Arizona Pavements and Materials Conference
November 2017

Feasibility of using Recycled Asphalt Pavements (RAP) in Phoenix

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City of Phoenix

CoP Sustainability Program

- Phase I: Preliminary Study
- Phase II: Field Study

Sustainability Benefits:

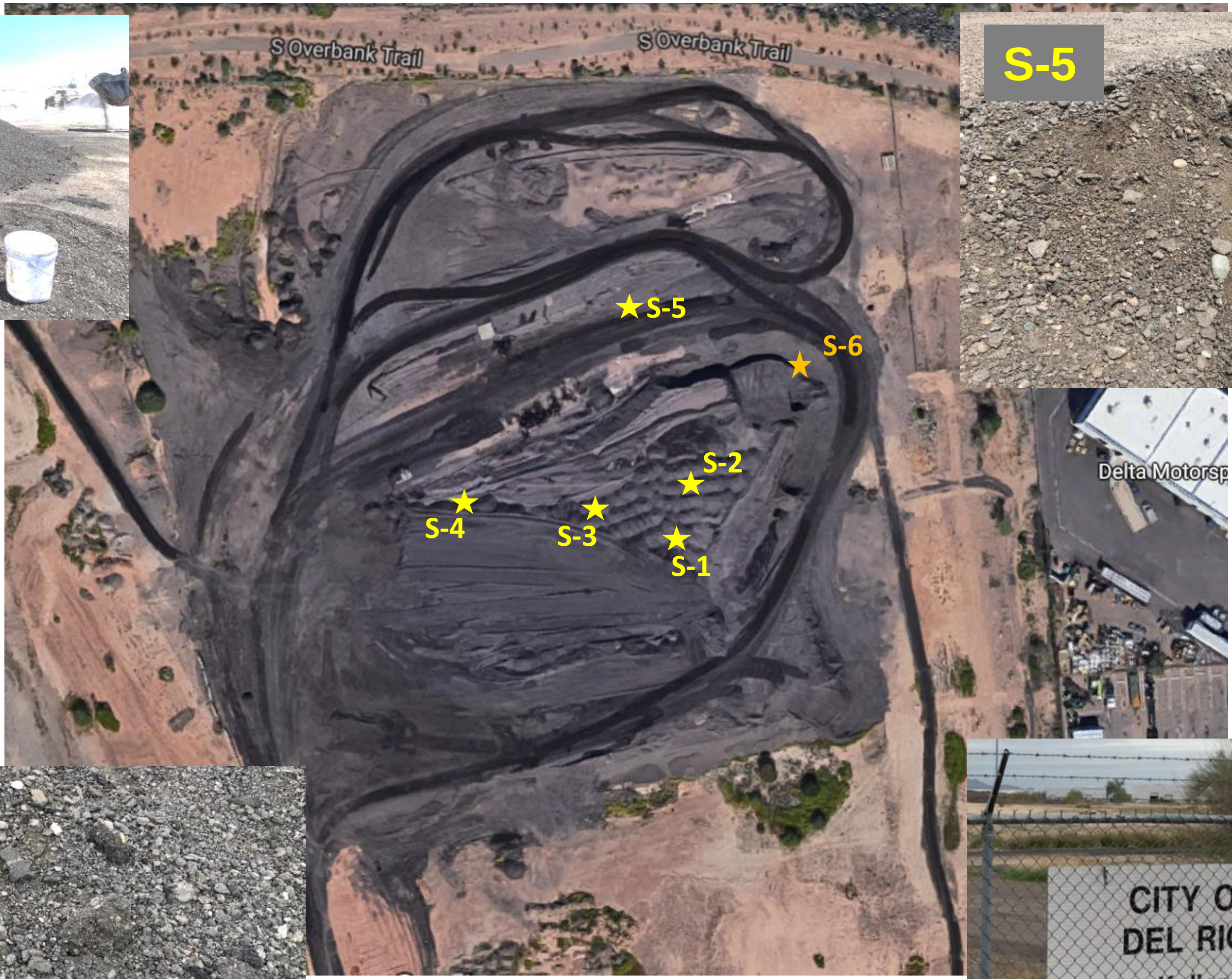
- Accordin
  - 50 m
  - More
  - Redu llion tons of ag
  - $2.6
  - Avera 09) to 20.4
- Accordin
  - 12% c -2016)
  - Binde
  - Aggre
  - $3.9 r since 2009

1. Survey

Agency	Asphalt Concrete		Unbound Base	Other
	Surface	Non-Surface		
City of Phoenix			X[1]	X
City of Tucson		X	X	X
Arizona Department of Transportation (ADOT)	X	X	X	X
Maricopa Association of Governments (MAG)	X	X	X	X
Pima Association of Governments (PAG)	X	X	X	
Maricopa County Dept. of Transportation (MCDOT)		X	X[2]	X
Pima County Dept. of Transportation (PCDOT)	X	X	X	X
East Valley Asphalt Committee (EVAC)		X		X
Apache Junction			X	X
Mesa		X	X	X
Gilbert				
Queen Creek			X	X
Las Vegas (Nevada)	X	X	X	X
Nevada Department of Transportation (NDOT)	X	X	X	X
Texas Department of Transportation (TxDOT)	X	X	X	X
New Mexico Department of Transportation (NMDOT)	X	X	X	X
California Department of Transportation (Caltrans)	X	X	X	X

[1] Only with the City of Phoenix Lab approval.
[2] Only for minor collectors or local roads. Arterial streets not exceed 20% and 30% for collectors.

