on new specimen. In DTC fatigue test, the macrocrack must develop within the gauge points, known as middle failure. A macrocrack outside the gauge length is an end failure. Per AASHTO TP 107-18 and AASHTO TP- 133- 19, the data must be discarded, and test must be repeated on new specimen.

Direct Tension Cyclic Fatigue Test Protocol

The FlexMAT Cracking computes the S-VECD fatigue properties as input for FlexPAVE software. The model describes material property as fatigue damage grows. The S-VECD embedded in FlexPAVE computes fatigue damage. The detail of the process is well documented (Hou, 2009, Underwood et al. 2009, Zhang, 2012, Underwood et al., 2012, Witczak et al., 2013, and Sabouri, 2014).

The AMPT test (AASHTO TP 107-18 and ASHTO TP 133-19) generates entire test run and initial five cycles run files. These files contain detailed S-VECD data on axial stress, axial micro strain, peak to peak strain for each LVDT, and dynamic modulus and phase angle at each cycle. FlexMAT computes S-VECD fatigue properties: C_{11} , C_{12} , α , G^R and D^R to be imported into FlexPAVE software.

According to Wang and Kim (2019), the material loses its stored pseudo strain energy in cyclic fatigue as the damage accumulates. The difference between undamaged state of material and current stored pseudo strain energy is referred to as total released pseudo strain energy denoted as W^R . This dissipated pseudo strain energy is related to accumulated amount of damage (S) over a given time under fatigue loading as:

$$\frac{\partial S}{\partial t} = \left(-\frac{\partial W^R}{\partial S} \right)^{\alpha} \quad (14)$$

Where,
 S = Accumulated amount of damage;
 t = Time, second;
 W^R = Dissipated pseudo strain energy;
 α = S-VECD Model Parameter

The accumulated damage is related to pseudo stiffness as:

$$C = 1 - C_{11}(S^{C_{12}}) \quad (15)$$

Where,
 S = Accumulated amount of damage;
 C = Pseudo stiffness;
 C_{11} and C_{12} = S-VECD Model Parameters

FlexPAVE analyses use either G^R or D^R based failure criterion to predict fatigue damage. Sabouri and Kim (2014) developed G^R failure criteria to have power relationship with number of cycles to failure, N_f . The research defined G^R as rate of change of average released pseudo strain energy (per cycle) throughout the entire loading history until failure.

$$G^R = \gamma(N_f)^\delta \quad (16)$$

Where,
 G^R = Rate of change of average released pseudo strain energy (per cycle);
 γ and δ = Coefficients of material properties;
 N_f = Number of cycles to failure

Sabouri and Kim (2014) stated that dissipation of pseudo strain energy results in reduction of pseudo stiffness. The reduction in pseudo stiffness is considered to be caused by damage. There is a log-log relation between G^R and number of cycles to failure is shown as:

$$G^R = \frac{\int_0^{N_f} \frac{1}{2} (1 - C) (\epsilon_{0,ta}^R)^2 dN}{(N_f)^2} \quad (17)$$

Where,

G^R = Rate of change of average released pseudo strain energy (per cycle);

N_f = Number of cycles to failure;

C = Pseudo stiffness;

$\epsilon_{0,ta}^R$ = Pseudo strain amplitude for the duration of the stress in tension;

N = Number of loading cycles

According to Wang et al. (2018) the exponential relationship for G^R makes this failure criteria highly sensitive to test variability. This shortcoming of G^R failure criteria led to the development of the D^R failure criteria (Wang et al., 2018). The linear relationship between sum (1-C) to failure versus N_f is denoted as D^R as shown in Figure 2. The sum (1- C) represents summation of reduction in pseudo stiffness.

Wang et al. (2018) defines D^R failure criteria as average integrity loss per cycle or reduction in pseudo stiffness up to failure, i.e. the slope of the line in Figure 2. It is independent of mode of loading, stress/strain amplitude, and temperature.

Figure 2: Relationship between Sum (1-C) and N_f (Wang and Kim., 2019)

Wang et al. (2018) defines D^R failure criteria as:

$$D^R = \frac{\int_0^{N_f} (1 - C) dN}{N_f} = \frac{\text{sum} (1 - C)}{N_f} \quad (18)$$

Where,

D^R = Pseudo stiffness reduction failure criteria;

N_f = Number of cycles to failure;

N = Number of loading cycles;

C = Pseudo stiffness

Since application of D^R is on an arithmetic scale, the application may be less sensitive to variability and reduce possible error. The D^R offers more reliability over G^R , if same number of tests are used for characterization (Wang et al., 2018) and (Wang and Kim, 2019).

The model parameters from G^R or D^R based failure criterion are used to predict fatigue damage. To account for cracking potential in asphalt mixtures, Wang (2019) developed S-VECD model-based index parameter called S_{app} . Wang (2019) found two main factors that affect cracking potential of asphalt mixtures: modulus and toughness. Modulus represents stiffness of asphalt mix and toughness is the ability to absorb energy without fracturing. The research highlights these two factors because when comparing asphalt mixes under same load amplitude, asphalt mix with poor cracking resistance can either have high modulus with low toughness or low modulus with high toughness. Therefore, S_{app} was developed to address the effect of these parameters on fatigue cracking.

Wang (2019) found the modulus effect can be determined from the damage characterization curve by plotting pseudo stiffness, C with respect to damage, S . The mix with higher modulus value appears higher on the plot compared to mix with low modulus value. Mixes with same modulus value but different toughness can be estimated with higher D_R value where D_R is equal to $1 - C_{avg}$.

$$C_{avg} = \frac{\int_0^{N_f} C dN}{N_f} \quad (19)$$

Where,

C_{avg} = Average pseudo stiffness;

N_f = Number of cycles to failure;

C = Pseudo stiffness;

N = Number of loading cycles

With increase in load cycles, pseudo stiffness, C decreases and as a result average pseudo stiffness, C_{avg} is also low throughout the entire fatigue life of mix. The corresponding S value when C_{avg} is located on the damage characterization curve is defined as representative fatigue damage, S_{rep} .

$$S_{rep} = \left(\frac{\frac{C_{12}}{a_T^{\alpha+1}}}{C_{11}} 1 - C_{avg} \right)^{\frac{1}{C_{12}}} \quad (20)$$

Where,

S_{rep} = Representative fatigue damage;

a_T = Time-Temperature superposition shift factor (Climatic PG Grade -3°C);

α, C_{11}, C_{12} = S-VECD model parameters;

C_{avg} = Average pseudo stiffness

To evaluate fatigue-based failure, S_{rep} parameter is related to number of cycles to failure, N_f .

$$N_f = \left(\frac{1}{m} + 1 \right)^m \times N_{S_{rep}} \quad (21)$$

$$p = 1 - \alpha C_{12} + \alpha \quad (22)$$

Where,

N_f = Number of cycles to failure;

$N_{S_{rep}}$ = Number of cycles for S to be equal to S_{rep} ;

m = Material constant equal to p/C_{12} ;

α, C_{12} = S-VECD model parameters

Wang (2019) proposed an empirical adjustment as S_{rep} failed to accurately represent damage behavior and modulus. The empirical adjusted parameter is called the apparent damage capacity, S_{app} . For

the adjustment, mixture dynamic modulus value at 10Hz and reference temperature was introduced. A power term of $\alpha/4$ was applied on dynamic modulus. Additionally, $1000^{\frac{\alpha}{2}-1}$ was applied to keep S_{app} value in the range of 0 to 50. The final formula to calculate S_{app} of an asphalt mixture is:

$$S_{app} = 1000^{\frac{\alpha}{2}-1} \frac{a_T^{\frac{1}{\alpha+1}} \left(\frac{D^R}{C_{11}} \right)^{\frac{1}{C_{12}}}}{|E^*|^{\frac{\alpha}{4}}} \quad (23)$$

Where,

S_{app} = Apparent damage capacity (In the range of 0-50);

a_T = Time-temperature shift factor for target temperature (Local climatic PG Grade minus 3°C);

α, C_{11}, C_{12} = S-VECD model parameters

D^R = Average reduction in pseudo stiffness up to failure;

$|E^*|$ = Material dynamic modulus at 10Hz and reference temperature

2.2.3 Stress Sweep Rutting

Stress Sweep Rutting Test Protocol

The SSR test (AASHTO TP 134-19) was developed for AMPT to predict permanent strain as a function of load time, temperature, and deviator stress for 100X150 mm specimens. The test requires four replicates at target air void content of $7\% \pm 0.5\%$. Two specimens are tested at low temperature and two specimens are tested at high temperature. The test is conducted at constant confining pressure of 69 kPa (10 psi) with the deviator stresses for each temperature. The low-test temperature is determined from the PG grade:

Table 7: SSR Low Test Temperature for PG Grades

PG Low Temperature, °C	Test Temperature, °C						
	PG High Temperature, °C						
	46	52	58	64	70	76	82
-10	23	26	29	32	32	32	32
-16	20	23	26	29	32	32	32
-22	17	20	23	26	29	32	32
-28	17	17	20	23	26	29	32
-34	17	17	17	20	23	26	29
-40	17	17	17	17	20	23	26
-46	17	17	17	17	17	20	23

The high-test temperature, determined from the depth of the top of the pavement layer and degree-days obtained from LTPPBind Version 3.1, is calculated as:

$$T_h = 0.87 \times \left(58 + 7 \times \frac{DD}{1000} - 15 \times \log(H + 45) \right) \quad (24)$$

Where,

T_h = High test temperature, °C;

DD = Degree Days > 10°C obtained from LTPPBind;

H = 0 for surface layer and design depth to top of layer for base layers, mm

Three levels of deviator stress are applied for 200 cycles each in the order as:

Temperature, °C	Deviator Stress	Load Time, sec	Rest Time, sec
High, T_h	689 kPa (100 psi), 483 kPa (70 psi), and 896 kPa (130 psi)	0.4	3.6
Low, T_l	483 kPa (70 psi), 689 kPa (100 psi), and 896 kPa (130 psi)	0.4	1.6

|Stress Sweep Rutting Analysis

The FlexMAT Rutting computes SSR model coefficients for input into FlexPAVE. AMPT test (AASHTO TP 134-19) generates entire test run for each test specimen. These files contain detailed SSR data on deviator stress, permanent microstrains, deviator load, contact load, and permanent deformation. FlexMAT rutting computes SSR model coefficients: p_1 , p_2 , d_1 , d_2 , β , ε_o , N_1 , and T_{ref} for use in FlexPAVE (FlexPAVE 1.1 Alpha., 2018).

Kim and Kim (2017) states that shift model was developed to calculate viscoplastic strain from deviatoric stress, load time, and temperature. The shift model comprises of viscoplastic strain master curve and shift functions as presented in equation 26 through equation 28 (Kim and Kim, 2017).

$$\varepsilon_{vp} = \frac{\varepsilon_o N_{red}}{(N_1 + N_{red})^\beta} \quad (25)$$

Where,

ε_{vp} = Viscoplastic strain or permanent strain;

$1-\beta$ = Slope of permanent strain versus number of loading cycles in log-log space;

ε_o = Intercept of permanent strain versus number of loading cycles in log-log space;

N_1 = Number of cycles at which secondary region begins as show in Figure 3;
 N_{red} = Reduced number of cycles at reference loading conditions;

$$N_{red} = N^{Physical} \times 10^{a_{10}} \quad (26)$$

Where,

N_{red} = Reduced number of cycles at reference loading conditions;

$N^{Physical}$ = Actual number of load cycles

$$a_{10} = p_1 \log_{10}(\xi_p) + p_2 + (d_1 T_{ref} + d_2) (\log_{10} \left(\frac{\sigma_v}{p_o} \right) - 0.877) \quad (27)$$

Where,

p_1 and p_2 = Coefficients of reduced load time shift factors;

d_1 and d_2 = Coefficients of vertical stress shift factors;

ξ_p = Reduced load Time, seconds;

T_{ref} = Reference temperature, °C;

σ_v = Vertical stress due to vertical loading, kPa;

p_o = Atmospheric pressure, psi

Figure 3: Permanent Deformation of Asphalt Concrete versus Number of Load Cycles (Chilukwa and Lungu, 2019)

2.3 FLEXPAVE

The NCSU researchers developed the FlexPAVE 3-D finite element program to predict pavement distress. The program has two analysis options:

1. Pavement Response Analysis computes stresses, strains and displacements.
2. Pavement Performance Analysis estimates fatigue cracking, damage evolution and rut depth.

FlexPAVE uses data imported from FlexMAT Cracking and FlexMAT Rutting along with user defined parameters for the pavement structure and traffic to analyze the pavement structure. The output and analysis option lets the user specify evaluation point coordinates. The pavement response output shows time history and spatial distribution. Time history graphs show selected response history at evaluation points. Spatial distribution shows contours of selected response at any time within pavement cross section. The pavement performance output shows time history and spatial distribution as part of response results. Fatigue failure criteria are based on pseudo stiffness value of the asphalt. The damage factor distribution over pavement life depicts the growth of damage within the pavement. Damage evolution plots percentage versus pavement life. Finally, rut depth of each layer and total rut depth can be plotted with respect to pavement life (FlexPAVE 1.1 Alpha, 2018).

While FlexPAVE performance analysis is a use tool for evaluating the effect of different mixes on pavement distresses, it does not provide an effective tool for ranking the rutting potential of different mixes. To this end, Ghanbari et. al. (2020) developed a Rutting Strain Index, RSI, for rating the relative performance of mixes. The essence of the RSI is the predication of the rutting level at 20 years of traffic for a standard pavement structure using FlexPAVE. This recently developed method should be evaluated for ranking mixtures.

2.4 VTM IN TEST SPECIMEN DIMENSIONS

Kutay et al. (2009) conducted DTC Fatigue test on 38.1X100 mm and 71.4X150 mm specimen with target VTM of 7%. The average VTM ranged from 6.9 to 8%. VTM of 7% was chosen because it was a good representation of field compaction (Kutay et al., 2009).

Bower et al. (2015) conducted dynamic modulus test on 38X135, 50X135, 38X110, 50X110 and 100X150 mm specimen. The intent was to fabricate the specimens with target air voids of 7% to 8%. However, VTM for some specimens was as high as 12% and as low as 2%. Figure 4 shows bulk air void content as cumulative percent. The VTM of 50% of specimens ranged between 6.5% and 7% (Bowers et al., 2015).

Figure 4: Bulk VTM as Cumulative Air Void Distribution (Bowers et al., 2015)

Blankenship and Anderson (2010) conducted laboratory test to evaluate pavement performance from various air void levels between 4% and 11.5%. The effect of VTM on fatigue performance was evaluated in accordance with AASHTO T 321-07. The results showed that as VTM increased from 7% to 11.5%, fatigue performance at 350 microstrain reduced by 42%. The research concluded that with 1% increase in VTM, reduction in fatigue life is 9.2%. The effect of VTM on rutting performance was also evaluated using flow number test in accordance with AASHTO TP 79. The results showed that with increase in VTM from 7% to 8.5%, rutting resistance of mixture decreased by 34%. The research corresponded reduction in rutting resistance to 22.7% for 1% increase in VTM (Blankenship and Anderson, 2010).

2.5 AIR VOID DISTRIBUTION IN SPECIMENS

Thyagarajan et al. (2010) tested vertical and lateral air void distribution for 12.5 mm NMA asphalt mix in SGC pill from Pine Compactor. The study tested:

Test	Diameter, mm	Height, mm
Vertical Heterogeneity	150	150
		100
		50

Test	Radius from the center of specimen, mm
Lateral Heterogeneity	25
	35
	43
	50

The results showed that higher air void content and more uniformity was seen in middle sawed sections of specimens. This was due to “cone effect” as shown in Figure 5. As specimen height increases, cones move away from each other leaving middle section more heterogeneous.

The air void non-uniformity is highest along the circumference where mix is in contact with the mold. Air void heterogeneity exponentially increases for cored specimens moving towards the SGC pill circumference. Lateral heterogeneity index was higher than vertical heterogeneity index as large surface area is in contact with the SGC wall compared to top and bottom plates. Although it was anticipated that cutting the SGC pill to desired height reduced vertical air void heterogeneity and coring the SGC pill to obtain desired diameter specimen affects lateral air void heterogeneity, coring and cutting the SGC pill significantly reduced vertical air void heterogeneity. Out of different compactors tested, pine compactor had highest lateral but lowest vertical air void heterogeneity. The effect of compaction plate on air void heterogeneity was observed even after trimming 10 mm from top and bottom of SGC pill (Thyagarajan et al., 2010).

Figure 5: Compaction of HMA specimen resulting in “Cone Shape” (Thyagarajan et al., 2010)

Chehab et al., (2000) performed a detailed air void distribution for the samples obtained from SGC pill as:

SGC pill	Test Sample
150X175 mm	75X150 mm
150X140 mm	75X115 mm
150X115 mm	75X76 mm
150X175 mm	100X150 mm

The results of air void variation from SGC pill and test samples is shown as:

SGC pill	SGC Pill VTM, %
150X175 mm	5.8
150X140 mm	7.0
150X115 mm	6.9
150X175 mm	5.0

Test Sample	Top to bottom Sectional VTM, %
75X150 mm	4.3
	2.8
	3.6
	3.5
	2.9
	4.2
75X115 mm	4.5
	3.4
	3.7
	3.1
	4.5
75X76 mm	4.3
	4.2
100X150 mm	4.1
	3.4
	3.4
	3.2
	2.1
	3.3

It was found that air void was highest on the top, bottom, and around the wall of SGC pill. The specimens were cut in 6 equal sections.

- Top and bottom sections of 75X150 mm specimens had higher air voids compared to other sections.
- 100X150 mm specimen sections had less air voids than the 75X150 mm specimens.
- The lower sections of 100X150 mm specimens has lower air voids compared to the top sections.
- 75X115 mm and 75X76 mm had the best air void uniformity.

Aguilar (2015) thesis also tested air void uniformity in 100X150 mm specimens (per AASHTO PP 60) for 9.5 mm and 12.5 mm NMAS asphalt mix. All specimens were fabricated at $4\% \pm 0.5\%$ from the center of 150X180 mm SGC pill. It was concluded that samples from SGC did not have uniform air void distribution. On average, VTM in middle section was 1.15% greater than VTM in top and bottom sections for Corelok data (Aguilar, 2015).

Dalton (2016) thesis analyzes air void uniformity in 100X150 mm specimens (per AASHTO PP 60) for 9.5 mm and 19 mm NMAS asphalt mix. All specimens were fabricated at $7\% \pm 0.5\%$ from the center of 150X180 mm SGC pill. It was concluded that the VTM of sections were higher than VTM of intact samples by 0.4%. More frequently, the top section had highest VTM followed by middle and bottom section. The t-test compared VTM of top-middle, middle-bottom, and top-bottom sections. Top-middle and middle-bottom with p-value between 0.06 and 0.6 failed to reject the null hypothesis of equal means for these comparisons. However, p-value of 0.03 in top-bottom comparison resulted in sufficient evidence to reject null hypothesis of equal means for this comparison (Dalton, 2016).

2.6 SAMPLE DIMENSIONS

Asphalt is inherently heterogeneous; however, analysis theories assume homogeneous properties. This disparity between the material structure and the theory assumptions presents issues with test sample size and variability. To accommodate this issue, the concept of a representative volume element, RVE, was developed. This concept has been addressed by several researchers (Weissman et al., 1999, Mitchell et al., 2010, and Lee et al., 2017a). The importance of RVE is stated as: Weissman et al. (1999) stated that consistent results are likely to be obtained when specimen size is larger than RVE. Many laboratory test exhibit variabilities and therefore specimen size should be large enough to enable results representative of AC mix. As RVE of asphalt mix depends on aggregate size, shape, and orientation, it should be unique for each mix due to aggregate effect within particular AC mix (Weissman et al., 1999).

Mitchell et al. (2010) and Lee et al. (2017a) stated RVE as the proper dimension of specimen size and gauge length. The research refers ASTM D 3497 to state two primary requirements for proper specimen dimensions:

- The minimum height to diameter ratio should be 2:1.

- The minimum diameter to MAS ratio should be 4:1

In essence, RVE is a term that expresses a concept that can be implemented through test sample dimensions such as aspect ratios, diameter to MAS ratio, and gauge length. These dimensional parameters should be altered for type of test, rate of loading and test temperature (Weissman et al., 1999 and Mitchell et al., 2010).

The following literature review concentrates on tests that can be replicated with the AMPT. Research using other testing modes, such as Indirect Tensile (IDT) test and Repeated Simple Shear Test at Constant Height (RSST-CH) are not in the scope of this review.

Witczak et al. (2000) tested asphalt mixes of 12.5 mm, 19 mm, and 37.5 mm NMAS with PG 64-22 binder. Uniaxial compression tests were conducted with 70, 100, and 150 mm diameters and aspect ratios of 1, 1.5, 2, and 3. Samples were tested for complex modulus and repeated load permanent deformation. The complex modulus test was performed using controlled stress with nominal stress of 145 psi for high stiffness and 5 psi for low stiffness mixes to produce an axial strain in the range of 75 to 200 microstrain. According to Fremont et al. (2015), high stiffness asphalt mix ranges between 14,000 MPa and 23,000 MPa at 15 °C and 10 Hz. Anything below 14,000 MPa is considered low stiffness asphalt mix. The repeated load permanent deformation test was conducted at 40°C with stress level of 20 psi and 6000 pulse load cycles. Duration of load cycles was 0.1 seconds with rest time of 0.9 seconds. Strain was measured with two LVDTs mounted 180 degree apart in the middle of the specimen with gauge length equal to specimen diameter.

All specimens were fabricated from 150X160 mm SGC pills. For test specimens greater than 150 mm in height, specimens were stacked and glued with epoxy under 5 psi load to achieve the required aspect ratio. Two replicates were tested for each aspect ratio. The target air voids were:

NMAS, mm	VTM, %
12.5	4%±0.5%
19	
37.5	4%±1%

The results showed an increase in dynamic modulus value and increase in standard deviation of data for high stiffness test for specimens with aspect ratio of 1. It was suggested that this was due to the effect of friction, alignment and roughness from the specimen ends. The LVDT's for specimens with aspect ratio of 1 was mounted few millimeters below the loading platen and specimen interface. As a result, greater variability was anticipated from specimen roughness and stress or strain concentrations caused by misalignment as measurements were made closer to specimen ends. However, analysis of

variance in low and high stiffness conditions concluded no significant difference in dynamic modulus due to specimen diameter or specimen aspect ratio. Although no statistically significant difference in dynamic modulus was identified due to aspect ratio, it was concluded that specimens should be tested with an aspect ratio of at least 1.5.

For low and high stiffness conditions, phase angle decreased with increase in diameter suggesting as the diameter increases, specimen response is more elastic. The analysis of variance concluded no significant effect of aspect ratio at any temperature, but significant effect of diameter was found at 4°C and 40°C. No explanation for the diameter effect on phase angle was found however, it was hypothesized that it may be caused due to radial changes in the structure of SGC pill.

The onset of tertiary flow is defined as flow number as it indicates resistance of mix to rutting. The flow number of samples with an aspect ratio of 1 was significantly higher than aspect ratios of 1.5, 2, and 3. Also, flow number for 70 mm diameter samples was less than 100 mm, and 150 mm diameter samples. This suggested a 100 mm diameter with aspect ratio of 1.5 or greater is good for testing flow number. The coefficient of variance was large for 100 mm diameter specimen with an aspect ratio of 1.5. The coefficient of variance was minimized with an aspect ratio of 2. The overall variance increased greatly for 19 mm and 37.5 mm NMA asphalt mix compared to 12.5 mm NMA asphalt mix.

Although 70X140 mm specimen was shown to provide low standard error in dynamic modulus test and low variability, 100X150 mm was recommended for permanent deformation test. Therefore, 100X150 mm specimen was recommended for both complex modulus and permanent deformation test (Witczak et al., 2000).

Chehab et al. (2000) analyzed four different geometries with 12.5 mm NMA asphalt mix and 5.2% PG 70-22 binder for dynamic modulus and constant crosshead-rate monotonic test until failure. Three replicates were used for each geometry with target air void content of $4\% \pm 0.5\%$. The test specimens were cored from SGC pill as:

SGC Pill, mm	Specimen Dimension, mm
150X140	75X115
150X175	75X150
	100X150
100X150 plus two 100X25 slices	100X200*

*Two 100X25 mm sections were glued on top and bottom of 100X150 mm specimen.

The specimens were preconditioned by applying 50 haversine loading at 10Hz and 120 kPa and tested for dynamic modulus and constant crosshead-rate monotonic test until failure. Each specimen was first tested for dynamic modulus followed by 2 hours of rest time to perform constant crosshead-rate monotonic test until failure. The dynamic modulus test was performed with 100 cycles for each loading frequency of 1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz at 40°C. The stress level for dynamic modulus corresponding to strain of 40 microstrain was chosen to keep response within linear viscoelastic range. A 5 minutes rest time was used between each test frequency. For constant crosshead-rate monotonic test until failure, the loading rate was 0.0004 strains/sec. The specimens were rested for two hours for sufficient material relaxation after dynamic modulus test and before crosshead-rate monotonic test. Four LVDTs were mounted at 90 degrees from each other. The gauge length was 57.5 mm for the 75X115 mm specimen and 50 mm for other geometries.

The results showed that dynamic modulus for 100X200 mm specimens was considerably higher than that of other geometries. The research attributed this to the effect of glue deforming between two sections, thereby relieving AC in the middle of specimen from applied stress. Other observations from dynamic modulus test were:

- At 1 Hz, dynamic modulus increased with increase in diameter and aspect ratio.
- At 20 Hz, dynamic modulus decreased with increase in aspect ratio and increased with increase in diameter.
- At 2 and 5 Hz, phase angle of 100X150mm specimen was higher than that of 75X150 mm specimen.
- At 10 Hz, 100X150 mm specimen had higher dynamic modulus than 75X150 mm specimen.

Following observations were made for constant crosshead-rate monotonic test:

- The 75X115 mm and 100X200 mm specimens exhibited lowest strength from stress versus strain curves.
- The 75X150 and 100X150 mm specimens exhibited similar stress versus strain curves.

The study recommended 75X150 mm and 100X150 mm geometry and concluded that it may not be universally applied to other AC mixes and SGC pills (Chehab et al., 2000).

Kutay et al. (2009) conducted dynamic modulus test and cyclic push-pull fatigue test on AMPT for 12.5 mm NMA asphalt mix with following binder types:

Binder Types
PG 72-23
PG 79-28
PG 74-31
PG 74- 28
PG 70-22
PG 73-23

The target air void of lab compacted specimens was 7% with average VTM ranging from 6.9 to 8%. The 38.1X150 mm specimens were cored horizontally from field slabs for push-pull fatigue test.

Dynamic modulus test was performed on only 100X150 mm specimens at following temperatures and loading frequencies:

Temperatures, °C	Frequency, Hz
4	20
19	10
31	5
46	0.5
58	0.1

Cyclic push pull tests were performed on 71.4X150 mm and 38.1X100 mm samples cored from the center of SGC pill. Three replicates for each geometry were tested. In cyclic push-pull test, 71.4X150 mm specimen was tested in stress controlled of ± 610 kPa and strain controlled of $\pm 300\mu\epsilon$. Additionally, 38.1X150 mm specimen was tested in strain controlled of $\pm 300\mu\epsilon$.

The dynamic modulus results from 100X150 mm specimens were in good agreement for all 12.5 mm NMAS mixes with different binder types. Dynamic modulus from the master curve at 19°C and 10 Hz ranked 12.5 mm asphalt mix with different binder from low to high modulus as:

Binder Types
PG 74-31
PG 74-28
PG 79-28
PG 72-23
PG 73-23
PG 70-22

The damage characterization curve for 71.4X150 mm and 38.1X100 mm samples fabricated from different binder types except PG 74-28, collapsed on a single curve. This indicated that 38.1X100 mm

samples can provide same information as 71.4X150 mm samples. The research concluded that 38.1X100 mm samples can be used to characterize asphalt pavements (Kutay et al., 2009).

Li and Gibson (2012) conducted dynamic modulus on seven plant and lab produced asphalt mixes of 4.75 mm, 9.5 mm, 12.5 mm, and 19 mm NMAAS asphalt mix. Dynamic modulus was tested on three replicates for 100X150 mm, 38X140 mm, and 38X110 mm with 70 mm gauge length at following test temperatures and frequencies.

Temperature, °C	Frequency, Hz
4.4	25
21.1	10
37.8	5
54.4	1
	0.5
	0.1

The pull-pull cyclic fatigue test was performed on four plant and lab produced asphalt mixes of 4.75 mm, 9.5 mm, and 19 mm NMAAS asphalt mix. The cyclic fatigue test was performed on 100X150 mm and 38X110 mm specimens with a 70 mm gauge length at 21°C and 10 Hz. For target failure cycle of 1,000 to 10,000, the range of microstrain was set between 50 and 70. The cyclic fatigue data was used to predict fatigue life at 200 $\mu\epsilon$ and 21°C. The binder ranged from PG 58-34 to PG 82-22. Target air voids were 3.5%, 6.5%, 7%, and 9% for dynamic modulus and fatigue tests. SGC pills were compacted at 150X185 mm to fabricate 100X150 mm, 38X110 mm, and 38X140 mm samples. The 100X150 mm specimen was obtained from the center of SGC pills and for 38 mm diameter specimens, six samples were cored from each pill as shown in Figure 6.

Figure 6: 38 mm diameter specimens cored from 150 mm diameter specimen (Li and Gibson, 2012)

The dynamic modulus results showed:

- 38X110 mm and 38X140 mm specimens had lower dynamic modulus value at high temperature and low frequency. 38X110 mm and 38X140 mm specimens had higher phase angle compared to 100X150 mm specimen.
- The 9.5 mm NMAAS mix had statistically different dynamic modulus value for all frequencies at 4.4 °C and 21.1°C. For other mixes, statistically different dynamic modulus value was found at 37.8°C and 54.4°C. The statistical difference in dynamic modulus value was thought to be due to aspect ratio of specimen geometries.

The 100X150 mm and 38X110 mm specimens predicted same fatigue life ranking for 4.75 mm, 9.5 mm, and one of the two 19 mm NMAAS asphalt mix. The other 19 mm NMAAS asphalt mix with PG 58-34 binder showed high fatigue resistance for 100X150 mm specimens compared to 38X110 mm sample. This was attributed to testing at 21°C for all four mixes instead of testing at temperature based on PG grade of binder. Li and Gibson concluded that although the fatigue life for 100X150 mm sample was higher than that of 38X110 mm samples, the values were comparable as shown in Table 8.

Table 8: Failure Cycles for 100X150 mm and 38X110 mm in Cyclic Fatigue Test (Li and Gibson, 2012)

	4.75 mm NMAAS		9.5 mm NMAAS		19 mm NMAAS		19 mm NMAAS	
	100X150 mm	38X110 mm	100X150 mm	38X110 mm	100X150 mm	38X110 mm	100X150 mm	38X110 mm
Failure Cycles (x1M)	24,000	22,800	5,730	9,170	3,210	6,250	4,620	512

Park and Kim (2013) tested uniaxial dynamic modulus test and controlled crosshead cyclic direct tension test on 9.5 mm NMAAS asphalt mix with PG 70-22 SCS modified binder. The research investigated two prismatic specimens of 25 mm thick, 50 mm wide, and 100 mm long, two 38X100 mm specimens, and one 75X150 mm specimen obtained from 150 mm diameter field core as shown in Figure 7.

Figure 7: Sample Fabrication Process: a) 150 mm Field Core, b) Sublayer Thickness in the Core, c) Horizontal Coring to Obtain Prismatic and Cylindrical small specimens, d) Prismatic and Small Performance Test Specimens(Park and Kim, 2013)

Controlled crosshead cyclic direct tension tests were performed at 19°C and 10 Hz and dynamic modulus was conducted at:

Temperature, °C	Frequency, Hz
5°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
20°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
40°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz

The dynamic modulus results showed that dynamic modulus values were very close for different geometries and tested statistically the same. The damage characterization curve for 75x150 mm specimens was below 38X100 mm specimens however, they were statistically same. For the ease of testing, 38X100 mm specimens were recommended (Park and Kim, 2013).

Bower et al. (2015) conducted dynamic modulus test (per AASHTO TP 79) on 38X135 mm, 50X135 mm, 38X110 mm, 50X110 mm and 100X150 mm specimens with LVDT gauge length of 70 mm. Plant produced asphalt mixes of 9.5 mm, 12.5 mm, 19 mm, and 25 mm NMAS were used with binder grades of PG 64-22, PG 70-22, and PG 76-22. Three replicate specimens were tested. The cored samples were prepared with a target air voids of 7% to 8%. However, only 50% of the sample VTM ranged between 6.5% and 7%. The 38X135 mm, 50X135 mm, 38X110 mm, and 50X110 mm specimens were horizontally cored from SGC pill as shown in Figure 8. Generally, three small specimens were cored from SGC pill however, if the pill was less than 200 mm in height, only two specimens were obtained. The dynamic modulus was tested at following temperatures and frequencies with peak to peak microstrain between 75 and 125.

Temperature, °C	Frequency, Hz
4.4°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
21.1°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
37.8°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
54.4°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz

Figure 8: 38 mm and 50 mm diameter specimens cored from SGC pill (Bowers et al., 2015)

The results showed that although sample to sample variability was highest for small scale specimens (38X135 mm, 50X135 mm, 38X110 mm, and 50X110 mm) at 54.4°C, they were statistically same to 100X150 mm sample for all mixes. Further investigation into aggregate anisotropy, effects of air voids, and NMAS was recommended. The analysis recommended 38 mm diameter specimens to be used

for 9.5 mm and 12.5 mm NMA mix and 50 mm diameter specimens to be used for 19 mm and 25 mm NMA diameter mix (Bowers et al., 2015).

Lee et al. (2017a) conducted dynamic modulus and DTC fatigue test on 9.5 mm NMA asphalt mixture with 5.2% virgin PG 70-22 binder and 19% Reclaimed Asphalt Pavement (RAP). The 1.2% by weight of PG 64-22 binder was obtained from the RAP. The same research was also published under NCHRP Idea Project 181 by Castorena et al. (2017)

The dynamic modulus test was conducted (per AASHTO TP 79) on three replicates of only 100X150 mm specimens with 70 mm gauge length, microstrain levels between 50 and 75 and temperatures and frequencies as:

Temperature, °C	Frequency, Hz
5°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
20°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
40°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
54.4 °C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz

The DTC fatigue was conducted on 75X130 mm, 75X150 mm, 100X130 mm, and 100X150 mm samples. Four replicates were tested (per AASHTO TP 107) at 18°C and 10 Hz to determine damage characterization curves.

The results showed that semi-log scale better demonstrated dynamic modulus values at low temperature and high frequency conditions. The log-log scale better demonstrated dynamic modulus values at high temperature and low frequency conditions.

The results showed that 75X150 mm and 100X150 mm specimens had end failure. Despite the end failure, damage characterization curve for 75X150 mm and 100X150 mm samples collapsed with 75X130 mm and 100X130 mm samples. Additionally, 100X150 mm and 100X130 mm samples' damage characterization curves were statistically same as those of 75X150 mm and 75X130 mm samples.

The end failure can cause significant errors and high variability for failure criteria as data is not recorded effectively by LVDTs. Although, damage characterization curves was not affected by end failure, the on-specimen deformation error was large, indicating the importance of new geometry that increases the propensity for failure within the gauge length. Although, 75X130 and 100X130 samples met RVE requirement (per ASTM D-3497) of minimum diameter to MAS ratio of 4 to 1 and an aspect ratio of 2 to 1, 100X130 mm specimen was recommended as it will satisfy RVE requirements for higher NMAAS asphalt mixes (Lee et al., 2017a).

Lee et al. (2017b) tested dynamic modulus on 9.5mm, 12.5 mm, 19mm, and 25mm NMAAS asphalt mixes with PG 64-22 and PG 76-22 binder types. The DTC fatigue test was performed on 9.5 mm, 19.5 mm, and 25 mm NMAAS mixes with PG 64-22 binder. The target air void content for all specimens was $4\% \pm 0.5\%$, however, only 60% of small test specimens had acceptable air voids. The dynamic modulus test (per AASHTO TP 79) was performed on 38X110 mm and 100X150 mm specimen with target on specimen microstrain of 63 with allowable microstrain range between 50 and 75. Three replicate specimens were tested with 70 mm gauge length at temperatures and frequencies:

Temperature, °C	Frequency, Hz
5°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
20°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
40°C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz
54.4 °C	25 Hz
	10 Hz
	5 Hz
	1 Hz
	0.5 Hz
	0.1 Hz

DTC fatigue test was performed (per AASHTO TP 107) with 100X130 mm, 38X110 mm, and prismatic specimens of 25 mm in thickness, 50 mm in width, and 110 mm in height at 18°C and 10Hz. The fabrication of specimens is shown in Figure 9.

The dynamic modulus and phase angle master curves for 38X110 mm and 100X150 mm specimens were statistically same for different NMAAS asphalt mixes at low and intermediate temperatures. However, at high temperature, 38X110 mm specimen displayed higher dynamic modulus and lower phase angle values compared to 100X150 mm specimens.

Damage characterization curves were in good agreement for all test geometries however two test specimen results demonstrating outlier behavior were omitted in demonstrating damage characterization curves for 9.5 mm NMAAS mix. It was concluded that additional 38X110 mm specimens will be required to obtain representative damage curve and failure criterion.

Figure 9: Fabrication of Test Specimen (Lee et al., 2017b)

The damage characterization curve for 19 mm NMAS asphalt mix showed good agreement between 100X130 mm and 38X110 mm specimens however, two out of four 38X110 mm test specimens resulted in end failure. The research attributed end failure to damage localization near larger aggregate present close to the edge of specimen. A high sample to sample variability was observed in 25 mm NMAS mix for 38X110 mm and 100X130 mm specimens in DTC fatigue test. Six out of eight 100X130 mm specimen of 25 mm NMAS resulted in end failure. The 38X110 mm specimen was recommended due to ease of fabrication (Lee et al., 2017b).

Karr (2018) proposed new test geometry with the goal of reducing end failure in DTC fatigue test specimens from field cores. The research used four types of asphalt mixes:

Asphalt Mix Name	NMAS, mm	Binder Type	% Binder
STIV	12.5	PG 64-16	6.2
STIV-R	12.5		6.0
FAA3Q	12.5	PG 70-22 SBS-modified	5.8
TLO	9.5	PG 72-22 SBS-modified	7.5

The STIV-R mix contained 20% RAP. The prismatic specimen was sliced horizontally from 150 mm diameter cylindrical pill and dimensions of 110 mm long by 100 mm wide with thickness between 25 to 38 mm, depending on the thickness of the pavement layer, as shown in Figure 10.

Figure 10: New Prismatic Specimen Proposed for DTC Fatigue Test (Karr, 2018)

The specimens were fabricated by cutting a horizontal slice from the SGC pill and discarding two end slices. The horizontal slices were cut into a rectangular shape. Finally, the radius of 175 mm was achieved from a jig with arched back that cut the specimen about the blade. Up to three specimens were fabricated from a SGC pill and took up to 1 to 2 hours to cut the desired specimen geometries from one pill. A typical glued test specimen on the fatigue platen is shown in Figure 11.

Figure 11: Tapered Prismatic Test Specimen on DTC Fatigue Platen (Karr, 2018)

The results showed that tapered prismatic specimen reduced the end failure drastically. The TLO and FAA3Q mixes with modified binder had higher number of cycles to failure compared to STIV and STIV-R. Karr (2018) also tested the effect of air voids on fatigue test and concluded that increase in VTM reduces fatigue life. One of the drawbacks was alignment of the specimen onto the platen and de-bonding issues. The specimen had to be fabricated properly because any eccentricity resulted in separation of specimen from platen and wastage of that specimen (Karr, 2018).

2.7 COMMENTARY ON LITERATURE REVIEW

The summary of aspect ratio and diameter to MAS ratio from literature is shown in Table 9, Table 10, Table 11, and Table 12.

Witczak et al. (2000) performed very detailed dynamic modulus testing with different NMAAS asphalt mix and aspect ratios. However, did not perform a similar extent of research for DTC fatigue test in AMPT. Additionally, the smallest specimen size in this research was 70X70 mm. More research is required to prove if 38X110 mm specimens will perform similar results.

Chehab et al. (2000) analyzed only 12.5 mm NMAAS asphalt mix with smallest specimen size of 75X115 mm. More research is required for higher NMAAS mix with smaller specimen size such as 38X110 mm.

Kutay (2009) tested 71.4X150 mm and 38.1X100 mm specimens for 12.5 mm NMAAS mix. No statistical analysis was performed to conclude that 38.1X100 mm samples can provide same information as 71.4X150 mm samples because damage characterization curves from different binder types except PG 74 - 28 collapsed on a single curve. Additionally, it is important to verify if small sample geometry will provide significant results for larger NMAAS mix such as 19 mm and 25mm NMAAS. More research is needed to compare results of small specimen geometry such as 71.4X150 mm and 38.1X100 mm to standard full-size specimens of 100X150 mm and 100X1130 mm.

