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Update of the PG Binder Map in California Using the Enhanced Integrated Climate Model (EICM) and LTTPBind Online

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ABSTRACT

California has a diverse climate that ranges from desert regions with some of the hottest places in North America to coastal regions with mild climates and cold summers. The selection of the binder's performance grade (PG) in California is based on a climate map that was developed in 2005 using 1960 to 1990 data from the National Climate Data Center (NCDC) analyzed using the Enhanced Integrated Climate Model (EICM) and the Long-Term Pavement Performance (LTPPBind 2.0) software. Climate change is happening all around the world, and California is no exception. Based on observed pavement performance, there was a need to revise the PG map using updated climatic data from various sources. In this study, the PG binder map for California was updated to better predict pavement performance using the latest available weather data. Thirty years of climate data (1991−2019) were considered to update the current binder's PG map. The weather data were collected from two main sources: NCDC and Modern-Era Retrospective Analysis for Research and Applications (MERRA). It was found that pavement structure types and thermal coefficients have insignificant effects on the binder performance grade. Also, it is recommended that the binder high PG for the central valley of California be changed based on the results obtained from analysis using EICM and LTPPBind Online.

INTRODUCTION

The two main external factors controlling the performance of pavements are traffic and environment (Harvey et al. 2000; Lu et al. 2009). The study of the environmental impact on pavement performance is complicated due to wide range of environmental factors that affect the pavement temperature and moisture condition, and the variability of climate with time and across different regions. California has a unique climate where notable differences in weather can be seen between different regions within the state. These differences occur over short distances, primarily driven by the presence of high mountain ranges, and low valleys caused by faults in geotectonic faults. These differences in climate have a significant impact on pavement distress mechanisms and pavement performance (Hernandez-Fernandez et al. 2022; Ullidtz et al. 2010). It is thus important to incorporate climatic data into the design process to account for changes in material properties due to variations in temperature. In the mechanistic-empirical design approach, climatic data are used to predict hourly pavement temperatures over the design life of the pavement. Previous work conducted at the University of California Pavement Research Center (UCPRC) resulted in the development of a binder performance grade map for California using nine different climatic regions (Harvey et al. 2000; Ongel and Harvey 2004). These regions were identified based on the amount of rainfall and air temperatures using data from the National Climatic Data Center (NCDC) between 1961 and 1990 and analyzed using the Climatic Database for Integrated Model (CDIM) and later its successor the Enhanced Integrated Climate Model (EICM) software (Harvey et al. 2000; Ongel and Harvey 2004). The nine different regions were: high mountain, low mountain, south mountain, central valley, north coast, central coast, south coast, high desert, and desert. Climate change is happening all around the world and California is no exception. In some regions, pavement is not showing the anticipated performance. Therefore, updating the PG binder map for California is necessary using the most recent climate data. The scope of this current study is to better predict pavement performance using the latest available weather data. The 30 years of climate data starting from 1990 to 2019 were considered to select an appropriate asphalt binder PG for different regions in California.

The objectives of this study are:

- Identify representative weather stations for different climate regions.
- Develop temperature gradients along the full depth of the asphalt pavement using EICM and most recent climate data from MERRA and NCDC.
- Assess the effect of different model parameters, pavement structures, and traffic levels on the pavement temperatures.
- Compare the EICM results with the LTTPBind Online results

METHODS

Climate Regions

Table 1 shows the nine different climate regions and the representative stations within each region selected in this study. Representative stations have been selected, starting with the 2000 study, based on completeness of data and where their data fit on the spectrum of stations in the same geographic area (geographic areas largely controlled by elevation and proximity to the Pacific Ocean). Some changes were made to the weather stations to select stations with the most complete set of climate data from the previous study as shown in Figure 1 (Ongel and Harvey 2004). For the central valley region, the weather station at Fresno Yosemite International Airport was selected instead of Sacramento, used in previous studies, because it is more representative of the high temperatures in the valley than Sacramento (Sacramento receives more marine influence than the rest of the valley). Figure 1 shows the locations of different weather stations in this study and previous study.