2. RAP Stockpile Sampling



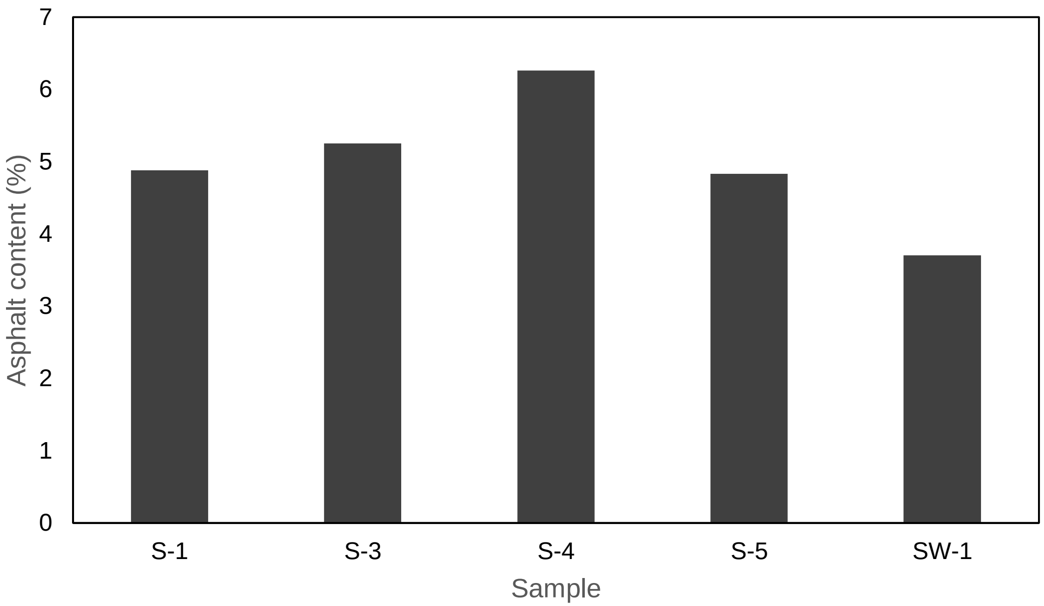
Del Rio Landfill

RAP from Southwest Asphalt Plant – El Mirage

- On the approved City of Phoenix list
- Processed RAP material
- Possible use on future paving projects for the City

Asphalt Content

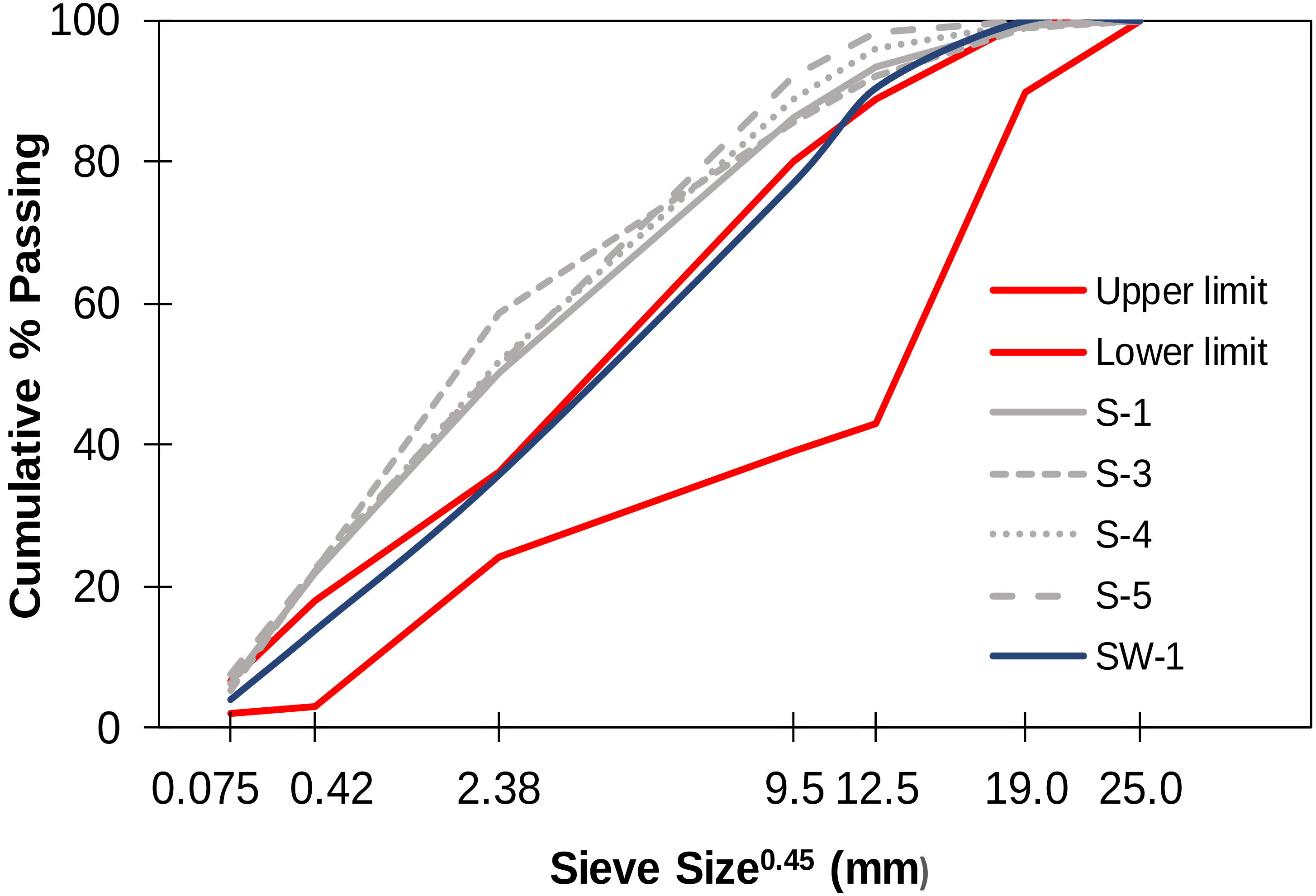
Sample	Asphalt content (%)
S-1	4.88
S-3	5.25
S-4	6.26
S-5	4.83
SW-1	3.82
Maximum (%)	6.26
Average (%)	5.01
Minimum (%)	3.82
Stand. Dev.(%)	0.79



