RAP in HMA Pavements

Peter E. Sebaaly, Ph.D., P.E.
Western Regional Superpave Center
University of Nevada

Recycled asphalt Pavements

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- **RAP is obtained by:**
  - **cold milling**
  - **heating/softening and removal**
  - **full depth removal**
  - **plant waste HMA materials.**

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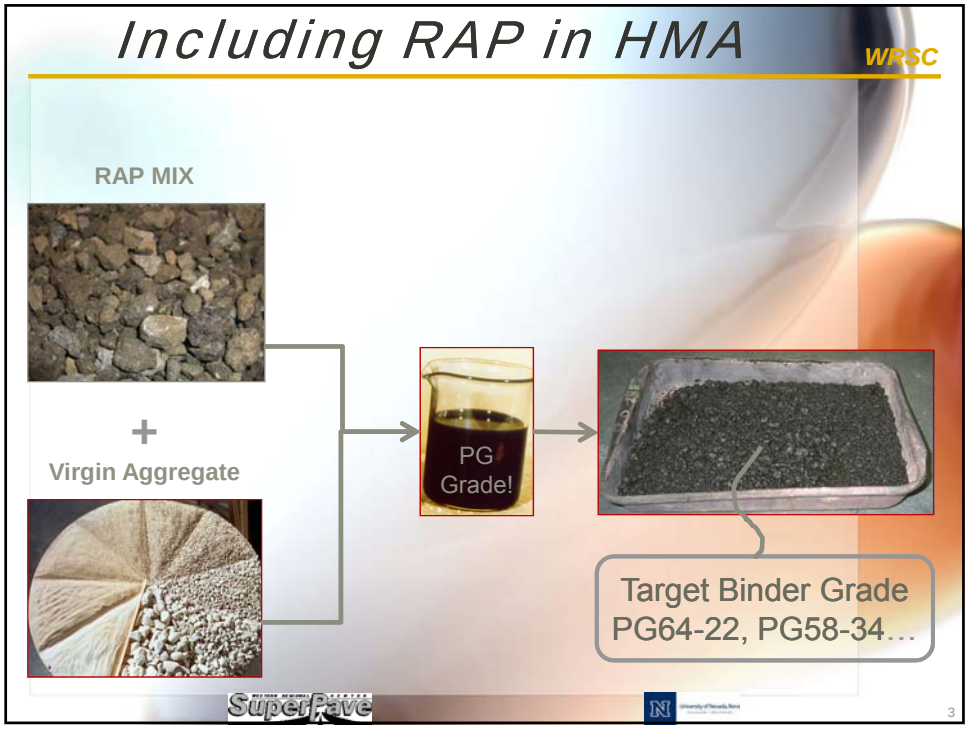
Including RAP in HMA
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RAP MIX
+
Virgin Aggregate
PG Grade!
Target Binder Grade
PG64-22, PG58-34…
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RAP before and after Extraction
RAP-I
RAP-I

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IMPACT OF RAP ON MIXTURES' PERFORMANCE PROPERTIES

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Impact of RAP on mixtures' properties


Stiffness


Rutting


Fatigue


Thermal


Moisture Damage

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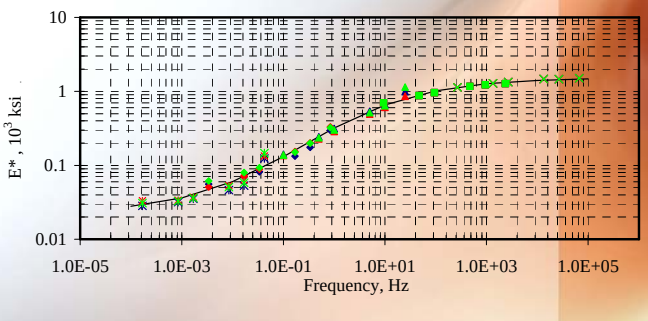
Stiffness

