Applications of Performance-Based Specifications for Mix Designs

Hasan Ozer, PhD
Illinois Center for Transportation
University of Illinois at Urbana-Champaign

February, 03, 2015
Outline and Objectives

- Introduction to the Performance Related/Based Specifications and Some Definitions
- Experiences of Four States:
  - California, Louisiana, Texas, New Jersey
  - PRS/PBS Framework
  - Some Results and Challenges
- Final Thoughts and Future Directions
First Some Terminology

**Performance-related specifications (PRS):**
“QA specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance (e.g. air voids, compressive strength).”

**Performance-based specifications (PBS):**
“QA specifications that describe the desired levels of fundamental engineering properties (e.g. resilient modulus, creep properties, and fatigue) that are predictors of performance and appear in primary prediction relationships (i.e., models that can be used to predict stress, distress, or performance from combinations of predictors that represent traffic, environment, supporting materials, and structural conditions).”

Highway Construction Specifications

1. RESPONSIBILITY

0% Contractor Responsibility

Material & Methods Specifications

QA Specifications

End Result Specifications

100% Contractor Responsibility

2. SAMPLING

Little Information

Representative Sampling

Statistical Specifications

100% Sampling

More information

3. RELATION TO PERFORMANCE

Unknown

Intuitive

Performance Related Specs

Performance Based Specs

Performance Specs

Known

Commonly Used Tests

**Uniaxial Modulus Tests**
- Hamburg Wheel Track
- Semi Circular Bending Beam
- Texas Overlay Test
- Disc Compact Tension
- Uniaxial Fatigue and Permanent Deformation
California Experience

Reference:
Harvey et al. (2014). Performance-Based Specifications: California Experience to Date.
Introduction

- California’s initial implementation of PBSs based on ME began in the late 1990s
- Pavement design framework includes PBSs and the CalME (Caltrans’ Mechanistic Empirical Design Program)
- There key mix performance criteria:
  - Repetitions to 5% strain in the repeated shear strain (RSST) – AASHTO T320
  - 50% loss of stiffness in the Beam Fatigue Test – AASHTO T 321
  - Flexural stiffness at 20 °C and 10 Hz – AASHTO T 321
Performance Tests and Limits

- CalTrans accepts 95% of the risk of laboratory test variability.
- Select limits based on 95% confidence intervals.

Beam Fatigue Test to find number of cycles to failure at 200 and 400 microstrains.
Pilot Projects (2012-2014)

- Long-life rehabilitation projects
- Pavement cross-sections were designed using CalME and mix types were selected using PBS

<table>
<thead>
<tr>
<th>Red Bluff (I-5 Tehama County)</th>
<th>Weed (I-5 Siskiyou)</th>
<th>Dixon (I-80 Solano County)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mm Rubberized Open Graded HMA</td>
<td></td>
<td>30 mm Rubberized Open Graded HMA</td>
</tr>
<tr>
<td>90 mm PG64-28 15% RAP</td>
<td>60 mm PG 64-28 15% RAP</td>
<td>60 mm PG 64-28 15% RAP</td>
</tr>
<tr>
<td>60-200 mm PG 64-10 25% RAP</td>
<td>110-180 mm PG64-16 25% RAP</td>
<td>75-180 mm PG 64-10 25% RAP</td>
</tr>
<tr>
<td>60 mm PG 64-10 rich bottom 15% RAP</td>
<td>60 mm PG 64-16 rich bottom 15% RAP</td>
<td>30 mm PG 64-10</td>
</tr>
<tr>
<td>110 mm existing CTB</td>
<td>150-230 mm varying CTB</td>
<td>200 mm JPC</td>
</tr>
</tbody>
</table>
# PBS Thresholds

<table>
<thead>
<tr>
<th>Design Parameters (Red Bluff)</th>
<th>Test Method</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permanent Deformation (min.)</strong>&lt;br&gt;PG 64-28 (w/ lime)</td>
<td>AASHTO T320 modified (Repeated Simple Shear)</td>
<td>360,000 stress repetitions</td>
</tr>
<tr>
<td><strong>Fatigue (min.)</strong>&lt;br&gt;PG 64-28 (w/ lime)&lt;br&gt;PG 64-10 (w/ lime)&lt;br&gt;PG 64-10 (w/ lime)</td>
<td>AASHTO T321 modified (Beam Fatigue)</td>
<td>23,000,000 and 345,000,000 repetitions for 400 and 200 microstrains&lt;br&gt;25,000,000 and 950,000,000 repetitions for 400 and 200 microstrains&lt;br&gt;182,000,000 and 2,700,000,000 repetitions for 400 and 200 microstrains</td>
</tr>
<tr>
<td><strong>Permanent Deformation (min.)</strong>&lt;br&gt;PG 64-10 (with RAP and lime)</td>
<td>AASHTO T 324 modified (Wheel Track)</td>
<td>20,000 repetitions</td>
</tr>
</tbody>
</table>

Note that PBS allows layer and project-specific thresholds and requirements!
Challenges

- Missing baseline material properties for locally available materials (for developing a regional database and realistic targets)
- Communicating the significance of PBS to the contractors
  - Can the PBS give explicit directions?
  - And how serious are the limits?
- Understanding mix design-PBS relationships
- Developing specifications for each layer
Challenges (cont’d)

