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Improving the Properties of Reclaimed Asphalt Pavement for Roadway Base Applications Final Report

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Problem Statement

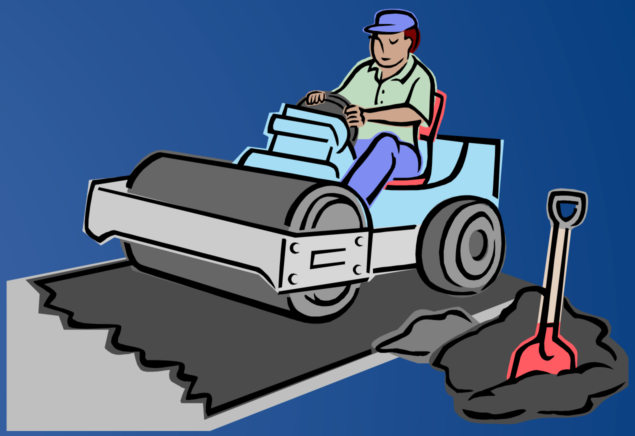
- FDOT specifications only allow RAP to be reused as a base in non-trafficked areas
- Florida's Aggregate production does not meet needs
- Aggregates are hauled in from as far away as Central America and Nova Scotia
- 10 mile I-95 widening project Brevard County
  - reusing RAP in base would save 40,000 tons of material
  - $800,000 - $1,000,000 estimated savings

Problem Statement

- Two problems limit RAP use:
  - Low strength
  - Creep deformation
- FDOT specifications use the Limerock Bearing Ratio (LBR) strength
  - Required LBR is 100 (800 psi) for base material
  - RAP LBR typically between 10 & 30
- RAP creep leads to rutting

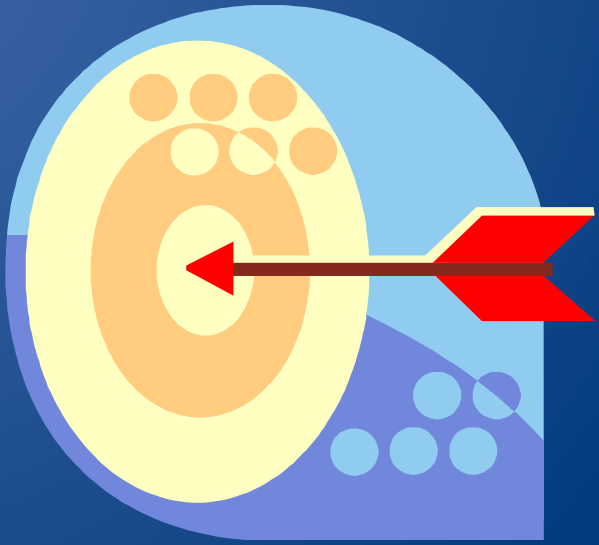
Outline

- Objective
- Tasks
- Results
  - Fractionating
  - Compaction
  - Blending
  - Chemical Stabilization
- Conclusions &Recommendations
- Questions



Objective

- Develop engineering methods to improve bearing ratios while reducing creep
- Leads to increased use of RAP as a base course.



Tasks

- Task 1 – Literature Review
- Task 2 – Testing Program Development
- Task 3 – Gradation Modification (Fractionating)
- Task 4 – Blends with High Quality Base
- Task 5 – Asphalt Content Evaluations
- Task 6 – Compaction Improvements Using
  - Mechanical Energy
  - Chemical Admixtures

Literature Review Focus

- General Characteristics of RAP
- Current use of RAP or RAP blends as base
- Compaction of RAP or RAP/aggregate blends
- Blending of RAP and virgin aggregates
- Use of chemical stabilizing additives with RAP including Cold In-place Recycling (CIR) or Full Depth Reclamation (FDR) pavement restoration
- Creep behavior of soils and RAP
- Mathematical modeling of the rheological response of viscoelastic materials to stress

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Relative Effects of increasing RAP content

Reference	Blends	Dry Density	Permeability	CBR	Resilient Modulus
Cooley (2005)	Yes	Decreased	---	Decreased	---
Garg & Thompson (1996)	*No*	Decreased	---	Decreased	---
MacGregor (1999)	Yes	---	No Change	---	Increased
Bennert & Maher (2005)	Yes	Decreased	*Decreased*	---	Increased
Papp (1998)	Yes	Decreased	---	---	Increased
Sayed (1993)	*No*	---	---	Decreased	---
Taha (1999)	Yes	Decreased	Increased	Decreased	---
Trzebiatowski (2005)	*No*	Decreased	Increased	---	---

- McGarrah (2007) literature summary

Current RAP Specifications

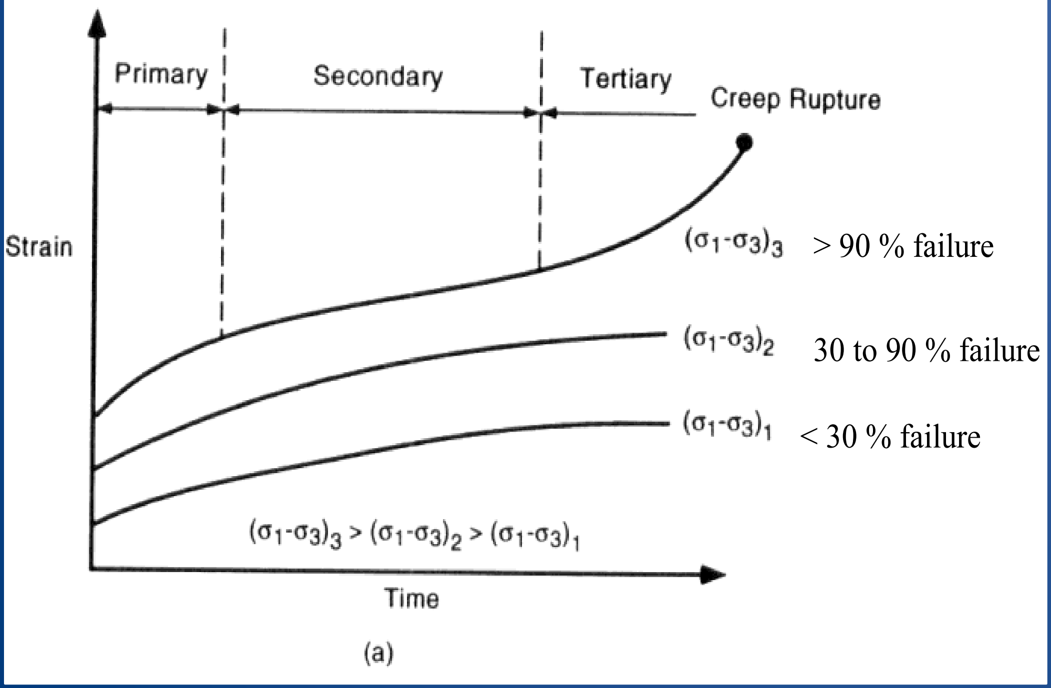
- McGarrah (2007) Summary of state practices

State	RAP Allowed	Max %	Processed	Testing
Florida	No	---	---	---
Illinois	No	---	---	---
Montana	Yes	50-60%	No	Corrected Nuc Gauge
New Jersey	Yes	50%[5]	Yes Gradation	Corrected Nuc Gauge + Sample
Minnesota	Yes	3%[6]	Yes Gradation	Dynamic Cone Penetrometer
Colorado	Yes	50%[5]	Yes Max Agg. Size	Roller Compaction Strip
Utah	Yes	2%[6]	Yes Gradation	Nuc Gauge or Breakdown Curve
Texas[7]	Yes	20%	Unknown	Various (Including Nuc Gauge)
California[7]	Yes	50%	Unknown	No special testing procedure listed
New Mexico[7]	Yes	Unknown	Unknown	Corrected Nuc Gauge
Rhode Island[7]	Yes	Unknown	Yes Gradation	Unknown
South Dakota[7]	No	---	---	---

Creep Theory for Soils

Singh and Mitchell (1968) developed a model to describe creep of clays.

$$\dot{\varepsilon} = Ae^{\alpha D}\left(\frac{t_1}{t}\right)^m$$



A – log strain rate vs. deviator stress and finding the intercept when D = 0.
m – slope of log strain versus log time straight line.
D – deviator stress
α – slope of the linear portion of the logarithm strain versus deviator-stress plot.
t_1 – reference time (1 day)
t – time

