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Evaluation of Poisson's Ratio for Use in the Mechanistic Empirical Pavement Design Guide (MEPDG)

FINAL REPORT
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16. Abstract

The pavement design industry is moving towards the use of mechanistic principles in designing flexible pavements. To determine the resultant strains in the pavement system using these principles, two material properties are required; 1) modulus and 2) Poisson's ratio. In flexible pavement design, the required modulus can be determined either in the laboratory or in the field. In the lab, the dynamic modulus and resilient modulus tests are used to determine the modulus values of asphalt and unbound materials, respectively. In the field, the Falling Weight Deflectometer (FWD) is commonly used to determine the modulus of the various materials. However, the value of the Poisson's Ratio is usually assumed. This research project encompassed the evaluation of whether or not the Poisson's Ratio can be measured using the same test procedures commonly used to obtain the modulus values for flexible pavement design (i.e. – dynamic modulus test for asphalt and resilient modulus test for unbound materials). The research project also evaluated the sensitivity of pavement performance and the FWD backcalculation procedure when varying the magnitude of the Poisson's Ratio parameter.

The results showed that the Poisson's Ratio can readily be measured during the dynamic modulus (AASHTO TP62) test procedure using a radial LVDT measuring system. Tests conducted on a number of asphalt mixtures also showed that there is a relationship between modulus and Poisson's Ratio (as modulus decreases, Poisson's Ratio increases). However, some discrepancies were found between the measured and predicted values when using the Poisson's Ratio prediction equation provided in the Mechanistic Empirical Pavement Design Guide (MEPDG) software, especially when higher PG asphalt binder grades were used. The results also showed that the Poisson's Ratio should not be measured during the resilient modulus (M_R) test for unbound materials. This is mainly due to the fact that the M_R test does not typically test the material in its natural linear elastic state, which is where the Poisson's Ratio concept is valid. Sensitivity analysis work with the FWD backcalculation and using the MPEDG illustrated how the predicted pavement response is affected by the selected Poisson's Ratio value.

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ABSTRACT

The pavement design industry is moving towards the use of mechanistic principles in designing flexible pavements. To determine the resultant strains in the pavement system using these principles, two material properties are required; 1) modulus and 2) Poisson's ratio. In flexible pavement design, the required modulus can be determined either in the laboratory or in the field. In the lab, the dynamic modulus and resilient modulus tests are used to determine the modulus values of asphalt and unbound materials, respectively. In the field, the Falling Weight Deflectometer (FWD) is commonly used to determine the modulus of the various materials. However, the value of the Poisson's Ratio is usually assumed. This research project encompassed the evaluation of whether or not the Poisson's Ratio can be measured using the same test procedures commonly used to obtain the modulus values for flexible pavement design (i.e. – dynamic modulus test for asphalt and resilient modulus test for unbound materials). The research project also evaluated the sensitivity of pavement performance and the FWD backcalculation procedure when varying the magnitude of the Poisson's Ratio parameter.

The results showed that the Poisson's Ratio can readily be measured during the dynamic modulus (AASHTO TP62) test procedure using a radial LVDT measuring system. Tests conducted on a number of asphalt mixtures also showed that there is a relationship between modulus and Poisson's Ratio (as modulus decreases, Poisson's Ratio increases). However, some discrepancies were found between the measured and predicted values when using the Poisson's Ratio prediction equation provided in the Mechanistic Empirical Pavement Design Guide (MEPDG) software, especially when stiffer PG graded asphalt binders were used. The results also showed that the Poisson's Ratio should not be measured during the resilient modulus (M_R) test for unbound materials. This is mainly due to the fact that the M_R test does not typically test the material in its natural linear elastic state, which is where the Poisson's Ratio concept is valid. Sensitivity analysis work with the FWD backcalculation and using the MPEDG and a linear elastic software illustrate how the predicted pavement response is affected by the selected Poisson's Ratio value.

INTRODUCTION

When a compressive force acts on a cylinder body, the force causes the sample to contract in the direction of the force and expand laterally. Within the elastic range of the material, the ratio of these strains is a constant for that particular material. The ratio of the strains, (δ/L) for longitudinal strain and (δ'/r) for lateral strain, is referred to as Poisson's ratio. Figure 1 illustrates this phenomenon.

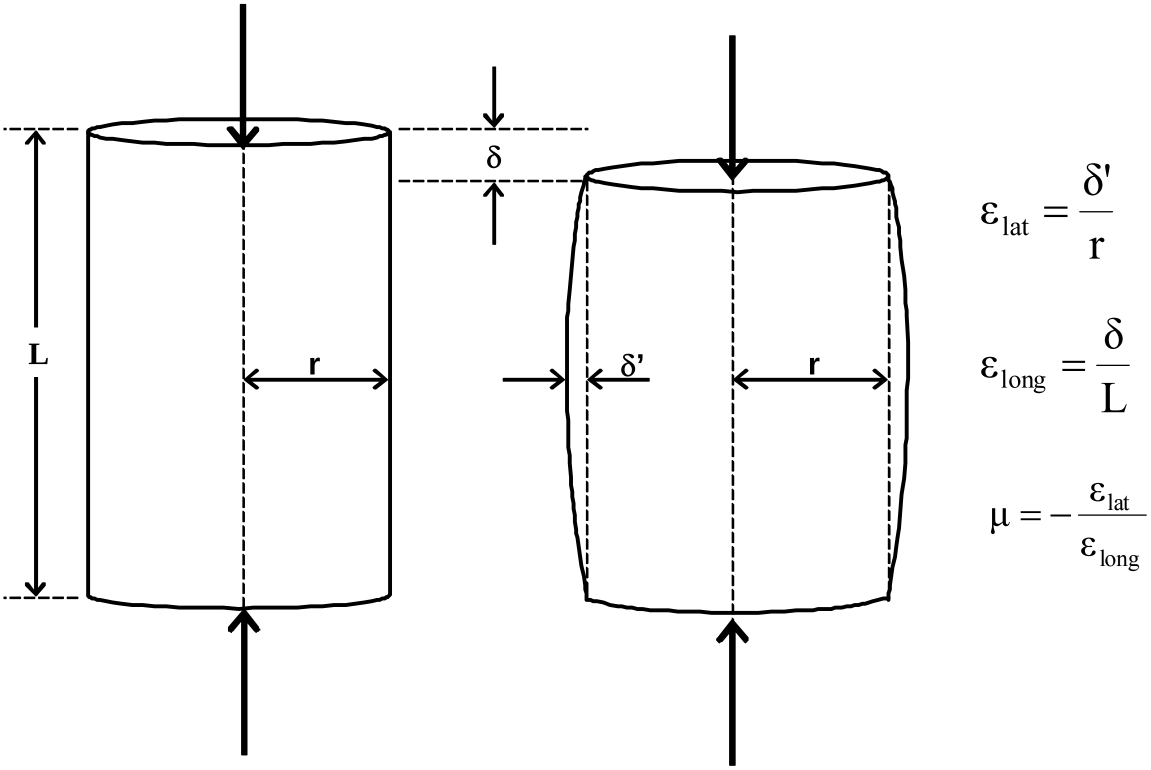


Figure 1 – Illustration of Poisson's Ratio for a Cylindrical Sample

The fundamental design methods for mechanistic pavement design are either based on linear elastic layered models (ELM) or finite element models (FEM), shown in Figure 2. The models generally assume that the layers are linearly elastic, homogeneous, and isotropic. Regardless of the model used, two independent elastic material constants are required to characterize each layer for determining the recoverable stress, strain, and displacement response of the pavement system. The two parameters utilized are: 1) stiffness (E) or resilient modulus (M_R) and 2) the Poisson's ratio (μ). There are standardized methods for determining the stiffness/resilient modulus of asphalt and soil; however, typical values for the Poisson's ratio for asphalt and soil have traditionally been assumed for analysis purposes. Table 1 shows typical values for materials used in pavement design.

Currently, there are standardized procedures to evaluate the stiffness parameters of both asphalt and soil. For hot mix asphalt, AASHTO TP62, Dynamic Modulus of Hot Mix Asphalt, is recommended for the measurement of modulus values over a wide range of temperatures and loading frequencies. Although designed to measure the vertical strain and resultant modulus, the new method also provides a means of determining the Poisson's ratio via the use of radial measurements. In the past, methods have been developed for the evaluation of the Poisson's Ratio utilizing the Indirect Tensile Test (IDT). However, the use of IDT-type testing at higher test temperatures, greater than 20°C, for stiffness determination is not recommended due to excessive deformations that may occur in the vicinity of the loading platens, as well as the inappropriateness of using linear elastic theory in the diametral loading position (Tayebali et al. 1995). Also, to be compliant with the needs of the MEPDG, only the Dynamic Modulus test is conducted over a wide range of test temperatures, while the IDT test is to be used at only low temperatures.

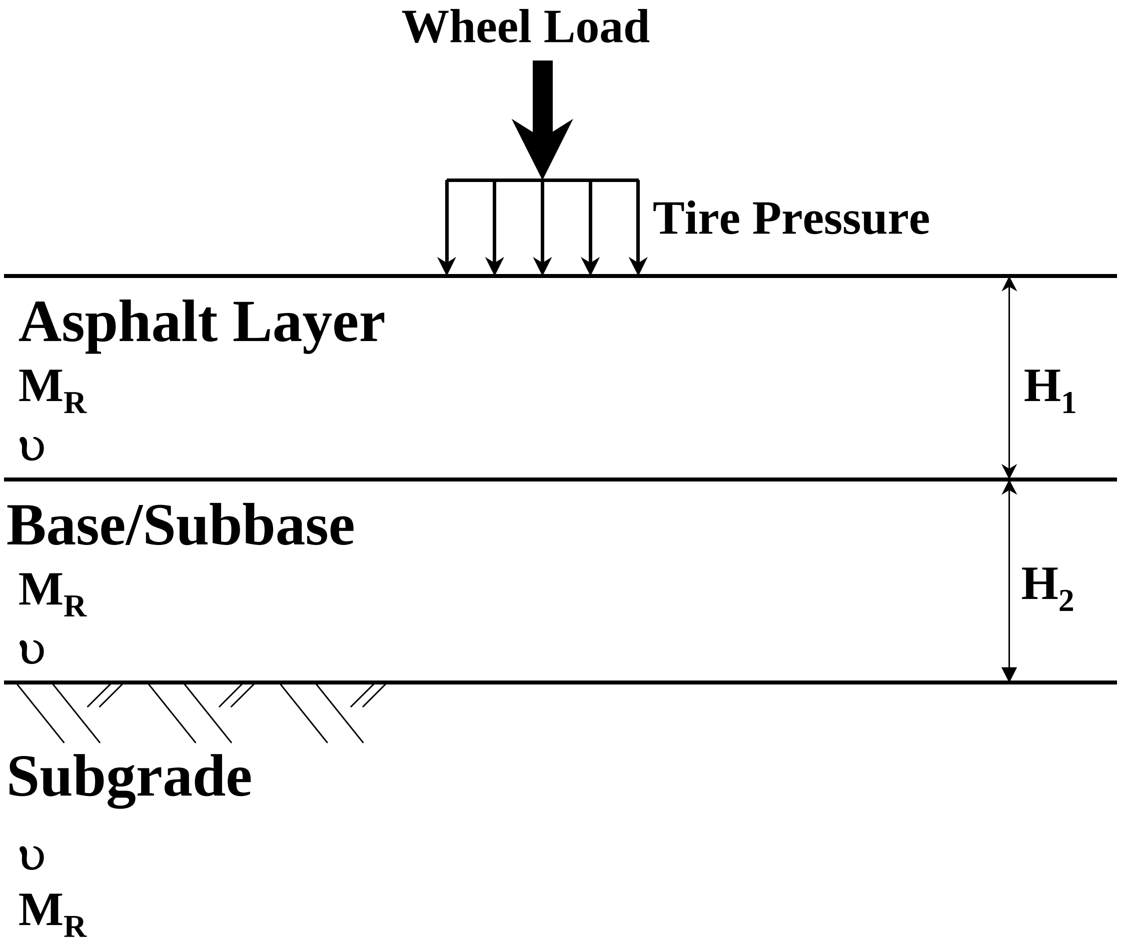


Figure 2 – Elastic Layer Model Diagram for a Typical Pavement Section

For unbound material (soils and aggregates), the resilient modulus test is commonly conducted. There have been many versions of this test used by researchers and practioners over the years. With the most common found below:

- SHRP P-46
- AASHTO T307
- NCHRP Harmonized Test Procedure

Similar to the Dynamic Modulus test, the Resilient Modulus test is conducted in the uniaxial mode, similar to the classical definition for the determination of Poisson's Ratio, shown earlier in Figure 1. Therefore, the Resilient Modulus test, commonly used to determine the modulus input parameters required for the Mechanistic Empirical Pavement Design Guide (MEPDG), also has the potential to be used to provide material specific Poisson's Ratio values to input as well.

Table 1 – Typical Values of Poisson's Ratio

Material	Range of Values	Typical Value
Hot Mix Asphalt	0.30 - 0.40	0.35
Portland Cement Concrete	0.15 - 0.20	0.15
Untreated Granular Materials	0.30 - 0.40	0.35
Cement-Treated Granular Materials	0.10 - 0.20	0.15
Cement-Treated Fine-Grained Soils	0.15 - 0.35	0.25
Lime-Stabilized Materials	0.10 - 0.25	0.20
Lime-Fly Ash Mixtures	0.10 - 0.15	0.15
Loose Sand or Silty Sand	0.20 - 0.40	0.30
Dense Sand	0.30 - 0.45	0.35
Fine-Grained Soils	0.30 - 0.50	0.40
Saturated Soft Clays	0.40 - 0.50	0.45

RESEARCH OBJECTIVES

There were two main goals to accomplish in this research study. The first goal of the study was to evaluate whether or not the Poisson's Ratio could be readily measured during the recommended laboratory tests for the Dynamic Modulus, stiffness parameter required for bituminous materials, and the Resilient Modulus, stiffness parameter required for unbound materials.

The second goal of the research study was to assess the impact of the Poisson's Ratio on pavement performance. To do so, three different analyses were conducted:

- Sensitivity analysis using the Linear Elastic Theory program called EVERSTRESS.

- Sensitivity analysis using the Mechanistic Empirical Pavement Design Guide software
- Sensitivity analysis of backcalculated modulus values from Falling Weight Deflectometer (FWD) testing.

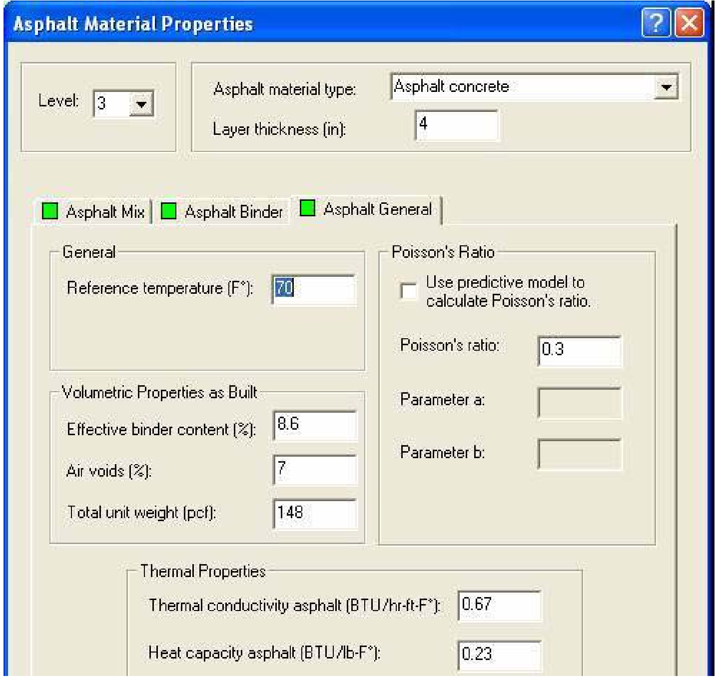
SELECTION OF POISSON'S RATIO IN THE MEPDG

The evaluation of Poisson's Ratio was driven by the development of the Mechanistic Empirical Pavement Design Guide (MEPDG). The MEPDG utilizes a linear elastic subprogram, called JULEA (Jacob Uzan's Linear Elastic Analysis), to determine the development of strains associated with traffic and climatic loading. In any elastic layer analysis system, the two main input parameters required to conduct the analysis are modulus and Poisson's Ratio. In the MEPDG software, the Poisson's Ratio are selected differently depending on the material type (asphalt or unbound materials).

Asphalt Materials

Poisson's ratio, μ_{ac}, for asphalt materials typically ranges from 0.1 to 0.5 and is known to be dependent on the stiffness of the asphalt material (ARA, 2004). Figure 3 shows a screenshot of the MEPDG software where the user would input the Poisson's ratio material constants. The current version of the MEPDG software allows the user three (3) options when inputting Poisson's Ratio values:

1. Input material specific *a* and *b* parameters;
2. Select the "Use Prediction Model" mode – this is use the default *a* and *b* parameters; and
3. Select a constant value for the Poisson's Ratio (i.e. 0.3).



Level: 3

Asphalt material type: Asphalt concrete

Layer thickness (in): 4

Reference temperature (F°): 70

☐ Use predictive model to calculate Poisson's ratio.

Poisson's ratio: 0.3

Parameter a:

Parameter b:

Effective binder content (%): 8.6

Air voids (%): 7

Total unit weight (pcf): 148

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

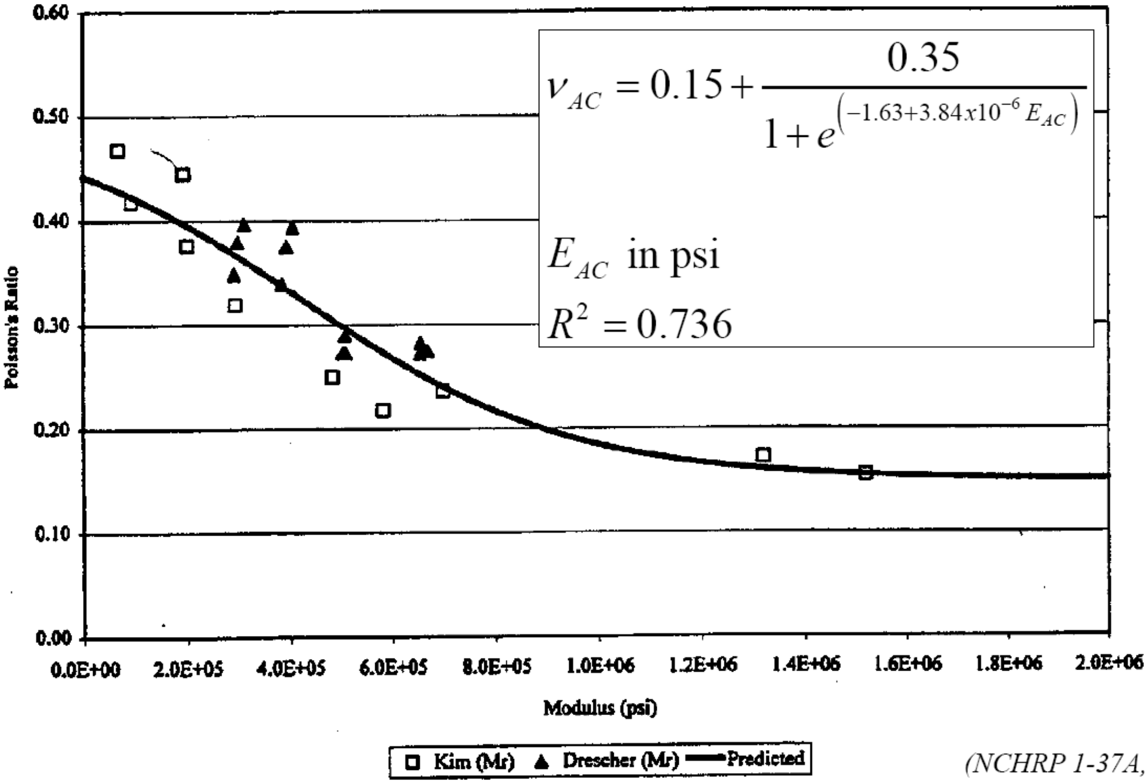
Heat capacity asphalt (BTU/lb-F°): 0.23

Figure 3 – Screenshot of the Poisson's Ratio Input Screen for Asphalt Materials

For an asphalt material specific Poisson's ratio, the MEPDG allows for the user to input material constants, *a* and *b*, to be used in Equation (1), which allows for the estimation of the Poisson's ratio with respect to the changing modulus, E_{ac}.

$$\mu_{ac} = 0.15 + \frac{0.35}{1 + e^{(a + bE_{ac})}} \qquad (1)$$

The default values for *a* and *b*, which were initially determined from Resilient Modulus testing of bituminous materials tested in the Indirect Tension mode, are -1.63 and 3.84E-6, respectively. Figure 4 shows the original dataset used to determine the default values (NCHRP 1-37A, 1999).



(NCHRP 1-37A, 1999)

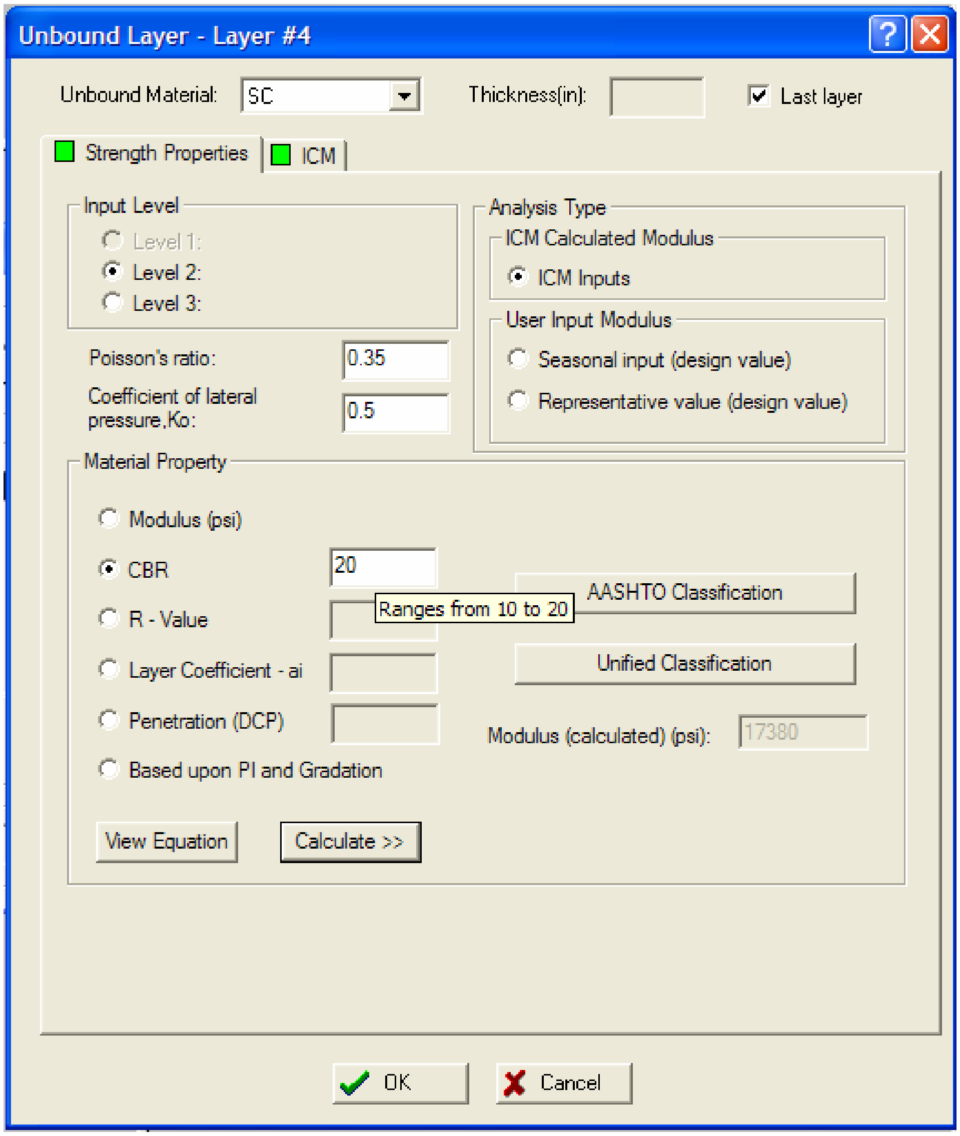
Figure 4 – Original Dataset Used to Develop Poisson's Ratio Prediction Equation Constants

Unfortunately, at the present time, the only means of inputting a material specific Poisson's ratio for asphalt materials is through the use of either using a regression analysis scheme to determine the *a* and *b* parameters, or to use a constant value that would represent the average measured Poisson's ratio from laboratory testing. Either method must use the material specific Poisson's ratio relationship shown as Equation (1).

