It all started in 1919

• Asphalt Association (later Asphalt Institute) was formed and hired Prevost Hubbard and Frederick Field as researchers

• Research led to the Hubbard-Field design method using rammers (like a Marshall hammer but with 2 size hammers) in mid 1920’s

AI Magazine article by Gerry Huber 2/15/2013
Hubbard-Field Stability

- Hubbard-Field Stability is the first known asphalt performance test.
- Sample was loaded by turning the wheel.
- Dial gage recorded the maximum load.
Testing Then and Now

• By the 1940’s:
  • Hubbard-Field stability test
  • Hveem stability test
  • Marshall stability and flow
  • Recorded data by hand or charts

• Today
  • TSR, Hamburg, APA, Texas Overlay tester, 4-point flexural fatigue, fracture energy (3-4 tests), resilient modulus, shear modulus, dynamic modulus, AMPT Flow Number, etc.
Fundamental Performance Tests

• Flexural Beam Fatigue
  • Brittleness

• Asphalt Mixture Performance Test
  • Dynamic modulus (*used in MEPDG for design*)
  • Flow number (rutting)

• Superpave Shear Tester
  • Rutting
  • Modulus

• Indirect Tension Test
  • Low temperature cracking
Performance Related Tests

- Other tests
  - Hamburg Wheel Tester
  - Asphalt Pavement Analyzer
  - Disk-Shaped Compact Tension test (DcT)
  - Overlay (crack) tester
  - Semi Circular Bend test (SCB)
  - Ideal CT
  - Others
<table>
<thead>
<tr>
<th>Performance Test Priorities</th>
<th>Inexpensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related to field performance</td>
<td></td>
</tr>
<tr>
<td>Repeatable / Reproducible</td>
<td>Relatively quick / easy</td>
</tr>
<tr>
<td>Sensitive to mix properties</td>
<td>Available</td>
</tr>
<tr>
<td>Available</td>
<td></td>
</tr>
<tr>
<td>Relatively quick / easy</td>
<td>Sensitive to mix properties</td>
</tr>
<tr>
<td>Inexpensive</td>
<td>Repeatable / Reproducible</td>
</tr>
<tr>
<td>Related to field performance</td>
<td></td>
</tr>
</tbody>
</table>
Why do we need performance tests?

Recycled Binders
Superpave

• Focus was initially on top 2 inches of pavement – virgin mixtures
• Later incorporated polymers and base courses
• Never included recycled materials
NCHRP REPORT 452 - Results

• Blending occurs at higher RAP contents. At low RAP contents, effects are not significant.

• Results from all phases support concept of a tiered system.
  • Mix ETG recommendations were largely confirmed.
RAP mixtures should be able to perform at least as well as virgin mixes.

<table>
<thead>
<tr>
<th>ACTION</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Change in Binder Grade</td>
<td>15% or less</td>
</tr>
<tr>
<td>One Grade Lower</td>
<td>16 - 25%</td>
</tr>
<tr>
<td>Use Blending Charts</td>
<td>&gt;25%</td>
</tr>
</tbody>
</table>

Adopted in AASHTO M323
Superpave Volumetric Mix Design
LTPP SPS-5 NJ: Forensic Study of NJ’s High RAP Sections

Thomas Bennert
Rutgers University
A Performance Comparison of RAP vs. Virgin Mixes (from Randy West, NCAT)

- LTPP SPS-5 pavement sections
- 18 U.S. states and Canadian provinces
- At least 30% RAP used in recycled mixes
- Projects range in age from 6 to 17 yrs
LTPP SPS-5: RAP vs. Virgin

- **Four comparison pairs per project (location)**
  - 2” overlay, no mill
  - 2” overlay with mill
  - 5” overlay, no mill
  - 5” overlay with mill

- **Five performance measurements (annual)**
  - Rutting, mm
  - IRI, m/km
  - Fatigue cracking, m²
  - Transverse cracking, # per section
  - Longitudinal cracking, m
SPS-5 Project Locations
# General Performance

## Percentage of Sections Below General Pavement Performance Thresholds

<table>
<thead>
<tr>
<th>Distress Parameter</th>
<th>Threshold</th>
<th>RAP Sections</th>
<th>Virgin Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRI</td>
<td>2.0 m/km</td>
<td>86%</td>
<td>89%</td>
</tr>
<tr>
<td>Rutting</td>
<td>10 mm</td>
<td>71%</td>
<td>78%</td>
</tr>
<tr>
<td>Fatigue Cracking</td>
<td>25% of WP area</td>
<td>60%</td>
<td>72%</td>
</tr>
<tr>
<td>Longtnl. Cracking</td>
<td>25% of section length</td>
<td>79%</td>
<td>86%</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>20 cracks per section</td>
<td>47%</td>
<td>64%</td>
</tr>
<tr>
<td>Block Cracking</td>
<td>10% of section area</td>
<td>89%</td>
<td>94%</td>
</tr>
<tr>
<td>Raveling</td>
<td>10% of section area</td>
<td>75%</td>
<td>69%</td>
</tr>
</tbody>
</table>
What Happened in NJ?

