High RAP Mixtures – Strategies and Their Implementation in the Northeast

Thomas Bennert, Ph.D.
Rutgers University, NJ

NEAUPG Annual Meeting
October 23\textsuperscript{rd} and 24\textsuperscript{th}, 2013
Portsmouth, New Hampshire
Acknowledgements

- Jo Sias-Daniel, UNH
- Walaa Mogawer, UMass – Dartmouth
- FHWA Pooled Fund Participants – *High RAP Mixtures in the Northeast*
- Eileen Sheehy, Materials Bureau of NJDOT
- Robert Blight and Susan Gresavage, NJDOT Pavement Design and Management
- Zoeb Zavery, Materials Bureau, NYSDOT
Pooled Fund Study Work Effort

- Ultimate Goal: Responsibly producing and placing higher recycled asphalt content mixtures that will perform well
- On-going FHWA Pooled Fund study to evaluate plant produced higher RAP mixtures
  - Survey to state and industry (separate surveys)
  - Laboratory evaluation of plant produced mixtures of varying RAP percentages (0 to 40%)
    - Field evaluation of those placed
  - Last phase, controlled laboratory expert
Asked State DOT’s in Northeast biggest concerns with higher RAP contents;
- All concerned with cracking
- Some concerned with quality control

Asked State DOT’s how they believed higher RAP contents should be adopted (“Strategy”);
- Use of softer asphalt binder to offset stiffer RAP
- Limiting amount of RAP binder credited to total asphalt content
- Adopt performance-based acceptance for final mixture
High RAP Content
Strategy #1 – Softer Binder Grade
Came from recommendations of NCHRP Report 452 (McDaniel and Anderson, 2001)

<table>
<thead>
<tr>
<th>Recommended Virgin Asphalt Binder Grade</th>
<th>Percent (%) RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change in binder selection</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Select virgin binder grade one grade softer than normal</td>
<td>15 – 25</td>
</tr>
<tr>
<td>Follow recommendations from blending charts</td>
<td>&gt; 25</td>
</tr>
</tbody>
</table>

Recent work by NCAT on NCHRP Project 9-46 suggests using “binder replacement” instead of by total weight. Also suggests adjustments only needed above 25%
Advantages/Disadvantages

**Advantages**
- Easiest Strategy to implement
- A simple change at the asphalt plant – no volumetric redesign required pending approval from state agency

**Disadvantages**
- Supply of grade may be limited in area
- May not address issue of “under-asphalted” if exists
- Blending charts may be required, which utilizes solvent extraction
Mixtures evaluated in Phase I of study looked at the influence of softer binder grade
- Callanan, NY (PG64-22 and PG58-28)
- Williston, VT (PG64-28 and PG52-34)

Intermediate Cracking
- Flexural Fatigue (Crack Initiation)
- Overlay Tester (Crack Propagation)

Low Temperature Cracking
- TSRST
- Critical Cracking Analysis using TCModel – same as MEPDG
Crack Initiation Test

- Flexural Beam Device, AASHTO T321
- Test mixes ability to withstand repeated bending
- Run at different strain levels to determine fatigue life vs applied strain curve
Crack Propagation

Overlay Tester

- Sample size: 6” long by 3” wide by 1.5” high
- Loading: Continuously triangular displacement 5 sec loading and 5 sec unloading
- Definition of failure
  - Discontinuity in Load vs Displacement curve
New York Mixtures

- Plant Produced Mixtures (Drum Plant & Silo Stored)
- PG58-28 and PG64-22 base binder
- RAP Contents
  - 0, 20, 30, 40% by weight of mixture (PG64-22)
  - 30, 40% by weight of mixture (PG58-28)
New York Mixtures

- From extracted/recovered binder (PG64-22)
  - 0% RAP: PG75.5-22.2; AC% = 5.0%
  - 20% RAP: PG78.3-21.8; AC% = 5.2%
  - 30% RAP: PG78.4-19.9; AC% = 5.5%
  - 40% RAP: PG80.9-17.6; AC% = 5.1%
- From extracted/recovered binder (PG58-28)
  - 30% RAP: PG72.1-26.5; AC% = 5.0%
  - 40% RAP: PG81.7-22.0; AC% = 4.9%
Fatigue Life, $N_{f, 50\%}$ (Cycles)

$$N_{f, 50\%} = k_1 \left( \frac{1}{\varepsilon_1} \right)^{k_2} \left( \frac{1}{E_O} \right)^{k_3}$$

