Performance Comparison of PG 64-22 versus PG 64-28 Asphalt in Hot Mix Asphalt Placed in Connecticut

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16. Abstract
This research was conducted to determine if switching from a low-temperature asphalt performance grade (PG) of -28°C to -22°C would be detrimental to the performance of Hot Mix Asphalt (HMA) pavements in Connecticut. Test sections were placed on two different resurfacing projects in CT in 2006, employing both PG 64-22 and PG 64-28 asphalt binders. Field tests and performance observations along with laboratory analysis and tests were used to determine the feasibility of increasing the cold temperature PG grade. The analysis was conducted utilizing several different methods, including field visits, photolog analysis, International Roughness Index (IRI) analysis, rutting analysis, cracking and distress analysis. Laboratory analyses included Asphalt Pavement Analyzer (APA) rut testing, tensile strength ratios, critical cracking temperature, PG grading and relaxation modulus. Results of all analysis and testing are not conclusive enough to make definitive statements regarding the use of PG 64-22 as compared with PG 64-28.

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Standard Conversions

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Executive Summary

Low-temperature performance of asphalt binders is a critical element in ensuring the longevity and durability of hot mix asphalt (HMA) pavements. Federal Highway Administration (FHWA) LTPPBind software has traditionally been used to determine what performance grades of asphalt binders should be used in certain areas, based on historical climate data. The Connecticut Department of Transportation (ConnDOT) has, in the past, required a low-temperature performance grade of -28°C. It has been recognized, by both industry and ConnDOT, that a low-temperature Performance Grade (PG) of -22° may be sufficient for use in most areas of Connecticut. In New England, -22°C grades are more available than -28°C grades and also come at a lesser cost.

This research was conducted to determine if the -22°C PG grade could be used in most areas in Connecticut without a negative impact on performance, longevity and durability. Pavement test sections were constructed on State routes in Kent and Easton, CT. Portions of each test section were constructed with both PG 64-28 and PG 64-22 binders. There were several modes of comparison performed to determine if there were significant differences in the performance of the test sections. The field performance analyses included multiple site visits in order to visually document deficiencies such as cracking. Other field performance analyses included viewing photolog images (images of the roadway collected annually via a ConnDOT survey vehicle) of the pavement to determine the extent and degree of cracking and raveling which had occurred since placement. International Roughness Index (IRI) data, which is also collected via the ConnDOT survey vehicle, were also analyzed, along with rutting data and acceptance test results. In the laboratory, Asphalt Pavement Analyzer (APA) rut tests, tensile strength ratios and multiple asphalt binder analyses were conducted. Results of all laboratory testing, field/site visits and field performance analyses did not suggest that one binder grade outperformed the other. PG grading of the binders actually suggest that the binders are quite similar from a temperature grading perspective. One test section, which is showing signs of distress at a faster rate than all the others, was placed over a surface which was not milled prior to placement, which could account for any difference in performance. Since the beginning of this study, ConnDOT specifications have changed to a default PG grade of PG 64-22 as opposed to the PG 64-28.

CHAPTER 1: Introduction

1.1 Introduction

Ensuring the low-temperature performance of asphalt mixtures poses a challenge to transportation agencies who maintain roads in colder regions across the United States. Extensive research has been conducted by numerous agencies to handle this difficult challenge. Table 1 lists some studies that have been conducted by others to examine the low-temperature performance for asphalt binders and mixtures.

Table 1. Studies of Performance of Low-Temperature Asphalt Binder Properties

Location of Pavement Sections Studied	Research Title
Minnesota, Illinois (USA) [1]	Comparison of Low-Temperature Field Performance and Laboratory Testing of 10 Test Sections in the Midwestern United States
Minnesota (USA) [2]	Low Temperature Cracking Performance at MnROAD
Minnesota (USA) [3]	Investigation of the Low-Temperature Fracture Properties of Three MnROAD Asphalt Mixtures
Texas (USA) [4]	Analysis of Flexible Pavement Response and Performance Using Isotropic and Anisotropic Material Properties
Texas (USA) [5]	Performance Evaluation of HMA Consisting of Modified Asphalt Binder
Alabama (USA) [6]	Validation of Superpave Mixture Design and Analysis Procedures Using the NCAT Test Track
China [7]	Research on High- and Low-Temperature Properties of Asphalt-Mineral Filler Mastic
Alabama (USA) [8]	Laboratory Performance Testing for the NCAT Pavement Test Track
Virginia (USA) [9]	Evaluation of Superpave Mixtures in West Virginia Using the APA
Washington DC [10]	The Future of Performance-Related Binder Specifications
Texas [11]	Predicting In-Service Fatigue Life of Flexible Pavements Based on Accelerated Pavement Testing
Texas, Illinois (USA) [12]	Validated Model for Predicting Field Performance of Aggregate Base Courses
Michigan (USA) [13]	Statistical Analysis of In-Service Pavement Performance Data for LTPP SPS-1 and SPS-2 Experiments
Washington DC (USA) [14]	Performance of Treated and Untreated Aggregate Bases

1.2 Problem Statement

In order to optimize the performance of asphalt pavements, the Superpave system grades asphalt binders for both the high- and low-end service temperatures. The LTPPBind V3.1 software indicates that using an asphalt binder grade with a low-end temperature of -28° C should be sufficient for roadways within the entire State of Connecticut. The software also indicates that -22° C is adequate for the vast majority of roadways in Connecticut.

The Connecticut Department of Transportation (ConnDOT)switched from the use of Performance Grade (PG) 64-28 to PG 64-22 for all paving projects in 2009. This change was warranted by concerns such as:

- Potential Delayed setting of PG 64-28 HMA.
- Higher cost of producing PG 64-28.
- Limited supply of PG 64-28.
- Concerns of the effect of polyphosphoric acid modification used by some suppliers to make PG 64-28.

1.3 Project Objective(s)

The purpose of this research project is to determine whether the use of PG 64-22 throughout Connecticut will have a detrimental effect on low-temperature pavement performance, and to determine if using PG 64-22 in colder regions is justified.

1.4 Research Approach

The approach that was used for this project is as follows:

- Collection of field performance data.
- Laboratory tests of binder samples and HMA specimens.
- Analysis of field performance data.
- Analysis of laboratory data.
- Comparison of field performance and laboratory data.

CHAPTER 2: Literature Review

Laboratory evaluations of low-temperature performance of asphalt mixtures are currently based heavily on testing of asphalt binder properties. Zofka et al., 2007, investigated three laboratory tests that evaluate cracking resistance of asphalt mixtures at low temperatures [1] by coring and subjecting ten sections of pavement in Minnesota and Illinois to indirect tensile (IDT), semicircular bending (SCB) and disk-shaped compact tension (DCT) tests. Results of the laboratory data analysis showed that IDT did not vary significantly for the ten mixtures. They concluded that the laboratory fracture tests (SCB and DCT), were better suited for qualitative cracking performance predictions at low temperatures than the IDT.

Clyne et al., 2006, studied the low-temperature cracking performance of three pavement sections constructed with PG 58-28, PG 58-34 and PG 58-40 [2]. These pavement sections were constructed on a low-volume road using the same Superpave mix design and varying asphalt binder grade. After several years in service, the PG 58-40 test section showed the most cracking even though it had the lowest temperature grade binder. The PG 58-28 section did exhibit typical thermal cracks as would be expected, given the low temperatures typically experienced in this region. The PG 58-34 test section had virtually no distress after six years.

Li et al., 2006, compared low temperature properties of field mixtures from Minnesota Department of Transportation (MnROAD) and laboratory-prepared mixtures [3], and concluded that the fracture tests performed on asphalt mixtures and binders have the potential to predict the field performance of asphalt pavements, such as thermal cracking.

CHAPTER 3: Description of Study Sections

Four test sections, each were constructed in October 2006 on State routes in Easton and in Kent, Connecticut. The test sections at these locations were constructed with PG 64-28 and PG 64-22 binders as indicated below:

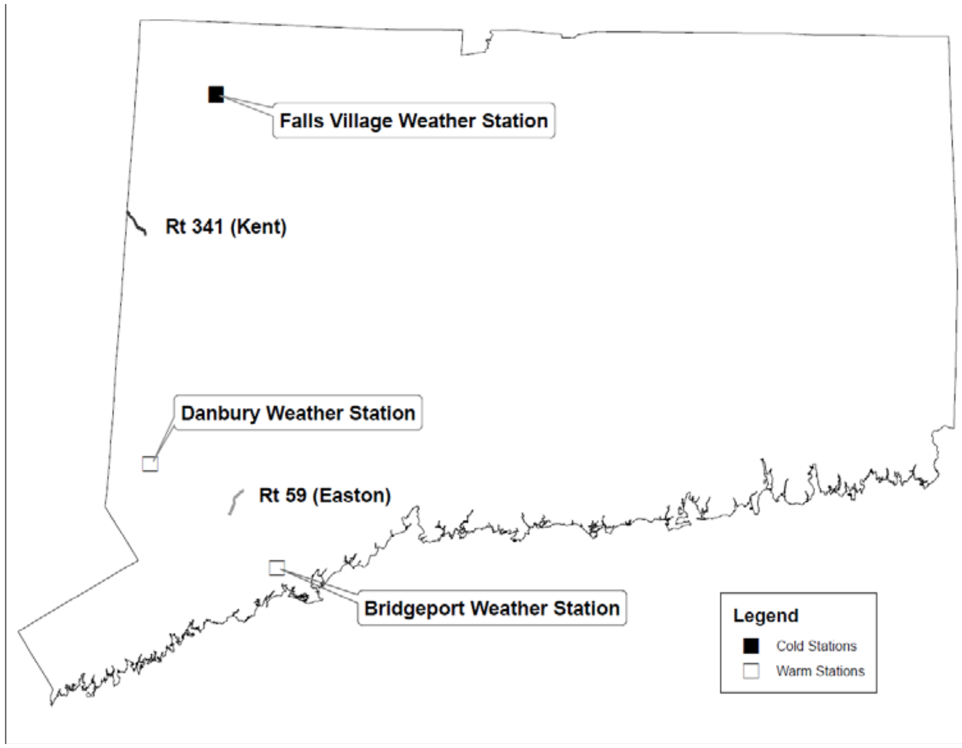
- First test section: PG 64-28.
- Second test section: PG 64-22.
- Third test section: PG 64-22.
- Fourth test section: PG 64-28.

As described, the reader can see that the two PG 64-22 sections for both projects were constructed between sections of pavement containing PG 64-28 binder.

3.1 Project Locations

The project in Easton began at the intersection of Rt. 25 and Rt. 59 and extended south, as seen in Figures 1 and 2 below. The project in Kent began 150 feet east of the New York State Line and extended east, as seen in Figures 1 and 3 below. Rt. 341 (Kent) was intended to represent colder conditions, while Rt. 59 (Easton) was intended to represent somewhat milder temperatures, based on average temperatures recorded there and the fact that Easton sits at a lower elevation.