NCHRP: Asphalt content maximum Std. Dev. = 0.5%

Extraction: AASHTO T164/ASTM D2172 Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)(trichloroethylene, n-propyl bromide or methylene chloride)

Recovery: ASTM D5404 Recovery of Asphalt from Solution Using the Rotary Evaporator



Extracted aggregates gradations

- Processed RAP shows coarser gradation

Statistical Measures

Extracted aggregates gradation
(Del Rio Landfill and Southwest Asphalt)

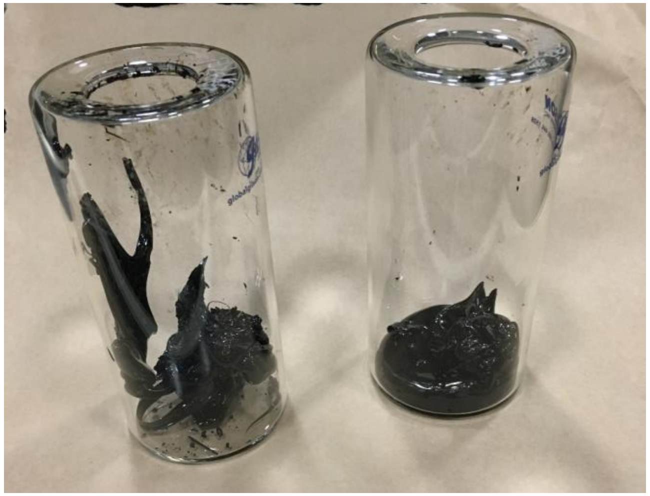
Sieve size	Average cumulative % passing	Maximum % Passing	Minimum % Passing	Standard Deviation (%)	CV (%)	Landfill only: Standard Deviation (%)	Landfill only: CV (%)
1 in	100	100	100	0.0	0.0	0.0	0.0
3/4 in.	100	100	99	0.4	0.4	0.4	0.4
1/2 in.	94	98	91	3.1	3.3	2.7	2.9
3/8 in.	86	92	77	5.6	6.5	3.0	3.4
#4	66	72	51	8.3	12.7	2.4	3.4
#8	49	58	36	**8.4**	16.9	**3.8**	7.3
#30	26	29	18	4.6	17.9	1.0	3.5
#40	20	22	14	3.8	18.5	0.3	1.3
#50	16	18	11	3.1	19.3	0.8	4.8
#100	10	12	7	2.0	21.0	1.2	11.9
#200	6	7	4	**1.3**	23.2	**1.0**	16.0

NCHRP: Passing #8 maximum Std. Dev. = 5.0%
Passing #200 maximum Std. Dev. = 1.5%

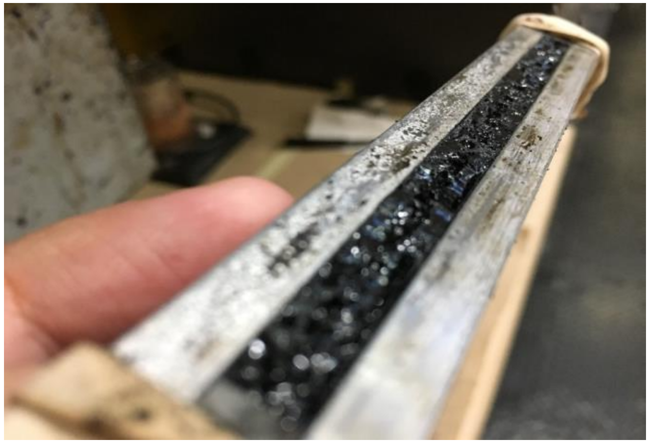
- Landfill unprocessed RAP shows less variability compared with including processed RAP
- Reasonable variability between samples

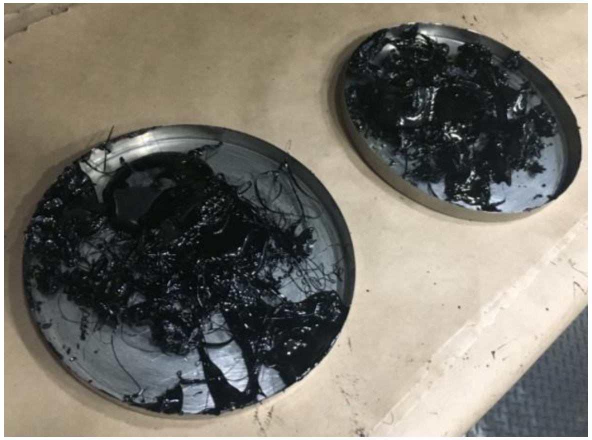
Extracted Binder Characterization

- Very stiff recovered binders



Binder tests:
- RTFO
- PAV
- DSR
- BBR





Performance Grade of Extracted Binders

Sample	Extracted PG Grade
	Standard
Stockpile 1	124 + 26
Stockpile 3	112 + 14
Stockpile 4	118 + 14
Stockpile 5	130 + 26
Stockpile SW1	112 + 14

In Phoenix, a PG 70-10 is a typical virgin binder.

Standard Specification for Superpave Volumetric Mix Design, AASHTO M 323-13

- **Table 2**—Binder Selection Guidelines for Reclaimed Asphalt Pavement (RAP) Mixtures

Recommended Virgin Asphalt Binder Grade	RAP %
No change in binder selection	<15
Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used	15 to 25
Follow recommendations from blending charts	>25

In consensus with COP it was decided to use 10% and 15% RAP contents considering PG 70-10 typical virgin binder.