- NJ LTPP 30% RAP sections designed using softer binder
  - Control: 0% RAP, AC-20
  - 30% RAP used AC-10

- NJ LTPP SPS-5 sections ready for rehab (milled out) in 2010

- Convinced NJDOT to provide funding for analysis of sections
NJ SPS-5 Cracking – 2 Inch Overlay Section (Milled)

- Virgin Mix
- 30% RAP Mix
NJ SPS-5 Cracking – 2 Inch Overlay
Section (No Mill)

- Virgin Mix
- 30% RAP Mix

Alligator Cracking - Deduct

Time After Construction (Years)
General Field Cracking Performance

- Both the virgin mixtures and 30% RAP mixtures appeared to initiate cracking within the same general time (1 to 3 years within each other).

- However, once cracking initiated, 30% RAP mixtures cracked at a “faster” rate than virgin mixtures.
  - Resulting in higher crack counts in the pavement section.
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
  - Sample reaches 93% of Initial Load
Overlay Tester Results

- Overlay Tester results match general field performance with Virgin mix outperforming 30% RAP mix
- TxDOT 300 cycle criteria for surface course mixtures seems appropriate as both mixtures resulted in some degree of cracking
Update for the FHWA ALF Research Activities
Project #1:
High RAP (RAS) + WMA
Accelerated Pavement Test
The Experiment

Structure
- 10 Lanes (10 Mixes)
- Build in 2013

Materials
- 2 Binder Grades
- RAP/RAS
- 2 WMA Technologies
- 3 ABR contents
# ALF Experimental Design

<table>
<thead>
<tr>
<th>Recycle Content</th>
<th>Drum Discharge Temperature</th>
<th>HMA / WMA</th>
<th>Warm Mix Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>300°F - 320°F</td>
<td>-</td>
<td>Foam</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PG64-22</td>
<td>Chem.</td>
</tr>
<tr>
<td>20% ABR RAP</td>
<td>240°F - 270°F</td>
<td>✓</td>
<td>PG64-22</td>
</tr>
<tr>
<td>≈ 23% by weight</td>
<td></td>
<td>PG64-22</td>
<td>PG64-22</td>
</tr>
<tr>
<td>20% ABR RAS</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>≈ 6% Shingle by weight</td>
<td></td>
<td>PG64-22</td>
<td>PG58-28</td>
</tr>
<tr>
<td>40% ABR RAP</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>≈ 44% by weight</td>
<td>300°F - 320°F</td>
<td>PG64-22</td>
<td>PG58-28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PG58-28</td>
<td>PG58-28</td>
</tr>
</tbody>
</table>
Loading Conditions

• Tire
  – 425/65R22.5 wide base
  – Tire pressure: 100 psi
• Total load: 14,200 lbf
• Speed = 11 mph (4.9 m/s)
• Isothermal at 20°C (target temperature at AC mid-thickness)
Cracking Measurements

Crack lengths are individually traced with planimeter.
# Crack Data Summary

<table>
<thead>
<tr>
<th>Lane</th>
<th>Mix</th>
<th>Age when tested (months)</th>
<th>Duration (Days)</th>
<th>Cycles to First Crack (Calculated)</th>
<th>Total Passes</th>
<th>Total Cracking (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0% ABR Control PG64-22</td>
<td>7</td>
<td>286</td>
<td>368,254</td>
<td>400,000</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>40% ABR RAP PG58-28 WMA Foamed</td>
<td>38</td>
<td>79</td>
<td>123,035</td>
<td>200,000</td>
<td>1,336</td>
</tr>
<tr>
<td>3</td>
<td>20% ABR RAS PG64-22</td>
<td>14</td>
<td>28</td>
<td>42,399</td>
<td>100,000</td>
<td>587</td>
</tr>
<tr>
<td>4</td>
<td>20% ABR RAP PG64-22 WMA Evotherm</td>
<td>16</td>
<td>71</td>
<td>88,740</td>
<td>125,000</td>
<td>271</td>
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<tr>
<td>5</td>
<td>40% ABR RAP PG64-22</td>
<td>11</td>
<td>98</td>
<td>36,946</td>
<td>60,000</td>
<td>670</td>
</tr>
<tr>
<td>6</td>
<td>20% ABR RAP PG64-22</td>
<td>24</td>
<td>81</td>
<td>122,363</td>
<td>175,000</td>
<td>403</td>
</tr>
<tr>
<td>7</td>
<td>20% ABR RAS PG58-22</td>
<td>18</td>
<td>43</td>
<td>23,005</td>
<td>62,200</td>
<td>526</td>
</tr>
<tr>
<td>8</td>
<td>40% ABR RAP PG58-28 WMA Evotherm</td>
<td>31</td>
<td>47</td>
<td>47,679</td>
<td>54,844</td>
<td>602</td>
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<tr>
<td>9</td>
<td>20% ABR RAP PG64-22 WMA Foamed</td>
<td>2</td>
<td>163</td>
<td>179,167</td>
<td>255,397</td>
<td>1,439</td>
</tr>
<tr>
<td>11</td>
<td>40% ABR RAP PG58-28</td>
<td>3</td>
<td>147</td>
<td>81,044</td>
<td>123,052</td>
<td>512</td>
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</tbody>
</table>
Revised Final Report