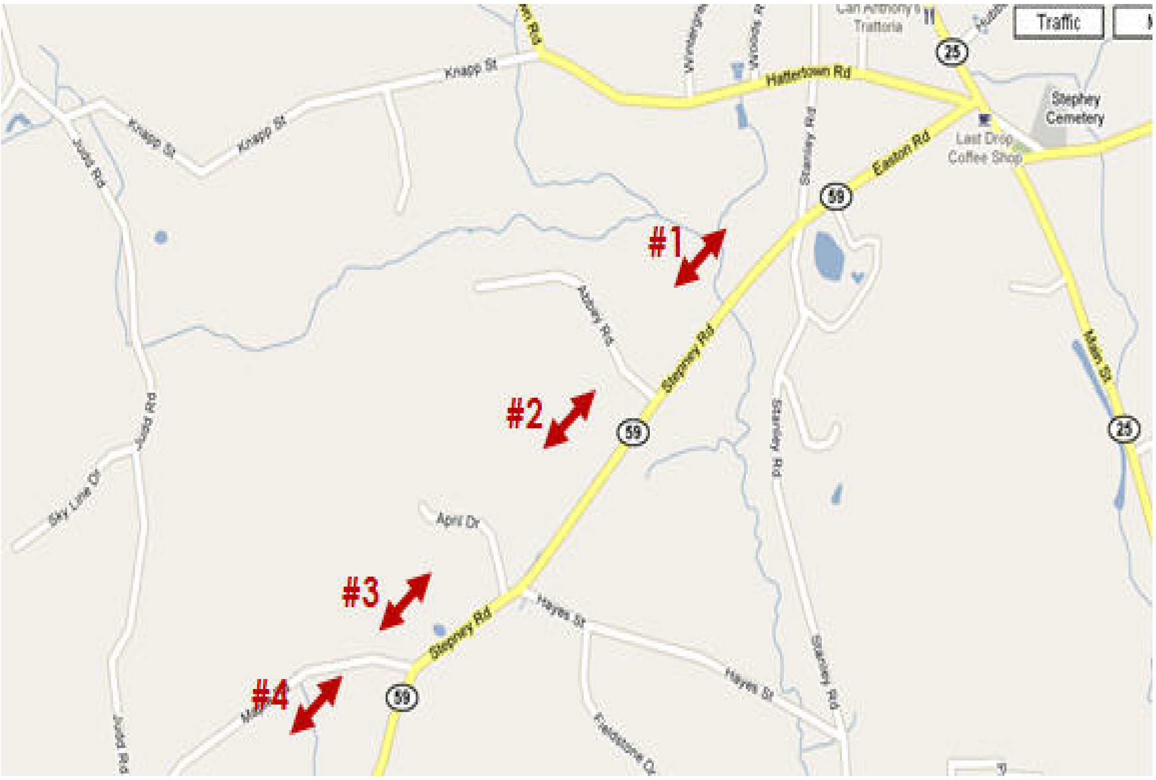
Figure 1. Location of Test Sections on Rt. 59 (Easton) and Rt. 341 (Kent)



3.2 Test Section Locations

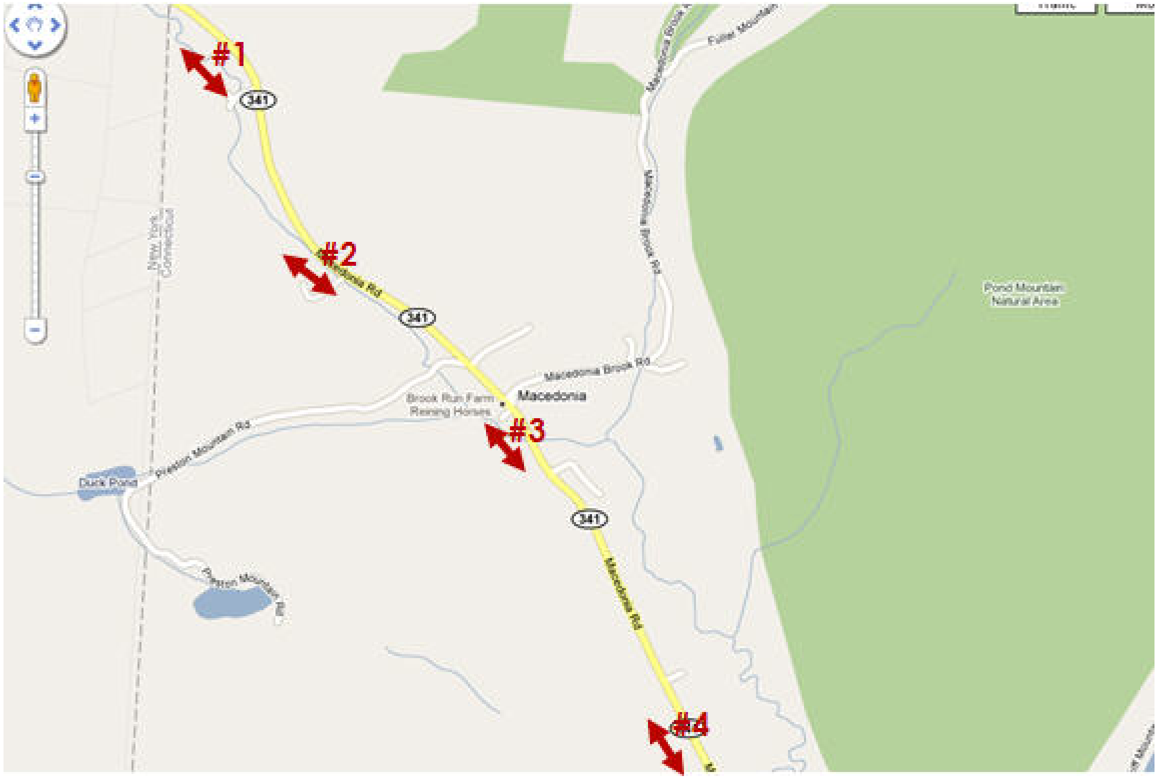
The test sections in Easton were constructed on October 2, 3 4, and 5, 2006. All of these test section locations are shown geographically in Figure 2.

Figure 2. Location of Test Sections on Rt. 59 (Easton)



The test section locations in Kent are shown geographically in Figure 3.

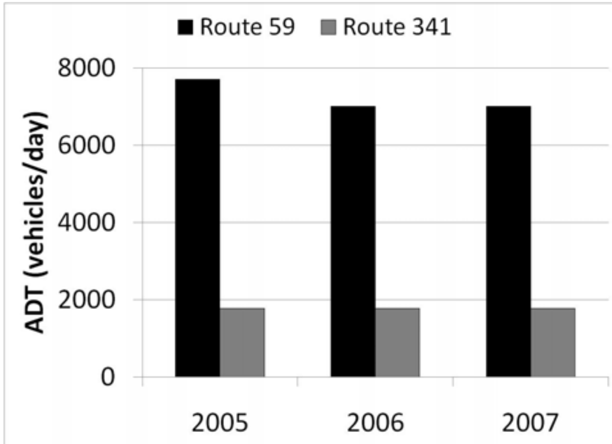
Figure 3. Location of Test Sections on Rt. 341 (Kent)



3.3 Test Section Traffic Levels

The test sections in Easton and Kent carry medium and light traffic, respectively. The average daily traffic on the project on the Easton sections for the years 2005, 2006 and 2007 are 7,700, 7,700 and 7,000 vehicles, respectively. The average daily traffic on the project on the Kent sections was 1,767 vehicles for the years 2005, 2006 and 2007. These numbers are shown graphically in Figure 4. This traffic data was provided by the Connecticut Department of Transportation Traffic Monitoring Volume Information Traffic Count Data [14].

Figure 4. Average Daily Traffic on Rt. 59 (Easton) and Rt. 341 (Kent)



3.4 Climatic Data

According to the website of National Climatic Data Center (NCDC) of the United States, the closest NCDC weather stations to the project at Easton are CT 0806, Bridgeport Sikorsky, and CT 1762, Danbury. Station CT 2658, Falls Village, is the closest weather station to the project at Kent. The project sites at Kent and Easton are 37.1 miles apart. The Easton project was approximately 520 feet higher in elevation as compared to the CT 0806, Bridgeport Sikorsky, weather station. Station CT 1762, Danbury, on the other hand, is approximately 120 feet below the project site at Easton. Station CT 2658, Falls Village, is approximately 120 feet above the project site at Kent. Figures 5 and 6 show the lowest temperature plots of the winter months for the closest weather stations to the projects for years 2006 to 2009. Figures 5 and 6 show that 2008-2009 generally had lower winter temperatures than 2006-2007 and 2007-2008 for all the closest weather stations. Station CT 0806, Bridgeport Sikorsky showed the lowest temperatures of winter months. Kent was intended to represent cold conditions, while Easton was intended to represent somewhat milder temperatures for this research. The plotted data in Figure 5 and 6 did not support this assumption; however, Bridgeport, Connecticut, is a coastal city on Long Island Sound which may not be an accurate representation of the conditions in Easton, so there remains the possibility that this initial assumption is valid.

Figure 5. Lowest Winter Temperatures - Easton Project Weather Stations

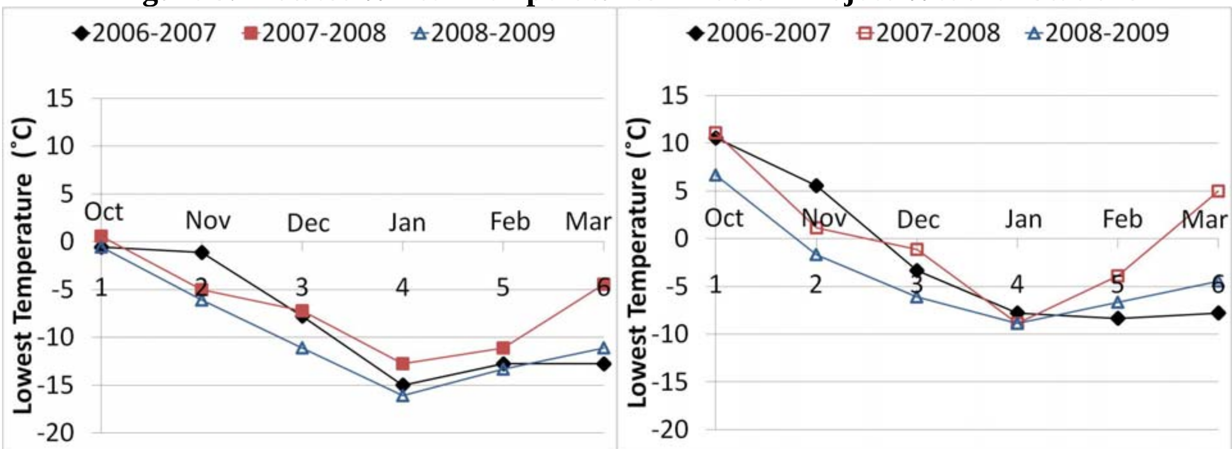
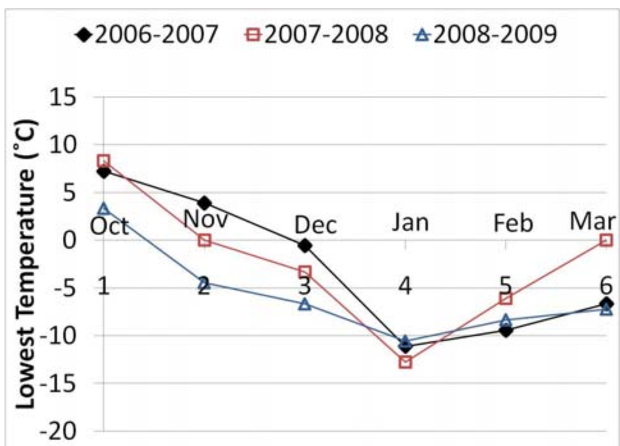