Li and Gibson (2012) cored six 38X110 mm specimens very close to the outside edge of SGC pill. This procedure may have resulted in non-uniform air void distribution within the test sample. No further test was done to assess test specimen uniformity by cutting the specimen into equal sections. More research is needed to verify how far away from the center of SGC pill can small test specimens be cored and sawed to result in less air void non-uniformity. Additionally, although Li and Gibson (2012) conducted dynamic modulus and DTC fatigue testing for small size and large specimens on larger NMAAS of up to 19 mm, the results were not accurately described. For the DTC fatigue testing, it was concluded that 38X110 mm and 100X150 mm specimens predicted same fatigue life ranking for 4.75 mm, 9.5 mm, and one of the two 19 mm NMAAS asphalt mix. The other 19 mm NMAAS AC mix showed high fatigue resistance for 100X150 mm specimens compared to 38X110 mm sample. This was not supported by the data as shown in Table 13. Additionally, the research concluded that fatigue life was comparable between 38X110 mm and 100X150 mm specimens however, no statistical analysis was performed.

Park and Kim (2013) tested 38X100 mm and 75X150 mm specimens for only 9.5 mm NMAAS asphalt mix. Although the results were meaningful, more research is needed to prove if 38X110 mm

specimens can be used for higher NMA mix. Additionally, this research did not compare the results to standard full-size specimens of 100X150 mm and 100X130 mm.

Bower (2015) compacted SGC pill to 150X200 mm to be cored and sawed to desired test specimens. The height of the SGC mold is 250 mm, with the top plate inside the mold. In our experience it was very difficult to fit higher NMA of 19 mm and 25 mm inside the mold and achieve 200 mm height with $7 \pm 0.5\%$ VTM. However, this can be done if mix is put into the mold in lifts and each lift is rodded into the lift below. Smaller NMA mix such as 4.75 mm, 9.5 mm, and 12.5 mm might be able to fit in to the mold with little or no rodding action to achieve $7 \pm 0.5\%$ VTM. Although, Bower (2015) results are promising for dynamic modulus test, more research is needed to evaluate how 50X110 mm small specimens will perform in DTC fatigue test. Also, since Bower (2015) cored the specimens horizontally, it is important to see how 50 mm specimens vertically cored from SGC pill will affect dynamic modulus and fatigue results

Lee et al., (2017a) performed dynamic modulus test on only 100X150 mm specimen. The smallest test specimen for DTC fatigue testing used in this research was 75X130 mm. Additionally, this research was done on 9.5 mm NMA asphalt mix. More research is needed to prove if 38X110 mm will provide similar results for higher NMA mix.

Lee et al., (2017b) compared 38X110 mm specimens with 100X150 mm specimens for smaller and larger NMA asphalt mix. In DTC Fatigue testing, 38X110 mm specimens did not perform well in 19 mm and 25 mm NMA asphalt mix. The research manipulated the data by omitting two outliers to demonstrate damage characterization curves for 9.5 mm NMA mix. No statistical analysis was performed in dynamic modulus or DTC fatigue test to determine agreement between 100X130 mm and 38X110 mm specimens. More research is needed to determine a good small size specimen for higher NMA.

Karr (2018) performed DTC fatigue test on tapered prismatic new geometry however did not compare results to standard full-size geometry of 100X150 mm and 100X130 mm. It is unknown how the results would compare. Although the results were promising for 9.5 mm and 12.5 mm NMA asphalt mix, this research could be extended to larger NMA asphalt mixes such as 19 mm and 25 mm.

Table 9: Summary of Diameter to MAS Ratio on Dynamic Modulus Test from Different Studies in Literature

	Diameter (mm)	NMAS (mm)	MAS (mm)	Diameter: MAS	Summary
Current specification	38	4.75	9.5	4.0:1	N/A
	38	19	25	1.5:1	
	100	4.75	9.5	10.5:1	
	100	25	37.5	2.7:1	
Witczak et al. (2000)	70	12.5	19	3.7:1	For low and high stiffness conditions, phase angle decreased with increase in diameter suggesting that as the diameter increases, specimen response becomes more elastic. Flow number for 70 mm diameter samples was less than 100 mm and 150 mm diameter samples. The overall variance in flow number increased greatly for 19 mm and 37.5 mm NMAS asphalt mix compared to 12.5 mm NMAS asphalt mix.
	70	19	25	2.8:1	
	70	37.5	50	1.4:1	
	100	12.5	19	5.3:1	
	100	19	25	4.0:1	
	100	37.5	50	2.0:1	
	150	12.5	19	7.9:1	
	150	19	25	6.0:1	
Chehab et al. (2000)	75	12.5	19	3.9:1	At 1 Hz, dynamic modulus increased with increase in diameter. At 20 Hz, dynamic modulus increased with increase in diameter.
	100	12.5	19	5.3:1	
Kutay et al. (2009)	100	12.5	19	8.0:1	The dynamic modulus results from 100X150 mm specimens were in good agreement for all 12.5 mm NMAS mix with different binder types.
Li and Gibson (2012)	38	4.75	9.5	4.0:1	The 9.5 mm NMAS mix had statistically different dynamic modulus value for all frequencies at 4.4°C and 21.1°C. The statistical difference in 9.5 mm dynamic modulus value was thought to be due to aspect ratio of specimen geometries. For other mixes, the statistical difference was found at 37.8°C and 54.4°C.
	38	9.5	12.5	3.0:1	
	38	12.5	19	2.0:1	
	38	19	25	1.5:1	
	100	4.75	9.5	10.5:1	
	100	9.5	12.5	8.0:1	
	100	12.5	19	5.3:1	
	100	19	25	4.0:1	

Park and Kim (2013)	38	9.5	12.5	3.0:1	N/A
	75	9.5	12.5	6:01	
Bower et al. (2014)	38	9.5	12.5	3.0:1	The analysis recommended 38 mm diameter specimens to be used for 9.5 and 12.5 mm NMA mix and 50 mm diameter specimens to be used for 19 and 25 mm NMA diameter mix
	38	12.5	19	2.0:1	
	38	19	25	1.5:1	
	38	25	37.5	1.0:1	
	50	9.5	12.5	4.0:1	
	50	12.5	19	2.6:1	
	50	19	12.5	2.0:1	
	50	25	37.5	1.3:1	
	100	9.5	12.5	8.0:1	
	100	12.5	19	5.3:1	
	100	19	25	4.0:1	
	100	25	37.5	2.7:1	
Lee, J.S. et al. (2017a)	75	9.5	12.5	6.0:1	N/A
	100	9.5	12.5	8.0:1	
Lee, K.P. et al. (2017b)	38	9.5	12.5	3.0:1	The dynamic modulus and phase angle master curves were statistically same for different NMA asphalt mixes at low and intermediate temperatures.
	38	12.5	19	2.0:1	
	38	19	25	1.5:1	
	38	25	37.5	1.0:1	
	100	9.5	12.5	8.0:1	
	100	12.5	19	5.3:1	
	100	19	25	4.0:1	
	100	25	37.5	2.7:1	

Table 10: Summary of Aspect Ratio on Dynamic Modulus Test from Different Studies in the Literature

	Diameter (mm)	Height (mm)	Aspect Ratio	Summary
Current specification	38	110	0.4:1	N/A
	100	130	1.3:1	
	100	150	1.5:1	
Witczak et al. (2000)	70	70	1.0:1	The results showed an increase in dynamic modulus value and increase in standard deviation of data for high stiffness test for specimens with aspect ratio of 1. Although no statistically significant difference in dynamic modulus was identified due to aspect ratio, it was concluded that specimens should be tested with an aspect ratio of at least 1.5. The flow number of samples with an aspect ratio of 1 was significantly higher than aspect ratios of 1.5, 2, and 3. Flow number for 70 mm diameter samples was less than 100 mm and 150 mm diameter samples. This suggested a 100 mm diameter with aspect ratio of 1.5 or greater is good for testing flow number. The coefficient of variance was large for 100 mm diameter specimen with aspect ratio of 1.5. The coefficient of variance was minimized with aspect ratio of 2. Although 70X140 mm specimen was shown to provide low standard error in dynamic modulus test and low variability, 100X150 mm was recommended for both complex modulus and permanent deformation test.
	70	105	1.5:1	
	70	140	2.0:1	
	70	210	3.0:1	
	100	100	1.0:1	
	100	150	1.5:1	
	100	200	2.0:1	
	100	300	3.0:1	
	150	150	1.0:1	
	150	225	1.5:1	
	150	300	2.0:1	
	150	450	3.0:1	
	100	100	1.0:1	
	100	69	1.5:1	
	100	35	3.0:1	
	100	17	6.0:1	
	150	150	1.0:1	
	150	100	1.5:1	
	150	50	3.0:1	
	150	25	6.0:1	

Chehab et al. (2000)	75	115	1.5:1	Dynamic modulus for 100X200 mm specimens was considerably higher than that of other geometries. At 1 Hz, dynamic modulus increased with increase in aspect ratio. At 20 Hz, dynamic modulus decreased with increase in aspect ratio. At 2 and 5 Hz, phase angle of 100X150mm was higher than that of 75X150 mm specimen. At 10 Hz, 100X150 mm specimen had higher dynamic modulus than 75X150 mm. The study recommended 75X150 mm and 100X150 mm geometry and concluded that it may not be universally applied to other AC mixes and SGC pills.
	100	150	1.5:1	
	75	150	2.0:1	
	100	200	2.0:1	
Kutay et al. (2009)	100	150	1.5:1	N/A
Li and Gibson (2012)	38	110	2.9:1	38X110 mm and 38X140 mm specimens had lower dynamic modulus value at high temperature. 38X110 mm and 38X140 mm specimens had higher phase angle compared to 100X150 mm specimen.
	38	140	3.7:1	
	100	150	1.5:1	
Park and Kim (2013)	38	100	2.6:1	The dynamic modulus results showed that dynamic modulus values were very close for different geometries and tested statistically the same.
	75	150	2:01	
Bower et al. (2014)	38	110	2.9:1	Sample to sample variability was highest for small scale specimens (38X135, 50X135, 38X110, and 50X110 mm) at 54.4°C. However, they were statistically same to 100X150 mm sample for all mixes.
	38	135	3.6:1	
	50	110	2.2:1	
	50	135	2.7:1	
	100	150	1.5:1	

Lee, J.S. et al. (2017a)	100	150	1.5:1	The semi-log scale better demonstrates dynamic modulus values at low temperature and high frequency conditions. The log-log scale better demonstrates dynamic modulus values at high temperature and low frequency conditions.
Lee, K.P. et al. (2017b)	38	110	2.9:1	The dynamic modulus and phase angle master curves for 38X110 mm and 100X150 mm specimens were statistically same at low and intermediate temperatures. However, at high temperature, 38X110 mm specimen displayed higher dynamic modulus and lower phase angle values compared to 100X150 mm specimens.
	100	150	1.5:1	

Table 11: Summary of Diameter to MAS Ratio on DTC Fatigue Test from Different Studies in Literature

	Diameter (mm)	NMAS (mm)	MAS (mm)	Diameter: MAS	Summary
Current specification	38	4.75	9.5	4.0:1	N/A
	38	19	25	1.5:1	
	100	4.75	9.5	10.5:1	
	100	25	37.5	2.7:1	
Chehab et al. (2000)	75	12.5	19	3.9:1	N/A
	100	12.5	19	5.3:1	
Kutay et al. (2009)	38.1	12.5	19	3.0:1	N/A
	71.4	12.5	19	5.7:1	
Li and Gibson (2012)	38	4.75	9.5	4.0:1	The 100X150 mm and 38X110 mm predicted same fatigue life ranking for 4.75 mm, 9.5 mm, and one of the two 19 mm NMAS asphalt mix. The other 19 mm NMAS AC mix with PG 58-34 binder showed high fatigue resistance for 100X150 mm specimens compared to 38X110 mm sample.
	38	9.5	12.5	3.0:1	
	38	19	25	1.5:1	
	100	4.75	9.5	10.5:1	
	100	9.5	12.5	8.0:1	
	100	19	25	4.0:1	
Park and Kim (2013)	38	9.5	12.5	3.0:1	N/A
	75	9.5	12.5	6:01	
Lee, J.S. et al. (2017a)	75	9.5	12.5	6.0:1	N/A
	100	9.5	12.5	8.0:1	
Lee, K.P. et al. (2017b)	38	9.5	12.5	3.0:1	A high sample to sample variability was observed in 25 mm NMAS mix. Six out of eight 100X130 mm specimen of 25 mm NMAS resulted in end failure. The damage characterization curve for 19 mm NMAS asphalt mix showed good agreement between 100X130 mm and 38X110 mm specimens however, two out of four 38X110 mm test specimens resulted in end failure.
	38	19	25	1.5:1	
	38	25	37.5	1.0:1	
	100	9.5	12.5	8.0:1	
	100	19	25	4.0:1	
	100	25	37.5	2.7:1	

Table 12: Summary of Aspect Ratio on DTC Fatigue Test from Different Studies in the Literature

	Diameter (mm)	Height (mm)	Aspect Ratio	Summary
Current specification	38	110	0.4:1	N/A
	100	130	1.3:1	
	100	150	1.5:1	
Chehab et al. (2000)	75	115	1.5:1	The 75X115 mm and 100X200 mm specimen exhibited lowest strength from stress versus strain curves. The 75X150 and 100X150 mm specimens exhibited similar stress versus strain curves. The study recommended 75X150 mm and 100X150 mm geometry and concluded that it may not be universally applied to other AC mixes and SGC pills
	100	150	1.5:1	
	75	150	2.0:1	
	100	200	2.0:1	
Kutay et al. (2009)	38.1	100	2.6:1	The damage characterization curve for 71.4X150 mm and 38.1X100 mm samples fabricated from different binder types except PG 74-28, collapsed on a single curve. This indicated that 38.1X100 mm samples can provide same information as 71.4X150 mm samples. The research concluded that 38.1X100 mm samples can be used to characterize asphalt pavements
	71.4	150	2.1:1	
Li and Gibson (2012)	38	110	2.9:1	Although the fatigue life for 100X150 mm sample was higher than 38X110 mm, the values were reasonable and comparable
	100	150	1.5:1	
Park and Kim (2013)	38	100	2.6:1	The damage characterization curve for 75x150 mm specimens was below 38X100 mm specimens however, they were statistically same. For the ease of testing, 38X100 mm specimens were recommended
	75	150	2:01	

Lee, J.S. et al. (2017a)	75	150	2.0:1	The results showed that 75X150 mm and 100X150 mm specimens had end failure. Despite the end failure, damage characterization curve for 75X150 mm and 100X150 mm samples collapsed with 75X130 mm and 100X130 mm samples. Additionally, 100X150 mm and 100X130 mm sample's damage characterization curves were statistically same to those of 75X150 mm and 75X130 mm. Although, 75X130 and 100X130 met RVE requirement of minimum diameter to MAS ratio of 4 to 1 and aspect ratio of 2 to 1, 100X130 mm specimen was recommended as it will satisfy RVE requirements for higher NMAS asphalt mixes
	100	150	1.5:1	
	75	130	1.7:1	
	100	130	1.3:1	
	100	150	1.5:1	
Lee, K.P. et al. (2017b)	38	110	2.9:1	The 38X110 mm specimen was recommended due to ease in fabrication.
	100	130	1.3:1	

Table 13: Failure Cycles for 100X150 mm and 38X110 mm in Cyclic Fatigue Test (Li and Gibson, 2012)

	4.75 mm NMAS		9.5 mm NMAS		19 mm NMAS		19 mm NMAS	
	100X150 mm	38X110 mm	100X150 mm	38X110 mm	100X150 mm	38X110 mm	100X150 mm	38X110 mm
Failure Cycles (x1M)	24,000	22,800	5,730	9,170	3,210	6,250	4,620	512
N_f large/ N_f small	1.05		0.625		0.532		9.02	

2.8 COMMENTARY ON AIR VOID DISTRIBUTION

The AMPT testing on different size test specimens must be conducted with uniform target VTM of $7\% \pm 0.5\%$ unlike Bower et al. (2015) where VTM of test specimens ranged from 2% to 12%. As concluded by Blankenship and Anderson (2010), this can cause variation in fatigue and rutting performance between replicates. With difference of as small as 1% VTM, disparity was seen in performance results

Target VTM of $7\% \pm 0.5\%$ is selected as Kutay et al. (2009) stated 7% VTM a good representation of field compaction to test lab compacted specimens for fatigue and rutting performance.

Researches (Thyagarajan et al., 2010 and Chehab et al., 2000) have investigated air void distribution in SGC pill and cored samples to conclude that air void gradient is the highest around mold wall, top, and bottom of SGC pill. Although Li and Gibson (2012) cored six 38X110 mm specimens from single SGC pill, no details were provided on how far away from center the small specimens were obtained. Although Thyagarajan et al. (2010) analyzed lateral air void distribution, no cores were obtained from the analyzed radius: 25 mm, 35 mm, 43 mm, and 50 mm. The research concluded that since coring and cutting the specimens result in erroneous interpretation of air void on core and cut selections, nondestructive method such as X-Ray Computed Tomography is efficient to study microstructure of asphalt mix. Romero and Masad (2001) used X-Ray Computed Tomography to quantify internal structure of asphalt mix by creating a 3-D analysis of aggregate structure and air void distribution (Romero and Masad, 2001).

Research (Thyagarajan et al., 2010) concluded that air void heterogeneity exponentially increases for cored specimens moving towards the circumference of SGC pill and AASHTO PP 99- 19 requires cored small specimens within 100 mm diameter. However, no research has been conducted to compare air void distribution in specimens obtained from within 100 mm diameter to those obtained outside 100 mm diameter. Researchers (Thyagarajan et al., 2010, and Chehab et al., 2000) have analyzed air void distribution within samples from single NMAAS asphalt mix. Although (Dalton, 2016 and Aguilar, 2015) researches have analyzed multiple NMAAS asphalt mix, only one 100X150 mm specimen was cored from the center of 150X180 mm SGC pill. It is important to look at different NMAAS asphalt mixes for different specimen dimensions and conclude if the lateral and vertical air void heterogeneity behavior compares.

CHAPTER 3. METHODOLOGY

3.1 OVERVIEW

This research focuses on one new small specimen geometry of 50X110 mm to be compared with 38X110 mm and one new full specimen geometry of 75X110 mm to be compared with 100X150 or 100X130 mm specimen. All performance tests were performed with the AMPT as described in Appendix A.

With the development of FlexPAVE, this research analyzes rutting using SSR test on a new geometry of 50X110 mm to be compared with 100X150 mm specimen. The summary of sample geometries with different inscribed circle is referred as Sample Type (ST). The inscribed circle defines the surface diameter from which all cored specimens are taken The ST used in this research are shown in Table 14. All samples are fabricated from 150X180 mm SGC pills.

Table 14: Summary of Sample Types

Sample Types	Dynamic Modulus Test, mm	DTC Fatigue Test, mm	Stress Sweep Rutting Test, mm
1	100X150- Three Samples from Three Pills	100X130- Three Samples from Three Pills	100X150- Four Samples from Four Pills
2	38X110- Four Samples from One Pill	38X110- Four Samples from One Pill	N/A
3	38X110- Three Samples from Three Pills	38X110- Three Samples from Three Pills	N/A
4	50X110- Three Samples from One Pill	50X110- Three Samples from One Pill	50X110- Four Samples from Two Pills
5	50X110- Three Samples from Three Pills	50X110- Three Samples from Three Pills	N/A
6	75X110- Three Samples from Three Pills	75X110- Three Samples from Three Pills	N/A

The diameter to MAS ratio and aspect ratio for the geometries as per AASHTO standards and proposed geometries are shown in Table 15.

Table 15: Aspect Ratio and Diameter to MAS Ratio for AASHTO and Researched Geometries

Data Set	Diameter, mm	Height, mm	Aspect Ratio	D: MAS Ratio		
				NMAS, mm		
				12.5	19	25
				MAS, mm		
				19	25	37.5
AASHTO T 378-17	100	150	1.5:1	5.3:1	4.0:1	2.7:1
AASHTO TP 107-18	100	130	1.3:1			
AASHTO TP 132-19 and AASHTO TP 133-19	38	110	2.9:1	2.0:1	1.5:1	1.0:1
Current research	50	110	2.2	2.6	2.0	1.3
	75	110	1.5	4.0	3.0	2.0

3.2 ASPHALT MIXES

Three asphalt mixes, Marshall and Superpave, are used to test dynamic modulus, fatigue, and SSR for different geometries. These mixes are plant produced and are obtained from two paving companies. The mix design sheets are in Appendix B and are summarized in Table 16.

Table 16: Summary of Plant Produced Asphalt Mix Obtained for This Research

Company	Plant Location	Mix Type	NMAS, mm	HMA Type	Binder Content, %	Binder Type	Design Traffic
West Virginia Paving, Inc.	Poca, WV	Superpave	12.5	12.5 mm Skid-RAP	5.5	PG 64H-22	3 to < 30 Million
J. F. Allen Company	Elkins, WV	Marshall	19	Wearing - 4 Skid	4.9	PG 64-22	Heavy
J. F. Allen Company	Lorentz, WV	Superpave	25	25 mm-RAP	4.4	PG 64S-22	3 to < 30 Million

The 12.5 mm and 25 mm NMAS mixes contain Reclaimed Asphalt Pavement (RAP). The percentage of aggregate and binder of RAP in the mix are:

Company	Mix NMAS, mm	RAP aggregate, %	Binder in RAP, %
West Virginia Paving, Inc.	12.5	15	4.7
J. F. Allen Company	25	15	3.4

The mix obtained from the plant was transported and stored in West Virginia University (WVU) Asphalt Technology Laboratory. Upon obtaining the mix, an inventory was prepared based on box number and weight of each box. This is done such that the box can be randomly selected from the inventory. An approximate amount of mix mass obtained was:

Mix NMAS, mm	Mix Mass, Kg
12.5	1,059
W-4 (19)	448
25	494

Each mix was verified as per AASHTO T 312 for Superpave and AASHTO R 68 for Marshall Mixes. The steps for verification are summarized in Appendix C. For verification of Superpave and Marshall asphalt mix, G_{sb} , P_b , and G_{mm} are obtained from T-400. The verification data, Table 17, demonstrate the mixes are within the 4 ± 0.5 percent tolerance.

Table 17: Summary of Asphalt Mix Verification

NMAS, mm	G_{sb}	P_b , %	G_{mm} , Kg/m ³	VTM, %
12.5	2.605	5.5	2.450	3.7
				4.2
				4.1
19	2.639	4.9	2.501	4.1
				4.2
				4.1
25	2.686	4.4	2.545	4.0
				3.8
				3.6

3.3 SAMPLE FABRICATION

All specimens are fabricated at target VTM of $7\% \pm 0.5\%$. The 150X180 mm SGC pills are compacted to achieve a VTM of $8\% \pm 1.0\%$ so that upon coring and sawing, the target VTM of $7\% \pm 0.5\%$ can be achieved. To fabricate 100X130 mm, 100X150 mm and 75X110 mm specimens, specimens are cored from the center of a SGC pill. Additionally, for one set of 50X110 mm and one set of 38X110mm specimens, specimens are cored from the center of a SGC pill. For other sets, a coring template is prepared such that three 50X110 mm and four 38X110mm specimens are cored from a single SGC pill. After coring, the samples are sawed to desired height.

For multiple specimens fabricated from SGC pill, Table 18 shows inscribed circle diameter within SGC pill from which samples are cored and spacing between consecutive cored samples. The inscribed circle diameter is shown in Figure 12.

Table 18: Multiple Test Specimens Fabricated from Inscribed Diameter within SGC Pill

Sample Type	Inscribed circle Diameter, mm	Spacing between samples, mm
1	100	N/A
2	104	8.5
3	38	N/A
4	120	11.0
5	50	N/A
6	75	N/A

Figure 12: Inscribed Circle Diameter of 100 mm from 150 mm Diameter of SGC pill (AASHTO PP-19)

Once specimens are cored and sawed, bulk specific gravity is measured by drying the sample in the Coredry and then performing Saturated Surface Dry (SSD) test (per AASHTO T 166). The samples are then dried overnight and placed in a zip lock bag and stored in a dark cabinet for up to 14 days. The samples are allotted a unique number based on the process in Figure 13.

Figure 13: Flow Diagram of Unique Sample Number Preparation

The unique numbers assigned to test specimens are shown in Table 19

Table 19: Experimental Design Variables and Unique Sample Numbers

Data Set	NMA5, mm						12.5			19			25					
	MAS, mm						19			25			37.5					
	Diameter	Height	H/D	D/MAS			DM	DTC	SSR	DM	DTC	SSR	DM	DTC	SSR			
MAS, 19 mm				MAS, 25 mm	MAS, 37.5 mm													
AASHTO Std	100	150	1.5	5.26	4.00	2.67	1	n/a	4	8	n/a	11	15	n/a	18			
							2		5	9		12	16		19			
							6		10	13		17	20					
	100	130	1.3				n/a	22	n/a	n/a	25	n/a	n/a	28	n/a	21		
							23	26		29								
							24	27		30								
K1m	38	110	2.89	2.00	1.52	1.01	31 a.	32 a.	n/a	33 a.	34 a.	n/a	35 a.	36 a.	n/a			
							31 b.	32 b.		33 b.	34 b.		35 b.	36 b.				
							31 c.	32 c.		33 c.	34 c.		35 c.	36 c.				
Alpha	38	110	2.89	2.00	1.52	1.01	37	40	n/a	43	46	n/a	49	52	n/a			
							38	41		44	47		50	53				
							39	42		45	48		51	54				
	50	110	2.20	2.63	2.00	1.33	55 a.	56 a.	57 a.	58 a.	59 a.	60 a.	61 a.	62 a.	63 a.	64 a.	65 a.	66 a.
							55 b.	56 b.	57 b.	58 b.	59 b.	60 b.	61 b.	62 b.	63 b.	64 b.	65 b.	66 b.
							55 c.	56 c.			59 c.	60 c.			63 c.	64 c.		
	50	110					67	70	n/a	73	76	n/a	79	82	n/a			
							68	71		74	77		80	83				
							69	72		75	78		81	84				
	75	110	1.47	3.95	3.00	2.00	85	88	n/a	91	94	n/a	97	100	n/a			
							86	89		92	95		98	101				
							87	90		93	96		99	102				

A total of 102 SGC pills are compacted for this research to fabricate 132 specimens. Table 20 shows minimum replicates required for each test dimension, total number of SGC pill compacted to produce replicates, number of specimens fabricated from SGC pill by coring and sawing, and number of extra specimens fabricated.

Table 20: Test Specimens and Extra Specimens obtained from SGC Pill for AMPT testing

Test	Dimension, mm	Replicates	Total SGC Pill compacted	Specimens from SGC Pill	Extra
DM and DTC Fatigue	100X150	3	3	3	None
	38X110		1	4	1
	50X110		1	3	None
	75X110		3	3	None
	50X110 (center)		3	3	None
	38X110 (center)		3	3	None
SSR	50X110	4	2	6	2
	100X150		4	4	None

3.4 TEST PARTS FOR AMPT TESTING

After the specimens are fabricated and the VTM verified, gauge points are attached using gauge point fixing jig as shown in Figure 14. The glue jig was designed for 100 mm samples. For the samples with a smaller diameter, arm extensions were fabricated.

Gauge points are glued to the specimen 120 degree apart. The gauge length is set at $70\text{mm} \pm 1\text{mm}$, where axial deformation is measured using LVDT. The gauge points are glued using “clearweld professional grade quick setting epoxy”. The dynamic modulus and SSR test specimen are ready to be tested after application of gauge points. However, for DTC fatigue test the end platens are glued on using the gluing jig, Figure 15.

Figure 14: Gauge Point Fixing Jig

Figure 15: End Platen Gluing Jig a) 100X130 mm specimens b) 38X110 mm, 50X110 mm, and 75X110 mm specimens

The jig ensures that end platen and specimen are centered, and specimen is standing perpendicular to two parallel end platens. The Top and bottom adapter holds end platen such that they are parallel to each

other. Top adapter also provides extra weight for specimen and platens while the epoxy cures. The bottom adapter provides additional height for 110 mm height specimens (38X110 mm, 50X110 mm, and 75X110 mm). This can be seen in Figure 14 where 100X130 mm specimen does not have bottom adapter because the specimen does not need an additional height for top adapter with weight to hit top end platen. However, for 38X110 mm, 50X110 mm, and 75X110 mm specimens, bottom adapter provides extra height.

The angle metal and plastic knob centers the specimen to the end platen. The weights used for each specimen dimension is shown as:

Specimen, mm	Weight, kN	Weight, lb
100X130	0.045	10
75X110	0.02	
50X110		
38X110		
		4.5

The amount of epoxy used for different specimens is:

Dimension, mm	Epoxy	Resin Mass, g	Hardner Mass, g	Hardening Time	Cure Time Before Testing, Hrs.
100X130	Devcon 10120	53.75	6.25	4 Hours	N/A
75X110	Devcon 10240	40	4.65	5 Min.	1
38X110		4	2.16		1
50X110		12	6.5		1

3.5 FABRICATION OF 50X110 MM AND 75X110 MM CUSTOM PARTS

The dynamic modulus and SSR test platens work interchangeably, with the only exception of drainage tube in SSR. Samples are simply placed on the platens and not glued to the platens in dynamic modulus and SSR test. A ball is used in both dynamic modulus and SSR test. The 50X110 mm is the only new specimen that is tested for both dynamic modulus and SSR. The new test parts designed for this research are described Appendix D.

The AMPT test specimen parts for 50X110 mm and 75X110 mm specimens are modeled such that they follow the same AMPT actuator movement as that of 100X150 mm or 100X130 mm and 38X110 mm specimens in dynamic modulus, fatigue, and SSR test.

3.6 DYNAMIC MODULUS PROCEDURE

The dynamic modulus test is conducted per AASHTO 378-17 for 100X150 mm and AASHTO 132-19 for 38X110 mm specimens. These test specifications require a minimum of two replicate

specimens. However, since for this research air void distribution within dynamic modulus samples is evaluated per AASHTO R 83-17, three replicate specimens are tested for dynamic modulus test. The test setup for dynamic modulus test is shown in Figure 16.

The high test temperature is determined from adjusted binder type calculated per Section 2.2.1 (per AASHTO 378-17 and AASHTO 132-19) in Tables 3 and 4. The adjusted binder is calculated from LTPPBind at layer depth, mm and 98% reliability for Morgantown, WV.

Figure 16: Dynamic Modulus Test Setup a) 100X150 mm Specimen b) 38X110 mm

The layer depth used in LTPPBind, the adjusted binder types and high-test temperatures are:

NMAS, mm	Layer Thickness, inch	Layer Depth, inch	T-400 Binder Type	Adjusted Binder Type	High test Temp. C
12	2	2	64H-22	70-22	40
19	3	5	64-22	58-22	35
25	6	11	64S-22	58-16	35

The test parameters used for the dynamic modulus test are summarized in Table 21. The test parameters: microstrain range and test frequencies for 50X110 mm and 75X110 mm specimens are same as for 38X110 mm (AASHTO 132-19).

Table 21: Test Parameters for Dynamic Modulus Test

Dimension, mm	Mix NMAS, mm	Microstrain	Temperature, °C	Frequencies, Hz
100X150	12.5	75-125	4, 20, and 40	0.01, 0.1, 1, and 10
	19		4, 20, and 35	
	25			
38X110	12.5	50-75	4, 20, and 40	0.1, 1, and 10
	19		4, 20, and 35	
	25			
50X110	12.5		4, 20, and 40	
	19		4, 20, and 35	
	25			
75X110	12.5		4, 20, and 40	
	19		4, 20, and 35	
	25			

The steps for dynamic modulus testing and air void uniformity are described in Appendix E.

The dynamic modulus and phase angle data from sum files (AASHTO T 378-17 and AASHTO TP 132-19) generated by the AMPT are uploaded into the FlexMAT Cracking Excel template with the number of test specimen replicates and average of VMA and VFA of replicates. The output of FlexMAT Cracking are linear viscoelastic properties and Prony series data. These are then imported to the FlexPAVE software. The flow diagram of this process is shown in Figure 17.

Figure 17: Flow Diagram of Dynamic Modulus AMPT Data Uploaded into FlexMAT Cracking

The Table 22 shows approximate time to perform dynamic modulus test for different geometries.

Table 22: Approximate Time to Perform Dynamic Modulus Test in AMPT

Dimension, mm	Quarter and Compact, hrs.	SSD Before Fabrication, hr.	Coring and Sawing, hrs.	SSD After Fabrication, hr.	Dynamic Modulus Test, hrs.			Total Time, hrs.
					4C	20C	40/35C	
100X150	4.5	1	1.5	1	5.5	2.5	5	21
38X110	3.5	1	1	1	4	2	2	14.5
38X110 (Center)	4.5	1	1.5	1	4	2	2	16
50X110	3.5	1	1	1	4.5	2	2.5	15.5
50X110 (Center)	4.5	1	1.5	1	4.5	2	2.5	17
75X110	4.5	1	1.5	1	5	2.5	3	18.5

3.7 DIRECT TENSION CYCLIC FATIGUE PROCEDURE

The DTC Fatigue test is conducted per AASHTO TP 107 for 100X130 mm and AASHTO TP 133 for 38X110 mm specimens. A minimum of three replicates are required for DTC fatigue testing. The test setup is shown in Figure 18.

Sample fabrication and testing for different specimen geometries is done per AASHTO specification as:

Dimension, mm	Fabrication Standard	Test Standard
100X130	AASHTO R 83-17	AASHTO TP 107
38X110	AASHTO PP 99-19	AASHTO TP 133
50X110		
75X110		

After specimen fabrication and gluing gauge points, the samples are glued to the platens which have been heated to 40°C. Heating the platen helps specimens from debonding. Prior to testing, glued sample and platen are temperature conditioned at target test temperature.

Figure 18: DTC Fatigue Test Setup a) 100X130 mm Specimen b) 75X110 mm

The test temperature is determined from adjusted binder type per Section 2.2.2, Equation 14. Adjusted binder is calculated from LTPPBind at layer depth, mm and 98% reliability for Morgantown, WV. The layer depth used in LTPPBind, adjusted binder type and test temperature are:

NMAS, mm	Layer Thickness, inch	Layer Depth, inch	T-400 Binder Type	Adjusted Binder Type	Test Temperature, °C
12	2	2	64H-22	70-22	21
19	3	5	64-22	58-22	15
25	6	11	64S-22	58-16	18

DTC fatigue test starts with dynamic modulus fingerprint test. The fingerprint test is performed at 10 Hz and a range of 50 to 75 microstrain for all dimension test specimens. The initial modulus value required for fingerprint test is computed using the master curve from the dynamic modulus test and at DTC fatigue test temperature. The unique sample numbers for dynamic modulus test that were used in MasterSolver at DTC fatigue test temperature to obtain initial estimated modulus for DTC fatigue test specimens are shown as:

Dynamic Modulus Specimens	Initial Estimated Modulus, MPa	DTC Fatigue specimen	Initial Fingerprint, MPa	Final Fingerprint, MPa
1, 2, and 3	6995.5	22	7126	6642
		23	7539	7527
		24	8562	7771
8, 9, and 10	8845.7	25	7636	7015
		26	8990	9057
		27	9696	9516
15, 16, and 17	10165.6	28	6285	6210
		29	9329	8866
		30	9355	8448
31 a, b, and c	7004.2	32 a	5518	5499
		32 b	7274	7198
		32 c	7315	7251
33 a, b, and c	9575.5	34 a	7132	7117
		34 b	8480	8437
		34 c	7464	7335
35 a, b, and c	9230.9	36 a	6591	6587
		36 b	9640	9554
		36 c	7285	7251
37, 38, and 39	7306.6	40	5296	5265
		41	7285	7223
		42	8085	8004
43, 44, and 45	7724.0	46	8274	8186
		47	8481	8409
		48	6570	6551
49, 50, and 51	9138.1	52	9367	9314
		53	8864	8819
		54	8580	8528
55 a, b, and c	7934.9	56 a	6026	5988
		56 b	6491	6433
		56 c	6640	6582
59 a, b, and c	9144.6	60 a	7957	7904
		60 b	8869	8789
		60 c	8002	7944
63 a, b, and c	9235.2	64 a	7100	7041
		64 b	7092	7075
		64 c	7229	7213
67, 68, and 69	6753.2	70	6300	6229
		71	8365	8253
		72	8593	8478
73, 74, and 75	7954.0	76	6549	6528
		77	6776	6731
		78	8893	8820

Dynamic Modulus Specimens	Initial Estimated Modulus, MPa	DTC Fatigue specimen	Initial Fingerprint, MPa	Final Fingerprint, MPa
79, 80, and 81	9898.2	82	8147	8148
		83	9424	9357
		84	8654	8621
85, 86, and 87	7648.6	88	7592	7498
		89	8361	8109
		90	7388	7297
91, 92, and 93	8360.8	94	9591	9477
		95	9412	9251
		96	8986	8878
97, 98, and 99	9252.3	100	7180	7136
		101	7796	7722
		102	8165	8034

The test parameters used for the DTC fatigue test are:

AASHTO	Dimension, mm	Seating Load	Minimum Number of Load Cycles
TP 107-18	100X130	0.09 kN (20 lbs.)	500
TP 133-19	38X110	0.01 kN (2.2 lbs.)	2,000 – 80,000
	50X110		
	75X110		

The file with all cycle data and file with initial cycle data (AASHTO T 378-17 and AASHTO TP 132-19) generated by the AMPT are uploaded into the FlexMAT Cracking Excel template with the number of test specimen replicates. The output of FlexMAT Cracking is S-VECD fatigue properties. These are further imported into FlexPAVE software. The flow diagram of this process is shown in Figure 19.

Figure 19: Flow Diagram of DTC Fatigue AMPT Data Uploaded into FlexMAT Cracking

The end failure data is discarded, and the data is analyzed only for samples with middle failure. The number of samples that resulted in end failure is shown as:

Mix, mm	Sample Type	Number of End Failures
12.5	1	none
19		1
25		2
12.5	2	1
19		none
25		2
12.5	3	none
19		none
25		none
12.5	4	none
19		none
25		none
12.5	5	none
19		none
25		none
12.5	6	none
19		none
25		none

The Table 23 shows approximate time to perform dynamic modulus test for different geometries.

Table 23: Approximate Time to Perform Cyclic Fatigue Test in AMPT

Dimension, mm	Quarter and Compact, hrs.	SSD Before Fabrication, hr.	Coring and Sawing, hrs.	SSD After Fabrication, hr.	DTC Fatigue Test, hrs.		Total Time, hrs.
					Gluing and Resting, hrs.	Test, hrs.	
100X150	4.5	1	1.5	1	14.5	4.5	27
38X110	3.5	1	1	1	4.5	4.5	15.5
38X110 (Center)	4.5	1	1.5	1	4.5	4.5	17
50X110	3.5	1	1	1	4.5	4.5	15.5
50X110 (Center)	4.5	1	1.5	1	4.5	4.5	17
75X110	4.5	1	1.5	1	4.5	4.5	17

The steps for DTC Fatigue testing using AMPT are described in Appendix E.

3.8 STRESS SWEEP RUTTING PROCEDURE

The SSR test is conducted per AASHTO TP 134-19 for 100X150 mm. A minimum of two replicates are tested for each of low and high temperatures. The test setup is shown in Figure 20. Sample fabrication and temperature conditioning are done as per AASHTO R 83-17 and TP 134-19 respectively.

The test temperature is determined from adjusted binder type per Section 2.2.3, Table 7 and Equation 25. Adjusted binder adjusted binder is calculated from LTPPBind at layer depth, mm and 98% reliability for Morgantown, WV. Although 19 mm and 25 mm have same T-400 binder type, the adjusted binder is not same because layer depth for 19 mm NMAS is different from layer depth for 25 mm NMAS. The test setup is shown in Figure 20.

Figure 20: SSR Test Setup for 100X150 mm Specimen

The layer depth used in LTPPBind, adjusted binder type and test temperatures are:

NMAS, mm	Layer Thickness, inch	Layer Depth, inch	T-400 Binder Type	Adjusted Binder Type	Low Temperature, °C	High Temperature, °C
12	2	2	64H-22	70-22	29	46
19	3	5	64-22	58-22	23	38
25	6	11	64S-22	58-16	26	35

The SSR test for 50X110 is conducted as per AASHTP TP 134-19. The deviatoric stress, confining pressure, load time and rest time for 50X110 mm specimens remain same as that for 100X150 mm specimens. The test parameters are shown in section 2.2.3.

The steps for SSR testing using AMPT are described in Appendix E.

Once SSR test is performed in AMPT, the entire test run data is output to an Excel file. The files for replicates are saved in different folders based on low and high temperature for each mix and each test geometry. These folders are then uploaded into FlexMAT Rutting. The SSR model coefficients generated from FlexMAT Rutting is used in FlexPAVE software. The flow diagram of this process is shown in Figure 21.