EICM Input and Data Sources

In this study, EICM version 3.0 was used to simulate the temperature of the pavement at different depths for different pavement structures. This software was originally developed by the University of Illinois in cooperation with Texas Transportation Institute and Texas A&M University (Larson and Dempsey 1997). The energy and mass conservation was used to calculate the pavement temperature at different depths based on a one-dimensional finite element model using heat and moisture flow (Bulut et al. 2013; Quintero 2007). Each EICM run covers 10 years of climate data to predict pavement temperatures. A minimum pavement thickness of 240 in.

(6000 mm) is required to run EICM (Quintero 2007). EICM determines the pavement's hourly high and low temperatures using either the daily or hourly climate data. In this study, the hourly climate data were not available for all representative cities hence the daily climate data were used instead. The climate data inputs include the daily maximum and minimum temperature, precipitation, wind speed, and solar radiation. These data were collected from two main sources: National Climate Data Center (NCDC) and MERRA. The analysis period covered the years 1990 to 2019 for all nine weather stations. The analysis was performed for each data source. The NCDC dataset did not contain solar data so the solar data from MERRA were added to the NCDC dataset. The wind data obtained from MERRA were unreasonably low for some weather stations located at a relatively higher elevation as shown the Table 2 (note that has been discussed with other researchers, and may be due to rounding and conversion between metric and US units that is endemic to the database). For those cases, NCDC wind data were used to replace the MERRA wind data. The United States Geological Survey (USGS) website was used to obtain the water depth data for the different regions.

Table 1: Selected Weather Station for Different Climate Regions

Climate Region	Location	Place	Latitude	Longitude	Elevation (m)
High Mountain	Blue Canyon	Blue Canyon Airport, CA, US	39.28	-120.71	1608
Low Mountain	Trinity River	Lonnie Pool Field Weaverville Airport, Trinity, CA, US	40.75	-122.92	716
South Mountain	Sandberg	Sandberg, CA, US	34.74	-118.72	1375
Central Valley	Fresno	Fresno Yosemite International, CA, US	36.78	-119.72	102
North Coast	Arcata	Arcata Eureka Airport, CA, US	40.98	-124.11	61
Central Coast	San Francisco	San Francisco International Airport, CA, US	37.62	-122.36	2
Desert	Daggett	Barstow Daggett Airport, CA, US	34.85	-116.79	584.3
South Coast	Los Angeles	Los Angeles International Airport, CA, US	33.94	-118.39	30
High Desert	Reno	Reno Airport, NV, US	39.48	-119.77	1344

Table 2: Comparison of Average Wind Speed Data from NCDC and MERRA for Blue Canyon (High Mountain)

Date	Wind Speed, kmph	
	From NCDC	From MERRA
January 1, 1990	7.3	0.0
January 2, 1990	10.5	0.0
January 3, 1990	4.0	0.3
January 4, 1990	3.4	0.5
January 5, 1990	3.1	0.6
January 6, 1990	6.6	1.1
January 7, 1990	10.1	1.0
January 8, 1990	9.0	0.0
January 9, 1990	7.3	0.0
January 10, 1990	4.2	1.1