– **Dynamic Modulus, |E*|**



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Stiffness

- ***Li et al.(2004):*** **10 mixes at 0, 20 and 40% RAP, two virgin asphalt binders (PG58-28 and PG58-34), and two RAP sources (RAP and millings).**
  - **20-40% RAP →|E*|↑.**
  - **No significant impact for RAP on |E*| at low temperatures and high frequencies.**

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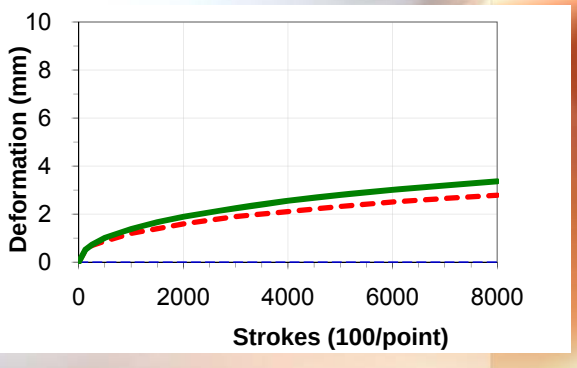
Stiffness

- *McDaniel et al. (2006):*
  - 15-25% RAP → No significant impact on |E*|.
  - 40% RAP → ↑|E*| at higher temperatures.

Rutting

Rutting

– **Asphalt Pavement Analyzer (APA)**



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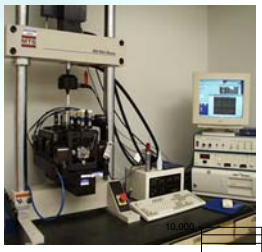
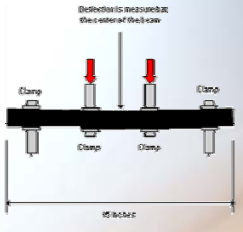
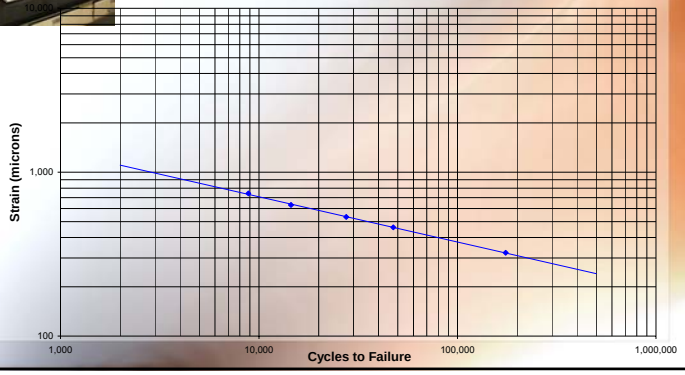
Fatigue Cracking

Fatigue

- **Flexural Beam Fatigue Test**







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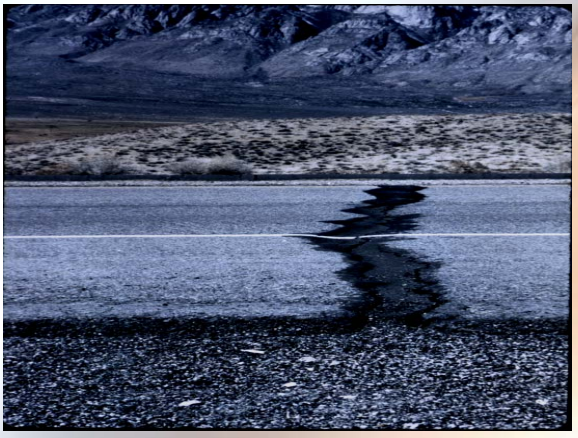
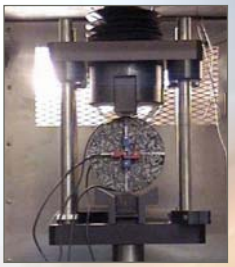
Thermal Cracking