Figure 21: Flow Diagram of SSR AMPT Data Uploaded into FlexMAT Rutting

The Table 24 shows approximate time to perform SSR test for different geometries.

Table 24: Approximate Time to Perform Stress Sweep Rutting in AMPT

Dimension, mm	Quarter and Compaction, hrs.	SSD Before Fabrication, hrs.	Coring and Sawing, hrs.	SSD After Fabrication, hrs.	SSR Test, hrs.		Total Time, hrs.
					Low Temp.	High Temp.	
100X150	4.5	1	1.5	1	4	4	16
50X110	3.5	1	1	1	2.5	2.5	11.5

3.9 FLEXPAVE PROCEDURE

The flow diagram of FlexPAVE process is shown in Figure 22. FlexPAVE is used to conduct response analysis or performance analysis for all specimen dimension sets.

Figure 22: Flow Diagram of FlexPAVE

The program lets the user conduct response analysis in which only stress, strain, and displacement values within the pavement are computed. The performance analysis also computes responses and additionally estimates fatigue cracking and rutting. In this research, performance analysis is conducted for six specimen dimension sets fabricated from three asphalt mixes.

3.9.1 Pavement Structures

Three pavement structures are used for the analysis. The three Structural Numbers of the pavement represent light, medium, and heavy-duty structures. The layer thicknesses and approximate AASHTO 93 structural number, using a structural coefficient of 0.45 is shown Table 25. For each pavement structure, twelve models are analyzed as shown in Table 26.

Table 25: Pavement Thicknesses for Three Pavement Structures used in FlexPAVE Analysis

	Mix Types	FlexPave Example-Structure 1		Structure assumed for testing-Structure 2		Heavy duty pavement-Structure 3	
Layer	mm	cm	inch	cm	inch	cm	inch
Wearing	12.5	5	1.9	5	2	6.4	2.5
Base 1	19	5	1.9	7.6	3	8.9	3.5
Base 2	25	30	11.8	15.3	6	40.6	16
Subgrade	N/A	380	150	380	150	380	150
Total thickness	N/A	40	15.7	27.9	11.0	55.9	22.0
Approximate Structural Number	N/A	7.07		4.95		9.9	

Table 26: Models for Each of the Three Pavement Structures used in FlexPAVE Analysis

Model	Dynamic Modulus Specimen, mm	DTC Fatigue Specimen, mm	SSR Specimen, mm
1	ST1		
2	ST2		ST1
3	ST3		ST1
4	ST4		
5	ST5		ST4
6	ST6		ST1
7	ST1		ST4
8	ST2		ST4
9	ST3		ST4
10	ST4		ST1
11	ST5		ST1
12	ST6		ST4

Once pavement structure is designated, Prony series, fatigue data, and rutting data are imported for each layer. Pavement structure with material properties are designed and imported for all 12 models shown in Table 26. Each of the three pavement structures are designed for 12 models making total of 36 runs. The subgrade is linearly elastic with modulus value of 95 MPa (13.78 ksi) and Poisson ratio of 0.4.

3.9.2 Climate Data

The climate data is selected for Morgantown, WV from EICM (Enhanced Integrated Climatic Model) database (NCHRP Report 602, 2008).

3.9.3 Traffic Data

A speed of 60 mph was assumed for the analysis.

FlexPAVE allows single axle analysis or single wheel analysis. Single axle represents entire axle and single wheel represents half an axle. An axle load of 18,000 lb (80kN) with dual tires, a tire pressure of 110 psi (827.37 kPa), and a spacing of 12 inches (30.47 cm) with a rectangular contact area was assumed. A single wheel analysis is used with 9,000 lbs on each side of the axle and 4,500 lbs. on each tire.

The daily Equivalent Single Axle Load (ESAL) used for this research is 2700 with linear growth rate of 0.4%.

3.9.4 Output and Analysis

The Y axis is the longitudinal axis in the direction of traffic. The output and analysis option in FlexPAVE are performed at several ZX planes where Y position is fixed. The longitudinal axis is converted into time by design velocity. Thus, instead of having several spatial segments in longitudinal axis, there are several time segments for different ZX planes. Add and replace mesh means that the user can change the display points of the ZX mesh of results, where user can add or replace different meshes depending on desired evaluation points. By using the auto generating evaluation point tool ( ), evaluation points are generated at both wheels in terms of asphalt pavement depth as shown in Figure 23.

General Information * Design Structure * Climate Information * Traffic * Analysis and Results Options *

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	0.1000
3	0	0.2000
4	0	0.3000
5	0	0.4000
6	0	0.5000
7	0.1000	0
8	0.1000	0.1000
9	0.1000	0.2000
10	0.1000	0.3000
11	0.1000	0.4000
12	0.1000	0.5000
13	0.2000	0
14	0.2000	0.1000
15	0.2000	0.2000
16	0.2000	0.3000
17	0.2000	0.4000
18	0.2000	0.5000
19	0.3000	0

Figure 23: Output and Analysis Option in Performance Analysis of FlexPAVE

3.9.5 Results

Response results (stress, strain, and displacement values), fatigue cracking (damage factor and pseudo stiffness), and rut depths can be investigated in FlexPAVE. For analyzing response results, user can choose a certain time and plot stress, strain, and displacement values. Contour and history plots can also be plotted for stress, strain, and displacement at predetermined nodes. For fatigue cracking, contour and history plots can also be plotted for modulus after damage (C). Additionally, percentage damage evolution of whole pavement can be plotted as a function of time. For rutting, rut depth is plotted as a function of time.

3.10 ANALYSIS METHODS

The objective of this research is to determine appropriate sample geometry for dynamic modulus, fatigue, and rutting test for accurate characterization of asphalt mix and ease of testing. To accomplish this objective, effect of sample geometry is analyzed using statistical analysis of the test results and performance predictions using FlexPAVE. The data analysis is divided into 5 analysis:

- 1) The Analysis 1 consists of ranking six samples types for three NMAS asphalt mixes used for three different tests performed in AMPT:
  - a) Dynamic modulus values from master curve are ranked for six sample types from three NMAS asphalt mixes. This also includes evaluating rutting potential from dynamic modulus master curve at a temperature of 54.4 °C and frequency of 5 Hz. The fatigue potential is evaluated from dynamic modulus master curve at a temperature of 20 °C and frequency of 73.2 Hz.
  - b) Fatigue – S_{app} parameter from FlexMAT cracking Excel is used to rank six sample types from three NMAS asphalt mixes.
  - c) Rutting –Rutting Strain Index (RSI) from FlexMAT rutting Excel is used to rank six sample types from three NMAS asphalt mixes.
- 2) The Analysis 2 consists of ranking 12 models for three pavement structures in FlexPAVE. Since the purpose of the performance is to have the ability to estimate pavement performance, it is important to examine how different sample dimensions affect pavement performance. This analysis determines if the sample dimensions affect pavement performance predictions.
- 3) The Analysis 3 performs comparative and statistical analysis of dynamic modulus and phase angle values of each replicate for six STs fabricated from three different NMAS mixes.
- 4) The Analysis 4 evaluates air void uniformity for samples tested for dynamic modulus test in AMPT using AASHTO R 83-17 for six STs each for three different NMAS mixes.
- 5) The Analysis 5 statistically compares air voids of STs for six different inscribed circles each for three different NMAS mixes.

CHAPTER 4. ANALYSIS AND RESULTS

4.1 RANKING ANALYSIS FROM MASTER CURVE AND FLEXMAT SOFTWARE

The Analysis 1 incorporates ranking of six Sample Types (STs) for three different NMAS asphalt mixes used for three different AMPT tests. The summary of sample geometries with unique inscribed circles are shown as:

Sample Types	Dynamic Modulus Test, mm	DTC Fatigue Test, mm	Stress Sweep Rutting Test, mm
1	100X150- Inscribed Circle of 100 mm- AASHTO T 378	100X130- Inscribed Circle of 100 mm- AASHTO TP 107-18	100X150- Inscribed Circle of 100 mm- AASHTO TP 134-19
2	38X110- Inscribed Circle of 104 mm- AASHTO TP 132-19 and AASHTO 133-19		Not Tested
3	38X110- Inscribed Circle of 38 mm		Not Tested
4	50X110- Inscribed Circle of 120 mm		50X110- Inscribed Circle of 120 mm
5	50X110- Inscribed Circle of 50 mm		Not Tested
6	75X110- Inscribed Circle of 75 mm		Not Tested

The ranking involves dynamic modulus values from master curve, S_{app} parameter from FlexMAT cracking for fatigue, and Rutting Strain Index (RSI) from FlexMAT rutting for rutting. For ranking analysis all STs are compared to ST1 as it is full size AASHTO standard dimension used for up to 37.5 mm NMAS mixes for dynamic modulus and rutting test and for up to 25 mm NMAS mixes for fatigue test. Data from replicates were combined, so it is not possible to perform statistical analysis since there is no variance term. Therefore, ranking is performed in this analysis. In dynamic modulus test, ranking is performed from master curves. Dynamic modulus values from master curve are ranked for six STs each for three NMAS asphalt mixes.

In DTC fatigue test, ranking is performed from FlexMAT Cracking Excel. The AMPT data for sample replicates were imported into FlexMAT cracking Excel to produce S-VECD properties. As there

is no variance term within S-VECD properties, S_{app} was chosen to rank the six sample types for each if the three NMAS asphalt mixes.

In SSR test, ranking was performed from FlexMAT Rutting Excel. The AMPT data for sample replicates were imported into FlexMAT Rutting Excel to produce shift factor model and RSI for layer type and location. As there is no variance term within shift factors, RSI was chosen to rank the six sample types for each of the three NMAS asphalt mixes.

4.1.1 Dynamic Modulus Master Curve

The fitting parameters for six STs for each NMAS mix using MasterSolver are in Table 27. Figures 24 to 26 show master curves for six STs for each NMAS mix. Master curve for all STs are compared to that of ST 1. In general, for 12.5 mm and 25 mm NMAS asphalt mix, dynamic modulus values for ST6 were close to the ST1 samples. This is in line with expectations as aspect ratio of sample type 1 and 6 is 1.5. For 19 mm NMAS mix, ST 4 and ST6 are closest to ST1. Again, this is in line with expected as aspect ratio of ST 4 is 2.2 which is next closest to 1.5 aspect ratio of ST 1 and ST 6.

Table 27: Master curve Fitting Parameters

NMAS, mm	Parameter	Sample Type					
		1	2	3	4	5	6
12.5	β	-1.53217	-1.40253	-1.61880	-1.35363	-1.34512	-1.41801
	γ	-0.39159	-0.41499	-0.39802	-0.46195	-0.41845	-0.41542
	ΔEA	252480	216740	230558	182030	231442	216602
	E_{max}	3156.8	3176.1	3171.1	3142.0	3139.3	3148.8
	E_{min}	0.7	2.4	0.9	5.4	3.0	2.3
19	β	-1.43638	-1.07081	-1.18714	-1.52446	-0.79246	-1.79099
	γ	-0.34949	-0.47837	-0.43304	-0.39357	-0.51742	-0.35928
	ΔEA	308118	219342	199053	226800	186464	225883
	E_{max}	3242.9	3249.0	3204.2	3201.4	3211.9	3207.0
	E_{min}	0.3	5.5	1.1	0.5	9.2	0.03
25	β	-1.67224	-1.58035	-1.33911	-1.48435	-1.35888	-1.80115
	γ	-0.40097	-0.44358	-0.50749	-0.47628	-0.53105	-0.42424
	ΔEA	338923	239440	213144	217844	210030	218329
	E_{max}	3255.4	3211.3	3220.0	3254.4	3267.0	3236.3
	E_{min}	0.5	0.7	2.1	1.0	2.8	0.1

Figure 24: Master curves Design Binder Content, NAMS 12.5 mm, Target 7.0 % VTM

Figure 25: Master curves Design Binder Content, NAMS 19 mm, Target 7.0 % VTM

Figure 26: Master curves Design Binder Content, NAMS 25 mm, Target 7.0 % VTM

Rutting Consideration from Master Curve

Pellinen and Witczak. (2002) recommended evaluating rutting potential from dynamic modulus master curve at a temperature of 54.4 °C and frequency of 5 Hz. The 54.4 °C represents high pavement temperature susceptible to rutting. The 5 Hz is approximately equivalent to a speed of 3.8 mph for a 6-inch layer per the Ullitz method. For this combination of temperature – frequency, dynamic modulus values for six STs were computed from the master curves with the fitting parameters shown in Table 27 to produce the results in Table 28. Bennert (2009) recommended the threshold dynamic modulus of 94 ksi to limit rutting potential of asphalt mixtures for less than 10 million ESAL's at 54.4 °C and 5Hz.

The modulus values comparisons are shown in Figure 27, (a) 9.5 mm mixes (b) 12.5 mm and (c) 25 mm mixes. The results show a highly variable effect of sample sizes on dynamic modulus values. In 12.5 mm mix, only ST4 crossed the minimum dynamic modulus threshold to limiting rutting. In 19 mm and 25 mm mixes, none of the STs crossed the threshold. The estimated dynamic modulus closest to ST 1 for 12.5 mm mix is ST 5, for 19 mm is ST 6, and for 25 mm mix is ST 2. Overall, dynamic modulus obtained from ST 3 was consistently close to that of ST 1 for all three NMA mixes. While there is not a definite answer as to why the specimens exhibit this behavior, several factors may apply. These include:

- The ST 3 cored specimens likely had rather uniform air voids throughout the specimen.
- The air voids for each ST were at $7\% \pm 0.5\%$. The $\pm 0.5\%$ difference may have caused significant difference in dynamic modulus values for STs in 19 mm and 25 mm asphalt mixes.

Table 28: Dynamic Modulus for Rutting Considerations at 54.4°C and 5 Hz

NMAS	Sample Type	Estimated Dynamic Modulus (ksi)
12.5	1	41.5
	2	88.4
	3	76.2
	4	152.5
	5	71.4
	6	88.2
19	1	15.5
	2	55.6
	3	45.9
	4	52.1
	5	68.2
	6	40.8
25	1	10.60
	2	38.60
	3	45.40
	4	45.30
	5	51.30
	6	53.00

Figure 27: Comparison of Dynamic modulus Values for Rutting Considerations at 54.4°C and 5 Hz

Fatigue Consideration from Master Curve

The fatigue potential was evaluated from dynamic modulus master curve at a temperature of 20°C and frequency of 5 Hz. The 5 Hz was used to compare dynamic modulus from this research to the threshold dynamic modulus value at 20°C and 5Hz obtained from Bennert (2009). Bennert (2009) performed detailed research on development of limiting fatigue cracking potential at 20°C and different loading frequencies. In this research, the combination of temperature – frequency, dynamic modulus values for six STs were computed from the master curves with the fitting parameters shown in Table 27 to produce the results in Table 29. Bennert (2009) recommended the threshold dynamic modulus of 670 ksi to limit fatigue cracking potential of asphalt mixtures for general cracking resistance at 20°C and 5Hz.

The modulus values comparisons are shown in Figure 28 and all STs crossed the fatigue cracking potential threshold. Estimated dynamic modulus closest to ST 1 for 12.5 mm mix is ST 5, for 19 mm is ST 3, and for 25 mm mix is ST 2. These results follow very closely to that of rutting considerations for master curve with the exception of sample type 6 instead of sample type 3 for 19 mm NMAS. When compared sample 3 and 6 in 19 mm NMAS mix, the dynamic modulus values for both sample types were very close with a difference of 3.7% and comparable to sample type 1. Overall, dynamic modulus obtained from sample type 6 was consistently close to that of sample type 1 for all three NMAS mixes.

Table 29: Dynamic Modulus for Fatigue Considerations at 20°C and 5 Hz

NMAS	Sample Type	Estimated Dynamic Modulus (ksi)
12.5	1	956.9
	2	1039.7
	3	1157.0
	4	1135.6
	5	1013.0
	6	1039.6
19	1	770.3
	2	923.5
	3	737.5
	4	919.8
	5	789.6
	6	835.8
25	1	1079
	2	1064
	3	1034
	4	1053
	5	1128
	6	1083

Figure 28: Comparison of Dynamic modulus Values Fatigue Considerations at 20°C and 73.2 Hz

4.1.2 DTC Fatigue FlexMAT Cracking

The fatigue potential was evaluated from the S_{app} parameter obtained from FlexMAT Cracking Excel at 21°C. Table 30 shows S_{app} value for six different STs each for three NMAS mixes. The values comparisons are shown in Figure 29, (a) 9.5 mm mixes (b) 12.5 mm and (c) 25 mm mixes.

The S_{app} was developed by Wang (2019) to address the effect of modulus and toughness parameter on fatigue cracking. Wang (2019) recommended threshold value of S_{app} of greater than 8 for less than 10 million ESALs. To compare apparent damage capacity of asphalt mix, the S_{app} values from different STs in FlexMAT Cracking for different NMAS mixes are compared to ST1. The S_{app} value closest to ST 1 for 12.5 mm mix is ST 3, for 19 mm is ST 4, and for 25 mm mix is ST 4. When compared sample 3 and 4 in 12.5 mm NMAS mix, the S_{app} values for both STs were very close with a difference of 8.2% and comparable to ST 1. Overall, S_{app} value obtained from ST 4 was consistently close to that of ST 1 for all three NMAS mixes. This is in line with the expectation because literature review shows that specimens with uniform air void distribution reduces test variability in terms of resistance to fatigue cracking. Additionally, results from S_{app} ranking do not match with the fatigue results considered from dynamic modulus master curves. Therefore, latter may not be a true representation of fatigue resistance of sample types.

Table 30: S_{app} Values at 21°C for Different Sample Types for Each NMAS asphalt Mix

NMAS	Sample Type	S_{app} at 21°C
12.5	1	18.80
	2	13.50
	3	17.97
	4	16.61
	5	14.00
	6	14.91
19	1	16.36
	2	20.72
	3	18.67
	4	17.84
	5	14.48
	6	17.91
25	1	11.55
	2	14.76
	3	18.07
	4	12.36
	5	15.19
	6	14.15

Figure 29: Fatigue Potential from S_{app} Ranking at 21°C for Different Sample Types

The damage characterization curves (C versus S) are visually evaluated for different samples fabricated from each STs and compared to that of samples obtained from ST 1. The C and S values are obtained from FlexMAT Cracking Excel. The graph comparisons for different STs to ST1 for three different NMA mixes are shown in Figure 30. As this is a ranking analysis, visually, least sample to sample variability and closest trend to ST 1 is seen in ST5 for 12.5 mm NMA mix. This is because in the first column consisting of five graphs, all three grey lines, which are replicates for ST 5, fall very closely with all three black lines, which are replicates of ST1. Similarly, for 19 mm NMA mix, ST6 show least sample to sample variability and closest trend to ST 1. For 25 mm NMA mix, ST2 and ST6 show least sample to sample variability and closest trend to ST 1.

The damage characterization curve is used to predict damage response for any given loading history using test results. Therefore, when STs, where grey lines for its replicates, fall closest to black line for ST1 replicates, it shows that the two STs will predict similar damage response for a given loading.

Figure 30: Damage Characterization Curve Comparison of Samples from Different Sample Types to Samples Obtained from Sample Type 1.

Figure 30 Cont.: Damage Characterization Curve Comparison of Samples from Different Sample Types to Samples Obtained from Sample Type 1.

Figure 30 Cont.: Damage Characterization Curve Comparison of Samples from Different Sample Types to Samples Obtained from Sample Type 1.

4.1.3 SSR FlexMAT Rutting

The rutting potential is evaluated from Rutting Strain Index (RSI) obtained from FlexMAT Rutting Excel at 21°C. The RSI is developed by Ghanbari et. al. (2020) to predict the rutting level at 20 years of traffic for a standard pavement structure using FlexPAVE. Ghanbari et. al. (2020) recommended RSI threshold of less than 12 for less than 10 million ESALs. Table 31 shows RSI value for two STs for three NMAS mixes. The values comparisons are shown in Figure 31, (a) 9.5 mm mixes (b) 12.5 mm and (c) 25 mm mixes. Figures 32 to 34 show average permanent microstrain for two STs for each NMAS mix.

All STs fall well below the threshold of 12%. The RSI for ST 4 varied widely from ST 1 in 12.5 mm and 19 mm NMAS mixes. This is in line with expectation as from the literature review (Blankenship and Anderson, 2010), rutting resistance is less sensitive to air void distribution and more influenced by air void percent of test sample. As ST 4 is expected to have more uniform air void distribution compared to ST 1, results may vary widely due to difference in air void content of specimen in 12.5 mm and 19 mm NMAS mix. ST 4 had higher air void content than ST 1 in 12.5 mm NMAS mix and ST1 had higher air void content than ST4 in 19 mm NMAS mix. Therefore, higher air void percent caused higher RSI indicating higher rutting level at 20 years of traffic.

The closest RSI comparison between ST 1 and ST 4 is in 25 mm NMAS mix, which is counter intuitive. ST 1 and 4 had similar air void content and although ST 4 may have air void uniformity, the RSI ranking results were affected by air void content.

Table 31: RSI Value for 20 Years of Traffic for Different Sample Types for Each NMAS asphalt Mix

NMAS	Sample Type	RSI for 20 Years of Traffic, %
12.5	1	0.4
	4	1.4
19	1	1.8
	4	0.9
25	1	0.5
	4	0.6

Figure 31: RSI Ranking for 20 Years of Traffic for Different Sample Types

Figure 32: Average Permanent Microstrain, 12.5 mm NMAS

Figure 33: Average Permanent Microstrain, 19 mm NMAS

Figure 34: Average Permanent Microstrain, 25 mm NMAS

4.2 RANKING ANALYSIS FROM FLEXPAVE

The Analysis 2 consists of ranking 12 models for three pavement structures in FlexPAVE. Since data is combined from replicates, it is not possible to perform statistical analysis as there is no variance term. Therefore, ranking is performed in analysis 2. The terminology of Run X.Y is used in this analysis where, X stands for one of the three different structures and Y stands for one of the twelve different models. This is also detailed in Table 25 and Table 26. The performance analysis is performed in FlexPAVE and for analysis of outputs, percentage damage for fatigue cracking as a function of time and rut depth development are compared.

4.2.1 DTC Fatigue

One of the outputs for ranking analysis from FlexPAVE is percentage damage for fatigue cracking as a function of time. As there is wide difference in the values obtained from each model ranging from 2.26E-05 to 1.9, it is not possible to depict them in bar chart.

As STs used for dynamic modulus and DTC fatigue in model 1 to 6 are same as that in model 7 to 12, values for percentage damage at the end of the 20 years remains same. The results show that the highest percentage damage at the end of 20 years was shown in ST2, four 38X110 mm samples fabricated from one SGC pill. The same geometry, 38X110 mm, but different inscribed circle in ST3, one 38X110 mm samples fabricated from one SGC pill, showed significantly lower percentage damage. The percentage damage at the end of the 20 years value for model 5 values were consistently close to model 1 for all three pavement structures.

Table 32: Percentage Damage at the end of 20 Years from FlexPAVE

% Damage at the end of 20 years	Structure 1	Structure 2	Structure 3
Model 1	0.00011	0.00078	0.00002
Model 2 ⁷	0.80850	1.89730	0.41560
Model 3	0.00080	0.00340	0.00025
Model 4	0.00640	0.02490	0.01880
Model 5	0.00047	0.00240	0.00014
Model 6	0.04740	0.15840	0.01720
Model 7	0.00011	0.00078	0.00002
Model 8	0.80850	1.89730	0.41560
Model 9	0.00080	0.00340	0.00025
Model 10	0.00640	0.02490	0.00220
Model 11	0.00047	0.00240	0.00014
Model 12	0.04740	0.15840	0.01720

4.2.2 Stress Sweep Rutting

One of the other outputs for ranking analysis as shown in Table 33 and Figure 35 obtained from FlexPAVE is total rut depth at the end of 20 years. Additionally, rut depth development over 20 years trend in Figure 35 for different models is compared to model 1 for all three different structures.

The total rut depth at the end of 20 years for model 2 and 10 values were same as that of model 1 for all three structures. Although model 4 values were consistent across all three structures, the rut depth is different model 1. From the trend observed in Figure 36, models that use 50X110 mm for SSR visually cause difference in trend from that of model 1 for all three structures. Additionally, structure 1, medium duty pavement, shows less rutting than structure 3, heavy duty pavement. The general trend is that as the thickness of pavement increases, total rut depth decreases. As the results of flexPAVE total rut depth in structure 1 compared to structure 3 does not follow this trend, the developers of the software are contacted to follow up on the counter intuitive results. The model 5 results for different structures are consistent with the trend of decrease in rut depth with increase in pavement thickness.

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⁷ Kim's geometry consisting of 38X110 mm for dynamic modulus and DTC fatigue testing and 100X150 mm for SSR testing.

Table 33: Total Rut Depth at the end of 20 Years from FlexPAVE

Total Rut Depth at the end of 20 years	Structure 1	Structure 2	Structure 3
Model 1	0.59	0.67	0.64
Model 2	0.59	0.67	0.64
Model 3	0.59	0.68	0.65
Model 4	0.65	0.67	0.65
Model 5	0.62	0.66	0.66
Model 6	0.59	0.67	0.65
Model 7	0.61	0.65	0.65
Model 8	0.61	0.65	0.66
Model 9	0.62	0.66	0.66
Model 10	0.59	0.67	0.64
Model 11	0.59	0.68	0.65
Model 12	0.61	0.66	0.66

Figure 35: Comparison of Total Rut Depth at the end of 20 Years between different Models and Structures

Figure 36: Total Rut Depth Comparison for different Models to Model 1 for each of the Three Structures

Figure 36 Cont.: Total Rut Depth Comparison for different Models to Model 1 for each of the Three Structures

Figure 36 Cont.: Total Rut Depth Comparison for different Models to Model 1 for each of the Three Structures

Figure 36 Cont.: Total Rut Depth Comparison for different Models to Model 1 for each of the Three Structures

Figure 36 Cont.: Total Rut Depth Comparison for different Models to Model 1 for each of the Three Structures

Figure 36 Cont.: Total Rut Depth Comparison for different Models to Model 1 for each of the Three Structures

4.3 COMPARATIVE AND STATISTICAL ANALYSIS

The Analysis 3 consists of performing comparative and statistical analysis of dynamic modulus and phase angle values obtained from master curve for six different STs fabricated from three different NMAS. In AMPT dynamic modulus test, three replicates are used for each sample type. Therefore, variance term exists for this analysis and statistical analysis can be performed to compare dynamic modulus and phase angle values obtained from AMPT.

As each replicate for sample types is assigned a unique number, Tables 34 to 36 show dynamic modulus and phase angle values for six STs for each of the three NMAS mix. Figures 37 to 48 illustrate the effects of temperature on dynamic modulus and phase angle for all STs fabricated from each NMAS. Although it is important to see how six different STs perform for each NMAs mix, it is also important to see how each ST yield different DM and PA values across different NMAS mix. The former analysis is done because per current AASHTO standard, full size sample (sample type 1) is used for up to 37.5 mm NMAS mix.

In addition to comparative analysis t-test, ANOVA, and MANOVA are also performed in this analysis. Table 37 to 54 show t-tests performed to compare dynamic modulus and phase angle values of STs to that of ST1 for each NMAS at different temperature and frequency pairs. Table 55 to 57 show that ANOVA is performed to compare dynamic modulus and phase angle values for all STs fabricated for each NMAS at different temperature and frequency pairs. Table 58 to 66 show that MANOVA is performed in SPSS Statistical Software to compare dynamic modulus and phase angle from STs to that of ST1 fabricated from three different NMAS at different temperature and frequency pairs.

Table 34: Dynamic Modulus and Phase Angle for 12.5 mm NMAS Unique Replicate Samples

NMAS		12.5																	
Sample Type		1			2			3			4			5			6		
Unique Sample Number		1	2	3	31 a.	31 b.	31 c.	37	38	39	55 a.	55 b.	55 c.	67	68	69	85	86	87
Temperature	Frequency	Dynamic Modulus (ksi)																	
4	0.1	1228.3	1109.7	1281.8	1349.4	1345.5	1426.3	1430.8	1385.7	1288.7	1372.8	1361.8	1366.983	1250.5	1388.9	1411.2	1349.4	1345.5	1426.3
	1	1643.4	1494.8	1688.1	1720.6	1700.6	1800.6	1820.7	1754.8	1674.8	1759.0	1737.6	1741.181	1627.8	1769.0	1796.9	1720.6	1700.6	1800.6
	10	2051.1	1876.8	2080.6	2108.6	2061.0	2179.2	2207.2	2125.1	2074.0	2136.4	2109.6	2104.936	2028.1	2148.4	2186.4	2108.6	2061.0	2179.2
20	0.1	439.5	389.4	466.4	454.5	469.9	417.0	558.0	501.4	426.7	460.6	479.1	454.6941	400.6	446.9	451.1	454.5	469.9	417.0
	1	752.5	684.9	796.4	754.3	776.1	608.4	901.4	806.1	741.6	780.3	800.3	767.251	684.3	731.0	738.8	754.3	776.1	608.4
	10	1146.1	1061.5	1201.9	1130.0	1149.6	864.4	1300.0	1194.1	1144.2	1160.7	1180.8	1143.625	1063.4	1102.7	1108.4	1130.0	1149.6	864.4
40	0.01	24.5	18.4	23.7															
	0.1	50.7	35.1	46.0	70.4	82.2	87.2	85.2	81.2	63.5	110.6	119.7	84.02051	63.5	75.2	71.2	70.4	82.2	87.2
	1	120.1	84.0	104.7	161.7	181.2	187.8	185.6	164.0	144.7	246.3	262.7	190.725	149.1	165.9	154.6	161.7	181.2	187.8
	10	269.8	199.3	234.5	337.2	366.1	374.2	376.4	333.7	310.2	483.8	505.3	402.4805	309.7	301.5	272.2	337.2	366.1	374.2
		Phase Angle																	
4	0.1	14.5	15.0	13.7	11.0	11.2	10.7	11.4	11.5	12.8	11.7	11.7	11.52	13.1	10.7	11.8	11.0	11.2	10.7
	1	10.9	11.2	10.3	8.6	8.8	8.7	8.8	8.8	9.9	9.0	8.9	8.87	10.0	8.1	9.0	8.6	8.8	8.7
	10	8.4	8.7	8.0	6.4	7.3	5.8	7.3	7.3	8.0	7.1	7.2	7.19	8.1	5.9	7.3	6.4	7.3	5.8
20	0.1	26.5	27.3	26.0	24.2	23.9	29.1	22.9	23.7	26.3	24.8	24.7	24.76	26.8	24.3	25.2	24.2	23.9	29.1
	1	20.9	21.6	20.3	18.9	18.4	19.8	17.5	18.5	20.8	19.2	18.9	19.09	21.3	19.8	20.1	18.9	18.4	19.8
	10	16.0	16.5	15.4	14.5	14.4	19.5	13.3	14.2	15.7	14.5	14.3	14.48	16.2	13.7	15.6	14.5	14.4	19.5
40	0.01	26.2	25.9	24.91															
	0.1	30.6	30.7	30	31.9	31.3	33.2	34.0	31.0	31.3	30.6	30.6	31.86	32.5	32.8	33.3	31.9	31.3	33.2
	1	33.3	34.7	33.84	31.7	30.8	33.2	33.1	32.2	32.5	29.5	28.9	31.86	32.5	32.9	33.1	31.7	30.8	33.2
	10	33.1	35.5	34.28	28.4	27.6	25.2	28.6	29.3	30.2	25.8	25.3	29.56	31.5	33.1	34.8	28.4	27.6	25.2

Table 35: Dynamic Modulus and Phase Angle for 19 mm NMAS Unique Replicate Samples

NMAS		19																	
Sample Type		1			2			3			4			5			6		
Unique Sample Number		8	9	10	33 a.	33 b.	33 c.	43	44	45	59 a.	59 b.	59 c.	73	74	75	91	92	93
Temperature	Frequency	Dynamic Modulus (ksi)																	
4	0.1	989.9	1030.8	1168.6	1272.6	1264.0	1109.7	898.4	904.0	1085.3	1255.884	1184.8	1176.5	846.3	1129.0	1095.9	998.6	1054.0	1078.4
	1	1432.8	1459.4	1597.3	1726.4	1729.3	1542.6	1302.2	1210.2	1522.3	1687.082	1560.9	1581.5	1215.0	1590.1	1545.1	1373.8	1420.4	1463.1
	10	1891.7	1893.0	2018.9	2172.4	2211.0	2000.7	1745.8	1443.6	1980.3	2126.982	1946.8	1987.9	1637.3	2079.6	2015.4	1762.9	1779.0	1848.4
20	0.1	317.5	357.4	376.5	340.7	336.2	313.1	230.3	208.1	276.7	370.7171	384.2	367.4	190.1	259.5	263.5	324.2	343.2	343.6
	1	607.4	654.8	660.2	647.0	629.0	606.5	466.3	384.4	546.6	672.1061	673.8	650.6	381.6	504.6	511.7	595.5	625.8	635.7
	10	1016.9	1041.7	1048.2	1079.2	1030.6	1011.2	837.4	613.1	939.8	1082.129	1043.8	1030.1	700.1	895.0	904.6	960.3	1003.4	1025.0
35	0.01	18.2	21.4	30.8															
	0.1	34.7	38.0	53.6	70.4	82.2	87.2	51.8	67.1	59.5	81.06174	89.8	82.2	42.6	58.8	54.4	76.3	66.1	73.5
	1	82.6	83.8	110.9	161.7	181.2	187.8	126.8	157.7	146.5	182.7479	199.3	178.5	113.5	137.2	125.9	170.9	149.1	166.8
	10	195.9	191.5	237.0	337.2	366.1	374.2	292.8	347.7	331.4	386.6713	405.8	367.8	248.5	257.6	226.0	357.4	312.3	350.1
		Phase Angle																	
4	0.1	18.3	17.1	15.1	14.8	15.0	16.1	19.1	22.1	16.9	14.17	13.6	14.3	19.0	16.7	17.3	15.6	14.8	15.3
	1	13.4	12.4	10.9	10.8	11.2	12.1	14.2	16.6	12.6	10.45	10.4	10.8	14.2	12.5	12.7	11.5	10.9	11.3
	10	10.1	9.3	8.5	8.3	9.0	8.4	10.6	13.3	9.4	8.24	8.2	8.5	10.7	9.4	9.6	8.7	8.4	8.5
20	0.1	29.8	28.9	27.1	30.9	30.6	30.3	33.8	32.4	33.6	28.48	26.6	26.7	33.9	32.3	32.0	28.7	29.7	29.2
	1	24.7	23.8	22.6	24.0	24.9	24.7	28.2	27.1	26.3	23.07	21.4	21.7	28.9	27.8	27.4	23.1	24.0	23.4
	10	19.1	18.1	17.7	17.3	19.1	18.8	21.6	22.3	20.0	17.55	16.5	16.9	22.7	21.4	21.3	17.4	18.0	17.6
35	0.01	23.8	23.0	24.0															
	0.1	28.6	27.3	28.0	31.9	31.3	33.2	34.3	34.9	35.8	32.82	30.0	30.0	35.4	32.1	32.5	32.1	32.9	32.7
	1	32.8	32.1	31.6	31.7	30.8	33.2	36.2	36.6	36.4	33.19	30.5	30.7	36.7	35.3	38.3	32.8	34.7	33.6
	10	35.2	35.6	32.6	28.4	27.6	25.2	33.6	33.1	32.4	30.83	28.6	28.7	35.5	37.9	43.9	30.6	32.3	30.8

Table 36: Dynamic Modulus and Phase Angle for 25 mm NMAS Unique Replicate Samples

NMAS		25																	
Sample Type		1			2			3			4			5			6		
Unique Sample Number		15	16	17	35 a.	35 b.	35 c.	49	50	51	63 a.	63 b.	63 c.	79	80	81	97	98	99
Temperature	Frequency	Dynamic Modulus (ksi)																	
4	0.1	1431.4	1430.4	1483.6	1313.5	1433.0	1454.3	1323.9	1359.3	1353.1	1412.5	1358.7	1358.716	1479.7	1348.6	1558.1	1157.7	1540.7	1294.5
	1	1924.2	1924.2	1975.6	1721.2	1888.0	1903.5	1788.2	1852.4	1838.9	1874.2	1815.9	1815.876	1991.2	1805.4	2100.9	1544.1	1996.7	1745.1
	10	2404.6	2406.0	2448.1	2152.5	2326.0	2350.5	2267.7	2336.7	2305.8	2312.8	2259.5	2259.547	2501.8	2264.0	2639.5	1927.7	2416.6	2197.0
20	0.1	477.3	519.7	517.6	428.0	403.9	429.6	343.2	337.1	365.9	372.5	378.7	378.6942	378.3	408.7	350.6	363.6	476.7	456.4
	1	876.0	923.3	900.7	772.9	738.2	778.4	660.1	654.0	703.1	702.4	707.6	707.6404	722.6	771.2	657.7	656.3	871.0	820.0
	10	1374.2	1416.9	1385.4	1220.6	1180.8	1232.5	1111.1	1107.7	1163.6	1143.3	1137.8	1137.823	1214.5	1289.8	1101.3	1018.5	1357.3	1253.3
35	0.01	17.4	18.5	27.4															
	0.1	33.1	37.4	56.8	88.9	66.6	70.9	66.7	67.9	68.5	71.3	72.0	71.95335	69.4	83.6	67.1	82.2	91.4	89.8
	1	82.2	93.1	135.2	200.6	165.5	171.0	171.9	179.3	174.5	185.6	185.6	185.6486	191.6	213.4	186.2	197.4	232.9	220.9
	10	205.7	229.7	310.4	433.1	370.6	386.4	396.0	413.4	407.6	423.5	423.5	423.511	455.1	481.4	422.1	414.2	511.4	468.8
		Phase Angle																	
4	0.1	15.0	14.8	13.7	14.5	12.8	11.1	15.1	14.3	15.1	14.1	14.4	14.4	15.2	14.4	14.7	14.7	13.5	15.3
	1	10.9	10.8	9.9	11.3	9.4	8.8	11.1	10.4	10.9	10.2	10.5	10.5	11.0	10.7	10.7	10.4	9.6	11.1
	10	8.3	8.0	7.2	7.3	6.6	6.7	8.6	7.5	8.2	7.7	7.9	7.9	8.3	8.4	8.2	7.8	7.4	8.3
20	0.1	28.4	27.5	27.3	28.4	29.2	29.4	32.9	32.7	30.9	31.1	30.1	30.1	32.0	30.8	30.7	29.9	28.9	28.8
	1	22.0	21.4	21.2	22.4	23.0	22.1	25.3	26.0	24.3	24.7	23.7	23.7	25.5	25.1	24.8	23.7	22.3	21.8
	10	16.4	15.8	15.7	16.8	16.9	15.9	19.1	19.2	18.0	18.2	17.7	17.7	18.9	18.9	18.7	17.4	16.2	15.9
35	0.01	22.3	23.7	22.5															
	0.1	28.2	29.3	28.7	31.2	32.6	32.3	34.3	35.6	38.0	32.8	31.8	31.8	35.4	33.8	36.1	35.6	33.8	33.7
	1	33.8	34.3	32.9	33.3	34.7	34.0	36.8	37.0	38.7	34.3	32.6	32.6	37.2	35.3	36.1	35.8	34.0	33.8
	10	37.3	36.7	34.4	30.7	32.1	31.5	32.5	32.7	32.5	31.6	30.3	30.3	34.2	31.9	32.5	31.9	30.3	29.6

Figure 37: Comparison of Dynamic Modulus for STs fabricated with 12.5 mm NMAS

Figure 37 Cont.: Comparison of Dynamic Modulus for STs fabricated with 12.5 mm NMA

Figure 38: Comparison of Phase Angle for STs fabricated with 12.5 mm NMAS

Figure 38 Cont.: Comparison of Phase Angle for STs fabricated with 12.5 mm NMAS

Figure 39: Comparison of Dynamic Modulus for STs fabricated with 19 mm NMA

Figure 39 Cont.: Comparison of Dynamic Modulus for STs fabricated with 19 mm NMA

Figure 40: Comparison of Phase Angle for STs fabricated with 19 mm NMAS

Figure 40 Cont.: Comparison of Phase Angle for STs fabricated with 19 mm NMA

Figure 41: Comparison of Dynamic Modulus for STs fabricated with 25 mm NMAS

Figure 41 Cont.: Comparison of Dynamic Modulus for STs fabricated with 25 mm NMA

Figure 42: Comparison of Phase Angle for STs fabricated with 25 mm NMAS

Figure 42 Cont.: Comparison of Phase Angle for STs fabricated with 25 mm NMAS

Figure 43: Comparison of Dynamic modulus and phase angle for ST 1 fabricated from different NMAS

Figure 44: Comparison of Dynamic modulus and phase angle for ST 2 fabricated from different NMAS

Figure 45: Comparison of Dynamic modulus and phase angle for ST 3 fabricated from different NMAS

Figure 46: Comparison of Dynamic modulus and phase angle for ST 4 fabricated from different NMAS

Figure 47: Comparison of Dynamic modulus and phase angle for ST 5 fabricated from different NMAS

Figure 48: Comparison of Dynamic modulus and phase angle for ST 6 fabricated from different NMAS

The comparative analysis in Figure 37 and 38 for dynamic modulus and phase angle for 12.5 mm NMA mix show that ST 5 values for three different test temperatures are consistently closer to that of ST1. From Figures 39 and 40, the dynamic modulus and phase angle for 19 mm NMA mix show that ST 5 values for three different test temperatures are consistently closer to that of ST1. From Figures 41 and 42, the dynamic modulus and phase angle for 25 mm NMA mix show that ST 3 values for three different test temperatures are consistently closer to that of ST1. To further verify if same ST can be used for all three NMA mixes, comparative analysis in Figure 43 to 48 is conducted for STs. Visually, ST 4 can be used for all three NMA mix however, the recommendation would be to use the right sample type for a specific NMA. This ST should have uniform air void distribution and dynamic modulus and phase angle values close to ST1. From comparative analysis ST5 performed consistently to ST1 for 12.5 and 25 mm NMA and ST 4 performed consistently to ST1 for 19 mm NMA mix.