New York Mixtures – Beam Fatigue

<table>
<thead>
<tr>
<th>RAP %</th>
<th>Temperatures (°F)</th>
<th>Silo Storage Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agg. Heating</td>
<td>Mix Discharge</td>
</tr>
<tr>
<td>PG58-28 40%</td>
<td>450</td>
<td>330</td>
</tr>
<tr>
<td>PG58-28 30%</td>
<td>410</td>
<td>305</td>
</tr>
<tr>
<td>PG64-22 0%</td>
<td>375</td>
<td>290</td>
</tr>
<tr>
<td>PG64-22 20%</td>
<td>410</td>
<td>320</td>
</tr>
<tr>
<td>PG64-22 30%</td>
<td>410</td>
<td>305</td>
</tr>
<tr>
<td>PG64-22 40%</td>
<td>450</td>
<td>330</td>
</tr>
</tbody>
</table>
New York Mixtures – Beam Fatigue

\[ N_{f,50\%} = k_1 \left( \frac{1}{\varepsilon_1} \right)^{k_2} \left( \frac{1}{E_0} \right)^{k_3} \]

- PG64-22, 0% RAP
- PG64-22, 20% RAP
- PG64-22, 30% RAP
- PG64-22, 40% RAP

<table>
<thead>
<tr>
<th>RAP %</th>
<th>Temperatures (°F)</th>
<th>Silo Storage Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Agg. Heating</td>
<td>Mix Discharge</td>
</tr>
<tr>
<td>PG58-28 40%</td>
<td>450</td>
<td>330</td>
</tr>
<tr>
<td>PG58-28 30%</td>
<td>410</td>
<td>305</td>
</tr>
<tr>
<td>PG64-22 0%</td>
<td>375</td>
<td>290</td>
</tr>
<tr>
<td>PG64-22 20%</td>
<td>410</td>
<td>320</td>
</tr>
<tr>
<td>PG64-22 30%</td>
<td>410</td>
<td>305</td>
</tr>
<tr>
<td>PG64-22 40%</td>
<td>450</td>
<td>330</td>
</tr>
</tbody>
</table>
New York Mixtures – Overlay Tester

![Bar chart showing fatigue life from overlay tester (cycles) for different mixtures and RAP percentages.](chart.png)

- **Fatigue Life from Overlay Tester (cycles)**

<table>
<thead>
<tr>
<th>RAP %</th>
<th>Temperatures (°F)</th>
<th>Silo Storage Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG58-28 40%</td>
<td>450 330</td>
<td>4</td>
</tr>
<tr>
<td>PG58-28 30%</td>
<td>410 305</td>
<td>3.5</td>
</tr>
<tr>
<td>PG64-22 0%</td>
<td>375 290</td>
<td>2.75</td>
</tr>
<tr>
<td>PG64-22 20%</td>
<td>410 320</td>
<td>0.75</td>
</tr>
<tr>
<td>PG64-22 30%</td>
<td>410 305</td>
<td>2.75</td>
</tr>
<tr>
<td>PG64-22 40%</td>
<td>450 330</td>
<td>3</td>
</tr>
</tbody>
</table>

Error bars represent 1 standard deviation above and below the average.
Vermont Mixtures

- Plant Produced Mixtures (Batch Plant)
- PG52-34 and PG64-28 base binder
- RAP Contents
  - 0, 20, 30, 40% by weight of mixture (PG64-28)
  - 0, 20, 30, 40% by weight of mixture (PG52-34)
Vermont Mixtures

- From extracted/recovered binder (PG52-34)
  - 0% RAP: PG65.4-28.3; AC% = 6.6%
  - 20% RAP: PG68.3-28.1; AC% = 6.3%
  - 30% RAP: PG71.4-26.3; AC% = 6.1%
  - 40% RAP: PG68.6-21.0; AC% = 6.1%

- From extracted/recovered binder (PG64-28)
  - 0% RAP: PG67.4-30.2; AC% = 5.8%
  - 20% RAP: PG69.6-27.0; AC% = 5.5%
  - 30% RAP: PG74.7-23.0; AC% = 5.3%
  - 40% RAP: PG78-24.9; AC% = 6.0%
Vermont Mixtures – Beam Fatigue

\[ N_{f,50\%} = k_1 \left( \frac{1}{\varepsilon_1} \right)^{k_2} \left( \frac{1}{E_O} \right)^{k_3} \]
Fatigue Life, $N_{f,50%}$ (Cycles)

\[ N_{f,50%} = k_1 \left( \frac{1}{\varepsilon_t} \right)^{k_2} \left( \frac{1}{E_0} \right)^{k_3} \]