Thermal Cracking

- *Indirect Tensile (IDT) creep stiffness*



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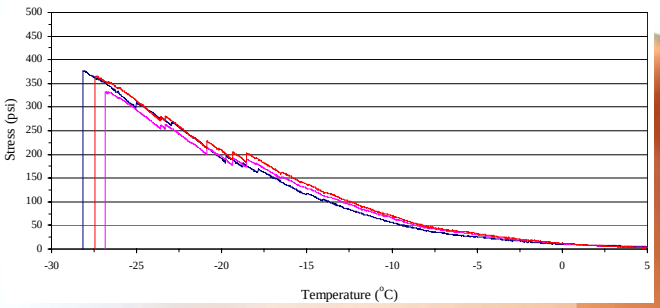
Thermal Cracking

- *Thermal Stress Restraint Specimen (TSRST)*



Load to keep beam at a constant height

2”×2”×10” beam

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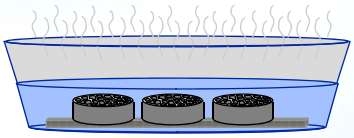
Evaluate Moisture Damage

3 Conditioned Specimens
"Wet Set"



3 Unconditioned Specimens
"Dry Set"

$$TSR = \frac{\text{Avg wet tensile strength}}{\text{Avg dry tensile strength}} \times 100$$

12-17

UNR – 2007

- PG64-22 (Neat)
- PG64-28 (polymer modified)
  - Source I — Plant waste (4.6% binder)
    - 0% RAP
    - 15% RAP
    - 30% RAP
  - Source II — 15-year old HMA pavement (5.4% binder content)
    - 0% RAP
    - 15% RAP
    - 30% RAP
  - Source III — 20-year old HMA pavement (5.8% binder content)
    - 0% RAP
    - 15% RAP
    - 30% RAP

SuperPave SuperPave

Summary of Selected Binder

RAP	Target Binder Grade			
	PG64-22		PG64-28NV	
	@ 15% RAP	@ 30% RAP	@ 15% RAP	@ 30% RAP
RAP I	PG64-22	PG58-28	PG64-34	PG58-34
RAP II	PG64-28	PG58-28	PG64-34	PG58-34
RAP III	PG64-28	PG58-28	PG64-34	PG58-34

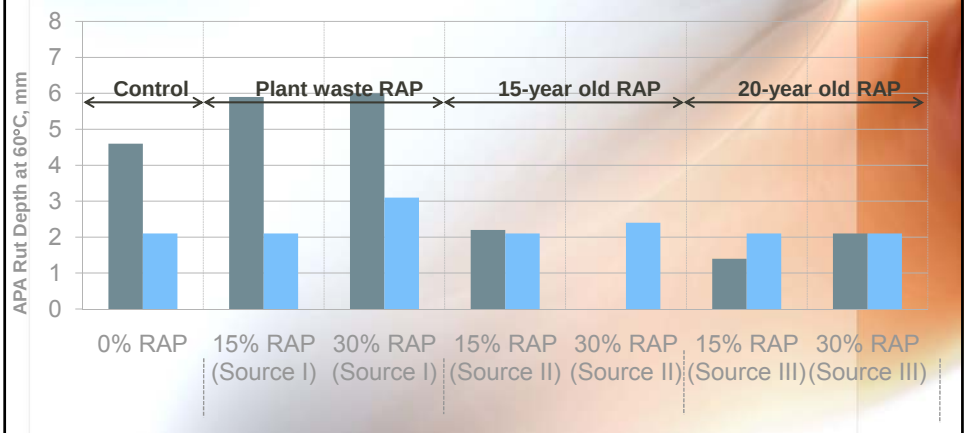
Summary Final PG Grades

Mix	Final Physically Blended	Final Extracted from Mixture	Mix	Final physically Blended	Final Extracted from Mixture
A0	PG64-22	PG64-22	B0	PG64-28	PG64-28
AI15	PG64-22	PG70-16	BI15	PG64-34	PG64-34
AI30	PG64-22	PG70-16	BI30	PG64-34	PG70-34
AII15	PG64-22	PG70-22	BII15	PG64-34	PG70-34
AII30	PG64-22	PG70-22	BII30	PG64-28	PG70-34
AIII15	PG70-22	PG76-22	BIII15	PG64-34	PG70-34
AIII30	PG64-22	PG76-22	BIII30	PG64-28	PG70-34