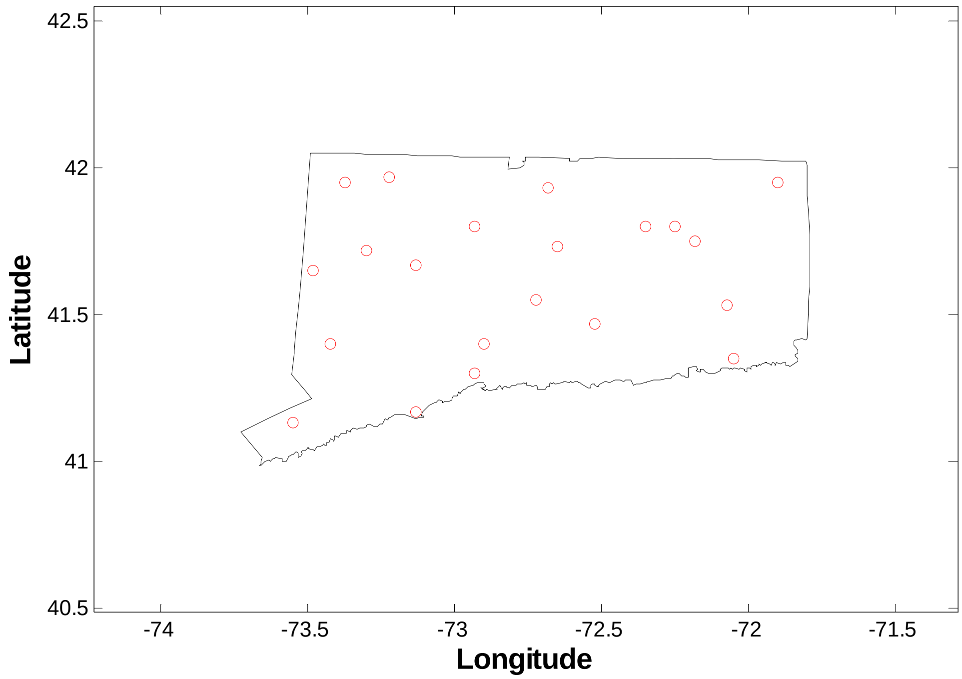
Figure 6. Lowest Winter Temperatures - Kent Project Weather Station



3.5 Analysis of LTPPBind V3.1 Binder Grades

The Federal Highway Administration LTPPBind V3.1 software makes provisions for two low-temperature zones with a 98% statistical reliability in Connecticut [16] at -22˚C and -28˚C. These values were determined from the climatic data of the 21 weather stations in Connecticut prior to 1996 and are shown graphically in Figure 7. Since there is the likelihood for the temperature ranges at these stations to change, new pavement service temperatures were determined by this research study by combining new temperature data (after 1996) and algorithms of LTPPBind V3.1 software. The ranges of the climate data for each station are shown in Tables 2 and 3.

Figure 7. Connecticut Weather Stations



The high service temperatures for the asphalt binders were determined by first creating a separate file for the daily maximum temperature (TMAX) Daily maximum temperatures of each station. The computation of the high PG was based on the following equations from LTPPBind V3.1 [16]:

$$PGd = 48.2 + 14 \times DD - 0.96 \times (DD)^2 - 2 \times RD \tag{1}$$

$$CVPG = 0.000034 \times (Lat - 20)^2 \times (RD)^2 \tag{2}$$

$$PGrel = PGd + Z \times PGd \times CVPG / 100 \tag{3}$$

where:

$PGrel$ = Performance Grade at a Reliability, ˚C

PGd = Damage Based PG, ˚C

$CVPG$ = Yearly Performance Grade Coefficient of Variation, %

$DD =$ Average Yearly Degree-Days Air Temp. Over 10˚C, x1000

$RD =$ Target Rut Depth, mm

$Lat =$ Latitude of Site, degrees (˚)

$Z =$ From Standard Probability Table, 2.055 for 98% Reliability

The parameter DD was calculated by summing temperatures in excess of 10˚C for the last 20 years of the six hot months. A separate file was created for the TMIN (Daily minimum temperatures of each station) in order to determine the low pavement service temperature. The low service temperature, Tpav, for each station was calculated using the equation:

$$Tpav = -1.56 + 0.72 \times T_{air} - 0.004 \times (Lat)^2 + 6.26 \times \log 10(H + 25) - z \times \left(4.4 + 0.52 \times (S_{air})^2\right)^{\frac{1}{2}} \quad (4)$$

where:

$Tpav =$ Low AC pavement temperature below surface, ˚C

$T_{air} =$ Low air temperature, ˚C

$Lat =$ Latitude of the section, degrees (˚)

$H =$ Depth to surface, mm

$S_{air} =$ Standard deviation of the mean low air temperature, ˚C

$z =$ Standard normal distribution table, $z = 2.055$ for 98% reliability

T_{air} = Lowest air temperature of the 6 cold months.

Tables 2 and 3, below, summarize low- and high-service temperatures determined before and after 1996. It is apparent from Table 2, below, that, with the exception of Falls Village and Storrs, the low-service temperatures for the weather stations did not change after 1996. The low-service temperature of Falls Village increased from -28˚C to -22˚C after 1996, and the low-service temperature for Storrs increased from -22˚C to -16˚C after 1996. The stations that had different low- and high-service temperatures after 1996 are shown in bold type in Tables 2 and 3.

Table 2. Comparison of Low Pavement Service Temperatures Before and After 1996

Station name	Range of years before 1996*	Range of years after 1996*	Original LTPPBind	Updated LTPPBind	Match **
Bridgeport Sikorsky Mem Airport	1958-1996	1949-2009	-22	-22	Yes
Bulls Bridge Dam	1958-1996	1958-1999	-28	-28	Yes
Burlington	1962-1996	1962-2009	-22	-22	Yes
Cockaponset Rs	1987-1989, 1990-1991, 1993-1996	1987-1989, 1990-1991, 1993-1996	-28	-28	Yes
Coventry	1958-1992	1958-1992	-28	-28	Yes
Danbury	1938-1986	1938-1986, 1991-2009	-22	-22	Yes
Falls Village	**1917-1996**	**1917-2009**	**-28**	**-22**	**No**
Groton	1958-1996	1958-2005, 2007-2009	-22	-22	Yes
Hartford Brainard Fd	1950-1996	1921-1999	-22	-22	Yes
Hartford Bradley International Airport	1954-1996	1950-2009	-22	-22	Yes
Mansfield Hollow Lake	1953-1996	1953-2007	-28	-28	Yes
Middletown 4 W	1885-1902, 1942, 1945-1996	1885-1902, 1942, 1945-1997	-22	-22	Yes
Mount Carmel	1937-1996	1937-1997	-22	-22	Yes
New Haven	1970-1992	1970-1992	-22	-22	Yes
Norfolk 2 Sw	1885-1887, 1942-1995	1885-1887, 1942-2009	-28	-28	Yes
Norwich Pub Util Plt	1957-1996	1957-2009	-22	-22	Yes
Shepaug Dam	1950-1996	1950-2003	-28	-28	Yes
Stamford 5 N	1956-1996	1950-2003	-22	-28	Yes
Storrs	**1889-1920, 1922-1996**	**1889-1920, 1922-2009**	**-22**	**-16**	**No**
West Thompson Lake	1963-1996	1963-2008	-28	-28	Yes
Wigwam Reservoir	1950-1996	1950-1997	-28	-28	Yes

*** Refers to years of complete data, in terms of days, which were used to determine low pavement service temperatures; years may/may not be continuous.**
**** *Match* indicates whether corresponding low pavement service temperatures of weather stations determined by original LTPPBind and updated LTPPBind V3.1 are the same or not.**

Table 3. Comparison of High Pavement Service Temperatures Before and After 1996

Station name	Range of years before 1996*	Range of years after 1996*	Original LTPPBind	Updated LTPPBind	Match **
Bridgeport Sikorsky Mem Airport	1977-1996	1989-1996, 1998-2009	58	58	Yes
Bulls Bridge Dam	1972-1974, 1976, 1980-1981, 1983-1996	1972-1974, 1976, 1980-1981, 1983-1996	58	58	Yes
Burlington	1970-1971, 1978-1979, 1982-1986, 1988-1989, 1991-1994, 1996-1997	1983-1986, 1988-1989, 1991-1994, 1996-1999, 2001-2002, 2004-2005, 2007, 2009	58	58	Yes
Cockaponset Rs	1987, 1989, 1991, 1994-1995	1987, 1989, 1991, 1994-1995	58	58	Yes
Coventry	1958-1960, 1962-1964, 1966-1972, 1975-1978, 1982, 1984-1989, 1992-1993	1958-1960, 1962-1964, 1966-1972, 1975-1978, 1982, 1984-1989, 1992-1993	58	58	Yes
Danbury	1973-1985, 1991-1997	1984-1985, 1991-2009	58	58	Yes
Falls Village	1978-1997	1982-2001	58	58	Yes
Groton	1973-1982, 1984-1986, 1990-1994, 1996-1997	1980-1982, 1984-1986, 1990-1994, 1996-1997, 1999-2000, 2002-2004, 2007-2008	58	58	Yes
Hartford Brainard Fd	1972-1977, 1979, 1981-1985, 1988-1991, 1993-1994, 1996-1997	1972-1977, 1979, 1981-1985, 1988-1991, 1993-1994, 1996-1997	58	58	Yes

Table 3. Comparison of High Pavement Service Temperatures Before and After 1996 (continued)

Station name	Range of years before 1996*	Range of years after 1996*	Original LTPPBind	Updated LTPPBind	Match **
Hartford Bradley International Airport	1978-1997	1990-2009	58	58	Yes
Mansfield Hollow Lake	1972-1990, 1996	1973-1990, 1996, 2004	58	58	Yes
Middletown 4 W	1972, 1974, 1976, 1978-1979, 1981-1991, 1993-1996	1972, 1974, 1976, 1978-1979, 1981-1991, 1993-1996	58	58	Yes
Mount Carmel	1973-1978, 1980-1991, 1995-1996	1973-1978, 1980-1991, 1995-1996	58	58	Yes
New Haven	1970, 1979, 1983, 1986	1970, 1979, 1983, 1986	58	58	Yes
Norfolk 2 Sw	1978-1997	1986-1999, 2003-2007, 2009	52	52	Yes
Norwich Pub Util Plt	1966, 1972, 1974, 1980-1989, 1991-1996	1986-1989, 1991-2004, 2006-2007	58	58	Yes
Shepaug Dam	1965, 1969, 1971-1976, 1978, 1980-1987, 1993-1995	1965, 1969, 1971-1976, 1978, 1980-1987, 1993-1995	58	58	Yes
Stamford 5 N	1974, 1976-1980, 1982-1991, 1993-1996	1983-1991, 1993-1996, 1998-2004	58	58	Yes
Storrs	**1963-1965, 1967-1971, 1974-1975, 1977, 1979, 1983-1986, 1988, 1991-1993**	**1970-1971, 1974-1975, 1977, 1979, 1983-1986, 1988, 1991-1993, 2002, 2005-2009**	**58**	**52**	**No**

Table 3. Comparison of High Pavement Service Temperatures Before and After 1996 (continued)

Station name	Range of years before 1996*	Range of years after 1996*	Original LTPPBind	Updated LTPPBind	Match **
West Thompson Lake	1964, 1968-1971, 1974-1978, 1982-1990, 1994	1969-1971, 1974-1978, 1982-1990, 1994, 2005, 2007	58	58	Yes
Wigwam Reservoir	1970-1972, 1974-1975, 1978-1980, 1982-1988, 1990-1991, 1993-1995	1970-1972, 1974-1975, 1978-1980, 1982-1988, 1990-1991, 1993-1995	58	58	Yes

*** Refers to 20 years of complete data, in terms of days which, were used to determine high pavement service temperatures; years may/may not be continuous.**
**** *Match* indicates whether corresponding low pavement service temperatures of weather stations determined by original LTPPBind and updated LTPPBind V3.1 are the same or not.**

3.6 Construction Information

The binder grades which were used for the construction of the test sections were PG 64-22 and PG 64-28. According to ConnDOT, both binders for both locations came from the same supplier and the same terminal. The sources of binder and aggregates used for construction of the test sections are summarized in Table 4.