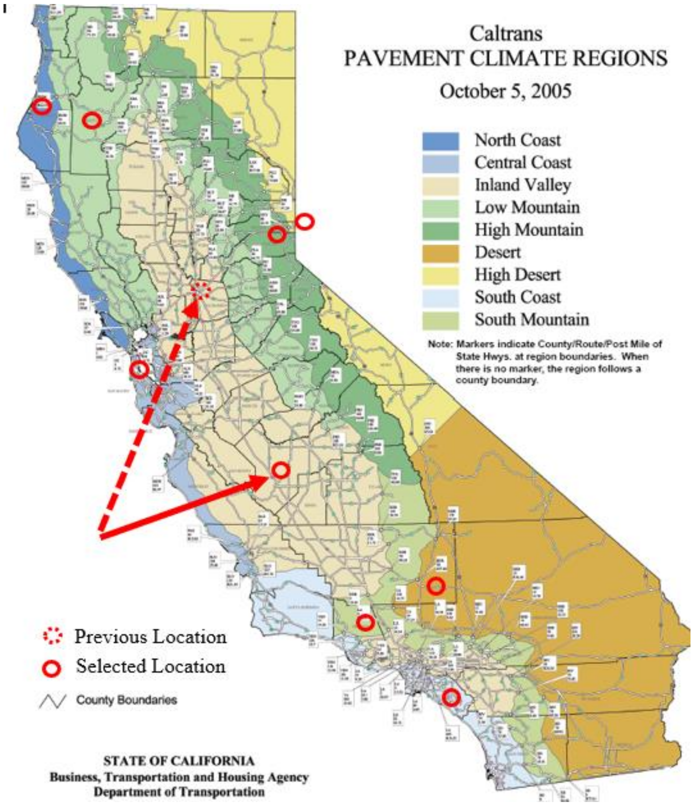


Figure 1: California Pavement Climate Regions with Selected Weather Stations (After Ongel and Harvey (2004))

Another important parameter for predicting pavement temperature is solar absorptivity. The solar absorptivity of pavement is found to vary with pavement type and age. The solar absorptivity can be calculated by deducting the albedo value from 1.0. It was reported in the previous literature that the albedo value of asphalt surfaced pavement can vary between 0.05 to 0.015 (Li et al. 2013; Li et al. 2017). Therefore, solar absorptivity values of 0.85 and 0.95 were considered for this study. For this research, the surface layers were divided into 0.67 in. (17 mm) increments while the base and subbase layers were divided into 2 in. (50 mm) increments. The subgrade was divided into eight increments regardless of the thickness since EICM gives stability errors if the layer is divided into too many small increments. For the determination of the high temperature PG, it was not possible to determine the temperature at exactly 0.80 in. (20 mm) pavement depth since this would have resulted in a very fine mesh in EICM, which leads to model instability. Therefore, pavement temperature at 0.67 in. (17 mm) depth was considered to determine the high temperature PG.

EICM Output

A single run in EICM can only include 10 years of data so it was necessary to run EICM three times and combine the output to cover the entire 30-year period from 1990 to 2019. The EICM output includes hourly data on pore water pressure, water content, frost heave, drainage performance and nodal temperatures. For this study, only the maximum and minimum nodal temperatures were considered for further analysis.

Pavement Structures

Eight different Asphalt Concrete (AC) and four composite pavements (asphalt surface on an underlying concrete pavement) were considered in this study. The structures of the asphalt and composite pavements are given in Table 3 and Table 4, respectively. The thickness of the subgrade was varied to keep the total pavement thickness including the subgrade as 240 in. (6000 mm). A designation of AC 0.2.6.12 indicates an asphalt concrete pavement with no overlays, 2 in. (50 mm) AC thickness, 6 in. (150 mm) aggregate base thickness, and 12 in. (300 mm) aggregate subbase. AC-PCC Comp. indicates an asphalt concrete on top of a concrete composite pavement.

Table 3: Flexible Pavement Structures

Structure Name	Designation	Layer Thickness, in.(mm)			
		Asphalt Concrete	Aggregate Base	Aggregate Subbase	Subgrade
AC Structure 1	AC 0.2.6.12	2(50)	6(150)	12(300)	220(5500)
AC Structure 2	AC 0.4.6.12	4(100)	6(150)	12(300)	218(5450)
AC Structure 3	AC 0.6.6.12	6(150)	6(150)	12(300)	216(5400)
AC Structure 4	AC 0.8.6.12	8(200)	6(150)	12(300)	214 (5350)
AC Structure 5	AC 0.12.6.12	12(300)	6(150)	12(300)	210(5230)
AC Structure 6	AC 0.16.6.12	16(400)	6(150)	12(300)	206(5150)
AC Structure 7	AC 0.22.6.12	22(550)	6(150)	12(300)	200(5000)
AC Structure 8	AC 0.28.6.12	28(700)	6(150)	12(300)	194(4850)

Table 4: Types of Composite Pavement

Structure Name	Designation	Layer thickness, in. (mm)				
		Asphalt Concrete	Portland Cement Concrete	Aggregate Base	Aggregate Subbase	Sub grade
Composite structure 1	AC-PCC Comp. 0.4.8.6.12	4(100)	8(200)	6(150)	12(300)	210
Composite structure 2	AC-PCC Comp. 0.4.12.6.12	4(100)	12(300)	6(150)	12(300)	206
Composite structure 3	AC-PCC Comp. 0.8.8.6.12	8(200)	8(200)	6(150)	12(300)	206
Composite structure 4	AC-PCC Comp. 0.8.12.6.12	8(200)	12(300)	6(150)	12(300)	202