To measure the Poisson's Ratio of hot mix asphalt during the dynamic modulus test (AASHTO TP62), Rutgers University utilized the specimen mounted LVDT holder manufactured for use during the volumetric test procedure for the Superpave Shear Tester (SST). This on-sample device allows for the measurement of the circumferential change in length due to compressive loading (Figure 6).

Unbound Materials

For unbound materials, the MEPDG only allows the user to input a constant value for the Poisson's Ratio, thereby nullifying any affect applied stress or change in resilient modulus may have on Poisson's Ratio. Figure 5 shows a screenshot of the unbound materials input page when conducting a rehabilitation design in the MEPDG.


Unbound Layer - Layer #4

Unbound Material: SC

Thickness(in):

☑ Last layer

🟩 Strength Properties

🟩 ICM

Input Level

○ Level 1:

● Level 2:

○ Level 3:

Poisson's ratio: 0.35

Coefficient of lateral pressure,Ko: 0.5

Analysis Type

ICM Calculated Modulus

● ICM Inputs

User Input Modulus

○ Seasonal input (design value)

○ Representative value (design value)

Material Property

○ Modulus (psi)

● CBR 20

Ranges from 10 to 20

○ R - Value

○ Layer Coefficient - ai

○ Penetration (DCP)

○ Based upon PI and Gradation

Modulus (calculated) (psi): 17380

Figure 5 – Screenshot of Material Data Input for Unbound Materials

Similar to the asphalt materials, the proposed methodology in this study was to utilize the resilient modulus test to determine both modulus of the unbound materials and Poisson's Ratio for a specific material type. This would allow an agency to conduct one test to provide material specific properties. Not to mention, the cyclic loading nature of the resilient modulus test is more representative of field loading conditions.

The traditional method of determining the Poisson's ratio for soils has been to measure the radial expansion of the sample under static or cyclic loading conditions via either LVDT's or extensometers. The sample is usually set-up in the standard triaxial test set-up, such as the one shown in Figure 7. Figure 7 is a picture of the triaxial testing apparatus for the Department of Civil and Environmental Engineering at Rutgers University. The test set-up measures the axial deformation utilizing LVDT's attached to the loading piston.

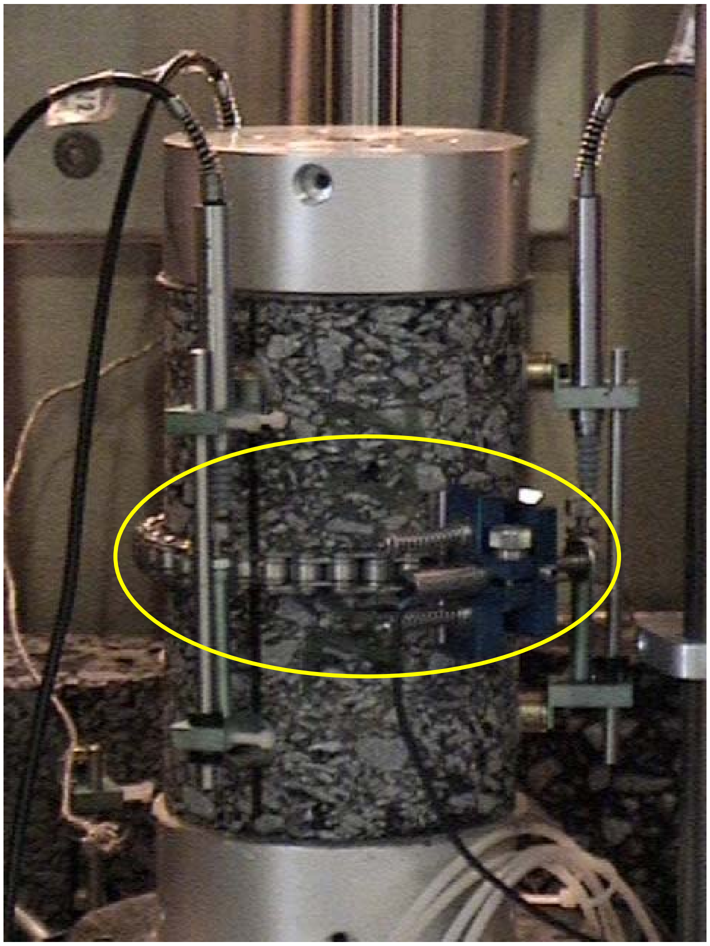


Figure 6 – On-sample Circumferential Deformation Measurement Set-up for Hot Mix Asphalt Specimens

Another in-direct method for determining the Poisson's ratio of soils is through the relationship developed by Bishop and Henkel (1969). The method involves using the axial strains imposed on the specimen to predict the radial strains using the following relationship;

$$A = A_O \frac{1}{1-\varepsilon} \tag{2}$$

where,

A = cross-sectional area of the specimen after undergoing ε
A_O = initial cross-sectional area
ε = axial strain imposed on the specimen

Assuming that the specimen has a circular cross section and that it undergoes deformation maintaining that circular cross section, equation (2) can be rearranged to determine the radial strain using equation (3).

$$\frac{\Delta r}{r_O} = \sqrt{\frac{1}{1-\varepsilon}} \tag{3}$$

where,

r_O = initial radius of the specimen's cross section
Δr = change in radius experienced by the specimen while under-going ε

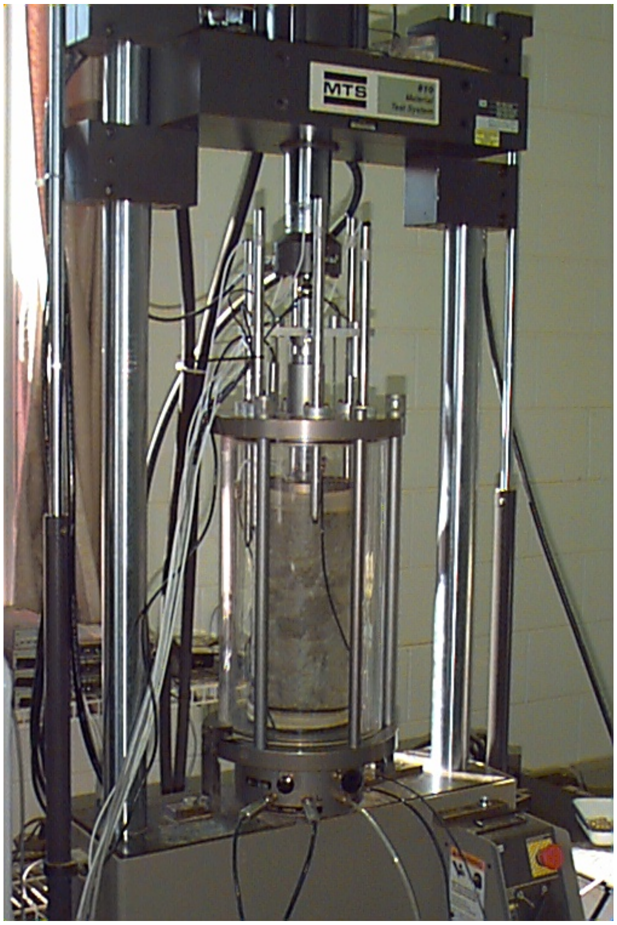


Figure 7 – Rutgers University Resilient Modulus Set-up for Coarse Aggregates

Equations (2) and (3) are recommended to be used during static triaxial testing (Pezo et al., 1998). Results obtained by Pezo et al. (1998) on synthetic samples show close agreement to measured and predicted radial strains, however, no attempt was made to test actual aggregate samples. Unfortunately, this methodology is not recommended for dynamic-type loading, such as the resilient modulus test.

A modification to the resilient modulus test set-up at Rutgers University was conducted to allow the measurements of radial deformation during the resilient modulus test. A schematic of the test set-up is shown as Figure 8. LVDT's were mounted on the support bars of the triaxial cell and were in contact with the center of the test specimen. Figure 9a and b show a close-up of the LVDT set-up used. Data acquisition was set-up to record the peak and valley of the applied stress, vertical deformation, and radial deformation.

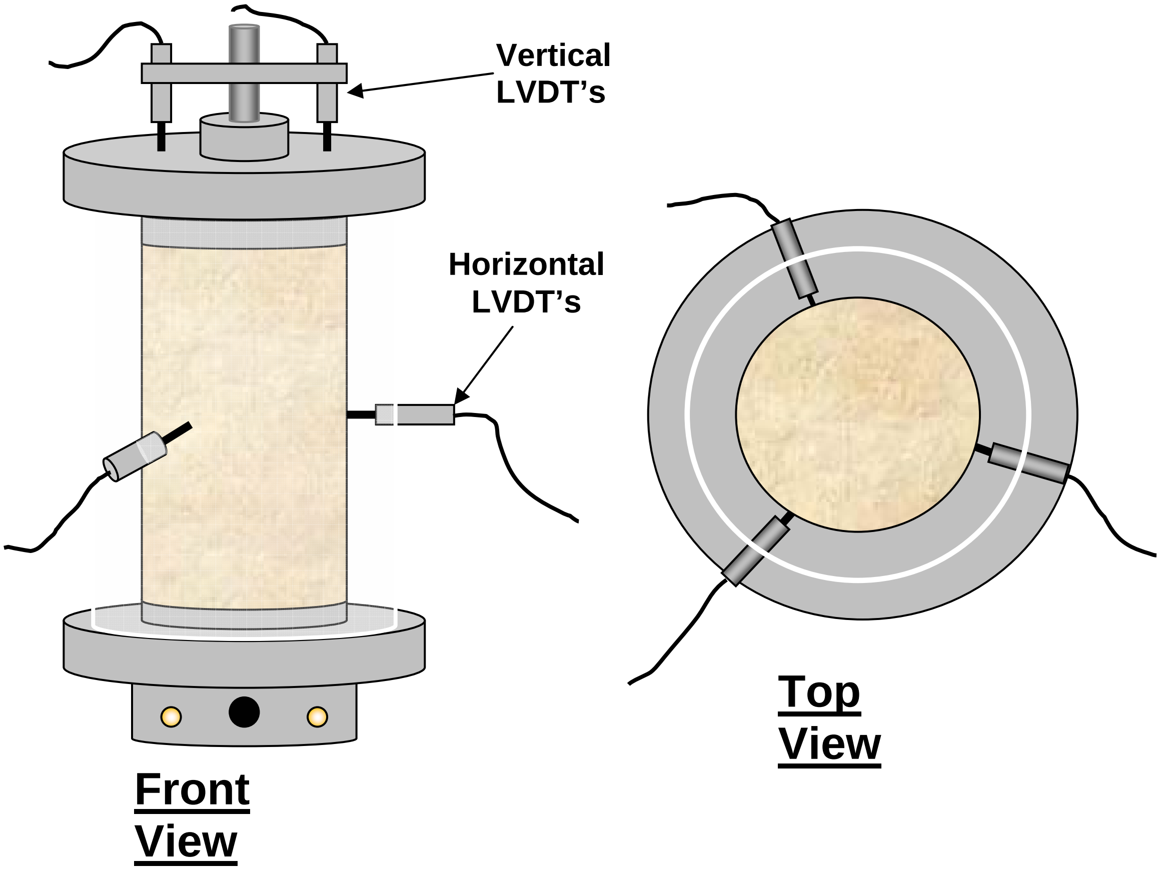


Figure 8 – Schematic of Modified Triaxial Cell for Poisson's Ratio Measurement During Resilient Modulus Testing

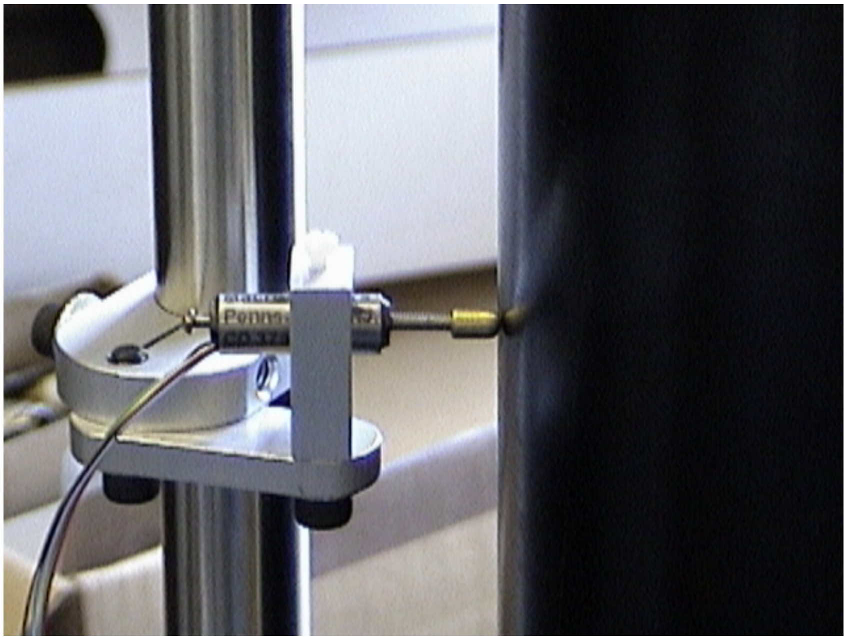


Figure 9a – Close-up of Radial LVDT Utilized in Resilient Modulus Testing

Figure 9b – Resilient Modulus with Radial LVDT Test Set-up

PAVEMENT SENSITIVITY TO POISSON'S RATIO

Prior to the laboratory testing program, a series of sensitivity analyses were conducted to evaluate how sensitive pavement response was to the change in Poisson's Ratio. In this analysis, two different methodologies were utilized;

1. Pavement Distress Prediction in the MEPDG
2. FWD Modulus Backcalculation

The pavement distress prediction in the MEPDG is dependent on the strain levels determine within the linear elastic subprogram in the MEPDG. Since Poisson's Ratio and Modulus are the two main inputs required in the elastic layer program, one would think that a major contributor to pavement distress predictions would be the change in the Poisson's Ratio. To verify this, a sensitivity analysis was conducted using the MEPDG software and the Poisson's Ratio was varied from 0.15 to 0.45, as well as using the "dynamic modulus" dependent Poisson's Ratio option.

The second critical area where it was believed that the Poisson's Ratio may make a difference is during the backcalculation of modulus values from the Falling Weight Deflectometer (FWD) deflection testing. The analysis of the FWD testing utilizes elastic theory to backcalculate the modulus values from the deflection basin. It is common that a value of 0.3 to 0.35 for asphalt, 0.35 to 0.4 for aggregate base courses, and 0.45 for subgrade soils be assumed during analysis. To evaluate the potential affect of Poisson's Ratio the FWD backcalculated modulus, an FWD deflection basin, measured at one of the LTPP FWD calibration facilities, was utilized. The backcalculation program, EVERCALC, developed by Washington State Department of Transportation, was utilized to conduct the backcalculation procedure. The Poisson's Ratio of the asphalt, base, and subgrade soil was varied that resulted in 120 different pavement analysis scenarios.

Poisson's Ratio – MEPDG Pavement Distress Sensitivity

The MEPDG software was used to conduct two different sensitivity analyses; 1) Varying Poisson's Ratio of HMA and 2) Varying Poisson's Ratio of base aggregate. In both cases, the same pavement scenario was used and is shown below:

- Initial 2-way AADTT = 5,000
- Number of Lanes in Design Direction = 2
- % Trucks in Design Direction = 50%
- % Trucks in Design Lane = 95%
- Operational Speed = 50 mph
- Climate: Trenton, NJ
- Pavement Cross-section:
  - HMA = 8 inches
  - Base Aggregate (Crushed Stone) = 8 inches
  - Subgrade = AASHTO A-4 Classification

For each case, the minimum, typical, and maximum Poisson's Ratio for the respective material was used in the sensitivity analysis.

Asphalt Layer – MEPDG Results

A brief sensitivity analysis was conducted using the MEPDG software program to evaluate how the change in Poisson's Ratio of the hot mix asphalt (HMA) layer affects the MEPDG distress predictions. Two different asphalt binder grades, common to New Jersey, were used in the analysis; PG64-22 and PG76-22. The sensitivity analysis results for the PG64-22 is shown in Figures 10 through 12 and the PG76-22 results are shown in Figures 13 through 15.

The sensitivity study included three different levels of Poisson's Ratio values (o.15, 0.3, and 0.45) as well as the "Default Equation", which is a prediction equation to predict the Poisson's Ratio of the HMA based on the modulus (shown as Equation 1). The sensitivity results indicated that:

- As the Poisson's Ratio of the HMA increases, the total pavement rutting decreases. This is most likely due to the HMA allowing for more horizontal deflection and transmittal of the applied stress, minimizes or reducing the magnitude of the vertical stress. The magnitude of the total pavement rutting was less severe for the PG76-22 asphalt binder mix.
- As the Poisson's Ratio of the HMA increases, the longitudinal cracking drastically decreases. It appears that as the HMA material is limited to transfer stresses lateral (or horizontally), the high magnitude of vertical stress induces longitudinal cracking. Note, that the Poisson's Ratio is the ratio between horizontal (or laterial) strain divided by the vertical strain. So lower Poisson's Ratio values means a greater difference between the lateral (horizontal) and vertical deflections. Longitudinal cracking for the PG76-22 asphalt binder was approximately 1/3 less than that of the PG64-22 asphalt binder mixture.
- As the Poisson's Ratio increases, alligator cracking in the HMA slightly decreases.