Table 4. Sources of Binder and Aggregates Used for Construction of Test Sections

Binders and Materials	Route 59 (Easton)	Route 341 (Kent)
PG 64-28	New York	New York
PG 64-22	New York	New York
Coarse Aggregate	Southbury	Burrville
Fine Aggregate	Danhill	Burrville

With the exception of the last section of Rt. 341 in Easton, the wearing surfaces were all milled to a depth of 2 inches before the test sections were constructed. 9.5-mm and 12.5-mm aggregate mixes were used for construction of leveling and wearing courses, respectively, for all of the test sections in Easton and Kent. The Job Mix Formulas (JMF) and gradations of the aggregates which were used for construction of all of the test sections are shown in Tables 5-10.

Table 5. JMF Gradation and Actual Average 9.5-mm Gradation – Rt. 59 (Easton)

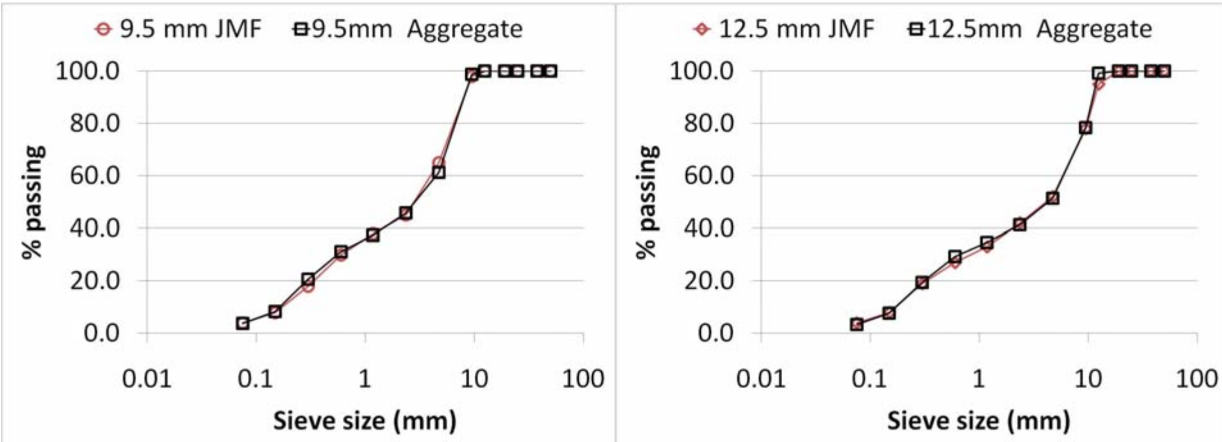
Sieve Size (mm)	% Passing (JMF Recommendation)	% Passing (Actual Quantitative Control Test Sheet)
0.075	4.0	3.7
0.15	8.0	8.3
0.3	18.0	20.6
0.6	30.0	31.1
1.18	38.0	37.4
2.36	45.0	45.7
4.75	65.0	61.4
9.5	98.0	98.7
12.5	100.0	100.0
19	100.0	100.0
25	100.0	100.0
37.5	100.0	100.0
50	100.0	100.0

Table 6. JMF Gradation and Actual Average 12.5-mm Gradation – Rt. 59 (Easton)

Sieve Size (mm)	% Passing (JMF Recommendation)	% Passing (Actual Quantitative Control Test Sheet)
0.075	4.0	3.3
0.15	8.0	7.6
0.3	19.0	19.5
0.6	27.0	29.3
1.18	33.0	34.7
2.36	42.0	41.3
4.75	52.0	51.5
9.5	78.0	78.4
12.5	95.0	99.1
19	100.0	100.0
25	100.0	100.0
37.5	100.0	100.0
50	100.0	100.0

It can be seen from Figure 8 below that the gradations of the 9.5 mm and 12.5 mm aggregate used for construction of the test sections on Rt. 59 in Easton both conform to the JMF.

Figure 8. JMF and Actual Gradations – Rt. 59 (Easton)



Specific gravities of the 9.5-mm and 12.5-mm aggregates used for construction of test sections in Easton conform to Job Mix Formula as demonstrated in Table 7.

Table 7. JMF and Actual Specific Gravities – Rt. 59 (Easton)

	9.5 mm-JMF	9.5-mm Actual	12.5-mm JMF	12.5-mm Actual
Gmm	2.542	2.547	2.587	2.585
Gse	2.793	2.811	2.804	2.826
Gsb	2.751	2.751	2.766	2.766
Gb	1.030	1.030	1.030	1.030

Table 8. JMF Gradation and Actual Average 9.5-mm Gradation – Rt. 341 (Kent)

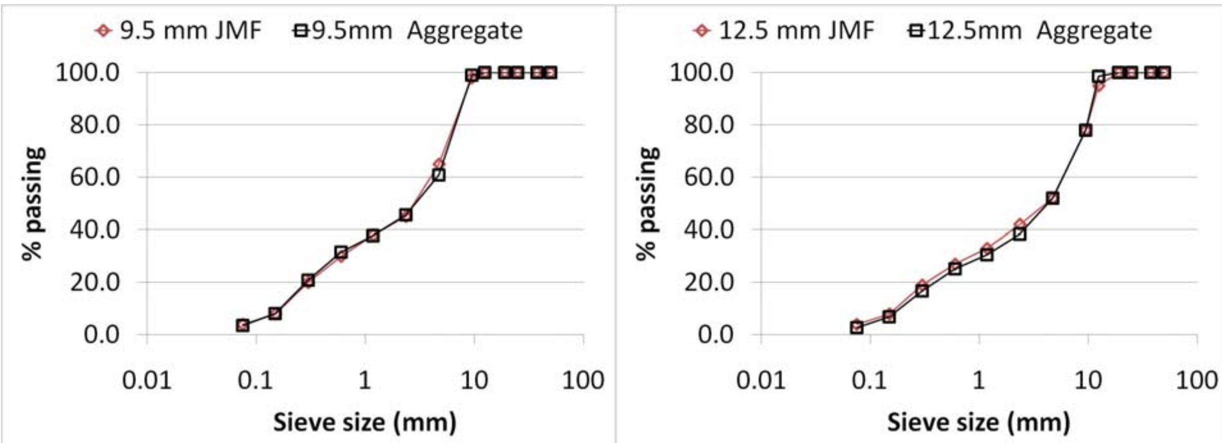
Sieve Size (mm)	% Passing (JMF Recommendation)	% Passing (Actual Quantitative Control Test Sheet)
0.075	4.0	3.6
0.15	8.0	8.2
0.3	20.0	20.9
0.6	30.0	31.7
1.18	38.0	37.8
2.36	45.0	45.6
4.75	65.0	60.8
9.5	98.0	99.0
12.5	100.0	100.0
19	100.0	100.0
25	100.0	100.0
37.5	100.0	100.0
50	100.0	100.0

Table 9. JMF Gradation and Actual Average 12.5-mm Gradation – Rt. 341 (Kent)

Sieve Size (mm)	% Passing (JMF Recommendation)	% Passing (Actual Quantitative Control Test Sheet)
0.075	4.0	2.7
0.15	8.0	6.9
0.3	19.0	16.8
0.6	27.0	25.2
1.18	33.0	30.6
2.36	42.0	38.4
4.75	52.0	52.0
9.5	78.0	78.0
12.5	95.0	98.5
19	100.0	100.0
25	100.0	100.0
37.5	100.0	100.0
50	100.0	100.0

It is apparent from Figure 9, below, that the gradations of the 9.5-mm and 12.5-mm aggregate used for construction of the test sections in Kent both conform to the JMF.

Figure 9. JMF and Actual Gradations – Rt. 341 (Kent)



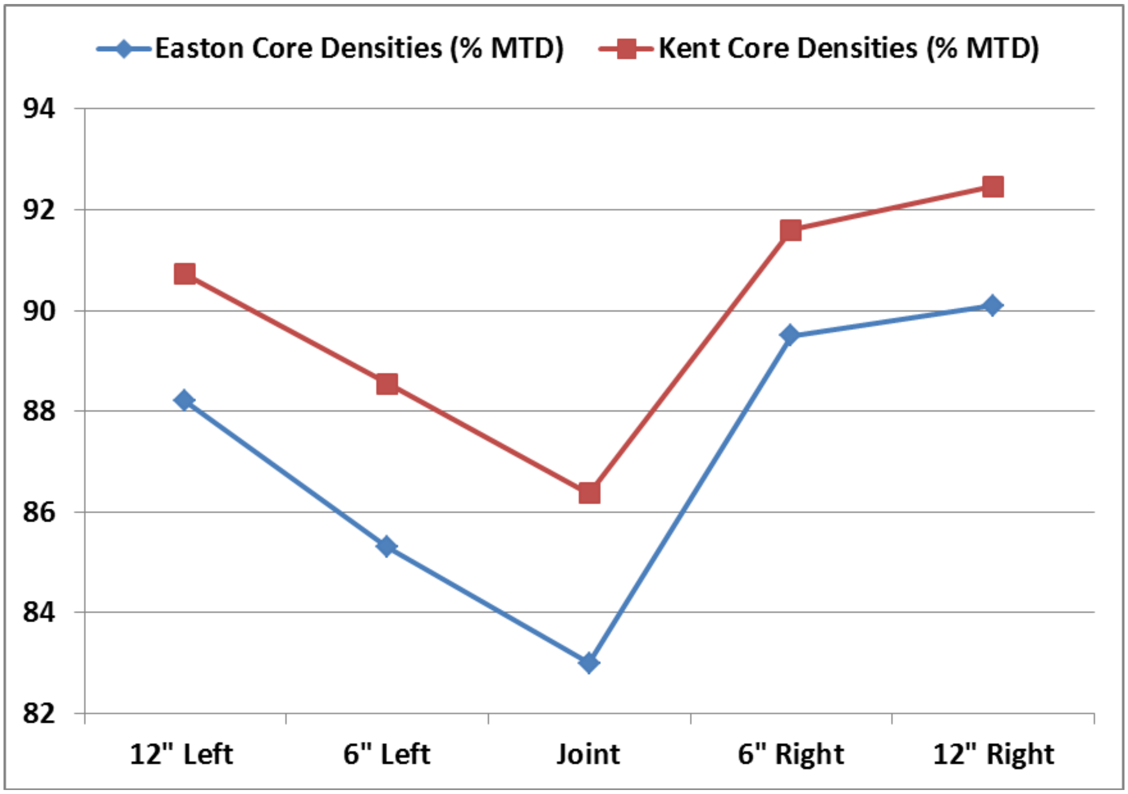
It is clear from Table 10 below that specific gravities of both the 9.5-mm and 12.5-mm aggregate used for construction of test sections in Kent conform to JMF requirements.

Table 10. JMF and Actual Specific Gravities – Rt. 341 (Kent)

	9.5-mm JMF	9.5-mm Actual	12.5-mm JMF	12.5-mm Actual
Gmm	2.542	2.550	2.587	2.588
Gse	2.793	2.809	2.804	2.829
Gsb	2.751	2.751	2.766	2.766
Gb	1.030	1.030	1.030	1.030

Figure 10 represents interval plots of core densities for both locations. These densities of cores taken from the test sections were measured by Connecticut Advanced Pavement Laboratory (CAP Lab) personnel in 2006. The cores were first taken at the longitudinal joint, followed by two measurements each at 6-in. intervals to the left and right of the longitudinal joint. It is clear from Figure 10, below, that the HMA in-place densities do not meet ConnDOT Hot Mix Asphalt (HMA) Specifications and Special Provisions Section 4.06.03-11 of 94.5 ± 2.5% of the maximum theoretical gravity [17]. It is apparent from Figure 10, below, that test sections of Rt. 341 (Kent) had higher measured densities than those of Rt. 59 (Easton) along the longitudinal joint locations.