Predicted Performance Grade change of virgin PG 70 - 10 binder by blending with the extracted binders

(based on NCHRP approach)

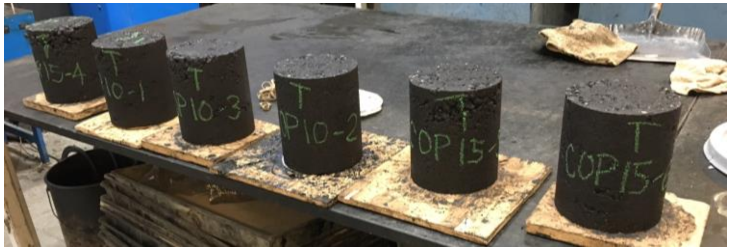
Stockpile	Extracted binder	RAP %	Blended binder
S-1	128.6 + 20.4	10	PG 70 – 4
		15	PG 76 – 4
		20	PG 76 + 2
S-3	115.7 + 10.2	10	PG 70 – 4
		15	PG 76 – 4
		20	PG 76 – 4
S-4	119.0 + 8.20	10	PG 70 – 4
		15	PG 76 – 4
		20	PG 76 – 4
S-5	130.8 + 22.3	10	PG 76 – 4
		15	PG 76 – 4
		20	PG 82 + 2
SW1	112.5 + 11.3	10	PG 70 – 4
		15	PG 76 – 4
		20	PG 76 – 4

3. Mix Design Procedure

- Guidelines for Mix Design:
  - Gyratory mix design criteria of CoP
  - Superpave mix design method
  - 3/4” Base course mix
  - Low traffic (0.3 to less than 3 million of 20-year ESALs)
  - Three mixes: Control (0% RAP), 10% RAP and 15% RAP
  - Virgin binder PG 70-10
  - RAP incorporation based on national and local practices.
  - Sample fabrication (at least 3 replicates for each test)

Mix Design Volumetric Information

Mix Property	COP Criteria 3/4" Mix	0%	10%	15%	Specifications
Asphalt Binder (%)		5.02	5.17	5.37	
Air Voids (%)	4.0+/-0.2	4.00	4.00	4.00	
VMA (%)	13 min.	14.76	14.05	13.45	Pass
VFA (%)	65 - 78	72.59	71.63	70.33	Pass
Absorbed Asphalt (%)	0 - 1.0	0.40	0.32	0.30	Pass
Dust Proportion	0.6 - 1.4	1.03	0.99	0.94	Pass
%Gmm @ Nini = 7	less than 90.5	89.42	89.33	89.34	Pass
%Gmm @ Nmax = 115	less than 98	97.01	96.94	96.94	Pass
Eff. Asphalt content (%)		4.64	4.87	5.08	
P0.075		4.80	4.80	4.80	
Total Binder (%)		5.02	5.17	5.37	(by weight of total mix)
Added Virgin Binder (%)		5.02	4.80	4.82	(by weight of total mix)
Contributed RAP Binder (%)		0.00	0.37	0.55	(by weight of total mix)
Gmm		2.458	2.452	2.445	
Gsb		2.629	2.634	2.635	

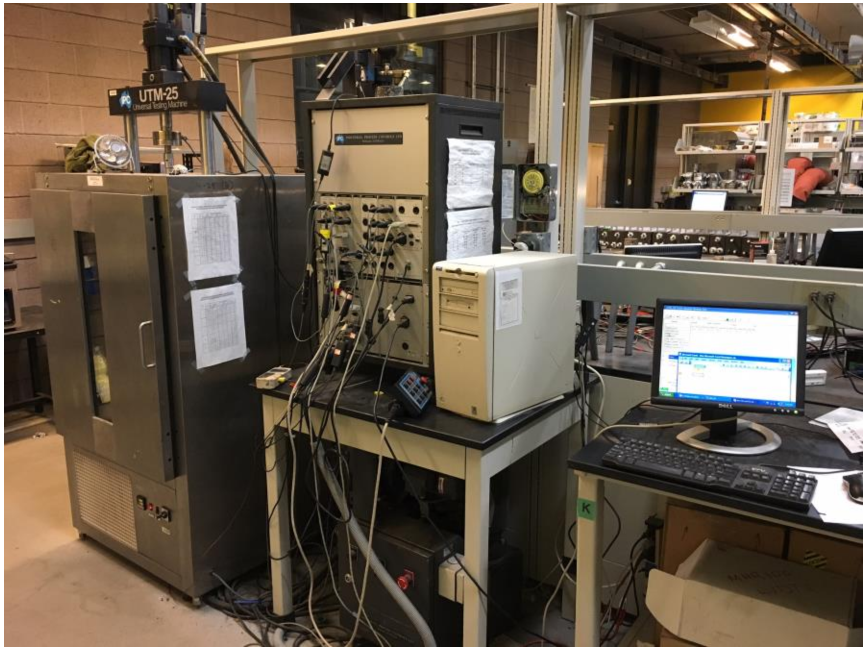


4. Laboratory Testing and Evaluation

- Performance evaluation:
  - Dynamic Modulus (E*): Stiffness of the material. Fundamental property for pavement design (temperature and frequency).
  - Flow Number (FN): to evaluate the resistance to rutting of the asphalt mix.
  - Tensile Strength Ratio (TSR): to measure the degree of susceptibility to moisture damage.

    [+ cracking potential]

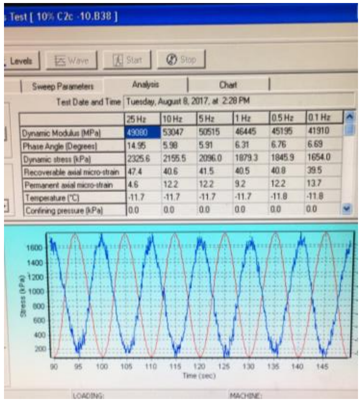
Dynamic modulus (E*)



