Damage Based High-Temperature Performance Grade for Binders

By:
Ala Mohseni (Pavement Systems)
Sam Carpenter (University of Illinois)

Sponsored by:
Federal Highway Administration
Contacts: Monte Symons and John D’Angelo

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Performance Grade (PG)

- Concept Used by SHRP for SUPERPAVE in early 90’s
- To Endure a Certain Climate, PG binders are selected Such That Rutting Damage is Below Critical Value.
- High Temp. $\text{PG} = \text{Mean 7-day High Pavement Temperature}$
- SHRP Used Integrated Climatic Model (ICM) to Estimate Pavement Temp. @ 20mm Depth From Air Temperature
  - Wind Speed and Cloud Cover Parameter values were Assumed
- SHRP Developed two Transfer Functions to Estimate High Surface and Pavement Temperature from Air Temperature
- Enhancements during $\text{SHRPBind}$ in 1994, $\text{LTPPBind}$ in 1998
High Temperature PG Distribution
Project Goals

- Develop Enhanced High Pavement Temperature Transfer Function Similar to SHRP
  - Use Hourly Climatic Data (Air Temp., Cloud Cover and Wind Speed) for 20 Years at 270 Locations in the U.S.
- Adjust High Pavement Temperature for Performance
- Compare New PG with SHRP PG
- Develop New Climatic Database and Enhanced Version of LTPPBind Software
New Mean 7-day Transfer Function

\[ T_{\text{pav}} = 32.7 + 0.837 \ T_{\text{air}} - 0.0029 \ \text{Lat}^2 + \epsilon \]

- \( T_{\text{air}} \) = Mean 7-Day High air Temp.@ 20mm Depth, °C
- \( T_{\text{pav}} \) = Mean 7-Day High Pavement Temp. °C
- Lat = Latitude, Degrees
- \( \sigma_{\text{model}} = 2.1 \ °C \)
- \( \epsilon = z \left( \sigma_{\text{model}}^2 + 0.7 \ \sigma_{\text{air}}^2 \right)^{0.5} \)
- \( R^2 = 74\% \)
- \( N = 187 \)
Adjust PG for Performance

Basis of SHRP PG:

- PG asphalt binders are graded according to the climatic conditions they will endure in the roadway.
- A PG 64 will perform in as high as a high pavement temperature of 64°C.

Basis of Damage Concept:

- PG that Provides Acceptable Performance Under 20 Years of Service
- Asphalt binder’s response to loading as a function of temperature, magnitude, repetition and rate of loading (J. Bukowski).
- PG is Directly Related to Climate and Rutting Level.
Pavement Temperature Frequency

Frequency of Pavement Temp. for TX12960

Pavement Temperature, C
Frequency, Hours
Hourly Pavement Temp. Frequencies (20-year)

The diagram shows the hourly pavement temperature frequencies for two locations, WA24157 and FL12844, over a 20-year period. The pavement temperatures are measured in degrees Celsius.

- **WA24157**:
  - DDP = 0.8
  - Hours: 1, 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77

- **FL12844**:
  - DDP = 1.7
  - Additional hours include: 8, 12, 14, 16, 18, 22, 24, 31, 35, 74, 76

The Y-axis represents the hours, ranging from 0 to 14,000. The X-axis represents the pavement temperature in degrees Celsius, ranging from 20 to 80.
DAMAGE?

- Need Commonly Agreeable Model for Rutting (AASHTO 2002)
  \[ \log(\epsilon_p/\epsilon_r) = a + b \log(N) + c \log(T) \]

- Mix stiffness using mix parameters (Witczak Model)

- Examine Loadings to Produce a Failure Level (Set by agency)

- Calculate Loads to Produce The Failure Limit Established – \( N_f \)
  In each temperature level

- Hours Pavement Within Temperature Range

- Calculate Applied Loads During Each Temperature Range – \( N_a \)

- For Each Temperature Range Damage = \( \frac{N_a}{N_f} \)

- Sum Each Range for Total Damage
Calculating PG Damage

To **Endure** a Certain Climate, PG binders are selected Such That Rutting Damage is Below Critical Value.

![Graph showing Damage vs. PG with SHRP PG = 57]
PG Damage Transfer Function

- Five Limiting Rut Depths (RD)
  - 0.2” to 0.5” every 0.05”
  - 5.1, 6.4, 7.6, 8.9, 10.2, 11.4 and 12.7mm
- Frequency = 10 Hz (for High Speed)
- Traffic Loading = 3 Million Standard Axle Uniformly Applied over 20 year Period
- Use PG Range of 40 to 88
- Database has 1307 Records (~187 Sites per Rut Depth)
Damage Based Transfer Function

\[ \text{PG}_D = 48.2 + 0.7 \text{DD}_{\text{air}} - 0.0024 \text{DD}_{\text{air}}^2 - 2 \text{RD} + \varepsilon \]

\( \text{PG}_D \) = PG Damage at a Rut Depth
\( \text{DD}_{\text{air}} \) = 20-Year Degree-Days\( >10^\circ \text{C} \) (x1000 °C)
\( \text{RD} \) = Rut Depth (5-13 mm)
\( \varepsilon \) = Error Term = \( z \sigma_{\text{model}} \)
\( \sigma_{\text{model}} \) = 2.5 °C
\( R^2 \) = 90 %
\( N \) = 1307
Predicted PG @ Rut Depth vs. Degree-Days

Degree-Days>10°C, x1000 °C

Predicted PG @ Rut Depth
- 5.1 mm
- 6.4 mm
- 7.6 mm
- 8.9 mm
- 10.2 mm
- 11.4 mm
- 12.7 mm
PG Damage vs. SHRP for 6106 Sites

SHRP vs. New PGs for 6106 N. American Sites

SHRP @ 98% Reliability
• New Mean 7day @98% Reliab.
• Damage for 11mm Rut
Mean 7-Day is Very Different Than Degree-Days Around 35°C
Frequency & Damage vs. Temp. TX12960 at PG 63

SHRP PG = 57

Frequency, Hours

0 2000 4000 6000 8000 10000 12000

0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18

Damage

Pavement Temperature, C

11 15 19 23 27 31 35 39 43 47 51 55 59 63 67 71 75
PG Damage Distribution

PG Distribution for 6106 Sites in the U.S.
Grade Bumping

Adjust PG Damage for Higher ESAL and Slower Speed than Standard:

- **Traffic Speed**
  - (High Speed 10 Hz, Median Speed 5Hz)

- **Traffic Loading**
  - (3 Million Standard Axles, 10, 30, 30+)

- **PG Adjustment**
  - \( \Delta PG = PG_n - PG_S \)
Grade Bumping by Base PG and Speed for All Rut Depths

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<th>Speed</th>
<th>Base Grade</th>
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<th>3-10</th>
<th>10-30</th>
<th>30+</th>
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Conclusions

- SHRP PG Algorithm was Insufficient.
- Mean 7-day High Temperature does not Relate well with Performance.
- Performance based on 20-Year Degree-Days above 10ºC Improved Recommended PGs.
- Transfer Function Based on Performance Provided Better PG Distribution.
- Grade Bumping based on Performance Possible.