Figure 10. Core Densities Across Longitudinal Joints – Easton and Kent



CHAPTER 4: Visual Field Evaluations

Both test locations were visited twice during the duration of this project. The visits took place on November 23, 2009, and on June 21, 2011. The details of both visits are attached in Appendix A, and the following observations can be made based on the 2011 visit:

- Rt. 59 Easton – the amount of transverse cracking is relatively equal on both PG 64-22 test sections and PG 64-28 test sections.
- Rt. 59 Easton – All sections show an equal amount of slight raveling and longitudinal cracking.

- Rt. 341 Kent – Sections with PG 64-28 show just a few more transverse cracks than PG 64-22 sections.
- Rt. 341 Kent – Shows no signs of mix-related issues (like raveling) or longitudinal cracking.

Based on this summarization, no significant difference in performance between the two different binder grades can be noted.

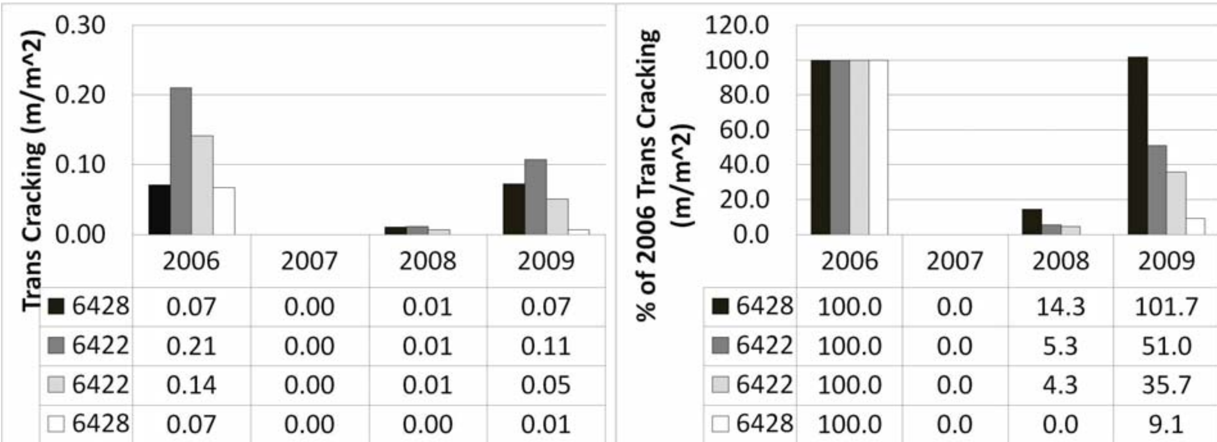
CHAPTER 5: Analysis of Historical Distress Data

This section presents comparison between the measured field performances of the test sections. Historical distress data including cracking, International Roughness Index (IRI) and rutting data, were collected on the test sections. IRI and rutting data were collected by the Automatic Road Analyzer (ARAN) van. The ARAN van is a specially built vehicle that incorporates sensors, computers and other systems for collecting pavement distress data. Due to inconsistencies in the condition data collected by the ARAN van, data for this project were collected using visual rating of the ARAN front view images. These images were evaluated using American Society for Testing and Materials (ASTM D 6433-03)-Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys [18]. The length of transverse cracks on test sections were determined visually by using pavement images from the Digital Highway software. This software compiles engineering data on all routes in Connecticut every year. Cracking intensities were determined by dividing total lengths of transverse cracking by corresponding areas of test sections.

5.1 Photolog Cracking

Levels of transverse cracking on Easton test sections are shown in Figure 11. The amount of cracking in year 2006 is relatively high because the cracking data was collected before the milling and resurfacing project took place. It is clear from Figure 11 that the amount of transverse cracking in 2009 was double on the PG 64-22 test sections, as compared with the 64-28 sections. The percentage of 2006 transverse cracking on the right of Figure 11 shows the opposite, as the PG 64-28 test sections had higher percentage of the level of transverse cracking present in 2006 than PG 64-22 test sections. These observations agree with the 2011 field evaluation summarized in Appendix A.

Figure 11. Transverse Cracking on Rt. 59 (Easton)

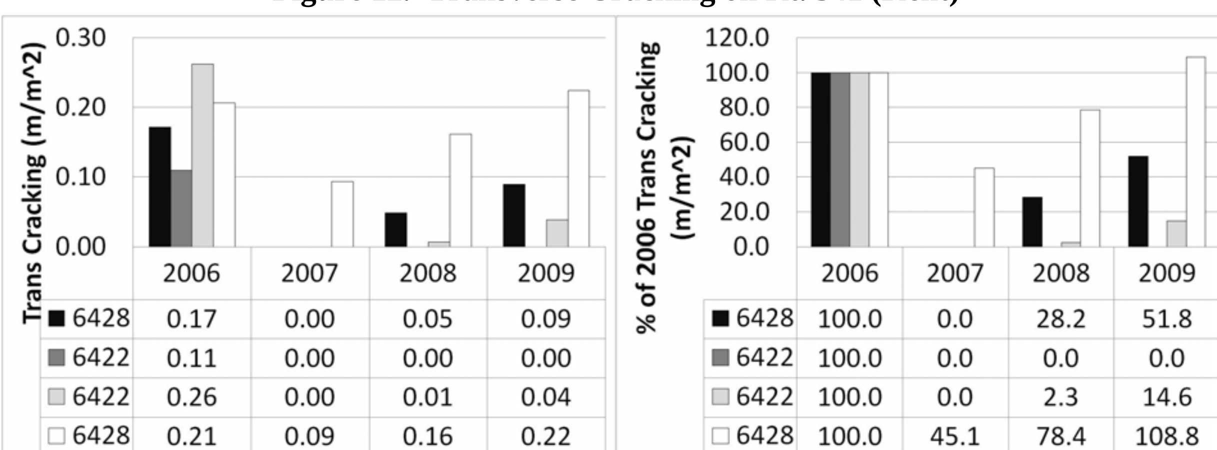


	2006	2007	2008	2009
6428	0.07	0.00	0.01	0.07
6422	0.21	0.00	0.01	0.11
6422	0.14	0.00	0.01	0.05
6428	0.07	0.00	0.00	0.01

	2006	2007	2008	2009
6428	100.0	0.0	14.3	101.7
6422	100.0	0.0	5.3	51.0
6422	100.0	0.0	4.3	35.7
6428	100.0	0.0	0.0	9.1

The last PG 64-28 test section in Kent was constructed on a non-milled surface. Reflective cracking, therefore, produced the highest amount of transverse cracking on this section. It is apparent from Figure 12 that the amount of transverse cracking and the percentage of 2006 transverse cracking on the first test section constructed with PG 64-28 is higher than the PG 64-22 test sections. This observation agrees with the 2011 field evaluation summarized in Appendix A.

Figure 12. Transverse Cracking on Rt. 341 (Kent)



	2006	2007	2008	2009
6428	0.17	0.00	0.05	0.09
6422	0.11	0.00	0.00	0.00
6422	0.26	0.00	0.01	0.04
6428	0.21	0.09	0.16	0.22

	2006	2007	2008	2009
6428	100.0	0.0	28.2	51.8
6422	100.0	0.0	0.0	0.0
6422	100.0	0.0	2.3	14.6
6428	100.0	45.1	78.4	108.8

5.1.1 Statistical Analysis of Pavement Cracking Data

The Student's t-test was used to determine whether there is a significant difference between the means of two different groups of test results from the two test sections. The one-tail t-test was used to test the hypothesis that PG 64-28 asphalt binder would outperform PG 64-22 asphalt binder in northern parts of Connecticut. The t-test was used because cracking and other distress data which were collected from the test sections were assumed to be normally distributed. The sample sizes of cracking and other distresses from PG 64-22 and PG 64-28 test sections are not the same; therefore, the t-tests were conducted assuming unequal variances. Transverse cracking on test sections from Easton and Kent from the year 2007 to 2009 were analyzed statistically using the described t-test.

The results of the t-test on cracking data from Easton and Kent from the years 2007 to 2009 are shown Tables 11 and 12, respectively. Table 11 shows that there is no significant statistical difference in cracking performance between PG 64-22 and PG 64-28 in Easton. There is, however, a significant statistical difference in cracking performance between the two binder grades on the Kent sections, as shown in Table 12. This could be attributed to the fact that the last PG 64-28 section in Kent was constructed on a non-milled wearing course and developed more cracking than the other sections as a result of reflection.

Table 11. Statistical Analysis (T-Test) of Cracking on Rt. 59 (Easton)

	PG 64-28	**PG 64-22**
Mean cracking density (m/m^2)	0.015	0.03
Variance	0.0008	0.0018
p-value (one-tail)	0.25	
Statistically different	**No**	

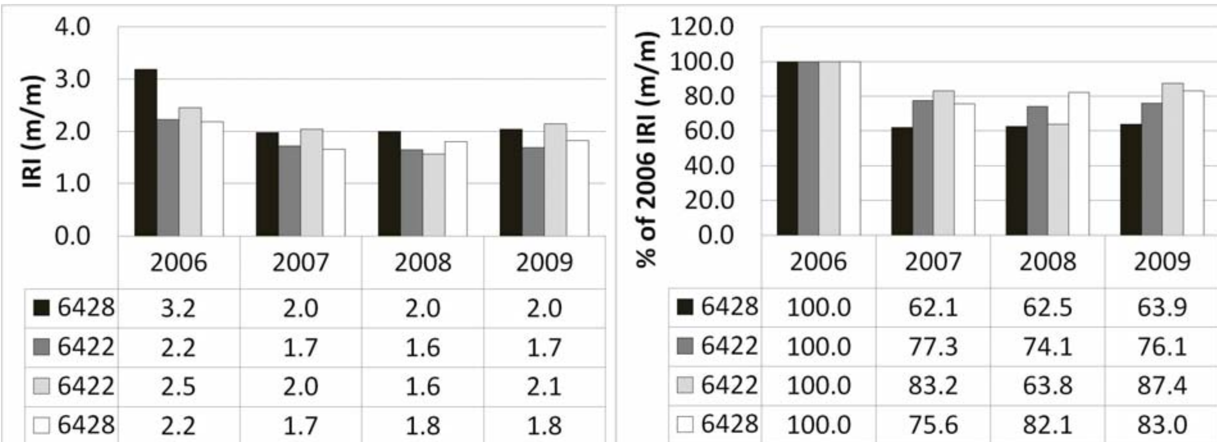
Table 12. Statistical Analysis (T-Test) of Cracking on Rt. 341 (Kent)

	PG 64-28	**PG 64-22**
Mean cracking density (m/m^2)	0.102	0.007
Variance	0.0064	0.0002
p-value (one-tail)	0.02	
Statistically different	**Yes**	

5.2 International Roughness Index (IRI)

There is a very small difference in the level of roughness on the Easton PG 64-22 and PG 64-28 test sections, as shown below in Figure 13. Figure 13 shows that PG 64-22 test sections have a higher percentage of 2006 roughness than PG 64-28.