http://wisconsindot.gov/documents/Research/14-06-

Resistance to ageing

Resistance to lead associated cracking

To improve durability

Asphalt mixtures that WISDOT should consider

— Evaluate changes to the composition of

Affecting Asphalt Durability

Project 0927-14-06 Critical Factors

Wisconsin Highway Research Program

Acknowledgement

Courtesy of R. Bonaquist
Transportation Research Circular

Place limits on Recycled Binder Effectiveness

Use softer grade of Binder

Use Polymer Modification

Increase Effective Volume of Binder

Associated Cracking Be Improved?

How Can Resistance to Load
Wisconsin Laboratory Experiment

Factors

- Resistance to intermediate temperature cracking
- Resistance to simulated long-term aging
- Polymer modification
- Virgin binder low temperature grade
- Recycled binder content
- Effective binder volume

Specifications
With increasing F1, resistance to cracking increases.

F1 = Energy/Peak Slope

Vertical Displacement, mm

Load, N

Illinois SCB (Flexibility Index)

Load

Slope @ 50% of Peak

SI = Stiffness Index

AI = Aging Index

SI = 5100/SIa
<table>
<thead>
<tr>
<th>Effective RAP Binder Ratio</th>
<th>Minimum Design VBE, vol %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>10.0</td>
</tr>
<tr>
<td>&gt;0.00 ≤0.05</td>
<td>10.4</td>
</tr>
<tr>
<td>&gt;0.05 ≤0.10</td>
<td>10.7</td>
</tr>
<tr>
<td>&gt;0.10 ≤0.15</td>
<td>11.1</td>
</tr>
<tr>
<td>&gt;0.15 ≤0.20</td>
<td>11.5</td>
</tr>
<tr>
<td>&gt;0.20 ≤0.25</td>
<td>11.9</td>
</tr>
<tr>
<td>&gt;0.25 ≤0.30</td>
<td>12.2</td>
</tr>
<tr>
<td>&gt;0.30 ≤0.35</td>
<td>11.2</td>
</tr>
<tr>
<td>&gt;0.35 ≤0.40</td>
<td>11.5</td>
</tr>
<tr>
<td>&gt;0.40 ≤0.45</td>
<td>11.9</td>
</tr>
<tr>
<td>&gt;0.45 ≤0.50</td>
<td>12.3</td>
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</table>

Low Temperature Grade Controls
<table>
<thead>
<tr>
<th>F1</th>
<th>F2</th>
<th>ABA</th>
<th>VBE</th>
<th>Low</th>
<th>Control</th>
<th>VBE</th>
<th>Low</th>
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<tbody>
<tr>
<td>97</td>
<td>69</td>
<td>02</td>
<td>82</td>
<td>0.05</td>
<td>60</td>
<td>65</td>
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<td>77</td>
<td>77</td>
<td>0.15</td>
<td>0.05</td>
<td>5.5</td>
<td>6.5</td>
<td>65</td>
<td>00</td>
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<tr>
<td>84</td>
<td>84</td>
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<td>5.5</td>
<td>0.05</td>
<td>60</td>
<td>00</td>
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<tr>
<td>92</td>
<td>92</td>
<td>0.05</td>
<td>0.05</td>
<td>6.0</td>
<td>0.05</td>
<td>65</td>
<td>00</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>0.00</td>
<td>0.00</td>
<td>6.5</td>
<td>6.5</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>F1</th>
<th>F2</th>
<th>ABA</th>
<th>VBE</th>
<th>Low</th>
<th>Control</th>
<th>VBE</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>97</td>
<td>69</td>
<td>02</td>
<td>82</td>
<td>0.05</td>
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<td>65</td>
<td>00</td>
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<td>0.15</td>
<td>0.05</td>
<td>5.5</td>
<td>6.5</td>
<td>65</td>
<td>00</td>
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<tr>
<td>84</td>
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<td>0.10</td>
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<td>5.5</td>
<td>0.05</td>
<td>60</td>
<td>00</td>
</tr>
<tr>
<td>92</td>
<td>92</td>
<td>0.05</td>
<td>0.05</td>
<td>6.0</td>
<td>0.05</td>
<td>65</td>
<td>00</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>0.00</td>
<td>0.00</td>
<td>6.5</td>
<td>6.5</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**Effect of Recycled Binder**