Rutting

- ***UNR - 2007: APA Tests***

Passed NDOT APA criterion of 8 mm at 60°C → good rutting resistance



Fatigue

- ***UNR- 2007:*** **mixtures with 0, 15 and 30% RAP.**
  - **PG64-22 (neat):**
    15% RAP → better or equivalent fatigue resistance.
  - **PG64-28 (polymer modified):**
    15-30% RAP → significant ↓in fatigue resistance.

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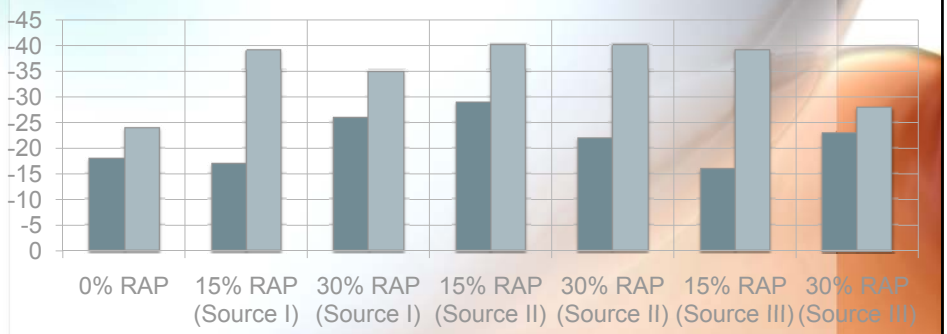
Thermal Cracking

- ***UNR - 2007:*** **RAP mixes with 0,15 and 30% RAP using TSRST**



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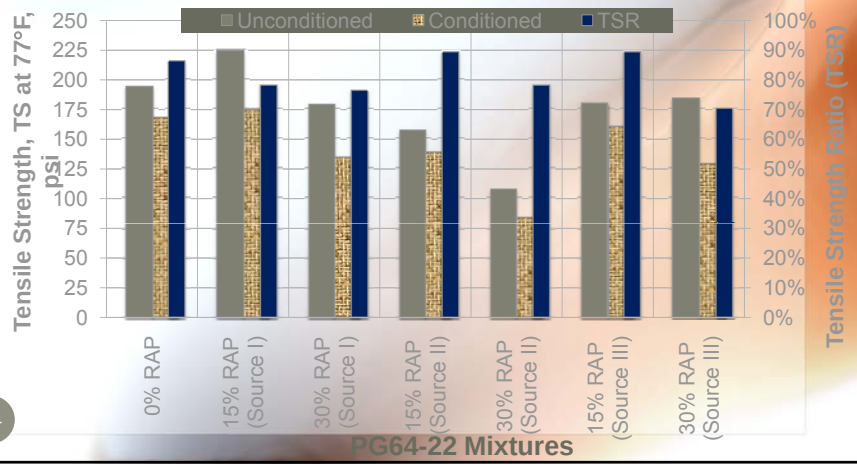
Moisture Damage