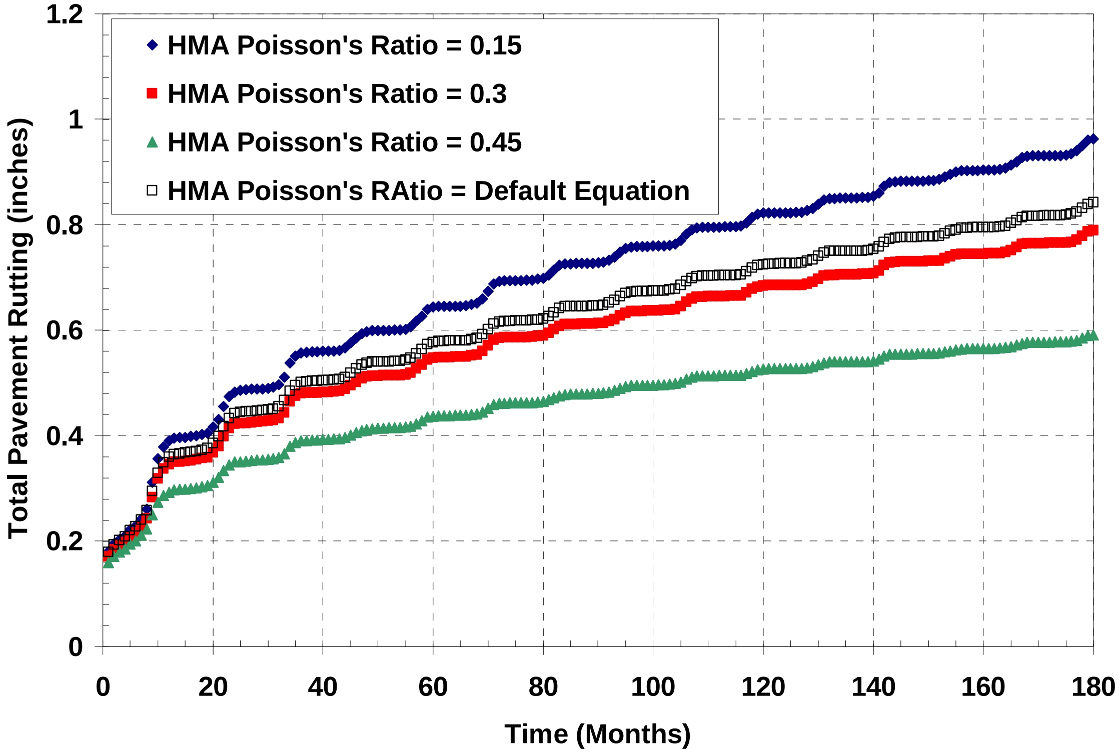


Figure 10 – Total Pavement Rutting for PG64-22 Asphalt Binder

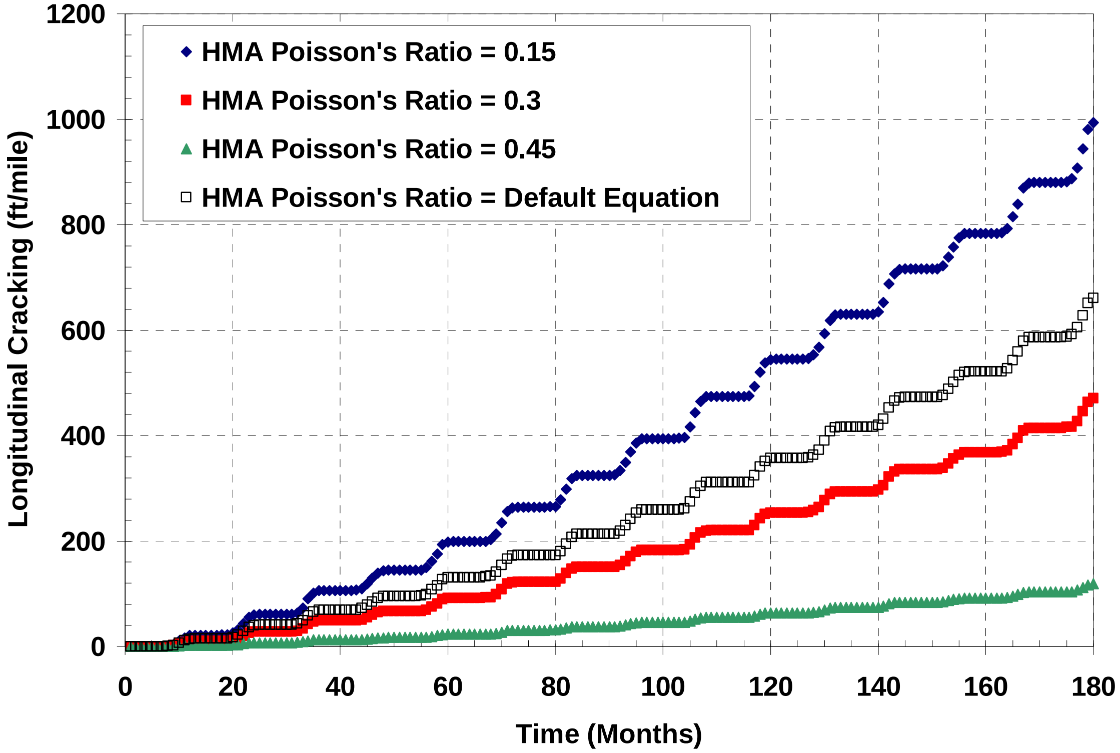


Figure 11 – Longitudinal Cracking for PG64-22 Asphalt Binder

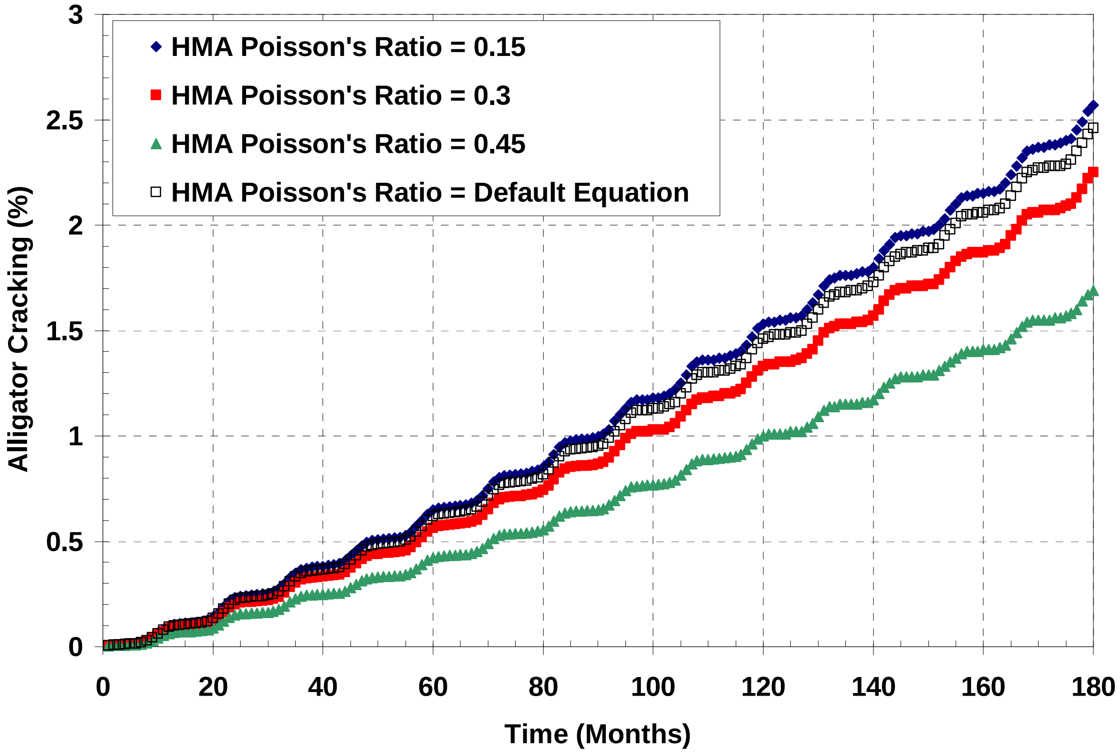


Figure 12 – Alligator Cracking for PG64-22 Asphalt Binder

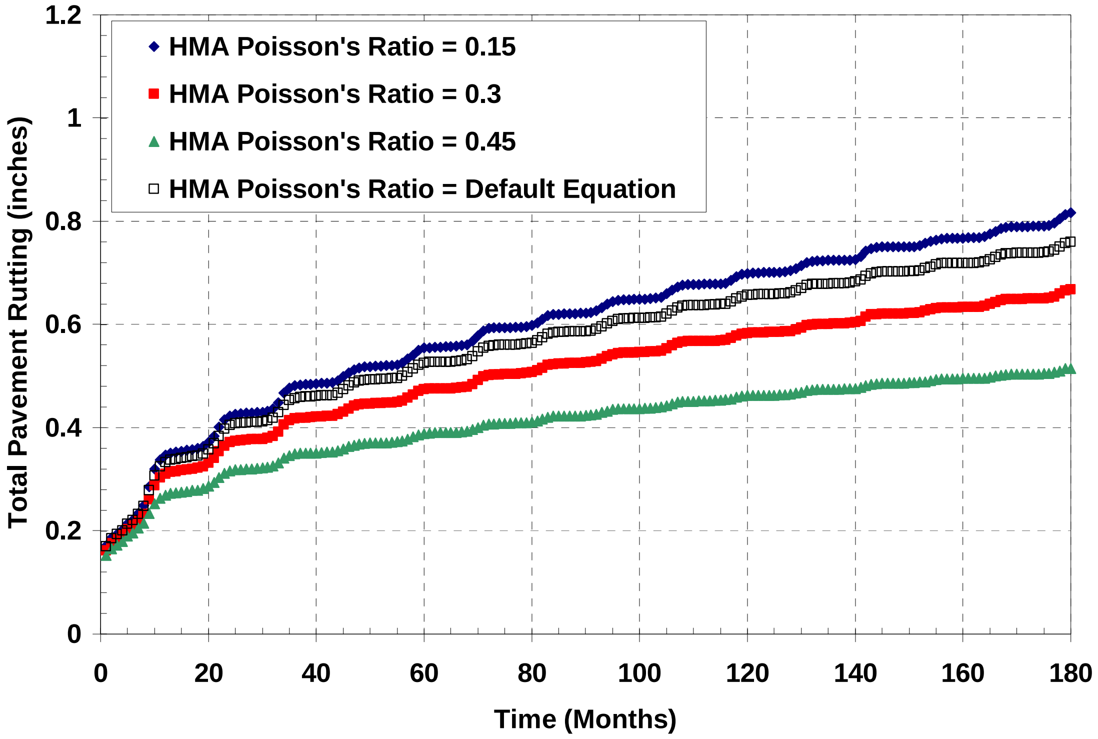


Figure 13 – Total Pavement Rutting for PG76-22 Asphalt Binder

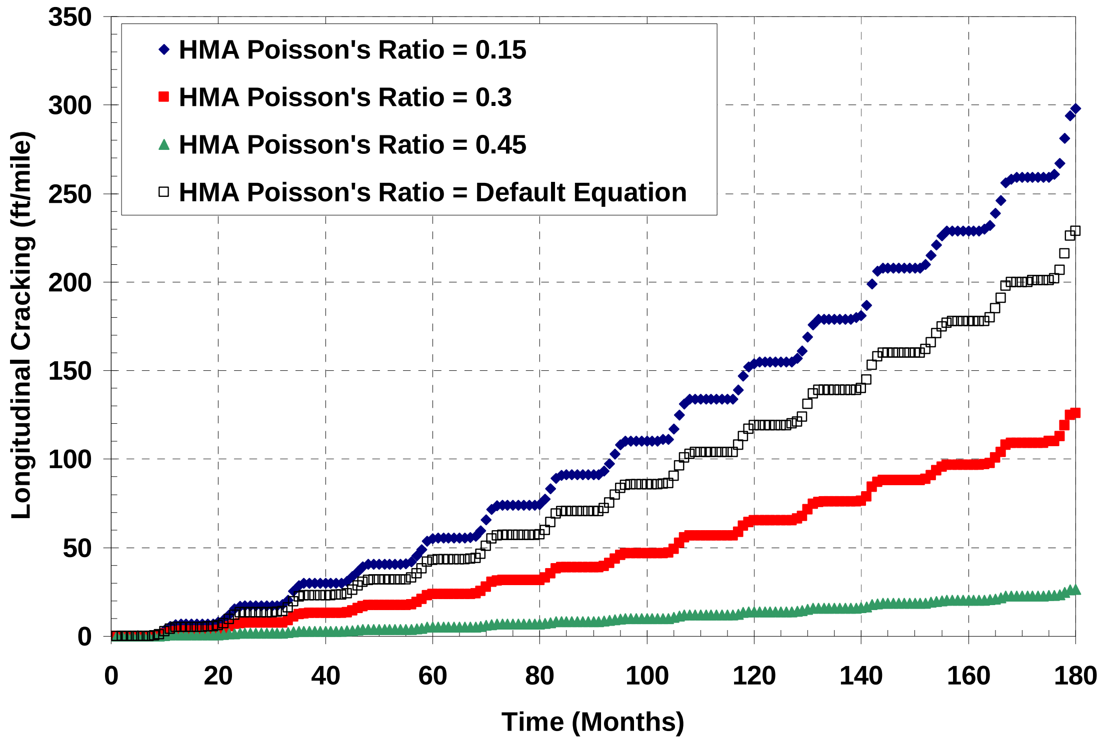


Figure 14 – Longitudinal Cracking for PG76-22 Asphalt Binder

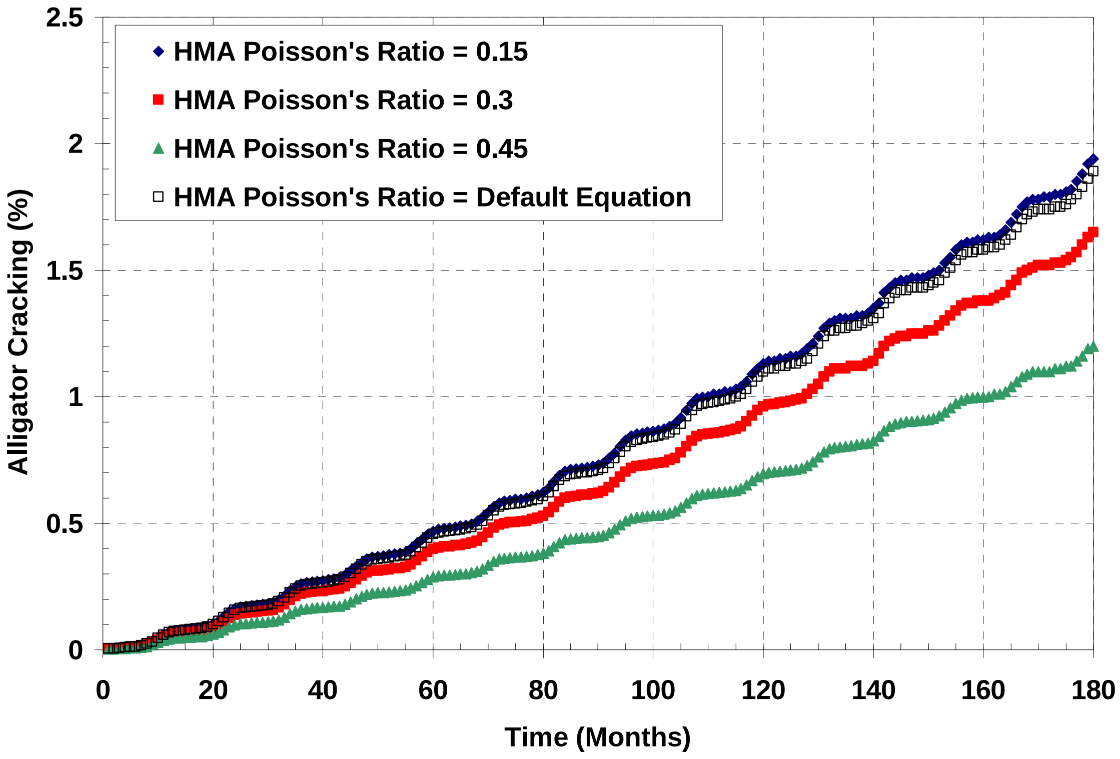


Figure 15 – Alligator Cracking for PG76-22 Asphalt Binder

Unbound Base Aggregate – MEPDG Results

A brief sensitivity analysis was conducted using the MEPDG software program to evaluate how the change in the Poisson's Ratio of the aggregate base course layer affects the MEPDG distress predictions. The pavement section that was utilized was shown earlier. Two different asphalt binder grades were used that are commonly used in New Jersey; PG64-22 and PG76-22. The sensitivity analysis results for the PG64-22 are shown in Figures 16 through 18 and the PG76-22 results are shown in Figures 19 through 21.

The sensitivity results indicated that:

- The change in Poisson's Ratio in the base aggregate layer has little influence on the total pavement rutting (i.e. – rutting of asphalt, base and subgrade). This was the case for the PG64-22 and PG76-22 asphalt binder. The PG76-22 pavement section did show lower levels of total pavement rutting when compared to the PG64-22.
- Top-down longitudinal cracking was affected by the change in Poisson's Ratio of the base aggregate layer for both the PG64-22 and PG76-22 asphalt layers. A difference of almost 350 ft/mile can be seen in the PG64-22 when the Poisson's Ratio changes from 0.15 to 0.45 with longitudinal cracking increasing with the increase in Poisson's Ratio. A difference of almost 100 ft/mile was found in the PG76-22 asphalt layer with Poisson's Ratio changing between 0.15 and 0.45. The magnitude of the top-down longitudinal cracking was significantly different between the PG64-22 and PG76-22 asphalt materials. The PG64-22 material had approximately 500 ft/mile more longitudinal cracking than the PG76-22 material at the same respective Poisson's Ratio.
- Percent wheelpath cracking (Alligator Cracking) was slightly affected by the change in Poisson's Ratio of the base aggregate layer with percent cracking decreasing as the Poisson's Ratio of the base aggregate layer decreasing. The magnitude of percent cracking was slightly greater in the PG64-22 pavement sections.

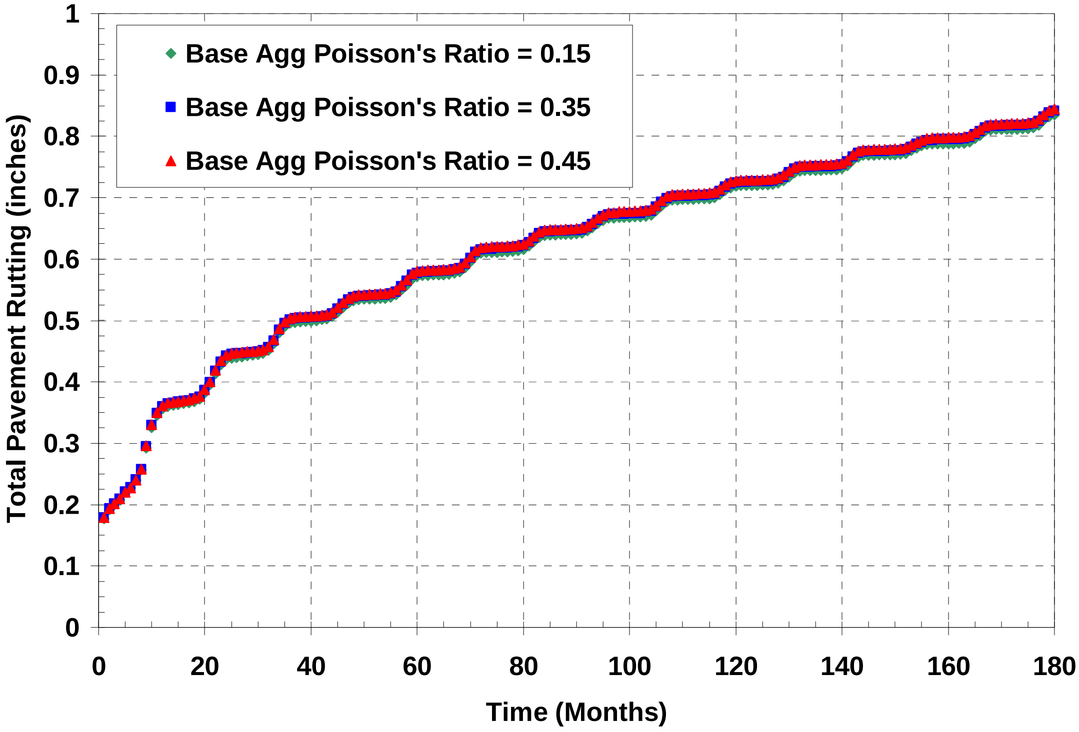


Figure 16 – Total Pavement Rutting for PG64-22 Asphalt Binder

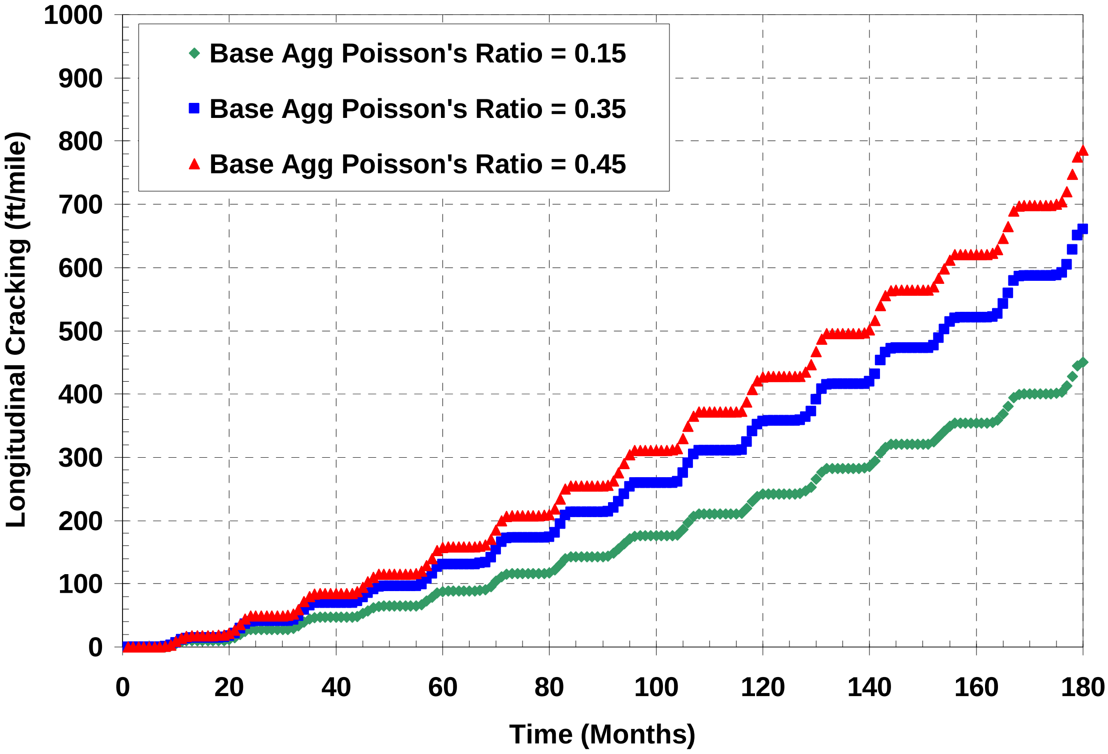


Figure 17 – Longitudinal Cracking for PG64-22 Asphalt Binder

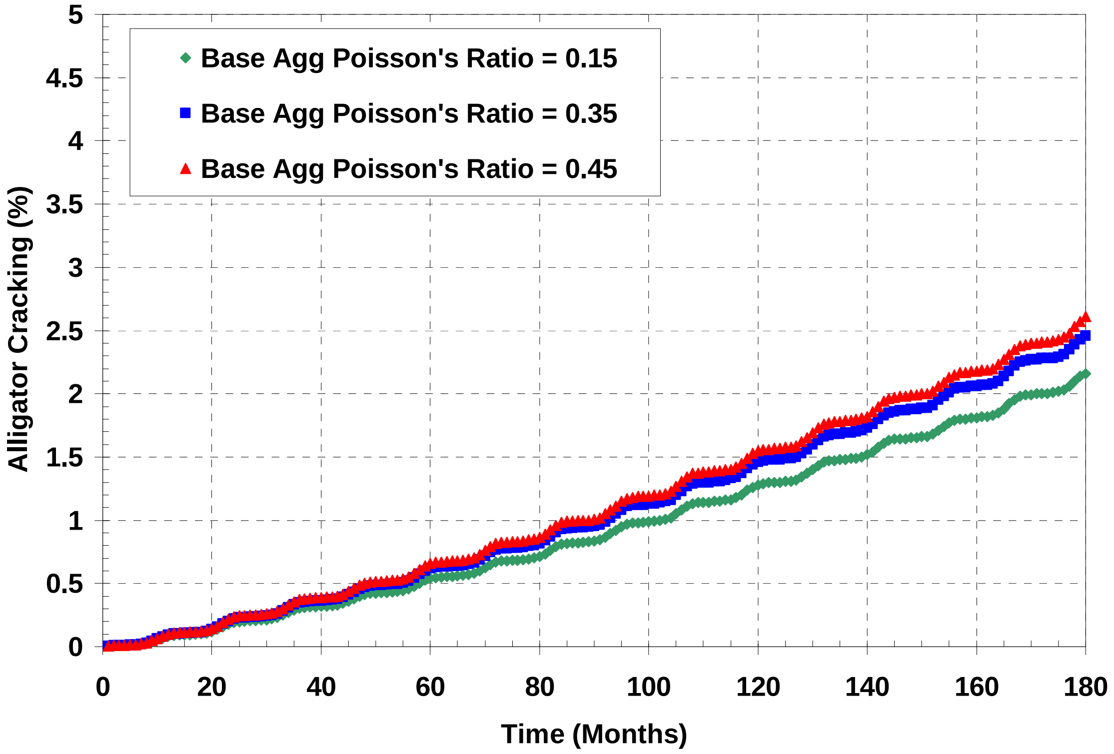


Figure 18 – Alligator Cracking for PG64-22 Asphalt Binder

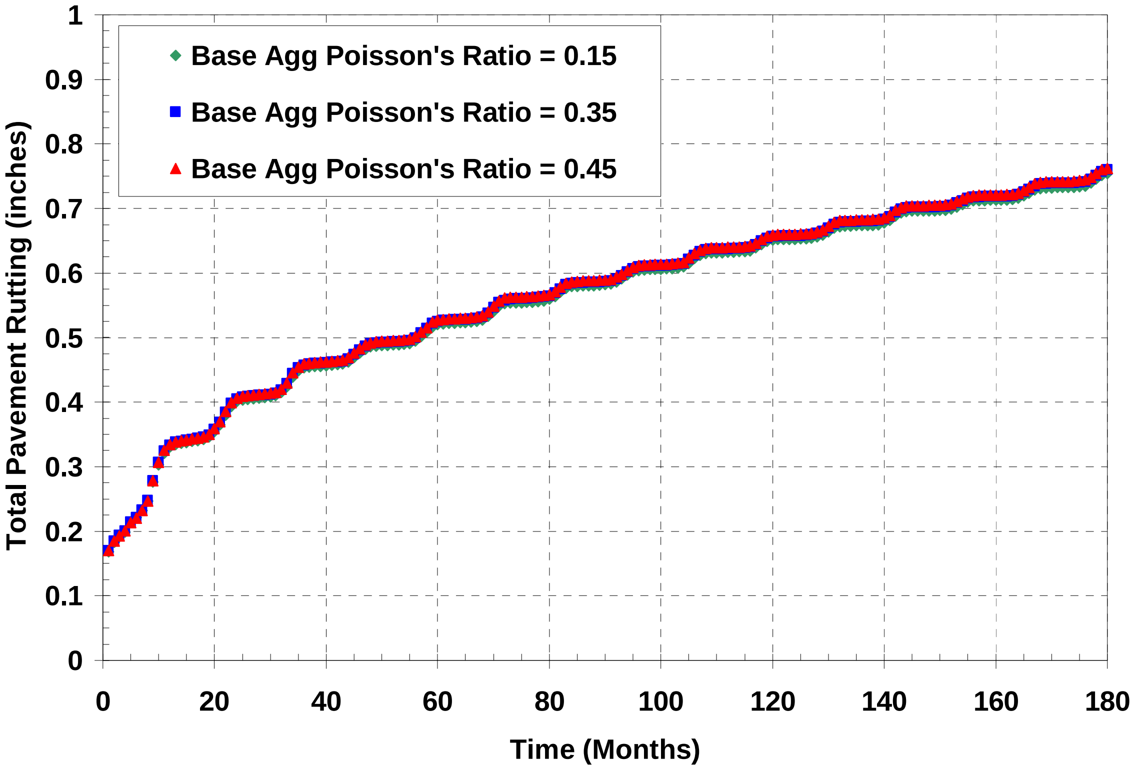


Figure 19 – Total Pavement Rutting for PG76-22 Asphalt Binder

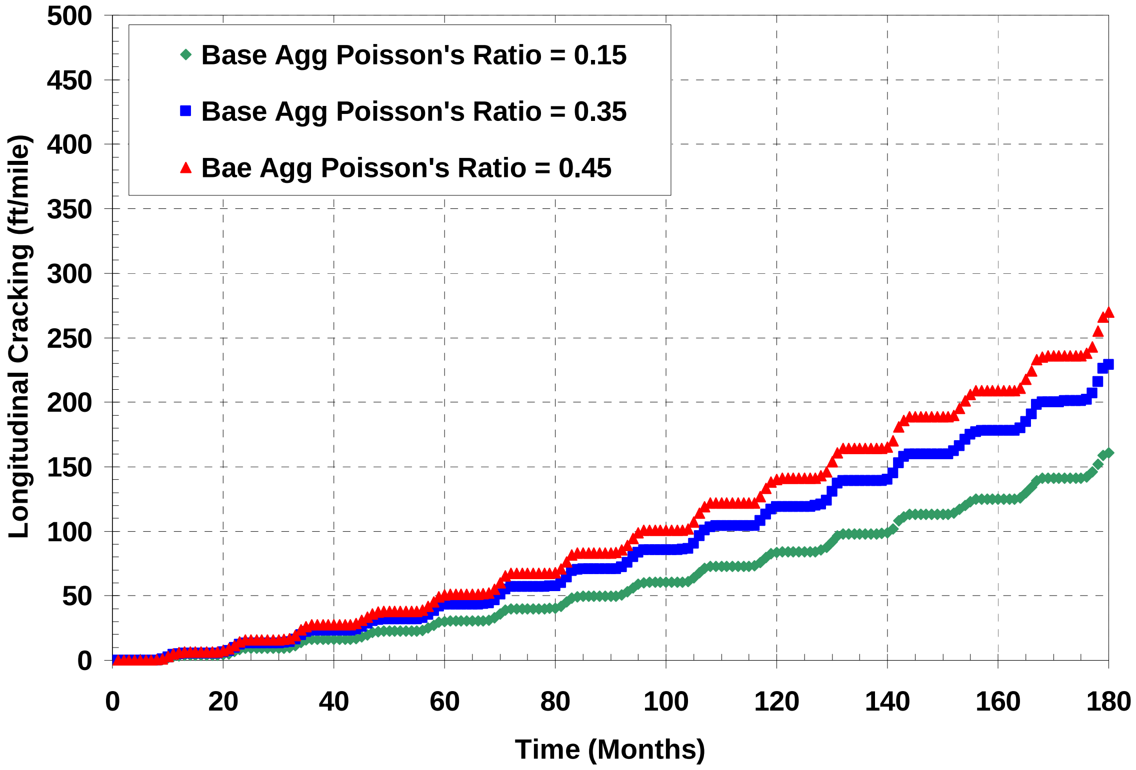


Figure 20 – Longitudinal Cracking for PG76-22 Asphalt Binder

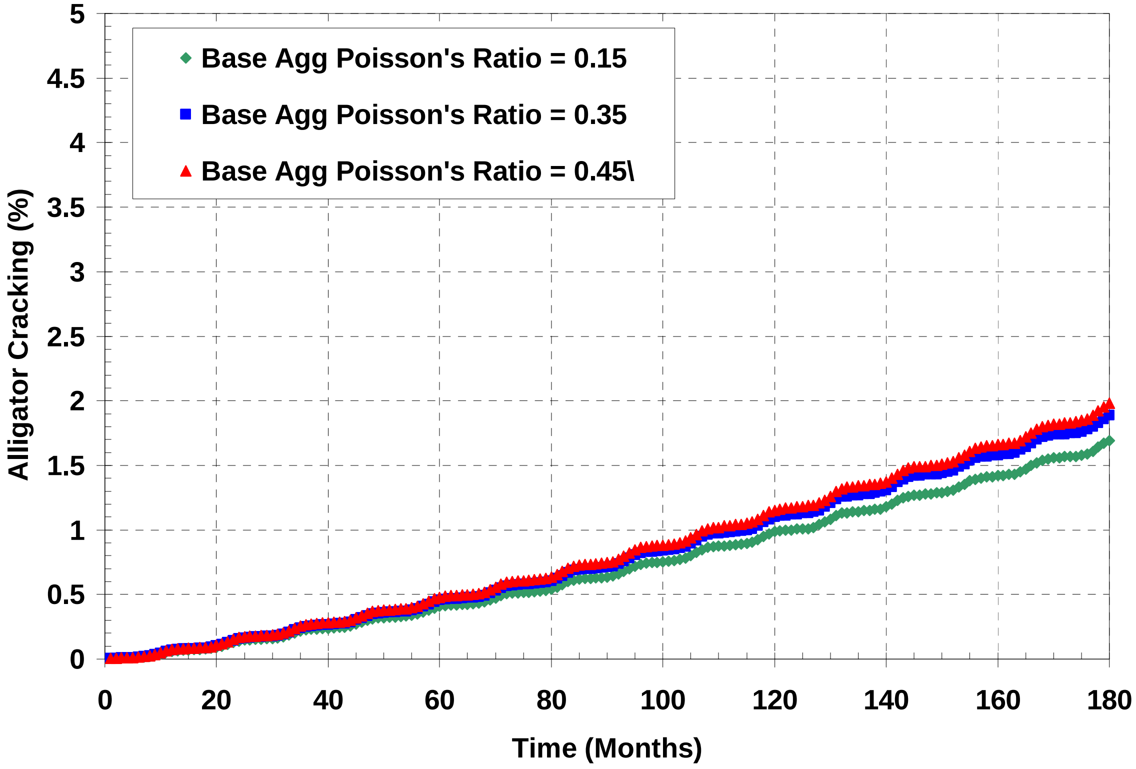


Figure 21 – Alligator Cracking for PG76-22 Asphalt Binder

Poisson’s Ratio – FWD Backcalculation Sensitivity

A sensitivity analysis was conducted to show the effect of Poisson’s Ratio on the backcalculation procedure when conducting Falling Weight Deflectometer deflection basin analysis. For the study, a SHRP test section, called Section F located in Kentucky, was utilized. The site has been fully investigated using both borings and Falling Weight Deflectometer (FWD) testing and is well documented in the NHI Course on Falling Weight Deflectometer (FWD) testing. The pavement cross-section was as follows:

AC Layer Thickness = 7.65 inches
Crushed Limestone Base layer = 14.47 inches
Silty Sand Subgrade = 186.66 inches
Shale layer underlying subgrade

The sensitivity analysis used the NHI course-provided deflection basin data from the FWD testing, along with the elastic layer program EVERCALC to determine the back-calculated layer stiffness’. 120 simulations were conducted using EVERCALC with all parameters held constant, except for the layer’s Poisson’s ratio values. Tables 2 to 7 show the determined layer stiffness’ (all values are shown in ksi).