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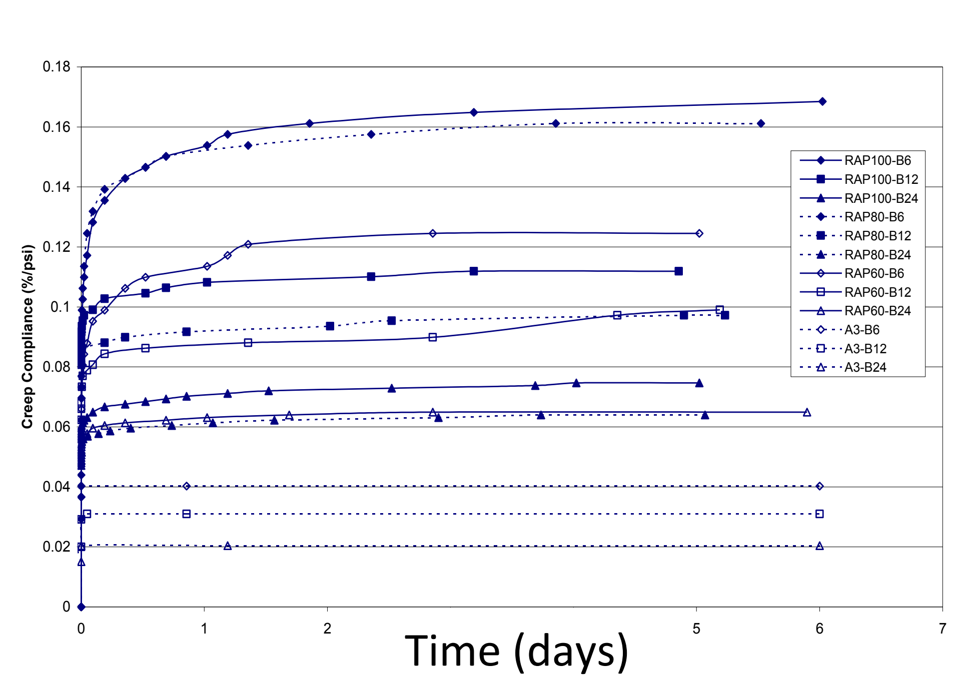
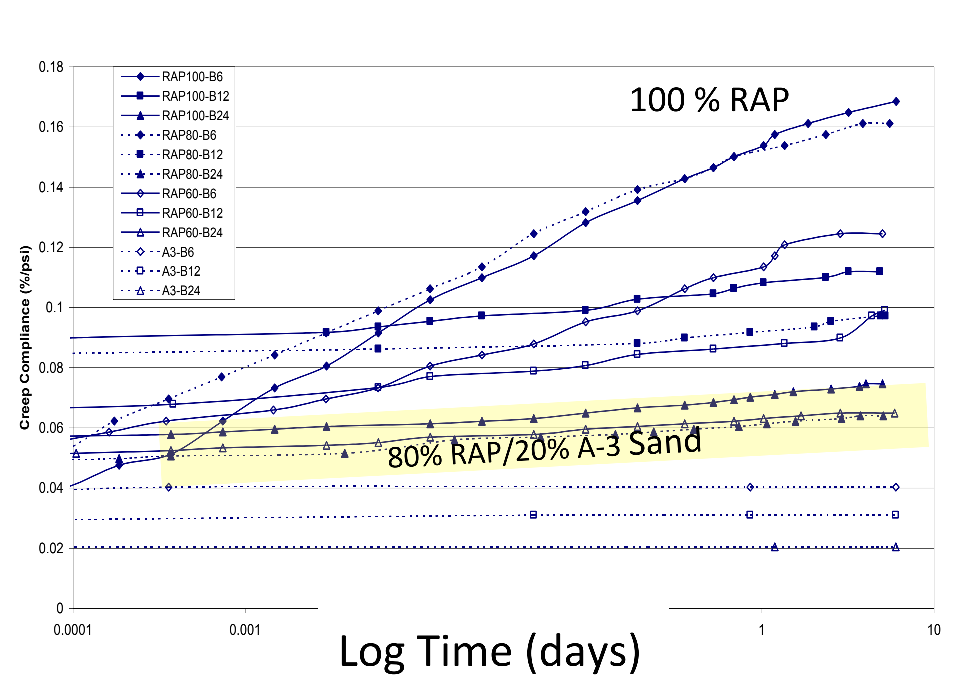
Background and Theory
Creep Behavior of RAP/A-3 Blends





Cleary (2005) and Dikova (2006)

Laboratory Investigation Program

- Test types
  - Index tests to describe the material
  - Strength tests to determine load capacity
  - Creep tests to determine susceptibility to long-term deformation
- Test materials
  - RAP, A-3 sand, limerock, cemented coquina, and crushed concrete base (FDOT spec)
  - 100% RAP, blends of RAP/aggregate base material containing 75%, 50%, and 25% RAP, and 100% aggregate base
  - 0%, 1%, 2%, and 3% stabilizing agent (asphalt emulsion, Portland cement or lime) by weight

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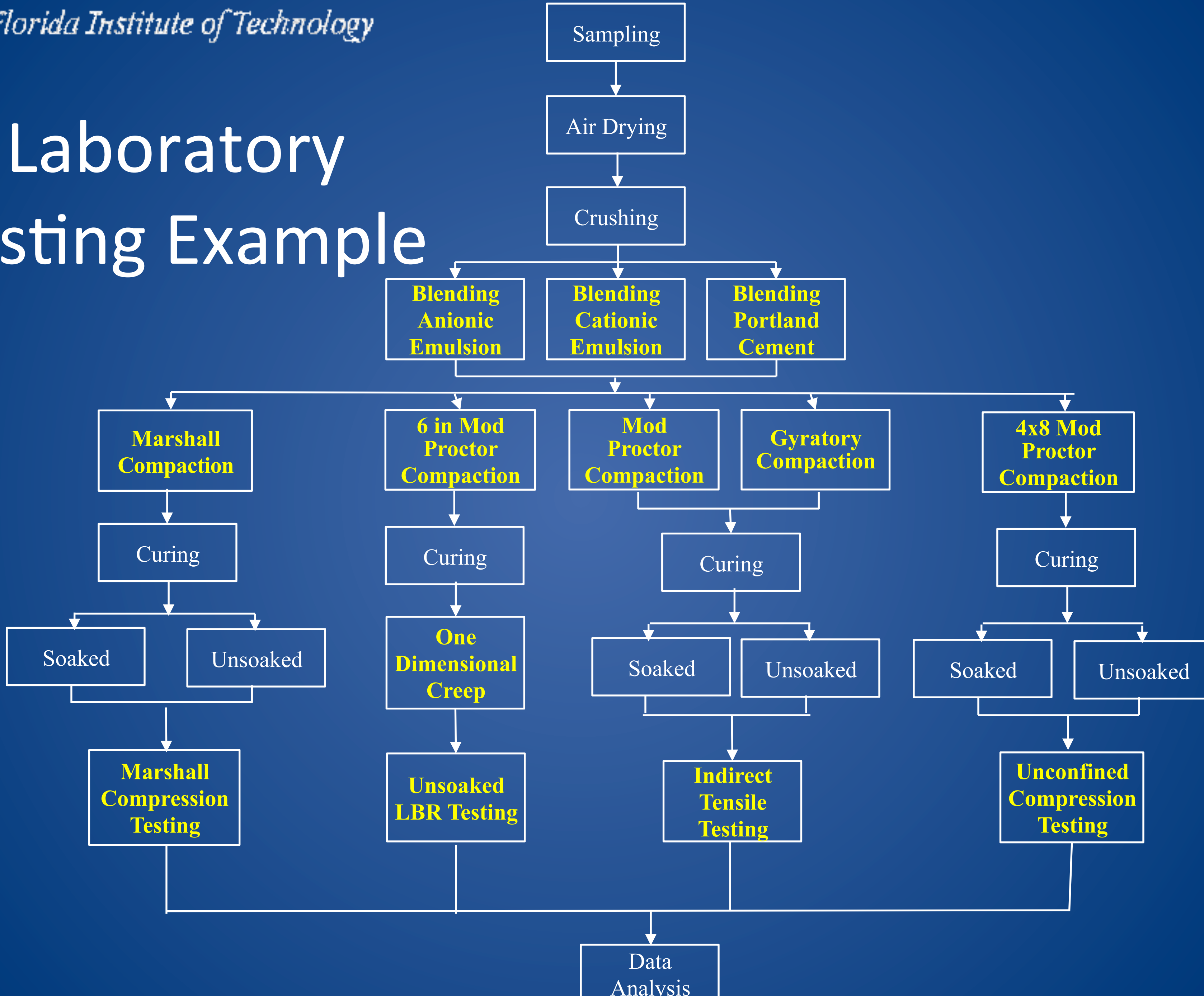
Laboratory Testing Example