Effect of base and subbase layer thicknesses

To determine the effect of the base and subbase layer thickness, different pavement structures with varying base and subbase thicknesses were analyzed in EICM for the Fresno station as given in Table 5. The letter "S" before the pavement designation represents that these structures were studied to determine the sensitivity of changing the base and subbase thicknesses. The thickness of the subgrade was varied to keep the total pavement thickness including the subgrade as 240 in. (6000 mm).

Table 5: Flexible Pavement Structures for Thickness Sensitivity

Structure Name	Designation	Layer Thickness, in.(mm)			
		Asphalt Concrete	Aggregate Base	Aggregate Subbase	Sub grade
Structure 1	S-AC 0.2.6.6	2(50)	6(150)	6(300)	226(5650)
Structure 2	S-AC 0.2.6.12	2(50)	6(150)	12(300)	220(5500)
Structure 3	S-AC 0.2.12.6	2(50)	12(300)	6(150)	220(5500)
Structure 4	S-AC 0.2.12.12	2(50)	12(300)	12(300)	214 (5350)

Effect of heat and thermal capacities

The default heat capacity, c and thermal capacity, k parameters in the EICM software are 924 Joules/ kg °C and 1.16 W/m °C. It was reported by Li et al. (2013) that the heat capacity, c value varies between 767 to 2000 Joules/m °C and thermal capacity, k value varies between 0.74 to 2.89 W/m °C for asphalt pavement (Li et al. 2013). The effect of the heat and thermal capacities on the selected binder's performance grade was studied.

Long-Term Pavement Performance (LTPP)

The LTTPBind software was developed by the Federal Highway Administration (FHWA) to provide transportation agencies with a tool to select the PG binder based on climate data. LTTPBind has undergone several versions introducing many changes that include incorporating various performance models and providing more comprehensive climate data. The latest version used in this study is LTTPBind Online. This section provides a general overview of the current LTTPBind Online version and the previous LTTPBind 3.1 version.

The LTPPBind version 3.1 software uses climate data from several weather stations across the US and Canada to select the appropriate PG binder for a certain region. The US climatic data were obtained from the National Climatic Data Center (NCDC). The NCDC contains a large set of climatic data that includes as an example, temperature, snowfall, precipitation, evaporation rate, and wind speed. The LTTPBind software utilizes the daily maximum and minimum temperatures, in addition to the location, to calculate the high-temperature and low-temperature PG binder limits. The PG calculation can be adjusted to account for the depth below the pavement surface. The models used in LTTPbind are empirical models which were developed based on seasonal monitoring data of Long-Term Pavement Performance (LTPP) (Mohseni et al. 2005).

The calculation of the low-temperature PG limit is based on the following equation:

$$T_{pav} = -1.56 + 0.72T_{air} - 0.004Lat^2 + 6.26\log(H+25) - z\sqrt{(4.4 + 0.52{S_{air}}^2)}$$

Where T_{pav} = 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.

The calculation of the high-temperature PG limit is based on a rutting model that relates the rut depth to the high-temperature PG. The model uses degree-days above 10°C over a period of 20 years, and it considers the traffic loading and speed, depth below the pavement surface, and reliability level. The high-temperature PG at 50 percent reliability, and a fast speed with less than 3 million ESALs traffic, is given by the following equation (Mohseni et al. 2005):

$$PG_d = 48.2 + 14\,DD - 0.96\,DD^2 - 2RD$$

Where PG_d = PG damage at a rut depth
DD = 20-year degree-days > 10 °C (x1000 °C)
RD = rut depth (5-13 mm)

The PG_d can be corrected for depth and adjusted for traffic loading and speed. The adjustment for the traffic loading and speed involves increasing the high-temperature PG by a factor depending on the high-temperature PG limit of the base binder, as well the number of ESALs and traffic speed expressed as either fast or slow (Mohseni et al. 2005).