Table 2 – Back-calculation of AC Stiffness (AC Poisson’s ratio = 0.15)

		μ of Crushed Limestone Base				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
μ of Silty Sand Subgrade	**0.15**	993	992.8	992.5	991.9	990.3
	0.25	966	965.1	964.1	962.3	959.3
	0.35	927.6	926.3	924.4	921.9	917.8
	0.45	867.5	865.9	864	861.4	857.8

Table 3 – Back-calculation of AC Stiffness (AC Poisson’s ratio = 0.45)

		μ of Crushed Limestone Base				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
μ of Silty Sand Subgrade	**0.15**	810.6	810.6	810.5	809.8	808.7
	0.25	788.7	788.1	787.2	785.9	783.5
	0.35	757.5	756.4	755	752.9	749.7
	0.45	708.5	707.2	705.7	703.9	700.9

Table 4 – Back-calculation of Base Layer Stiffness (AC Poisson's ratio = 0.15)

		μ of Crushed Limestone Base				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
μ of Silty Sand Subgrade	**0.15**	81.8	88.7	95.4	101.6	107.1
	0.25	88	95.5	102.7	109.6	115.7
	0.35	97.8	106.1	114.2	121.8	128.6
	0.45	116.5	126.1	135.1	143.5	150.8

Table 5 – Back-calculation of Base Layer Stiffness (AC Poisson's ratio = 0.45)

		μ of Crushed Limestone Base				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
μ of Silty Sand Subgrade	**0.15**	78	84.6	91	97.1	102.5
	0.25	83.4	90.6	97.5	104.1	110.1
	0.35	92	99.9	107.5	114.8	121.5
	0.45	108	116.9	125.5	133.5	140.7

Table 6 – Back-calculation of Subgrade Layer Stiffness (AC Poisson's ratio = 0.15)

		μ of Crushed Limestone Base				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
μ of Silty Sand Subgrade	**0.15**	31.8	31.7	31.4	31.2	30.8
	0.25	32.2	32.1	31.9	31.7	31.4
	0.35	31.4	31.4	31.2	31.1	30.9
	0.45	28.7	28.6	28.6	28.5	28.4

Table 7 – Back-calculation of Subgrade Layer Stiffness (AC Poisson's ratio = 0.45)

		μ of Crushed Limestone Base				
		0.1	**0.2**	**0.3**	**0.4**	**0.5**
μ of Silty Sand Subgrade	**0.15**	31.5	31.4	31.2	30.9	30.5
	0.25	32	31.8	31.7	31.4	31.1
	0.35	31.3	31.2	31	30.9	30.7
	0.45	28.6	28.6	28.5	28.4	28.3

What is interesting in the analysis is that as the Poisson's Ratio of both the base and subgrade increases, the stiffness of the asphalt layer decreases. This is somewhat expected since an increase in Poisson's Ratio is an indication of greater volume change. A larger volume change (i.e. horizontal movement in the base and subgrade layers) would indicate that the asphalt layer has to vertically deflect more. Greater vertical strain under an identical load would result in a lower modulus value (as modulus is simply stress divided by strain). However, what is somewhat unexpected in the analysis is that as the Poisson's Ratio for the base and subgrade increases, the stiffness of the base layer also increases, with little change occurring in the subgrade. This is contradictive to what occurs in asphalt where as the Poisson's Ratio increases, the dynamic modulus of the asphalt material decreases.

The "Typical" Poisson's Ratio values used for FWD back-calculation are shown below, with their corresponding back-calculated modulus values when they are all used together in the same pavement system;

AC Layer = 0.35, Back-calculated Modulus = 773.8 ksi
Aggregate Base Layer = 0.4, Back-calculated Modulus = 137.7 ksi
Subgrade Layer = 0.45, Back-calculated Modulus = 28.5 ksi

Based on the sensitivity analysis, the following conclusions can be drawn:

1) In the AC layer, errors as high as 40 % in the modulus can be made when comparing the possible Poisson's Ratio scenarios;
2) In the base layer, errors as high as 45% in the modulus can be made when comparing the possible Poisson's ratio scenarios;
3) The subgrade layer seems to be minimally affected by the changes in Poisson's Ratio when using FWD back-calculation techniques;
4) Rather large differences (as high as 35%) in the modulus back-calculation can occur when using "Typical" Poisson Ratio values and comparing them to the range of values included in the study.

From the FWD sensitivity analysis, it appears that both the Poisson's Ratio of the asphalt layer and the unbound aggregates layer (base layer) have an influence on the backcalculated modulus values.

LABORATORY EVALUATION

Dynamic Modulus – Asphalt Materials

The dynamic (complex) modulus test has been the basis for developing the predictive models to characterize the hot mix asphalt (HMA) mixtures over the last 30 years. The dynamic modulus, E*, is defined as the ratio of the amplitude of the sinusoidal vertical stress applied on the material ($\sigma = \sigma_1 \sin(\omega t)$) and the resulting amplitude of the vertical sinusoidal strain response ($\varepsilon = \varepsilon_1 \sin(\omega t - \delta)$). Thus, the dynamic modulus, as determined in the axial loading mode, is defined as:

$$\left|E^*\right| = \frac{\sigma_1}{\varepsilon_1} \qquad (4)$$

where σ_1 is the axial stress amplitude and ε_1 is the axial strain amplitude. The lag time between the stress and strain cycles is defined by the phase angle (ϕ), defined as:

$$\phi = \omega \Delta t \qquad (5)$$

where ω is the angular velocity (rad/sec) and Δt is the time lag between the stress and strain cycles (sec). For a purely elastic material (which represents HMA at very cold temperatures) the phase angle approaches 0^o. For a purely viscous material (which represents HMA at very warm temperatures) the phase angle approaches 90^o.

The dynamic modulus test was originally adopted in 1979 by the American Society of Testing and Materials (ASTM) as a standard method: *Test Method for Dynamic Modulus of Asphalt Concrete Mixtures* (ASTM D 3479-79). The test was conducted by applying a haversine load between 0 and 35 psi using temperatures of 5, 25, and 40^oC (41, 77, and 104^oF) and loading frequencies of 1, 4, and 16 Hz. Recent research (Witczak et al., 1996; Pellinen and Witczak, 1998) evaluated ASTM D 3479-79 and incorporated additional temperatures and loading frequencies to the procedure to enable the construction of a full master curve of a mix. The new test procedure, dated June 2002, now incorporates the following five test temperatures (10, 40, 70, 100, and 130^oF) and six loading frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz).

The data collected during the dynamic modulus test is extremely extensive. For one loading frequency at a single test temperature, almost a thousand lines of test data are collected. And during the data collection, it is inevitable that some “noise” may appear simply due to instrumentation compliance. Therefore, for the analysis of the test data to determine the dynamic modulus, phase angle, and Poisson’s Ratio, a linear regression method was used.

The linear regression was performed using the Excel Solver function and a least squared error linear regression approach to determine the coefficients. The applied stress, vertical deformation and radial deformation were fitted with the following equation:

$$F(t) = A_0 + A_1 \cdot t + B \cdot \cos(\omega \cdot t) + C \cdot \sin(\omega \cdot t) \qquad (6)$$

All coefficients are solved simultaneously using the Excel Solver function. Once solved, the Amplitude of the wave forms, which are used to determine the total applied stress and total resultant strain, as well as the Phase Angle, can be determined from Equations (7) and (8).

$$\mathrm{Amplitude} = \sqrt{\mathrm{B}^2 + \mathrm{C}^2} \qquad (7)$$

$$\mathrm{Phase\ Angle} = \tan^{-1}\left(\frac{\mathrm{C}}{\mathrm{B}}\right) \qquad (8)$$

This methodology was also successfully used by researchers at the University of Florida (Birgisson et al., 2004) to evaluate over 20 different FDOT asphalt mixtures for dynamic modulus. The use of Equation (6) to represent the test data also allows for the easy determination of the Poisson's Ratio as only the Amplitude value needs to be determined for the radial and vertical deformations and then their ratio determined. An example of the linear regression fit to the applied stress and vertical deformation data from one of the test specimens at a single test temperature and loading frequency is shown in Figure 22 for the stress and micro-strain determination, as well as Figure 23 for the vertical and horizontal micro-strain determinations. As both figures show, there is a very good fit between the measured data points and the linear regression equation used (Equation 6).

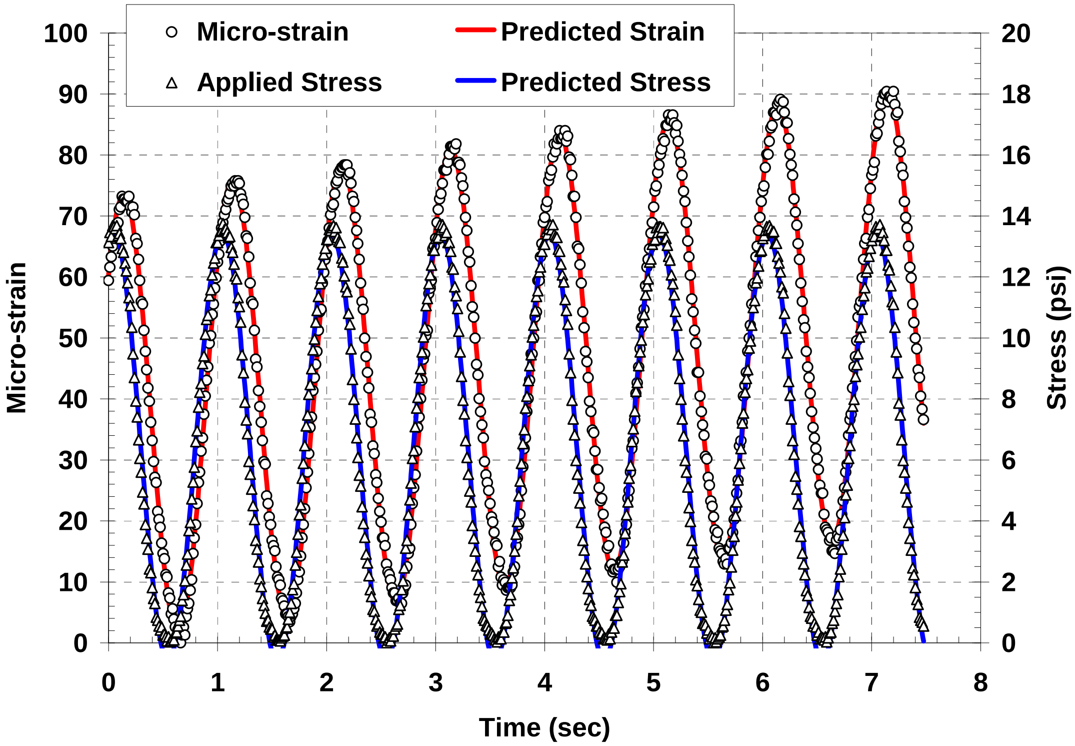


Figure 22 – Linear Regression Fit of Applied Stress and Resultant Micro-strain at 100F and 1 Hz (12H64 Sample)

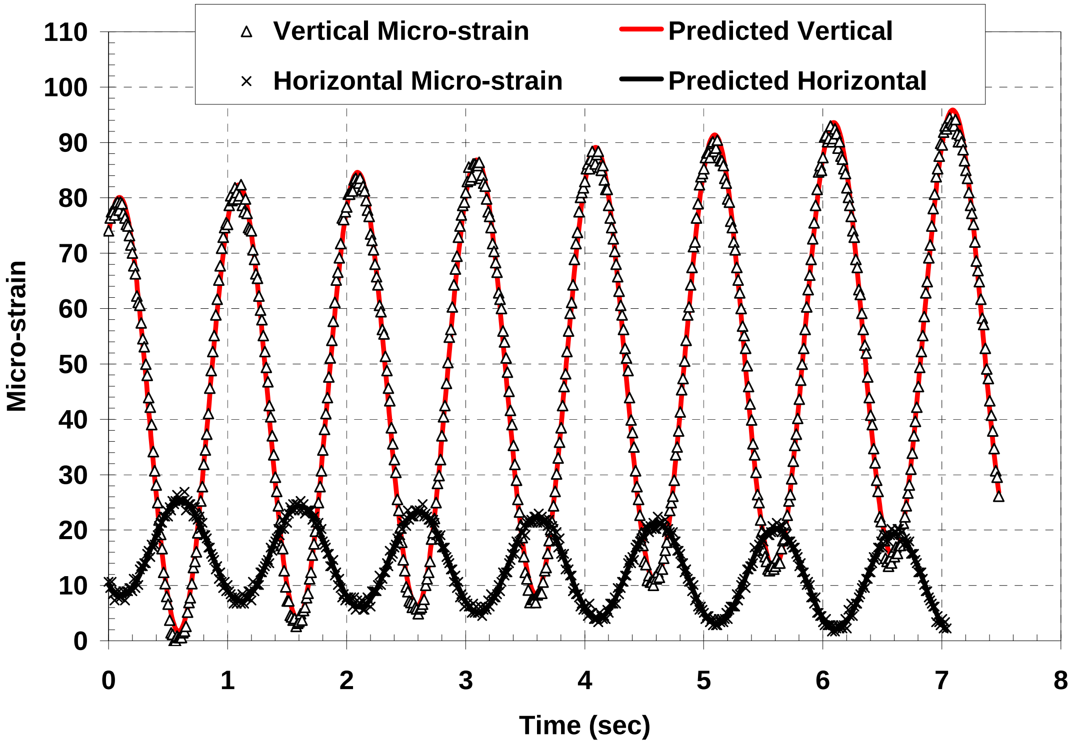


Figure 23 – Linear Regression Fit of Resultant Vertical and Radial Micro-Strain at 100F and 1 Hz (AR-HMA Sample)

Laboratory Test Results – Asphalt Materials

Dynamic modulus testing was conducted on nine (9) different asphalt mixtures; three (3) laboratory-produced, two (2) plant produced mixes and three (3) field mixes that were tested from extracted field cores. Since the MEPDG changes Poisson's ratio with the changing modulus, the main premise of the materials selected was to ensure a wide range of dynamic modulus values were obtainable for analysis.

Laboratory Design – NJDOT 12.5mm "H" Mixes

The first laboratory design to be evaluated in the laboratory was a 12.5mm Nominal Maximum Aggregate Size (NMAS) Superpave mix designed using a design gyration level of 100 gyrations. Two different asphalt binders were used in the laboratory design and evaluation; a PG64-22, PG76-22, and asphalt rubber (AR) that was developed by blending the PG64-22 with a #30 mesh crumb rubber at a concentration of 20% crumb rubber by weight of asphalt binder. The final mixture design properties are shown as Table 8.

Table 8 – Final Mixture Volumetric Design for NJDOT 12.5H Mixes

Volumetric Property	AR	PG76-22	PG64-22
Asphalt Content (%)	6.1	5.1	5.1
VMA (> 14%)	17.9	15.7	15.7
VFA (65 to 75%)	77.4	74.3	74.3
Dust/Binder (0.6 to 1.2%)	0.9	1.1	1.1
TSR (> 80%)	93.4	96	87.3

Each mixture was evaluated using the dynamic modulus protocol in accordance with AASHTO TP62. Examples of the some of the vertical and radial strains are shown in Figures 24 through 26. A final comparison of the Poisson's Ratio values, plotted against modulus, is shown as Figure 27. The results are compared with the MEPDG Poisson's Ratio prediction equation, shown earlier as Equation (1). The test results show that the PG64-22 compares favorably to the MEPDG prediction equation. However, the test results for the PG76-22 and the Asphalt Rubber (AR) samples did not compare as well. In fact, the AR sample showed a poor correlation that obtained a trend not consistent with the prediction equation or the other two test specimens.

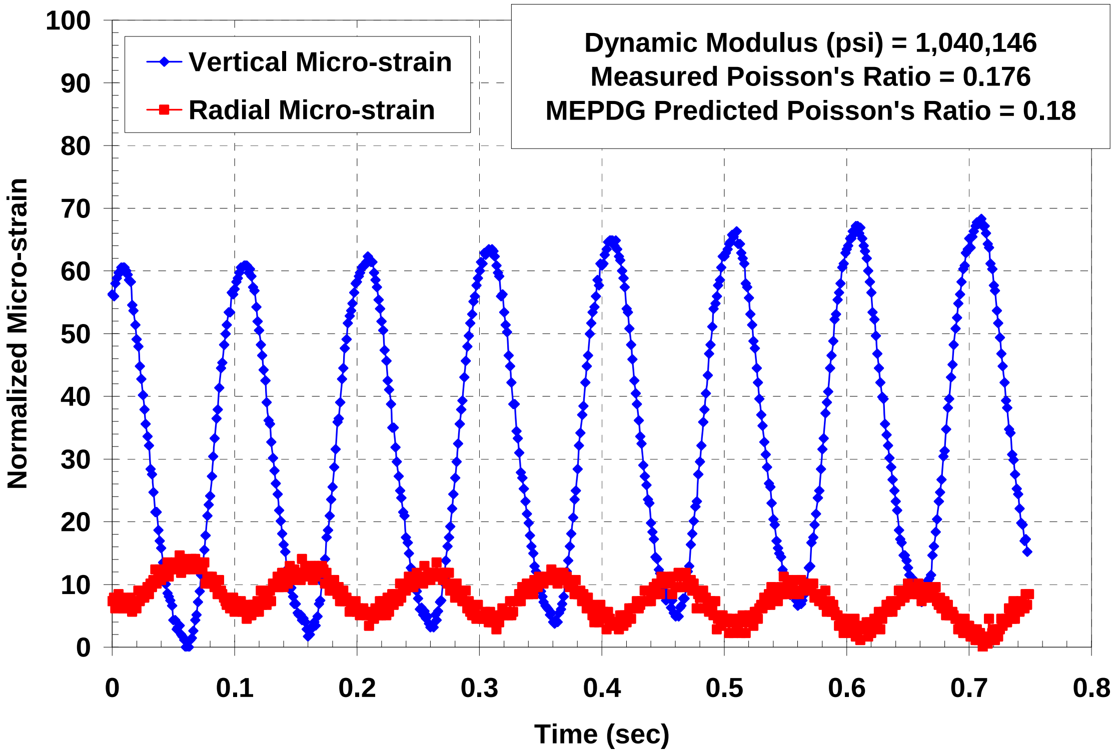


Figure 24 – Vertical and Radial Micro-strains of 12H64 Sample at 70°F and 10 Hz

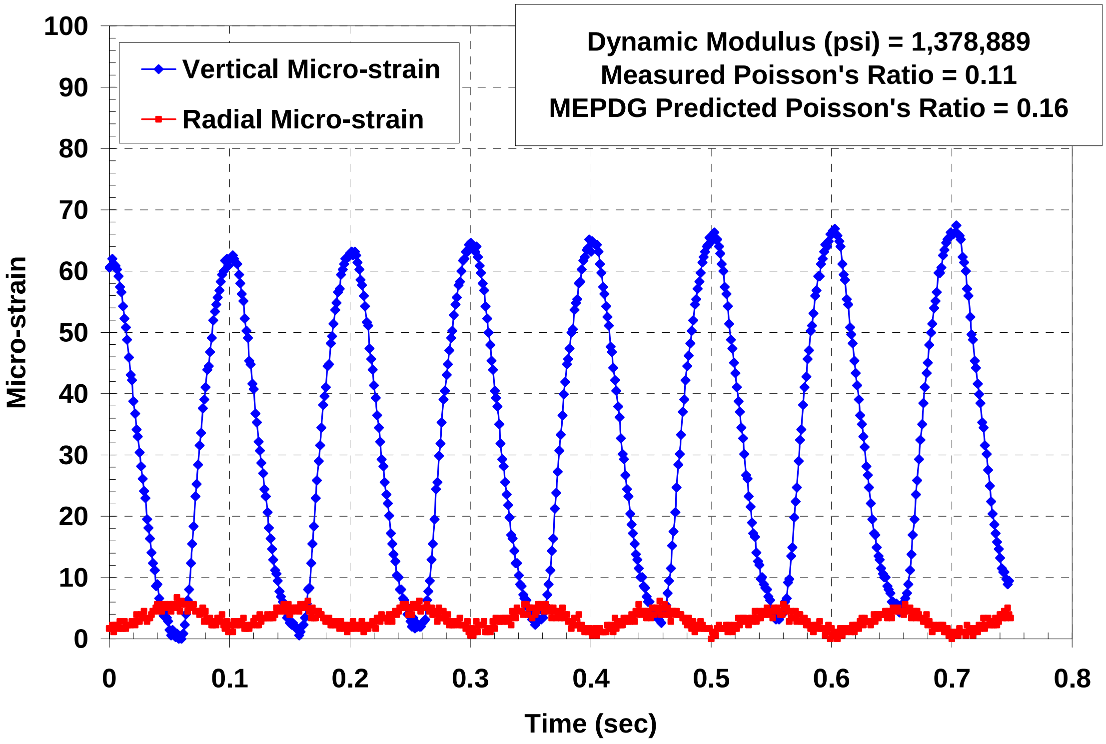


Figure 25 – Vertical and Radial Micro-strains of 12H76 Sample at 70°F and 10 Hz

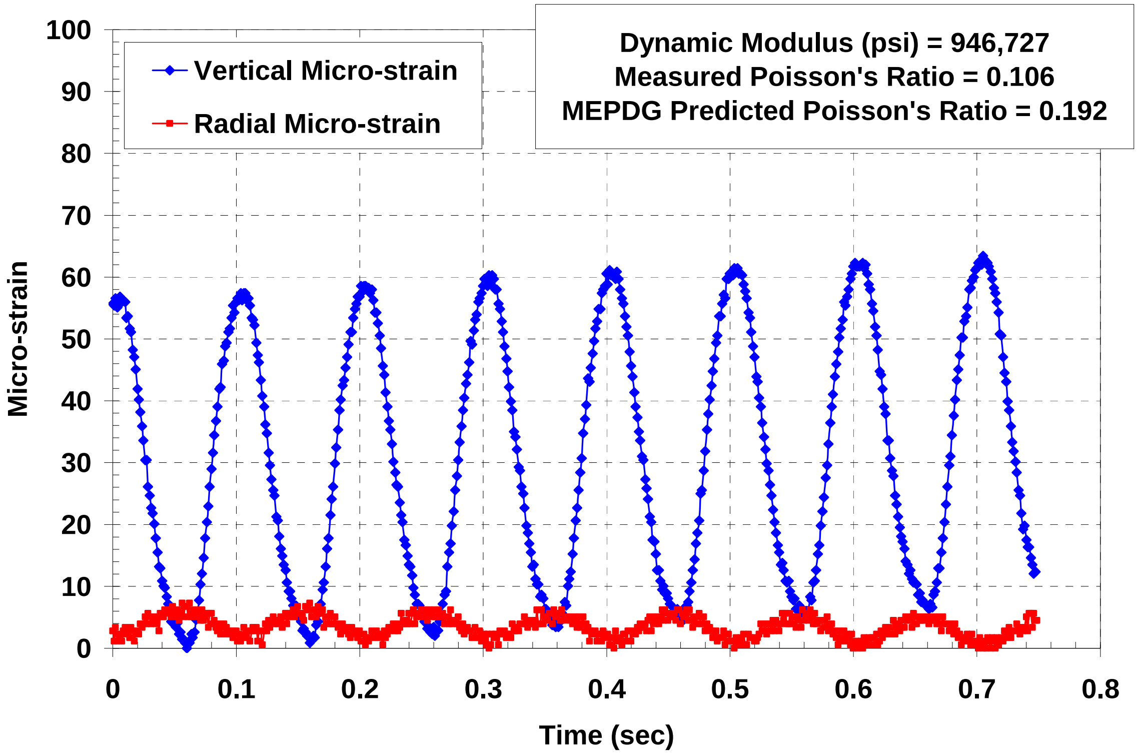


Figure 26 – Vertical and Radial Micro-strains of 12H Asphalt Rubber (AR) at 70°F and 10 Hz