Figure 13. IRI – Rt. 59 (Easton)

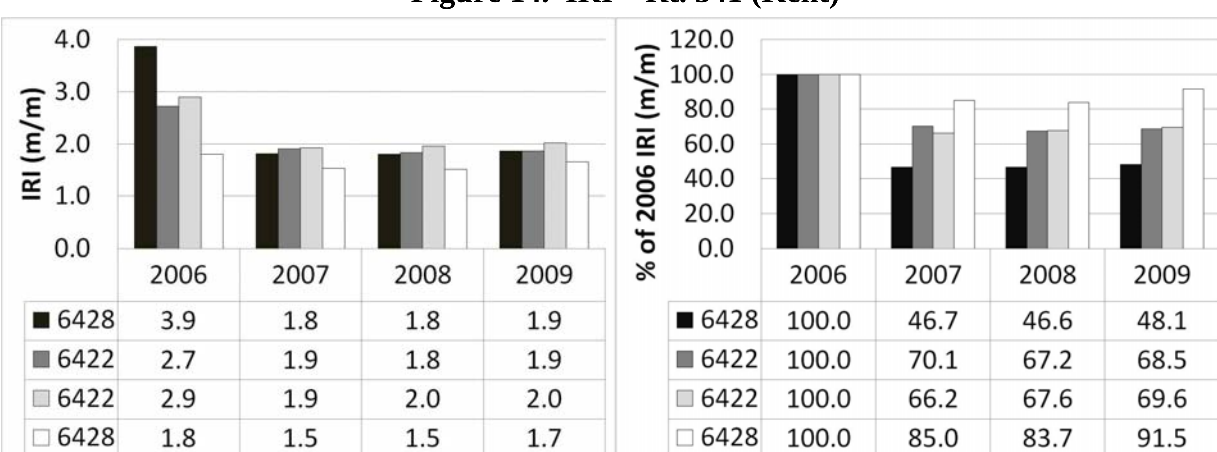


	2006	2007	2008	2009
■ 6428	3.2	2.0	2.0	2.0
■ 6422	2.2	1.7	1.6	1.7
□ 6422	2.5	2.0	1.6	2.1
□ 6428	2.2	1.7	1.8	1.8

	2006	2007	2008	2009
■ 6428	100.0	62.1	62.5	63.9
■ 6422	100.0	77.3	74.1	76.1
□ 6422	100.0	83.2	63.8	87.4
□ 6428	100.0	75.6	82.1	83.0

The roughness levels shown in Figure 14 below indicate that the amount of roughness on the Kent PG 64-22 test sections is higher than that of PG 64-28 for the years 2007 to 2009. With the exception of the fourth test section constructed with PG 64-28 in Kent, the percentage of 2006 roughness on the PG 64-22 test sections is higher than the first PG 64-28 test section, as seen in Figure 14. The reader should note that the fourth test section, which was constructed with PG 64-28, was not milled and this likely contributes to higher roughness values.

Figure 14. IRI – Rt. 341 (Kent)



	2006	2007	2008	2009
■ 6428	3.9	1.8	1.8	1.9
■ 6422	2.7	1.9	1.8	1.9
□ 6422	2.9	1.9	2.0	2.0
□ 6428	1.8	1.5	1.5	1.7

	2006	2007	2008	2009
■ 6428	100.0	46.7	46.6	48.1
■ 6422	100.0	70.1	67.2	68.5
□ 6422	100.0	66.2	67.6	69.6
□ 6428	100.0	85.0	83.7	91.5

5.2.1 Statistical Analysis of International Roughness Index (IRI) Data

Roughness data on the sections from Easton and Kent from the year 2007 to 2009 was analyzed statistically using the two-sample t-test, assuming unequal variances. Table 13 shows that there is no significant difference between the roughness performance of PG 64-28 and PG 64-22 in Easton. There is, however, significant difference between the roughness performance of PG 64-28 and PG 64-22 in Kent, as shown in Table 14.

Table 13. Statistical Analysis (T-Test) of Roughness – Rt. 59 (Easton)

	PG 64-28	**PG 64-22**
Mean roughness (m/m)	1.88	1.80
Variance	0.02	0.05
p-value (one-tail)	0.25	
Statistically different	**No**	

Table 14. Statistical Significance of Roughness on Rt. 341 (Kent)

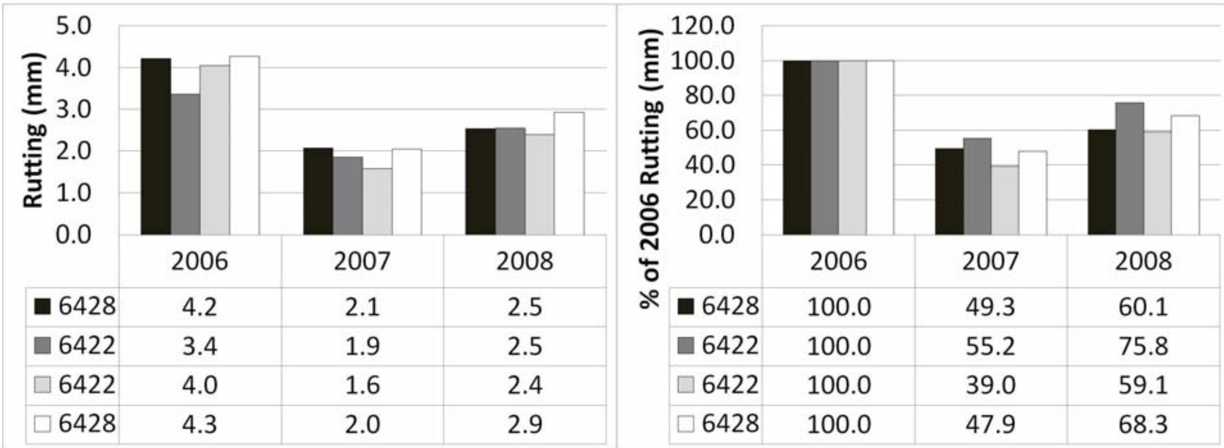
	PG 64-28	**PG 64-22**
Mean roughness (m/m)	1.69	1.91
Variance	0.023	0.005
p-value (one-tail)	0.01	
Statistically different	**Yes**	

A possible explanation for the statistical difference in IRI values between the different test sections in Kent is the percentage of 2006 roughness which was present in the fourth test section which was not milled, unlike all the other sections. It is the opinion of the research team that this statistical difference is unrelated to the binder performance grade.

5.3 Photolog Rutting

The amount of rutting on PG 64-28 test sections is higher than PG 64-22 test sections from 2007 to 2008 in Easton, as shown in Figure 15. Figure 15 does not, however, show any apparent difference between the percentage of 2006 rutting for PG 64-22 and PG 64-28 test sections from the year 2007 to 2008. There was no rutting data available for the Kent sections.

Figure 15. Rutting – Rt. 59 (Easton)



5.3.1 Statistical Analysis of Rutting Data

Rutting data from the Easton test sections from the year 2007 to 2008 were subjected to statistical analysis using the two-sample t-test, assuming unequal variances. It is evident from results of the statistical analysis in Table 15, that there is no significant statistical difference between the rutting resistance of PG 64-22 and PG 64-28 on the Easton test sections. There was no rutting data available for the Kent test sections.

Table 15. Statistical Analysis (T-Test) of Rutting – Rt. 59 (Easton)

	PG 64-28	**PG 64-22**
Mean Rutting (mm)	2.40	2.09
Variance	0.17	0.20
p-value (one-tail)	0.18	
Statistically different	**No**	

5.4 Summary of Historical Distress Data

Statistical analyses of historical distress data on PG 64-22 versus PG 64-28 test sections from both sites were conducted using the two-sample t-test, assuming unequal variances. The results of statistical analyses of cracking on the Easton test sections indicate that there was no significant statistical difference in performance between PG 64-22 and PG 64-28 binders. However, PG 64-28 test sections in Kent showed significantly more cracking than the PG 64-22 test sections. This could be attributed to the fact that the last PG 64-28 section in Kent was constructed on a non-milled surface. This was a straight overlay on an untreated, existing HMA surface, and it developed more cracking than the other test sections.

Results of statistical analyses showed that there was no statistically significant difference in roughness between PG 64-22 and PG 64-28 test sections in Easton. There was, however, a significant difference in the roughness performance between PG 64-28 and PG 64-22 sections in Kent, which can be contributed to the differences in levels of cracking.

Rutting data were available for only the Easton test sections. There was no statistically significant difference in rutting between PG 64-22 and PG 64-28 test sections.

Tables 16 and 17 summarize statistical comparisons of distresses between PG 64-28 and PG 64-22 test sections in Easton and Kent.

Table 16. Statistical Comparisons of Distresses – Rt. 59 (Easton)

Distress	Statistically Different
Cracking	No
Roughness	No
Rutting	No

Table 17. Statistical Comparisons of Distresses – Rt. 341 (Kent)

Distress	Statistically Different
Cracking	Yes
Roughness	Yes

CHAPTER 6: Analysis of Laboratory Data

In order to further establish the performance comparison of PG 64-28 and PG 64-22 binders, HMA specimens were fabricated utilizing the two different binders, and these specimens were subjected to the following AASHTO laboratory tests:

- Determination of Low-Temperature Performance Grade (PG) of Asphalt Binders (AASHTO PP 42-07) [19];
- Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage (AASHTO T 283-07) [20]; and,
- Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the APA (TP 63-07) [21].

The results of the laboratory data analysis were correlated with field performance data to draw conclusions on the performance comparison of the two different binder grades.

6.1 Asphalt Binders

Samples of PG 64-22 and PG 64-28 binders from Easton and Kent were collected in 2006 and tested in the laboratory to determine their true low- and high-temperature PG grades.

6.1.1 Continuous PG Grades

The true high-temperature performance grade of the original and aged (Rolling Thin Film Oven aged to simulate oxidation from production of HMA) binders from Easton and Kent are shown in Table 18 and compared in Figure 16. The true high-temperature performance grades for the PG 64-22 and PG 64-28 yield an official high PG grade for both binders of 64˚C.

Table 18. True High PG of Rt. 59 (Easton) and Rt. 341 (Kent) Binders

Project	Original Binder (˚C)	RTFOT (˚C)	True Grade (˚C)	PG Grade (˚C)
Rt. 59 (Easton) PG 64-22	67.48	69.79	67.48	64
Rt. 59 (Easton) PG 64-28	65.96	69.99	65.96	64
Rt. 341 (Kent) PG 64-22	67.94	69.88	67.94	64
Rt. 341 (Kent) PG 64-28	66.02	71.34	66.02	64

Figure 16. True High PG – Rt. 59 (Easton) and Rt. 341 (Kent)

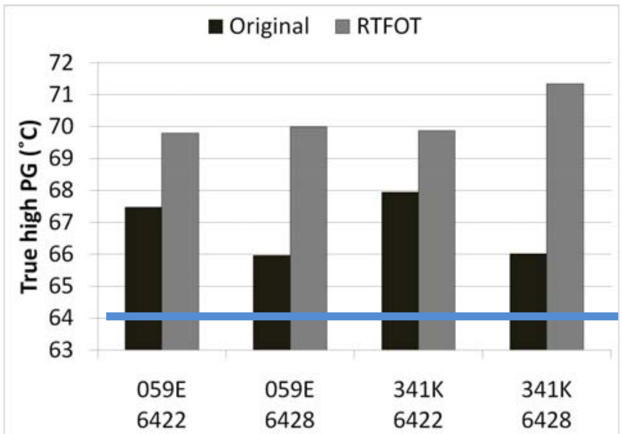
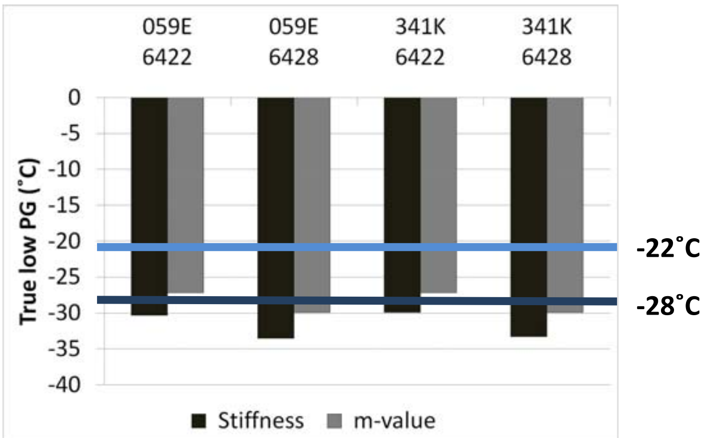


Table 19 and Figure 17 show the true low PG binder grades from Easton and Kent. For a binder to be given a low-temperature performance grade of -22, the m-value (measured via the bending beam rheometer) must meet a minimum of -22.0 °C. Likewise, to be given a low-temperature performance grade of -28, the m-value must meet the minimum of -28 °C. Based on the m-values in Table 19, the low PG grade for the PG 64-22 binders for both the Easton and Kent projects is -22˚C. Also shown in Table 19 is that the low PG grade for the PG 64-28 binders for both the Easton and Kent projects is -28˚C. It should be noted that the true low PG grades of -22 binders from both locations were very close (within 0.8 °C) to passing the low-temperature criteria for PG 64-28 binders.