- Procurement of lab testing services (not foreseen in near future)
- Testing repeatability (not likely part of AMRL)
- Lab vs. plant produced mixes (shift factor?)
- What if a material exceeded one by a wide margin but missed other property?
Texas Experience

Reference:
Introduction

- Primarily designed for selecting mixes for overlays
- Motivated by the increasing use of RAP and RAS
- “Balanced” mix design approach is introduced using:
  - Performance tests (Texas Overlay Test and others)
  - Project-specific cracking requirement
Texas Overlay Test (OT)

- Developed by Zhou et al. 2005 and improved over the years
- Conducted at room temperature at a displacement of 0.025 in and 1 Hz
- Recent studies showed good correlation to field performance (Walubita et al. 2012, Gibson et al. 2013)
Balanced Mix Design Steps

Balancing Rutting and Cracking Requirements

- Acceptable Rutting
- Acceptable Cracking

Graph showing Rut Depth (mm) vs. Cracking Life (cycles) with acceptable rutting and cracking regions.
Project-Specific Cracking Criteria

- Acknowledging the fact that mixture performance is not the only parameter
  - Switching to developing mix designs for project-specific conditions

- Two-step process:
  - Step 1: Predict performance and select cracking requirement to meet design performance goal (i.e. target OT cycles to failure required to achieve less than 50% reflective cracking after 5 years)
  - Step 2: Design a mix with the required OT cycles
An overlay cracking prediction program is developed to:

- Predict crack propagation using inputs from overlay test
- Make project-specific recommendations based on climate, traffic, and existing pavement structure
New Jersey DOT Experience

Reference:
Introduction

- NJDOT has developed a Performance-Based Mixture Design and Quality Program
- The objective of the program is to “engineer” mixes for specific performance needs

PERFORMANCE-BASED ACCEPTANCE PROCEDURE

1. Volumetric Design
2. PB Tests at NJDOT
3. Construction of Test Strip
4. Production and Sampling

Flowchart:

- Volumetric Design → PB Tests at NJDOT → Construction of Test Strip → Production and Sampling
- Feedback loop from Production and Sampling back to Volumetric Design
Performance Tests

- A combination of the three following tests:
  - Asphalt Pavement Analyzer (APA) – AASHTO T340
  - Flexural Beam Fatigue – AASHTO T 321
  - Overlay Tester (Texas DOT Procedures)
Mixture Categorization

- Five mixture categories were established for specific applications:
  - High-performance thin overlay (HPTO)
  - Binder-rich intermediate course (BRIC)
  - Bridge-deck waterproofing course
  - Bottom-rich base course (BRBC)
  - High RAP (HRAP)
Mixture Fine-Tuning (BRIC)

![Bar chart showing flexural beam fatigue life for BRIC PG64-22, BRIC PG70-28, and BRIC PG76-22. The chart indicates significantly increased fatigue life for BRIC PG70-28 compared to BRIC PG64-22 and BRIC PG76-22.](image-url)
High RAP (HRAP) Mixes

- In 2012, NJDOT implemented PBS for HRAP:
  - Final mixture to meet a fatigue cracking and permanent deformation test criteria
  - No maximum limits
  - “If you can produce a RAP mixture that performs as well as a virgin mix, then the NJDOT will accept it.”

<table>
<thead>
<tr>
<th>Tests</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface Course</td>
</tr>
<tr>
<td></td>
<td>PG 64-22</td>
</tr>
<tr>
<td>APA @ 8,000 loading cycles</td>
<td>&lt; 7 mm</td>
</tr>
<tr>
<td>Overlay Tester (NJDOT B-10)</td>
<td>&gt; 150 cycles</td>
</tr>
</tbody>
</table>
Louisiana’s Experience

Reference:
Introduction

- Developed a “Balanced” mix design approach
- Two laboratory tests and performance criteria:
  - Rutting: Loaded Wheel Tracking (LWT) Test – AASHTO T 324
  - Cracking: Semi-Circular Bend (SCB) Test
- Thresholds were determined based on a regional database
Modified SCB Test

- Conducted at 25 °C
- Slow loading rate
- Requires 3 sets of specimens at different notch lengths
- Test output is critical J-integral
“Three Pillars” of Performance
Final Thoughts

- There are other states in the process of adapting various versions of PRS/PBS
  - Minnesota, Wisconsin, New Hampshire, Illinois etc.
- Each state has its own way
- PRS/PBS provide opportunities for states/contractors to improve their mix designs as well as developing project-specific requirements
Challenges and Future Directions

- Recall the caveat in the TRR Circular E-C037 appended to the definition of PBS as of 2002:
  - “[Because most fundamental engineering properties associated with pavements are currently not amenable to timely acceptance testing, performance-based specifications have not found application in highway construction.]”

- Reliability of performance prediction models
- Suitability of contracting delivery methods to adapt a true PBS framework
References for Case Studies

Harvey et al. (2014). Performance-Based Specifications: *California Experience to Date*. TRR Circular E-C189


Bennert et al. (2014). Implementation of Performance-Based Specifications for Asphalt Mix Design and Production Quality Control for New Jersey. TRR Circular E-C189