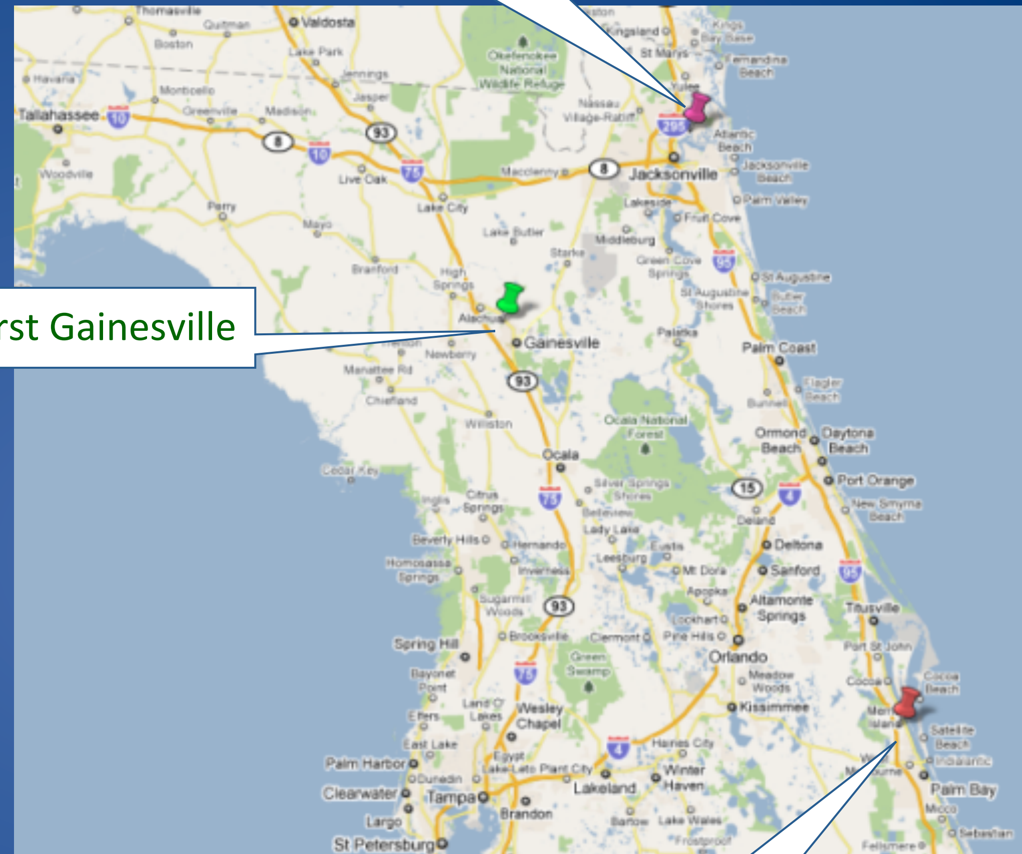
Locations

- Sampling
- Drying
- Sample reduction
- Oversize material

APAC Jacksonville

Whitehurst Gainesville

APAC Melbourne



Stabilizing Agents

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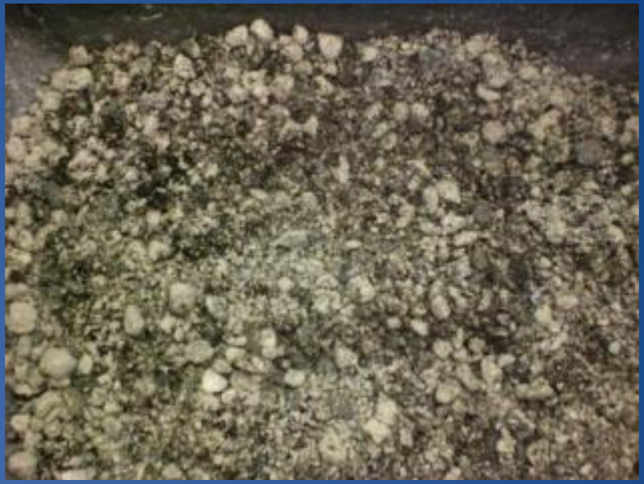
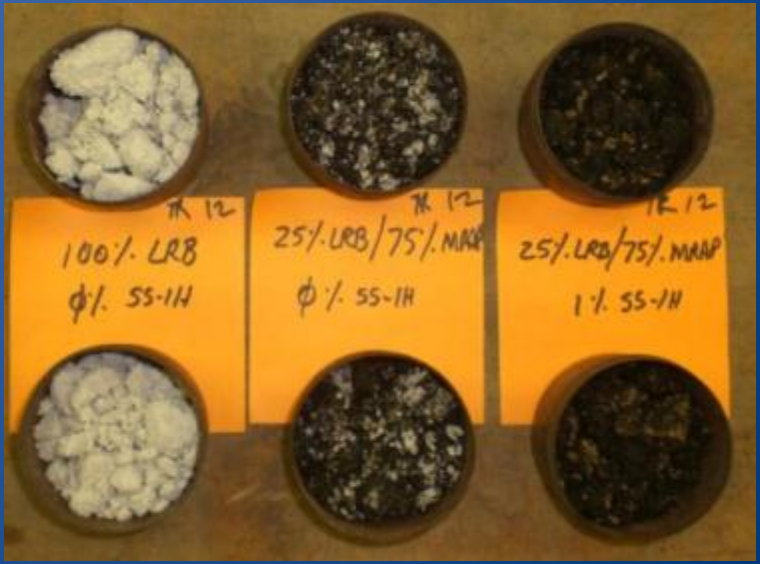
Blending





Compaction

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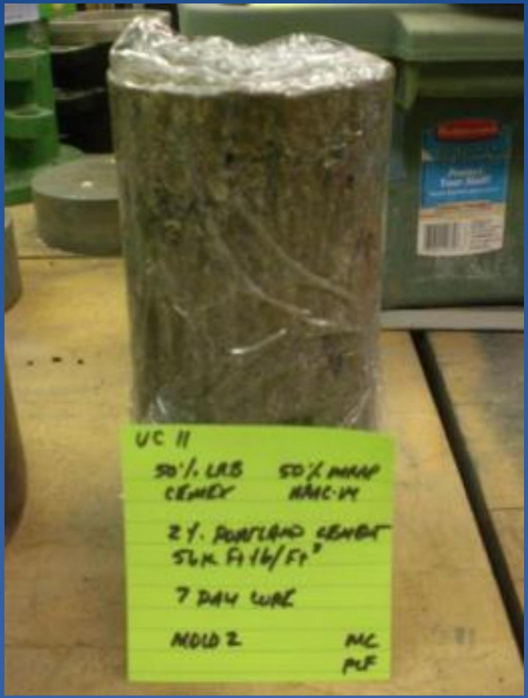
Curing



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Soaking

Creep Test

LBR Test

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Marshall Test

Unconfined Compression Test

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Indirect Tensile Test

RAP Index Properties

Properties	APAC - Melbourne	APAC - Melbourne	Whitehurst- Gainesville	APAC - Jacksonville
	Milled	Crushed	Milled	Crushed
Passing #4 (%)	58.1	75.8	46.0	73.38
Passing #8 (%)	32.8	50	42.0	55.27
Passing #40 (%)	7.68	14.35	11.0	33.33
Passing #200 (%)	0.50	0.60	0.30	6.82
C_u	9.80	10.7	12.0	28.0
C_c	1.73	0.94	0.88	0.32
AASHTO	A-1-a	A-1-a	A-1-a	A-1-b
USCS	SW	SW	SW	SW

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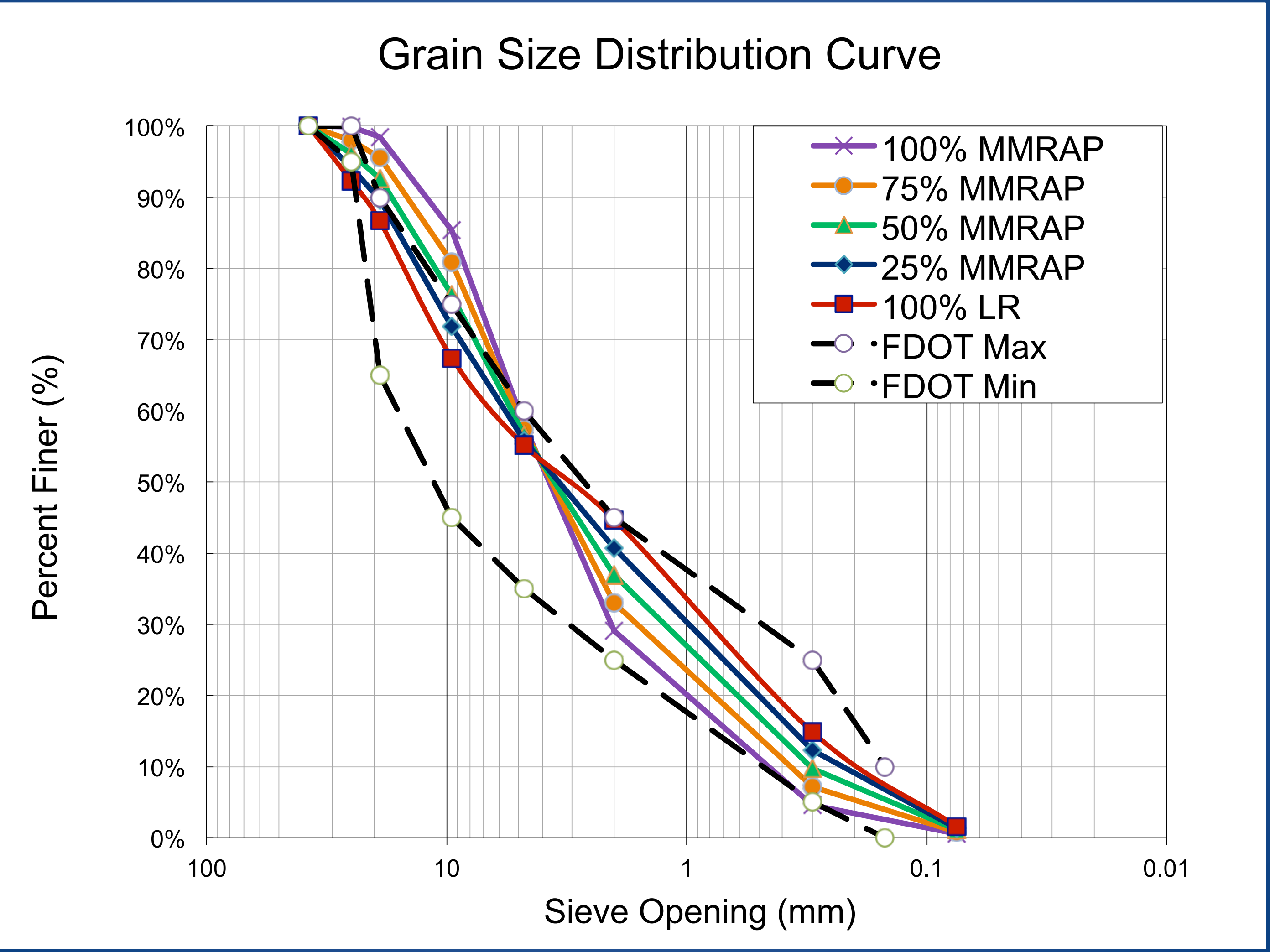
Sieve Analysis



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Permeability

	Permeability (cm/s)						
% RAP	Milled Melb. RAP/ Limerock	Milled Melb. RAP/ Cemented Coquina	Milled Melb. RAP/ Crushed Concrete	Crushed Jax. RAP/ Limerock	Crushed Jax. RAP/ Cemented Coquina	Milled W.H. RAP/ Limerock	Milled W.H. RAP/ Cemented Coquina
100	3.1E-03	3.1E-03	3.1E-03	1.8E-05	1.8E-05	1.3E-04	1.3E-04
50	3.2E-04	1.8E-05	1.2E-04	2.1E-05	5.5E-05	8.3E-05	3.6E-05
25	3.2E-05	5.9E-06	1.4E-04	4.2E-06	5.4E-04	1.2E-06	2.7E-04
0	1.2E-06	3.0E-06	2.9E-05	1.2E-06	3.0E-06	1.2E-06	3.0E-06