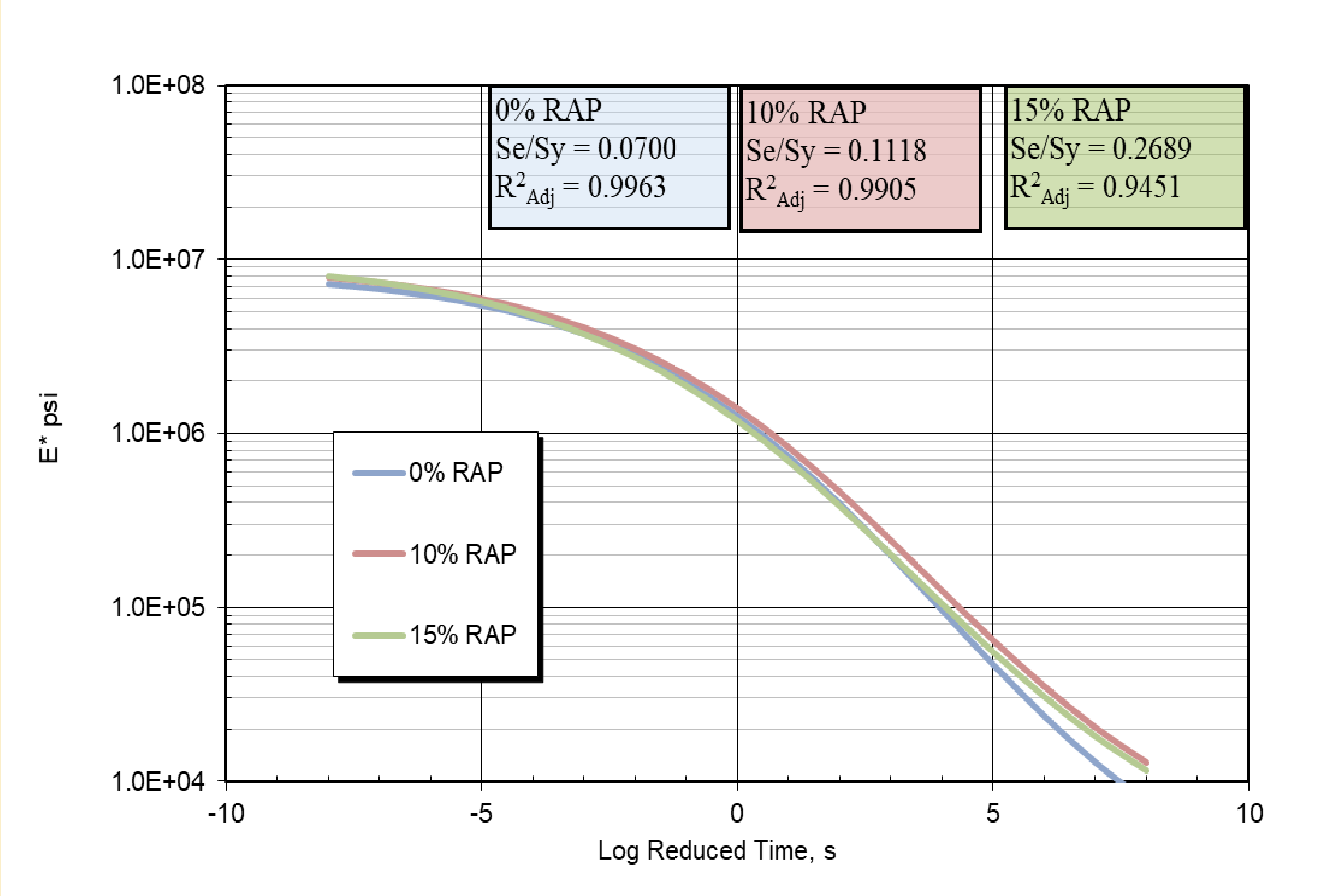
- AASHTO TP 62
- Primary material parameter for MEPDG
- Stiffness
- Sinusoidal repetitive load
- Reduced temperature set:

 -10, 4.4, 21.1, 37.8 and 54.4 °C.

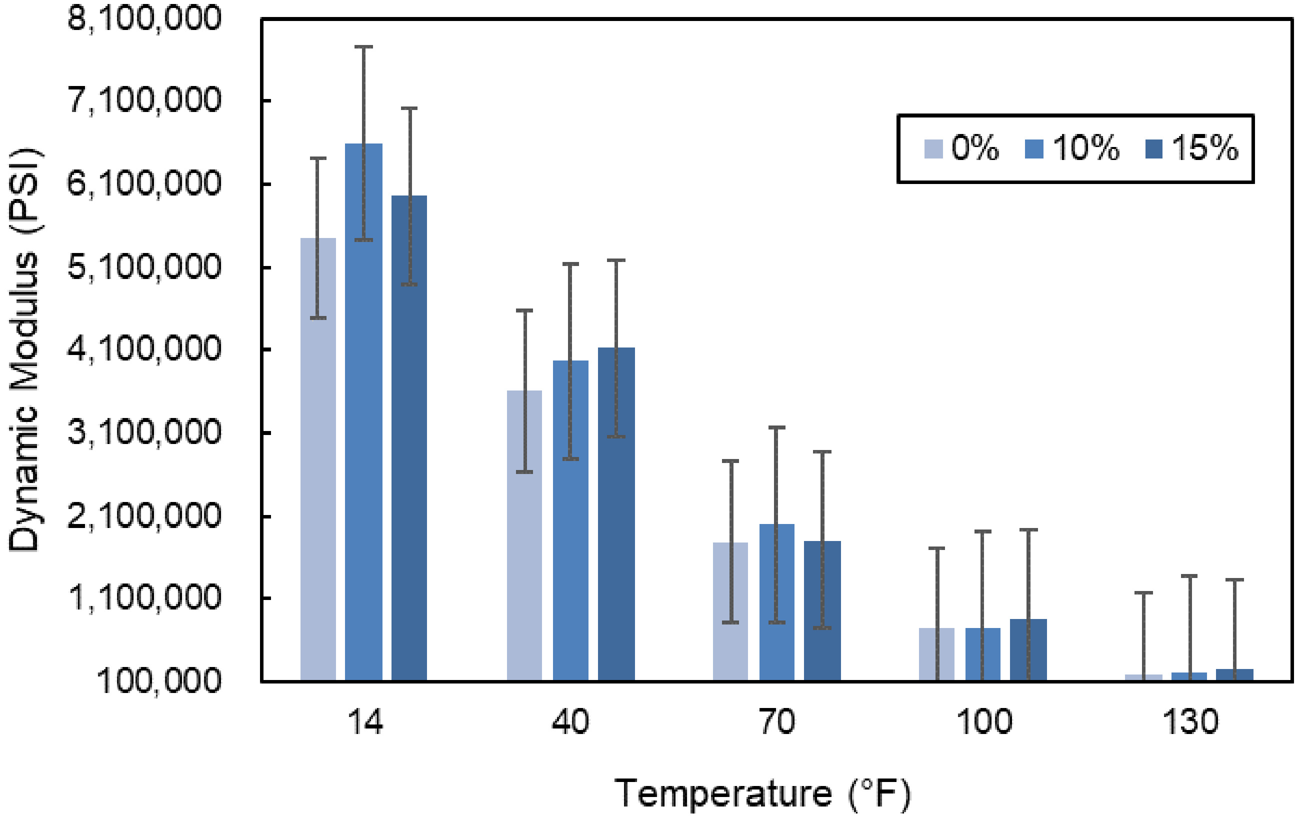
- For 6 frequencies: 25, 10, 5, 1, 0.5 and 0.1 Hz.
- 3 replicates for each RAP content