**Asphalt M 32 Change**

**No Grade Change**
“Asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure.”
What Is a Balanced Mix Design

• Balanced mix design is simply design a mix to “balance” the rutting and cracking resistance
• We do this by varying the asphalt content (increase) as we do in volumetric design trials and perform:
  • Rutting: Hamburg Wheel Tracker or AMPT Flow Number
  • Cracking: DC(T), SCB-iFit, Ideal CT, or beam fatigue
Balanced Mix Design
Level A: Performance

Select Trial Gradation; Ensure Aggregate Blend Properties

Adjust to Satisfy Performance

Conduct Performance Tests

Performance Passed?

RUTTING
AASHTO T324
Hamburg LWT
AASHTO T340
APA
AASHTO TP-79
AMPT – Fₙ

CRACKING
AASHTO ???
AASHTO TP197
Tx DOT 248F
SCB
AMPT Cyclic Fatigue
Tx OT

Moisture Damage
Hamburg LWT
AASHTO T324
Relative Strength
AASHTO T-283(NP)

Moisture Damage Passed?

Determine Volumetric Properties
Volumetric Analysis

Validate JMF / Production

Yes

No

Adjust to Satisfy Moisture Damage

Note: Rutting and Cracking Performance Tests Shown are Examples, Not A Finite List of Potential Tests
Balanced Mix Design
Level B:
Superpave (Volumetrics) ±
Plus Performance

Select
Trial Gradation;
Ensure Aggregate
Blend Properties

Determine
Optimum/Design
Binder Content
Volumetric Analysis

Conduct
Performance Tests

RUTTING
AASHTO T224
Hamburg LWT
AASHTO T240
APA
AASHTO TP-79
AMPT – F

Moisture Damage
Hamburg LWT
Relative
Strength
AASHTO T-253(lyd)

CRACKING
AASHTO P77
SCB
AASHTO TP197
AMPT
Cyclic Fatigue
TxDOT 248F
Tx OT

Redesign
No
Yes
Performance Passed?

Validate JMF / Production

Note: Rutting and Cracking Performance Tests Shown are Examples, Not A Finite List of Potential Tests
Balanced Mix Design
Level C: Superpave (Volumetrics) Plus Performance

Select Trial Gradation; Ensure Aggregate Blend Properties

Determine Initial Optimum/Design Binder Content Volumetrics Analysis

Adjust to Satisfy Performance

Rutting

- AASHTO T325
- AASHTO T340
- APA
- AASHTO TP-29
- AMPT – F

Hamburg LWT

Moisture Damage

Relative Strength

- AASHTO T283 (lye)

CRACKING

- AASHTO T99
- AMPT TP107
- NDOT248
- SCB
- Cyclic Fatigue
- TX OT

Performance Passed?

No

Yes

Verify Volumetrics / Validate MIF / Production

Note: Rutting and Cracking Performance Tests Shown are Examples, Not A Finite List of Potential Tests
• Balanced Mixture Design Concept
• Mixes are designed to optimize performance
   • Not around a target air void content
• Take an existing mix design
  • Start at a “dry” binder content
  • Add binder at 0.5% increments – measure rutting and cracking
  • Determine range where rutting and cracking are optimized
  • Conduct volumetric work
• Performance criteria (limits) already determined based upon virgin mixtures
New Jersey Balanced Design

Overlay Tester Fatigue Cracking (cycles)

Asphalt Pavement Analyzer Rutting (mm)

Asphalt Content (%)

APA Rutting (mm)

Overlay Tester Fatigue (cycles)

Optimum AC% (JMF)

Area of Balanced Performance 5.2 - 5.9%

Courtesy of Tom Bennert
• All NJ mixes found to be below (dry) of the balanced area (all contain around 15% RAP)
• Plant QC air voids requirements need to be re-evaluated to account for the added binder
• Changes in production volumetrics are likely required to move the mixes in the right direction
The 2-day course focuses on:

- Pavement distress
- Pavement design
- Construction
- Pavement preservation

Register now for these locations:
Feb. 19-21, 2019 – Fall River, Massachusetts

http://www.asphaltinstitute.org/training/seminars/maximizing-pavement-life/
Questions?

Gregory A. Harder, P.E.
Regional Engineer

5791 Route 80
Tully, NY 13159

Office: 315-238-7000
Mobile: 315-807-7306
Fax: 315-238-7000

gharder@asphaltinstitute.org