Table 19. True Low PG Binder Grades

Project	Stiffness (˚C)	m-value (˚C)	True Grade (˚C)	PG Grade (˚C)
Rt. 59 (Easton) PG 64-22	-30.3	-27.2	-27.2	-22
Rt. 59 (Easton) PG 64-28	-33.5	-29.2	-29.2	-28
Rt. 341 (Kent) PG 64-22	-29.9	-27.2	-27.2	-22
Rt. 341 (Kent) PG 64-28	-33.3	-29.9	-29.9	-28

Figure 17. True Low PG Binder Grades



6.1.2 Critical Cracking Temperature

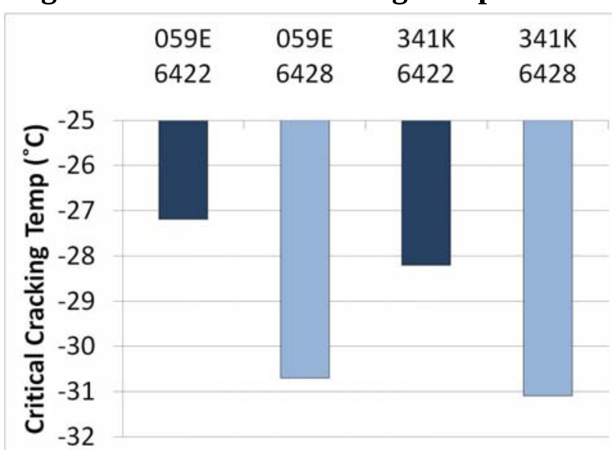
The critical cracking temperatures of PG 64-22 and PG 64-28 mixes from both locations were determined in accordance with the AASHTO PP 42-07 [19]. Creep compliance data was taken from the bending beam rheometer (BBR). Based on the creep compliance data, the tensile stresses developed in the binders under standardized conditions were determined. Afterwards, the strength of the asphalt binder was taken from the direct tension test (DTT). The tensile stresses were then compared with the strength of the binders, and the temperature at which the tensile stress was equal to the strength of the asphalt binder was determined as the critical cracking temperature.

Table 20 and Figure 18 show the critical cracking temperatures of the binders from both projects. Table 20 indicates that the PG 64-28 binders from both locations are more resistant to cracking than PG 64-22. It should be noted that the critical cracking temperatures of the PG 64-22 binders went below -22˚C by more than 5˚C, while critical temperatures for PG 64-28 pass their low PG grade by only 3˚C. This indicates, similar to the true PG grading, that the PG 64-22 binders in both locations were very close to passing as PG 64-28 binders.

Table 20. Critical Cracking Temperatures

Mix	Critical Cracking Temperature
Rt. 59 (Easton) PG 64-22	-27.2
Rt. 59 (Easton) PG 64-28	-30.7
Rt. 341 (Kent) PG 64-22	-28.2
Rt. 341 (Kent) PG 64-28	-31.1

Figure 18. Critical Cracking Temperatures



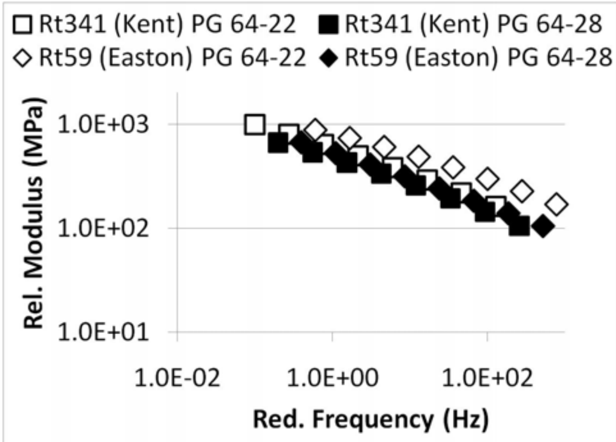
6.1.3 Relaxation Modulus Master Curves

BBR creep compliance data from both projects were converted to relaxation modulus master curves, using numerical methods proposed by Hopkins and Hamming [22]. These curves are shown in Figure 19. The temperatures at which creep stiffness of the mixes were determined are summarized in Table 21. Figure 19 indicates that PG 64-22 binders, from both locations, produced higher relaxation moduli than those of PG 64-28 binders.

Table 21. Temperatures for Determination of Stiffness of Binders

Mix	Temperature (˚C)
Rt. 59 (Easton) PG 64-22	-12, -18, -24
Rt. 59 (Easton) PG 64-28	-18, -24, -30
Rt. 341 (Kent) PG 64-22	-12, -18, -24
Rt. 341 (Kent) PG 64-28	-18, -24

Figure 19. Relaxation Modulus Master Curves



6.2 Hot Mix Asphalt (HMA) Specimens Prepared in the Laboratory

HMA specimens were fabricated and subjected to the following tests in the laboratory:

- AASHTO T-283, Tensile Strength Ratio (TSR); and,
- AASHTO TP-63, Asphalt Pavement Analyzer (APA) rut depth.

6.2.1 Tensile Strength Ratio (TSR)

The tensile strengths of the HMA mixes were tested in accordance with AASHTO T 283-07 [20]. To determine the TSRs, gyratory specimens were prepared using both of the different binder grades. The number of gyratory specimens per set for this test is three, as shown in Table 23. The gyratory specimens were prepared by compacting HMA mix in a gyratory compactor to a height of 95 mm. Gyratory specimens were prepared to a target air void content of 7 ± 0.5%. Table 22 summarizes the measured, average air void content of mixes which were prepared for determination of the TSR values. The conditioned specimens were saturated to fill 70-80% of the air voids with water. They were then wrapped in plastic wrap and frozen for at least 16 hours. The conditioned specimens were then soaked in a 60˚C water bath for 24 hours, removed and placed in a 25˚C water bath for two hours before testing. Unconditioned specimens were also placed in a 25˚C water bath for two hours before testing. The ConnDOT specification requirement for TSRs is that the tensile strength of the conditioned specimens be a minimum of 80% of the tensile strength of the unconditioned specimens [23]. Figure 20 shows that the TSR from the Easton PG 64-22 mix exceeded that of the Easton PG 64-28 mix. This was not the case for the Kent specimens, as the TSR of PG 64-28 mix exceeded that of PG 64-22.

Table 22. Measured Average Air Void Content of TSR Specimens

Mix	Measured Air Voids (%)
Rt. 59 (Easton) PG 64-22	7.20
Rt. 59 (Easton) PG 64-28	6.88
Rt. 341 (Kent) PG 64-22	6.98
Rt. 341 (Kent) PG 64-28	6.63

Table 23. HMA Specimens Prepared for Each Binder

Specimens	Number of PG 64-28 HMA Specimens	Number of PG 64-22 HMA Specimens
Conditioned TSR	3	3
Unconditioned TSR	3	3

Figure 20. Tensile Strength Ratios

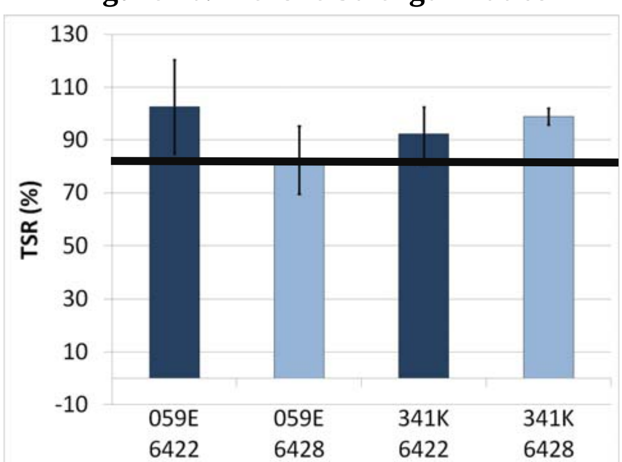


Table 24. TSR Values – Rt. 59 (Easton)

	Rt. 59 (Easton) PG 64-28	Rt. 59 (Easton) PG 64-22
Tensile Strength Ratio (%)	82.1	101.0

Table 25. TSR Values – Rt. 341 (Kent)

	Rt. 341 (Kent) PG 64-28	Rt. 341 (Kent) PG 64-22
Tensile Strength Ratio (%)	98.8	91.9

The TSR values presented in Tables 24 and 25 indicate that both binders are adequate in meeting the required resistance to moisture induced damage. That minimum value is 80% [17], and all specimen averages from both projects meet this minimum requirement.

6.2.2 Asphalt Pavement Analyzer (APA) Rut Depths

APA rut depths at 8,000 cycles for all mixes were determined in accordance with AASHTO TP 63-07 [21]. Six (6) HMA specimens each for both types of binders were conditioned at a target temperature of 64˚C before testing in the APA. A total of 8,000 cycles of wheel loading were applied to the HMA specimens in the APA chamber. The measured average air void contents of APA mixes are shown in Table 26.

6.2.2.1 Statistical Analysis of Asphalt Pavement Analyzer (APA) Rut Depths

APA rut depths were analyzed statistically using the two-sample t-test, assuming unequal variances. There is no significant difference between APA rut depth resistance of PG 64-22 and PG 64-28 mixes from either location. The means and variances are shown in Tables 27 and 28 support this statement.

Table 26. Measured Average Air Void Content of APA Specimens

Mix	Measured Air Void (%)
Rt. 59 (Easton) PG 64-22	3.30
Rt. 59 (Easton) PG 64-28	4.70
Rt. 341 (Kent) PG 64-22	3.43
Rt. 341 (Kent) PG 64-28	3.47

Figure 21. APA Rut Depths

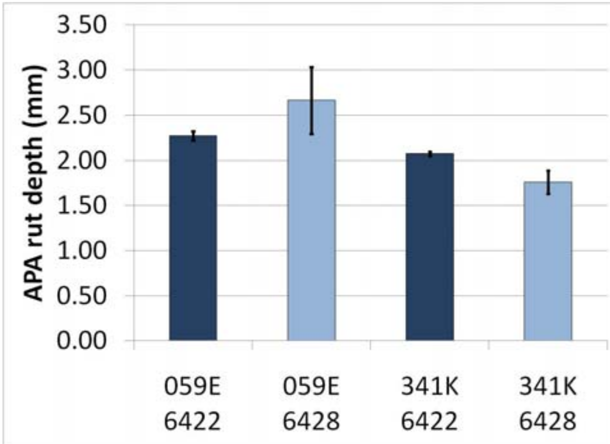


Table 27. Statistical Analysis (T-Test) of APA Rut Depths – Rt. 59 (Easton)

	Rt. 59 (Easton) 64-28	Rt. 59 (Easton) 64-22
Mean rut @8,000 cycles (mm)	2.66	2.27
Variance	0.137	0.003
p-value (one-tail)	0.19	
Statistically significant	**No**	

Table 28. Statistical Analysis (T-Test) of APA Rut Depths – Rt. 341 (Kent)

	Rt. 341 (Kent) 64-28	Rt. 341 (Kent) 64-22
Mean rut @8,000 cycles (mm)	1.76	2.07
Variance	0.017	0.001
p-value (one-tail)	0.09	
Statistically significant	**No**	