	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
Dynamic Modulus (MPa)	49080	53047	50515	46445	45195	41910
Phase Angle (Degrees)	14.95	5.98	5.91	6.31	6.76	6.69
Dynamic stress (kPa)	2325.6	2155.5	2096.0	1879.3	1845.9	1654.0
Recoverable axial micro-strain	47.4	40.6	41.5	40.5	40.8	39.5
Permanent axial micro-strain	4.6	12.2	12.2	9.2	12.2	13.7
Temperature (°C)	-11.7	-11.7	-11.7	-11.7	-11.8	-11.8
Confining pressure (kPa)	0.0	0.0	0.0	0.0	0.0	0.0



Dynamic modulus (E*)



Dynamic modulus (E*) for different temperatures and 10 Hz frequency

ANOVA and t-Test Analysis on Dynamic Modulus

Comparing three mixes:

Frequency (Hz)	Temperatures (°C)				
	14	40	70	100	130
25	NS	NS	NS	NS	NS
10	NS	NS	NS	NS	NS
5	NS	NS	NS	NS	NS
1	NS	NS	NS	NS	NS
0.5	NS	NS	NS	NS	NS
0.1	NS	NS	NS	NS	NS

NS= Not Statistically Significant S= Statistically Significant

- 0%, 10% and 15% RAP mixes are not statistically different.
- Dynamic modulus of 15% RAP is slightly higher for 100°F (37.8°C).

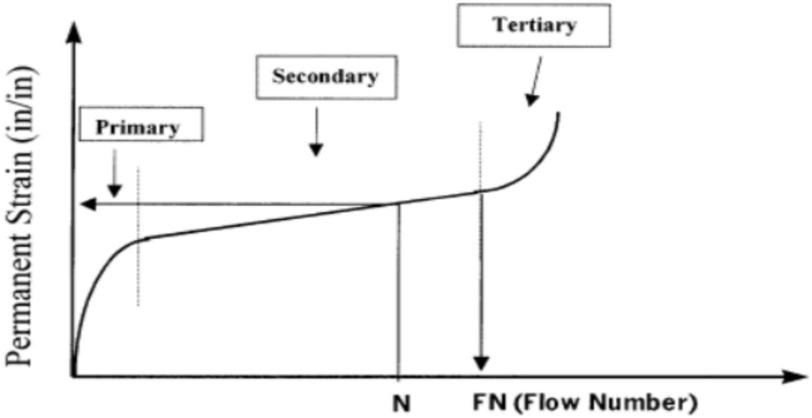
Comparing two mixes at a time:

Frequency (Hz)	Mix	Temperatures (°C)				
		14	40	70	100	130
25	0% to 10%	CNR	CNR	CNR	CNR	CNR
	0% to 15%	CNR	CNR	CNR	CNR	CNR
	10% to 15%	CNR	CNR	CNR	CNR	CNR
10	0% to 10%	CNR	CNR	CNR	CNR	CNR
	0% to 15%	CNR	CNR	CNR	CNR	CNR
	10% to 15%	CNR	CNR	CNR	CNR	CNR
5	0% to 10%	CNR	CNR	CNR	CNR	CNR
	0% to 15%	CNR	CNR	CNR	CNR	CNR
	10% to 15%	CNR	CNR	CNR	CNR	CNR
1	0% to 10%	CNR	CNR	CNR	CNR	CNR
	0% to 15%	CNR	CNR	CNR	R	CNR
	10% to 15%	CNR	CNR	R	CNR	CNR
0.5	0% to 10%	CNR	CNR	CNR	CNR	CNR
	0% to 15%	CNR	CNR	CNR	R	CNR
	10% to 15%	CNR	CNR	CNR	CNR	CNR
0.1	0% to 10%	CNR	CNR	CNR	CNR	CNR
	0% to 15%	CNR	CNR	CNR	R	CNR
	10% to 15%	CNR	CNR	CNR	CNR	CNR

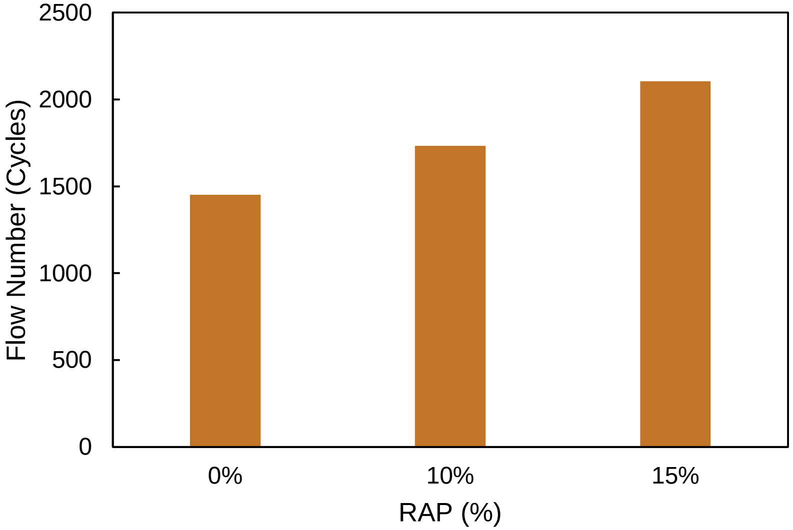
R= Reject H_0 CNR= Cannot reject H_0

Flow Number (FN)