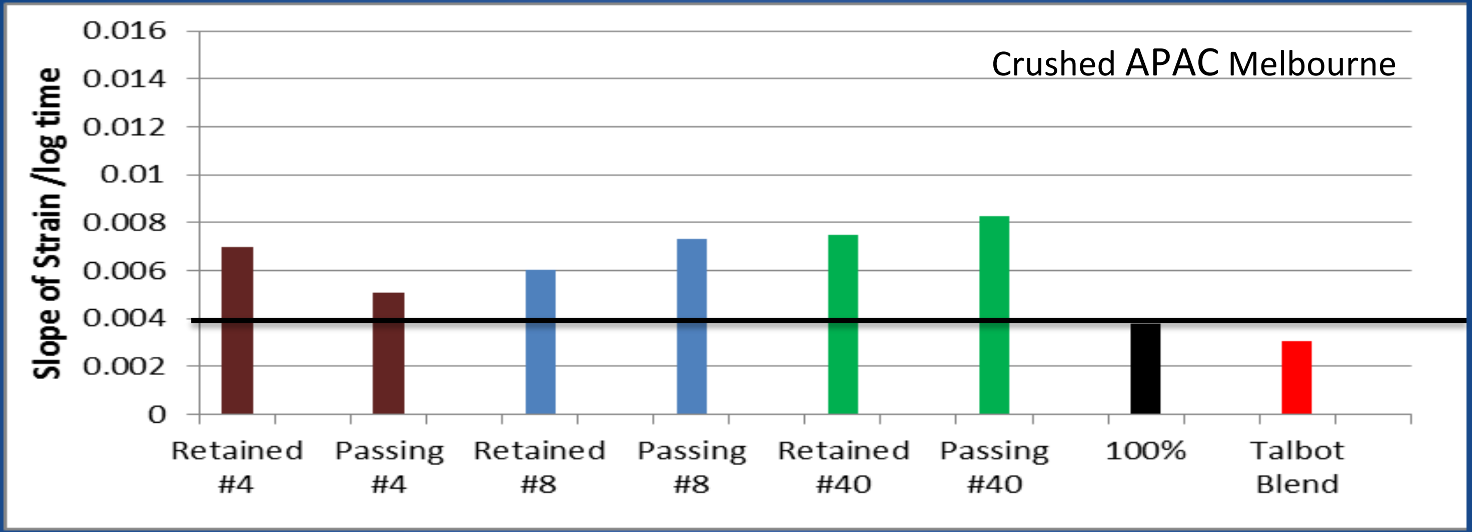
Fractionating or Gradation Modification
Thesis by: Babacar Diouf

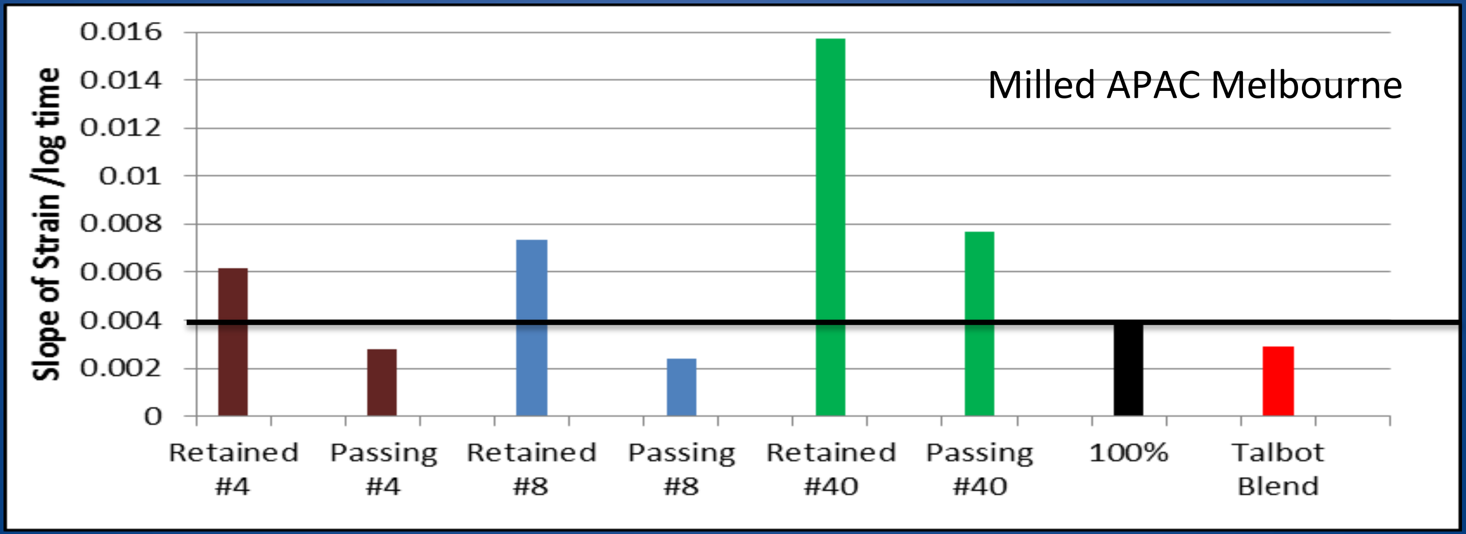
- 100% RAP
- 2 sources for each crushed and milled RAP
- Specimens of +/- #4,#8,#40 and Talbot curve mixes

$$P = \left(\frac{d}{D\max} \right)^m$$

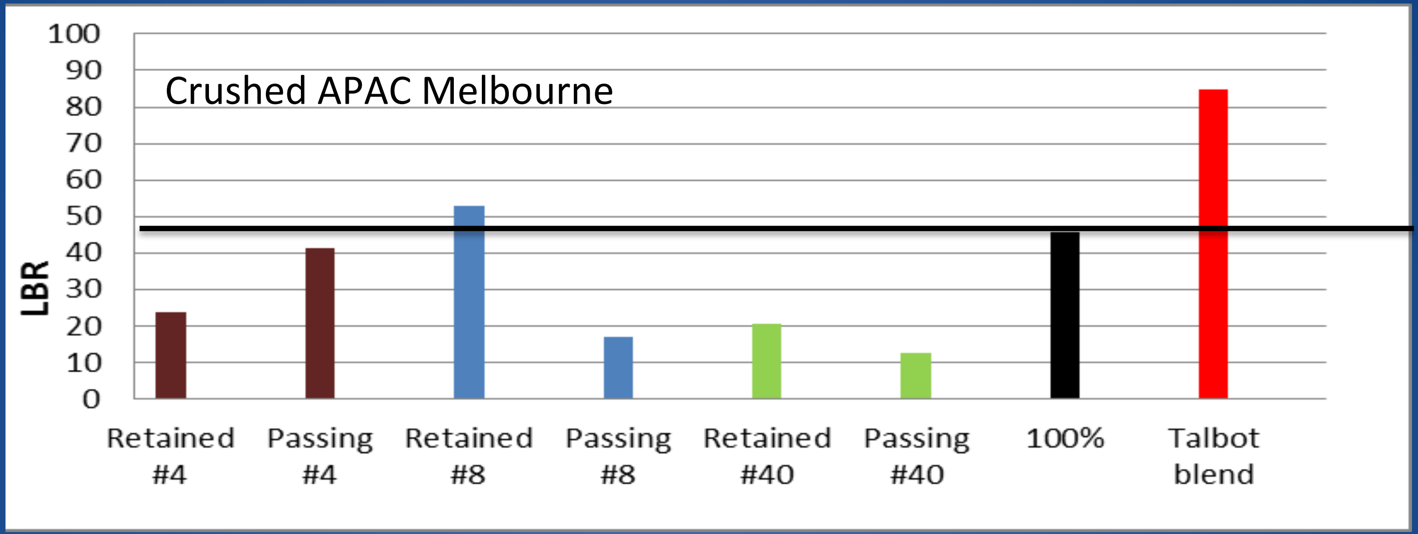
- Creep and post creep LBR on each specimen