CHAPTER 7: Comparison of Field Performance and Laboratory Data

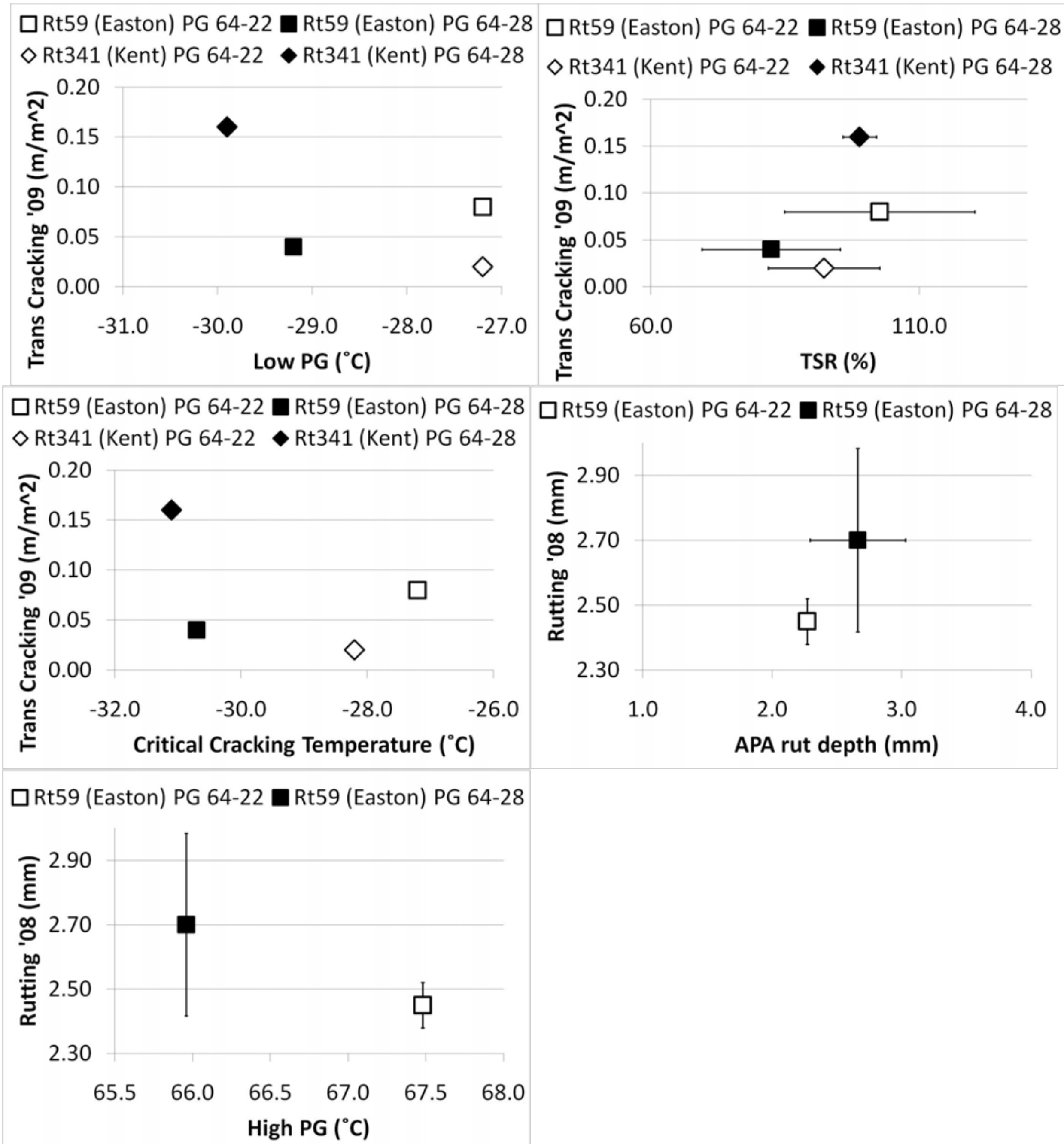
In order to further establish the performance comparison of PG 64-28 versus PG 64-22, field performance and laboratory data were compared. Figure 22 shows how field performance and laboratory data from both locations compare. Figure 22 shows average comparative values of performance and laboratory data from each location.

Rutting data were not available for test sections on Rt. 341 (Kent). Correlations between rutting and laboratory parameters were therefore not determined. Correlation results in Table 29 show that field cracking correlated weakly with laboratory parameters such as true low PG, TSR (%) and critical cracking temperature.

Table 29. Correlation: Field Performance and Laboratory Data

Comparison	R-square Value
Transverse Cracking versus True Low PG Temperature	0.34
Transverse Cracking versus TSR (%)	0.29
Transverse Cracking versus Critical Cracking Temperature	0.10

Figure 22. Comparison Between Field Performance and Laboratory Data



CHAPTER 8: Summary and Conclusions

This research was conducted to determine if a low-temperature performance binder grade of -22° C could be used in Connecticut without a negative impact on performance, longevity and durability. The results of this research do not indicate that a low-temperature performance grade of -22 °C would have a negative impact on performance of HMA pavements. While the previous statement holds true with respect to this research, the reader should consider that the true low-temperature grade of the 64-22 binder was only 0.8° C from being classified as a PG 64-28 binder. It is still possible that a binder with a true low-temperature grade closer to -22° C would underperform with respect to the analysis presented through this research. The following paragraphs summarize the analysis for the performance data and laboratory results:

1. Statistical analyses of historical distress data on PG 64-22 versus PG 64-28 test sections of both locations from the year 2007 to 2009 were conducted using two-sample t-tests, assuming unequal variances. Results of statistical analyses of cracking on Rt. 59 (Easton) indicate that there was no significant difference in cracking performance of PG 64-22 and PG 64-28. On the other hand, cracking on PG 64-28 test sections of Rt. 341 (Kent) was significantly higher than those of PG 64-22 test sections. As stated previously, this could be attributed to the fact that the last PG 64-28 section of Rt. 341 (Kent) was constructed on an untreated surface, and developed more cracking than the other test sections.

2. Results of statistical analyses showed that there was no significant difference in roughness between PG 64-22 and PG 64-28 test sections on Rt. 59 (Easton). There was, however, a significant difference in the roughness performance of PG 64-28 and PG 64-22 on Rt. 341 (Kent).

3. Rutting data was only available for Rt. 59 (Easton). There was no statistically significant difference in rutting of PG 64-22 versus PG 64-28 test sections.

Laboratory tests and analyses were also performed on PG 64-22 and PG 64-28 binders. The following statements can be made:

1. True low PG grades of corresponding binders in both locations were very close, as illustrated in Table 19 and Figure 17.

2. The relaxation moduli of PG 64-22 binders from both locations were greater than those of PG 64-28.

3. Statistical analysis of TSR (%) on PG 64-22 and PG 64-28 mixes from both locations produced results of no significant difference in performance of the two binders.

4. APA rut depth test results of PG 64-22 and PG 64-28 mixes from both locations were also subjected to statistical analysis. There was no significant difference in the APA rutting performance between the two binders from either location.

It should be also noted that some of the assumptions used in this research project did not work out as well as originally planned. For example, the Rt. 341 (Kent) location was supposed to represent colder temperatures and Rt. 59 (Easton) was supposed to represent milder temperatures. Climatic data does not support this assumption. According to the climate data which were used in this project, weather station CT 0806, Bridgeport Sikorsky, which is close to Rt. 59 (Easton) located in the southern part of Connecticut, has colder temperatures than weather station CT 2658, Falls Village, which is close to Rt. 341 (Kent), located in the northern part of Connecticut. As stated, this could be due in part to the Bridgeport weather station being in such close proximity to Long Island Sound.

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Appendix A. Summary of Field Evaluations

November 23, 2009

Rt. 59 EASTON Section #1, paved Oct. 2nd 2006 PG 64-28
Westbound: ~ 10 transverse cracks only in this lane (most stop at the longitudinal joint), this is most level section (no hill), some rutting, no fatigue/long cracks Eastbound: zero transverse cracks
Rt. 59 EASTON Section #2, paved Oct. 3 2006 PG 64-22
Westbound: some fatigue (long) cracks, some interconnected cracks; more transverse cracks than in the Eastbound Eastbound: some transverse cracks but less than in the Westbound
Rt. 59 EASTON Section #3, paved Oct. 4 2006 PG 64-22
Westbound: (uphill), some rutting, some long cracks but NO transverse cracks Eastbound: some surface distresses (loosing fine aggregate, open texture) but NO cracks at all
Rt. 59 EASTON Section #4, paved Oct. 5 2006 PG 64-28
Westbound: 1 long crack at the beginning and 1 in the middle; no transverse cracks, some surface distresses (loosing fine aggregate, open texture) Eastbound: no cracks at all, some surface distresses (loosing fine aggregate, open texture)

Rt. 341 KENT Section #1 PG 64-28
Westbound: 1 long crack at the start, no other cracks except for one full width transverse crack Eastbound: 3-4 transverse cracks
Rt. 341 KENT Section #2 PG 64-22
Westbound: long crack in the middle of lane due to paver, no other cracks Eastbound: 1 minor transverse crack
Rt. 341 KENT Section #3 PG 64-22
Westbound: 1-2 full width transverse cracks (both W and E bound), ~5 transverse in this lane only Eastbound: 1-2 full width transverse cracks (both W and E bound) and no other cracks
Rt. 341 KENT Section #4 PG 64-28

<u>Westbound:</u> – beginning of paving job – <u>multiple</u> full width transverse cracks (both W and E bound), ~9m apart, no long cracks – part of field section – 1-2 full width transverse cracks (both W and E bound), no other transverse or long cracks, surface look good <u>Eastbound:</u> – beginning of paving job – no long cracks – part of field section - 1-2 full width transverse cracks, no other cracks, surface OK

<u>**June 21, 2011**</u>

Rt. 59 EASTON Section #1, based on <u>700ft</u> PG 64-28		
Transverse cracking	Eastbound	Westbound
Full width	**1**	
Full lane	**1**	**6**
Short crack	**0**	**4**

Some longitudinal cracks (traffic-related); some raveling

Rt. 59 EASTON Section #2, based on <u>1500ft</u> PG 64-22		
Transverse cracking	Eastbound	Westbound
Full width	**8**	
Full lane	**5**	**20**
Short crack	**7**	**6**

Some longitudinal cracks (more than Section #1); some raveling

Rt. 59 EASTON Section #3, based on 700ft PG 64-22		
Transverse cracking	Eastbound	Westbound
Full width	**4**	
Full lane	**5**	**13**
Short crack	**2**	**8**

Some longitudinal cracks; some raveling

Rt. 59 EASTON Section #4, based on 500ft PG 64-28		
Transverse cracking	Eastbound	Westbound
Full width	**0**	
Full lane	**0**	**1**
Short crack	**0**	**1**

Some longitudinal cracks; some raveling

Rt. 341 KENT Section #1, based on 1346ft PG 64-28		
Transverse cracking	Eastbound	Westbound
Full width	**4**	
Full lane	**1**	**5**
Short crack	**4**	**5**

Rt. 341 KENT Section #2, based on 1000ft PG 64-22		
Transverse cracking	Eastbound	Westbound
Full width	**0**	
Full lane	**0**	**3**
Short crack	**2**	**0**

Rt. 341 KENT Section #3, based on 1000ft PG 64-22		
Transverse cracking	Eastbound	Westbound
Full width	**3**	
Full lane	**4**	**4**
Short crack	**0**	**0**

Rt. 341 KENT Section #4, based on 800ft PG 64-28		
Transverse cracking	Eastbound	Westbound
Full width	**14**	
Full lane	**12**	**10**
Short crack	**2**	**0**