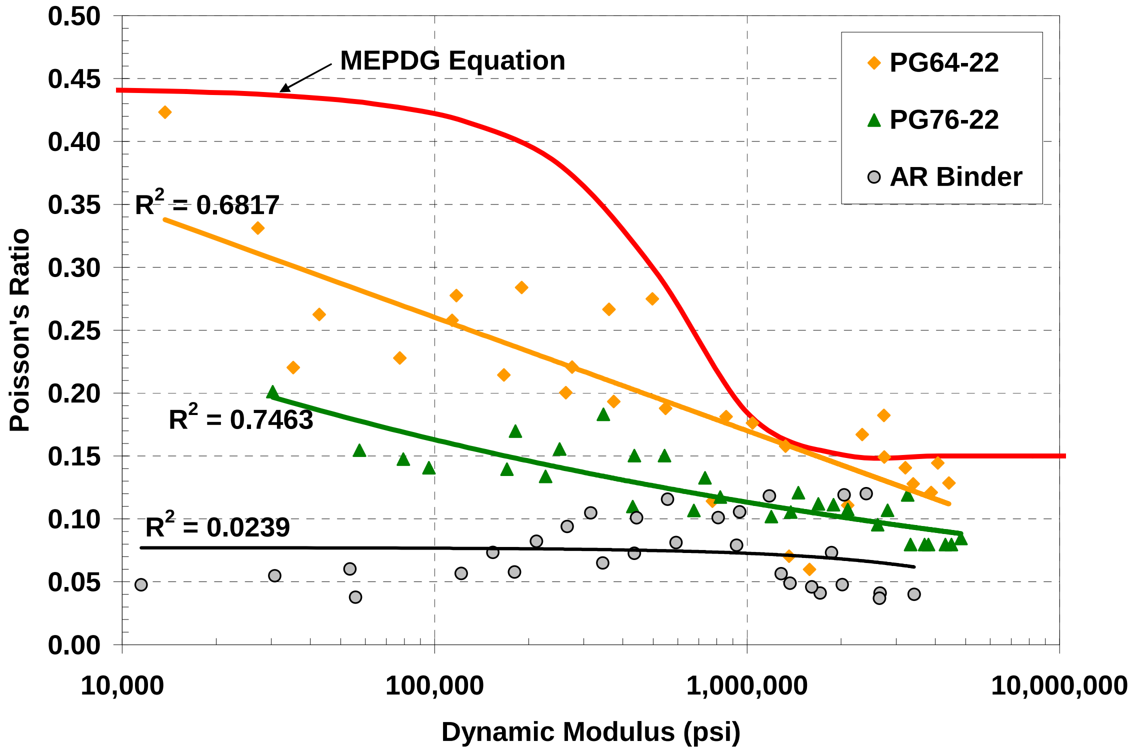


Figure 27 – Poisson's Ratio vs Measured Dynamic Modulus

Plant Produced – Strata on PA Turnpike

Plant produced loose mix was sampled during the production and placement of a reflective crack relief interlayer (RCRI) mixture on the Pennsylvania Turnpike. A RCRI mixture does not resemble a typical dense-graded mixture, as previously shown with the 12.5mm Superpave mixture. The RCRI mixture is designed to an air void level between 1 to 3% air voids with a minimal asphalt content of 7%. The aggregate structure is developed with 100% passing the 3/8 inch sieve and the asphalt binder is highly polymerized to maximize resiliency and low temperature cracking resistance. An example of the vertical and radial strains is shown in Figure 28.

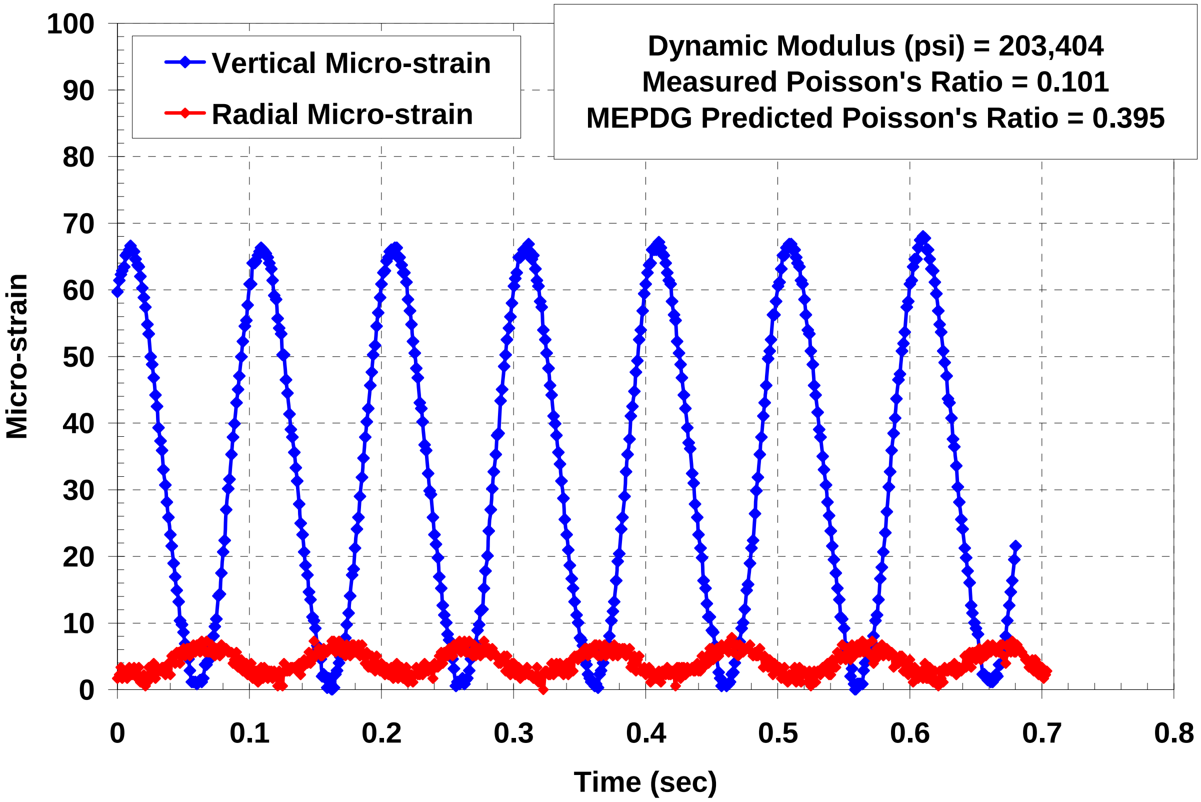


Figure 28 – Vertical and Radial Micro-strains of a Reflective Crack Relief Interlayer (RCRI) at 70^{o}F and 10 Hz

The Poisson's Ratio was also plotted against the Dynamic Modulus for the entire AASHTO TP62 data set and shown in Figure 29. Again, the measured Poisson's Ratio does not compare favorably to the MEPDG prediction equation (Equation 1). Similar to the PG76-22 sample tested earlier, a good correlation existed between the measured dynamic modulus and the measured Poisson's Ratio, but the data still did not compare well with the MEDPG Prediction Equation (Equation 1).

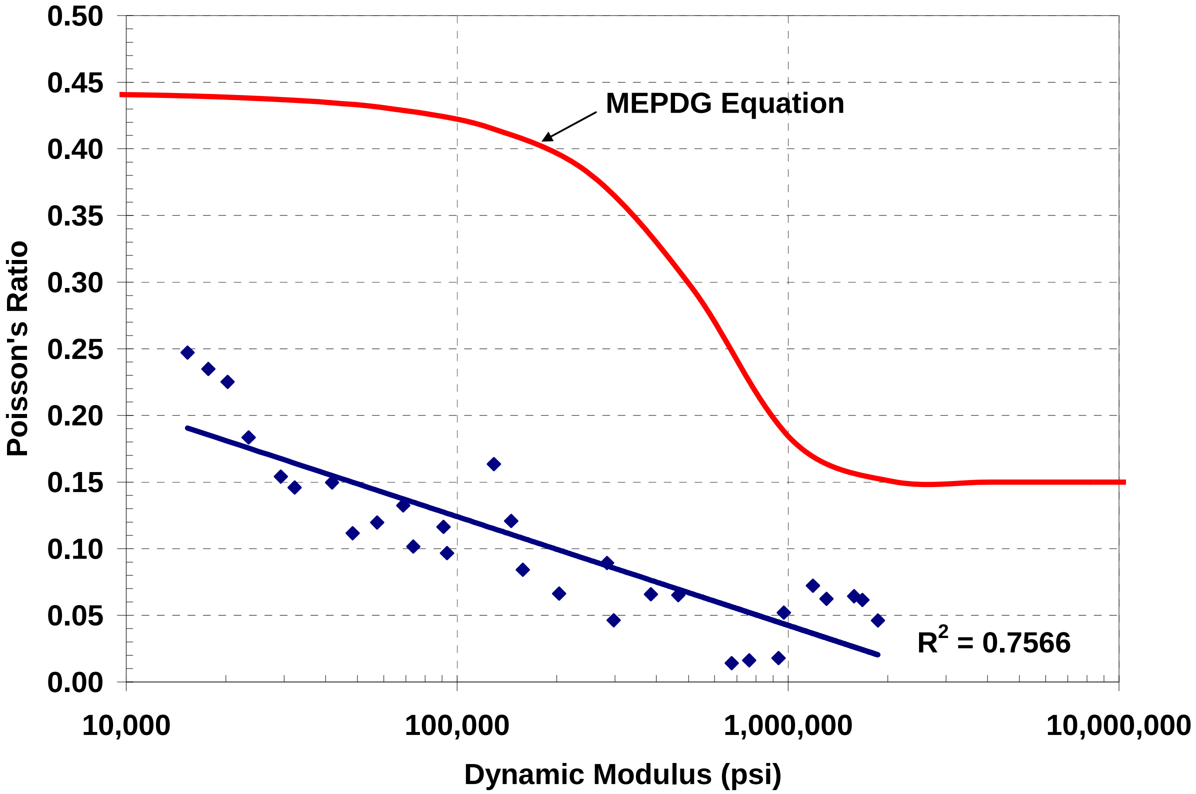


Figure 29 – Measured Poisson's Ratio for a Reflective Crack Relief Interlayer (RCRI) Mixture Compared to the MEPDG Prediction Equation

Field Cores from I-287 Seasonal Variation Study

Cores were extracted from the I-287 Rest Area near New Brunswick during the NJDOT research "Seasonal Variation" study. The main idea behind testing the cores for dynamic modulus was to compare the laboratory modulus to the Non-destructive testing that was occurring at the site. During the dynamic modulus testing, the radial LVDT was used to measure the Poisson's Ratio of the specimen. One thing to note is that the I-287 specimen is actually a composite of different HMA materials placed in lifts, unlike the laboratory prepared samples which are compacted on one lift in the gyratory compactor of the same HMA mixture. It is believed that the primary PG graded asphalt for the Rest Area hot mix asphalt was a PG64-22.

An example of the vertical and radial strains for the I-287 cores is shown as Figure 30. The comparison between the measured Poisson's Ratio of the test specimens and the prediction equation used in the MEPDG are shown in Figure 31. The measured results compare favorably to the predicted results. This is similar to the PG64-22 laboratory produced samples discussed earlier.

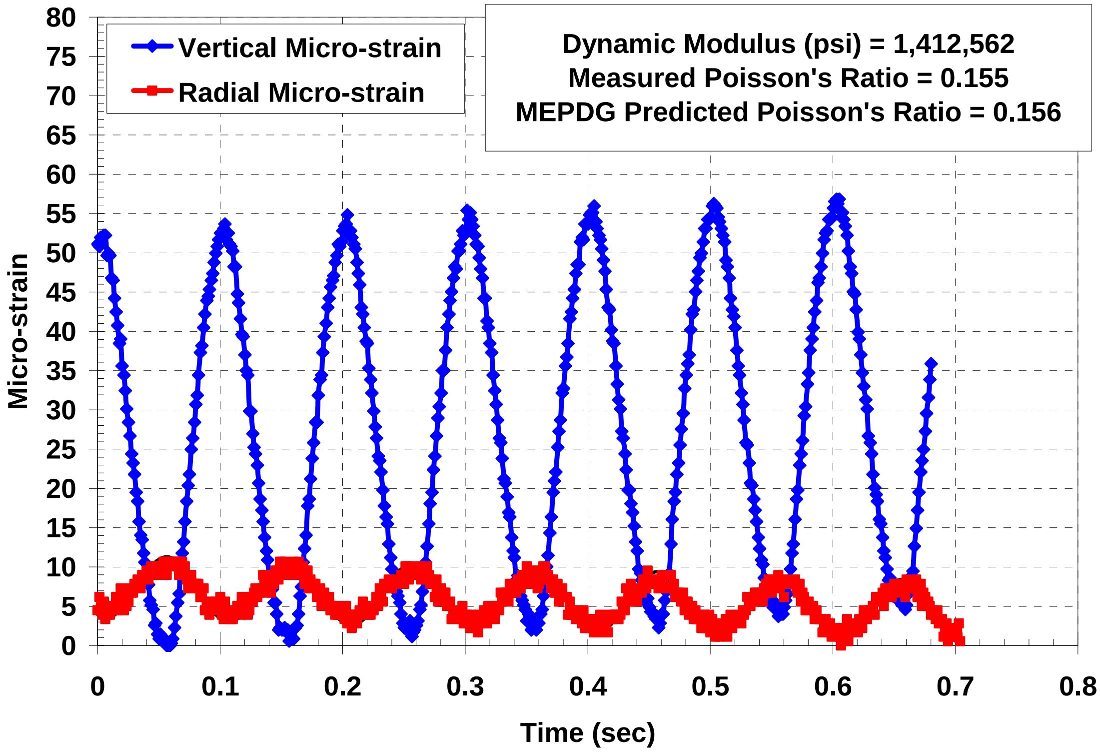


Figure 30 – Vertical and Radial Micro-strains of Cores from I-287 Rest Area at 70^{o}F and 10 Hz

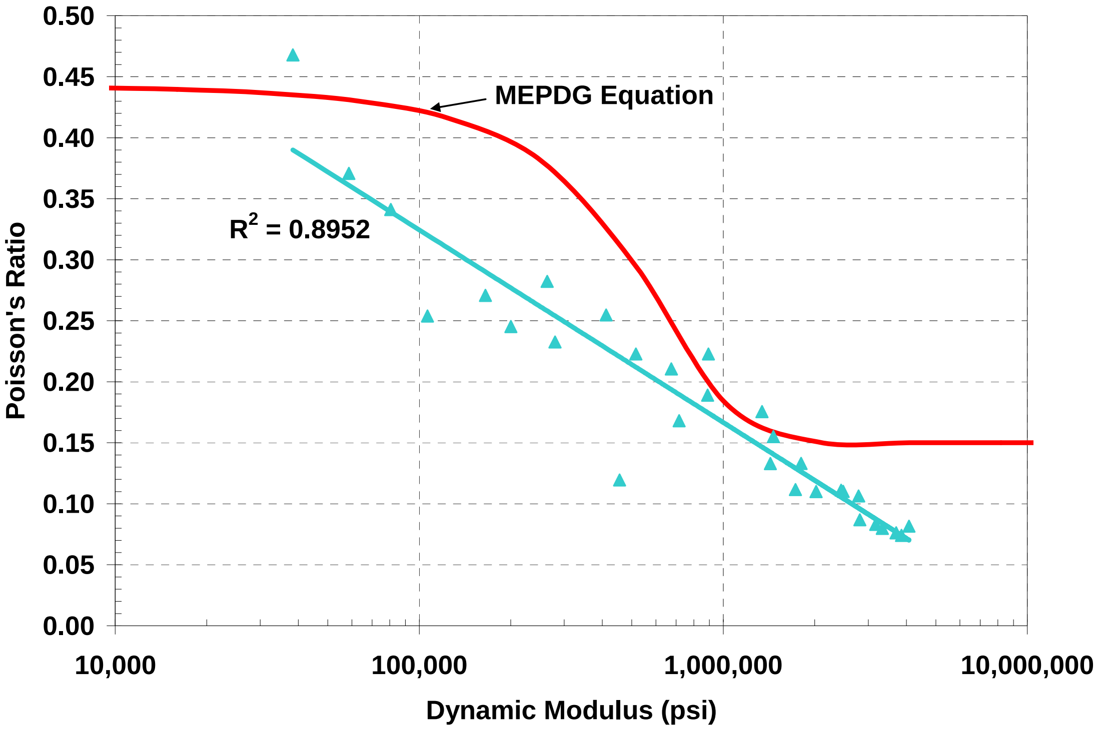


Figure 31 – Measured Poisson's Ratio for I-287 Rest Area Cores

Field Cores from I-295 Seasonal Variation Study

Similar to the I-287 Seasonal Variation cores, test specimens were extracted from the I-295 Weigh Station and tested under AASHTO TP62 while measuring the radial strains to determine the Poisson's Ratio of the material. However, unlike the Rest Area on I-287 that contained a PG64-22 asphalt binder, information collected from Stantec showed that the asphalt binder associated with the I295 Weigh Station was a PG76-22 asphalt binder.

Examples of the vertical and radial strains recorded during testing are shown in Figure 32. The comparison between the measured Poisson's Ratio and the MEPDG Poisson's Ratio prediction equation are shown as Figure 33. The results again indicate that polymer-modified asphalt binders are achieving Poisson's Ratio values that are far lower than those predicted using the equation in the MEPDG. The trendline in the data (Figure 22) is not as strong as the previously tested specimens, although the general range of measured Poisson's Ratio is consistent.

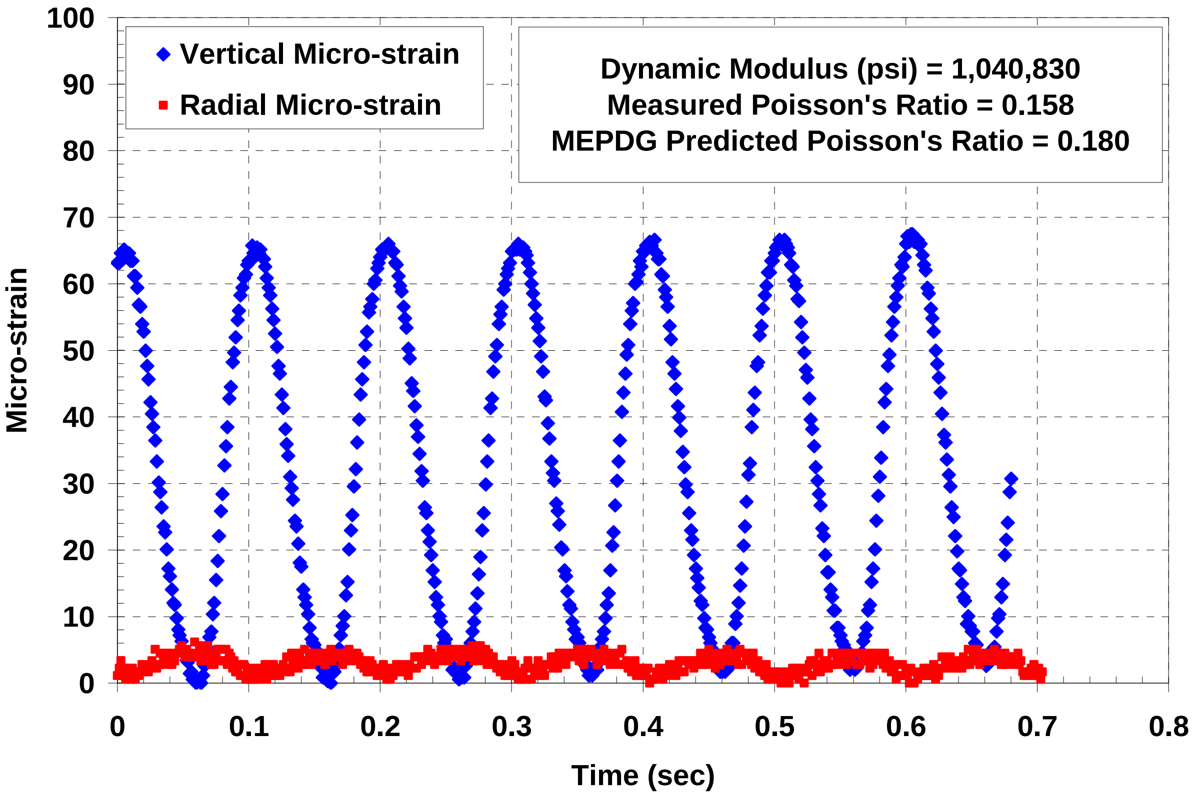


Figure 32 – Vertical and Radial Micro-strains of Cores from I-295 Weigh Station

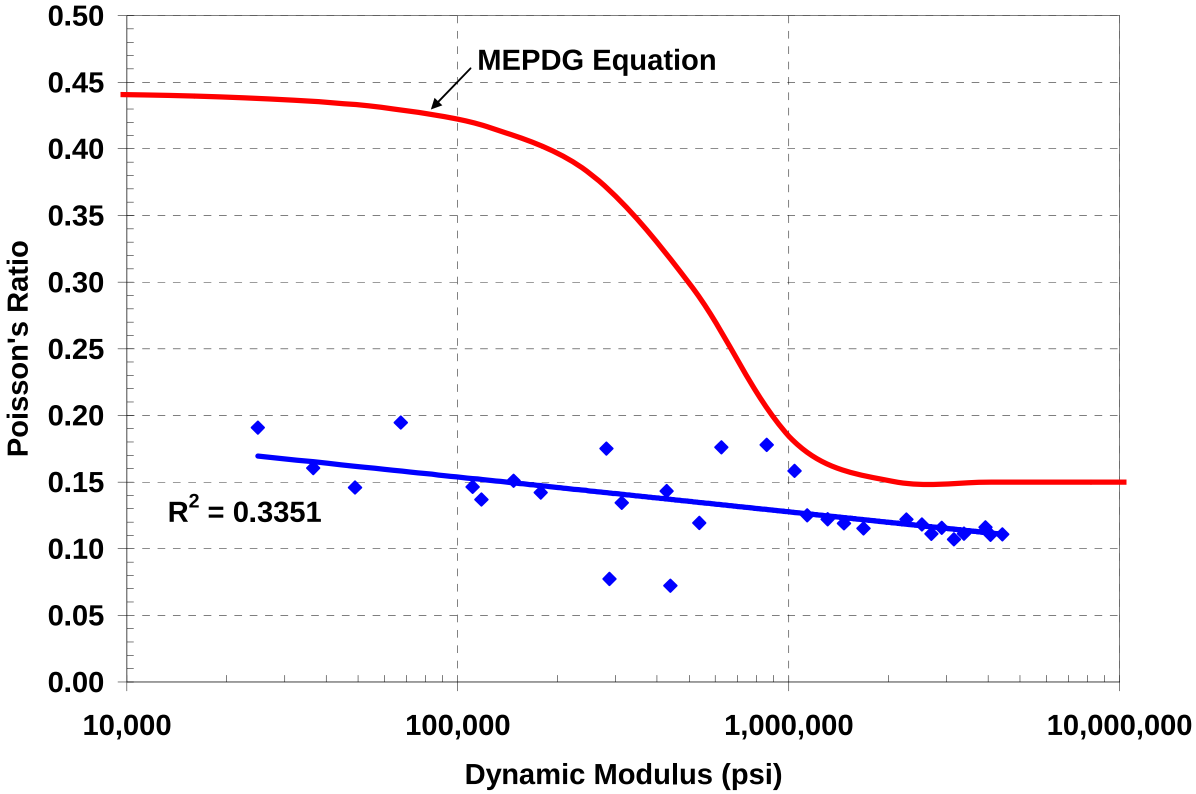


Figure 33 - Measured Poisson's Ratio of I-295 Weigh Station Cores Compared to the MEPDG Poisson's Ratio Prediction Equation

Field Cores from Newark Airport

As part of a field forensic testing program for the Port Authority of NY/NJ, cores were extracted from Newark Airport and various mechanistic testing were conducted at Rutgers University. As part of the testing program, dynamic modulus testing, instrumented with the radial LVDT to measure the Poisson's Ratio, were conducted. Two different sets of test specimens were conducted; FAA #2 mix using a PG76-22 asphalt binder (shown in the report as PANYNJ 3-1) and FAA #3 mix using a PG82-22 asphalt binder (shown in the report as PANYNJ 6-2).