- AASHTO TP 79
- A measure of permanent deformation in HMA mixes, correlates with rutting potential
- Haversine pulse load
- Describes the cycle number at which tertiary flow begins
- Testing temperature: 122°F (50°C)
- 3 replicates for each RAP content



Flow Number (FN)



Rodezno's rutting prediction model:

$$R = 0.0038{*}FN^{-0.242}{*}ESALs^{0.485}{*}h^{-1.021}$$

Mixture	FN	ESALs	Pavement Thickness (in)	Rutting	
				(in)	(mm)
0%	1452	3,000,000	3	**0.29**	**7.5**
10%	1732	3,000,000	3	**0.28**	**7.2**
15%	2106	3,000,000	3	**0.27**	**6.8**

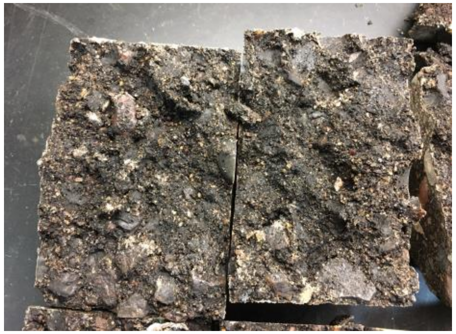
Mixture	Flow Number (Cycles)		α = 0.05			t-Test comparing:
	Average	CV(%)	ANOVA	t-Test one-tail	t-Test two-tail	
0%	1452	39.7		**CNR**	**CNR**	0% to 10%
10%	1732	21.3	**NS**	**CNR**	**CNR**	0% to 15%
15%	2106	37.8		**CNR**	**CNR**	10% to 15%

ANOVA: NS= Not Statistically Significant S= Statistically Significant
t-TEST: R= Reject H_0 CNR= Cannot reject H_0

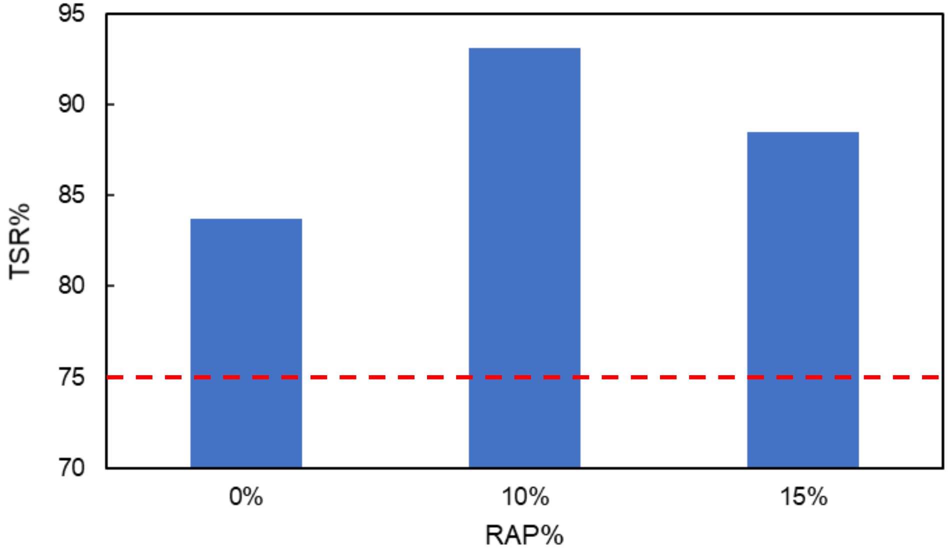
- Slight increase in performance as RAP percent increases.
- No statistical difference between the three mixes.

Tensile Strength Ratio (TSR)

- ASTM D4867
- Ratio of tensile strengths of conditioned to dry specimens
- COP specifies a minimum of 75% TSR
- Conditioned (wet and freeze-thaw cycle)
- Testing temperature: 77°F (25°C)
- Tensile splitting test
- 6 replicates for each RAP content



Tensile Strength Ratio (TSR)



Condition	Mixture	Tensile Strength (kPa		α = 0.05			t-Test comparing:
		Average	CV(%)	ANOVA	t-Test one-tail	t-Test two-tail	
Dry	0%	1504	4.2	NS	CNR	CNR	0% to 10%
	10%	1439	5.2		CNR	CNR	0% to 15%
	15%	1613	6.4		CNR	CNR	10% to 15%
Wet Freeze-Thaw	0%	1260	2.8	NS	CNR	CNR	0% to 10%
	10%	1339	6.2		CNR	CNR	0% to 15%
	15%	1427	9.0		CNR	CNR	10% to 15%

ANOVA: NS= Not Statistically Significant S= Statistically Significant
t-TEST: R= Reject H_0 CNR= Cannot reject H_0

- Slight improvement in TSR for RAP mixes compared to control mix.
- No statistical difference between the three mixes.