The Student's t-test in Table 37 to 54 is used for comparison of difference between the mean of different STs and ST 1 for various combinations of temperature and frequencies in dynamic modulus test. All tests used a 95 percent confidence level, alpha of 0.05. The null hypothesis for all tests was the means of the two data sets are equal. Failure to reject the null hypothesis indicates the means of each data set are statistically same. Rejecting the null hypothesis implies the data sets are statistically different. In the tables of t-test results, comparisons with alpha of less than 0.05 are shown with a bold font.

Table 37: t-test of Dynamic Modulus for STs fabricated from 12.5 mm NMA at 4°C

Comparison	4°C and 0.1 Hz				4°C and 1 Hz				4°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	1206.6	7763.2	5	0.06	1608.8	10245.9	5	0.14	2002.8	12130.9	5	0.22
ST 2	1373.8	2075.1			1740.6	2804.2			2116.3	3537.5		
ST 1	1206.6	7763.2	5	0.07	1608.8	10245.9	5	0.12	2002.8	12130.9	5	0.17
ST 3	1368.4	5275.4			1750.1	5339.1			2135.4	4512.2		
ST 1	1206.6	7763.2	5	0.08	1608.8	10245.9	5	0.15	2002.8	12130.9	5	0.22
ST 4	1367.2	30.4			1745.9	132.0			2116.9	288.7		
ST 1	1206.6	7763.2	5	0.12	1608.8	10245.9	5	0.19	2002.8	12130.9	5	0.21
ST 5	1350.2	7578.2			1731.2	8221.9			2120.9	6836.7		
ST 1	1206.6	7763.2	5	0.06	1608.8	10245.9	5	0.14	2002.8	12130.9	5	0.22
ST 6	1373.8	2075.1			1740.6	2804.2			2116.3	3537.5		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 38: t-test of Phase Angle for STs fabricated from 12.5 mm NMAS at 4°C

Comparison	4°C and 0.1 Hz				4°C and 1 Hz				4°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	14.4	0.5	5	0.004	10.8	0.2	5	0.02	8.4	0.1	5	0.03
ST 2	10.9	0.07			8.7	0.006			6.5	0.6		
ST 1	14.4	0.5	5	0.02	10.8	0.2	5	0.02	8.4	0.1	5	0.04
ST 3	11.9	0.7			9.2	0.4			7.5	0.2		
ST 1	14.4	0.5	5	0.02	10.8	0.2	5	0.02	8.4	0.1	5	0.02
ST 4	11.6	0.007			8.9	0.003			7.2	0.001		
ST 1	14.4	0.5	5	0.05	10.8	0.2	5	0.07	8.4	0.1	5	0.19
ST 5	11.9	1.4			9.1	0.9			7.1	1.2		
ST 1	14.4	0.5	5	0.004	10.8	0.2	5	0.02	8.4	0.1	5	0.22
ST 6	10.9	0.07			8.7	0.006			4.4	15.0		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 39: t-test of Dynamic Modulus for STs fabricated from 12.5 mm NMAS at 20°C

Comparison	20°C and 0.1 Hz				20°C and 1 Hz				20°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	431.8	1527.2	5	0.61	744.6	3156.5	5	0.64	1136.5	4996.5	5	0.44
ST 2	447.2	741.7			712.9	8312.3			1047.9	25369.2		
ST 1	431.8	1527.2	5	0.25	744.6	3156.5	5	0.27	1136.5	4996.5	5	0.28
ST 3	495.4	4334.7			816.4	6465.0			1212.8	6327.3		
ST 1	431.8	1527.2	5	0.29	744.6	3156.5	5	0.38	1136.5	4996.5	5	0.61
ST 4	464.8	161.4			782.6	277.4			1161.7	345.3		
ST 1	431.8	1527.2	5	0.97	744.6	3156.5	5	0.52	1136.5	4996.5	5	0.41
ST 5	432.9	784.3			718.0	869.4			1091.5	599.7		
ST 1	431.8	1527.2	5	0.61	744.6	3156.5	5	0.64	1136.5	4996.5	5	0.44
ST 6	447.2	741.7			712.9	8312.3			4996.5	25369.2		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 40: t-test of Phase Angle for STs fabricated from 12.5 mm NMAS at 20°C

Comparison	20°C and 0.1 Hz				20°C and 1 Hz				20°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	26.6	0.4	5	0.68	20.9	0.4	5	0.03	15.9	0.3	5	0.93
ST 2	25.8	8.5			19.0	0.5			16.1	8.6		
ST 1	26.6	0.4	5	0.13	20.9	0.4	5	0.15	15.9	0.3	5	0.14
ST 3	24.3	3.2			18.9	2.8			14.4	1.4		
ST 1	26.6	0.4	5	0.04	20.9	0.4	5	0.04	15.9	0.3	5	0.05
ST 4	24.7	0.004			19.1	0.02			14.4	0.01		
ST 1	26.6	0.4	5	0.25	20.9	0.4	5	0.41	15.9	0.3	5	0.43
ST 5	25.4	1.6			20.4	0.7			15.2	1.8		
ST 1	26.6	0.4	5	0.68	20.9	0.4	5	0.03	15.9	0.3	5	0.93
ST 6	25.8	8.5			19.1	0.5			16.1	8.6		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 41: t-test of Dynamic Modulus for STs fabricated from 12.5 mm NMAS at 40°C

Comparison	40°C and 0.1 Hz				40°C and 1 Hz				40°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	43.9	79.9	5	0.006	102.9	328.6	5	0.005	234.5	1242.2	5	0.01
ST 2	63.6	74.8			176.8	183.9			359.2	377.9		
ST 1	43.9	79.9	5	0.02	102.9	328.6	5	0.02	234.5	1242.2	5	0.02
ST 3	76.6	134.3			164.7	419.8			1242.2	1124.1		
ST 1	43.9	79.9	5	0.01	102.9	328.6	5	0.01	234.5	1242.2	5	0.008
ST 4	104.8	343.4			233.2	1421.6			463.9	2942.6		
ST 1	43.9	79.9	5	0.01	102.9	328.6	5	0.02	234.5	1242.2	5	0.08
ST 5	69.9	35.5			156.5	73.6			294.5	387.4		
ST 1	43.9	79.9	5	0.006	102.9	328.6	5	0.0005	234.5	1242.2	5	0.01
ST 6	79.9	74.8			176.9	183.9			359.2	377.9		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 42: t-test of Phase Angle for STs fabricated from 12.5 mm NMAS at 40°C

Comparison	40°C and 0.1 Hz				40°C and 1 Hz				40°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	30.4	0.2	5	0.07	33.9	0.5	5	0.08	34.2	1.4	5	0.004
ST 2	32.1	0.9			31.9	1.5			27.1	2.7		
ST 1	30.4	0.2	5	0.24	33.9	0.5	5	0.05	34.2	1.4	5	0.004
ST 3	32.1	2.8			32.6	0.2			29.3	0.7		
ST 1	30.4	0.2	5	0.30	33.9	0.5	5	0.03	34.2	1.4	5	0.02
ST 4	31.0	0.5			30.1	2.4			26.9	5.4		
ST 1	30.4	0.2	5	0.001	33.9	0.5	5	0.08	34.2	1.4	5	0.38
ST 5	32.9	0.2			32.9	0.09			33.1	2.6		
ST 1	30.4	0.2	5	0.07	33.9	0.5	5	0.08	34.2	1.4	5	0.004
ST 6	32.1	0.9			31.9	1.5			27.1	2.7		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 43: t-test of Dynamic Modulus for STs fabricated from 19 mm NMAS at 4°C

Comparison	4°C and 0.1 Hz				4°C and 1 Hz				4°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	1063.1	8764.5	5	0.11	1496.5	7796.8	5	0.10	1934.6	5338.4	5	0.09
ST 2	1215.4	8402.9			1666.1	11436.8			2128.0	12534.4		
ST 1	1063.1	8764.5	5	0.29	1496.5	7796.8	5	0.25	1934.6	5338.4	5	0.32
ST 3	962.6	11308.7			1344.9	25724.9			1723.2	72417.0		
ST 1	1063.1	8764.5	5	0.10	1496.5	7796.8	5	0.15	1934.6	5338.4	5	0.28
ST 4	1205.7	1902.2			1609.8	4582.5			2020.6	8913.4		
ST 1	1063.1	8764.5	5	0.73	1496.5	7796.8	5	0.74	1934.6	5338.4	5	0.88
ST 5	1023.7	23884.8			1450.0	41944.7			1910.8	57106.5		
ST 1	1063.1	8764.5	5	0.76	1496.5	7796.8	5	0.27	1934.6	5338.4	5	0.07
ST 6	1043.6	1671.1			1419.1	1996.7			1796.8	2060.6		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 44: t-test of Phase Angle for STs fabricated from 19 mm NMAS at 4°C

Comparison	4°C and 0.1 Hz				4°C and 1 Hz				4°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	16.8	2.7	5	0.23	12.3	1.6	5	0.36	9.3	0.6	5	0.21
ST 2	15.3	0.5			11.4	0.4			8.5	0.1		
ST 1	16.8	2.7	5	0.25	12.3	1.6	5	0.21	9.3	0.6	5	0.24
ST 3	19.4	6.9			14.4	4.1			11.1	3.9		
ST 1	16.8	2.7	5	0.10	12.3	1.6	5	0.15	9.3	0.6	5	0.16
ST 4	14.0	0.1			10.5	0.1			8.3	0.0		
ST 1	16.8	2.7	5	0.53	12.3	1.6	5	0.30	9.3	0.6	5	0.39
ST 5	17.6	1.5			13.2	0.9			9.9	0.5		
ST 1	16.8	2.7	5	0.24	12.3	1.6	5	0.38	9.3	0.6	5	0.24
ST 6	15.2	0.1			11.2	0.1			8.6	0.0		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 45: t-test of Dynamic Modulus for STs fabricated from 19 mm NMAS at 20°C

Comparison	20°C and 0.1 Hz				20°C and 1 Hz				20°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	350.5	907.0	5	0.37	640.8	844.2	5	0.55	1035.6	273.2	5	0.84
ST 2	330.0	218.6			627.5	411.1			1040.4	1227.6		
ST 1	350.5	907.0	5	0.01	640.8	844.2	5	0.04	1035.6	273.2	5	0.13
ST 3	238.4	1225.5			465.8	6585.3			796.8	27934.6		
ST 1	350.5	907.0	5	0.32	640.8	844.2	5	0.27	1035.6	273.2	5	0.43
ST 4	374.1	79.4			665.5	167.1			1052.0	727.9		
ST 1	350.5	907.0	5	0.02	640.8	844.2	5	0.03	1035.6	273.2	5	0.10
ST 5	237.7	1701.5			466.0	5350.6			833.2	13318.6		
ST 1	350.5	907.0	5	0.52	640.8	844.2	5	0.35	1035.6	273.2	5	0.16
ST 6	337.0	123.2			619.0	438.4			996.2	1084.5		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 46: t-test of Phase Angle for STs fabricated from 19 mm NMAS at 20°C

Comparison	20°C and 0.1 Hz				20°C and 1 Hz				20°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	28.6	1.9	5	0.13	18.3	0.5	5	1.1E-03	18.3	0.5	5	0.92
ST 2	30.6	0.1			24.5	0.2			18.4	0.9		
ST 1	28.6	1.9	5	0.01	18.3	0.5	5	1.9E-04	18.3	0.5	5	0.03
ST 3	33.3	0.6			27.2	0.9			21.3	1.3		
ST 1	28.6	1.9	5	0.24	18.3	0.5	5	5.3E-03	18.3	0.5	5	0.06
ST 4	27.3	1.1			22.0	0.8			17.0	0.3		
ST 1	28.6	1.9	5	0.01	18.3	0.5	5	9.3E-05	18.3	0.5	5	0.01
ST 5	32.7	1.0			28.0	0.6			21.8	0.7		
ST 1	28.6	1.9	5	0.54	18.3	0.5	5	1.8E-03	18.3	0.5	5	0.25
ST 6	29.2	0.2			23.5	0.2			17.7	0.1		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 47: t-test of Dynamic Modulus for STs fabricated from 19 mm NMAS at 35°C

Comparison	35°C and 0.1 Hz				35°C and 1 Hz				35°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	42.1	101.8	5	0.01	92.5	255.6	5	2.2E-03	208.1	629.8	5	1.2E-03
ST 2	79.9	74.8			176.9	184.0			359.2	377.8		
ST 1	42.1	101.8	5	0.08	92.5	255.6	5	1.7E-02	208.1	629.8	5	6.0E-03
ST 3	59.5	58.0			143.7	244.0			324.0	793.0		
ST 1	42.1	101.8	5	0.01	92.5	255.6	5	1.1E-03	208.1	629.8	5	6.0E-04
ST 4	84.3	22.5			186.9	120.2			386.8	361.0		
ST 1	42.1	101.8	5	0.26	92.5	255.6	5	0.05	208.1	629.8	5	0.13
ST 5	51.9	70.7			125.5	140.7			244.0	264.8		
ST 1	42.1	101.8	5	0.02	92.5	255.6	5	3.6E-03	208.1	629.8	5	2.8E-03
ST 6	71.9	27.8			162.2	133.8			339.9	586.7		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 48: t-test of Phase Angle for STs fabricated from 19 mm NMAS at 35°C

Comparison	35°C and 0.1 Hz				35°C and 1 Hz				35°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	28.0	0.4	5	8.2E-03	32.2	0.4	5	0.76	34.4	2.7	5	0.01
ST 2	32.1	0.9			31.9	1.5			27.1	2.7		
ST 1	28.0	0.4	5	2.2E-04	32.2	0.4	5	0.01	34.4	2.7	5	0.25
ST 3	35.0	0.5			36.4	0.0			33.0	0.4		
ST 1	28.0	0.4	5	0.06	32.2	0.4	5	0.50	34.4	2.7	5	0.01
ST 4	30.9	2.7			31.4	2.3			29.4	1.6		
ST 1	28.0	0.4	5	0.04	32.2	0.4	5	0.02	34.4	2.7	5	0.18
ST 5	33.3	3.3			36.8	2.3			39.1	19.0		
ST 1	28.0	0.4	5	4.9E-04	32.2	0.4	5	0.10	34.4	2.7	5	0.06
ST 6	32.5	0.2			33.7	0.9			31.2	0.9		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 49: t-test of Dynamic Modulus for STs fabricated from 25 mm NMAS at 4°C

Comparison	4°C and 0.1 Hz				4°C and 1 Hz				4°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	1448.4	926.8	5	0.38	1941.3	878.7	5	0.23	2419.6	610.7	5	0.15
ST 2	1400.2	5761.9			1837.5	10216.5			2276.3	11647.7		
ST 1	1448.4	926.8	5	0.02	1941.3	878.7	5	0.01	2419.6	610.7	5	9.1E-03
ST 3	1345.4	356.9			1826.5	1147.9			2303.4	1195.9		
ST 1	1448.4	926.8	5	0.05	1941.3	878.7	5	0.01	2419.6	610.7	5	3.3E-03
ST 4	1376.7	965.1			1835.3	1133.2			2277.3	944.4		
ST 1	1448.4	926.8	5	0.85	1941.3	878.7	5	0.81	2419.6	610.7	5	0.70
ST 5	1462.1	11211.9			1965.8	22304.7			2468.5	36082.9		
ST 1	1448.4	926.8	5	0.41	1941.3	878.7	5	0.31	2419.6	610.7	5	0.23
ST 6	1331.0	37680.2			1762.0	51439.6			2180.5	59967.7		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 50: t-test of Phase Angle for STs fabricated from 25 mm NMAS at 4°C

Comparison	4°C and 0.1 Hz				4°C and 1 Hz				4°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	14.5	12.8	5	.28	10.5	9.8	5	0.44	7.8	0.3	5	0.09
ST 2	0.5	3.0			0.3	1.7			6.9	0.1		
ST 1	14.5	12.8	5	0.58	10.5	9.8	5	0.50	7.8	0.3	5	0.60
ST 3	14.8	0.2			10.8	0.1			8.1	0.3		
ST 1	14.5	12.8	5	0.65	10.5	9.8	5	0.75	7.8	0.3	5	0.98
ST 4	14.3	0.0			10.4	0.0			7.9	0.0		
ST 1	14.5	12.8	5	0.59	10.5	9.8	5	0.46	7.8	0.3	5	0.30
ST 5	14.8	0.1			10.8	0.0			8.3	0.0		
ST 1	14.5	12.8	5	0.98	10.5	9.8	5	0.81	7.8	0.3	5	1.00
ST 6	14.5	0.8			10.4	0.5			7.8	0.2		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 51: t-test of Dynamic Modulus for STs fabricated from 25 mm NMAS at 20°C

Comparison	20°C and 0.1 Hz				20°C and 1 Hz				20°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	504.9	570.6	5	1.4E-02	900.0	559.2	5	1.8E-03	1392.2	488.9	5	8.6E-04
ST 2	420.5	206.9			763.2	474.3			1211.3	735.6		
ST 1	504.9	570.6	5	2.4E-03	900.0	559.2	5	3.8E-04	1392.2	488.9	5	2.8E-04
ST 3	348.7	231.4			672.4	718.4			1127.5	983.8		
ST 1	504.9	570.6	5	1.2E-02	900.0	559.2	5	5.0E-03	1392.2	488.9	5	2.6E-03
ST 4	376.6	13.0			705.9	9.1			1139.7	10.1		
ST 1	504.9	570.6	5	4.4E-03	900.0	559.2	5	1.4E-02	1392.2	488.9	5	0.08
ST 5	379.2	846.3			717.2	3238.0			1201.9	9008.1		
ST 1	504.9	570.6	5	0.15	900.0	559.2	5	0.22	1392.2	488.9	5	0.21
ST 6	432.3	3637.8			782.4	12580.4			1209.7	30124.1		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 52: t-test of Phase Angle for STs fabricated from 25 mm NMAS at 20°C

Comparison	20°C and 0.1 Hz				20°C and 1 Hz				20°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	27.8	0.3	5	0.04	21.5	0.2	5	0.06	16.0	16.5	5	0.24
ST 2	29.0	0.3			22.5	0.2			0.1	0.3		
ST 1	27.8	0.3	5	8.5E-03	21.5	0.2	5	7.4E-03	16.0	16.5	5	8.4E-03
ST 3	32.2	1.2			25.2	0.8			18.8	0.5		
ST 1	27.8	0.3	5	4.7E-03	21.5	0.2	5	4.1E-03	16.0	16.5	5	1.9E-03
ST 4	30.4	0.3			24.0	0.3			17.9	0.1		
ST 1	27.8	0.3	5	3.4E-03	21.5	0.2	5	4.1E-04	16.0	16.5	5	5.8E-03
ST 5	31.2	0.6			25.1	0.1			18.8	0.0		
ST 1	27.8	0.3	5	0.05	21.5	0.2	5	0.18	16.0	16.5	5	0.39
ST 6	29.2	0.4			22.6	0.9			16.5	0.6		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 53: t-test of Dynamic Modulus for STs fabricated from 25 mm NMAS at 35°C

Comparison	35°C and 0.1 Hz				35°C and 1 Hz				35°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	42.4	159.7	5	0.03	103.5	785.3	5	0.02	248.6	3008.1	5	0.03
ST 2	75.5	140.2			179.0	356.3			396.7	1056.5		
ST 1	42.4	159.7	5	0.07	103.5	785.3	5	0.05	248.6	3008.1	5	0.04
ST 3	67.7	0.8			175.2	14.1			405.6	78.5		
ST 1	42.4	159.7	5	0.06	103.5	785.3	5	0.04	248.6	3008.1	5	0.03
ST 4	71.7	0.1			185.6	0.0			423.5	0.0		
ST 1	42.4	159.7	5	0.03	103.5	785.3	5	0.01	248.6	3008.1	5	0.01
ST 5	73.4	80.4			197.1	206.3			452.9	883.6		
ST 1	42.4	159.7	5	0.01	103.5	785.3	5	0.01	248.6	3008.1	5	0.01
ST 6	87.8	24.0			217.1	326.6			464.8	2372.6		

* Bold font indicates the null hypothesis of equal means is rejected.

Table 54: t-test of Phase Angle for STs fabricated from 25 mm NMAS at 35°C

Comparison	35°C and 0.1 Hz				35°C and 1 Hz				35°C and 10 Hz			
	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*	Mean	Variance	df	P-value*
ST 1	28.7	0.3	5	3.0E-03	33.7	0.5	5	0.58	36.1	2.3	5	0.02
ST 2	32.0	0.5			34.0	0.4			31.5	0.5		
ST 1	28.7	0.3	5	2.3E-02	33.7	0.5	5	0.01	36.1	2.3	5	0.06
ST 3	36.0	3.5			37.5	1.1			32.6	0.0		
ST 1	28.7	0.3	5	1.8E-03	33.7	0.5	5	0.51	36.1	2.3	5	0.01
ST 4	32.1	0.3			33.2	0.9			30.7	0.5		
ST 1	28.7	0.3	5	3.3E-03	33.7	0.5	5	0.02	36.1	2.3	5	0.04
ST 5	35.1	1.4			36.2	0.9			32.9	1.4		
ST 1	28.7	0.3	5	3.9E-03	33.7	0.5	5	0.33	36.1	2.3	5	0.01
ST 6	34.3	1.1			34.5	1.2			30.6	1.4		

* Bold font indicates the null hypothesis of equal means is rejected.

The t-test results of dynamic modulus and phase values for same combinations of temperature and frequency does not follow the same pattern. Meaning, if dynamic modulus is statistically significant, phase angle may/may not be statistically significant. The results from t- test analysis are:

- For 12.5 mm NMAS mix at 4°C- different frequencies, combination of ST1 with all STs are statistically same for dynamic modulus. For phase angle, ST1-ST5 are statistically same at two of three frequencies. At 20°C- different frequencies, ST1-ST3 and ST1-ST5 are statistically same for both dynamic modulus and phase angle. At 40°C- different frequencies, none was statistically same to ST1 for dynamic modulus values however two of three frequencies for ST1-ST 5 and ST1-ST 6 were statistically same for phase angle.
- For 19 mm NMAS mix at 4°C- different frequencies, combination of ST1 with all STs are statistically same for dynamic modulus and phase angle. At 20°C and different frequencies, ST1-ST2, ST1-ST4 and ST1-ST6 are statistically same for dynamic modulus. For phase angle, ST1-ST2, ST1-ST4, and ST1-ST6 are statistically same for two of three frequencies. At 35°C- different frequencies, ST1-ST5 for dynamic modulus values is statistically same. For phase angle, ST1-ST2 and ST1-ST6 are statistically same at different frequencies.

- For 25 mm NMA mix at 4°C- different frequencies, ST1-all STs are statistically same for dynamic modulus and phase angle. At 20°C and different frequencies, ST1- ST6 are statistically same for dynamic modulus and phase angle. At 35°C for dynamic modulus, ST1-ST3 is statistically same for two of three frequencies. For phase angle, ST1-ST3 is statistically same for one of three frequencies.

ANOVA in Table 55 to 57 is used for comparing different STs for various combinations of temperature and frequencies in dynamic modulus test. All tests used a 95 percent confidence level, alpha of 0.05. The null hypothesis states no difference in means of ST1, ST2, ST3, ST4, ST5, and ST6. Failure to reject the null hypothesis indicates the means of ST1, ST2, ST3, ST4, ST5, and ST6 are statistically same. Rejecting the null hypothesis implies the data sets are statistically different. In the tables of ANOVA results, comparisons with alpha of less than 0.05 are shown with a bold font.

Table 55: ANOVA of STs for Dynamic Modulus and Phase Angle from 12.5 mm NMA

ANOVA Comparison of ST1, ST2, ST3, ST4, ST5, and ST6	12.5 mm					
	Dynamic Modulus			Phase Angle		
	TSS	Degrees of freedom	P-value*	TSS	Degrees of freedom	P-value*
4°C and 0.1 Hz	84487.0	17	0.13	19.3	17	0.02
4°C and 1 Hz	77811.0		0.27	8.1		0.03
4°C and 10 Hz	77011.5		0.37	8.9		0.26
20°C and 0.1 Hz	10966.1		0.91	40.7		0.87
20°C and 1 Hz	52118.5		0.77	10.9		0.40
20°C and 10 Hz	146983.6		0.65	42.9		0.75
40°C and 0.1 Hz	5082.3		0.03	14.2		0.15
40°C and 1 Hz	22411.3		0.02	26.6		0.23
40°C and 10 Hz	72719.7		0.005	160.1		0.007
* Bold = reject null hypothesis						

Table 56: ANOVA of STs for Dynamic Modulus and Phase Angle from 19 mm NMAS

ANOVA Comparison of ST1, ST2, ST3, ST4, ST5, and ST6	19 mm					
	Dynamic Modulus			Phase Angle		
	TSS	Degrees of freedom	P-value*	TSS	Degrees of freedom	P-value*
4°C and 0.1 Hz	91055.8	17	0.29	53.3	17	0.14
4°C and 1 Hz	174073.9		0.32	29.8		0.15
4°C and 10 Hz	394952.2		0.33	20.7		0.22
20°C and 0.1 Hz	33590.8		0.004	61.5		5.1E-04
20°C and 1 Hz	82609.6		0.03	52.9		9.8E-05
20°C and 10 Hz	167783.8		0.15	38.7		0.002
35°C and 0.1 Hz	2729.9		0.004	70.5		2.9E-04
35°C and 1 Hz	12595.2		0.002	76.3		0.007
35°C and 10 Hz	52286.3		0.001	277.8		0.005
* Bold = reject null hypothesis						

Table 57: ANOVA of STs for Dynamic Modulus and Phase Angle from 25 mm NMAS

ANOVA Comparison of ST1, ST2, ST3, ST4, ST5, and ST6	25 mm					
	Dynamic Modulus			Phase Angle		
	TSS	Degrees of freedom	P-value*	TSS	Degrees of freedom	P-value*
4°C and 0.1 Hz	75322.6	17	0.78	15.0	17	0.09
4°C and 1 Hz	107670.1		0.78	5.5		0.14
4°C and 10 Hz	150888.0		0.66	4.2		0.09
20°C and 0.1 Hz	42506.3		0.002	25.1		0.002
20°C and 1 Hz	92665.3		0.007	26.9		0.003
20°C and 10 Hz	134755.5		0.04	19.0		0.002
35°C and 0.1 Hz	2302.4		0.02	78.5		0.002
35°C and 1 Hz	15542.5		0.004	37.2		0.002
35°C and 10 Hz	63464.2		0.005	43.6		0.003
* Bold = reject null hypothesis						

The results from t-test analysis are:

- All the STs are statistically same in DM and PA for 12.5 mm NMAS mix at 20°C at 0.1, 1 and 10HZ
- All the STs are statistically same in DM and PA for 19 mm NMAS mix at 4°C at 0.1, 1 and 10HZ
- All the STs are statistically same in DM and PA for 25 mm NMAS mix at 4°C at 0.1, 1, and 10HZ.

MANOVA in Table 58 to 66 is used for comparing ST1 and other STs for all three different NMAS for various combinations of temperature and frequencies in dynamic modulus test. This is performed because for all NMAS mixes up to 37.5 mm, ST1 is used to perform dynamic modulus test per current

AASHTO standard. Therefore, MANOVA is performed to verify if jointly ST1 and other STs are statistically same for all NMAAS mixes.

All tests used a 95 percent confidence level, alpha of 0.05. The null hypothesis states no difference in means of ST1 and other ST for all three different NMAAS mixes. Failure to reject the null hypothesis indicates no significant difference between 12.5 mm, 19mm, and 25 mm when considered jointly on ST1 and other ST. Rejecting the null hypothesis implies the data sets are statistically different for all three different NMAAS mixes. In the tables of MANOVA results, comparisons with alpha of less than 0.05 are shown with a bold font.

The MANOVA results show that a significant difference between 12.5 mm, 19mm, and 25 mm when considered jointly on ST1 and other STs for various combinations of temperature and frequencies in dynamic modulus test. This confirms that specific ST must be used to test dynamic modulus test of a given NMAAS mix.

Table 58: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 4°C and 0.1Hz

	4°C and 0.1Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
12.5	ST1	1206.6	88.0	17	0.006	14.4	.6	17	0.027
19		1063.1	93.6			16.8	1.6		
25		1448.4	30.4			14.5	.7		
12.5	ST2	1373.7	45.5			10.9	.2		
19		1215.4	91.6			15.3	.7		
25		1400.2	75.8			12.8	1.7		
12.5	ST1	1206.6	88.0	17	0.000	14.4	.6	17	0.022
19		1063.1	93.6			16.8	1.6		
25		1448.4	30.4			14.5	.7		
12.5	ST3	1368.4	72.6			11.9	.7		
19		962.6	106.3			19.3	2.6		
25		1345.4	18.9			14.8	.4		
12.5	ST1	1206.6	88.0	17	0.000	14.4	.6	17	0.022
19		1063.1	93.6			16.8	1.6		
25		1448.4	30.4			14.5	.7		
12.5	ST4	1368.4	72.6			11.900	.7		
19		962.6	106.3			19.367	2.6		
25		1345.4	18.9			14.833	.4		
12.5	ST1	1206.6	88.0	17	0.007	14.4	.6	17	0.008
19		1063.1	93.6			16.8	1.6		
25		1448.4	30.4			14.5	.7		
12.5	ST5	1350.2	87.1			11.867	1.2		
19		1023.7	154.6			17.667	1.1		
25		1462.1	105.8			14.767	.4		
12.5	ST1	1206.6	88.0	17	0.004	14.4	.6	17	0.001
19		1063.1	93.6			16.8	1.6		
25		1448.4	30.4			14.5	.7		
12.5	ST6	1373.7	45.6			10.967	.2		
19		1043.7	40.9			15.233	.4		
25		1330.9	194.1			14.500	.9		
* Bold = reject null hypothesis									

Table 59: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 4°C and 1Hz

	4°C and 1Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
12.5	ST1	1608.7	101.1	17	0.010	10.8	.4	17	0.044
19		1496.5	88.3			12.2	1.2		
25		1941.3	29.6			10.5	.5		
12.5	ST2	1740.6	52.9			8.7	.1		
19		1666.1	106.9			11.3	.6		
25		1837.5	101.0			9.8	1.3		
12.5	ST1	1608.7	101.1	17	0.001	10.8	.4	17	0.028
19		1496.5	88.3			12.2	1.2		
25		1941.3	29.6			10.5	.5		
12.5	ST3	1750.1	73.0			9.1	.6		
19		1344.9	160.3			14.4	2.0		
25		1826.5	33.8			10.8	.3		
12.5	ST1	1608.7	101.1	17	0.001	10.8	.4	17	0.028
19		1496.5	88.3			12.2	1.2		
25		1941.3	29.6			10.5	.5		
12.5	ST4	1750.1	73.0			9.1	.6		
19		1344.9	160.3			14.4	2.0		
25		1826.5	33.8			10.8	.3		
12.5	ST1	1608.7	101.1	17	0.008	10.8	.4	17	0.010
19		1496.5	88.3			12.2	1.2		
25		1941.3	29.6			10.5	.5		
12.5	ST5	1731.2	90.6			9.0	.9		
19		1450.0	204.8			13.1	.9		
25		1965.8	149.3			10.8	.2		
12.5	ST1	1608.7	101.1	17	0.003	10.8	.4	17	0.005
19		1496.5	88.3			12.2	1.2		
25		1941.3	29.6			10.5	.5		
12.5	ST6	1740.6	52.9			8.7	.1		
19		1419.1	44.6			11.2	.3		
25		1761.9	226.7			10.3	.7		
* Bold = reject null hypothesis									

Table 60: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 4°C and 10Hz

	4°C and 10Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
12.5	ST1	2002.8	110.1	17	0.007	8.3	.35	17	0.025
19		1934.5	73.1			9.3	.80		
25		2419.5	24.7			7.8	.56		
12.5	ST2	2116.2	59.47 1	17	0.007	6.5	.75	17	0.025
19		2128.0	111.9			8.5	.37		
25		2276.3	107.9			6.8	.37		
12.5	ST1	2002.8	110.1	17	0.007	8.3	.35	17	0.056
19		1934.5	73.1			9.3	.80		
25		2419.5	24.7			7.8	.56		
12.5	ST3	2116.2	59.4	17	0.007	7.5	.40	17	0.056
19		2128.0	111.9			11.1	1.9		
25		2276.3	107.9			8.1	.5		
12.5	ST1	2002.8	110.1	17	0.001	8.3	.35	17	0.056
19		1934.5	73.1			9.3	.80		
25		2419.5	24.7			7.8	.56		
12.5	ST4	2135.4	67.1	17	0.001	7.5	.40	17	0.056
19		1723.2	269.1			11.1	1.9		
25		2303.4	34.5			8.1	.56		
12.5	ST1	2002.8	110.1	17	0.005	8.3	.35	17	0.021
19		1934.5	73.1			9.3	.80		
25		2419.5	24.7			7.8	.56		
12.5	ST5	2120.9	82.6	17	0.005	7.1	1.1	17	0.021
19		1910.7	238.9			9.9	.70		
25		2468.4	189.9			8.3	.10		
12.5	ST1	2002.8	110.1	17	0.002	8.3	.35	17	0.011
19		1934.5	73.1			9.3	.80		
25		2419.5	24.7			7.8	.56		
12.5	ST6	2116.2	59.4	17	0.002	6.500	.75	17	0.011
19		1796.7	45.4			8.533	.15		
25		2180.4	244.8			7.8	.45		
* Bold = reject null hypothesis									

Table 61: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 20°C and 0.1Hz

	20°C and 0.1Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
12.5	ST1	431.7	39.1	17	0.000	26.6	.65	17	0.053
19		350.4	30.1			28.6	1.37		
25		504.9	23.9			27.7	.58		
12.5	ST2	447.1	27.2			25.7	2.91		
19		330.0	14.8			30.6	.30		
25		420.5	14.3			29.0	.52		
12.5	ST1	431.7	39.1	17	0.000	26.6	.65	17	0.003
19		350.4	30.1			28.6	1.37		
25		504.9	23.9			27.7	.58		
12.5	ST3	495.3	65.8			24.3	1.7		
19		238.3	35.0			33.2	.75		
25		348.7	15.1			32.1	1.1		
12.5	ST1	431.7	39.1	17	0.000	26.6	.65	17	0.001
19		350.4	30.1			28.6	1.37		
25		504.9	23.9			27.7	.58		
12.5	ST4	495.3	65.8			24.3	1.7		
19		238.3	35.0			33.26	.75		
25		348.7	15.1			32.16	1.10		
12.5	ST1	431.7	39.1	17	0.000	26.6	.65	17	0.004
19		350.4	30.1			28.6	1.37		
25		504.9	23.9			27.7	.58		
12.5	ST5	432.8	28.0			25.4	1.26		
19		237.7	41.2			32.73	1.02		
25		379.2	29.1			31.16	.72		
12.5	ST1	431.7	39.1	17	0.007	26.6	.65	17	0.078
19		350.4	30.1			28.6	1.37		
25		504.9	23.9			27.7	.58		
12.5	ST6	447.1	27.2			25.73	2.91		
19		337.0	11.1			29.20	.50		
25		432.2	60.2			29.20	.60		
* Bold = reject null hypothesis									

Table 62: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 20°C and 1Hz

	20°C and 1Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
12.5	ST1	744.6	56.1	17	0.003	20.9	.65	17	0.000
19		640.8	29.1			23.7	1.05		
25		640.8	29.1			21.5	.41		
12.5	ST2	712.9	91.1			19.03	.71		
19		627.5	20.3			24.5	.47		
25		763.2	21.8			22.50	.45		
12.5	ST1	744.6	56.1	17	0.005	20.9	.65	17	0.001
19		640.8	29.1			23.7	1.05		
25		744.6	56.1			21.5	.41		
12.5	ST3	816.3	80.3			18.9	1.6		
19		465.7	81.1			27.2	.95		
25		672.4	26.7			25.2	.85		
12.5	ST1	744.6	56.1	17	0.005	20.9	.65	17	0.001
19		640.8	29.1			23.7	1.05		
25		744.6	56.1			21.5	.41		
12.5	ST4	816.3	80.3			18.9	1.69		
19		465.7	81.1			27.2	.95		
25		672.4	26.7			25.2	.85		
12.5	ST1	744.6	56.1	17	0.002	20.9	.65	17	0.000
19		640.8	29.1			23.7	1.05		
25		744.6	56.1			21.5	.41		
12.5	ST5	718.03	29.4			20.40	.79		
19		465.96	73.1			28.03	.77		
25		717.16	56.9			25.13	.35		
12.5	ST1	744.6	56.1	17	0.040	20.9	.65	17	0.001
19		640.8	29.1			23.7	1.05		
25		744.6	56.1			21.5	.41		
12.5	ST6	712.9	91.18			19.03	.70		
19		619.0	20.94			23.50	.45		
25		782.4	112.17			22.60	.98		
* Bold = reject null hypothesis									

Table 63: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 20°C and 10Hz

	20°C and 10Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
12.5	ST1	1136.5	70.6	17	0.000	15.9	.55	17	0.006
19		1035.6	16.5			18.3	.72		
25		1392.2	22.1			15.9	.37		
12.5	ST2	1048.0	159.3			16.1	2.9		
19		1040.3	35.0			18.4	.96		
25		1211.3	27.1			16.5	.55		
12.5	ST1	1136.5	70.6	17	0.000	15.9	.55	17	0.000
19		1035.6	16.5			18.3	.72		
25		1392.2	22.1			15.9	.37		
12.5	ST3	1212.7	79.6			14.4	1.2		
19		796.8	167.1			21.3	1.1		
25		1127.5	31.3			18.7	.665		
12.5	ST1	1136.5	70.6	17	0.000	15.9	.55	17	0.000
19		1035.6	16.5			18.3	.72		
25		1392.2	22.1			15.9	.37		
12.5	ST4	1212.7	79.6			14.4	1.2		
19		796.7	167.1			21.3	1.1		
25		1127.5	31.3			18.7	.66		
12.5	ST1	1136.5	70.6	17	0.001	15.9	.55	17	0.000
19		1035.6	16.5			18.3	.72		
25		1392.2	22.1			15.9	.37		
12.5	ST5	1091.5	24.5			15.1	1.3		
19		833.2	115.4			21.8	.78		
25		1201.9	94.9			18.8	.11		
12.5	ST1	1136.5	70.6	17	0.002	15.9	.55	17	0.017
19		1035.6	16.5			18.3	.72		
25		1392.2	22.1			15.9	.37		
12.5	ST6	1048.0	159.3			16.1	2.9		
19		996.2	32.9			17.6	.30		
25		1209.7	173.6			16.5	.79		
* Bold = reject null hypothesis									

Table 64: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 35°C and 0.1Hz

	35°C and 0.1Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
19	ST1	42.1	10.1	11	0.903	27.9	.65	11	0.350
25		42.4	12.6			28.7	.55		
19	ST2	79.9	8.62			32.1	.97		
25		75.4	11.8			32.0	.73		
19	ST1	42.1	10.1	11	0.388	27.9	.65	11	0.438
25		42.4	12.6			28.7	.55		
19	ST3	59.4	7.6			35.0	.75		
25		67.7	.91			35.9	1.8		
19	ST1	42.1	10.1	11	0.388	27.9	.65	11	0.438
25		42.4	12.6			28.7	.55		
19	ST4	59.4	7.6			35.0	.75		
25		67.7	.91			35.9	1.8		
19	ST1	42.1	10.1	11	0.165	27.9	.65	11	0.399
25		42.4	12.6			28.7	.55		
19	ST5	51.9	8.3			33.3	1.8		
25		73.3	8.9			35.1	1.1		
19	ST1	42.1	10.1	11	0.090	27.9	.65	11	0.030
25		42.4	12.6			28.7	.55		
19	ST6	71.9	5.2			32.5	.41		
25		87.8	4.9			34.3	1.0		
* Bold = reject null hypothesis									

Table 65: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 35°C and 1Hz

	35°C and 1Hz								
	Dynamic Modulus					Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
19	ST1	92.4	16.0	11	0.860	32.1	.60	11	0.080
25		103.5	27.9			33.6	.70		
19	ST2	176.9	13.5			31.9	1.2		
25		179.0	18.8			34.0	.70		
19	ST1	92.4	16.0	11	0.130	32.1	.60	11	0.026
25		103.5	27.9			33.6	.70		
19	ST3	143.6	15.6			36.4	.20		
25		175.2	3.7			37.5	1.0		
19	ST1	92.4	16.0	11	0.130	32.1	.60	11	0.026
25		103.5	27.9			33.6	.70		
19	ST4	143.6	15.6			36.4	.20		
25		175.2	3.7			37.5	1.0		
19	ST1	92.4	16.0	11	0.019	32.1	.60	11	0.192
25		103.5	27.9			33.6	.70		
19	ST5	125.5	11.8			36.7	1.5		
25		197.0	14.4			36.2	.95		
19	ST1	92.4	16.0	11	0.065	32.1	.60	11	0.167
25		103.5	27.9			33.6	.70		
19	ST6	162.2	11.5			33.7	.95		
25		217.0	18.0			34.5	1.1		
* Bold = reject null hypothesis									

Table 66: MANOVA of NMAS and STs for Dynamic Modulus and Phase Angle at 35°C and 10Hz

		35°C and 10Hz							
		Dynamic Modulus				Phase Angle			
NMAS	Sample Type	Mean	SD	df	P-value*	Mean	SD	df	P-value*
19	ST1	208.1	25.0	11	0.269	34.4	34.4	11	0.072
25		248.6	54.8			1.6	1.6		
19	ST2	359.1	19.4			36.1	36.1		
25		396.7	32.4			1.5	1.5		
19	ST1	208.1	25.0	11	0.057	34.4	34.4	11	0.016
25		248.6	54.8			1.6	1.6		
19	ST3	323.9	28.1			36.1	36.1		
25		405.6	8.8			1.5	1.5		
19	ST1	208.1	25.0	11	0.057	34.4	34.4	11	0.157
25		248.6	54.8			1.6	1.6		
19	ST4	323.9	28.1			36.1	36.1		
25		405.6	8.8			1.5	1.5		
19	ST1	208.1	25.0	11	0.001	33.0	33.0	11	0.261
25		248.6	54.8			.60	.60		
19	ST5	244.0	16.2			32.5	32.5		
25		452.8	29.71			.11	.11		
19	ST1	208.1	25.0	11	0.091	34.4	34.4	11	0.229
25		248.6	54.8			1.6	1.6		
19	ST6	339.9	24.2			36.1	36.1		
25		464.8	48.7			1.5	1.5		
* Bold = reject null hypothesis									

4.4 WITHIN SAMPLE AIR VOID VARIABILITY ANALYSIS

The Analysis 4 evaluates air void uniformity using samples tested for dynamic modulus test in AMPT. The air void uniformity is conducted using AASHTO R 83-17 with the exception that all six STs are tested. The AASHTO standard specifies only ST1, which is 100X150 mm samples cored from the center of SGC pill to be tested for air void uniformity. It is beneficial to investigate uniformity at 7.0 ± 0.5 percent of all replicates for six different STs. Each ST was cut into equal thirds:

Sample Types	Approximate Height of Thirds, mm
ST 1	50 mm
ST 2	
ST 3	
ST 4	
ST 5	
ST 6	

The VTM of thirds and intact samples were measured using SSD method and the G_{mb} was computed. The air void data for comparison of sample third to intact sample for each NMAS is shown in Table 67, 68, and 69.