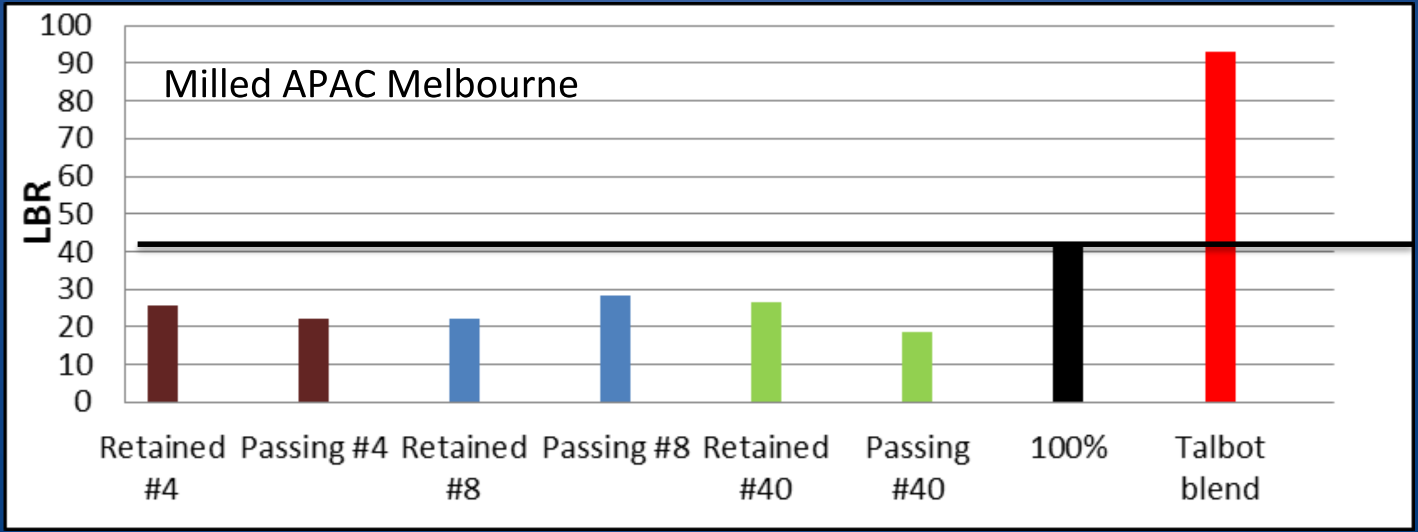
Results-Creep Tests





Results-Post Creep LBR





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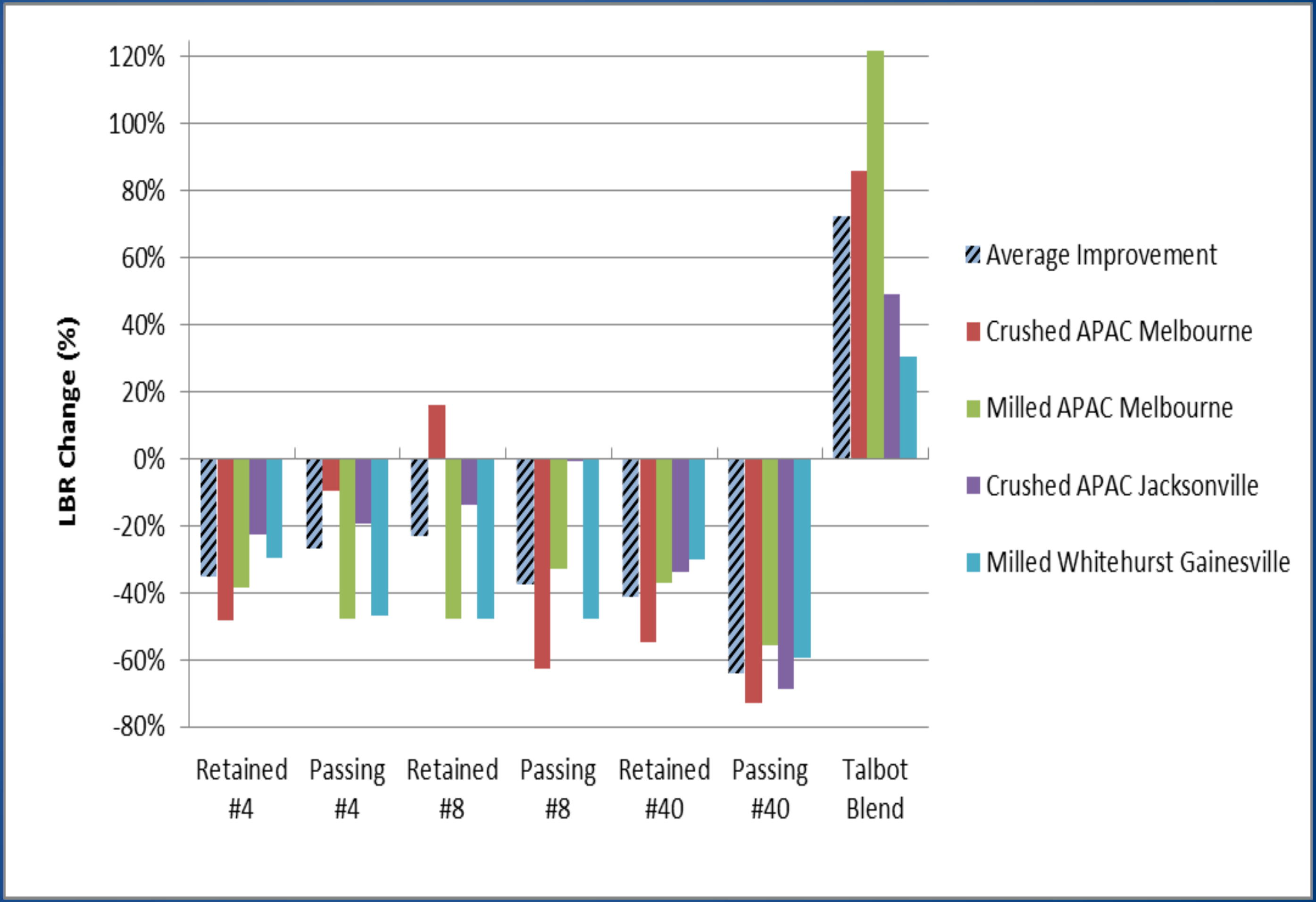
Post Creep LBR Comparisons

- RAP Fractions had lower LBR than non-fractionated RAP
- Talbot blends (i.e. maximum density) improved LBR



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Compaction Methods
Thesis by: Andrew Petersen

- Vibratory
- Gyratory
- Modified Proctor
- ~~Combination of Methods~~

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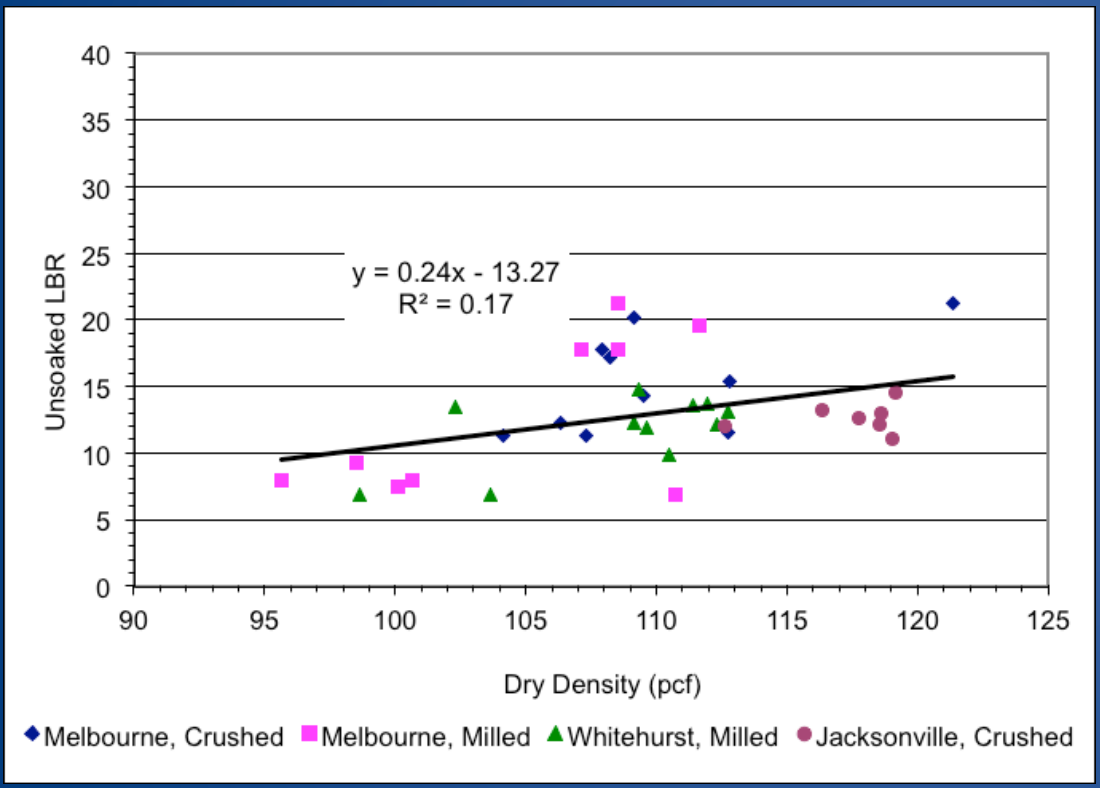
LBR – Vibratory Compaction



- Weak linear increase in LBR as dry density increased
- Approximate LBR increase 0.24 per 1 pcf dry density
- Maximum value of 21 below FDOT specification
- Lower densities than mod Proctor or gyratory