- ***UNR- 2007:*** **RAP mixtures with 0,15 and 30% RAP, AASHTO T283 test.**



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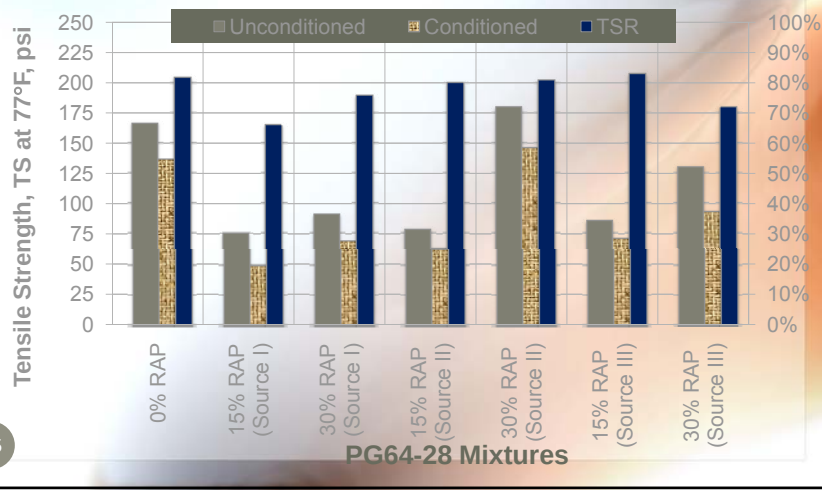
Moisture Damage

- *UNR - 2007* (cont'd)



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Moisture Damage

- *UNR - 2007 (cont'd)*
  - 15 and 30% RAP → acceptable moisture resistance (TSR>70).
  - 15 and 30% RAP → ↓ TS conditioned and unconditioned.

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FIELD PERFORMANCE REVIEW OF RAP CONTAINING MIXES

Field performance

- ***CALTRANS:* Evaluated life expectancy of 15% RAP pavements in California**

Environmental Zone	Expected Service Lives (years) Based on			Triggering Failure Mode
	Structural Performance	Distress Performance	Roughness Performance	
North Coast	18	21	17	Ride quality
Desert	15	9	15	Distress
Mountain	11	13	15	Structural

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Field performance

- ***Louisiana DOT:*** **Compared the performances of 5 RAP sections (20-50%) and 4 virgin mix pavement sections**
  - **after 6 - 9 years: long & trans cracking and rutting were the Major type of distresses.**
  - **20-50% RAP sections perform equally to virgin sections.**
  - **No significant diff. between recovered binder from virgin and RAP sections.**

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Field performance

- ***Connecticut DOT:*** **3 Connecticut sections Containing 20% RAP.**
  - **Good field performance after 8 years in service .**
  - **No fatigue and transverse cracking.**
  - **Lower rutting than other sections.**
  - **Slightly higher non-wheel path longitudinal cracking.**

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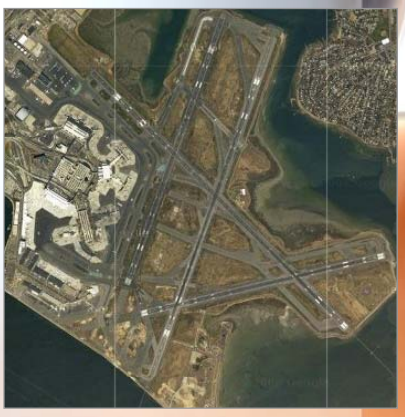
Field performance

- ***Boston Logan International airport:***
  - 20 feet above sea level
  - Loads up to 873,000 lb
  - Tire pressure in excess of 200 psi



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Field performance

Boston Logan International airport: (cont'd)

- In 2001: 18.5% RAP mix was used as a surface course on a section of Taxiway November.
- In 2003 RAP mix showed good performance.
- Good experience → Logan airport mix design specs include 15-20% RAP in all surface mixes

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STATE HIGHWAY AGENCIES USE OF RAP

RAP in HMA Surface Mixes
(After NCDOT)