Examples of the vertical and radial strains recorded during testing are shown in Figures 34 and 35. The comparisons to the MEPDG Poisson's Ratio prediction equation are shown as Figure 36. The test results are similar to the polymer-modified samples shown earlier (PG76-22, AR, and Strata) where the measured Poisson's Ratio is approximately 30 to 50% of the MEPDG predicted Poisson's Ratio.

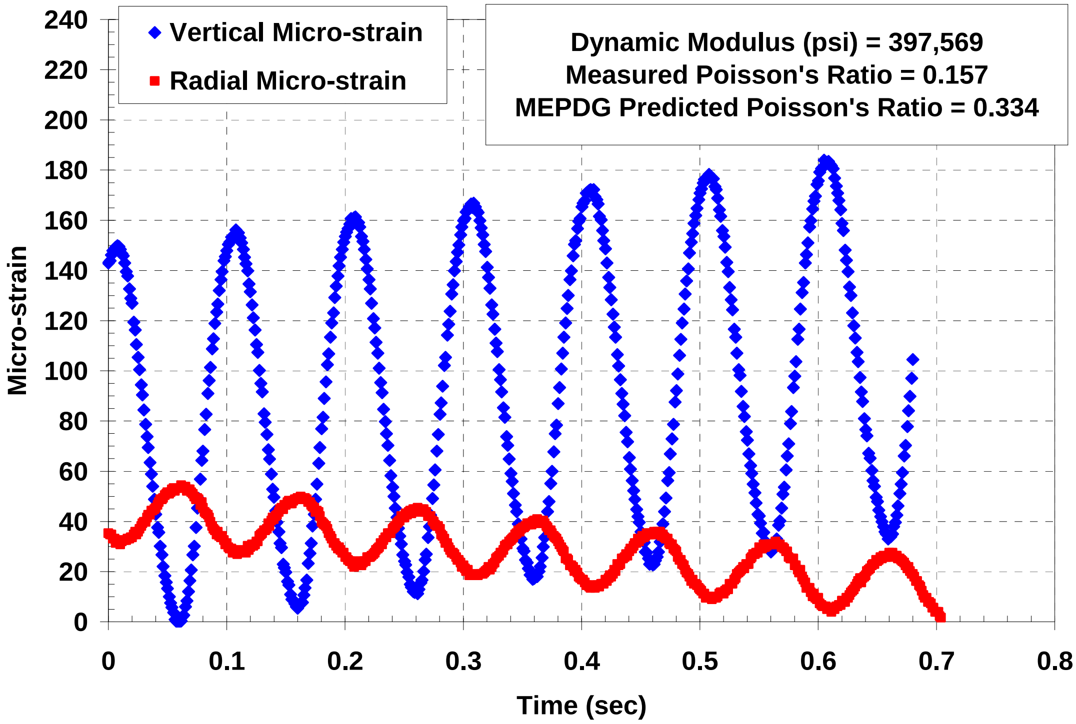


Figure 34 - Vertical and Radial Micro-strains of Cores from Newark Airport (Cores 3-1)

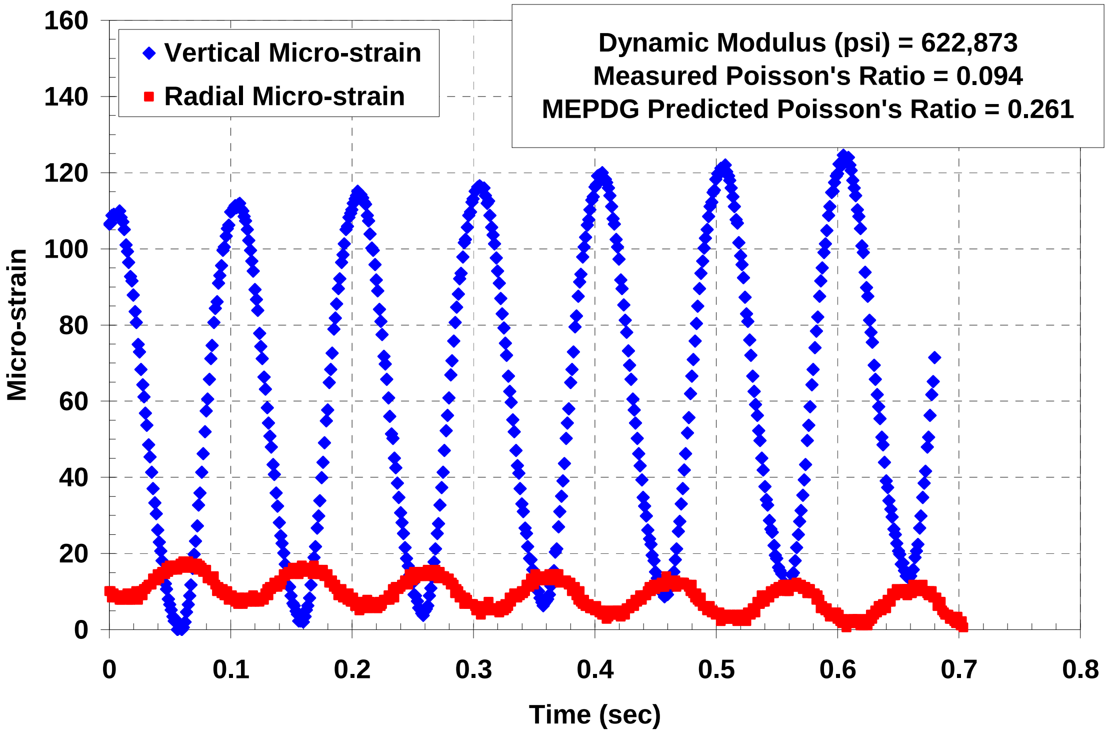


Figure 35 – Vertical and Radial Micro-strains of Cores from Newark Airport (Cores 6-2)

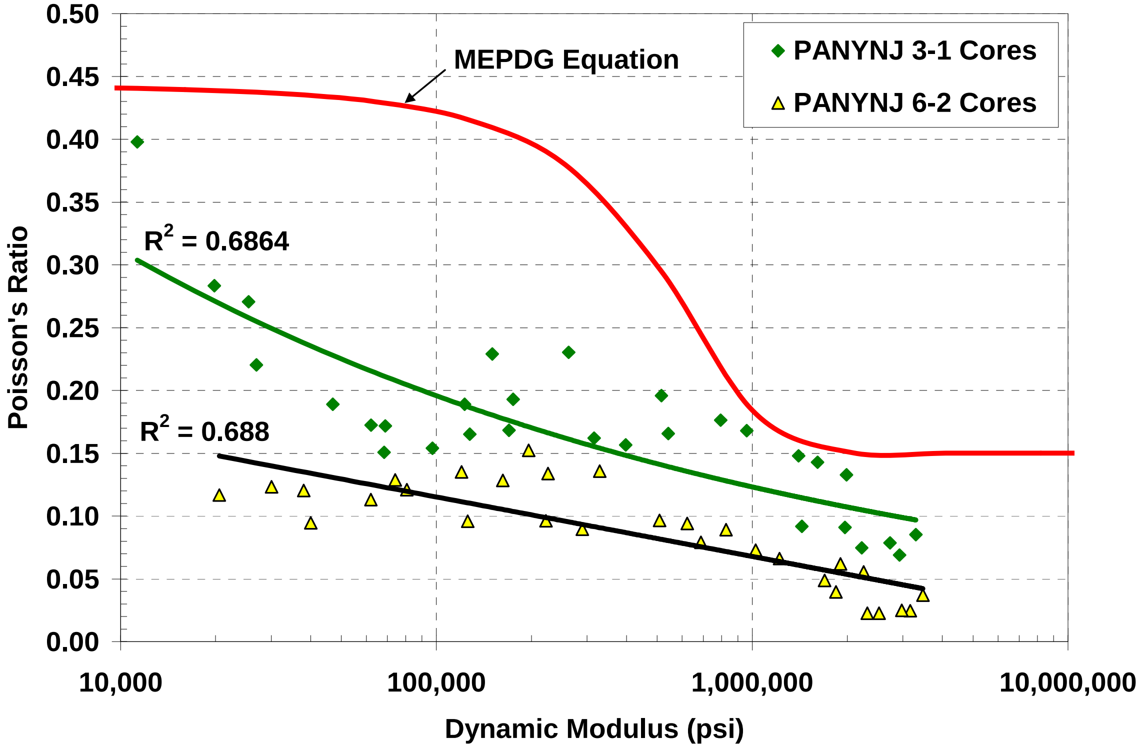


Figure 36 – Measured Poisson's Ratio of Newark Airport Cores Compared to the MEPDG Poisson's Ratio Prediction Equation

Plant Produced 12H76 on I-95/Rt 31

Loose mix was sampled from Trap Rock Industries during a rehabilitation HMA overlay on I-95/Rt 31 area. The loose mix produced was a 12H76 with 15% RAP. The loose mix was reheated and once it reached compaction temperature, it was compacted into dynamic modulus test specimens and evaluated. An example of the vertical and radial strains for the I-95/Rt 31 material is shown in Figure 37. Measured Poisson's Ratio compared to the MEPDG Poisson's Ratio is shown in Figure 38. The results from Figure 25 once again show the poor comparison between the MEPDG Prediction Equation and the measured Poisson's Ratio for polymer-modified asphalt binders, in this case, a PG76-22. Figure 37 does show that a good relationship existed between the dynamic modulus and measured Poisson's Ratio of the I-95/Rt 31 material.

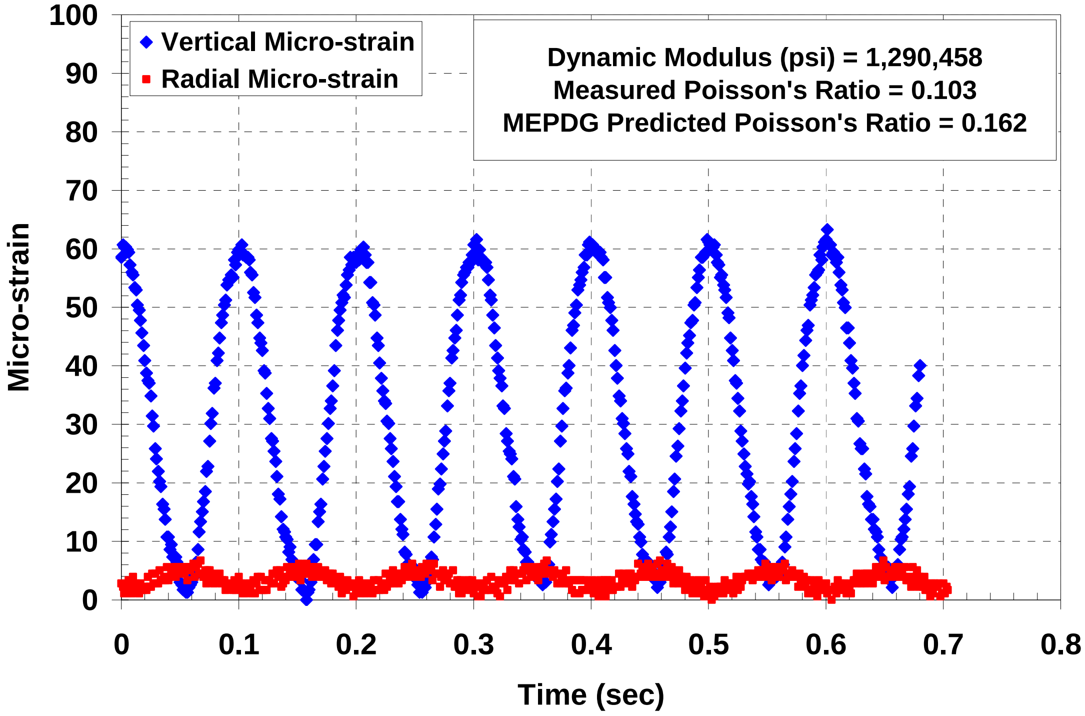


Figure 37 – Vertical and Radial Micro-strains of Plant Produced Mix from I-95/Rt 31 Maintenance

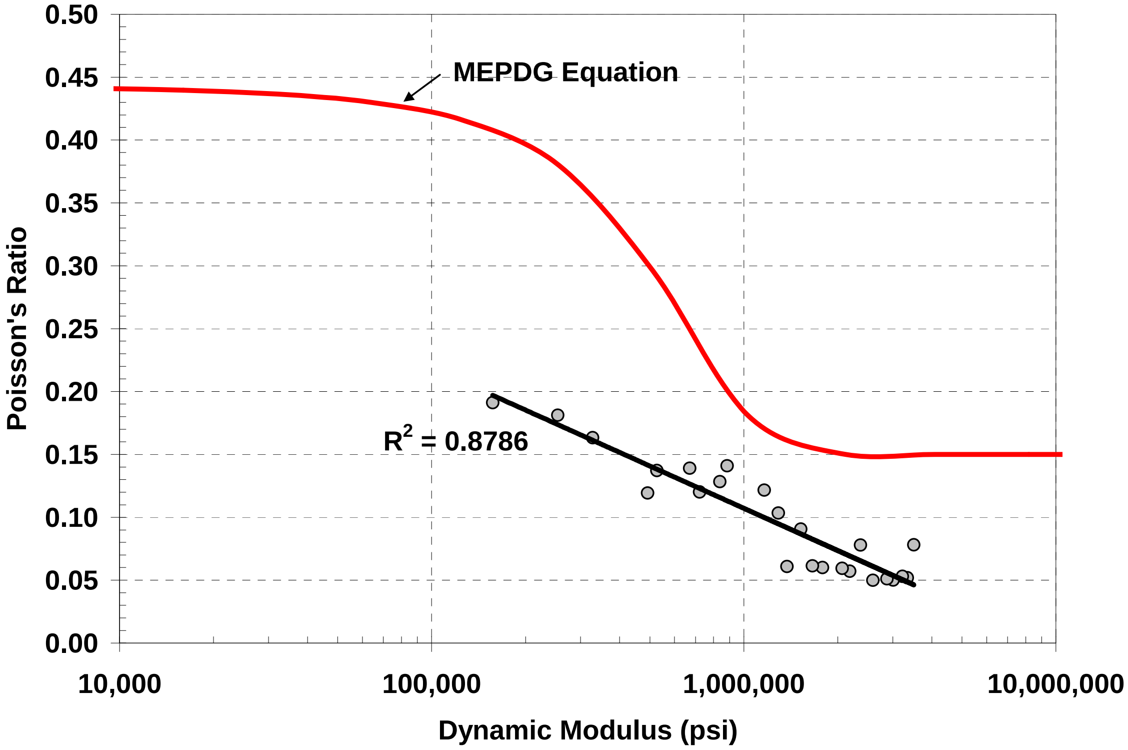


Figure 38 – Measured Poisson's Ratio of I-95/Rt 31 HMA Mix Compared to the MEPDG Poisson's Ratio Prediction Equation

Summary of Laboratory Measured Poisson's Ratio

A laboratory testing program that was conducted using the Dynamic Modulus testing protocol to measure and record the Poisson's Ratio. The following samples types were used in the study:

- 3 laboratory prepared mixtures that were developed using the Superpave mixture design. The mixtures were a 12.5mm Nominal Aggregate Size and each contained a different asphalt binder (PG64-22, PG76-22, and an asphalt rubber).
- 2 plant produced mixtures that were sampled at the plant during production. One mixture was a reflective crack relief interlayer mixture while the second mix was NJDOT 12H76.
- 4 different mixtures where the test specimens were field cores extracted from various locations. The I-287 Rest Area cores consisted of a 12.5mm Superpave mixture with a PG64-22, as indicated by Stantec Co. during the NJDOT Seasonal Variation study. The I-295 Weigh Station cores again consisted of a 12.5mm Superpave mixture with a PG76-22, as indicated by Stantec Co. during the NJDOT Seasonal Variation study. The FAA 3-1 mix was a PG76-22, 19mm Maximum Nominal Aggregate size mix that was being used on the apron area of Newark Airport. The FAA 6-2 was a PG82-22, 12.5mm Maximum Nominal Aggregate size mix that was being used on the runway area of Newark Airport.

Based on the test results developed during the laboratory study, it appears that the MEPDG Poisson's Ratio prediction equation is more suitable for softer asphalt binders, such as the PG64-22 used in this study. A compilation of all of the PG64-22 data points collected in this study compared to the MEPDG Poisson's Ratio equation is shown in Figure 39. The test results show that the slope of the Sigmoidal function MEPDG Poisson's Ratio curve may be too steep when compared with the PG64-22 test data. The trend of the Poisson's Ratio vs Dynamic Modulus does provide a good correlation, with an $R^2 = 0.75$

The PG76-22 test data was also evaluated under a similar methodology, as shown in Figure 40. With the PG76-22 data, the results are not as comparable and the PG76-22 data appears to be one half to one third of that of the MEPDG Poisson's Ratio Prediction equation.

The test results indicate that there is a distinct trend of polymer-modified asphalt binders not comparing well to the MEPDG predictions (Figure 41). This is most likely due to the limited number of materials utilized during the development of the prediction equation (Equation 1). Although the general function of the prediction equation is valid, it is obviously not accurate for all hot mix asphalt materials, especially those that have polymer modification to the asphalt binder. Therefore, the next steps need to be to readjust the Poisson's Ratio prediction equation based on the measured test results from this study and then to determine how this would affect the pavement distress predictions when compared to the current (default) equation.

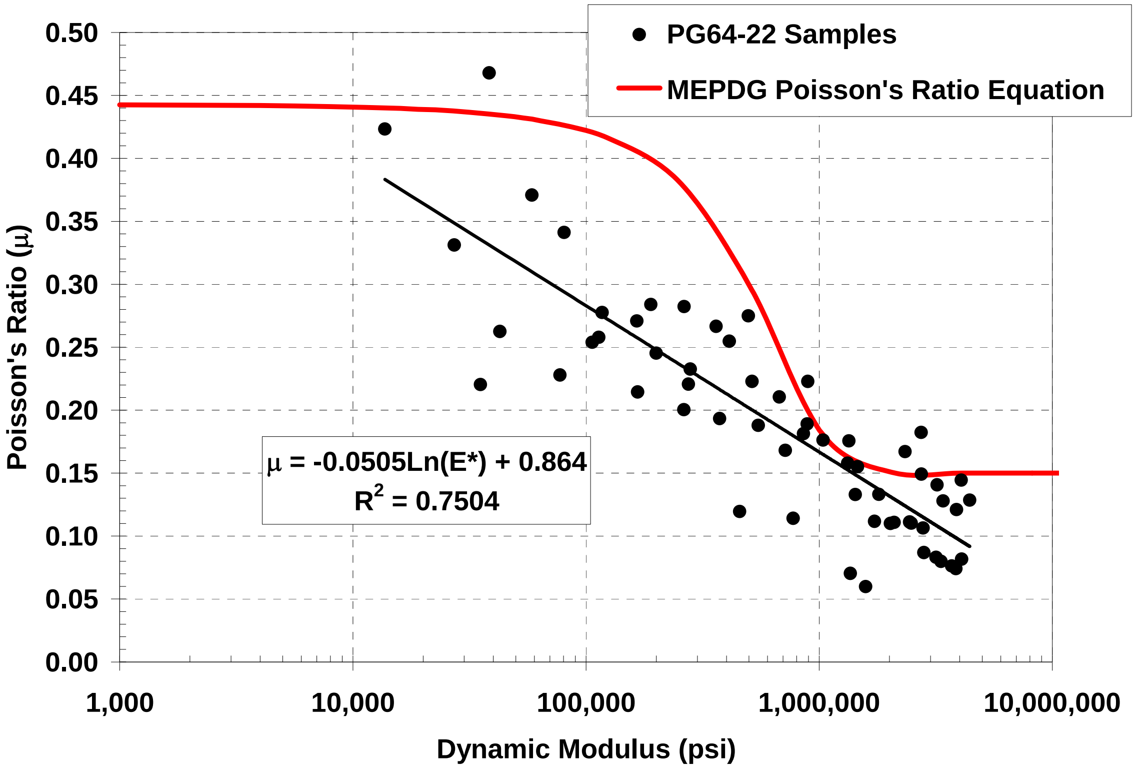


Figure 39 – Test Results of All of the PG64-22 Mixtures Tested Compared with the MEPDG Poisson’s Ratio Equation

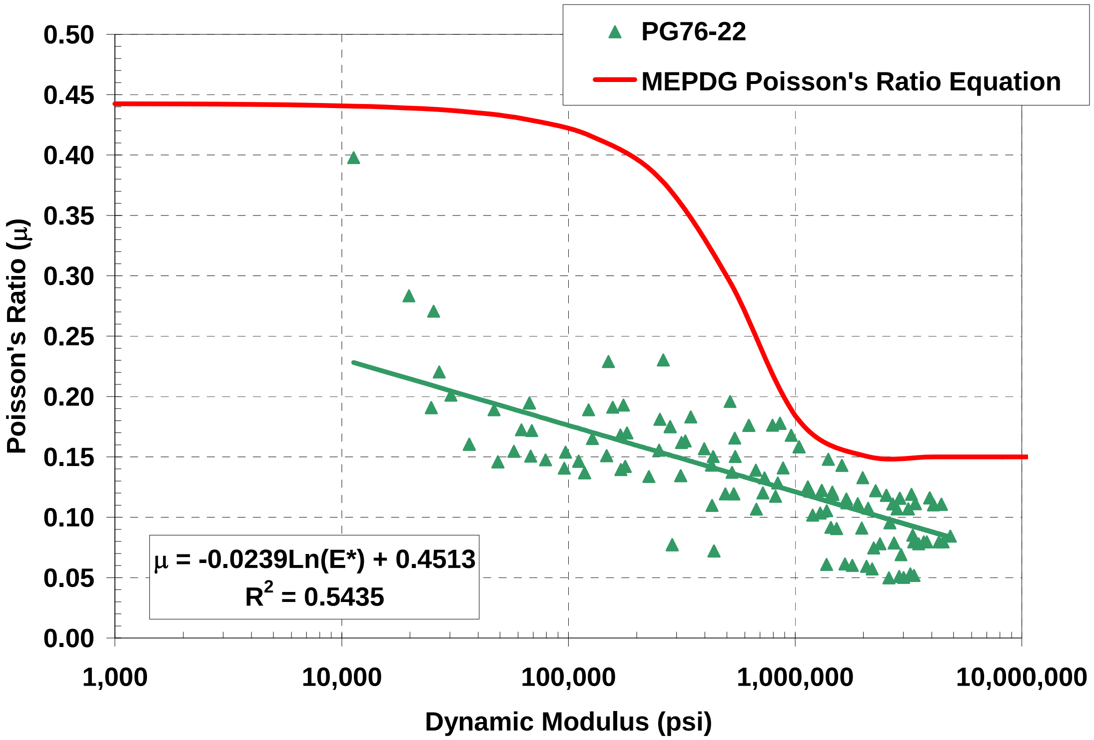


Figure 40 – Test Results of All of the PG76-22 Mixtures Tested and Compared with the MEPDG Poisson’s Ratio Equation

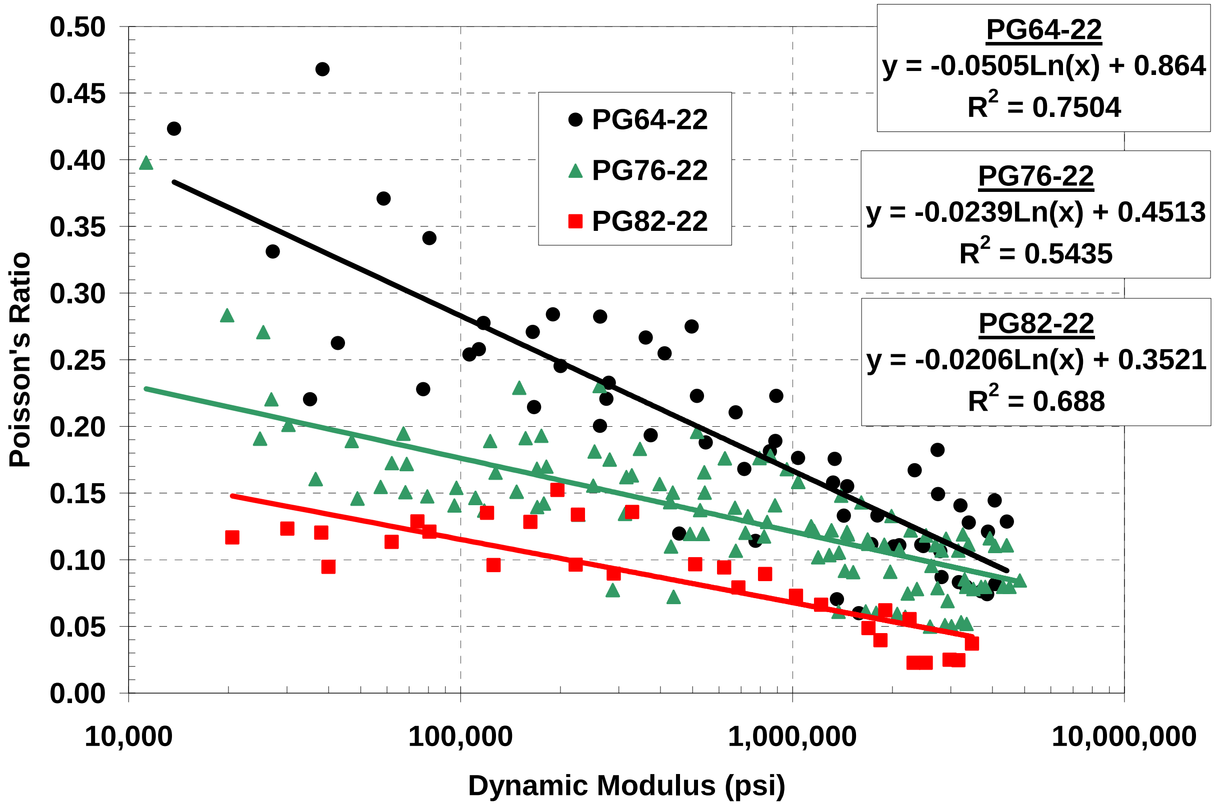


Figure 41 – Measured Poisson's Ratio for Different PG Grades

Incorporating HMA Material Specific Poisson's Ratio into the MEPDG

The Mechanistic Empirical Pavement Design Guide software allows for the user to input material specific parameters into the Poisson's Ratio prediction equation (Equation 1) by adjusting the "a" and "b" coefficients. To accomplish this, the least squares error linear regression approach in the Excel Solver was used. The data was divided into all PG64-22 samples and PG76-22 samples. Only these two asphalt binder types were used during this phase since it was decided that there was not enough data to fully represent the other asphalt types.