Table 67: Comparison of Sample Third Air Void to Entire Sample Air Void for 12.5 mm NMAS mix

Sample	VTM %			Ranking			Thirds Average, %	Intact Sample, %	Difference, %
	T	M	B	T	M	B			
1	7.5	6.9	8.0	0	-1	1	7.4	7.4	0.0
2	8.2	7.0	7.4	1	-1	0	7.5	7.4	0.1
3	8.1	6.8	6.5	1	0	-1	7.1	7.1	0.0
31 a.	8.0	7.0	6.3	1	0	-1	7.1	6.9	0.2
31 b.	7.5	6.3	7.2	1	-1	0	7.0	6.9	0.1
31 c.	7.8	6.5	6.3	1	0	-1	6.9	6.6	0.3
37	7.1	6.8	6.3	1	0	-1	6.7	6.7	0.0
38	7.8	7.4	7.0	1	0	-1	7.4	7.4	0.0
39	7.2	6.8	7.1	1	-1	0	7.0	7.0	0.0
55 a.	7.6	8.0	7.2	0	1	-1	7.6	7.5	0.1
55 b.	8.0	7.7	7.1	1	0	-1	7.6	7.5	0.1
55 c.	7.2	8.0	7.2	0	1	0	7.5	7.5	0.0
67	7.6	7.5	7.3	1	0	-1	7.5	7.5	0.0
68	7.5	7.6	7.3	0	1	-1	7.5	7.5	0.0
69	7.6	8.0	7.6	0	1	0	7.7	7.5	0.2
85	7.3	7.1	7.0	1	0	-1	7.2	7.2	0.0
86	7.7	7.6	7.5	1	0	-1	7.6	7.4	0.2
87	7.5	7.4	7.5	1	0	1	7.5	7.5	0.0

Table 68: Comparison of Sample Third Air Void to Entire Sample Air Void for 19 mm NMAS mix

Sample	VTM %			Ranking			Thirde Average, %	Intact Sample, %	Difference, %
	T	M	B	T	M	B			
8	6.1	6.4	7.6	-1	0	1	6.7	6.7	0.0
9	6.6	5.8	7.2	0	-1	1	6.5	6.5	0.0
10	6.6	7.3	5.8	0	1	-1	6.6	6.6	0.0
33 a.	7.9	6.0	6.3	1	-1	0	6.7	6.5	0.2
33 b.	8.1	6.3	6.1	1	0	-1	6.8	6.6	0.2
33 c.	7.0	6.6	6.5	1	0	-1	6.7	6.5	0.2
43	8.2	7.3	7.2	1	0	-1	7.5	7.4	0.1
44	7.8	6.5	7.4	1	-1	0	7.2	7.0	0.2
45	8.1	7.2	7.6	1	-1	0	7.6	7.4	0.2
59 a.	6.4	7.2	6.9	-1	1	0	6.9	6.6	0.3
59 b.	7.1	8.1	7.3	-1	1	0	7.5	7.5	0.0
59 c.	7.8	8.3	7.3	0	1	-1	7.8	7.5	0.3
73	7.3	7.9	7.4	-1	1	0	7.5	7.5	0.0
74	6.7	7.1	6.6	0	1	-1	6.8	6.5	0.3
75	7.9	7.5	7.1	1	0	-1	7.5	7.2	0.3
91	7.1	6.5	7.4	0	-1	1	7.0	7.0	0.0
92	8.0	7.2	7.4	1	-1	0	7.5	7.5	0.0
93	7.2	6.8	6.9	1	-1	0	6.9	6.9	0.0

Table 69: Comparison of Sample Third Air Void to Entire Sample Air Void for 25 mm NMAS mix

Sample	VTM %			Ranking			Thirds Average, %	Intact Sample, %	Difference, %
	T	M	B	T	M	B			
15	5.8%	6.1%	8.4%	-1	0	1	6.8	6.8	0.0
16	6.8%	5.3%	8.0%	-1	0	1	6.7	6.7	0.0
17	5.5%	6.6%	8.2%	-1	0	1	6.8	6.5	0.3
35 a.	7.4%	6.5%	8.5%	0	-1	1	7.5	7.5	0.0
35 b.	7.7%	8.3%	6.2%	0	1	-1	7.4	7.2	0.2
35 c.	8.5%	7.0%	6.3%	1	0	-1	7.3	7.2	0.1
49	6.8%	7.1%	6.2%	0	1	-1	6.7	6.5	0.2
50	7.4%	7.0%	6.4%	1	0	-1	6.9	6.5	0.4
51	7.0%	7.1%	6.2%	0	1	-1	6.8	6.5	0.3
63 a.	7.0%	6.7%	6.1%	1	0	-1	6.6	6.5	0.1
63 b.	6.7%	7.2%	6.4%	0	1	-1	6.7	6.5	0.2
63 c.	6.9%	7.4%	6.8%	0	1	-1	7.0	7.0	0.0
79	7.3%	8.6%	7.2%	0	1	-1	7.7	7.5	0.2
80	6.0%	7.2%	7.8%	-1	0	1	7.0	6.8	0.2
81	6.9%	8.1%	7.3%	-1	1	0	7.4	7.1	0.3
97	7.3%	6.5%	6.7%	1	-1	0	6.8	6.8	0.0
98	7.0%	6.7%	6.5%	1	0	-1	6.7	6.7	0.0
99	7.8%	7.1%	7.3%	1	-1	0	7.4	7.2	0.2

The analysis of thirds and intact samples show that in some cases the air void of sections were higher than the air void of intact samples. The possible reasoning is when the thirds were sawed, an aggregate might have chipped towards the end from the edge. This gap from the chipped aggregate might have caused an increase in air void.

With most compactive efforts in the middle section, the section should have lowest air void content. Although few samples demonstrated this behavior, it was not the same for all the samples. The segments were assigned 1, 0, or -1 to highest, second highest, and lowest air void measurement for each sample third. In 12.5 mm NMAS mix, ST 6 showed consistent results with lowest air voids in the lower section and highest in the top section. Additionally, ST 6 had the lowest variation in air void between thirds. In 19 mm NMAS mix, ST 2, ST 3, and ST 4 showed consistent results. However, ST 4 had the lowest variation in air void between the thirds. ST 4 demonstrated lowest air voids in the top section and highest in the middle section. In 25 mm NMAS mix, ST 1 was most consistent with the ranking. The

lowest air voids were observed in the top section and the highest air voids in the top section. ST 6 showed lowest variation in the air voids between the thirds.

The results for air void uniformity are shown in Table 70 to 72. All tests used a 95 percent confidence level, alpha of 0.05. The null hypothesis for all tests was the mean G_{mb} of the two data sets are equal. Failure to reject the null hypothesis indicates the mean G_{mb} of each data set are statistically same. The precision is calculated per AASHTO T 312-15. The precision values show that the comparison of thirds that does not fall within the precision range should only be considered for statistical analysis. And therefore, if the comparison of third is within the limits of precision, they are statistically same. Per AASHTO T 312-15, the precision of percent relative density for 12.5 mm NMAS should be within the range of 0.3 and 0.9. The precision of percent relative density for 19 mm and 25 mm NMAS should be within the range of 0.5 and 1.4

Table 70: Statistical Analysis of Air Void Variability for Different STs in 12.5 mm NMAS Mix

	12.5 mm NMAS							
Comparison	Unique Sample Number	Gmb Mean of comparison		Precision	Variance of comparison		df	P-Value*
T-M	1	2.26	2.28	1.1%	9.2E-05	6.1E-06	5	0.02
M-B	2	2.28	2.27	0.5%	6.1E-06	3.4E-04		0.21
B-T	3	2.27	2.26	0.6%	3.4E-04	9.2E-05		0.16
T-M	31 a.	2.26	2.29	1.2%	4.0E-05	7.2E-05		0.01
M-B	31 b.	2.29	2.29	0.0%	7.2E-05	1.5E-04		0.47
B-T	31 c.	2.29	2.26	1.2%	1.5E-04	4.0E-05		0.02
T-M	37	2.27	2.28	0.4%	7.5E-05	7.2E-05		0.13
M-B	38	2.28	2.28	0.2%	7.2E-05	1.2E-04		0.31
B-T	39	2.28	2.27	0.6%	1.2E-04	7.5E-05		0.09
T-M	55 a.	2.26	2.26	0.2%	1.8E-04	1.7E-05		0.35
M-B	55 b.	2.26	2.28	0.8%	1.7E-05	2.4E-06		0.06
B-T	55 c.	2.28	2.26	0.5%	2.4E-06	1.8E-04		0.21
T-M	67	2.26	2.26	0.2%	1.1E-06	5.0E-05		0.23
M-B	68	2.26	2.27	0.3%	5.0E-05	1.5E-05		0.10
B-T	69	2.27	2.26	0.2%	1.5E-05	1.1E-06		0.12
T-M	85	2.27	2.27	0.1%	1.9E-05	3.8E-05		0.27
M-B	86	2.27	2.27	0.1%	3.8E-05	4.4E-05		0.37
B-T	87	2.27	2.27	0.2%	4.4E-05	1.9E-05		0.19

* Bold font indicates the null hypothesis of equal means is rejected.

Table 71: Statistical Analysis of Air Void Variability for Different STs in 19 mm NMAS Mix

	19 mm NMAS							
Comparison	Unique Sample Number	Gmb Mean of comparison		Precision	Variance of comparison		df	P-Value*
T-M	8	2.34	2.35	0.5%	5.6E-05	9.1E-05	5	0.10
M-B	9	2.35	2.32	1.5%	9.1E-05	2.7E-05		5.4E-03
B-T	10	2.32	2.34	1.1%	2.7E-05	5.6E-05		4.6E-03
T-M	33 a.	2.31	2.34	1.5%	1.9E-04	5.0E-05		0.02
M-B	33 b.	2.34	2.34	0.0%	5.0E-05	2.1E-05		0.50
B-T	33 c.	2.34	2.31	1.5%	2.1E-05	1.9E-04		0.03
T-M	43	2.30	2.33	1.3%	2.6E-05	1.5E-04		0.10
M-B	44	2.33	2.31	0.7%	1.5E-04	1.4E-05		0.16
B-T	45	2.31	2.30	0.5%	1.4E-05	2.6E-05		0.06
T-M	59 a.	2.32	2.30	0.8%	1.4E-04	2.0E-05		0.14
M-B	59 b.	2.30	2.32	1.0%	2.0E-05	3.1E-07		0.05
B-T	59 c.	2.32	2.32	0.1%	3.1E-07	1.4E-04		0.40
T-M	73	2.32	2.32	0.0%	4.1E-04	5.4E-05		0.49
M-B	74	2.32	2.33	0.5%	5.4E-05	5.7E-05		0.13
B-T	75	2.33	2.32	0.5%	5.7E-05	4.1E-04		0.29
T-M	91	2.31	2.33	0.6%	2.1E-04	4.0E-05		0.21
M-B	92	2.33	2.32	0.2%	4.0E-05	9.1E-05		0.32
B-T	93	2.32	2.31	0.4%	9.1E-05	2.1E-04		0.25

* Bold font indicates the null hypothesis of equal means is rejected.

Table 72: Statistical Analysis of Air Void Variability for Different STs in 25 mm NMAS Mix

	25 mm NMAS							
Comparison	Unique Sample Number	Gmb Mean of comparison		Precision	Variance of comparison		df	P-Value*
T-M	15	2.39	2.39	0.0%	3.1E-04	2.8E-04	5	0.49
M-B	16	2.39	2.34	2.4%	2.8E-04	3.0E-05		0.02
B-T	17	2.34	2.39	2.4%	3.0E-05	3.1E-04		0.02
T-M	35 a.	2.37	2.36	0.3%	2.0E-05	8.9E-05		0.19
M-B	35 b.	2.36	2.38	0.7%	8.9E-05	6.2E-05		0.04
B-T	35 c.	2.38	2.37	0.5%	6.2E-05	2.0E-05		0.06
T-M	49	2.37	2.36	0.1%	5.2E-05	1.6E-06		0.39
M-B	50	2.36	2.39	0.9%	1.6E-06	1.2E-05		1.1E-03
B-T	51	2.39	2.37	0.8%	1.2E-05	5.2E-05		0.01
T-M	63 a.	2.35	2.36	0.6%	2.0E-04	5.7E-04		0.22
M-B	63 b.	2.36	2.37	0.3%	5.7E-04	1.1E-03		0.40
B-T	63 c.	2.37	2.35	0.9%	1.1E-03	2.0E-04		0.20
T-M	79	2.37	2.34	1.3%	2.8E-04	3.3E-04		0.05
M-B	80	2.34	2.36	0.6%	3.3E-04	5.5E-05		0.16
B-T	81	2.36	2.37	0.8%	5.5E-05	2.8E-04		0.10
T-M	97	2.36	2.37	0.6%	1.0E-04	4.6E-05		0.06
M-B	98	2.37	2.37	0.1%	4.6E-05	1.2E-04		0.43
B-T	99	2.37	2.36	0.6%	1.2E-04	1.0E-04		0.09

* Bold font indicates the null hypothesis of equal means is rejected.

The issues with lack of uniformity is evident in ST 1 and ST 2 in 12.5 and 19 mm NMAS mixes. In 25 mm NMAS mix, the lack of uniformity was observed in ST 1, ST 2, and ST 3. The issue with ST 1 was probably due to bigger dimension compared to other dimensions. Although samples were cored and trimmed from SGC pill, bigger dimension of ST would still show non uniformity of air voids. The issue with ST 2 and ST 3 is the smallest dimension compared to other dimensions. The smallest dimensions probably did not account the maximum aggregate size within the mix. Since ST 3 was seen to have uniform air void distribution in 12.5 and 19 mm NMAS mixes. This confirms that the correct sample dimension not only depends on maximum aggregate size of asphalt mix but also depends on the inscribed circle the sample was fabricated within.

4.5 WITHIN INSCRIBED CIRCLES AIR VOID VARIABILITY ANALYSIS

The Analysis 5 statistically compares STs for six different inscribed circles each for three different NMAAS mixes. This analysis is performed to analyze if staying within 100 mm inscribed circle is statistically same to other inscribed circles. The comparisons of data set using t-test are shown in Table 73.

The results for air void comparisons from 6 different inscribed circles for each of the 3 NMAAS mix are shown in Table 74 to 76. All tests used a 95 percent confidence level, alpha of 0.05. The null hypothesis for all tests was the mean air void of the two data sets are equal. Failure to reject the null hypothesis indicates the mean air void of each data set are statistically same. Rejecting the null hypothesis implies the data sets are statistically different. In the tables of t-test results, comparisons with alpha of less than 0.05 are shown with a bold font.

Table 73: Data Set Comparisons for Different Inscribed Circles used in Sample Types

ST	1	2	3	4	5	6
1	X		o		o	o
2		X	o			
3			X		o	o
4				X	o	
5					X	o
6						X

Table 74: Statistical Analysis of Air Void Variability within different inscribed Circles of Sample Types in 12.5 mm NMA Mix

Comparison	12.5 mm NMA					
	t- Test	VTM Mean of comparison, %		Variance of comparison		P-Value*
T-T	ST1-ST3	8.1	7.5	7.5E-07	1.8E-05	0.13
M-M		6.9	7.1	2.0E-06	1.7E-05	0.30
B-B		7.0	7.1	4.1E-05	3.7E-07	0.44
T-T	ST1-ST5	8.1	7.5	7.5E-07	3.1E-07	7.6E-03
M-M		6.9	7.8	2.0E-06	7.9E-06	0.07
B-B		7.0	7.4	4.1E-05	3.8E-06	0.25
T-T	ST1-ST6	8.1	7.6	7.5E-07	1.2E-06	0.02
M-M		6.9	7.5	2.0E-06	2.0E-06	0.02
B-B		7.0	7.5	4.1E-05	5.1E-08	0.23
T-T	ST2-ST3	7.7	7.5	6.8E-06	1.8E-05	0.32
M-M		6.4	7.1	2.1E-06	1.7E-05	0.14
B-B		6.7	7.1	4.0E-05	3.7E-07	0.31
T-T	ST3-ST5	7.5	7.5	1.8E-05	3.1E-07	0.41
M-M		7.1	7.8	1.7E-05	7.9E-06	0.08
B-B		7.1	7.4	3.7E-07	3.8E-06	0.11
T-T	ST3-ST6	7.5	7.6	1.8E-05	1.2E-06	0.35
M-M		7.1	7.5	1.7E-05	2.0E-06	0.19
B-B		7.1	7.5	3.7E-07	5.1E-08	0.03
T-T	ST4-ST5	7.6	7.5	3.1E-05	3.1E-07	0.43
M-M		7.9	7.8	2.9E-06	7.9E-06	0.47
B-B		7.1	7.4	4.0E-07	3.8E-06	0.14
T-T	ST5-ST6	7.5	7.6	3.1E-07	1.2E-06	0.29
M-M		7.8	7.5	7.9E-06	2.0E-06	0.21
B-B		7.4	7.5	3.8E-06	5.1E-08	0.41

* Bold font indicates the null hypothesis of equal means is rejected.

Table 75: Statistical Analysis of Air Void Variability within different inscribed Circles of Sample Types in 19 mm NMA Mix

Comparison	19 mm NMA					
	t- Test	VTM Mean of comparison, %		Variance of comparison		P-Value*
T-T	ST1-ST3	6.6	8.0	1.7E-07	4.1E-06	0.03
M-M		6.5	6.8	1.2E-04	2.5E-05	0.40
B-B		6.5	7.5	1.1E-04	2.3E-06	0.21
T-T	ST1-ST5	6.6	7.3	1.7E-07	6.5E-05	0.21
M-M		6.5	7.3	1.2E-04	8.6E-06	0.26
B-B		6.5	6.8	1.1E-04	9.1E-06	0.37
T-T	ST1-ST6	6.6	7.6	1.7E-07	3.3E-05	0.13
M-M		6.5	7.0	1.2E-04	6.4E-06	0.34
B-B		6.5	7.2	1.1E-04	1.5E-05	0.28
T-T	ST2-ST3	7.6	8.0	5.5E-05	4.1E-06	0.30
M-M		6.4	6.8	3.4E-06	2.5E-05	0.24
B-B		6.3	7.5	6.6E-06	2.3E-06	0.01
T-T	ST3-ST5	8.0	7.3	4.1E-06	6.5E-05	0.23
M-M		6.8	7.3	2.5E-05	8.6E-06	0.18
B-B		7.5	6.8	2.3E-06	9.1E-06	0.11
T-T	ST3-ST6	8.0	7.6	4.1E-06	3.3E-05	0.26
M-M		6.8	7.0	2.5E-05	6.4E-06	0.37
B-B		7.5	7.2	2.3E-06	1.5E-05	0.23
T-T	ST4-ST5	7.4	7.3	2.3E-05	6.5E-05	0.44
M-M		8.2	7.3	3.2E-06	8.6E-06	0.03
B-B		7.3	6.8	5.0E-08	9.1E-06	0.13
T-T	ST5-ST6	7.3	7.6	6.5E-05	3.3E-05	0.38
M-M		7.3	7.0	8.6E-06	6.4E-06	0.19
B-B		6.8	7.2	9.1E-06	1.5E-05	0.23

* Bold font indicates the null hypothesis of equal means is rejected.

Table 76: Statistical Analysis of Air Void Variability within different inscribed Circles of Sample Types in 25 mm NMAS Mix

Comparison	25 mm NMAS					
	t- Test	VTM Mean of comparison, %		Variance of comparison		P-Value*
T-T	ST1-ST3	6.1	7.2	8.5E-05	7.9E-06	0.19
M-M		6.0	7.1	8.3E-05	3.4E-07	0.17
B-B		8.1	6.3	2.0E-06	2.5E-06	3.5E-03
T-T	ST1-ST5	6.1	6.4	8.5E-05	3.5E-05	0.37
M-M		6.0	7.6	8.3E-05	3.6E-05	0.08
B-B		8.1	7.5	2.0E-06	9.5E-06	0.13
T-T	ST1-ST6	6.1	7.4	8.5E-05	3.2E-05	0.12
M-M		6.0	6.9	8.3E-05	6.2E-06	0.20
B-B		8.1	6.9	2.0E-06	3.3E-05	0.11
T-T	ST2-ST3	6.8	7.2	3.5E-06	7.9E-06	0.14
M-M		7.3	7.1	2.3E-06	3.4E-07	0.15
B-B		6.6	6.3	7.1E-06	2.5E-06	0.17
T-T	ST3-ST5	7.2	6.4	7.9E-06	3.5E-05	0.18
M-M		7.1	7.6	3.4E-07	3.6E-05	0.20
B-B		6.3	7.5	2.5E-06	9.5E-06	0.06
T-T	ST3-ST6	7.2	7.4	7.9E-06	3.2E-05	0.34
M-M		7.1	6.9	3.4E-07	6.2E-06	0.25
B-B		6.3	6.9	2.5E-06	3.3E-05	0.19
T-T	ST4-ST5	8.1	6.4	2.9E-05	3.5E-05	0.05
M-M		7.7	7.6	8.2E-05	3.6E-05	0.48
B-B		6.3	7.5	9.5E-07	9.5E-06	0.06
T-T	ST5-ST6	6.4	7.4	3.5E-05	3.2E-05	0.12
M-M		7.6	6.9	3.6E-05	6.2E-06	0.18
B-B		7.5	6.9	9.5E-06	3.3E-05	0.15

* Bold font indicates the null hypothesis of equal means is rejected.

The results show that air voids obtained from data set comparisons: ST3-ST5 and ST5-ST6 are statistically same from all the three NMAS mixes. This concludes that air voids of sampled fabricated from within 38 mm inscribed circle are statistically same to 50 mm inscribed circle. Also, means of air voids fabricated from within 50 mm inscribed circle are statistically same to 75 mm inscribed circle. Although in 12.5 mm and 25 mm, ST2-ST3 and ST4-ST5 comparisons were statistically same. This tells us that the air voids obtained from 104 mm inscribed circle is same as 38 mm inscribed circle. And air

voids obtained from 120 mm inscribed circle is same as 50 mm inscribed circle. Therefore, more variability in air void distribution is caused axially than radially.

CHAPTER 5. SUMMARY AND RECOMMENDATIONS

This research used the Asphalt Mixture Performance Tester to evaluate six sample types, including six different inscribed circles and four different sample dimensions using three NMA mix types, 12.5 mm, 19 mm, and 25 mm. All samples are fabricated at air voids of $7\% \pm 0.5\%$.

Dynamic modulus, rutting, and fatigue tests were performed in AMPT and the data were analyzed using FlexPAVE. In addition to FlexPAVE, statistical analysis such as ANOVA, MANOVA and t-tests were performed. In addition, sample air void variability was investigated by cutting the sample into three equal thirds and fabricating different STs from within different inscribed circles.

Five different analysis were performed in this research and the first analysis evaluated rankings of different STs by comparing them to ST1. For data analysis all STs are compared to ST1 because it is full size AASHTO standard dimension used for up to 37.5 mm NMA mixes for dynamic modulus and rutting test and for up to 25 mm NMA mixes for fatigue test. This analysis used results from master curve to capture time and frequency relationship to dynamic modulus for different STs. The master curves were also used to examine rutting and fatigue potential of different STs for different mixes.

The comparison of fitting parameters and dynamic modulus values for STs using Master Solver shows ST6 performed very closely to ST1 for all the three different NMA mixes. This is attributed to the same aspect ratio of ST5 and ST6. The rutting potential from dynamic modulus master curve shows ST3 performed closely to ST1 for all the three different NMA mixes. The evaluation of fatigue potential from dynamic modulus master curve shows ST6 to be consistently close to that of ST 1 for all three NMA mixes.

The results of S_{app} to evaluate fatigue from FlexMAT Cracking shows ST 4 to be consistently close to ST 1 for all three NMA mixes. The damage characterization curves show ST 5 in 12.5 mm NMA mix, ST 4 in 19 mm NMA mix, and ST 4 in 25 mm NMA mix to be close to ST1.

The RSI results to evaluate rutting from FlexMAT Rutting shows wide different between ST 4 and ST1 in 12.5 mm and 19 mm NMA mixes. However, closest RSI comparison between ST 1 and ST 4 was observed in 25 mm NMA mix.

One of the other outputs for ranking analysis obtained from FlexPAVE is percentage damage and total rut depth at the end of 20 years. The percentage damage at the end of the 20 years value for model 5

values were consistently close to model 1 for all three structures. The total rut depth at the end of 20 years for model 2 and 10 values were same as that of model 1 for all three structures.

The Analysis 2 analyzed twelve models for each of the three pavement structures in the FlexPAVE software. Upon analyzing percentage damage at the end of the 20 years values, model 5 values were consistently close to model 1 for all the three structures. Also, the total rut depth at the end of 20 years for model 2 and 10 values were same as that of model 1 for all three structures. This concludes that for both percentage damage and total rut depth at the end of 20 years, sample dimension 50X110 mm provided results closest to 100X150 mm sample dimension.

The statistical analysis in Analysis 3 evaluates dynamic modulus and phase angle values for six different STs fabricated from three different NMA. The dynamic modulus and phase angle for 12.5 mm NMA mix show that ST 5 values for all three different test temperatures to be consistently closer to that of ST1. The dynamic modulus and phase angle for 19 mm NMA mix show that ST 4 values for all three different test temperatures to be consistently closer to that of ST1. The dynamic modulus and phase angle for 25 mm NMA mix show that ST 4 values for all three different test temperatures to be consistently closer to that of ST1.

The t-test results of dynamic modulus and phase values for same combinations of temperature and frequency does not follow the same pattern. Meaning, if dynamic modulus is statistically significant, phase angle may/may not be statistically significant. For 12.5 mm NMA mix, over ST1-ST5 were statistically same. For 19 mm NMA ST1-ST6 were statistically same. ST1- ST6 and ST1-ST3 were statistically same for 25 mm. The MANOVA results showed that when considered ST1 and other STs jointly for three different NMA mixes, there is a statistical difference for different temperatures and frequencies in dynamic modulus test. This confirms that specific ST must be used to test a given NMA mix in dynamic modulus test.

The air void variability analysis within samples of each ST in Analysis 4 show ST6 to have consistent results between replicates with most uniform air voids for 12.5 mm NMA mix. In 19 mm NMA mix, ST 2, ST 3, and ST 4 showed consistent results between replicates. Out of different STs, ST 4 showed the most uniform air void distribution for 19 mm NMA mix. In 25 mm NMA mix, ST 1 showed consistent results between replicates. Additionally, ST 6 showed the most uniform air void distribution for 25 mm NMA mix.

The air void variability for STs fabricated from within different inscribed circle in Analysis 5 show ST3-ST5 and ST5-ST6 are statistically same for all the three different NMA mixes. This concludes that air voids of sampled fabricated from within 38 mm inscribed circle are statistically same to 50 mm inscribed circle. Also, means of air voids fabricated from within 50 mm inscribed circle are statistically same to 75 mm inscribed circle. Although in 12.5 mm and 25 mm, ST2-ST3 and ST4-ST5 comparisons were statistically same. This tells us that the air voids obtained from 104 mm inscribed circle is same as 38 mm inscribed circle. And air voids obtained from 120 mm inscribed circle is same as 50 mm inscribed circle. Therefore, more variability in air void distribution is caused axially than radially. For the ease of fabrication, ST4 is recommended in Analysis 5.

In summary, recommended sample size for different analysis are:

Table 77: Recommendations of this Research for AASHTO Tests performed in AMPT

Test	12.5 mm	19 mm	25 mm
Dynamic Modulus	ST5- 50X110 mm from 50 mm inscribed circle	ST6- 75X110 mm from 75 mm inscribed circle	
DTC Fatigue	ST4- 50X110 mm inscribed from 120 mm inscribed circle		
SSR	ST1- 100X150 mm from 100 mm inscribed circle	ST4- 50X110 mm inscribed from 120 mm inscribed circle	
Air Void Uniformity	ST6- 75X110 mm from 75 mm inscribed circle	ST4- 50X110 mm inscribed from 120 mm inscribed circle	ST6- 75X110 mm from 75 mm inscribed circle

This research presents state of art contribution by evaluating RVE of four sample dimensions fabricated from six different inscribed circles and three different NMA mixes. This research has distinctively evaluated different inscribed circles and in parallel analyzed sample uniformity within different STs. The results are conclusive that more air void variability occurs axially than radially. Additionally, in this research, the unique in-depth laboratory analysis of RVE has concluded variability within different STs in three different AMPT tests and NMA mixes. The variability is determined by comparing and ranking all STs to ST1 as it is a full size AASHTO standard dimension. This research concludes that the STs that have more uniform air void distribution performs comparable to ST1 and have low variability. ST5 for 12.5 mm and ST4 or ST6 for 19 mm and 25 mm NMA mixes have uniform air void distribution from statistical analysis and performed comparable to ST1 from ranking analysis. Thus, from the evaluation of lab experiments and statistically analysis, STs should be unique to each NMA mix.

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Appendix A – General AMPT Test Setup

The general description of AMPT test setup is shown in Figure 49.

Figure 49: General Schematic of AMPT Test Setup

The AMPT testing takes place inside AMPT chamber. In this research, an external conditioning chamber (such as fridge, freezer, and oven) is used for achieving specimen test temperature. AMPT chamber is also temperature conditioned at the target test temperature. However, in getting the specimen ready for testing, the specimen temperature is altered as user removes test specimen from external conditioning chamber to setup inside AMPT chamber. Once specimen is setup for testing, AMPT chamber is closed to bring back the specimen to the test temperature. Table 77 provides vertical space description available in AMPT testing chamber for testing.

Table 78: Description of Vertical Space in AMPT Testing Chamber for Dynamic Modulus, DTC Fatigue, and SSR Test

Test Description	Original size(mm)
Actuator Movement	30
Maximum Distance between AMPT Top and Bottom Load Plate	215
Minimum Distance between AMPT Top and Bottom Load Platen	185

The actuator controls the movement of load cell from -15 mm to +15 mm, providing 30 mm of extra space after specimen and top and bottom platen are placed inside the chamber. The purpose of placing ball bearing between top platen and top load platform is an attempt to account for loading eccentricity. The steel ball is used only in dynamic modulus and SSR test and not used in DTC test as it could have a negative effect if screws are overtightened leading to debonding the platen from specimen. LVDT measures specimen deformation in AMPT testing. One end of drainage tube is attached to port fitting inside AMPT chamber and another end is connected to platen for only SSR test. Drainage tube helps specimen to be vented to atmospheric pressure.

Appendix B –Design Mix Sheet

49565

T400SP
04-10

WVDOH MCS&T Approval

Recommended for Approval:

P. Cyrus - April 02, 2019

Approved By:

John Lane
04/05/2019

WEST VIRGINIA DIVISION OF HIGHWAYS JOB MIX FORMULA FOR SUPERPAVE HOT-MIX ASPHALT

Report Number: 1462859				Date Accepted: April 2, 2019			
HMA Type: 12.5 mm Skid-RAP				HMA Code: 402.002.015			
Producer: West Virginia Paving, Inc				Plant Location: Poca, WV			
Designed By: Wayne Ingram				Design Lab: Southern WV Asphalt-Ingleside, WV			
Plant Type: Drum				Plant Make: ASTEC			
Plant Code: WVP1.03.400				Design ESALs: 3 to < 30 million			

MIX COMPOSITION								
Coarse Aggregate Source			Code	Fine Aggregate Source			Code	
CA ₁	Mulzer Stone-Charlestown, IN		MCS2.02.704	FA ₁	Mulzer Stone-Cape Sandy, IN		MCS2.01.704	
CA ₂	Appalachian Aggregates-Beckley, WV		BAC1.01.704	FA ₂	Mulzer Stone-New Amsterdam, IN		MCS2.03.704	
CA ₃				FA ₃				
CA ₄				FA ₄	Bag House Fines		WVP1.03.400	
	CA ₁	CA ₂	CA ₃	CA ₄	FA ₁	FA ₂	FA ₃ FA ₄	
Agg. Type	#78 Limestone-Skid	#8 Sandstone			Man Sand Limestone	W Limestone	BHF	
Agg. Code	703.001.078	703.001.008			702.003.001	702.003.001	702.003.001	
% Total Agg.	23.528	29.428			12.910	34.229		
% RAP Total Agg.:			15	Blended Binder G ₁ /sln delta if > 25% RAP:				
% Binder In RAP Design:			4.7	Binder Type:	PG 64H-22	Binder Code:	705.005.009	
Binder Source:			Shelly Liquid Division-Kanauga, OH		Binder Source Code:			SLD1.01.705

Sieve Fraction							Fines/Effective	Tensile
Sieve Size	Target	Allowable		Sieve Size	Target	Allowable	Asphalt Ratio	Strn. Ratio
		Min.	Max.			Min.	Max.	
2" (50 mm)				#4 (4.75 mm)	54			1.3
1.5" (37.5 mm)				#8 (2.36 mm)	32	28	40	90.6
1" (25 mm)				#16 (1.18 mm)	19			
3/4" (19 mm)	100	100	100	#30 (600 µm)	13			
1/2" (12.5 mm)	95	90	100	#50 (300 µm)	10			
3/8" (9.5 mm)	85		90	#200 (75 µm)	5.9	2.0	10.0	

JOB MIX FORMULA VALUES					
		Job Mix Formula		Job Mix Formula Tolerances	
Specific gravity stone	Design Property	Design Targets		Minimum	Maximum
bulk (G _{sb}): 2.605	Asphalt (%)	5.5		5.1	5.9
Maximum	Air Voids (%)	4.0		2.8	5.2
Density (kg/m ³)	VMA (%)	14.7		14.0	16.0
2450	VFA (%)	73		72	79
Gyrations @ 1800 rpm	80	Desirable Mean Temp. for Lab. Specimens (°F):		Comp. Temp.: 308	Mixing Temp.: 328

Remarks: Additional mix design data can be found accompany PG 64S-22 design. 1462858

sister mixes
1462858 - PG64S-22
1462859 - PG64H-22

T400
04-10

WEST VIRGINIA DIVISION OF HIGHWAYS JOB MIX FORMULA FOR HOT-MIX ASPHALT

Report Number: 1420001		Date Accepted: November 10, 2010	
HMA Type: Wearing-4 Skid		HMA Code: 13947	
Producer: J. F. Allen Company		Plant Location: Elkins, WV	
Designed By: Chadley Miller		Design Lab: J. F. Allen, Elkins, WV	
Plant Type: Drum		Plant Make: Astec	
Plant Code: A007A		Traffic Type: Heavy	

MIX COMPOSITION					
Coarse Aggregate Source		Code	Fine Aggregate Source		Code
CA ₁	J. F. Allen, Elkins, WV	A007A	FA ₁	J. F. Allen, Elkins, WV	A007A
CA ₂	J. F. Allen, Elkins, WV	A007A	FA ₂	J. F. Allen, Elkins, WV	A007A
CA ₃			FA ₃	Bag House Fines (BHF)	I0000
	CA ₁	CA ₂	CA ₃	FA ₁	FA ₂
Agg. Type	#67 Limestone	#8 Limestone		#9 Limestone	Limestone
Agg. Code	1131	1135		1137	1116
% Total Agg.	32	15		14	38
% RAP Total Agg.:		Blended Binder G*/sin delta if > 25% RAP:			
% Binder in RAP Design:		Binder Type: PG 64-22		Binder Code: 1093	
Binder Source: Marathon-Petroleum, Catlettsburg, KY		Binder SourceCode:		A022A	

Sieve Fraction							Voids filled with Asphalt (VFA) %	Fines to Asphalt Ratio	
Sieve Size	Target	Allowable		Sieve Size	Target	Allowable		70	1.1
		Min.	Max.			Min.	Max.		
2" (50 mm)				#4 (4.75 mm)	52	47		Temperature Range	
1.5" (37.5 mm)				#8 (2.36 mm)	36	30	42	Completed Mixture (°F)	
1" (25 mm)	100	100	100	#16 (1.18 mm)	22			Desirable	Temp. Range
3/4" (19 mm)	99	90	100	#30 (600 µm)	15			Mean Temp.	Min. Max.
1/2" (12.5 mm)	85		90	#50 (300 µm)	10			308	283 333
3/8" (9.5 mm)	74			#200 (75 µm)	5.3	2.0	8.0		

JOB MIX FORMULA VALUES				
	Design Property	Job Formula Design Targets	Job Mix Formula Tolerances	
			Minimum	Maximum
Specific gravity stone bulk (G _{sb}):	2.639	Asphalt (%)	4.5	5.3
Maximum Density (kg/m ³)		Air Voids (%)	2.5	5.5
		VMA (%)	12.5	14.5
		Stability (N)	14500	NA
2501		Flow (0.25mm)	8	14
Desirable Mean Temperature for Laboratory Specimens (°F):			287	308
Compaction Temperature:			287	Mixing Temperature:
Remarks:				

**WEST VIRGINIA DIVISION OF HIGHWAYS
JOB MIX FORMULA FOR SUPERPAVE HOT-MIX ASPHALT**

Report Number:		Date Accepted:	
HMA Type:	25 mm - RAP	HMA Code:	401.002.007
Producer:	J. F. Allen Company	Plant Location:	Lorentz, WV
Designed By:	Chadley Miller	Design Lab:	J. F. Allen (Elkins, WV)
Plant Type:	Batch	Plant Make:	McCarter
Plant Code:	JFA1.02.400	Design ESALs:	3 to < 30 Million (3)

MIX COMPOSITION						
Coarse Aggregate Source		Code	Fine Aggregate Source		Code	
CA ₁	J. F. Allen Company (Mashey Gap, WV)	JFA2.01.704	FA ₁	J. F. Allen Company (Mashey Gap, WV)	JFA2.01.704	
CA ₂	J. F. Allen Company (Mashey Gap, WV)	JFA2.01.704	FA ₂			
CA ₃			FA ₃			
	CA ₁	CA ₂	CA ₃	FA ₁	FA ₂	FA ₃
Agg. Type	# 57	# 8		L. Stone Sand		
Agg. Code	703.004.057	703.004.008		702.003.001		
% Total Agg.	39	22		24		
% RAP Total Agg.:		15	Blended Binder G*/sin delta if > 25% RAP:			-
% Binder In RAP Design:		3.40%	Binder Type:		PG 64S -22	Binder Code: 705.005.003
Binder Source:		Marathon Petroleum - Catlettsburg KY			Binder Source Code: MPC1.01.705	

Sieve Fraction							Fines / Effective Asphalt Ratio	Tensile		
Sieve Size	Target	Allowable		Sieve Size	Target	Allowable		Strn. Ratio		
		Min.	Max.			Min.	Max.	1.0	84.2	
2" (50 mm)				#4 (4.75 mm)	45			Temperature Range		
1.5" (37.5mm)	100	100	100	#8 (2.36 mm)	31	25	37	Completed Mixture (°F)		
1" (25 mm)	98	90	100	#16 (1.18 mm)	20			Desirable	Temp. Range	
3/4" (19 mm)	89		90	#30 (600 µm)	13			Mean Temp.	Min.	Max.
1/2" (12.5mm)	74			#50 (300 µm)	8					
3/8" (9.5 mm)	66			#200 (75 µm)	3.9	2.0	7.0	309	284	334

JOB MIX FORMULA VALUES				
Specific Gravity Stone Bulk (Gsb): 2.686	Design Property	Job Mix Formula Design Targets	Job Mix Formula Tolerances	
			Minimum	Maximum
Maximum Density (kg/m ³) 2545	Asphalt (%)	4.4	4.0	4.8
	Air Voids (%)	4.0	2.8	5.2
	VMA (%)	13.1	12.1	14.1
	VFA (%)	70	68	76
Gyrations @ N _{design} :	80	Desirable Mean Temp. for Lab. Specimens (°F):	Comp. Temp. : 288	Mixing Temp. : 309

Remarks:

Appendix C –Mix Verification

MARSHALL VERIFICATION

Steps for verification of Marshall mix (per AASHTO R 68) using Marshall compaction hammer are:

- Three replicate specimens are prepared by weighing 1200 g for each replicate into three separate pans.
- The asphalt mix in the pan is heated to 5°C above compaction temperature of 153°C (308°F) such that when the batch is taken out to be poured in the mold, the temperature drop brings the mixture close to the compaction temperature. This can be done with infrared no touch thermometer.
- The Marshall mold and funnel are placed in a separate oven and heated to compaction temperature of 153°C. Additionally, spatula and Marshall hammer are heated on a hot plate.
- Insert thermometer in the mix to monitor temperature.
- When mix is reached 5°C above compaction temperature of 153°C, pan with heated mix is removed from the oven. Place a filter paper at the bottom of mold and carefully pour the mix into the mold using heated funnel. Use spatula to scrape fines from the pans and empty it into the mold.
- Use heated spatula to spade the mix 15 times around the perimeter and 10 times in the interior region.
- Place the filter paper on the top of the heated asphalt mix.
- Apply 75 blows with the heated Marshall hammer on top side. Stop and rotate the mold to apply 75 blows on the bottom side.