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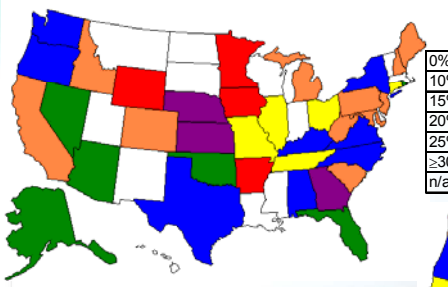
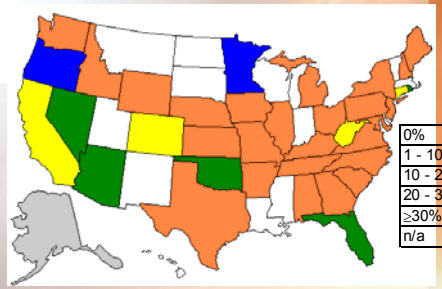
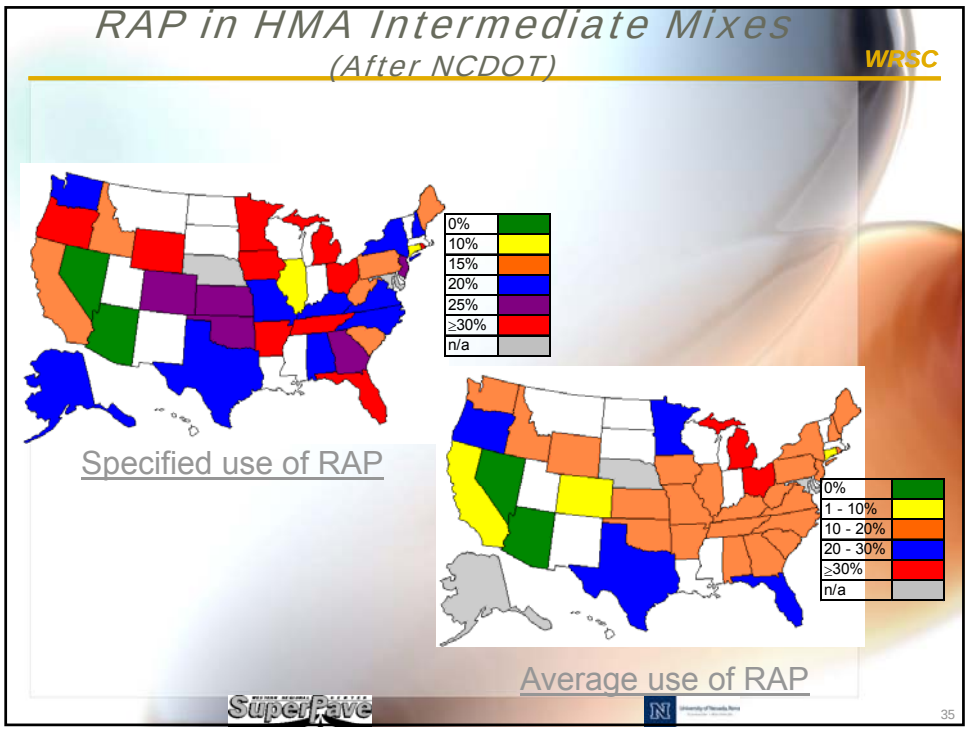
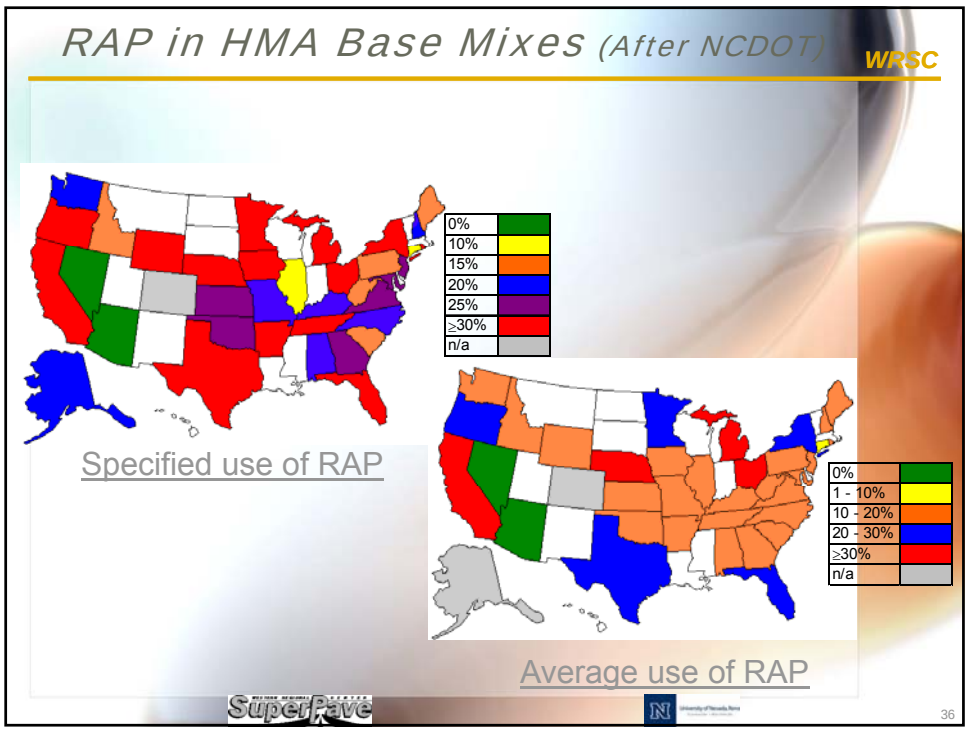