Based on the least squares error linear regression approach, the following coefficients were determined:

- PG64-22: a = -1.0; b = 9.0E-6
- PG76-22: a = -1.3; b = 7.5E-5
- Default values (currently in MEPDG): a = -1.63; b = 3.84E-6

The binder grade Poisson's Ratio equations are shown in Figures 42 and 43 with their respective test data. As the figures show, the new equations represent the measured data more accurately than the MEPDG default equation.

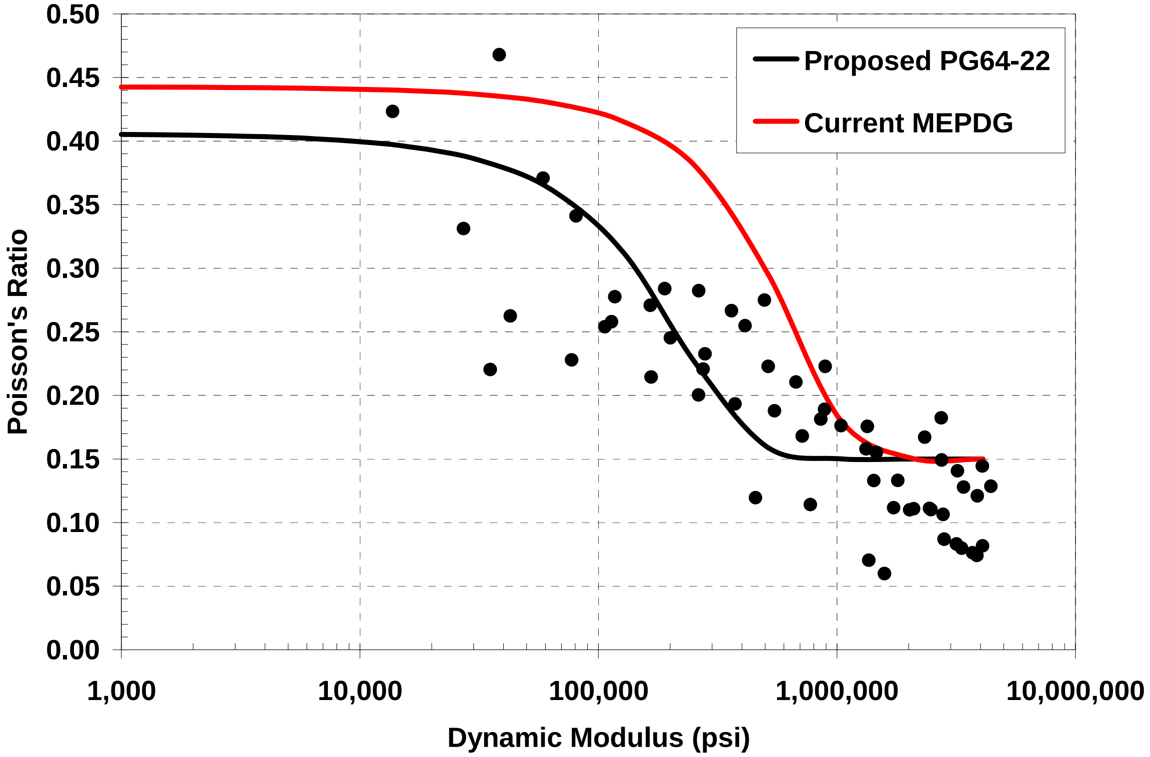


Figure 42 – Proposed PG64-22 Poisson's Ratio Prediction Equation

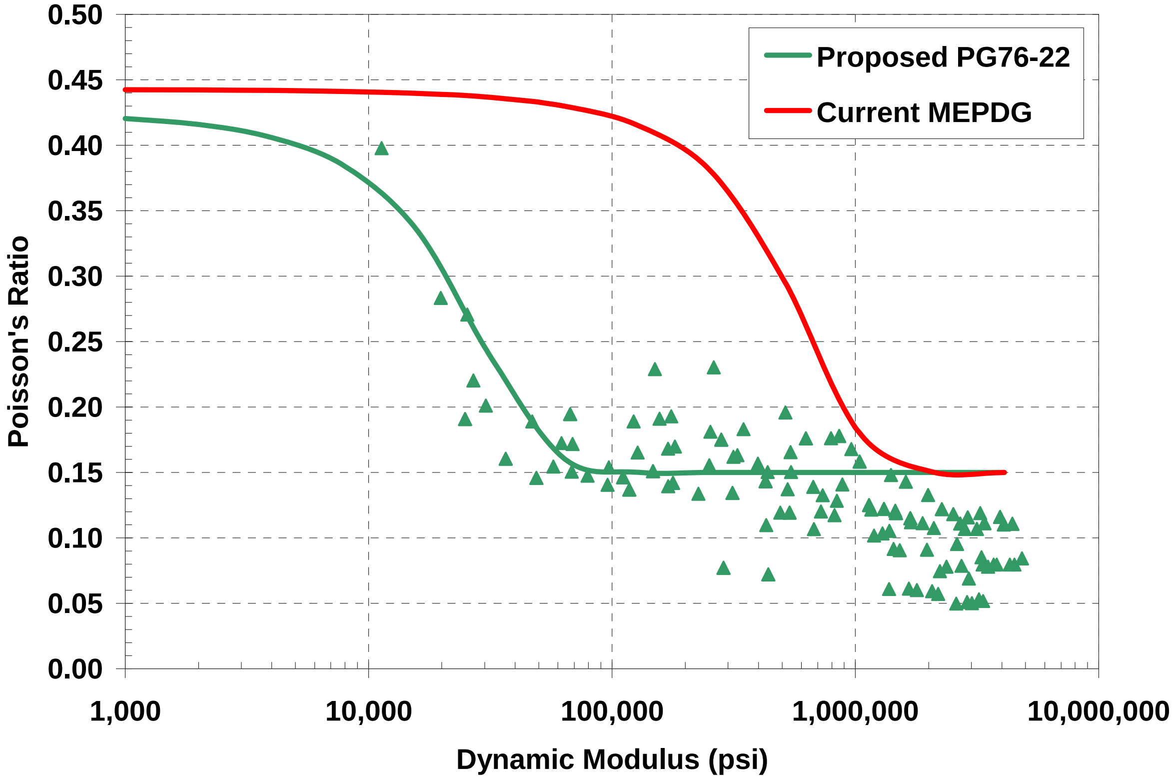


Figure 43 – Proposed PG76-22 Poisson's Ratio Prediction Equation

As shown in Figures 42 and 43, the proposed prediction equations do a better job at representing the measured Poisson's Ratio values. However, due to the equation incorporated in the MEPDG (Equation 1), further accuracy is prohibited. Currently, the Poisson's Ratio prediction equation limits the lower end value to 0.15. Therefore, based on the prediction equation, it is not possible to obtain Poisson's Ratio values less than 0.15. However, as the data in Figures 42 and 43 suggests, at higher dynamic modulus values, Poisson's Ratio values were measured as low as 0.1. If the MEPDG software would allow for all of the coefficients in the prediction equation to be modified, a better fit to the measured Poisson's Ratio values would have been obtainable.

Impact of Proposed Poisson's Ratio Coefficients to MEPDG Distress Predictions

The MEPDG software was used to conduct a brief sensitivity analysis using the Default Poisson's Ratio prediction equation in the MEPDG and the proposed equations developed with the PG64-22 and PG76-22 database shown earlier. The pavement section and test parameters were as follows:

- Initial 2-way AADTT = 5,000
- Number of Lanes in Design Direction = 2
- % Trucks in Design Direction = 50%
- % Trucks in Design Lane = 95%
- Operational Speed = 50 mph
- Climate: Trenton, NJ
- Pavement Cross-section:
  - HMA = 8 inches
  - Base Aggregate (Crushed Stone) = 8 inches
  - Subgrade = AASHTO A-4 Classification

Each of the proposed Poisson's Ratio prediction equations (one for PG64-22 and one for PG76-22) was utilized and compared with the Default equation for the same asphalt binder grade. The pavement distress predictions from the MEPDG are shown in Figures 44 to 46. The MEPDG outputs show that the Proposed equations, which were based on measured Poisson's Ratio values during the Dynamic Modulus test (AASHTO TP62), result in larger levels of accumulated damage in both rutting and cracking. Greater differences are shown for the PG64-22 asphalt than the PG76-22.

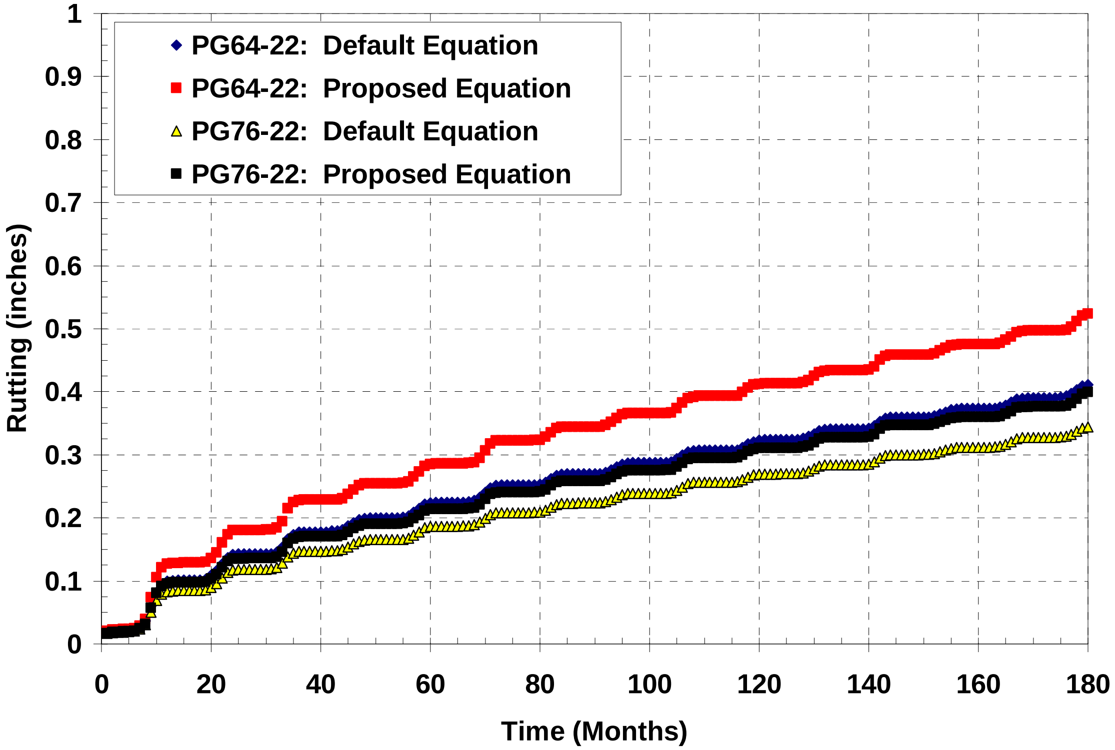


Figure 44 – HMA Rutting Predictions from MEPDG

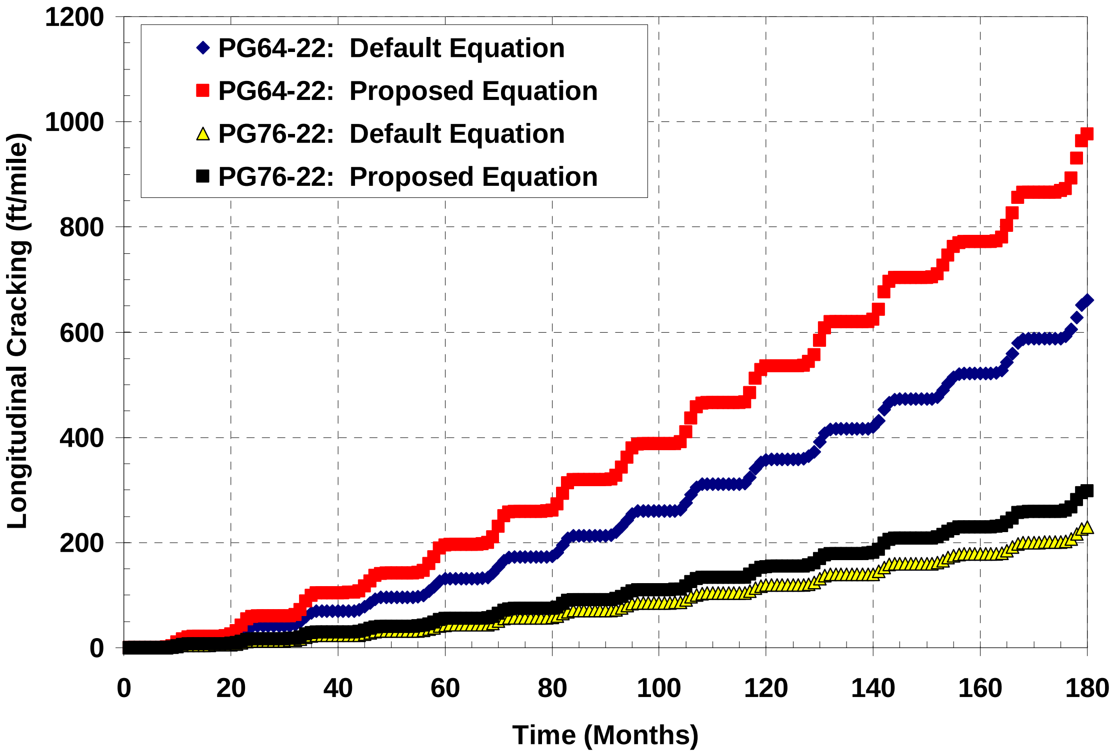


Figure 45 – Longitudinal Cracking Predictions from MEPDG

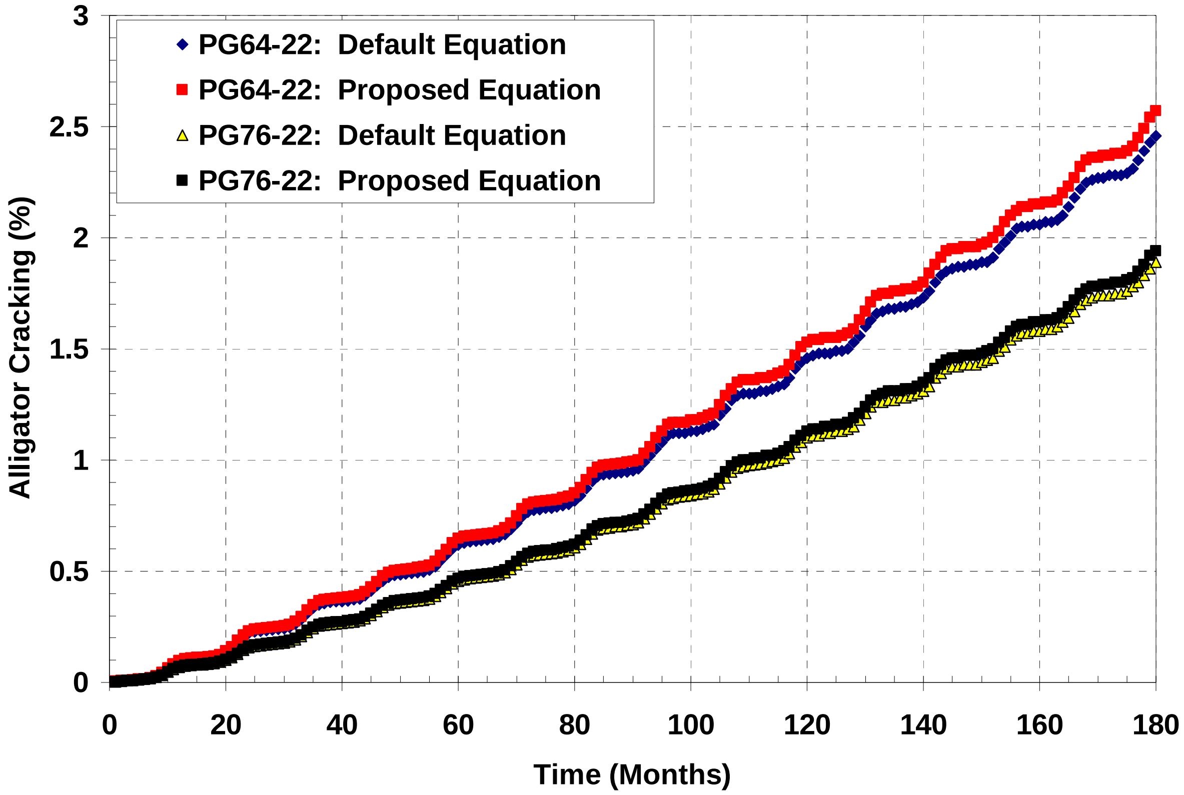


Figure 46 – Alligator Cracking Predictions from MEPDG

A more detailed look at the computed modulus values were taken for each asphalt type. The modulus in the asphalt layer is a product of the material properties of the particular asphalt mixture (binder grade, volumetric properties, aggregate gradation), climate conditions, and vehicle speed (operational speed). Figures 47 and 48 show the computed modulus values of the asphalt layer at various depths. What is intriguing about these figures is that it appears for this pavement scenario, the modulus of the asphalt layer barely goes below 500,000 psi. In fact, the PG76-22 asphalt material never went below 600,000 psi. Utilizing the Default and Proposed Poisson's Ratio prediction equations, a "general" range of Poisson's Ratio values can be determined. The results can be found in Figure 49. For the analysis, a "conservative" value of 400,000 psi was used as the lower bound modulus value. The results in Figure 48 indicate that when using the Current MEPDG Poisson's Ratio prediction equation, the general range of possible Poisson's Ratio values is 0.15 to 0.33. If the PG64-22 equation is used, the range decreases to 0.15 to 0.23. For the PG76-22, the Poisson's Ratio never deviates from 0.15.

The best application of Figure 49 is during FWD backcalculation. As mentioned earlier, the typical Poisson's Ratio value used for the asphalt layer during backcalculation analysis is 0.35. According to the MEPDG equation, it would be close to impossible (unless the asphalt pavement was damaged) to obtain a modulus value of the HMA lower than 400,000. Therefore, Figure 48 immediately justifies the recommendation of using a lower Poisson's Ratio value during backcalculation for the HMA layer. A value of 0.25, which would result in an HMA modulus of approximately 700,000 to 800,000 psi, is better representative of the real life situation.