Marshall traffic detail is obtained from T-400 and number of blows on each side of sample is selected (per MP 401.02.22) as:

Marshall traffic	Number of blows	ESAL
Medium	50	10^4 to 10^6
Heavy	75	$10^6 <$

- After compaction, carefully extract the specimen and place on a flat surface to be cooled overnight.
- VTM is calculated after pills are cooled. VTM must be within the job mix tolerance found in T-400 sheet.

SUPERPAVE VERIFICATION

Steps for verification of Superpave mix (per AASHTO T 312) using PINE compactor are:

- Three replicate specimens are prepared by weighing 4500 g to 4700 g for each replicate into separate pans.
- Superpave pill is compacted to 150X115 mm at number of design gyrations stated in T 400.
- The asphalt mix in the pan is heated to 5°C above compaction temperature for each mix such that when the batch is taken out to be poured in the mold, the temperature drop brings the mixture close to the compaction temperature. The compaction temperature number of design gyrations for each mix is also obtained from T-400 as:

NMAS, mm	Compaction Temperature, °C	Number of Gyrations
12.5	164	80
25	153	

- The Superpave mold and funnel is placed in a separate oven and heated to compaction temperature. Additionally, spatula, is heated on a hot plate.
- Insert thermometer in the mix to monitor temperature.
- When mix is reached 5°C above compaction temperature, pan with heated mix is removed from the oven. Place a filter paper at the bottom of mold and carefully pour the mix into the mold using heated funnel. Use spatula to scrape fines from the pans and empty it into the mold.
- Place a filter paper on top of the heated asphalt mix and gently place the top plate of mold.
- Both mixes are gyrated to 80 gyrations per T-400. The Pine compactor applies a pressure of 600 ± 18 kPa on the specimen during compaction.
- After compaction, carefully extract the specimen and place on a flat surface to be cooled overnight.
- VTM is calculated after pills are cooled. VTM must be within the job mix tolerance found in T-400 sheet.

Appendix D Custom Parts Fabricated for Research

Table 78 provides summary and description of fabricated custom parts for 50X110 mm and 75X110 mm dynamic modulus and SSR test specimens.

Table 79: Summary of Custom Parts for Dynamic Modulus and SSR Test for This Research

Test	Dimension, mm	Custom Part Description	Custom Part Drawing
Dynamic Modulus and SSR	50X110	Bottom Platen cross section. The bottom platen is in direct contact with AMPT cell bottom plate.	Figure 50
		Bottom Platen top view.	Figure 51
		Stem cross section. The stem is a new term used throughout this research for 50X110 mm specimen in both dynamic modulus and SSR test. Stem has port fitting for drainage tube in SSR test that helps specimen to be vented to atmospheric pressure. The drainage tube is not used for dynamic modulus test however can be left in place. Stem has dowel pin that slides into the bottom platen to provide extra height of 40 mm (1.575 inch) to specimen and platen. Stem is detachable from bottom platen. The specimen sits on the stem inside AMPT chamber.	Figure 52
		Top platen with ball cross section with steel ball.	Figure 53
		Top platen top view.	Figure 54
Dynamic Modulus	75X110	Bottom Platen cross section. The bottom platen is in direct contact with AMPT cell bottom plate.	Figure 56
		Bottom Platen top view.	Figure 57
		Stem cross section. The stem is a new term used throughout this research for 75X110 mm specimen in only dynamic modulus test. Stem has dowel pin that slides into the bottom platen to provide extra height of 40 mm (1.575 inch) to specimen and platen. Stem is detachable from bottom platen. The specimen sits on the stem inside AMPT chamber.	Figure 58
		Top platen with ball cross section with steel ball.	Figure 59
		Top platen top view.	Figure 60

For different specimens tested in this research, only 50X110 mm (dynamic modulus and SSR test) is designed to have a stem.

Table 80: Summary of New Custom Test Parts for DTC Fatigue Test for This Research

Test	Dimension, mm	Custom Part Description	Custom Part Drawing
DTC Fatigue	50X110	Gauge point gluing Jig spacer cross section. The spacer has dowel pin that slides into the center hole of jig.	Figure 64
	75X110	Gauge point gluing Jig spacer cross section. The spacer has dowel pin that slides into the center hole of jig.	Figure 65
		Top fatigue end platen gluing adapter cross section	Figure 66
		Top fatigue end platen gluing adapter top view	Figure 68
		Bottom fatigue end platen gluing adapter cross section	Figure 69
		Bottom fatigue end platen gluing adapter top view	Figure 70
	50X110	Top and bottom platens cross-section. The platen shown is same for both top and bottom.	Figure 71
		Top and bottom platens top view.	Figure 72
	75X110	Top and bottom platens cross-section. The platen shown is same for both top and bottom.	Figure 73
		Top and bottom platens top view.	Figure 74
	50X110 and 75X110	Top and bottom spacer cross-section. The spacer provides additional height to 110 mm height specimens and provides same bolt pattern as the load platform and platen. Spacer is bolted to top and bottom AMPT cell plate. The specimen glued to platen is then bolted to top and bottom spacer.	Figure 75
		Top and bottom spacer top view	Figure 76

In DTC fatigue, top and bottom platen are glued to 100X130 mm specimen, which is then attached to the top and bottom of AMPT cell plate. The 38X110 mm, 50X110 mm, and 75X110 mm specimens are glued to platen, which is then attached to spacers with bolts. The spacers serve two purpose in the fabrication:

1. It provides additional height for small specimens so that the actuator does not have to go complete 30 mm upwards.
2. It provides same bolt pattern as the load platform and platen. Load platform and platen have two different bolt patterns. By placing spacer between them, the AMPT cell plate can be attached to the spacer which can be attached to the platen.

Figure 50: Dynamic Modulus and SSR Test Bottom Platen Cross Section for 50X110 mm Specimen

Figure 51: Dynamic Modulus and SSR Test Bottom Platen Top View for 50X110 mm Specimen

Figure 52: Dynamic Modulus and SSR Test Stem Cross Section for 50X110 mm Specimen

Figure 53: Dynamic Modulus and SSR Test Top Platen Cross Section for 50X110 mm Specimen

Figure 54: Dynamic Modulus and SSR Test Top Platen Top View for 50X110 mm Specimen

Figure 55: Dynamic Modulus and SSR Test Setup for 50X110 mm Specimen

Figure 56: Dynamic Modulus Test Bottom Platen Cross Section for 75X110 mm Specimen

Figure 57: Dynamic Modulus Test Bottom Platen Top View for 75X110 mm Specimen

Figure 58: Dynamic Modulus Test Stem Cross Section for 75X110 mm Specimen

Figure 59: Dynamic Modulus Test Top Platen Cross Section for 75X110 mm Specimen

Figure 60: Dynamic Modulus Test Top Platen Top View for 75X110 mm Specimen

Figure 61: Dynamic Modulus Test Setup for 75X110 mm Specimen

Figure 62: Dynamic Modulus Test Setup Comparison of Four Different Specimen Geometries

Figure 63: SSR Test Setup Comparison for of Different Specimen Geometries

Figure 64: Gauge point gluing Jig spacer cross section for 50X110 mm Specimen

Figure 65: Gauge point gluing Jig spacer cross section for 75X110 mm Specimen

Figure 66: Top Fatigue End Platen Gluing Adapter Cross Section for 75X110 mm Specimen

Figure 67: Gauge point gluing Jig Comparison of Four Different Specimen Geometries

Figure 68: Top Fatigue End Platen Gluing Adapter Top View for 75X110 mm Specimen

Figure 69: Bottom Fatigue End Platen Gluing Adapter Cross Section for 75X110 mm Specimen

Figure 70: Bottom Fatigue End Platen Gluing Adapter Top View for 75X110 mm Specimen

Figure 71: DTC Fatigue Top and Bottom Platens Cross-Section for 50X110 mm Specimen

Figure 72: DTC Fatigue Top and Bottom Platens Top View for 50X110 mm Specimen

Figure 73: DTC Fatigue Top and Bottom Platens Cross-Section for 75X110 mm Specimen

Figure 74: DTC Fatigue Top and Bottom Platens Top View for 75X110 mm Specimen

Figure 75: DTC Fatigue Top and Bottom Spacer Cross Section for 50X110 mm and 75X110 mm Specimen

Figure 76: DTC Fatigue Top and Bottom Spacer Top View for 50X110 mm and 75X110 mm Specimen

Figure 77: DTC Fatigue End Platens Gluing Jig and Test Set Up for 100X130 mm Specimen⁸

Figure 78: DTC Fatigue End Platens Gluing Jig and Test Set Up for 75X110 mm Specimen⁷

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⁸ The figures are for depiction purposes only and epoxy is not used to glue the end platens and specimen. For the real test, all specimens were tested per AASHTO TP 107-18 and AASHTO TP 133-19

Figure 79: DTC Fatigue End Platens Gluing Jig and Test Set Up for 50X110 mm Specimen⁷

Figure 80: DTC Fatigue End Platens Gluing Jig and Test Set Up for 38X110 mm Specimen⁷

Appendix E Test Procedure Steps

Steps for dynamic modulus testing

- Place the test specimens in environment chamber for temperature conditioning. The temperature conditioning for all specimen geometries is done using 100X150 mm dummy specimen with the assumption that if the core of 100X150 mm specimen has reached the test temperature, other specimen geometries is also at the same temperature.
- The AMPT chamber is also temperature conditioned at the target test temperature with top and bottom platens, top and bottom Teflon end-friction reducers cut slightly larger than the loading platen, steel ball, and stem (required for 50X110 mm and 75X110 mm specimens).
- When specimens reach target test temperature, remove them from the external temperature and quickly place them inside the AMPT chamber.
- Assemble specimen bottom to top: bottom platen, stem (if applicable), specimen, top platen, and steel ball.
- Install the LVDTs on the gauge points.
- Close the AMPT chamber and allow the temperature to return to target test temperature.
- This procedure above shall be completed within 5 minutes. After AMPT chamber returns to target test temperature, typically specimen sits in the chamber for 20 minutes before dynamic modulus test begins.
- Enter specimen identification number and input software prompts to begin the test. The AMPT will automatically unload when test is completed.
- Save the AMPT test files and repeat same steps for all replicates.

Steps for air void uniformity (per AASHTO R 83-17)

- Label top, middle, and bottom of specimen and saw into three equal sections.
- Determine G_{mb} of each slide per AASHTO T 166
- Assemble a summary table to calculate mean and variance of G_{mb}
- Perform statistical analysis of means.

Steps for DTC Fatigue testing using AMPT

- Place the test specimens in environment chamber for temperature conditioning. The temperature conditioning for all specimen geometries is done using 100X150 mm dummy specimen with the

assumption that if the core of 100X150 mm specimen has reached the test temperature, other specimen geometries is also at the same temperature.

- The AMPT chamber is also temperature conditioned at the target test temperature with spacers (required for 38X110 mm, 50X110 mm and 75X110 mm specimens).
- When specimens reach target test temperature, remove them from the external temperature and quickly place them inside the AMPT chamber.
- Assemble specimen bottom to top: bottom platen, stem (if applicable), specimen, and top platen. This is bolted to top and bottom AMPT cell plate.
- Caution needs to be taken when attaching glued small specimen geometry of 38X110 mm, 50X110 mm, and 75X110 mm and platens to AMPT cell plate. As very little shear can cause debonding of specimen from the platens. The steps followed for attaching glued specimen and platen to the AMPT cell plate are:
  1. The actuator that controls the movement of load cell should be at -15 mm, providing 30 mm space inside the chamber.
  2. Bolt the spacers on top and bottom of the AMPT cell plate for 38X110 mm, 50X110 mm, and 75X110 mm samples.
  3. Support the glued sample and platen from the bottom and avoid lifting the specimens from the ends as that would cause tension stress on the glue, causing debonding.
  4. Place the glued sample and platen on the spacer and bolt the lower platen to the lower spacer.
  5. Move the actuator up so that the top platen bolts are aligned with top spacer bolts.
  6. Stop and start the bolts such that when actuator is moved up the spacer holes and top platen holes are still aligned. Do not tighten the bolts as that would cause tension and shear, ultimately leading to debonding.
  7. Bring the actuator up and stop when the seating load reaches 0.09 kN (20 lb.) for 100X130 mm specimen and 0.01 kN (2.25 lb.) for 38X110 mm, 50X110 mm, and 75X110 mm specimens.
  8. Start tightening the bolts of top spacer and top platen such that the seating load is maintained. If seating load goes in negative, glued specimen and platen are in tension which will lead to debonding.
  9. If specimens are debonded from the platen, specimens are discarded, and new test specimen is fabricated.
- Install the LVDTs on the gauge points.
- Close the AMPT chamber and allow the temperature to return to target test temperature.

- This procedure above shall be completed within 5 minutes. After AMPT chamber returns to target test temperature, typically specimen sits in the chamber for 20 minutes before dynamic modulus test begins.
- Enter specimen identification number and input software prompts to begin the test. The AMPT will automatically unload when test is completed.
- Save the AMPT test files and repeat same steps for all replicates.

Steps for SSR testing using AMPT

- Place the test specimens in environment chamber for temperature conditioning. The temperature conditioning for all specimen geometries is done using 100X150 mm dummy specimen with the assumption that if the core of 100X150 mm specimen has reached the test temperature, other specimen geometries is also at the same temperature.
- The AMPT chamber is also temperature conditioned at the target test temperature with top and bottom platens, top and bottom two greased double latex end-friction reducers cut slightly larger than the loading platen, membrane, O-ring seals, steel ball, and stem (required for 50X110 mm specimens).
- When specimens reach target test temperature, remove them from the external temperature and quickly place them inside the AMPT chamber.
- Assemble specimen bottom to top: bottom platen, stem (if applicable), bottom greased double latex end-friction reducers, specimen, top greased double latex end-friction reducers, top platen, membrane, O-ring seal, and steel ball
- Close the AMPT chamber and allow the temperature to return to target test temperature.
- This procedure above shall be completed within 5 minutes. After AMPT chamber returns to target test temperature, typically specimen sits in the chamber for 1 hour at 69 kPa (10 psi) confining pressure before SSR test begins.
- Enter specimen identification number and input software prompts to begin the test. The AMPT will automatically unload when test is completed.
- Save the AMPT test files and repeat same steps for all replicates.

Appendix F FlexPAVE Models Inputs

Three pavement structures with different STs for data analysis in FlexPAVE, are shown as:

Model	Dynamic Modulus Specimen, mm	DTC Fatigue Specimen, mm	SSR Specimen, mm
1	ST1	ST1	ST1
2	ST2		ST1
3	ST3		ST1
4	ST4		
5	ST5		ST4
6	ST6		ST1
7	ST1		ST4
8	ST2		ST4
9	ST3		ST4
10	ST4		ST1
11	ST5		ST1
12	ST6		ST4

The terminology of Run X.Y is used in this analysis where, X stands for one of the three different structures and Y stands for one of the twelve different models.

Run 1.1

General Information

Pavement Type

☒ New Pavement

☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude

Longitude

Traffic

☒ Design Vehicle

☐ Traffic Spectrum

Optional Description

Project Name	Run 1.1 100X130 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	5/17/2020
Note	1 sample from 1 pill

Analysis Options

☐ Pavement Response Analysis

☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking

☒ Thermal Stress

☐ Healing

☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 81: General Information for Run 1.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.9204	Beta	0.7162	p1	1.1482
Einf (KPa)	1.7780e+04	C11	0.0016	Epsilon0	0.0012	p2	0.4569
Ref. Temp. (C)	21.1000	C12	0.4936	NI	4.8789	d1	0.3348
Shift Factor a1	-5.1641e-04	Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a2	-0.1185	DR	0.5456				
Shift Factor a3	2.7299						

Ti (sec)	Ei (KPa)
1 200000000	1.2258e+04
2 200000000	5.4320e+03
3 200000000	1.4847e+04
4 2000000	2.9079e+04
5 20000	6.4247e+04
6 2000	1.4957e+05
7 200	3.5223e+05
8 20	7.7864e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 82: Design Structure of AC Layer for Run 1.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	4.0367	Beta	0.7234	p1	0.6831
Einf (KPa)	3.0759e+04	C11	0.0024	Epsilon0	0.0013	p2	0.2718
Ref. Temp. (C)	21.1000	C12	0.4667	NI	5.2319	d1	0.3014
Shift Factor a1	-0.0020	Initial C	0.8000	TR(C)	38	d2	-3.9917
Shift Factor a2	-0.0774	DR	0.5376				
Shift Factor a3	2.5365						

Ti (sec)	Ei (KPa)
1 200000000	1.1966e+04
2 200000000	5.0313e+03
3 200000000	1.3408e+04
4 2000000	2.4691e+04
5 20000	5.1262e+04
6 2000	1.1330e+05
7 200	2.6179e+05
8 20	5.9567e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 83: Design Structure of Base 1 Layer for Run 1.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.6931	Beta	0.7188	Rutting	p1	1.4993
Einf (KPa)	2.9818e+04	C11	6.4681e-04	Epsilon0	0.0014		p2	0.5966
Ref. Temp. (C)	21.1000	C12	0.5751	NI	8.6361		d1	0.5257
Shift Factor a1	-0.0023	Initial C	0.8000	TR(C)	35		d2	-11.97...
Shift Factor a2	-0.0773	DR	0.4490					
Shift Factor a3	2.6341							

Ti (sec)	Ei (KPa)
1 200000000 9.4794e+03	
2 200000000 4.8283e+03	
3 2000000 1.2657e+04	
4 200000 2.5098e+04	
5 20000 5.6424e+04	
6 2000 1.3767e+05	
7 200 3.5283e+05	
8 20 8.6760e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 84: Design Structure of Base 2 Layer for Run 1.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Figure 85: Design Structure of Subgrade Layer for Run 1.1

Figure 86: Climate Data for Run 1.1

General Information Design Structure Climate Information Traffic Analysis and Results Options Result Information Fatigue Cracking Results Rutting Results

Design Vehicle Information

Single axle Tandem axle Tridem axle

D_2 D_3

Note: D_1 is always zero

Choose a Vehicle New Vehicle Special Truck

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s) 27

More

Advanced

Traffic Information

Daily ESAL 700 Growth Type Linear Growth Rate (%) 2.5

Lane Distribution Factor 1

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa)

Contact Area Shape Aspect Ratio (length/width)

Shear Traction

Figure 87: Traffic Data for Run 1.1

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 88: Output and Analysis Options for Run 1.1

Run 1.2

General Information

Pavement Type

☒ New Pavement

☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0

Longitude: 0.0

Traffic

☒ Design Vehicle

☐ Traffic Spectrum

Optional Description

Project Name	Run 1.2- 38X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/17/2020
Note	Four 38X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis

☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking

☒ Thermal Stress

☐ Healing

☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 89: General Information for Run 1.2

General Information **Design Structure**

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	2.1363	Beta	0.7162	p1	1.1482
Einf (KPa)	296.4907	C11	0.0044	Epsilon0	0.0012	p2	0.4569
Ref. Temp. (C)	21.1000	C12	0.4654	NI	4.8789	d1	0.3348
Shift Factor a1	0.0018	Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a2	-0.2250	DR	0.5962				
Shift Factor a3	3.9549						

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 90: Design Structure of AC Layer for Run 1.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.7039	Beta	0.7234	Rutting	p1	0.6831
Einf (KPa)	1.5015e+04	C11	9.6414e-04	Epsilon0	0.0013		p2	0.2718
Ref. Temp. (C)	21.1000	C12	0.5521	NI	5.2319		d1	0.3014
Shift Factor a1	1.9809e-04	Initial C	0.8000	TR(C)	38		d2	-3.9917
Shift Factor a2	-0.1529	DR	0.6124					
Shift Factor a3	3.1384							

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 91: Design Structure of Base 1 Layer for Run 1.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.6744	Beta	0.7188	Rutting	p1	1.4993
Einf (KPa)	1.6958e+04	C11	6.8800e-04	Epsilon0	0.0014		p2	0.5966
Ref. Temp. (C)	21.1000	C12	0.5728	NI	8.6361		d1	0.5257
Shift Factor a1	2.1305e-04	Initial C	0.8000	TR(C)	35		d2	-11.97...
Shift Factor a2	-0.1531	DR	0.4951					
Shift Factor a3	3.1352							

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 92: Design Structure of Base 2 Layer for Run 1.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 93: Design Structure of Subgrade Layer for Run 1.2

General Information ☐ Design Structure ☒ Climate Information ☐

Temperature Profile Input

☒ EICM

☐ EICM Text File

☐ Isothermal

EICM DataBase Temperature

State Year Day

City Month

Time\Depth (cm)	0	2.54	5.08	7.62	10.16	12.7
☒ Midnight	3.06	3.61	4.06	4.39	4.72	4.94
☒ 1:00 AM	2.94	3.39	3.83	4.17	4.50	4.78
☒ 2:00 AM	2.83	3.28	3.67	4.00	4.33	4.61
☐ 3:00 AM	2.94	3.28	3.61	3.94	4.22	4.50
☐ 4:00 AM	2.67	3.06	3.44	3.83	4.11	4.39
☐ 5:00 AM	2.50	2.94	3.33	3.72	4.00	4.33
☐ 6:00 AM	2.33	2.78	3.17	3.56	3.89	4.22
☐ 7:00 AM	2.39	2.72	3.11	3.44	3.83	4.11
☐ 8:00 AM	2.89	2.94	3.17	3.44	3.78	4.06
☐ 9:00 AM	4.22	3.83	3.67	3.72	3.89	4.11
☐ 10:00 AM	5.33	4.67	4.33	4.22	4.22	4.28
☐ 11:00 AM	6.78	5.89	5.22	4.83	4.67	4.61
☐ Noon	8.06	6.78	6.06	5.50	5.17	5.00
☐ 1:00 PM	9.83	8.44	7.28	6.44	5.89	5.50
☐ 2:00 PM	10.33	9.17	8.11	7.28	6.61	6.11
☐ 3:00 PM	9.72	9.11	8.44	7.72	7.11	6.56
☐ 4:00 PM	8.39	8.39	8.11	7.72	7.28	6.83
☐ 5:00 PM	6.17	6.89	7.22	7.22	7.11	6.83
☐ 6:00 PM	6.11	6.33	6.50	6.67	6.67	6.56

Errors and Warnings

Figure 94: Climate Data for Run 1.2

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 95: Traffic Data for Run 1.2

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 96: Output and Analysis Options for Run 1.2

Run 1.3

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Optional Description

Project Name	Run 1.3- 38X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/17/2020
Note	one 38X110 mm from one SGC pill

Units Advanced

Errors and Warnings

Figure 97: General Information for Run 1.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		
Einf (KPa)	1.1374e+04	Alpha	3.9327
Ref. Temp. (C)	21.1000	C11	0.0011
Shift Factor a1	4.3231e-04	C12	0.5328
Shift Factor a2	-0.1585	Initial C	0.8000
Shift Factor a3	3.1519	DR	0.5834

Beta	0.7162	Rutting	
Epsilon0	0.0012	p1	1.1482
NI	4.8789	p2	0.4569
TR(C)	46	d1	0.3348
		d2	-8.5089

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 98: Design Structure of AC Layer for Run 1.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		
Einf (KPa)	1.6775e+03	Alpha	3.4508
Ref. Temp. (C)	21.1000	C11	0.0014
Shift Factor a1	0.0014	C12	0.5347
Shift Factor a2	-0.1851	Initial C	0.8000
Shift Factor a3	3.2790	DR	0.5725

Beta	0.7234	Rutting	
Epsilon0	0.0013	p1	0.6831
NI	5.2319	p2	0.2718
TR(C)	38	d1	0.3014
		d2	-3.9917

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 99: Design Structure of Base 1 Layer for Run 1.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type   ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	1.2973e+04	Alpha	3.4660	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	8.1716e-04	Epsilon0	0.0014
Shift Factor a1	0.0010	C12	0.5659	NI	8.6361
Shift Factor a2	-0.1759	Initial C	0.8000	TR(C)	35
Shift Factor a3	3.2657	DR	0.5536		

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Errors and Warnings

Figure 100: Design Structure of Base 2 Layer for Run 1.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type   ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 101: Design Structure of Subgrade Layer for Run 1.3

Figure 102: Climate Data for Run 1.3

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 103: Traffic Data for Run 1.3

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 104: Output and Analysis Options for Run 1.3

Run 1.4

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.4 50X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/17/2020
Note	Three 50X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 105: General Information for Run 1.4

General Information ☐ Climate Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	2.3983e+03	Alpha	3.4186	Beta	0.6906	p1	0.8085
Ref. Temp. (C)	21.1000	C11	0.0014	Epsilon0	0.0012	p2	0.3217
Shift Factor a1	9.9379e-04	C12	0.5301	NI	5.6761	d1	0.2323
Shift Factor a2	-0.1793	Initial C	0.8000	TR(C)	46	d2	-4.2184
Shift Factor a3	3.3411	DR	0.6033				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	6.4332e+03	+
2	☐ 20000000	3.8348e+03	-
3	☐ 2000000	1.1142e+04	
4	☐ 200000	2.6285e+04	
5	☐ 20000	6.7748e+04	
6	☐ 2000	1.7543e+05	
7	☐ 200	4.2656e+05	
8	☐ 20	9.0715e+05	-

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 106: Design Structure of AC Layer for Run 1.4

General Information ☐ Climate Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.2422e+04	Alpha	3.8938	Beta	0.7680	p1	1.3648
Ref. Temp. (C)	21.1000	C11	0.0015	Epsilon0	0.0022	p2	0.5431
Shift Factor a1	4.3664e-04	C12	0.5113	NI	1.9636	d1	0.3884
Shift Factor a2	-0.1553	Initial C	0.8000	TR(C)	38	d2	-7.7527
Shift Factor a3	3.0827	DR	0.5958				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	1.0561e+04	+
2	☐ 20000000	4.5849e+03	-
3	☐ 2000000	1.2686e+04	
4	☐ 200000	2.4973e+04	
5	☐ 20000	5.5462e+04	
6	☐ 2000	1.2948e+05	
7	☐ 200	3.0541e+05	
8	☐ 20	6.7839e+05	-

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 107: Design Structure of Base 1 Layer for Run 1.4

General Information ☐ Climate Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	7.5159e+03	Alpha	3.4442	
Ref. Temp. (C)	21.1000	C11	6.4904e-04	Beta
Shift Factor a1	5.5961e-04	C12	0.5934	Epsilon0
Shift Factor a2	-0.1595	Initial C	0.8000	NI
Shift Factor a3	3.1158	DR	0.4972	TR(C)

p1	1.2119		
p2	0.4823		
d1	0.3867		
d2	-7.7981		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 108: Design Structure of Base 2 Layer for Run 1.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 109: Design Structure of Subgrade Layer for Run 1.4

Figure 110: Climate Data for Run 1.4

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 111: Traffic Data for Run 1.4

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 112: Output and Analysis Options for Run 1.4

Run 1.5

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.5- 50X110 mm CENTER and 50X110
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/17/2020
Note	one 50X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 113: General Information for Run 1.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	4.1510	Beta	0.6906	Rutting	p1	0.8085
Einf (KPa)	1.5271e+04	C11	7.5528e-04	Epsilon0	0.0012		p2	0.3217
Ref. Temp. (C)	21.1000	C12	0.5665	NI	5.6761		d1	0.2323
Shift Factor a1	9.0989e-04	Initial C	0.8000	TR(C)	46		d2	-4.2184
Shift Factor a2	-0.1877	DR	0.5301					
Shift Factor a3	3.5563							

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 114: Design Structure of AC Layer for Run 1.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	4.0036	Beta	0.6412	Rutting	p1	1.2119
Einf (KPa)	2.8257e+04	C11	0.0011	Epsilon0	8.088...		p2	0.4823
Ref. Temp. (C)	21.1000	C12	0.5519	NI	7.7802		d1	0.3867
Shift Factor a1	6.4033e-04	Initial C	0.8000	TR(C)	35		d2	-7.7981
Shift Factor a2	-0.1705	DR	0.5107					
Shift Factor a3	3.3132							

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 115: Design Structure of Base 1 Layer for Run 1.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

☐ GR Based Criterion ☒ DR Based Criterion

Strength/Modulus

Poisson's Ratio	0.3000				
Einf (KPa)	7.7913e+03				
Ref. Temp. (C)	21.1000				
Shift Factor a1	0.0012				
Shift Factor a2	-0.1882				
Shift Factor a3	3.4161				

Fatigue		Rutting		Rutting	
Alpha	3.3341	Beta	0.7680	p1	1.3648
C11	9.5852e-04	Epsilon0	0.0022	p2	0.5431
C12	0.5561	NI	1.9636	d1	0.3884
Initial C	0.8000	TR(C)	38	d2	-7.7527
DR	0.5219				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	4.0046e+03	+
2	☐ 20000000	2.0941e+03	-
3	☐ 2000000	5.6871e+03	
4	☐ 200000	1.2090e+04	
5	☐ 20000	2.9775e+04	
6	☐ 2000	8.1131e+04	
7	☐ 200	2.3361e+05	
8	☐ 20	6.4066e+05	

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Errors and Warnings

Figure 116: Design Structure of Base 2 Layer for Run 1.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

☐ GR Based Criterion ☒ DR Based Criterion

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 117: Design Structure of Subgrade Layer for Run 1.5

Figure 118: Climate Data for Run 1.5

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 119: Traffic Data for Run 1.5

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 120: Output and Analysis Options for Run 1.5

Run 1.6

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.6 75X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/17/2020
Note	one 75X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 121: General Information for Run 1.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting		Rutting	
Einf (KPa)	2.5789e+03	Alpha	3.0655	Beta	0.7162	p1	1.1482
Ref. Temp. (C)	21.1000	C11	0.0024	Epsilon0	0.0012	p2	0.4569
Shift Factor a1	4.5983e-04	C12	0.4906	NI	4.8789	d1	0.3348
Shift Factor a2	-0.1530	Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a3	3.0228	DR	0.5654				

	Ti (sec)	Ei (KPa)
1	200000000	8.9563e+03
2	20000000	5.3223e+03
3	2000000	1.5336e+04
4	200000	3.5284e+04
5	20000	8.7047e+04
6	2000	2.1186e+05
7	200	4.7962e+05
8	20	9.5282e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 122: Design Structure of AC Layer for Run 1.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting		Rutting	
Einf (KPa)	1.0290e+04	Alpha	3.8736	Beta	0.7234	p1	0.6831
Ref. Temp. (C)	21.1000	C11	0.0015	Epsilon0	0.0013	p2	0.2718
Shift Factor a1	-6.3943e-05	C12	0.5149	NI	5.2319	d1	0.3014
Shift Factor a2	-0.1307	Initial C	0.8000	TR(C)	38	d2	-3.9917
Shift Factor a3	2.7865	DR	0.5782				

	Ti (sec)	Ei (KPa)
1	200000000	9.4603e+03
2	20000000	4.0575e+03
3	2000000	1.1284e+04
4	200000	2.2218e+04
5	20000	4.9385e+04
6	2000	1.1543e+05
7	200	2.7311e+05
8	20	6.1127e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 123: Design Structure of Base 1 Layer for Run 1.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.2677e+03	Alpha	3.5580	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	4.3195e-04	Epsilon0	0.0014
Shift Factor a1	3.0193e-04	C12	0.6238	NI	8.6361
Shift Factor a2	-0.1466	Initial C	0.8000	TR(C)	35
Shift Factor a3	2.9584	DR	0.5227		

	Ti (sec)	Ei (KPa)
1	200000000	6.5691e+03
2	20000000	3.3105e+03
3	2000000	9.2256e+03
4	200000	1.9803e+04
5	20000	4.8430e+04
6	2000	1.2610e+05
7	200	3.2966e+05
8	20	7.8916e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 124: Design Structure of Base 2 Layer for Run 1.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 125: Design Structure of Subgrade Layer for Run 1.6

Figure 126: Climate Data for Run 1.6

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 127: Traffic Data for Run 1.6

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 128: Output and Analysis Options for Run 1.6

Run 1.7

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.7 100X130 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	Three 50X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 129: General Information for Run 1.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.9204	Beta	0.6906	Rutting	p1	0.8085
Einf (KPa)	1.7780e+04	C11	0.0016	Epsilon0	0.0012		p2	0.3217
Ref. Temp. (C)	21.1000	C12	0.4936	NI	5.6761		d1	0.2323
Shift Factor a1	-5.1641e-04	Initial C	0.8000	TR(C)	46		d2	-4.2184
Shift Factor a2	-0.1185	DR	0.5456					
Shift Factor a3	2.7299							

	Ti (sec)	Ei (KPa)
1	200000000	1.2258e+04
2	20000000	5.4320e+03
3	2000000	1.4847e+04
4	200000	2.9079e+04
5	20000	6.4247e+04
6	2000	1.4957e+05
7	200	3.5223e+05
8	20	7.7864e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 130: Design Structure of AC Layer for Run 1.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	4.0367	Beta	0.6412	Rutting	p1	1.2119
Einf (KPa)	3.0759e+04	C11	0.0024	Epsilon0	8.088...		p2	0.4823
Ref. Temp. (C)	21.1000	C12	0.4667	NI	7.7802		d1	0.3867
Shift Factor a1	-0.0020	Initial C	0.8000	TR(C)	35		d2	-7.7981
Shift Factor a2	-0.0774	DR	0.5376					
Shift Factor a3	2.5365							

	Ti (sec)	Ei (KPa)
1	200000000	1.1966e+04
2	20000000	5.0313e+03
3	2000000	1.3408e+04
4	200000	2.4691e+04
5	20000	5.1262e+04
6	2000	1.1330e+05
7	200	2.6179e+05
8	20	5.9567e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 131: Design Structure of Base 1 Layer for Run 1.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.6931	Beta	0.7680	Rutting	p1	1.3648
Einf (KPa)	2.9818e+04	C11	6.4681e-04	Epsilon0	0.0022		p2	0.5431
Ref. Temp. (C)	21.1000	C12	0.5751	NI	1.9636		d1	0.3884
Shift Factor a1	-0.0023	Initial C	0.8000	TR(C)	38		d2	-7.7527
Shift Factor a2	-0.0773	DR	0.4490					
Shift Factor a3	2.6341							

	Ti (sec)	Ei (KPa)	
1	200000000	9.4794e+03	+
2	20000000	4.8283e+03	-
3	2000000	1.2657e+04	
4	200000	2.5098e+04	
5	20000	5.6424e+04	
6	2000	1.3767e+05	
7	200	3.5283e+05	
8	20	8.6760e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 132: Design Structure of Base 2 Layer for Run 1.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 133: Design Structure of Subgrade Layer for Run 1.7

Figure 134: Climate Data for Run 1.7

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 135: Traffic Data for Run 1.7

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 136: Output and Analysis Options for Run 1.7

Run 1.8

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.8- 38X110 and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	four and three samples from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 137: General Information for Run 1.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	296.4907	Alpha	2.1363	
Ref. Temp. (C)	21.1000	C11	0.0044	Beta
Shift Factor a1	0.0018	C12	0.4654	Epsilon0
Shift Factor a2	-0.2250	Initial C	0.8000	NI
Shift Factor a3	3.9549	DR	0.5962	TR(C)

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 138: Design Structure of AC Layer for Run 1.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.5015e+04	Alpha	3.7039	
Ref. Temp. (C)	21.1000	C11	9.6414e-04	Beta
Shift Factor a1	1.9809e-04	C12	0.5521	Epsilon0
Shift Factor a2	-0.1529	Initial C	0.8000	NI
Shift Factor a3	3.1384	DR	0.6124	TR(C)

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 139: Design Structure of Base 1 Layer for Run 1.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.6744	Beta	0.7680	p1	1.3648
Einf (KPa)	1.6958e+04	C11	6.8800e-04	Epsilon0	0.0022	p2	0.5431
Ref. Temp. (C)	21.1000	C12	0.5728	NI	1.9636	d1	0.3884
Shift Factor a1	2.1305e-04	Initial C	0.8000	TR(C)	38	d2	-7.7527
Shift Factor a2	-0.1531	DR	0.4951				
Shift Factor a3	3.1352						

	Ti (sec)	Ei (KPa)
1	200000000	8.2963e+03
2	20000000	3.9729e+03
3	2000000	1.0680e+04
4	200000	2.1355e+04
5	20000	4.8641e+04
6	2000	1.1949e+05
7	200	3.0455e+05
8	20	7.3878e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 140: Design Structure of Base 2 Layer for Run 1.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 141: Design Structure of Subgrade Layer for Run 1.8

Figure 142: Climate Data for Run 1.8

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 143: Traffic Data for Run 1.8

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 144: Output and Analysis Options for Run 1.8

Run 1.9

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.9 38X110 mm CENTER and 50X110mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	one 38X110 and three 50X110 from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 145: General Information for Run 1.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.1374e+04	Alpha	3.9327	Beta
Ref. Temp. (C)	21.1000	C11	0.0011	Epsilon0
Shift Factor a1	4.3231e-04	C12	0.5328	NI
Shift Factor a2	-0.1585	Initial C	0.8000	TR(C)
Shift Factor a3	3.1519	DR	0.5834	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 146: Design Structure of AC Layer for Run 1.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.6775e+03	Alpha	3.4508	Beta
Ref. Temp. (C)	21.1000	C11	0.0014	Epsilon0
Shift Factor a1	0.0014	C12	0.5347	NI
Shift Factor a2	-0.1851	Initial C	0.8000	TR(C)
Shift Factor a3	3.2790	DR	0.5725	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 147: Design Structure of Base 1 Layer for Run 1.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.2973e+04	Fatigue		Beta		Rutting	
Ref. Temp. (C)	21.1000	Alpha		Epsilon0		p1	
Shift Factor a1	0.0010	C11		NI		p2	
Shift Factor a2	-0.1759	C12		TR(C)		d1	
Shift Factor a3	3.2657	Initial C		38		d2	
		DR					

	Ti (sec)	Ei (KPa)	
1	200000000	4.9290e+03	+
2	20000000	2.4704e+03	-
3	2000000	6.5687e+03	
4	200000	1.3254e+04	
5	20000	3.0693e+04	
6	2000	7.8322e+04	
7	200	2.1403e+05	
8	20	5.7398e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 148: Design Structure of Base 2 Layer for Run 1.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 149: Design Structure of Subgrade Layer for Run 1.9

Figure 150: Climate Data for Run 1.9

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 151: Traffic Data for Run 1.9

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 152: Output and Analysis Options for Run 1.9

Run 1.10

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.10- 50X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	Three and one samples from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 153: General Information for Run 1.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.4186	Beta	0.7162	Rutting	p1	1.1482
Einf (KPa)	2.3983e+03	C11	0.0014	Epsilon0	0.0012		p2	0.4569
Ref. Temp. (C)	21.1000	C12	0.5301	NI	4.8789		d1	0.3348
Shift Factor a1	9.9379e-04	Initial C	0.8000	TR(C)	46		d2	-8.5089
Shift Factor a2	-0.1793	DR	0.6033					
Shift Factor a3	3.3411							

	Ti (sec)	Ei (KPa)
1	200000000	6.4332e+03
2	20000000	3.8348e+03
3	2000000	1.1142e+04
4	200000	2.6285e+04
5	20000	6.7748e+04
6	2000	1.7543e+05
7	200	4.2656e+05
8	20	9.0715e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 154: Design Structure of AC Layer for Run 1.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.8938	Beta	0.7234	Rutting	p1	0.6831
Einf (KPa)	1.2422e+04	C11	0.0015	Epsilon0	0.0013		p2	0.2718
Ref. Temp. (C)	21.1000	C12	0.5113	NI	5.2319		d1	0.3014
Shift Factor a1	4.3664e-04	Initial C	0.8000	TR(C)	38		d2	-3.9917
Shift Factor a2	-0.1553	DR	0.5958					
Shift Factor a3	3.0827							

	Ti (sec)	Ei (KPa)
1	200000000	1.0561e+04
2	20000000	4.5849e+03
3	2000000	1.2686e+04
4	200000	2.4973e+04
5	20000	5.5462e+04
6	2000	1.2948e+05
7	200	3.0541e+05
8	20	6.7839e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 155: Design Structure of Base 1 Layer for Run 1.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.4442	Beta	0.7188	p1	1.4993
Einf (KPa)	7.5159e+03	C11	6.4904e-04	Epsilon0	0.0014	p2	0.5966
Ref. Temp. (C)	21.1000	C12	0.5934	NI	8.6361	d1	0.5257
Shift Factor a1	5.5961e-04	Initial C	0.8000	TR(C)	35	d2	-11.97...
Shift Factor a2	-0.1595	DR	0.4972				
Shift Factor a3	3.1158						

	Ti (sec)	Ei (KPa)
1	200000000	5.1238e+03
2	20000000	2.6316e+03
3	2000000	7.2487e+03
4	200000	1.5537e+04
5	20000	3.8336e+04
6	2000	1.0278e+05
7	200	2.8343e+05
8	20	7.2696e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 156: Design Structure of Base 2 Layer for Run 1.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 157: Design Structure of Subgrade Layer for Run 1.10

Figure 158: Climate Data for Run 1.10

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 159: Traffic Data for Run 1.10

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 160: Output and Analysis Options for Run 1.10

Run 1.11

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.11- 50X110 mm CENTER and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	ONE sample from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 161: General Information for Run 1.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.5271e+04	Alpha	4.1510	Beta
Ref. Temp. (C)	21.1000	C11	7.5528e-04	Epsilon0
Shift Factor a1	9.0989e-04	C12	0.5665	NI
Shift Factor a2	-0.1877	Initial C	0.8000	TR(C)
Shift Factor a3	3.5563	DR	0.5301	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 162: Design Structure of AC Layer for Run 1.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	2.8257e+04	Alpha	4.0036	Beta
Ref. Temp. (C)	21.1000	C11	0.0011	Epsilon0
Shift Factor a1	6.4033e-04	C12	0.5519	NI
Shift Factor a2	-0.1705	Initial C	0.8000	TR(C)
Shift Factor a3	3.3132	DR	0.5107	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 163: Design Structure of Base 1 Layer for Run 1.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

☐ GR Based Criterion ☒ DR Based Criterion

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.7913e+03	Alpha	3.3341	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	9.5852e-04	Epsilon0	0.0014
Shift Factor a1	0.0012	C12	0.5561	NI	8.6361
Shift Factor a2	-0.1882	Initial C	0.8000	TR(C)	35
Shift Factor a3	3.4161	DR	0.5219		

p1	1.4993	
p2	0.5966	
d1	0.5257	
d2	-11.97...	