The LTTPBind Online uses the same pavement temperature prediction models that are used in the 3.1 version. LTTPBind Online is an easily accessible web-based tool that relies on an extensive climate dataset from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) (Wiser 2017). The MERRA dataset is administered by the National Aeronautics and Space Administration (NASA). It contains climate data from 1979 and has a spatial resolution of 0.5 degrees latitude by 0.67 degrees longitude.

For LTPPBind Online software target rut depth and traffic considered were 0.5 in. (12.5 mm) and fast traffic with 43.5 mph (70 km/ hr) speed, respectively. In this study, MERRA data source was used in the LTPPBind Online software to determine the PG binder. The climate region were selected by providing the specific latitude and longitude values of a known weather station or by searching the location name (Wiser 2017).

RESULTS AND DISCUSSION

Base and Subbase Thickness

The effect of base and subbase thicknesses on pavement temperature at different depths was studied for the Fresno station in the central valley region. The thicknesses were varied for both the base and subbase layers to evaluate their effect on the pavement temperature as shown in Table 5.

The pavement temperatures at different depths on a randomly selected time (14th June 1994 at 2 pm) were determined as shown in Table 6. For all cases, the difference in pavement temperature with respect to the S-AC 0.2.6.12 case did not exceed 0.2 ºC. This temperature difference is not expected to change the determination of the PG binder. Based on these results, it was concluded that varying the base or subbase thicknesses would not significantly affect the selection of the PG binder.

Effect of Thermal Parameters on PG binder.

As discussed earlier, the heat capacity, c, varies between 767 to 2000 Joules/m °C and the thermal capacity, k, varies between 0.74 to 2.89 W/m °C for asphalt pavements (Li et al. 2013).

To account for this variation, different EICM runs were conducted using a range of c and k values to evaluate their effect on the pavement temperature. The sensitivity analysis on the thermal parameters was conducted for Fresno (Central Valley). An absorptivity level of 0.95 and 0.85 resulted in the critical high PG (average 7-days maximum temperature at 17 mm depth) and low PG (1-day minimum temperature at surface) values at a 98 percent confidence level, respectively. This result is expected since higher absorptivity levels cause more heat to be stored in the pavement. Table 7 and Figure 2 present the effect of thermal parameters on the PG binder for Fresno. Case 1 with the lowest heat capacity and thermal conductivity showed the maximum high and minimum low PG. However, the differences between the EICM default case and case 1 were less than 6 ºC for both high and low PG. Therefore, binder grade bumping is not expected due to variations in the heat capacity and thermal conductivity values of pavement. Model instability was observed for case 2 as shown in Table 7 due to the combination of very large thermal conductivity (2.89 W/m °C) with a relatively small heat capacity value (767 Joules/m °C).

Table 6: Effect on Base and Subbase Thickness on Pavement Temperature

Pavement Designation	**S-AC 0.2.6.12**	**S-AC 0.2.6.6**		**S-AC 0.2.12.6**		**S-AC 0.2.12.12**	
Pavement Depth, mm	**Temp., °C**	**Temp., °C**	**Difference, °C**	**Temp., °C**	**Difference, °C**	**Temp., °C**	**Difference, °C**
0	47.8	47.9	-0.1	47.8	0.0	47.8	0.0
25	44.5	44.6	-0.1	44.5	0.0	44.5	0.0
50	41.6	41.7	-0.1	41.6	0.0	41.6	0.0
100	39.9	40.0	-0.1	39.9	0.0	39.9	0.0
150	36.9	37.1	-0.2	36.9	0.0	36.8	0.1
200	34.5	34.7	-0.2	34.5	0.0	34.4	0.1
250	32.7	32.9	-0.2	32.7	0.0	32.6	0.1
300	31.4	31.6	-0.2	31.5	-0.1	31.3	0.1
350	30.6	30.6	0.0	30.6	0.0	30.4	0.2

Table 7: Effect of Thermal Parameters in EICM

Cases	**Heat Capacity, c (Joules/m °C)**	**Thermal Conductivity, k (W/m °C)**	**High PG (Absorptivity 0.95)**	**Low PG (Absorptivity 0.85)**
Default	924	1.16	64.9	-2.8
Case 1	767	0.74	65.8	-4.2
Case 2	767	2.89	Model instability	
Case 3	2000	0.74	61.2	-0.9
Case 4	2000	2.89	59.9	2.1