Specified use of RAP



Average use of RAP


RAP in HMA Intermediate Mixes
(After NCDOT)
WRSC
0%
10%
15%
20%
25%
≥30%
n/a
Specified use of RAP
0%
1 - 10%
10 - 20%
20 - 30%
≥30%
n/a
Average use of RAP
SuperPave
35


RAP in HMA Base Mixes (After NCDOT)
WRSC
0%
10%
15%
20%
25%
≥30%
n/a
Specified use of RAP
0%
1 - 10%
10 - 20%
20 - 30%
≥30%
n/a
Average use of RAP
SuperPave
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State highway agencies use of RAP

- **Most highway agencies allow max 10-25% of RAP in surface mixes and a higher %RAP in base mixes.**
- **Some highway agencies restrict or limit RAP to 10% with PMB mixes.**
- **Most highway agencies require an adjustment to the binder grade when > 15-20% RAP is used.**

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RAP Variability

- ***Kallas (1984):* RAP composition**

Sample	No. of samples tested	% Passing				Asphalt binder content	
		No. 8 sieve		No. 200 sieve			
		Ave	σ_{n-1}	Ave.	σ_{n-1}	Ave	σ_{n-1}
California Road cores	12	54	8.3	9.9	2.01	5.4	0.71
California stockpile after milling	5	69	6.5	11.8	0.34	5.2	0.04
North Carolina Road cores	12	69	3.2	6.1	0.66	5.7	0.11
NC stockpile after milling	5	72	0.9	8.0	0.11	5.7	0.11
Utah Road cores	12	52	3.8	8.7	2.60	6.5	0.28
Utah stockpile after milling	10	58	2.8	9.9	1.15	6.2	0.44
Virginia Road cores	12	41	2.1	9.7	0.79	5.3	0.20
Virginia stockpile after milling	6	52	1.1	13.0	0.30	5.2	0.12
Typical HMA surface variability	--	--	2.81	--	0.94	--	0.28
HMA surface variability on Airport Pavements (P-401-6.5)	--	--	--	--	1.00	--	0.23

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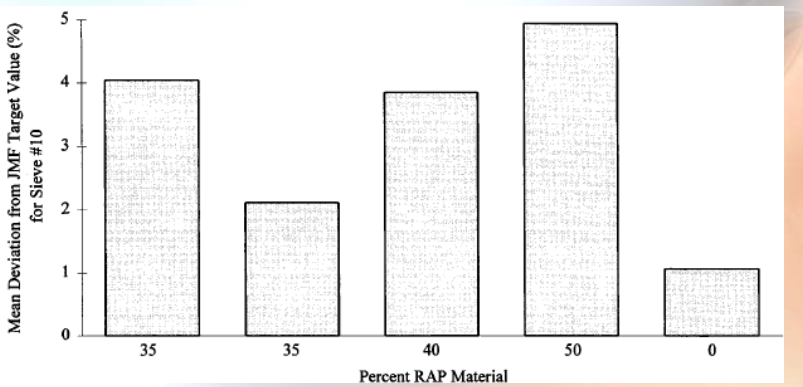
RAP Variability