- PG64-28, 0% RAP
- PG64-28, 20% RAP
- PG64-28, 30% RAP
- PG64-28, 40% RAP

Micro-strain ($\mu$s)
Vermont Mixtures – Overlay Tester

- 0% RAP PG52-34: >1200
- 20% RAP PG52-34: >1200
- 30% RAP PG52-34: 217
- 40% RAP PG52-34: 112
- 0% RAP PG64-28: 1032
- 20% RAP PG64-28: 127
- 30% RAP PG64-28: 126
- 40% RAP PG64-28: 44
Low Temperature Cracking - TSRST

![Graph showing TSRST critical cracking temperature for different asphalt binders and RAP percentages.](image-url)
Low Temperature – IDT TCModel
**Soft Binder Grade - Conclusions**

- Resulted in slightly better low temperature cracking performance
  - Improvement not the full PG grade as in the drop
  - Less of improvement in critical cracking than TSRST
- Softer binder did not always improve the crack propagation performance in the Overlay Tester
- Softer binder showed mixed results for crack initiation in Flexural Beam Fatigue
- May indicate production and mixture parameters may negate or minimize effectiveness of softer grade
High RAP Content
Strategy #2 – Limiting RAP Binder Contribution
Advantages/Disadvantages

- **Advantages**
  - Immediately addresses issue of lack of potential blending/non-mobilized RAP binder
  - Increases effective asphalt content of the mix
  - No binder grade change required

- **Disadvantages**
  - Would require slight adjustment in the mix. Same adjustment to increase VMA
    - Limit natural sand/add more angular sand
    - Reduce dust content
    - Gradation more “gap-graded”
Looked at changing the allowable asphalt binder credited to the total binder content from RAP

Based on the assumption that not all of the RAP binder mobilizes and blends with the virgin binder

Arbitrarily selected as 100, 75, and 50% of RAP Binder credited to total binder content

Asphalt supplier required to modify mixture (gradation) to allow additional virgin binder
NYSDOT Binder Credit Study

- 100% RAP Contribution: 5.3% AC
- 75% RAP Contribution: 5.6% AC
- 50% RAP Contribution: 5.8% AC

<table>
<thead>
<tr>
<th>Property</th>
<th>RAP Binder Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>High Temp Grade (°C)</td>
<td>80.1</td>
</tr>
<tr>
<td>Low Temp Grade (°C)</td>
<td>-23.6</td>
</tr>
<tr>
<td>Intermediate Temp Grade (°C)</td>
<td>25.3</td>
</tr>
<tr>
<td>Resultant PG Grade</td>
<td>PG76-22</td>
</tr>
<tr>
<td>Jnr @ 64°C (1/kPa)</td>
<td>0.471</td>
</tr>
<tr>
<td>% Recovery @ 64°C (%)</td>
<td>15.8</td>
</tr>
<tr>
<td>Recovered Asphalt Content (%)</td>
<td>5.29</td>
</tr>
</tbody>
</table>
Fatigue Life, $N_{f,50\%}$ (Cycles)

$N_{f,50\%} = k_1 \left( \frac{1}{\varepsilon_t} \right)^{k_2} \left( \frac{1}{E_O} \right)^{k_3}$

- 50% RAP Binder Contribution
- 75% RAP Binder Contribution
- 100% RAP Binder Contribution
NYSDOT Binder Credit – Overlay Tester

![Bar chart showing Overlay Tester Fatigue Life (cycles) for 100% RAP Binder Contribution, 75% RAP Binder Contribution, and 50% RAP Binder Contribution.]

- 100% RAP Binder Contribution: 185 cycles
- 75% RAP Binder Contribution: 293 cycles
- 50% RAP Binder Contribution: 359 cycles
NYSDOT Binder Credit – Overlay Tester on 1 Year Old Cores

Overlay Tester Fatigue Life (Cycles)

- 100% RAP Binder Contribution: 129
- 75% RAP Binder Contribution: 208
- 50% RAP Binder Contribution: 447
NYSDOT Binder Credit – Rutting Check

![Bar chart showing AMT Flow Number (cycles) for 50%, 75%, and 100% RAP Binder Contribution. The values are 687, 579, and 662 respectively.](image-url)
Immediately after placement and in the first year, field engineers commented “100% Contribution section not as dark as other sections.”