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

	Ti (sec)	Ei (KPa)
1	200000000	4.0046e+03
2	20000000	2.0941e+03
3	2000000	5.6871e+03
4	200000	1.2090e+04
5	20000	2.9775e+04
6	2000	8.1131e+04
7	200	2.3361e+05
8	20	6.4066e+05

Errors and Warnings

Figure 164: Design Structure of Base 2 Layer for Run 1.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

☐ GR Based Criterion ☒ DR Based Criterion

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 165: Design Structure of Subgrade Layer for Run 1.11

Figure 166: Climate Data for Run 1.11

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 167: Traffic Data for Run 1.11

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

Errors and Warnings

Figure 168: Output and Analysis Options for Run 1.11

Run 1.12

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 1.12- 75X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	one and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 169: General Information for Run 1.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	2.5789e+03	Alpha	3.0655	
Ref. Temp. (C)	21.1000	C11	0.0024	Beta
Shift Factor a1	4.5983e-04	C12	0.4906	Epsilon0
Shift Factor a2	-0.1530	Initial C	0.8000	NI
Shift Factor a3	3.0228	DR	0.5654	TR(C)
				46

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 170: Design Structure of AC Layer for Run 1.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.0290e+04	Alpha	3.8736	
Ref. Temp. (C)	21.1000	C11	0.0015	Beta
Shift Factor a1	-6.3943e-05	C12	0.5149	Epsilon0
Shift Factor a2	-0.1307	Initial C	0.8000	NI
Shift Factor a3	2.7865	DR	0.5782	TR(C)
				35

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 171: Design Structure of Base 1 Layer for Run 1.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 30 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.5580	Beta	0.7680	p1	1.3648
Einf (KPa)	7.2677e+03	C11	4.3195e-04	Epsilon0	0.0022	p2	0.5431
Ref. Temp. (C)	21.1000	C12	0.6238	NI	1.9636	d1	0.3884
Shift Factor a1	3.0193e-04	Initial C	0.8000	TR(C)	38	d2	-7.7527
Shift Factor a2	-0.1466	DR	0.5227				
Shift Factor a3	2.9584						

	Ti (sec)	Ei (KPa)	
1	200000000	6.5691e+03	+
2	20000000	3.3105e+03	-
3	2000000	9.2256e+03	
4	200000	1.9803e+04	
5	20000	4.8430e+04	
6	2000	1.2610e+05	
7	200	3.2966e+05	
8	20	7.8916e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 172: Design Structure of Base 2 Layer for Run 1.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 173: Design Structure of Subgrade Layer for Run 1.12

Figure 174: Climate Data for Run 1.12

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐ Result Information ☐ Fatigue Cracking Results ☐ Rutting Results ☐

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 175: Traffic Data for Run 1.12

General Information
Design Structure
Climate Information
Traffic
Analysis and Results Options

Output Option

☒ Results in Contour
☒ Evaluation Points

☒ Fatigue Cracking Results
☒ Rutting Results
☒ Thermal Stress

☒ Stress
☒ Strain
☒ Displacement

Stress Components

☒ Sxx
☒ Syy
☒ Szz
☒ Sxz
☒ Syz
☒ Sxy

Strain Components

☒ Exx
☒ Eyy
☒ Ezz
☒ Exz
☒ Eyz
☒ Exy

Displacements

☒ Ux
☒ Uy
☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh

Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	8
3	0	16
4	0	24
5	0	32
6	0	40
7	36.5000	0
8	36.5000	8
9	36.5000	16
10	36.5000	24
11	36.5000	32
12	36.5000	40
13	73	0
14	73	8
15	73	16
16	73	24
17	73	32
18	73	40
19	109.5000	0

+

-

...

Errors and Warnings

Figure 176: Output and Analysis Options for Run 1.12

Run 2.1

General Information

Pavement Type

☒ New Pavement

☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0

Longitude: 0.0

Traffic

☒ Design Vehicle

☐ Traffic Spectrum

Optional Description

Project Name	Run 2.1 100X130 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/18/2020
Note	one sample from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis

☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking

☒ Thermal Stress

☐ Healing

☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 177: General Information for Run 2.1

General Information **Design Structure**

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.9204	Beta	0.7162	p1	1.1482
Einf (KPa)	1.7780e+04	C11	0.0016	Epsilon0	0.0012	p2	0.4569
Ref. Temp. (C)	21.1000	C12	0.4936	NI	4.8789	d1	0.3348
Shift Factor a1	-5.1641e-04	Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a2	-0.1185	DR	0.5456				
Shift Factor a3	2.7299						

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 178: Design Structure of AC Layer for Run 2.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	3.0759e+04			
Ref. Temp. (C)	21.1000			
Shift Factor a1	-0.0020			
Shift Factor a2	-0.0774			
Shift Factor a3	2.5365			

	Fatigue		
Alpha	4.0367		
C11	0.0024		
C12	0.4667		
Initial C	0.8000		
DR	0.5376		

	Rutting		
Beta	0.7234		
Epsilon0	0.0013		
NI	5.2319		
TR(C)	38		

	Rutting		
p1	0.6831		
p2	0.2718		
d1	0.3014		
d2	-3.9917		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 179: Design Structure of Base 1 Layer for Run 2.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	2.9818e+04			
Ref. Temp. (C)	21.1000			
Shift Factor a1	-0.0023			
Shift Factor a2	-0.0773			
Shift Factor a3	2.6341			

	Fatigue		
Alpha	3.6931		
C11	6.4681e-04		
C12	0.5751		
Initial C	0.8000		
DR	0.4490		

	Rutting		
Beta	0.7188		
Epsilon0	0.0014		
NI	8.6361		
TR(C)	35		

	Rutting		
p1	1.4993		
p2	0.5966		
d1	0.5257		
d2	-11.97...		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 180: Design Structure of Base 2 Layer for Run 2.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 181: Design Structure of Subgrade Layer for Run 2.1

General Information ☐ Design Structure ☒ Climate Information ☐

Temperature Profile Input

☒ EICM

☐ EICM Text File

☐ Isothermal

EICM DataBase Temperature

State Year Day

City Month

Time\Depth (cm)	0	2.54	5.08	7.62	10.16	12.7
☒ Midnight	3.06	3.61	4.06	4.39	4.72	4.94
☒ 1:00 AM	2.94	3.39	3.83	4.17	4.50	4.78
☒ 2:00 AM	2.83	3.28	3.67	4.00	4.33	4.61
☐ 3:00 AM	2.94	3.28	3.61	3.94	4.22	4.50
☐ 4:00 AM	2.67	3.06	3.44	3.83	4.11	4.39
☐ 5:00 AM	2.50	2.94	3.33	3.72	4.00	4.33
☐ 6:00 AM	2.33	2.78	3.17	3.56	3.89	4.22
☐ 7:00 AM	2.39	2.72	3.11	3.44	3.83	4.11
☐ 8:00 AM	2.89	2.94	3.17	3.44	3.78	4.06
☐ 9:00 AM	4.22	3.83	3.67	3.72	3.89	4.11
☐ 10:00 AM	5.33	4.67	4.33	4.22	4.22	4.28
☐ 11:00 AM	6.78	5.89	5.22	4.83	4.67	4.61
☐ Noon	8.06	6.78	6.06	5.50	5.17	5.00
☐ 1:00 PM	9.83	8.44	7.28	6.44	5.89	5.50
☐ 2:00 PM	10.33	9.17	8.11	7.28	6.61	6.11
☐ 3:00 PM	9.72	9.11	8.44	7.72	7.11	6.56
☐ 4:00 PM	8.39	8.39	8.11	7.72	7.28	6.83
☐ 5:00 PM	6.17	6.89	7.22	7.22	7.11	6.83
☐ 6:00 PM	6.11	6.33	6.50	6.67	6.67	6.56

Errors and Warnings

Figure 182: Climate Data for Run 2.1

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 183: Traffic Data for Run 2.1

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 184: Output and Analysis Options for Run 2.1

Run 2.2

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.2-38X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/18/2020
Note	Four 38X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 185: General Information for Run 2.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	296.4907	Alpha	2.1363	Beta	0.7162	p1	1.1482
Ref. Temp. (C)	21.1000	C11	0.0044	Epsilon0	0.0012	p2	0.4569
Shift Factor a1	0.0018	C12	0.4654	NI	4.8789	d1	0.3348
Shift Factor a2	-0.2250	Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a3	3.9549	DR	0.5962				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	3.4789e+03	+
2	☐ 20000000	3.0595e+03	-
3	☐ 2000000	9.3305e+03	
4	☐ 200000	2.5002e+04	
5	☐ 20000	6.8745e+04	
6	☐ 2000	1.7960e+05	
7	☐ 200	4.2113e+05	
8	☐ 20	8.4761e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 186: Design Structure of AC Layer for Run 2.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.5015e+04	Alpha	3.7039	Beta	0.7234	p1	0.6831
Ref. Temp. (C)	21.1000	C11	9.6414e-04	Epsilon0	0.0013	p2	0.2718
Shift Factor a1	1.9809e-04	C12	0.5521	NI	5.2319	d1	0.3014
Shift Factor a2	-0.1529	Initial C	0.8000	TR(C)	38	d2	-3.9917
Shift Factor a3	3.1384	DR	0.6124				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	7.2467e+03	+
2	☐ 20000000	3.2693e+03	-
3	☐ 2000000	8.8034e+03	
4	☐ 200000	1.7133e+04	
5	☐ 20000	3.7991e+04	
6	☐ 2000	9.0949e+04	
7	☐ 200	2.2861e+05	
8	☐ 20	5.6067e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 187: Design Structure of Base 1 Layer for Run 2.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

☐ GR Based Criterion
☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Poisson's Ratio	0.3000				
Einf (KPa)	1.6958e+04				
Ref. Temp. (C)	21.1000				
Shift Factor a1	2.1305e-04				
Shift Factor a2	-0.1531				
Shift Factor a3	3.1352				

		Fatigue		Rutting		Rutting	
		Alpha	3.6744	Beta	0.7188	p1	1.4993
		C11	6.8800e-04	Epsilon0	0.0014	p2	0.5966
		C12	0.5728	NI	8.6361	d1	0.5257
		Initial C	0.8000	TR(C)	35	d2	-11.97...
		DR	0.4951				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	8.2963e+03	+
2	☐ 20000000	3.9729e+03	
3	☐ 2000000	1.0680e+04	-
4	☐ 200000	2.1355e+04	
5	☐ 20000	4.8641e+04	
6	☐ 2000	1.1949e+05	
7	☐ 200	3.0455e+05	
8	☐ 20	7.3878e+05	

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Errors and Warnings

Figure 188: Design Structure of Base 2 Layer for Run 2.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

☐ GR Based Criterion
☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 189: Design Structure of Subgrade Layer for Run 2.2

Figure 190: Climate Data for Run 2.2

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 191: Traffic Data for Run 2.2

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 192: Output and Analysis Options for Run 2.2

Run 2.3

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.3- 38X110 mm CENTER and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	one 38X110 from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 193: General Information for Run 2.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.9327	Beta	0.7162	Rutting	p1	1.1482
Einf (KPa)	1.1374e+04	C11	0.0011	Epsilon0	0.0012		p2	0.4569
Ref. Temp. (C)	21.1000	C12	0.5328	NI	4.8789		d1	0.3348
Shift Factor a1	4.3231e-04	Initial C	0.8000	TR(C)	46		d2	-8.5089
Shift Factor a2	-0.1585	DR	0.5834					
Shift Factor a3	3.1519							

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 194: Design Structure of AC Layer for Run 2.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.4508	Beta	0.7234	Rutting	p1	0.6831
Einf (KPa)	1.6775e+03	C11	0.0014	Epsilon0	0.0013		p2	0.2718
Ref. Temp. (C)	21.1000	C12	0.5347	NI	5.2319		d1	0.3014
Shift Factor a1	0.0014	Initial C	0.8000	TR(C)	38		d2	-3.9917
Shift Factor a2	-0.1851	DR	0.5725					
Shift Factor a3	3.2790							

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 195: Design Structure of Base 1 Layer for Run 2.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	1.2973e+04	Alpha	3.4660	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	8.1716e-04	Epsilon0	0.0014
Shift Factor a1	0.0010	C12	0.5659	NI	8.6361
Shift Factor a2	-0.1759	Initial C	0.8000	TR(C)	35
Shift Factor a3	3.2657	DR	0.5536		

	Ti (sec)	Ei (KPa)
1	200000000	4.9290e+03
2	20000000	2.4704e+03
3	2000000	6.5687e+03
4	200000	1.3254e+04
5	20000	3.0693e+04
6	2000	7.8322e+04
7	200	2.1403e+05
8	20	5.7398e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 196: Design Structure of Base 2 Layer for Run 2.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 197: Design Structure of Subgrade Layer for Run 2.3

Figure 198: Climate Data for Run 2.3

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 199: Traffic Data for Run 2.3

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 200: Output and Analysis Options for Run 2.3

Run 2.4

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.4 50X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	Three 50X110 mm from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 201: General Information for Run 2.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	2.3983e+03						
Ref. Temp. (C)	21.1000						
Shift Factor a1	9.9379e-04						
Shift Factor a2	-0.1793						
Shift Factor a3	3.3411						

		Fatigue		Rutting		Rutting	
		Alpha	3.4186	Beta	0.6906	p1	0.8085
		C11	0.0014	Epsilon0	0.0012	p2	0.3217
		C12	0.5301	NI	5.6761	d1	0.2323
		Initial C	0.8000	TR(C)	46	d2	-4.2184
		DR	0.6033				

	Ti (sec)	Ei (KPa)	
1	200000000	6.4332e+03	+
2	20000000	3.8348e+03	-
3	2000000	1.1142e+04	
4	200000	2.6285e+04	
5	20000	6.7748e+04	
6	2000	1.7543e+05	
7	200	4.2656e+05	
8	20	9.0715e+05	-

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 202: Design Structure of AC Layer for Run 2.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.2422e+04						
Ref. Temp. (C)	21.1000						
Shift Factor a1	4.3664e-04						
Shift Factor a2	-0.1553						
Shift Factor a3	3.0827						

		Fatigue		Rutting		Rutting	
		Alpha	3.8938	Beta	0.7680	p1	1.3648
		C11	0.0015	Epsilon0	0.0022	p2	0.5431
		C12	0.5113	NI	1.9636	d1	0.3884
		Initial C	0.8000	TR(C)	38	d2	-7.7527
		DR	0.5958				

	Ti (sec)	Ei (KPa)	
1	200000000	1.0561e+04	+
2	20000000	4.5849e+03	-
3	2000000	1.2686e+04	
4	200000	2.4973e+04	
5	20000	5.5462e+04	
6	2000	1.2948e+05	
7	200	3.0541e+05	
8	20	6.7839e+05	-

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 203: Design Structure of Base 1 Layer for Run 2.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.5159e+03	Alpha	3.4442	Beta	0.6412
Ref. Temp. (C)	21.1000	C11	6.4904e-04	Epsilon0	8.088...
Shift Factor a1	5.5961e-04	C12	0.5934	NI	7.7802
Shift Factor a2	-0.1595	Initial C	0.8000	TR(C)	35
Shift Factor a3	3.1158	DR	0.4972		

	Ti (sec)	Ei (KPa)
1	200000000	5.1238e+03
2	20000000	2.6316e+03
3	2000000	7.2487e+03
4	200000	1.5537e+04
5	20000	3.8336e+04
6	2000	1.0278e+05
7	200	2.8343e+05
8	20	7.2696e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 204: Design Structure of Base 2 Layer for Run 2.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 205: Design Structure of Subgrade Layer for Run 2.4

Figure 206: Climate Data for Run 2.4

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 207: Traffic Data for Run 2.4

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 208: Output and Analysis Options for Run 2.4

Run 2.5

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Optional Description

Project Name	Run 2.5 50X110 mm CENTER and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	one sample from one SGC pill

Units Advanced

Errors and Warnings

Figure 209: General Information for Run 2.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			Rutting		
Einf (KPa)	1.5271e+04		Alpha	4.1510	Beta	0.6906	p1	0.8085
Ref. Temp. (C)	21.1000		C11	7.5528e-04	Epsilon0	0.0012	p2	0.3217
Shift Factor a1	9.0989e-04		C12	0.5665	NI	5.6761	d1	0.2323
Shift Factor a2	-0.1877		Initial C	0.8000	TR(C)	46	d2	-4.2184
Shift Factor a3	3.5563		DR	0.5301				

	Ti (sec)	Ei (KPa)
1	200000000	1.6927e+04
2	20000000	7.0657e+03
3	2000000	1.9697e+04
4	200000	3.8057e+04
5	20000	8.1825e+04
6	2000	1.8078e+05
7	200	3.9433e+05
8	20	7.9844e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 210: Design Structure of AC Layer for Run 2.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			Rutting		
Einf (KPa)	2.8257e+04		Alpha	4.0036	Beta	0.6412	p1	1.2119
Ref. Temp. (C)	21.1000		C11	0.0011	Epsilon0	8.088...	p2	0.4823
Shift Factor a1	6.4033e-04		C12	0.5519	NI	7.7802	d1	0.3867
Shift Factor a2	-0.1705		Initial C	0.8000	TR(C)	35	d2	-7.7981
Shift Factor a3	3.3132		DR	0.5107				

	Ti (sec)	Ei (KPa)
1	200000000	8.8987e+03
2	20000000	3.5549e+03
3	2000000	9.4434e+03
4	200000	1.6825e+04
5	20000	3.3776e+04
6	2000	7.2347e+04
7	200	1.6476e+05
8	20	3.8213e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 211: Design Structure of Base 1 Layer for Run 2.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type   ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	7.7913e+03						
Ref. Temp. (C)	21.1000						
Shift Factor a1	0.0012						
Shift Factor a2	-0.1882						
Shift Factor a3	3.4161						

Fatigue		Rutting		Rutting	
Alpha	3.3341	Beta	0.7680	p1	1.3648
C11	9.5852e-04	Epsilon0	0.0022	p2	0.5431
C12	0.5561	NI	1.9636	d1	0.3884
Initial C	0.8000	TR(C)	38	d2	-7.7527
DR	0.5219				

	Tr (sec)	Ei (KPa)	
1	☐ 200000000	4.0046e+03	+
2	☐ 20000000	2.0941e+03	-
3	☐ 2000000	5.6871e+03	
4	☐ 200000	1.2090e+04	
5	☐ 20000	2.9775e+04	
6	☐ 2000	8.1131e+04	
7	☐ 200	2.3361e+05	
8	☐ 20	6.4066e+05	

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Errors and Warnings

Figure 212: Design Structure of Base 2 Layer for Run 2.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type   ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 213: Design Structure of Subgrade Layer for Run 2.5

Figure 214: Climate Data for Run 2.5

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 215: Traffic Data for Run 2.5

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 216: Output and Analysis Options for Run 2.5

Run 2.6

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.6- 75X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/19/2020
Note	one sample from one pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 217: General Information for Run 2.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	2.5789e+03	Alpha	3.0655	Beta	0.7162
Ref. Temp. (C)	21.1000	C11	0.0024	Epsilon0	0.0012
Shift Factor a1	4.5983e-04	C12	0.4906	NI	4.8789
Shift Factor a2	-0.1530	Initial C	0.8000	TR(C)	46
Shift Factor a3	3.0228	DR	0.5654		

1	☐	200000000	8.9563e+03		
2	☐	200000000	5.3223e+03		
3	☐	2000000	1.5336e+04		
4	☐	200000	3.5284e+04		
5	☐	20000	8.7047e+04		
6	☐	2000	2.1186e+05		
7	☐	200	4.7962e+05		
8	☐	20	9.5282e+05		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 218: Design Structure of AC Layer for Run 2.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	1.0290e+04	Alpha	3.8736	Beta	0.7234
Ref. Temp. (C)	21.1000	C11	0.0015	Epsilon0	0.0013
Shift Factor a1	-6.3943e-05	C12	0.5149	NI	5.2319
Shift Factor a2	-0.1307	Initial C	0.8000	TR(C)	38
Shift Factor a3	2.7865	DR	0.5782		

1	☐	200000000	9.4603e+03		
2	☐	200000000	4.0575e+03		
3	☐	2000000	1.1284e+04		
4	☐	200000	2.2218e+04		
5	☐	20000	4.9385e+04		
6	☐	2000	1.1543e+05		
7	☐	200	2.7311e+05		
8	☐	20	6.1127e+05		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 219: Design Structure of Base 1 Layer for Run 2.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.5580	Beta	0.7188	Rutting	p1	1.4993
Einf (KPa)	7.2677e+03	C11	4.3195e-04	Epsilon0	0.0014		p2	0.5966
Ref. Temp. (C)	21.1000	C12	0.6238	NI	8.6361		d1	0.5257
Shift Factor a1	3.0193e-04	Initial C	0.8000	TR(C)	35		d2	-11.97...
Shift Factor a2	-0.1466	DR	0.5227					
Shift Factor a3	2.9584							

	Ti (sec)	Ei (KPa)	
1	200000000	6.5691e+03	+
2	20000000	3.3105e+03	-
3	2000000	9.2256e+03	
4	200000	1.9803e+04	
5	20000	4.8430e+04	
6	2000	1.2610e+05	
7	200	3.2966e+05	
8	20	7.8916e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 220: Design Structure of Base 2 Layer for Run 2.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 221: Design Structure of Subgrade Layer for Run 2.6

Figure 222: Climate Data for Run 2.6

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 223: Traffic Data for Run 2.6

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 224: Output and Analysis Options for Run 2.6

Run 2.7

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.7 100X150, 100X130 and 50X110
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/20/2020
Note	one, one, and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 225: General Information for Run 2.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Beta	0.6906	Rutting	p1	0.8085
Einf (KPa)	1.7780e+04	Alpha	3.9204	Epsilon0	0.0012	NI	p2	0.3217
Ref. Temp. (C)	21.1000	C11	0.0016	TR(C)	46		d1	0.2323
Shift Factor a1	-5.1641e-04	C12	0.4936				d2	-4.2184
Shift Factor a2	-0.1185	Initial C	0.8000					
Shift Factor a3	2.7299	DR	0.5456					

Ti (sec)	Ei (KPa)
1 200000000	1.2258e+04
2 20000000	5.4320e+03
3 2000000	1.4847e+04
4 200000	2.9079e+04
5 20000	6.4247e+04
6 2000	1.4957e+05
7 200	3.5223e+05
8 20	7.7864e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 226: Design Structure of AC Layer for Run 2.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Beta	0.6412	Rutting	p1	1.2119
Einf (KPa)	3.0759e+04	Alpha	4.0367	Epsilon0	8.088...	NI	p2	0.4823
Ref. Temp. (C)	21.1000	C11	0.0024	TR(C)	35		d1	0.3867
Shift Factor a1	-0.0020	C12	0.4667				d2	-7.7981
Shift Factor a2	-0.0774	Initial C	0.8000					
Shift Factor a3	2.5365	DR	0.5376					

Ti (sec)	Ei (KPa)
1 200000000	1.1966e+04
2 20000000	5.0313e+03
3 2000000	1.3408e+04
4 200000	2.4691e+04
5 20000	5.1262e+04
6 2000	1.1330e+05
7 200	2.6179e+05
8 20	5.9567e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 227: Design Structure of Base 1 Layer for Run 2.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	2.9818e+04	Alpha	3.6931	Beta	0.7680
Ref. Temp. (C)	21.1000	C11	6.4681e-04	Epsilon0	0.0022
Shift Factor a1	-0.0023	C12	0.5751	NI	1.9636
Shift Factor a2	-0.0773	Initial C	0.8000	TR(C)	38
Shift Factor a3	2.6341	DR	0.4490		

	Ti (sec)	Ei (KPa)
1	200000000	9.4794e+03
2	20000000	4.8283e+03
3	2000000	1.2657e+04
4	200000	2.5098e+04
5	20000	5.6424e+04
6	2000	1.3767e+05
7	200	3.5283e+05
8	20	8.6760e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 228: Design Structure of Base 2 Layer for Run 2.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 229: Design Structure of Subgrade Layer for Run 2.7

Figure 230: Climate Data for Run 2.7

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 231: Traffic Data for Run 2.7

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 232: Output and Analysis Options for Run 2.7

Run 2.8

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.8- 38X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/20/2020
Note	Four and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 233: General Information for Run 2.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	296.4907	Alpha	2.1363	Beta	0.6906	p1	0.8085
Ref. Temp. (C)	21.1000	C11	0.0044	Epsilon0	0.0012	p2	0.3217
Shift Factor a1	0.0018	C12	0.4654	NI	5.6761	d1	0.2323
Shift Factor a2	-0.2250	Initial C	0.8000	TR(C)	46	d2	-4.2184
Shift Factor a3	3.9549	DR	0.5962				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	3.4789e+03	+
2	☐ 20000000	3.0595e+03	-
3	☐ 2000000	9.3305e+03	
4	☐ 200000	2.5002e+04	
5	☐ 20000	6.8745e+04	
6	☐ 2000	1.7960e+05	
7	☐ 200	4.2113e+05	
8	☐ 20	8.4761e+05	+

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 234: Design Structure of AC Layer for Run 2.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.5015e+04	Alpha	3.7039	Beta	0.6412	p1	1.2119
Ref. Temp. (C)	21.1000	C11	9.6414e-04	Epsilon0	8.088...	p2	0.4823
Shift Factor a1	1.9809e-04	C12	0.5521	NI	7.7802	d1	0.3867
Shift Factor a2	-0.1529	Initial C	0.8000	TR(C)	35	d2	-7.7981
Shift Factor a3	3.1384	DR	0.6124				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	7.2467e+03	+
2	☐ 20000000	3.2693e+03	-
3	☐ 2000000	8.8034e+03	
4	☐ 200000	1.7133e+04	
5	☐ 20000	3.7991e+04	
6	☐ 2000	9.0949e+04	
7	☐ 200	2.2861e+05	
8	☐ 20	5.6067e+05	+

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 235: Design Structure of Base 1 Layer for Run 2.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.6744	Beta	0.7680	Rutting	p1	1.3648
Einf (KPa)	1.6958e+04	C11	6.8800e-04	Epsilon0	0.0022		p2	0.5431
Ref. Temp. (C)	21.1000	C12	0.5728	NI	1.9636		d1	0.3884
Shift Factor a1	2.1305e-04	Initial C	0.8000	TR(C)	38		d2	-7.7527
Shift Factor a2	-0.1531	DR	0.4951					
Shift Factor a3	3.1352							

	Ti (sec)	Ei (KPa)
1	200000000	8.2963e+03
2	20000000	3.9729e+03
3	2000000	1.0680e+04
4	200000	2.1355e+04
5	20000	4.8641e+04
6	2000	1.1949e+05
7	200	3.0455e+05
8	20	7.3878e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 236: Design Structure of Base 2 Layer for Run 2.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 237: Design Structure of Subgrade Layer for Run 2.8

Figure 238: Climate Data for Run 2.8

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 239: Traffic Data for Run 2.8

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 240: Output and Analysis Options for Run 2.8

Run 2.9

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.9- 38X110 mm CENTER and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	5/20/2020
Note	One and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 241: General Information for Run 2.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.1374e+04			
Ref. Temp. (C)	21.1000			
Shift Factor a1	4.3231e-04			
Shift Factor a2	-0.1585			
Shift Factor a3	3.1519			

	Fatigue		
Alpha	3.9327		
C11	0.0011		
C12	0.5328		
Initial C	0.8000		
DR	0.5834		

	Rutting		
Beta	0.6906		
Epsilon0	0.0012		
NI	5.6761		
TR(C)	46		

	Rutting		
p1	0.8085		
p2	0.3217		
d1	0.2323		
d2	-4.2184		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 242: Design Structure of AC Layer for Run 2.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.6775e+03			
Ref. Temp. (C)	21.1000			
Shift Factor a1	0.0014			
Shift Factor a2	-0.1851			
Shift Factor a3	3.2790			

	Fatigue		
Alpha	3.4508		
C11	0.0014		
C12	0.5347		
Initial C	0.8000		
DR	0.5725		

	Rutting		
Beta	0.6412		
Epsilon0	8.088...		
NI	7.7802		
TR(C)	35		

	Rutting		
p1	1.2119		
p2	0.4823		
d1	0.3867		
d2	-7.7981		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 243: Design Structure of Base 1 Layer for Run 2.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

☐ GR Based Criterion
☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.2973e+04						
Ref. Temp. (C)	21.1000						
Shift Factor a1	0.0010						
Shift Factor a2	-0.1759						
Shift Factor a3	3.2657						

		Fatigue					
		Alpha		3.4660			
		C11		8.1716e-04			
		C12		0.5659			
		Initial C		0.8000			
		DR		0.5536			

		Rutting					
		Beta		0.7680			
		Epsilon0		0.0022			
		NI		1.9636			
		TR(C)		38			

		Rutting					
		p1		1.3648			
		p2		0.5431			
		d1		0.3884			
		d2		-7.7527			

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	4.9290e+03	+
2	☐ 20000000	2.4704e+03	-
3	☐ 2000000	6.5687e+03	
4	☐ 200000	1.3254e+04	
5	☐ 20000	3.0693e+04	
6	☐ 2000	7.8322e+04	
7	☐ 200	2.1403e+05	
8	☐ 20	5.7398e+05	v

Errors and Warnings

Figure 244: Design Structure of Base 2 Layer for Run 2.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

☐ GR Based Criterion
☒ DR Based Criterion

Specific Gravity (optional) Expansion Co. (1/C)

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 245: Design Structure of Subgrade Layer for Run 2.9

Figure 246: Climate Data for Run 2.9

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 247: Traffic Data for Run 2.9

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 248: Output and Analysis Options for Run 2.9

Run 2.10

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.10- 50X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/20/2020
Note	three and one from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 249: General Information for Run 2.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			
Einf (KPa)	2.3983e+03		Alpha	3.4186	Beta	0.7162
Ref. Temp. (C)	21.1000		C11	0.0014	Epsilon0	0.0012
Shift Factor a1	9.9379e-04		C12	0.5301	NI	4.8789
Shift Factor a2	-0.1793		Initial C	0.8000	TR(C)	46
Shift Factor a3	3.3411		DR	0.6033		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help..

Errors and Warnings

Figure 250: Design Structure of AC Layer for Run 2.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			
Einf (KPa)	1.2422e+04		Alpha	3.8938	Beta	0.7234
Ref. Temp. (C)	21.1000		C11	0.0015	Epsilon0	0.0013
Shift Factor a1	4.3664e-04		C12	0.5113	NI	5.2319
Shift Factor a2	-0.1553		Initial C	0.8000	TR(C)	38
Shift Factor a3	3.0827		DR	0.5958		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help..

Errors and Warnings

Figure 251: Design Structure of Base 1 Layer for Run 2.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

☐ GR Based Criterion ☒ DR Based Criterion

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.5159e+03	Alpha	3.4442	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	6.4904e-04	Epsilon0	0.0014
Shift Factor a1	5.5961e-04	C12	0.5934	NI	8.6361
Shift Factor a2	-0.1595	Initial C	0.8000	TR(C)	35
Shift Factor a3	3.1158	DR	0.4972		

1	☐	200000000	5.1238e+03
2	☐	20000000	2.6316e+03
3	☐	2000000	7.2487e+03
4	☐	200000	1.5537e+04
5	☐	20000	3.8336e+04
6	☐	2000	1.0278e+05
7	☐	200	2.8343e+05
8	☐	20	7.2696e+05

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Errors and Warnings

Figure 252: Design Structure of Base 2 Layer for Run 2.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name

Pavement/Lane Width (m)

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer

Thickness (cm) ☐ Infinite Layer

Material Type

Specific Gravity (optional) Expansion Co. (1/C)

☐ GR Based Criterion ☒ DR Based Criterion

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 253: Design Structure of Subgrade Layer for Run 2.10

Figure 254: Climate Data for Run 2.10

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 255: Traffic Data for Run 2.10

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☐

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 256: Output and Analysis Options for Run 2.10

Run 2.11

General Information ☐

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.11- 50X110 mm CENTER and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/20/2020
Note	One sample from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 257: General Information for Run 2.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	1.5271e+04	Alpha	4.1510	Beta	0.7162
Ref. Temp. (C)	21.1000	C11	7.5528e-04	Epsilon0	0.0012
Shift Factor a1	9.0989e-04	C12	0.5665	NI	4.8789
Shift Factor a2	-0.1877	Initial C	0.8000	TR(C)	46
Shift Factor a3	3.5563	DR	0.5301		

	Ti (sec)	Ei (KPa)
1	200000000	1.6927e+04
2	20000000	7.0657e+03
3	2000000	1.9697e+04
4	200000	3.8057e+04
5	20000	8.1825e+04
6	2000	1.8078e+05
7	200	3.9433e+05
8	20	7.9844e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 258: Design Structure of AC Layer for Run 2.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	2.8257e+04	Alpha	4.0036	Beta	0.7234
Ref. Temp. (C)	21.1000	C11	0.0011	Epsilon0	0.0013
Shift Factor a1	6.4033e-04	C12	0.5519	NI	5.2319
Shift Factor a2	-0.1705	Initial C	0.8000	TR(C)	38
Shift Factor a3	3.3132	DR	0.5107		

	Ti (sec)	Ei (KPa)
1	200000000	8.8987e+03
2	20000000	3.5549e+03
3	2000000	9.4434e+03
4	200000	1.6825e+04
5	20000	3.3776e+04
6	2000	7.2347e+04
7	200	1.6476e+05
8	20	3.8213e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 259: Design Structure of Base 1 Layer for Run 2.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	7.7913e+03	Alpha	3.3341	
Ref. Temp. (C)	21.1000	C11	9.5852e-04	Beta
Shift Factor a1	0.0012	C12	0.5561	Epsilon0
Shift Factor a2	-0.1882	Initial C	0.8000	NI
Shift Factor a3	3.4161	DR	0.5219	TR(C)

p1	1.4993		
p2	0.5966		
d1	0.5257		
d2	-11.97...		