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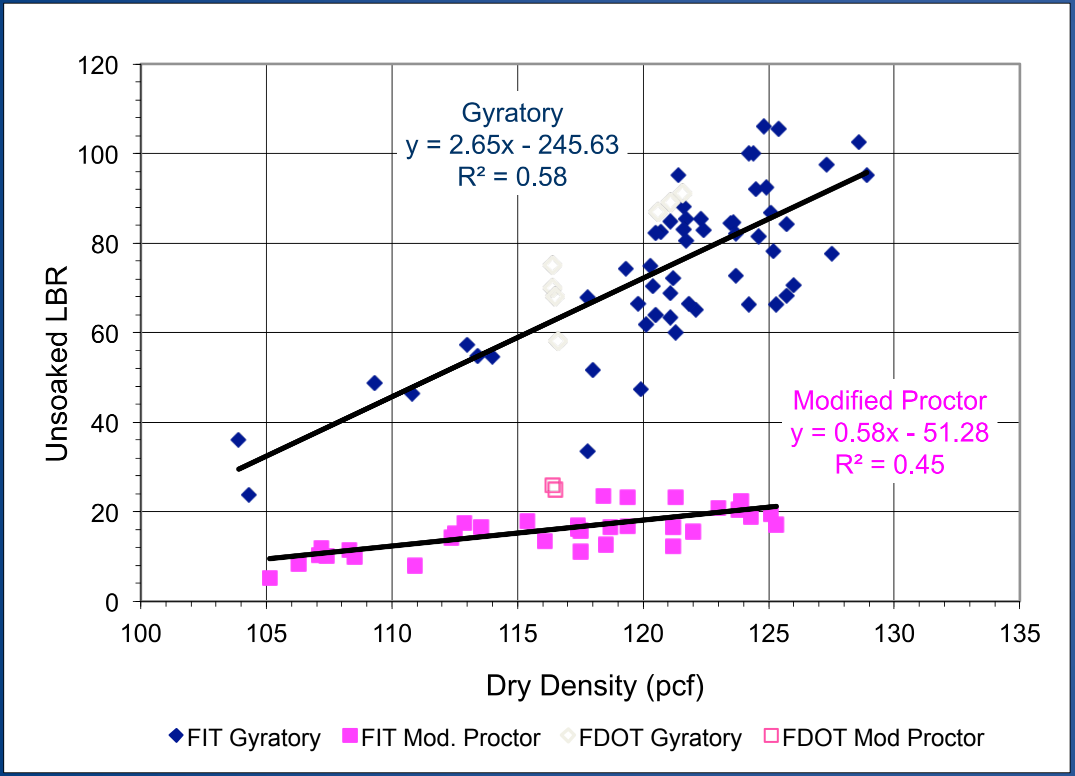
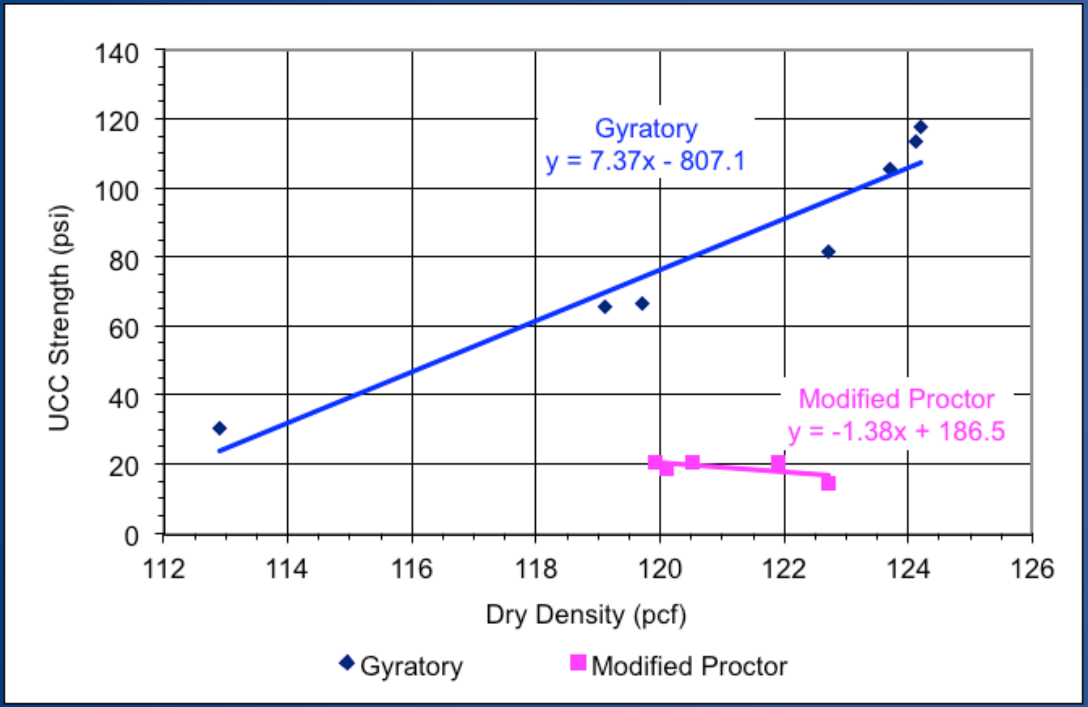
Modified Proctor – Gyratory Comparison: LBR



- Linear increase in LBR as dry density increased
- Gyratory compacted specimens 2 - 4 times higher LBR than mod Proctor
- Some unsoaked LBR over 100

Modified Proctor – Gyratory Comparison: Unconfined Compression (UCC)



- Gyratory resulted in 2 to 3 times higher unconfined compressive strength than modified Proctor

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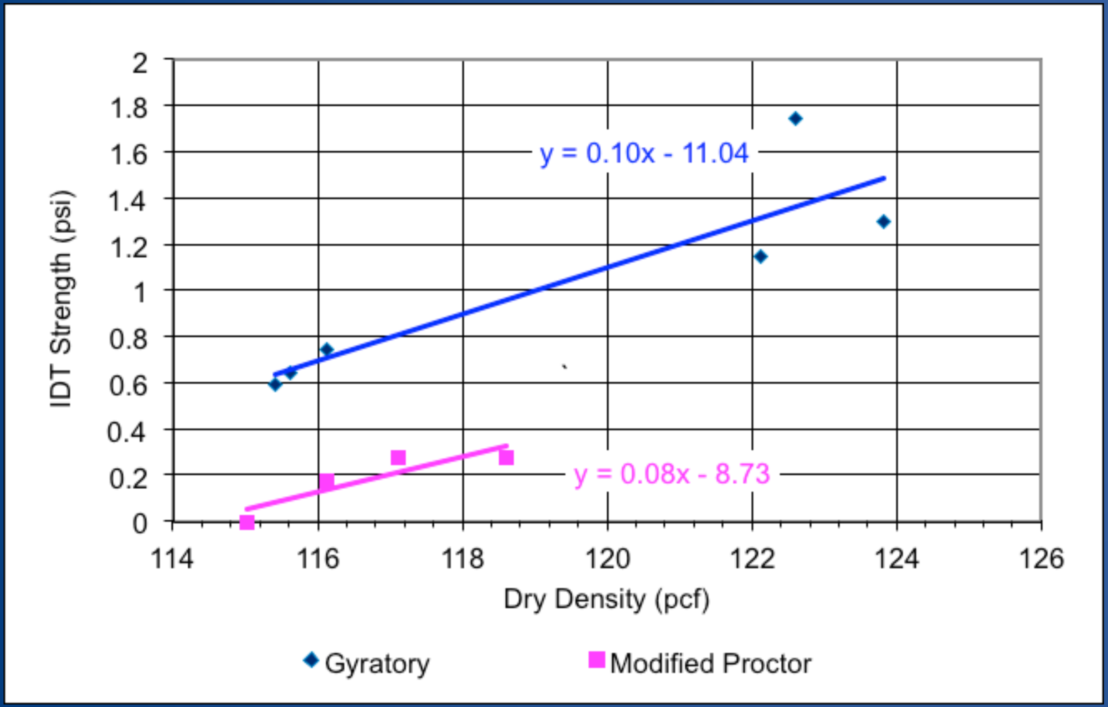
Modified Proctor – Gyratory Comparison: Indirect Tensile Test



- Gyratory resulted in 2 to 3 times higher indirect tensile strength than modified Proctor

Follow-on Proctor-Gyratory Comparison

- Indirect Tensile and LBR testing of three aggregate materials without asphalt binder
  - Limerock base
  - Cemented coquina
  - Clayey sand