- ***Solaimanian and Tahmoressi (1996), TxDOT***



39 Mean deviations from job mix formula target gradation for sieve No. 10

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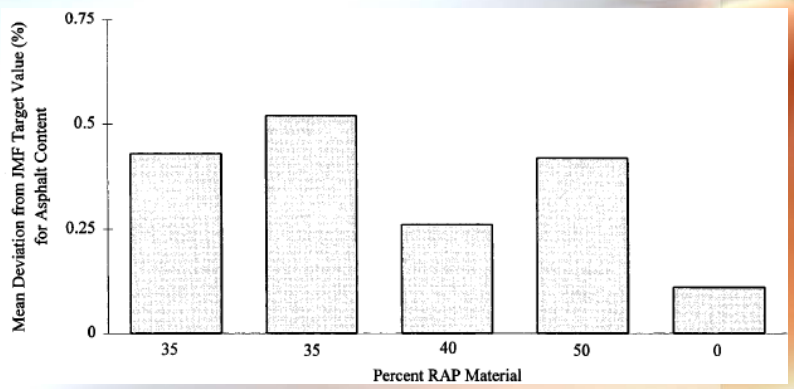
RAP Variability

- ***Solaimanian and Tahmoressi (1996) (cont'd)***



40 Mean deviations from target job mix formula asphalt content

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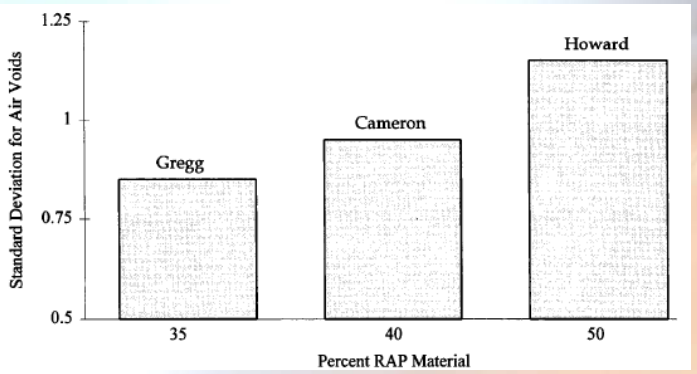
RAP Variability

- ***Solaimanian and Tahmoressi (1996) (cont'd)***



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Standard deviations for air voids as a function of RAP content in the mix

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RAP Variability

- ***Estakhri et al. (1998):* 33 projects with RAP containing FDOT mixes.**
  - **At the asphalt plant site: variability of RAP is not statistically different from that of stockpiled virgin aggregates.**
  - **RAP did not show an adverse effect on the variability of HMA (*Based on aggregate gradations*).**

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RAP materials evaluation

1. **Measuring RAP aggregate SG would require:**
   - **Extracting the RAP**
   - **Sieving it into coarse and fine fractions**
   - **Determining the specific gravity of each fraction.**
   - **Measured BSG of RAP aggregate may not accurately present actual value.**

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RAP materials evaluation

2. **G_{sb} of RAP aggregate may be estimated by determining G_{mm} of the RAP mix & using an assumed asphalt absorption for the RAP aggregate.**

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}}$$

$$G_{sb} = \frac{G_{se}}{\left(\frac{P_{ba} G_{se}}{100 \times G_b}\right) + 1}$$

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RAP materials evaluation

3. RAP aggregate G_{se} may be used in lieu of the G_{sb} at the discretion of the engineering consultant or agency.

- This may introduce an error into the combined aggregate BSG → VMA calculations.
- An increase in minimum VMA may be required.

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Current Activities Nevada - Wisconsin

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- Develop a procedure to determine binder grade without extraction/recovery
- Define the proper method for evaluating aggregate properties
- Define the proper method of lab mixing