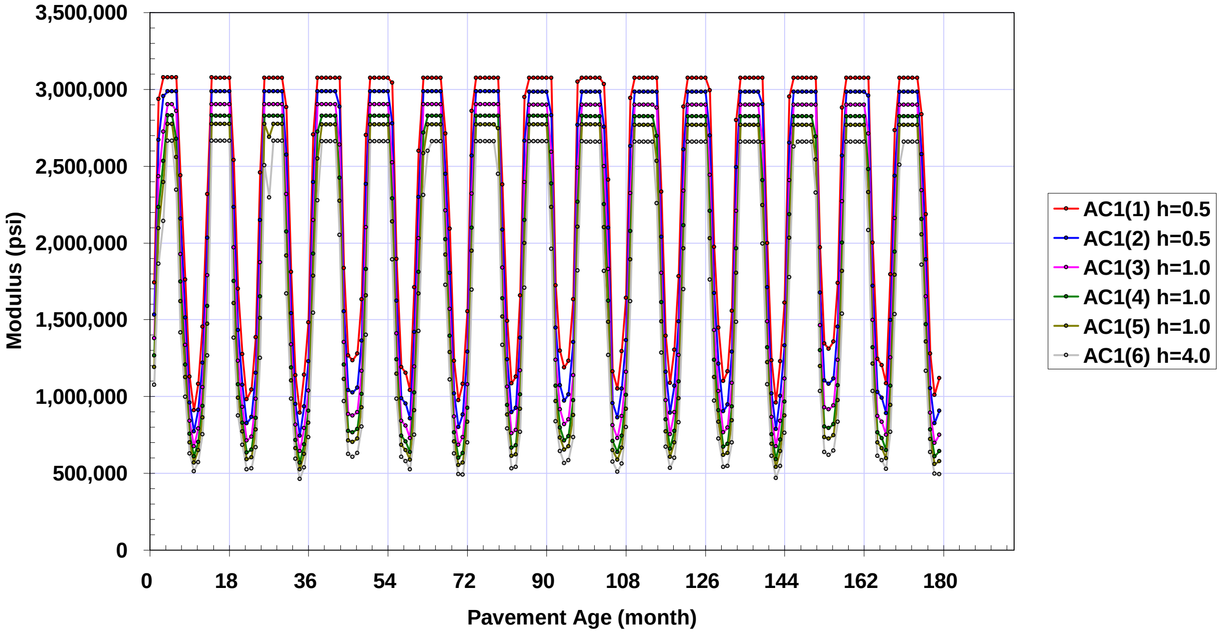


Figure 47 – Computed Modulus for Asphalt Sub-layers (PG64-22)

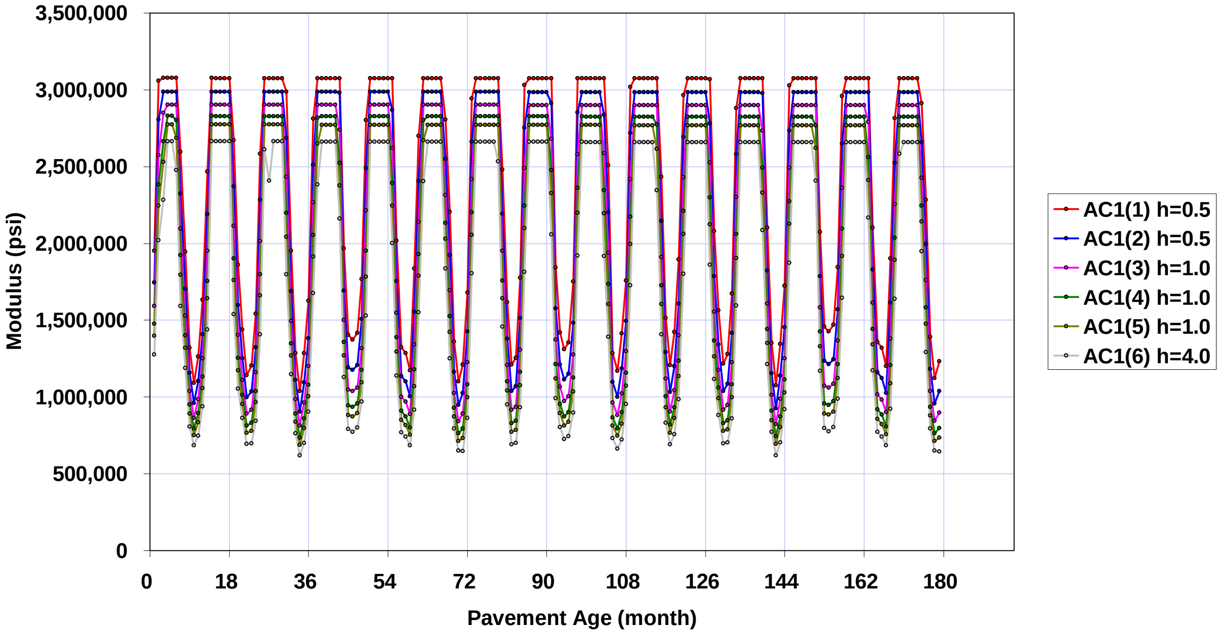


Figure 48 – Computed Modulus for Asphalt Sub-layers (PG76-22)

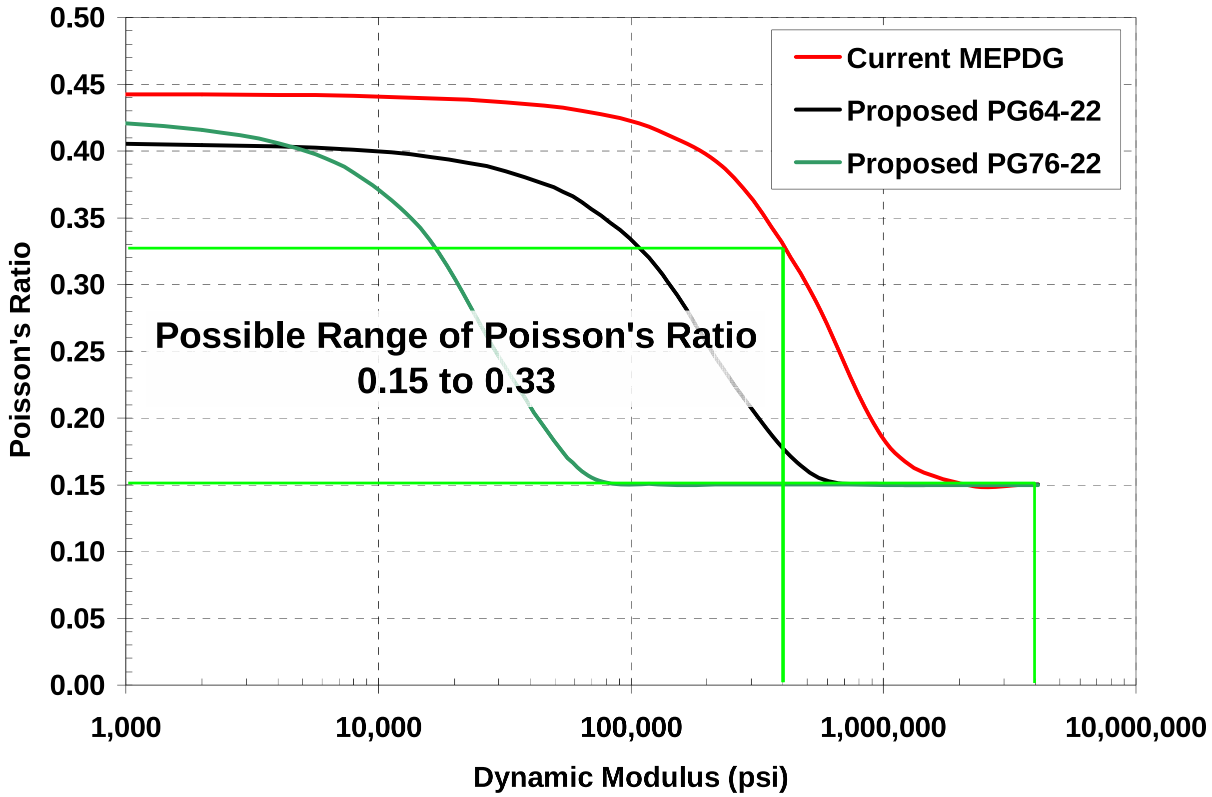


Figure 49 – Possible “Practical” Range of Poisson’s Ratio Values

Laboratory Results – Base Aggregate Testing

The measurement of the Poisson's Ratio for unbound materials was proposed to be conducted during the resilient modulus test. The main idea behind this was that a state agency could utilize the resilient modulus test to determine the modulus properties of the unbound material while obtaining material specific Poisson's Ratio input values. However, during the early stages of testing, it was evident that the resilient modulus test would not be appropriate to determine the Poisson's Ratio.

The Poisson's Ratio parameter is only valid with testing materials within their linear elastic range. This means that theoretically there should be no permanent deformation accumulated during any of the loading cycles and the vertical strain should be in the low strain range (< 0.001%).

An example of the laboratory resilient modulus testing, under the SHRP P46 testing protocol, with the respective Poisson's Ratio is shown in Figure 50. The results were plotted in this manner to be consistent with the asphalt materials. The results show that for the same material, identical modulus values result in different levels of Poisson's Ratio values. For example, a Poisson's Ratio value of approximately 0.15 occurred at all five confining pressures and had resilient modulus values that ranged from 22,000 to almost 90,000 psi.

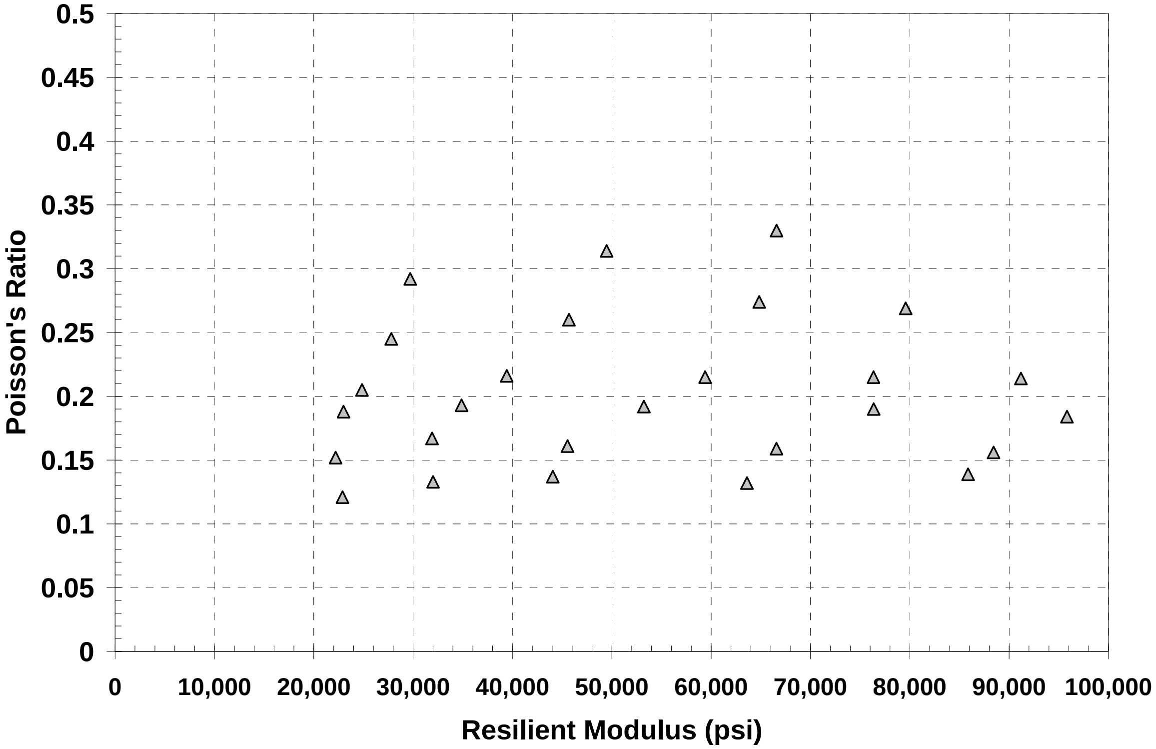


Figure 50 – Measured Resilient Modulus and Poisson's Ratio for NJDOT DGABC under the SHRP P46 Testing Protocol

A more detailed look at resilient modulus values and their respective vertical strains from a database generated at Rutgers University shows that a difference in applied vertical strain levels exists between base/subbase and subgrade soils due to the testing procedures (i.e. – base/subbase aggregates are tested at higher levels of applied deviatoric and confining pressure). The general range of resultant applied vertical strains is shown as Figure 51. As one can see, the general range of vertical strains does not lend itself to producing properties that can be classified as "linear elastic" (<0.001%).

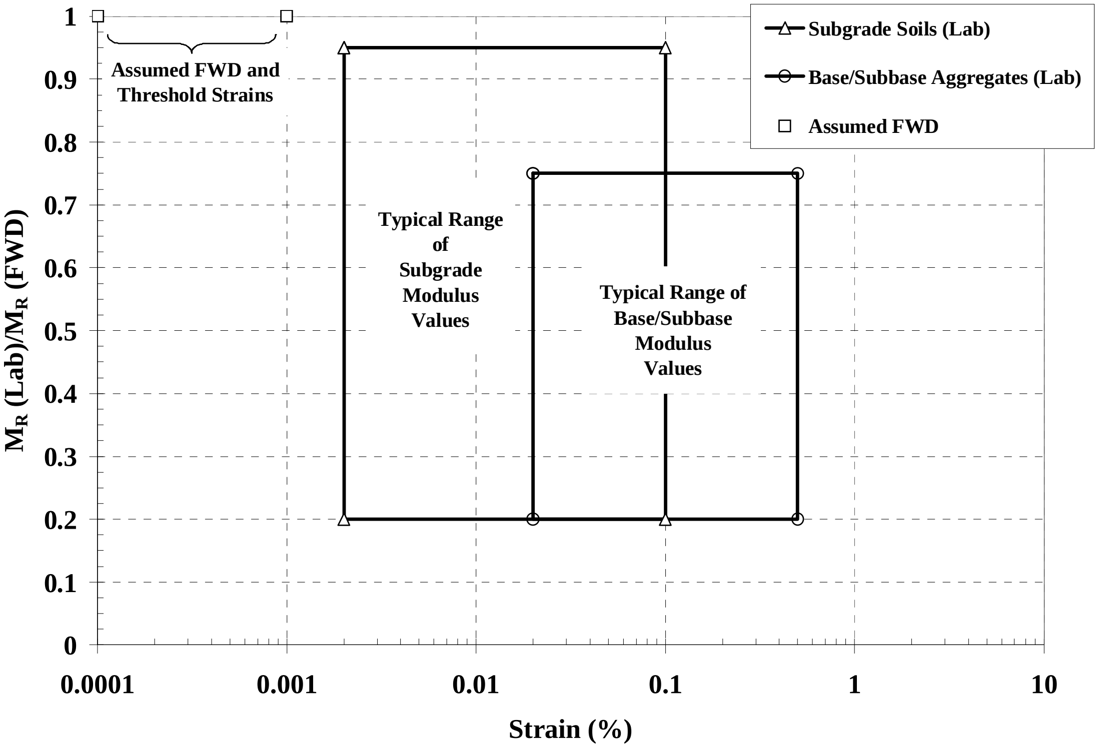


Figure 51 – General Range of "Typical" Modulus Values and Vertical Strains During the Resilient Modulus Test

In fact, the general decreasing in modulus values during the resilient modulus test can be attributed to the increasing in vertical strains. This phenomena has been well documented in the soil dynamic field of Geotechnical Engineering and is called Modulus Degradation. A few examples of Shear Modulus Degradation can be found as Figures 52a and b. This type of phenomena is the reason that Falling Weight Deflectometer (FWD) backcalculated modulus values of unbound materials must be "corrected" to coincide with laboratory resilient modulus values. An example of this can be found from the Ph.D. work of Horhota (2002) where the author compared the modulus results of SASW testing with that of resilient modulus laboratory test results (Figure 53). The figure clearly shows the decrease in the ratio between laboratory resilient modulus and SASW modulus as the vertical strain level increases for different subgrade soils tested.

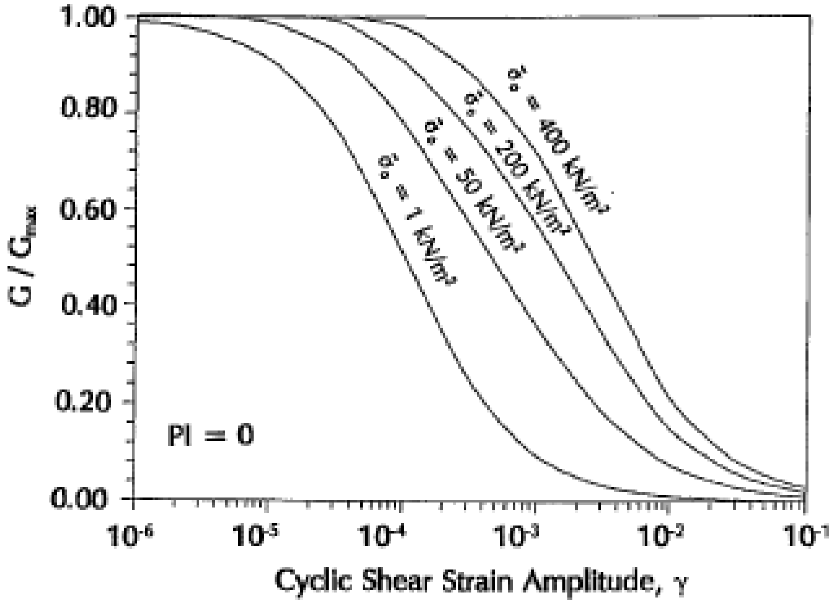


Figure 52a – Shear Modulus Degradation Curve as a Function of Overburden Pressure and Plasticity Index = 0 (as adapted from Dobry and Vucetic, 1987)

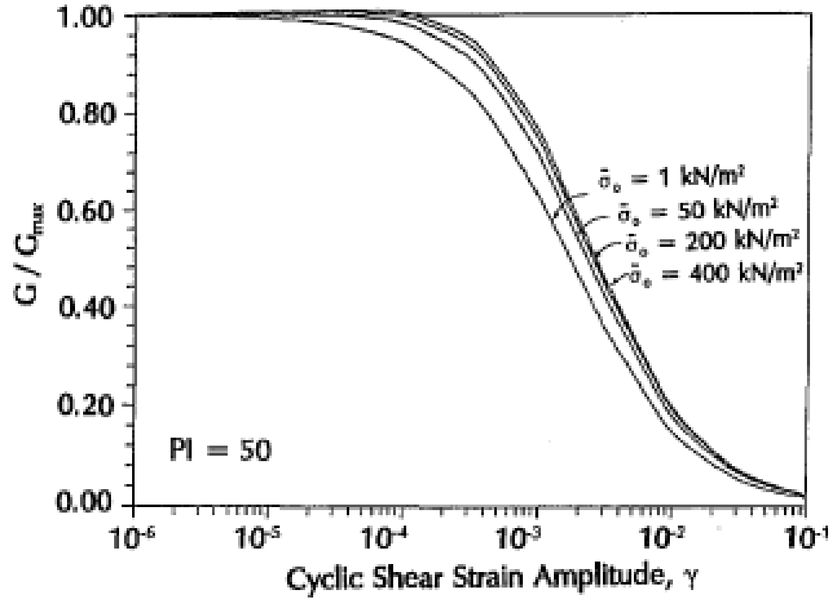


Figure 52b – Shear Modulus Degradation Curve as a Function of Overburden Pressure and Plasticity Index = 50 (as adapted from Dobry and Vucetic, 1987)

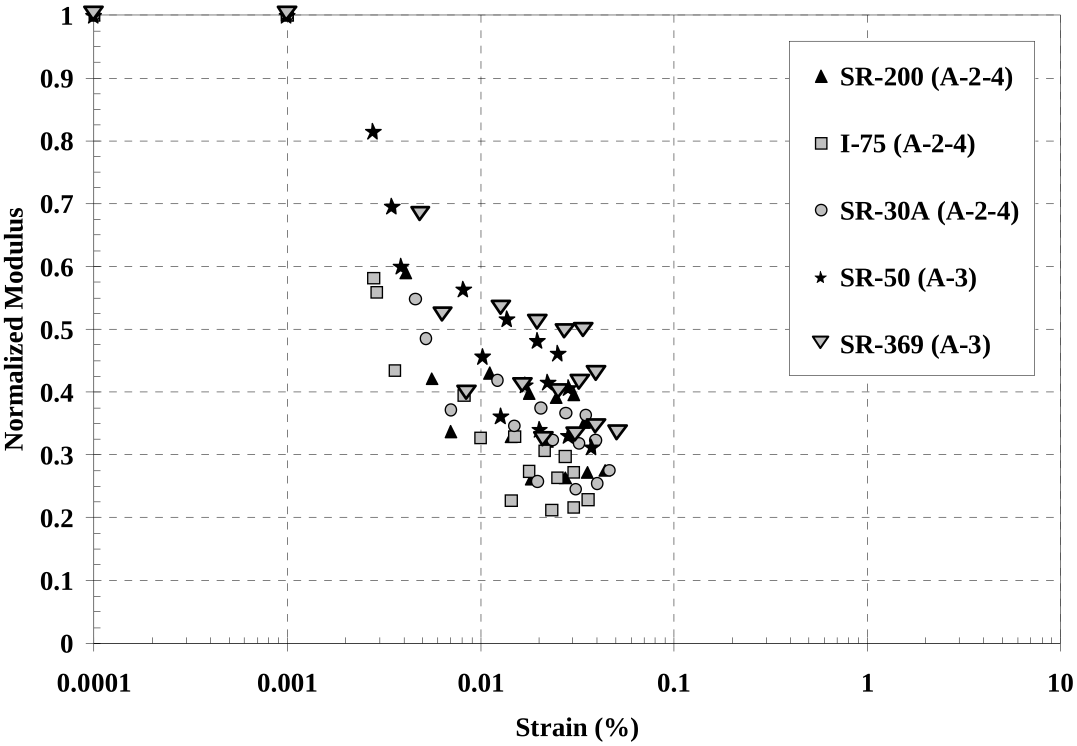


Figure 53 – Decrease in Modulus vs Vertical Strain for Five (5) Subgrade Soils in Florida

Potential Methodology to Develop Poisson's Ratio for Unbound Materials

As mentioned earlier, due to the magnitude of the vertical strains involved in the laboratory resilient modulus test, the linear elastic Poisson's Ratio, as required by the MEPDG, is not possible to be measured during testing. Therefore, the continued evaluation of different unbound materials did not occur. However, a literature review was conducted to determine if there was a means of measuring the Poisson's Ratio while maintaining the linear elastic properties of the unbound materials.

The literature review resulted in low strain, seismic test methods as the only way of maintaining the linear elastic nature of the unbound material while measuring the Poisson's Ratio. Figure 54 shows the recommended device for future evaluation. The device can apply two different type of seismic waves, compression and shear, that would propagate through the compacted and confined test specimen. By applying compression waves, the elastic modulus, E, can be determined by Equation (9) and the shear modulus, G, can be determined by Equation (10). In elastic theory, the elastic modulus and the shear modulus are related by the Poisson's Ratio, as shown in Equation (11). Equation (11) can then be rearranged using Equations (9) and (10) and then solving for Poisson's Ratio results in Equation (12).

Figure 54 – Low Strain Ultrasonic Test Device to Determine the Poisson's Ratio of Unbound Materials

$$\mathrm{E} = \rho \mathrm{V_C}^2 \tag{9}$$

$$G = \rho V_S^2 \tag{10}$$

$$G = \frac{E}{2(1+\mu)} \tag{11}$$

$$\mu = \frac{V_C^2}{2V_S^2} - 1 \tag{12}$$

Although the evaluation of the Ultrasonic test device was not part of the study, the literature review does indicate that there is a methodology that can produce Poisson's Ratio values within the linear elastic range of the material.

CONCLUSIONS

A research effort was conducted to evaluate the influence of the Poisson's Ratio of hot mix asphalt and unbound aggregates for use in the Mechanistic Empirical Pavement Design Guide (MEPDG). In the study, a series of Sensitivity Analyses were conducted to assess the impact that the Poisson's Ratio has on the distress predictions from the MEPDG, as well as how the Poisson's Ratio effects the backcalculated modulus values from the Falling Weight Deflectometer (FWD) deflection testing.

After the Sensitivity Analyses were complete, a laboratory investigation was conducted to determine; 1) if the Poisson's Ratio of hot mix asphalt (HMA) and unbound materials can be measured in the laboratory during laboratory modulus testing and 2) how the measured values compare to the current "Default" values/prediction equation used in the MEPDG.

Based on the results and data generated in the study, the following conclusions can be drawn:

1. The magnitude of the Poisson's Ratio in the hot mix asphalt (HMA) has a clear influence of the pavement distress predictions in the Mechanistic Empirical Pavement Design Guide (MEPDG). As shown in the MEPDG Sensitivity Analyses, top-down longitudinal cracking and total pavement rutting showed large variations in distress magnitude with the change in Poisson's Ratio – as the Poisson's Ratio increases, the magnitude of the MEPDG pavement distress predictions decreased. This occurred in all three pavement distresses (longitudinal cracking, total pavement rutting, and alligator cracking), with the longitudinal cracking showing the greatest sensitivity.
2. The magnitude of the Poisson's Ratio in the unbound materials did not have as severe an impact on the MEPDG distress predictions as the HMA. In fact, the total pavement rutting showed almost no difference between the range in Poisson's Ratio values utilized. Once again, the top-down longitudinal cracking was the most sensitive to the change in the Poisson's Ratio.
3. The backcalculated modulus values from the Falling Weight Deflectometer (FWD) deflection testing showed to be sensitive to the Poisson's Ratio selected for the individual layer analyzed. A 20 to 40% change in backcalculated modulus values was witnessed in the various layers depending on the Poisson's Ratio selected in the backcalculation program. This is important to note since the FWD modulus values are routinely used for design purposes and the incorrect selection for a Poisson's Ratio for a particular material may result in an incorrect design modulus.
4. The asphalt mixture laboratory testing program showed that the measured Poisson's Ratio of mixtures in this study that contained an asphalt binder grade of a PG64-22 compared favorably with the MEPDG Poisson's Ratio prediction equation, although the measured values were consistently lower than the predicted values. The PG76-22 asphalt mixtures obtained approximately 1/3 of the Poisson's Ratio values as the MEPDG prediction equation, even when the PG76-22 mixtures achieved modulus values that were equivalent to the PG64-22

mixtures. This is most likely due to the polymer modification that occurs in the manufacturing of the PG76-22 asphalt binder.

5. Proposed prediction equations were developed for the PG64-22 and PG76-22 mixtures based on the laboratory testing conducted in the study. The MEPDG allows for the modification of the prediction equation via the coefficients “a” and “b” in Equation (1). The proposed equations were used in a MEPDG Sensitivity Analysis to determine the difference in distress predictions between the proposed and MEPDG “Default” equations. The sensitivity analysis results showed that the “Proposed” equations, developed during this study, produced higher levels of pavement distresses in the MEPDG. This is most likely due to the fact that the “Proposed” equations consistently resulted in lower Poisson’s Ratio values than the “Default” equation. And based on the earlier Sensitivity Analysis work, it was apparent that as the Poisson’s Ratio decreases, the magnitude of the pavement distress increases.
6. The laboratory testing of the unbound materials was not successful due to the fact that the resultant modulus values measured are not within the linear elastic range due to the excessive strains (> 0.001%) that occurs during the testing. Preliminary laboratory and literature reviews clearly showed that as the vertical strain in the resilient modulus test increased, the measured resilient modulus value decreased. Therefore, it is not recommended to use the resilient modulus test as a means to measure Poisson’s Ratio of unbound material unless the applied strains can be maintained below 0.001%. However, the literature review did identify a potential means of measuring the Poisson’s Ratio of unbound materials through the use of Ultrasonic testing that utilizes compression and shear waves to determine the elastic and shear modulus of the unbound material.

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