Pavement ME Design Modeling: Rutting and Fatigue cracking

- Pavement design comparison:

Road type	AADT (veh.)	Speed (mph)	Thickness (in)
Major	10000	45	5.0
Local	1000	25	2.0

- Tested measured Dynamic Modulus (E*):

Road type	Rutting (in)		
	0%	10%	15%
Major	0.482	0.474	0.466
Local	0.247	0.242	0.242

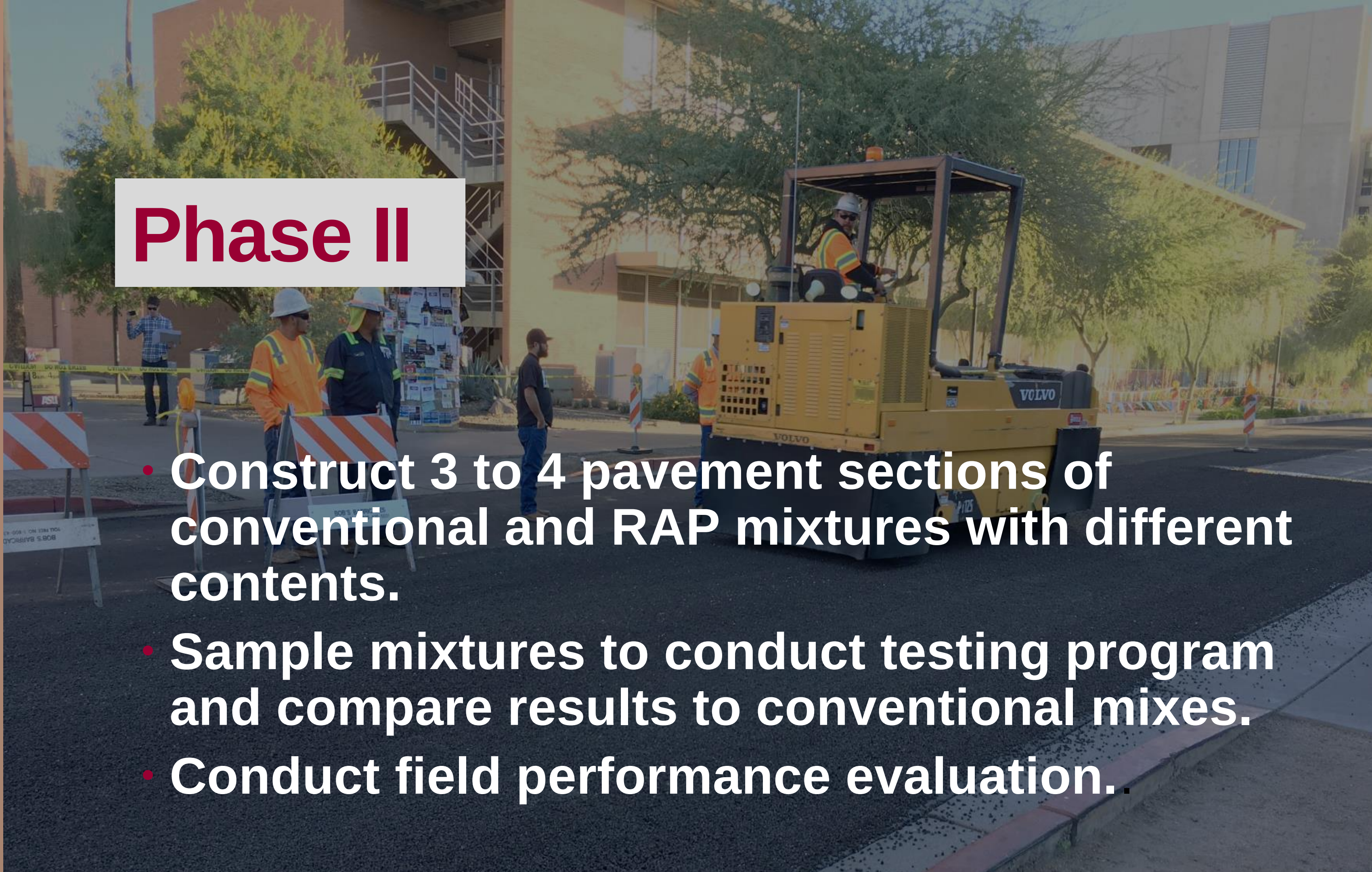
Road type	Fatigue cracking (%)		
	0%	10%	15%
Major	29	29	29
Local	18	17	18

- RAP percentage increase shows slightly less rutting depth.
- Fatigue is similar for all three mixes.
- The predicted pavement performance of all three mixes is similar.

Source: ROADEX Network / Coastal Road Repair

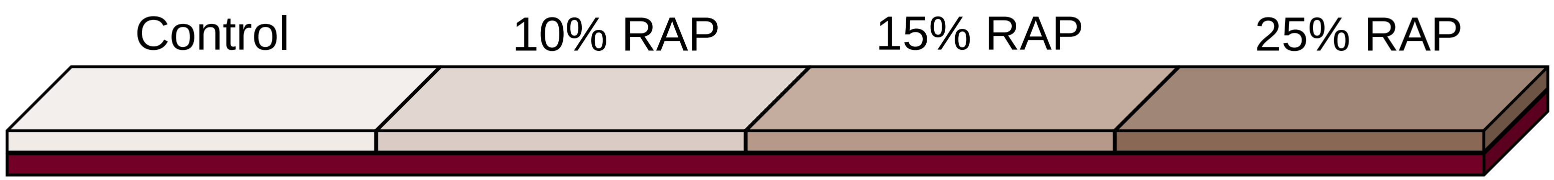
Concluding Remarks

- Mixes with RAP show higher stiffness than the control mix with higher dynamic moduli.
- The increase in RAP percentage show improvement on the pavement resistance to rutting.
- Fatigue cracking (predicted) not affected by low RAP contents.
- RAP mixtures show higher TSR values meaning less susceptible to moisture damage.
- No statistical significant difference in properties measured between the control, 10% and 15% RAP mixtures
- The use of low RAP contents (10% and 15%) has no negative effect on the material properties or pavement performance.



Phase II

- Construct 3 to 4 pavement sections of conventional and RAP mixtures with different contents.
- Sample mixtures to conduct testing program and compare results to conventional mixes.
- Conduct field performance evaluation.



Test sections

Rob and Melani Walton Sustainability Solutions Initiatives
Arizona State University

City of Phoenix

Thank you!

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RISN Resource Innovation and Solutions Network

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