- 2 Years later, 100% and 75% look similar
- No cracking or rutting to date in any of the sections
RAP Binder Credit - Conclusions

- As RAP Binder Credit decreased, fatigue resistance increased
  - Occurred in both modes (crack initiation and crack propagation)
  - Not enough material to conduct low temperature testing
- Rutting was not issue based on AMPT Flow Number
- NYSDOT continuing to evaluate field performance
- Question is: what is the appropriate % RAP Credit?
High RAP Content
Strategy #3 – Performance Based Specification for Final Mixture
Advantages/Disadvantages

- **Disadvantages**
  - Most complex of 3 presented
  - Most likely requires mix redesign and possibly asphalt binder not common to region
  - Laboratory equipment for performance testing
  - Establishment of criteria
- **Advantages**
  - Provides state agency high level of assurance the mixture should perform to level of expectations
In winter 2012, Rutgers and NJDOT worked to develop a Performance-Based High RAP (HRAP) specification. Utilized database of performance testing results to establish performance requirements for both rutting (Asphalt Pavement Analyzer) and cracking (Overlay Tester).
The supplier is not held to PG grade, max. RAP content, etc.
- Have to meet basic Superpave requirements
- NJDOT increased VMA 1% over current specs
- Could use softer binder, rejuvenators, WMA, etc.

However, acceptance based on final mixture performance, based on database of typical “virgin” HMA
Minimum of 20% RAP in Surface Course
Minimum of 30% RAP in Intermediate/Base
Lab design and plant produced material must meet rutting (APA) and cracking (Overlay Tester) requirements

<table>
<thead>
<tr>
<th>Test</th>
<th>Surface Course</th>
<th>Intermediate Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>APA @ 8,000 loading cycles (AASHTO T 340)</td>
<td>&lt; 7 mm</td>
<td>&lt; 7 mm</td>
</tr>
<tr>
<td></td>
<td>&lt; 4 mm</td>
<td>&lt; 4 mm</td>
</tr>
<tr>
<td>Overlay Tester (NJDOT B-10)</td>
<td>&gt; 150 cycles</td>
<td>&gt; 100 cycles</td>
</tr>
<tr>
<td></td>
<td>&gt; 175 cycles</td>
<td>&gt; 125 cycles</td>
</tr>
</tbody>
</table>
NJDOT HRAP – I295

- I295 SB – Milepost 11.26 to 14.48
- Contractor
  - Arawak Paving
- Supplier
  - R.E. Pierson
- Asphalt liquid
  - NuStar Refining
Final HRAP Mix Designs

9.5M76 (SURFACE COURSE)
- 25% RAP
- 6.0% Total AC
  - 27.4% Binder Replacement
- PG70-22 (74.6-26.99)
- 25% Fine RAP Fraction Only

12.5M64 (INTERMED. COURSE)
- 35% RAP
- 5.8% Total AC
  - 29.7% Binder Replacement
- PG64-28 (64.8-28.29)
- 17.5% Fine RAP/ 17.5% Coarse RAP
APA Rutting Performance

APA PG76-22 Surface Course Criteria ≤ 4 mm Rutting

64°C Test Temp.; 100psi Hose Pressure; 100 lb Load

APA Rutting @ 8,000 Cycles
RE Pierson 9.5mm PG76-22 25% RAP = 3.56 mm (Std Dev = 0.82 mm)
Plant Produced August, 2012

APA PG64-22 Surface Course Criteria ≤ 7 mm Rutting

APA Rutting @ 8,000 Cycles
RE Pierson 12.5mm PG64-22 35% RAP = 6.57 mm (Std Dev = 0.63 mm)
Plant Produced August, 2012
Overlay Tester

Red line represents minimum for PG64-22 Intermediate Course (> 100 cycles)
Black line represents minimum for PG76-22 Surface Course (> 175 cycles)

Overlay Tester Fatigue Life (cycles)

Overlay Tester Fatigue Life (cycles)

12.5mm HRAP, 35% RAP

9.5mm HRAP, 25% RAP

409

1691
Final Product
A learning curve for supplier (binder and mixture)
  - Collaboration between academia, agency and industry helped make successful
- Mix supplier felt better control fractionating RAP. Believe could have increased RAP % if had more time to experiment in lab
- NJDOT looking for additional projects and will continue evaluating field performance.
There are Strategies out there to help utilize more RAP
- From easy to complex
- Not all will provide same degree of assurance
- Supplier needs to know there materials (RAP) and which Strategy makes the most sense
  - What the agency is looking for
  - What is cost effective for the Contractor
Thank you for your time!

Questions?

Thomas Bennert, Ph.D.
Rutgers University
732-445-5376
bennert@rci.rutgers.edu