Comparison between Different Pavement Structures

As mentioned in the research method section of this paper, eight different AC structures and four different composite pavement structures with asphalt on the top were considered in this study. For the Blue Canyon station (High Mountain region), the low temperature and high temperature PG obtained from EICM using MERRA data are plotted in Figure 3. The high and low PG values were observed for the AC pavement with 12 in. (300 mm) surface layer thickness. As expected, relatively greater high PG values were observed as MERRA wind data were considered for this analysis. Based on this finding, the AC 0.12.6.12 pavement was further considered for the determination of PG binder for other regions.

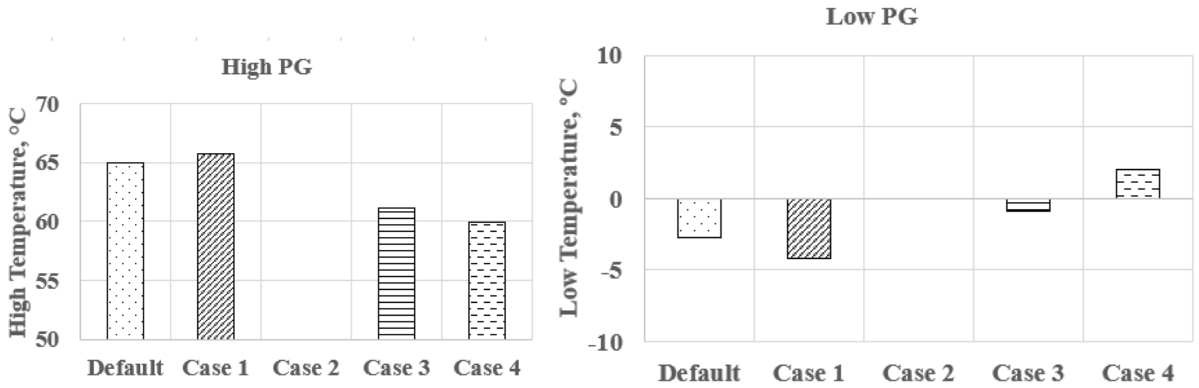
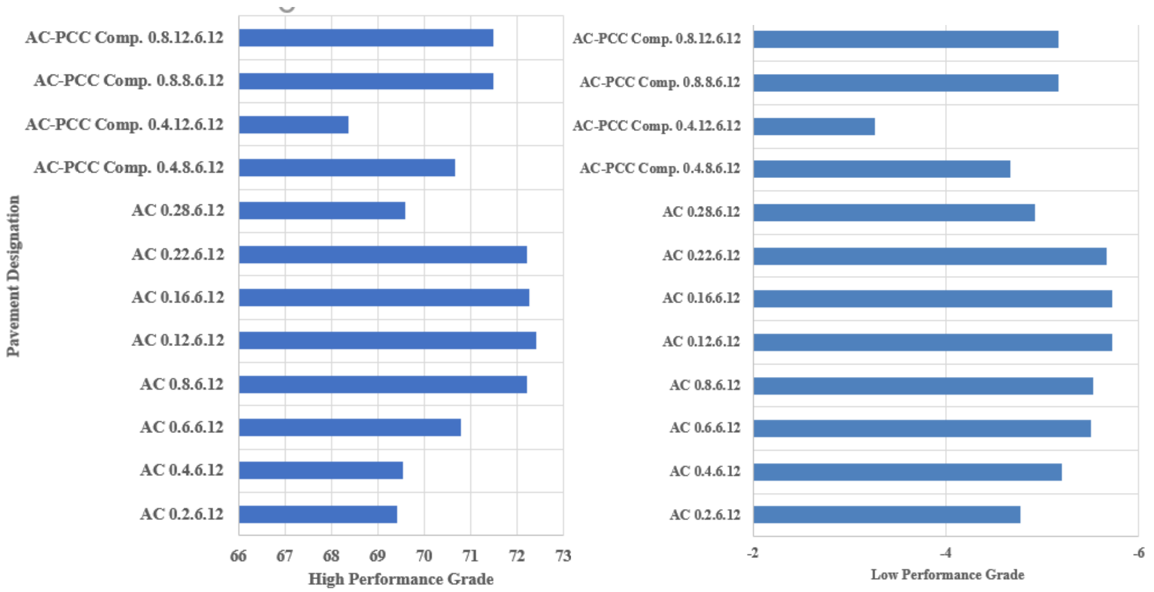