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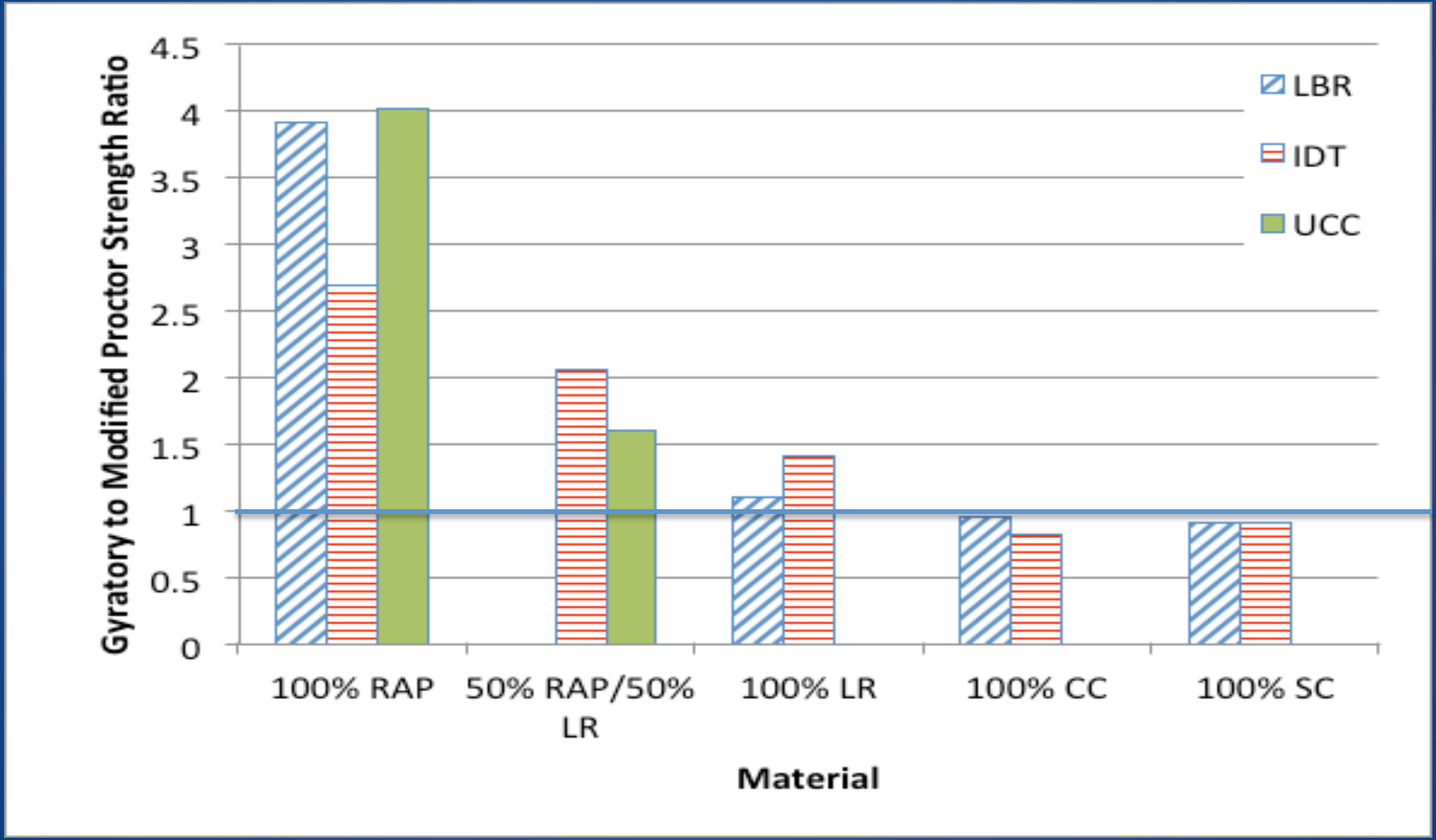
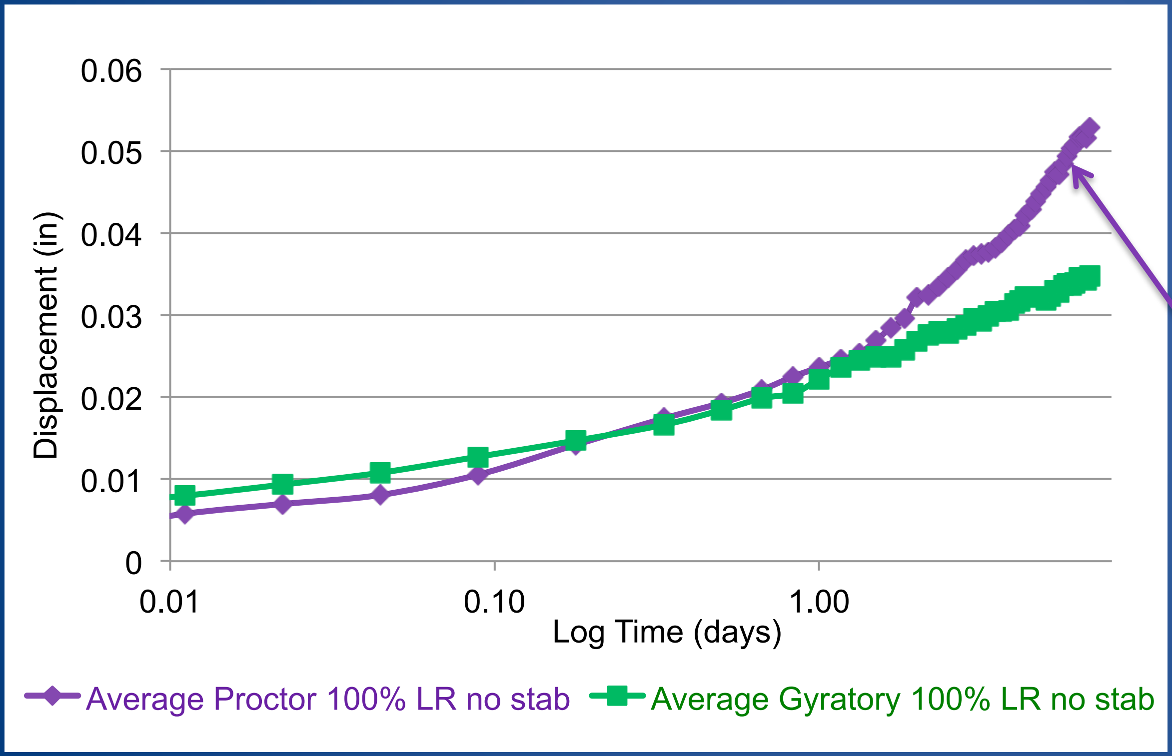
Average Gyratory/Proctor Strength Ratios



Gyratory – Proctor Unconfined Creep
100% RAP



- Initially similar creep
- Proctor specimen in tertiary creep

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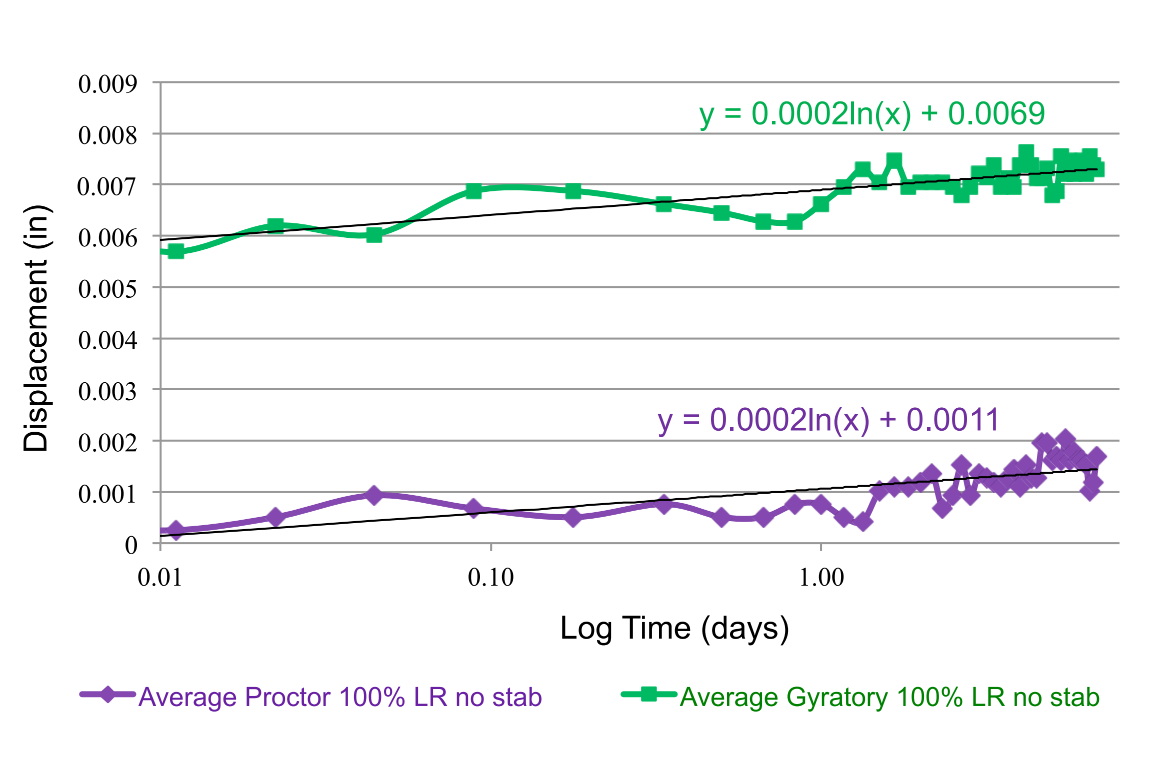
Gyratory – Proctor Unconfined Creep
100% Limerock