	Ti (sec)	Ei (KPa)	
1	200000000	4.0046e+03	+
2	20000000	2.0941e+03	-
3	2000000	5.6871e+03	
4	200000	1.2090e+04	
5	20000	2.9775e+04	
6	2000	8.1131e+04	
7	200	2.3361e+05	
8	20	6.4066e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 260: Design Structure of Base 2 Layer for Run 2.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 261: Design Structure of Subgrade Layer for Run 2.11

Figure 262: Climate Data for Run 2.11

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 263: Traffic Data for Run 2.11

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	5.5800
3	0	11.1600
4	0	16.7400
5	0	22.3200
6	0	27.9000
7	36.5000	0
8	36.5000	5.5800
9	36.5000	11.1600
10	36.5000	16.7400
11	36.5000	22.3200
12	36.5000	27.9000
13	73	0
14	73	5.5800
15	73	11.1600
16	73	16.7400
17	73	22.3200
18	73	27.9000
19	109.5000	0

Errors and Warnings

Figure 264: Output and Analysis Options for Run 2.11

Run 2.12

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 2.12- 75X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/20/2020
Note	One and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 265: General Information for Run 2.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 5 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.0655	Beta	0.6906	p1	0.8085
Einf (KPa)	2.5789e+03	C11	0.0024	Epsilon0	0.0012	p2	0.3217
Ref. Temp. (C)	21.1000	C12	0.4906	NI	5.6761	d1	0.2323
Shift Factor a1	4.5983e-04	Initial C	0.8000	TR(C)	46	d2	-4.2184
Shift Factor a2	-0.1530	DR	0.5654				
Shift Factor a3	3.0228						

	Ti (sec)	Ei (KPa)
1	200000000	8.9563e+03
2	200000000	5.3223e+03
3	2000000	1.5336e+04
4	200000	3.5284e+04
5	20000	8.7047e+04
6	2000	2.1186e+05
7	200	4.7962e+05
8	20	9.5282e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 266: Design Structure of AC Layer for Run 2.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 7.6 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.8736	Beta	0.6412	p1	1.2119
Einf (KPa)	1.0290e+04	C11	0.0015	Epsilon0	8.088...	p2	0.4823
Ref. Temp. (C)	21.1000	C12	0.5149	NI	7.7802	d1	0.3867
Shift Factor a1	-6.3943e-05	Initial C	0.8000	TR(C)	35	d2	-7.7981
Shift Factor a2	-0.1307	DR	0.5782				
Shift Factor a3	2.7865						

	Ti (sec)	Ei (KPa)
1	200000000	9.4603e+03
2	200000000	4.0575e+03
3	2000000	1.1284e+04
4	200000	2.2218e+04
5	20000	4.9385e+04
6	2000	1.1543e+05
7	200	2.7311e+05
8	20	6.1127e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 267: Design Structure of Base 1 Layer for Run 2.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.2677e+03	Alpha	3.5580	Beta	0.7680
Ref. Temp. (C)	21.1000	C11	4.3195e-04	Epsilon0	0.0022
Shift Factor a1	3.0193e-04	C12	0.6238	NI	1.9636
Shift Factor a2	-0.1466	Initial C	0.8000	TR(C)	38
Shift Factor a3	2.9584	DR	0.5227		

	Ti (sec)	Ei (KPa)	
1	200000000	6.5691e+03	+
2	20000000	3.3105e+03	-
3	2000000	9.2256e+03	
4	200000	1.9803e+04	
5	20000	4.8430e+04	
6	2000	1.2610e+05	
7	200	3.2966e+05	
8	20	7.8916e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 268: Design Structure of Base 2 Layer for Run 2.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 269: Design Structure of Subgrade Layer for Run 2.12

Figure 270: Climate Data for Run 2.12

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 271: Traffic Data for Run 2.12

Figure 272: Output and Analysis Options for Run 2.12

Run 3.1

General Information

Pavement Type

☒ New Pavement

☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude:

Longitude:

Traffic

☒ Design Vehicle

☐ Traffic Spectrum

Optional Description

Project Name	Run 3.1- 100X130 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	One from one SGC pill

Analysis Options

☐ Pavement Response Analysis

☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking

☒ Thermal Stress

☐ Healing

☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date:

Traffic Opening Date:

Pavement Design Life (years):

Errors and Warnings

Figure 273: General Information for Run 3.1

General Information **Design Structure**

Structure General Information

Structure Name:

Pavement/Lane Width (m):

Layer Properties

Layer:

Thickness (cm): ☐ Infinite Layer

Material Type:

Specific Gravity (optional): Expansion Co. (1/C):

Strength/Modulus

Poisson's Ratio	0.3000				
Einf (KPa)	1.7780e+04				
Ref. Temp. (C)	21.1000				
Shift Factor a1	-5.1641e-04				
Shift Factor a2	-0.1185				
Shift Factor a3	2.7299				

		Fatigue		Rutting		Rutting	
		Alpha	3.9204	Beta	0.7162	p1	1.1482
		C11	0.0016	Epsilon0	0.0012	p2	0.4569
		C12	0.4936	NI	4.8789	d1	0.3348
		Initial C	0.8000	TR(C)	46	d2	-8.5089
		DR	0.5456				

Subgrade Properties

	Ti (sec)	Ei (KPa)
1	200000000	1.2258e+04
2	20000000	5.4320e+03
3	2000000	1.4847e+04
4	200000	2.9079e+04
5	20000	6.4247e+04
6	2000	1.4957e+05
7	200	3.5223e+05
8	20	7.7864e+05

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Errors and Warnings

Figure 274: Design Structure of AC Layer for Run 3.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	3.0759e+04						
Ref. Temp. (C)	21.1000						
Shift Factor a1	-0.0020						
Shift Factor a2	-0.0774						
Shift Factor a3	2.5365						

		Fatigue					
		Alpha		4.0367			
		C11		0.0024			
		C12		0.4667			
		Initial C		0.8000			
		DR		0.5376			

		Rutting					
		Beta		0.7234			
		Epsilon0		0.0013			
		NI		5.2319			
		TR(C)		38			

		Rutting					
		p1		0.6831			
		p2		0.2718			
		d1		0.3014			
		d2		-3.9917			

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 275: Design Structure of Base 1 Layer for Run 3.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	2.9818e+04						
Ref. Temp. (C)	21.1000						
Shift Factor a1	-0.0023						
Shift Factor a2	-0.0773						
Shift Factor a3	2.6341						

		Fatigue					
		Alpha		3.6931			
		C11		6.4681e-04			
		C12		0.5751			
		Initial C		0.8000			
		DR		0.4490			

		Rutting					
		Beta		0.7188			
		Epsilon0		0.0014			
		NI		8.6361			
		TR(C)		35			

		Rutting					
		p1		1.4993			
		p2		0.5966			
		d1		0.5257			
		d2		-11.97...			

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 276: Design Structure of Base 2 Layer for Run 3.1

General Information ☐ Design Structure ☒

Structure General Information

Structure Name:

Pavement/Lane Width (m):

Layer Properties

Layer:

Thickness (cm): ☐ Infinite Layer

Material Type:

Specific Gravity (optional): Expansion Co. (1/C):

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

GR Based Criterion ☐ DR Based Criterion ☒

Errors and Warnings

Figure 277: Design Structure of Subgrade Layer for Run 3.1

General Information ☐ Design Structure ☒ Climate Information ☐

Temperature Profile Input

☒ EICM

☐ EICM Text File

☐ Isothermal

EICM DataBase Temperature

State: Year: Day:

City: Month:

Time\Depth (cm)	0	2.54	5.08	7.62	10.16	12.7
☒ Midnight	3.06	3.61	4.06	4.39	4.72	4.94
☒ 1:00 AM	2.94	3.39	3.83	4.17	4.50	4.78
☒ 2:00 AM	2.83	3.28	3.67	4.00	4.33	4.61
☐ 3:00 AM	2.94	3.28	3.61	3.94	4.22	4.50
☐ 4:00 AM	2.67	3.06	3.44	3.83	4.11	4.39
☐ 5:00 AM	2.50	2.94	3.33	3.72	4.00	4.33
☐ 6:00 AM	2.33	2.78	3.17	3.56	3.89	4.22
☐ 7:00 AM	2.39	2.72	3.11	3.44	3.83	4.11
☐ 8:00 AM	2.89	2.94	3.17	3.44	3.78	4.06
☐ 9:00 AM	4.22	3.83	3.67	3.72	3.89	4.11
☐ 10:00 AM	5.33	4.67	4.33	4.22	4.22	4.28
☐ 11:00 AM	6.78	5.89	5.22	4.83	4.67	4.61
☐ Noon	8.06	6.78	6.06	5.50	5.17	5.00
☐ 1:00 PM	9.83	8.44	7.28	6.44	5.89	5.50
☐ 2:00 PM	10.33	9.17	8.11	7.28	6.61	6.11
☐ 3:00 PM	9.72	9.11	8.44	7.72	7.11	6.56
☐ 4:00 PM	8.39	8.39	8.11	7.72	7.28	6.83
☐ 5:00 PM	6.17	6.89	7.22	7.22	7.11	6.83
☐ 6:00 PM	6.11	6.33	6.50	6.67	6.67	6.56

Errors and Warnings

Figure 278: Climate Data for Run 3.1

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 279: Traffic Data for Run 3.1

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 280: Output and Analysis Options for Run 3.1

Run 3.2

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude: 0.0 Longitude: 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.2- 38X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	Four and one from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date: January 2014

Traffic Opening Date: January 2014

Pavement Design Life (years): 20

Errors and Warnings

Figure 281: General Information for Run 3.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000				
Einf (KPa)	296.4907	Alpha	2.1363	Beta	0.7162
Ref. Temp. (C)	21.1000	C11	0.0044	Epsilon0	0.0012
Shift Factor a1	0.0018	C12	0.4654	NI	4.8789
Shift Factor a2	-0.2250	Initial C	0.8000	TR(C)	46
Shift Factor a3	3.9549	DR	0.5962		

				p1	1.1482
				p2	0.4569
				d1	0.3348
				d2	-8.5089

	Ti (sec)	Ei (KPa)	
1	200000000	3.4789e+03	+
2	20000000	3.0595e+03	-
3	2000000	9.3305e+03	
4	200000	2.5002e+04	
5	20000	6.8745e+04	
6	2000	1.7960e+05	
7	200	4.2113e+05	
8	20	8.4761e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 282: Design Structure of AC Layer for Run 3.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000				
Einf (KPa)	1.5015e+04	Alpha	3.7039	Beta	0.7234
Ref. Temp. (C)	21.1000	C11	9.6414e-04	Epsilon0	0.0013
Shift Factor a1	1.9809e-04	C12	0.5521	NI	5.2319
Shift Factor a2	-0.1529	Initial C	0.8000	TR(C)	38
Shift Factor a3	3.1384	DR	0.6124		

				p1	0.6831
				p2	0.2718
				d1	0.3014
				d2	-3.9917

	Ti (sec)	Ei (KPa)	
1	200000000	7.2467e+03	+
2	20000000	3.2693e+03	-
3	2000000	8.8034e+03	
4	200000	1.7133e+04	
5	20000	3.7991e+04	
6	2000	9.0949e+04	
7	200	2.2861e+05	
8	20	5.6067e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 283: Design Structure of Base 1 Layer for Run 3.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	1.6958e+04	Alpha	3.6744	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	6.8800e-04	Epsilon0	0.0014
Shift Factor a1	2.1305e-04	C12	0.5728	NI	8.6361
Shift Factor a2	-0.1531	Initial C	0.8000	TR(C)	35
Shift Factor a3	3.1352	DR	0.4951		

	Ti (sec)	Ei (KPa)
1	200000000	8.2963e+03
2	20000000	3.9729e+03
3	2000000	1.0680e+04
4	200000	2.1355e+04
5	20000	4.8641e+04
6	2000	1.1949e+05
7	200	3.0455e+05
8	20	7.3878e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 284: Design Structure of Base 2 Layer for Run 3.2

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 285: Design Structure of Subgrade Layer for Run 3.2

Figure 286: Climate Data for Run 3.2

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 287: Traffic Data for Run 3.2

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Szx ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Ezx ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 288: Output and Analysis Options for Run 3.2

Run 3.3

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.3- 38X110 CENTER and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	one and one from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 289: General Information for Run 3.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.1374e+04			
Ref. Temp. (C)	21.1000			
Shift Factor a1	4.3231e-04			
Shift Factor a2	-0.1585			
Shift Factor a3	3.1519			

	Fatigue		Rutting	
Alpha	3.9327		Beta	0.7162
C11	0.0011		Epsilon0	0.0012
C12	0.5328		NI	4.8789
Initial C	0.8000		TR(C)	46
DR	0.5834			

	Rutting	
p1	1.1482	
p2	0.4569	
d1	0.3348	
d2	-8.5089	

	Ti (sec)	Ei (KPa)	
1	200000000	1.4254e+04	+
2	20000000	6.6246e+03	-
3	2000000	1.8509e+04	
4	200000	3.7843e+04	
5	20000	8.5944e+04	
6	2000	2.0014e+05	
7	200	4.5376e+05	
8	20	9.3353e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 290: Design Structure of AC Layer for Run 3.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.6775e+03			
Ref. Temp. (C)	21.1000			
Shift Factor a1	0.0014			
Shift Factor a2	-0.1851			
Shift Factor a3	3.2790			

	Fatigue		Rutting	
Alpha	3.4508		Beta	0.7234
C11	0.0014		Epsilon0	0.0013
C12	0.5347		NI	5.2319
Initial C	0.8000		TR(C)	38
DR	0.5725			

	Rutting	
p1	0.6831	
p2	0.2718	
d1	0.3014	
d2	-3.9917	

	Ti (sec)	Ei (KPa)	
1	200000000	2.8359e+03	+
2	20000000	1.4219e+03	-
3	2000000	4.0843e+03	
4	200000	9.0400e+03	
5	20000	2.2710e+04	
6	2000	6.0459e+04	
7	200	1.6217e+05	
8	20	4.0676e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 291: Design Structure of Base 1 Layer for Run 3.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.2973e+04			
Ref. Temp. (C)	21.1000			
Shift Factor a1	0.0010			
Shift Factor a2	-0.1759			
Shift Factor a3	3.2657			

	Fatigue			
Alpha	3.4660			
C11	8.1716e-04			
C12	0.5659			
Initial C	0.8000			
DR	0.5536			

	Rutting			
Beta	0.7188			
Epsilon0	0.0014			
NI	8.6361			
TR(C)	35			

	Rutting			
p1	1.4993			
p2	0.5966			
d1	0.5257			
d2	-11.97...			

	Ti (sec)	Ei (KPa)		
1	200000000	4.9290e+03	+	
2	20000000	2.4704e+03	-	
3	2000000	6.5687e+03		
4	200000	1.3254e+04		
5	20000	3.0693e+04		
6	2000	7.8322e+04		
7	200	2.1403e+05		
8	20	5.7398e+05		

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 292: Design Structure of Base 2 Layer for Run 3.3

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 293: Design Structure of Subgrade Layer for Run 3.3

Figure 294: Climate Data for Run 3.3

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 295: Traffic Data for Run 3.3

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 296: Output and Analysis Options for Run 3.3

Run 3.4

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.4- 50X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	three samples from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 297: General Information for Run 3.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Beta	Rutting	Rutting
Einf (KPa)	2.3983e+03	Alpha	3.4186	Epsilon0	0.0012	p1 0.8085
Ref. Temp. (C)	21.1000	C11	0.0014	NI	5.6761	p2 0.3217
Shift Factor a1	9.9379e-04	C12	0.5301	TR(C)	46	d1 0.2323
Shift Factor a2	-0.1793	Initial C	0.8000			d2 -4.2184
Shift Factor a3	3.3411	DR	0.6033			

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 298: Design Structure of AC Layer for Run 3.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Beta	Rutting	Rutting
Einf (KPa)	1.2422e+04	Alpha	3.8938	Epsilon0	0.0022	p1 1.3648
Ref. Temp. (C)	21.1000	C11	0.0015	NI	1.9636	p2 0.5431
Shift Factor a1	4.3664e-04	C12	0.5113	TR(C)	38	d1 0.3884
Shift Factor a2	-0.1553	Initial C	0.8000			d2 -7.7527
Shift Factor a3	3.0827	DR	0.5958			

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 299: Design Structure of Base 1 Layer for Run 3.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 15.3 ☐ Infinite Layer

Material Type: Aggregate Base more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			Rutting		
Einf (KPa)	7.5159e+03		Alpha	3.4442	Beta	0.6412	p1	1.2119
Ref. Temp. (C)	21.1000		C11	6.4904e-04	Epsilon0	8.088...	p2	0.4823
Shift Factor a1	5.5961e-04		C12	0.5934	NI	7.7802	d1	0.3867
Shift Factor a2	-0.1595		Initial C	0.8000	TR(C)	35	d2	-7.7981
Shift Factor a3	3.1158		DR	0.4972				

	Ti (sec)	Ei (KPa)
1	☐ 200000000	5.1238e+03
2	☐ 20000000	2.6316e+03
3	☐ 2000000	7.2487e+03
4	☐ 200000	1.5537e+04
5	☐ 20000	3.8336e+04
6	☐ 2000	1.0278e+05
7	☐ 200	2.8343e+05
8	☐ 20	7.2696e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 300: Design Structure of Base 2 Layer for Run 3.4

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 301: Design Structure of Subgrade Layer for Run 3.4

Figure 302: Climate Data for Run 3.4

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 303: Traffic Data for Run 3.4

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 304: Output and Analysis Options for Run 3.4

Run 3.5

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.5- 50X110 mm CENTER and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	one and three samples from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 305: General Information for Run 3.5

Figure 306: Design Structure of AC Layer for Run 3.5

Figure 307: Design Structure of Base 1 Layer for Run 3.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.3341	Beta	0.7680	Rutting p1	1.3648
Einf (KPa)	7.7913e+03	C11	9.5852e-04	Epsilon0	0.0022	p2	0.5431
Ref. Temp. (C)	21.1000	C12	0.5561	NI	1.9636	d1	0.3884
Shift Factor a1	0.0012	Initial C	0.8000	TR(C)	38	d2	-7.7527
Shift Factor a2	-0.1882	DR	0.5219				
Shift Factor a3	3.4161						

	Ti (sec)	Ei (KPa)
1	200000000	4.0046e+03
2	20000000	2.0941e+03
3	2000000	5.6871e+03
4	200000	1.2090e+04
5	20000	2.9775e+04
6	2000	8.1131e+04
7	200	2.3361e+05
8	20	6.4066e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 308: Design Structure of Base 2 Layer for Run 3.5

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 309: Design Structure of Subgrade Layer for Run 3.5

Figure 310: Climate Data for Run 3.5

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 311: Traffic Data for Run 3.5

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 312: Output and Analysis Options for Run 3.5

Run 3.6

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run-3.6- 75X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	one sample from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 313: General Information for Run 3.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.0655	Beta	0.7162	p1	1.1482
Einf (KPa)	2.5789e+03	C11	0.0024	Epsilon0	0.0012	p2	0.4569
Ref. Temp. (C)	21.1000	C12	0.4906	NI	4.8789	d1	0.3348
Shift Factor a1	4.5983e-04	Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a2	-0.1530	Gamma	9.6978e+03				
Shift Factor a3	3.0228	Delta	-0.3928				

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 314: Design Structure of AC Layer for Run 3.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.8736	Beta	0.7234	p1	0.6831
Einf (KPa)	1.0290e+04	C11	0.0015	Epsilon0	0.0013	p2	0.2718
Ref. Temp. (C)	21.1000	C12	0.5149	NI	5.2319	d1	0.3014
Shift Factor a1	-6.3943e-05	Initial C	0.8000	TR(C)	38	d2	-3.9917
Shift Factor a2	-0.1307	Gamma	6.5559e+04				
Shift Factor a3	2.7865	Delta	-0.5832				

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 315: Design Structure of Base 1 Layer for Run 3.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☒ DR Based Criterion ☐

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.2677e+03	Alpha	3.5580	Beta	0.7188
Ref. Temp. (C)	21.1000	C11	4.3195e-04	Epsilon0	0.0014
Shift Factor a1	3.0193e-04	C12	0.6238	NI	8.6361
Shift Factor a2	-0.1466	Initial C	0.8000	TR(C)	35
Shift Factor a3	2.9584	Gamma	1.9406e+04	p1	1.4993
		Delta	-0.5040	p2	0.5966
				d1	0.5257
				d2	-11.97...

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 316: Design Structure of Base 2 Layer for Run 3.6

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 317: Design Structure of Subgrade Layer for Run 3.6

Figure 318: Climate Data for Run 3.6

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 319: Traffic Data for Run 3.6

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 320: Output and Analysis Options for Run 3.6

Run 3.7

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.7- 100X150 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	one and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 321: General Information for Run 3.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.7780e+04	Alpha	3.9204	
Ref. Temp. (C)	21.1000	C11	0.0016	Beta
Shift Factor a1	-5.1641e-04	C12	0.4936	Epsilon0
Shift Factor a2	-0.1185	Initial C	0.8000	NI
Shift Factor a3	2.7299	DR	0.5456	TR(C)

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 322: Design Structure of AC Layer for Run 3.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	3.0759e+04	Alpha	4.0367	
Ref. Temp. (C)	21.1000	C11	0.0024	Beta
Shift Factor a1	-0.0020	C12	0.4667	Epsilon0
Shift Factor a2	-0.0774	Initial C	0.8000	NI
Shift Factor a3	2.5365	DR	0.5376	TR(C)

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 323: Design Structure of Base 1 Layer for Run 3.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	2.9818e+04	Alpha	3.6931	Beta	0.7680
Ref. Temp. (C)	21.1000	C11	6.4681e-04	Epsilon0	0.0022
Shift Factor a1	-0.0023	C12	0.5751	NI	1.9636
Shift Factor a2	-0.0773	Initial C	0.8000	TR(C)	38
Shift Factor a3	2.6341	DR	0.4490		

	Ti (sec)	Ei (KPa)	
1	200000000	9.4794e+03	+
2	20000000	4.8283e+03	-
3	2000000	1.2657e+04	
4	200000	2.5098e+04	
5	20000	5.6424e+04	
6	2000	1.3767e+05	
7	200	3.5283e+05	
8	20	8.6760e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 324: Design Structure of Base 2 Layer for Run 3.7

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 325: Design Structure of Subgrade Layer for Run 3.7

Figure 326: Climate Data for Run 3.7

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 327: Traffic Data for Run 3.7

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 328: Output and Analysis Options for Run 3.7

Run 3.8

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.8- 38X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	four and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 329: General Information for Run 3.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	296.4907			
Ref. Temp. (C)	21.1000			
Shift Factor a1	0.0018			
Shift Factor a2	-0.2250			
Shift Factor a3	3.9549			

	Fatigue		Rutting	
Alpha	2.1363		Beta	0.6906
C11	0.0044		Epsilon0	0.0012
C12	0.4654		NI	5.6761
Initial C	0.8000		TR(C)	46
DR	0.5962			

	Rutting	
p1	0.8085	
p2	0.3217	
d1	0.2323	
d2	-4.2184	

	Ti (sec)	Ei (KPa)	
1	200000000	3.4789e+03	+
2	20000000	3.0595e+03	-
3	2000000	9.3305e+03	
4	200000	2.5002e+04	
5	20000	6.8745e+04	
6	2000	1.7960e+05	
7	200	4.2113e+05	
8	20	8.4761e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 330: Design Structure of AC Layer for Run 3.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.5015e+04			
Ref. Temp. (C)	21.1000			
Shift Factor a1	1.9809e-04			
Shift Factor a2	-0.1529			
Shift Factor a3	3.1384			

	Fatigue		Rutting	
Alpha	3.7039		Beta	0.6412
C11	9.6414e-04		Epsilon0	8.088...
C12	0.5521		NI	7.7802
Initial C	0.8000		TR(C)	35
DR	0.6124			

	Rutting	
p1	1.2119	
p2	0.4823	
d1	0.3867	
d2	-7.7981	

	Ti (sec)	Ei (KPa)	
1	200000000	7.2467e+03	+
2	20000000	3.2693e+03	-
3	2000000	8.8034e+03	
4	200000	1.7133e+04	
5	20000	3.7991e+04	
6	2000	9.0949e+04	
7	200	2.2861e+05	
8	20	5.6067e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 331: Design Structure of Base 1 Layer for Run 3.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue	
Einf (KPa)	1.6958e+04	Alpha	3.6744
Ref. Temp. (C)	21.1000	C11	6.8800e-04
Shift Factor a1	2.1305e-04	C12	0.5728
Shift Factor a2	-0.1531	Initial C	0.8000
Shift Factor a3	3.1352	DR	0.4951

Beta	0.7680	Rutting	
Epsilon0	0.0022	p1	1.3648
NI	1.9636	p2	0.5431
TR(C)	38	d1	0.3884
		d2	-7.7527

	Ti (sec)	Ei (KPa)	
1	200000000	8.2963e+03	+
2	20000000	3.9729e+03	-
3	2000000	1.0680e+04	
4	200000	2.1355e+04	
5	20000	4.8641e+04	
6	2000	1.1949e+05	
7	200	3.0455e+05	
8	20	7.3878e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 332: Design Structure of Base 2 Layer for Run 3.8

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Figure 333: Design Structure of Subgrade Layer for Run 3.8

Figure 334: Climate Data for Run 3.8

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 335: Traffic Data for Run 3.8

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 336: Output and Analysis Options for Run 3.8

Run 3.9

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.9- 38X110 mm CENTER and 50X110 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/21/2020
Note	one and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 337: General Information for Run 3.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.9327	Beta	0.6906	Rutting	p1	0.8085
Einf (KPa)	1.1374e+04	C11	0.0011	Epsilon0	0.0012		p2	0.3217
Ref. Temp. (C)	21.1000	C12	0.5328	NI	5.6761		d1	0.2323
Shift Factor a1	4.3231e-04	Initial C	0.8000	TR(C)	46		d2	-4.2184
Shift Factor a2	-0.1585	DR	0.5834					
Shift Factor a3	3.1519							

	Ti (sec)	Ei (KPa)
1	200000000	1.4254e+04
2	20000000	6.6246e+03
3	2000000	1.8509e+04
4	200000	3.7843e+04
5	20000	8.5944e+04
6	2000	2.0014e+05
7	200	4.5376e+05
8	20	9.3353e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 338: Design Structure of AC Layer for Run 3.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.4508	Beta	0.6412	Rutting	p1	1.2119
Einf (KPa)	1.6775e+03	C11	0.0014	Epsilon0	8.088...		p2	0.4823
Ref. Temp. (C)	21.1000	C12	0.5347	NI	7.7802		d1	0.3867
Shift Factor a1	0.0014	Initial C	0.8000	TR(C)	35		d2	-7.7981
Shift Factor a2	-0.1851	DR	0.5725					
Shift Factor a3	3.2790							

	Ti (sec)	Ei (KPa)
1	200000000	2.8359e+03
2	20000000	1.4219e+03
3	2000000	4.0843e+03
4	200000	9.0400e+03
5	20000	2.2710e+04
6	2000	6.0459e+04
7	200	1.6217e+05
8	20	4.0676e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help

Errors and Warnings

Figure 339: Design Structure of Base 1 Layer for Run 3.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	1.2973e+04	Alpha	3.4660	Beta
Ref. Temp. (C)	21.1000	C11	8.1716e-04	Epsilon0
Shift Factor a1	0.0010	C12	0.5659	NI
Shift Factor a2	-0.1759	Initial C	0.8000	TR(C)
Shift Factor a3	3.2657	DR	0.5536	

Rutting		
p1	1.3648	
p2	0.5431	
d1	0.3884	
d2	-7.7527	

Ti (sec)	Ei (KPa)
1 200000000	4.9290e+03
2 20000000	2.4704e+03
3 2000000	6.5687e+03
4 200000	1.3254e+04
5 20000	3.0693e+04
6 2000	7.8322e+04
7 200	2.1403e+05
8 20	5.7398e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 340: Design Structure of Base 2 Layer for Run 3.9

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 341: Design Structure of Subgrade Layer for Run 3.9

Figure 342: Climate Data for Run 3.9

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 343: Traffic Data for Run 3.9

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 344: Output and Analysis Options for Run 3.9

Run 3.10

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude Longitude

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.10- 50X110 mm and 100X150 mm
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/22/2020
Note	three and one from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date

Traffic Opening Date

Pavement Design Life (years)

Errors and Warnings

Figure 345: General Information for Run 3.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	2.3983e+03						
Ref. Temp. (C)	21.1000						
Shift Factor a1	9.9379e-04						
Shift Factor a2	-0.1793						
Shift Factor a3	3.3411						

		Fatigue					
		Alpha	3.4186				
		C11	0.0014				
		C12	0.5301				
		Initial C	0.8000				
		DR	0.6033				

		Rutting					
		Beta	0.7162				
		Epsilon0	0.0012				
		NI	4.8789				
		TR(C)	46				

		Rutting					
		p1	1.1482				
		p2	0.4569				
		d1	0.3348				
		d2	-8.5089				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	6.4332e+03	+
2	☐ 20000000	3.8348e+03	-
3	☐ 2000000	1.1142e+04	
4	☐ 200000	2.6285e+04	
5	☐ 20000	6.7748e+04	
6	☐ 2000	1.7543e+05	
7	☐ 200	4.2656e+05	
8	☐ 20	9.0715e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 346: Design Structure of AC Layer for Run 3.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000						
Einf (KPa)	1.2422e+04						
Ref. Temp. (C)	21.1000						
Shift Factor a1	4.3664e-04						
Shift Factor a2	-0.1553						
Shift Factor a3	3.0827						

		Fatigue					
		Alpha	3.8938				
		C11	0.0015				
		C12	0.5113				
		Initial C	0.8000				
		DR	0.5958				

		Rutting					
		Beta	0.7234				
		Epsilon0	0.0013				
		NI	5.2319				
		TR(C)	38				

		Rutting					
		p1	0.6831				
		p2	0.2718				
		d1	0.3014				
		d2	-3.9917				

	Ti (sec)	Ei (KPa)	
1	☐ 200000000	1.0561e+04	+
2	☐ 20000000	4.5849e+03	-
3	☐ 2000000	1.2686e+04	
4	☐ 200000	2.4973e+04	
5	☐ 20000	5.5462e+04	
6	☐ 2000	1.2948e+05	
7	☐ 200	3.0541e+05	
8	☐ 20	6.7839e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 347: Design Structure of Base 1 Layer for Run 3.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000			
Einf (KPa)	7.5159e+03	Alpha	3.4442	Beta
Ref. Temp. (C)	21.1000	C11	6.4904e-04	Epsilon0
Shift Factor a1	5.5961e-04	C12	0.5934	NI
Shift Factor a2	-0.1595	Initial C	0.8000	TR(C)
Shift Factor a3	3.1158	DR	0.4972	

1	☐	200000000	5.1238e+03	+
2	☐	20000000	2.6316e+03	-
3	☐	2000000	7.2487e+03	
4	☐	200000	1.5537e+04	
5	☐	20000	3.8336e+04	
6	☐	2000	1.0278e+05	
7	☐	200	2.8343e+05	
8	☐	20	7.2696e+05	

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 348: Design Structure of Base 2 Layer for Run 3.10

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Errors and Warnings

Figure 349: Design Structure of Subgrade Layer for Run 3.10

Figure 350: Climate Data for Run 3.10

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 351: Traffic Data for Run 3.10

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 352: Output and Analysis Options for Run 3.10

Run 3.11

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.11 50X110 CENTER and 100X150
Author	Abha Dwivedy
City/State	Morgantown, WV
Date	05/22/2020
Note	one sample from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 353: General Information for Run 3.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue		Rutting		Rutting	
Einf (KPa)	1.5271e+04		Alpha	4.1510	Beta	0.7162	p1	1.1482
Ref. Temp. (C)	21.1000		C11	7.5528e-04	Epsilon0	0.0012	p2	0.4569
Shift Factor a1	9.0989e-04		C12	0.5665	NI	4.8789	d1	0.3348
Shift Factor a2	-0.1877		Initial C	0.8000	TR(C)	46	d2	-8.5089
Shift Factor a3	3.5563		DR	0.5301				

	Ti (sec)	Ei (KPa)
1	200000000	1.6927e+04
2	20000000	7.0657e+03
3	2000000	1.9697e+04
4	200000	3.8057e+04
5	20000	8.1825e+04
6	2000	1.8078e+05
7	200	3.9433e+05
8	20	7.9844e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help..

Errors and Warnings

Figure 354: Design Structure of AC Layer for Run 3.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

GR Based Criterion ☐ DR Based Criterion ☒

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue		Rutting		Rutting	
Einf (KPa)	2.8257e+04		Alpha	4.0036	Beta	0.7234	p1	0.6831
Ref. Temp. (C)	21.1000		C11	0.0011	Epsilon0	0.0013	p2	0.2718
Shift Factor a1	6.4033e-04		C12	0.5519	NI	5.2319	d1	0.3014
Shift Factor a2	-0.1705		Initial C	0.8000	TR(C)	38	d2	-3.9917
Shift Factor a3	3.3132		DR	0.5107				

	Ti (sec)	Ei (KPa)
1	200000000	8.8987e+03
2	20000000	3.5549e+03
3	2000000	9.4434e+03
4	200000	1.6825e+04
5	20000	3.3776e+04
6	2000	7.2347e+04
7	200	1.6476e+05
8	20	3.8213e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help..

Errors and Warnings

Figure 355: Design Structure of Base 1 Layer for Run 3.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	3.3341	Beta	0.7188	Rutting	p1	1.4993
Einf (KPa)	7.7913e+03	C11	9.5852e-04	Epsilon0	0.0014		p2	0.5966
Ref. Temp. (C)	21.1000	C12	0.5561	NI	8.6361		d1	0.5257
Shift Factor a1	0.0012	Initial C	0.8000	TR(C)	35		d2	-11.97...
Shift Factor a2	-0.1882	DR	0.5219					
Shift Factor a3	3.4161							

	Ti (sec)	Ei (KPa)
1	200000000	4.0046e+03
2	20000000	2.0941e+03
3	2000000	5.6871e+03
4	200000	1.2090e+04
5	20000	2.9775e+04
6	2000	8.1131e+04
7	200	2.3361e+05
8	20	6.4066e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 356: Design Structure of Base 2 Layer for Run 3.11

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Figure 357: Design Structure of Subgrade Layer for Run 3.11

Figure 358: Climate Data for Run 3.11

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (KN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (KPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 359: Traffic Data for Run 3.11

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☐ Analysis and Results Options ☒

Output Option

☒ Results in Contour ☒ Evaluation Points

☒ Fatigue Cracking Results ☒ Rutting Results ☒ Thermal Stress

☒ Stress ☒ Strain ☒ Displacement

Stress Components

☒ Sxx ☒ Syy ☒ Szz ☒ Sxz ☒ Syz ☒ Sxy

Strain Components

☒ Exx ☒ Eyy ☒ Ezz ☒ Exz ☒ Eyz ☒ Exy

Displacements

☒ Ux ☒ Uy ☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

Errors and Warnings

Figure 360: Output and Analysis Options for Run 3.11

Run 3.12

General Information ☒

Pavement Type

☒ New Pavement ☐ AC-on-AC overlay Rehabilitation

Pavement Location

Latitude 0.0 Longitude 0.0

Traffic

☒ Design Vehicle ☐ Traffic Spectrum

Optional Description

Project Name	Run 3.12- 75X110 mm and 50X110 mm
Author	Abha Dwivedy
City/State	05/22/2020
Date	Morgantown, WV
Note	one and three from one SGC pill

Units Advanced

Analysis Options

☐ Pavement Response Analysis ☒ Pavement Performance Analysis

Fatigue Options

☒ Fatigue Cracking ☒ Thermal Stress ☐ Healing ☐ Aging

Rutting Options

☒ Rutting

Pavement Construction Timeline

Pavement Construction Date January 2014

Traffic Opening Date January 2014

Pavement Design Life (years) 20

Errors and Warnings

Figure 361: General Information for Run 3.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: AC

Thickness (cm): 6.4 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			Rutting		Rutting
Einf (KPa)	2.5789e+03		Alpha	3.0655	Beta	0.6906	p1	0.8085
Ref. Temp. (C)	21.1000		C11	0.0024	Epsilon0	0.0012	p2	0.3217
Shift Factor a1	4.5983e-04		C12	0.4906	NI	5.6761	d1	0.2323
Shift Factor a2	-0.1530		Initial C	0.8000	TR(C)	46	d2	-4.2184
Shift Factor a3	3.0228		DR	0.5654				

	Ti (sec)	Ei (KPa)
1	200000000	8.9563e+03
2	20000000	5.3223e+03
3	2000000	1.5336e+04
4	200000	3.5284e+04
5	20000	8.7047e+04
6	2000	2.1186e+05
7	200	4.7962e+05
8	20	9.5282e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 362: Design Structure of AC Layer for Run 3.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 1

Thickness (cm): 8.9 ☐ Infinite Layer

Material Type: Asphalt Concrete more..

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000		Fatigue			Rutting		Rutting
Einf (KPa)	1.0290e+04		Alpha	3.8736	Beta	0.6412	p1	1.2119
Ref. Temp. (C)	21.1000		C11	0.0015	Epsilon0	8.088...	p2	0.4823
Shift Factor a1	-6.3943e-05		C12	0.5149	NI	7.7802	d1	0.3867
Shift Factor a2	-0.1307		Initial C	0.8000	TR(C)	35	d2	-7.7981
Shift Factor a3	2.7865		DR	0.5782				

	Ti (sec)	Ei (KPa)
1	200000000	9.4603e+03
2	20000000	4.0575e+03
3	2000000	1.1284e+04
4	200000	2.2218e+04
5	20000	4.9385e+04
6	2000	1.1543e+05
7	200	2.7311e+05
8	20	6.1127e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Errors and Warnings

Figure 363: Design Structure of Base 1 Layer for Run 3.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Base 2

Thickness (cm): 40.6 ☐ Infinite Layer

Material Type: Aggregate Base more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Fatigue		Rutting	
Einf (KPa)	7.2677e+03	Alpha	3.5580	Beta	0.7680
Ref. Temp. (C)	21.1000	C11	4.3195e-04	Epsilon0	0.0022
Shift Factor a1	3.0193e-04	C12	0.6238	NI	1.9636
Shift Factor a2	-0.1466	Initial C	0.8000	TR(C)	38
Shift Factor a3	2.9584	DR	0.5227		

	Ti (sec)	Ei (KPa)
1	200000000	6.5691e+03
2	200000000	3.3105e+03
3	2000000	9.2256e+03
4	200000	1.9803e+04
5	20000	4.8430e+04
6	2000	1.2610e+05
7	200	3.2966e+05
8	20	7.8916e+05

Import Damage Data Import Rutting Data

Please note that FlexPAVE 1.1 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.

Import Prony Series Data Help...

Figure 364: Design Structure of Base 2 Layer for Run 3.12

General Information ☐ Design Structure ☒

Structure General Information

Structure Name: Flexible 3-Layer Pavement

Pavement/Lane Width (m): 3.65

Add Layer Remove Layer Move Layer

AC (Click to Edit Layer)

Base 1 (Click to Edit Layer)

Base 2 (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer: Subgrade

Thickness (cm): 380 ☐ Infinite Layer

Material Type: Subgrade more.. ☐ GR Based Criterion ☒ DR Based Criterion

Specific Gravity (optional): 2.5 Expansion Co. (1/C): 1.0e-5

Strength/Modulus

Elastic Modulus (KPa)	6.8948e+04
Poisson's Ratio	0.4000

Figure 365: Design Structure of Subgrade Layer for Run 3.12

Figure 366: Climate Data for Run 3.12

General Information ☐ Design Structure ☐ Climate Information ☐ Traffic ☒

Design Vehicle Information

Choose a Vehicle:

	Axle Type	Wheel Type	Distance (m)	Axle Load (kN)
1	☐ Single Axle	☐ Single Tire	0	80

Design Velocity (m/s):

Traffic Information

Daily ESAL: Growth Type: Growth Rate (%):

Lane Distribution Factor:

Monthly Adjustment Factor

	MAF
January	1
February	1
March	1
April	1
May	1
June	1
July	1
August	1
September	1
October	1
November	1
December	1

Hourly Truck Distribution (%)

	HTD
Midnight	4.1667
1:00 AM	4.1667
2:00 AM	4.1667
3:00 AM	4.1667
4:00 AM	4.1667
5:00 AM	4.1667
6:00 AM	4.1667
7:00 AM	4.1667
8:00 AM	4.1667
9:00 AM	4.1667
10:00 AM	4.1667
11:00 AM	4.1667
Noon	4.1667
1:00 PM	4.1667
2:00 PM	4.1667
3:00 PM	4.1667
4:00 PM	4.1667
5:00 PM	4.1667
6:00 PM	4.1667

Errors and Warnings

Axle Configuration

Axle	Type	Wheel Type	Width (m)	Axle Spacing (m)	Dual Tires Spacing (cm)
Axle 1	Single Axle	Single Tire	2.6000	0	0

Tire Pressure (kPa):

Contact Area Shape: Aspect Ratio (length/width):

Shear Traction:

Figure 367: Traffic Data for Run 3.12

General Information
Design Structure
Climate Information
Traffic
Analysis and Results Options

Output Option

☒ Results in Contour
☒ Evaluation Points

☒ Fatigue Cracking Results
☒ Rutting Results
☒ Thermal Stress

☒ Stress
☒ Strain
☒ Displacement

Stress Components

☒ Sxx
☒ Syy
☒ Szz
☒ Szx
☒ Syz
☒ Sxy

Strain Components

☒ Exx
☒ Eyy
☒ Ezz
☒ Ezx
☒ Eyz
☒ Exy

Displacements

☒ Ux
☒ Uy
☒ Uz

Advanced

Evaluation Point Properties

Note: Origin of coordinates is the mid-point of End Axle

	Transverse	Depth
Origin of Mesh	0	0
Number of steps	5	5
Increment (cm)	0.1000	0.1000

Add Mesh

Replace Mesh

	X (cm)	Z (cm)
1	0	0
2	0	11.1800
3	0	22.3600
4	0	33.5400
5	0	44.7200
6	0	55.9000
7	36.5000	0
8	36.5000	11.1800
9	36.5000	22.3600
10	36.5000	33.5400
11	36.5000	44.7200
12	36.5000	55.9000
13	73	0
14	73	11.1800
15	73	22.3600
16	73	33.5400
17	73	44.7200
18	73	55.9000
19	109.5000	0

+

-

...

Errors and Warnings

Figure 368: Output and Analysis Options for Run 3.12