Figure 2: High and Low PG for Different Thermal Parameters



(a) **(b)**

Figure 3: (a) High PG binder (b) Low PG Binder for Blue Canyon with MERRA Data

Typical EICM and LTPPBind Online Outcomes (Central Valley)

Table 8 presents the summary of pavement high and low temperatures for central valley. For the LTTPBind Online, the MERRA data were used whereas for the EICM analysis, different combinations of climate data were considered. As explained earlier, for some climate regions, especially with higher elevations (Trinity river, Blue Canyon, and Sandberg) the wind speed data were unreasonably low from the MERRA data source compared to corresponding NCDC wind data. Therefore, NCDC wind data with MERRA climate data were also considered in the EICM analysis. A solar absorptivity value of 0.95 resulted in higher pavement temperature due to more heat storage compared to a solar absorptivity of 0.85. The combination of MERRA climate data with NCDC wind data for 0.95 solar absorptivity was found to show reasonable critical high PG (average 7-days maximum temperature at 98% confidence level at 17 mm pavement depth) for central valley. On the other hand, NCDC data with MERRA solar data with 0.85 solar absorptivity mostly shows the critical low temperature (1-day minimum temperature at 98% confidence level at pavement surface) from EICM analysis as shown in Table 8. The high average pavement temperature of 7 Days at a 98% confidence level at 17 mm depth obtained from LTPPBind Online was 65.9°C. A similar high temperature (64.9°C) was found from the EICM software while considering the MERRA data source with NCDC wind data. Similar trends were also observed for all other climate regions. Therefore, a summary of the outputs is shown in Table 9.

Table 8. High and Low Pavement Temperature for Fresno (Central Valley)

Data Source	Albedo	At 17 mm depth			At surface		
		High Average Pavement Temperature of 7 Days, °C	High Average Pavement Temperature of 7 Days at 98%, °C	High Average Pavement Temperature of 7 Days at 50%, °C	Low Pavement Temperature, °C	Low Pavement Temperature at 98%, °C	Low Pavement Temperature at 50%, °C
LTPPBind Online (ESAL < 3 millions)*	--	--**	65.9	--	--	-7.6	-2.7
MERRA	0.85	66.0	65.5	62.6	-1.5	0.1	3.6
MERRA	0.95	69.0	68.5	65.3	-1.4	0.2	3.7
NCDC+MERRA (Solar)	0.85	59.9	58.8	56.3	-3.1	-2.8	3.2
NCDC+MERRA (Solar)	0.95	62.2	61.2	58.6	-2.9	-2.6	3.3
MERRA+NCDC (Wind)	0.85	62.7	62.4	59.7	0.3	0.5	3.7
MERRA+NCDC (Wind)	0.95	65.3	64.9	62.2	0.4	0.6	3.8

*For the LTPPBind Online, MERRA dataset was used.

** LTPPBind Online gives output pavement data in 50 and 98 percentile statistics

Summary of Binder High and Low PG for California

A summary of the results obtained using LTTPBind Online and EICM is shown in Table 9. The pavement temperatures from LTPPBind Online were obtained at a default ESAL level of less than 3 million. To assess the effect of traffic level on the selected binder's performance grade, the pavement temperatures were calculated for different ESAL ranges. For most climate regions, the high temperature performance grade was shown to increase by two grades as the ESAL level increases from less than 3 million to above 30 million. Based on the EICM and LTPP data analysis, the recommended PG binder is shown in Table 9.

In this study, the PG specification suggested by Ongel and Harvey (2004) was considered as the baseline value (Table 9). Then high and low PGs obtained from EICM software with updated climate data and LTPPbind Online were compared with the baseline data. Based on the comparison the final PG binder was recommended in this study. In some cases, a higher binder PG was suggested to avoid producing different types of base binder from the manufacturers. For example, PG 58-10 might be sufficient for the central coast (San Francisco) as shown in Table 9. However, PG 64-10 was suggested for this region to avoid producing too complex a regime of base binders for the refining industry. As shown in Table 9, the recommended PG binder for the central valley region should be changed from PG 64-10 to PG 70-10. For all other regions, no change in the PG binder is recommended.

Table 9: Summary of PG binder Results for California

Climate Region	**Location, CA**	**LTPPBind Online**						**From EICM**		**Current PG Specification (Typical)**	**Recommended PG binder**
		Pavement Temperature at 98%		**ESAL <3 million**	**ESAL 3 to 10 million**	**ESAL 10 to 30 million**	**ESAL >30 million**	**High PG**	**Low PG**		
		High at 17 mm	**Low at Surface**								
High Mountain	Blue Canyon	57.1	-20.2	PG 52-22	PG 58-22	PG 64-22	PG 64-22	64.0	-20.6	PG 64-22	PG 64-22
Low Mountain	Trinity River	59.9	-16.3	PG 58-16	PG 64-16	PG 70-16	PG 70-16	66.4	-6.9	PG 64-16	PG 64-16
South Mountain	Sandberg	62.2	-6.5	PG 64-10	PG 70-10	PG 76-10	PG 76-10	61.5	-8.1	PG 64-16	PG 64-16
Central Valley	Fresno	65.9	-7.6	PG 70-10	PG 76-10	PG 76-10	PG 82-10	64.9	-2.8	PG 64-10	PG 70-10
North Coast	Arcata	45.0	-5.2	PG 52-10	PG 52-10	PG 52-10	PG 52-10	50.5	-0.5	PG 64-16	PG 64-16
Central Coast	San Francisco	53.6	-5.7	PG 52-10	PG 58-10	PG 58-10	PG 64-10	55.6	1.6	PG 64-10	PG 64-10
Desert	Daggett	64.5	-9.2	PG 64-10	PG 70-10	PG 76-10	PG 82-10	65.0	-5.1	PG 70-10	PG 70-10
South Coast	Los Angeles	59.2	-4.1	PG 58-10	PG 64-10	PG 70-10	PG 70-10	62.0	2.1	PG 64-10	PG 64-10
High Desert	Reno	57.0	-23.5	PG 52-28	PG 58-28	PG 64-28	PG 64-28	63.9	-14.9	PG 64-22	PG 64-22

CONCLUSIONS

This study evaluated the current California binder's performance grade map that was developed in 2005 by the University of California Pavement Research Center. The work included using climate data from 1990 to 2019. The climate data were obtained from two different sources: MERRA and NCDC. Several pavement structures were analyzed using the EICM 3.0 software, and pavement temperatures were obtained at different depths in the pavement. The study also included a sensitivity analysis of different modeling parameters including base and subbase thicknesses, heat capacity, and thermal capacity of the pavement. For each of the nine climatic regions, a representative city was selected. The main criteria in the selection of the representative city were to ensure that the weather in that city is typical of the entire climate region and that the weather data in that city are complete. Based on the analysis of all nine regions, recommendations were provided to update the binder's performance grade map. Based on the findings from this study, the following conclusions can be made:

- The rutting model used in the LTPPBind Online is not well validated. Therefore, the high temperature PG calculation from LTTPBind Online may not be totally accurate for some regions.
- The use of Reclaimed Asphalt Pavement (RAP) (15% or higher) is not accounted for in this study. The use of RAP is expected to stiffen the binder causing an increase in the blended binder grade. The degree of blending and hence the final binder grade is unknown.
- The change in the base and subbase thickness in the EICM software has an insignificant effect on the final binder PG selection. The change in the base and subbase thickness was found to change maximum 0.2 °C pavement temperature for central valley.
- The changes in heat capacity (c) and thermal capacity (k) values also caused insignificant changes in the high and low PG. Lower heat and thermal capacity values were found to show the most critical combination for both high and low PGs.
- For most climate regions, LTPPBind online and EICM analysis were found to show similar high and low binder PG. The MERRA weather data with NCDC wind at 0.95 solar absorptivity was found to show reasonable critical high PG.

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