- Gyratory – Proctor same CSR
- No tertiary creep

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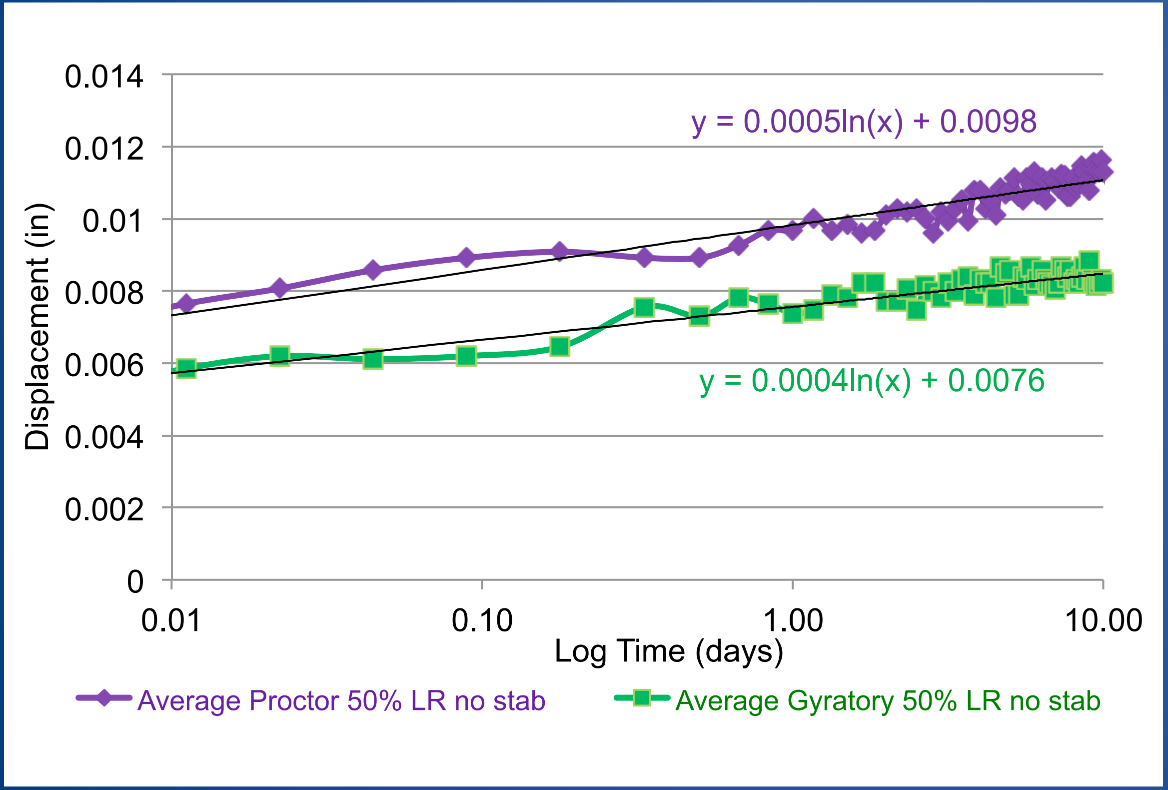
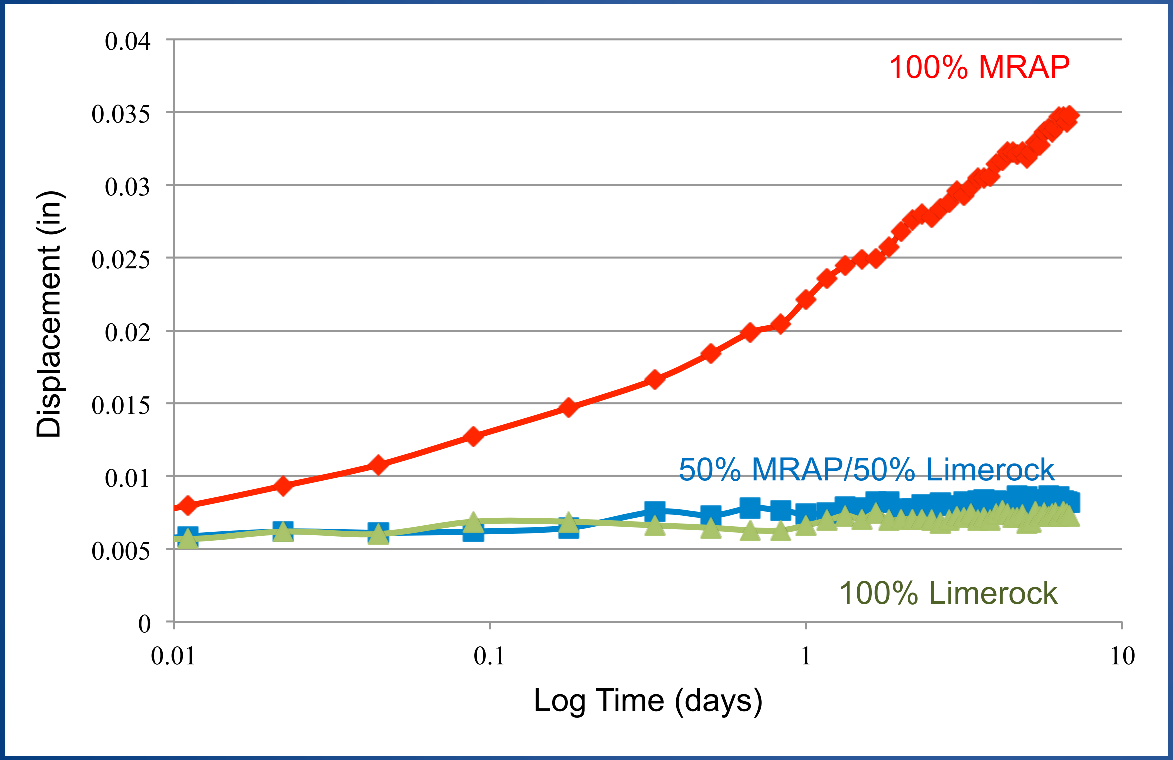
Gyratory – Proctor Unconfined Creep
50% RAP/ 50% Limerock



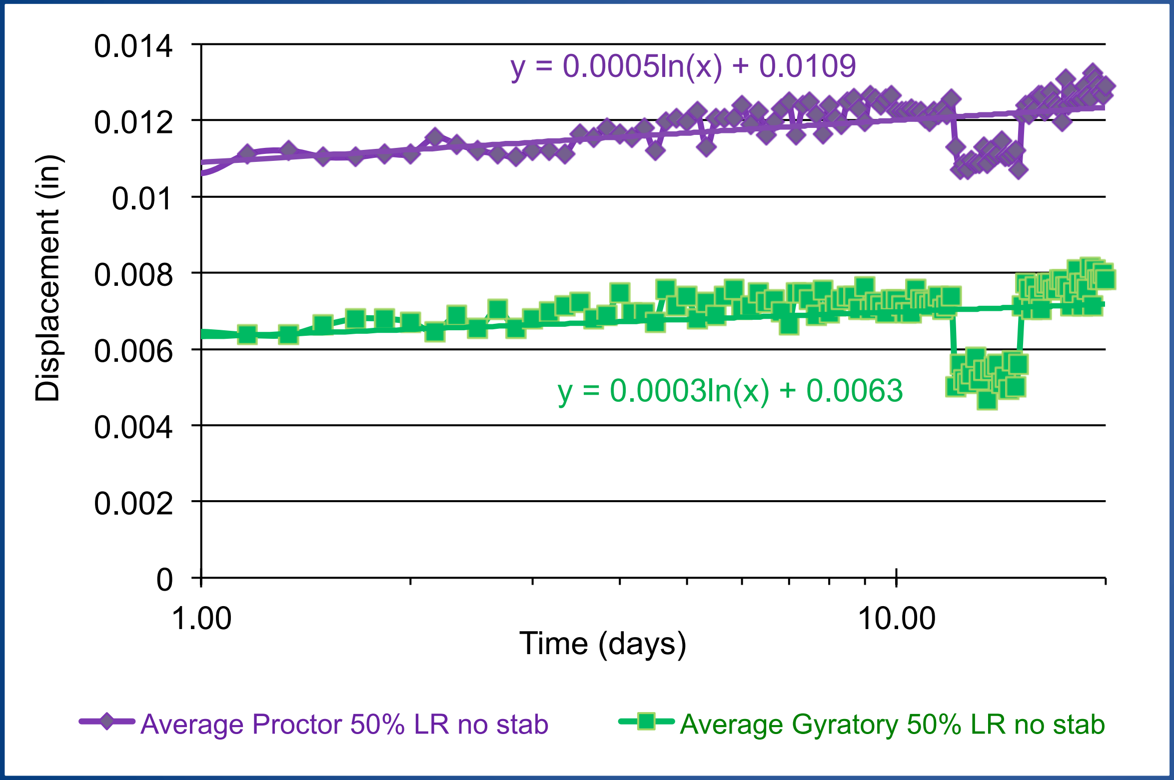
- Gyratory – Proctor similar CSR
- No tertiary creep

Gyratory Unconfined Creep Summary



- 50%/50% blend creep similar to 100% LR
- No tertiary creep
- Proctor similar results (not shown)

Unload/reload effect on creep



- Both gyratory and modified Proctor compacted specimens rebounded 20% when unloaded
- After reload, creep continued at same rate

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Task 4 – Blending RAP with High Quality Materials

Thaddeus (TJ) Misilo

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Blends with High Quality Materials

- Milled RAP
- Select Base Materials
  - Limerock
  - Cemented Coquina
  - Recycled Concrete
- Different Blend Combinations
  - 100% - 0%
  - 75% - 25%
  - 50% - 50%
  - 25% - 75%
- Same tests as fractionated samples

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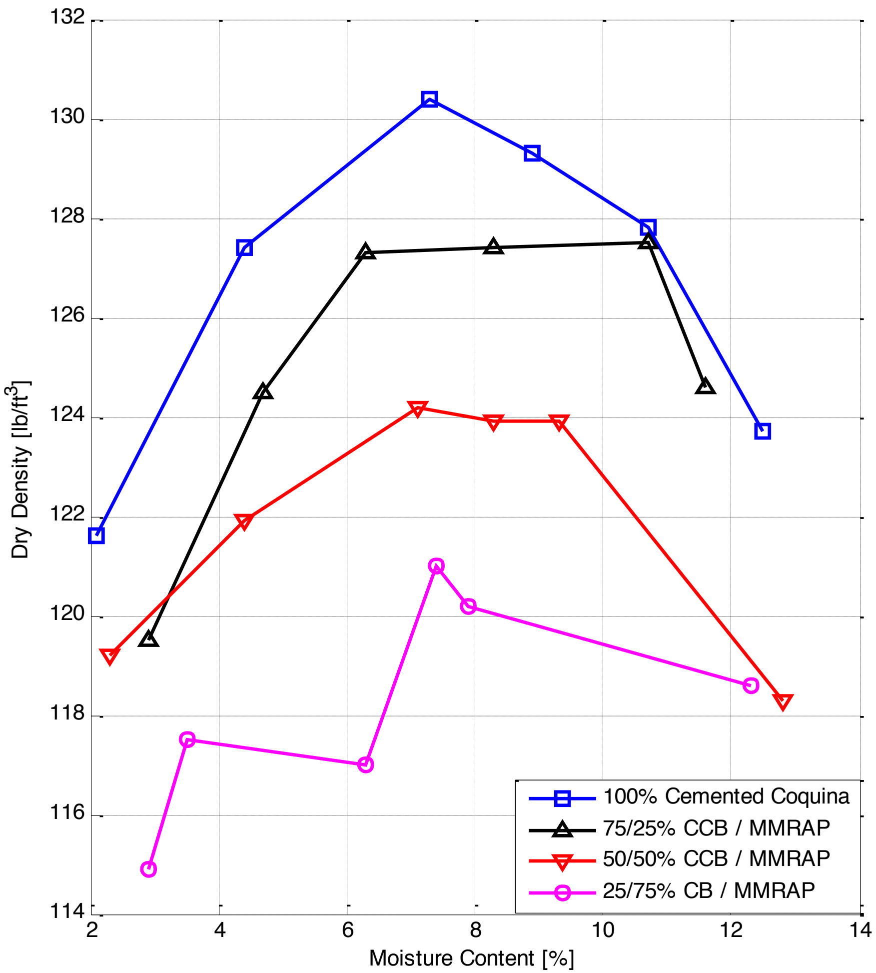
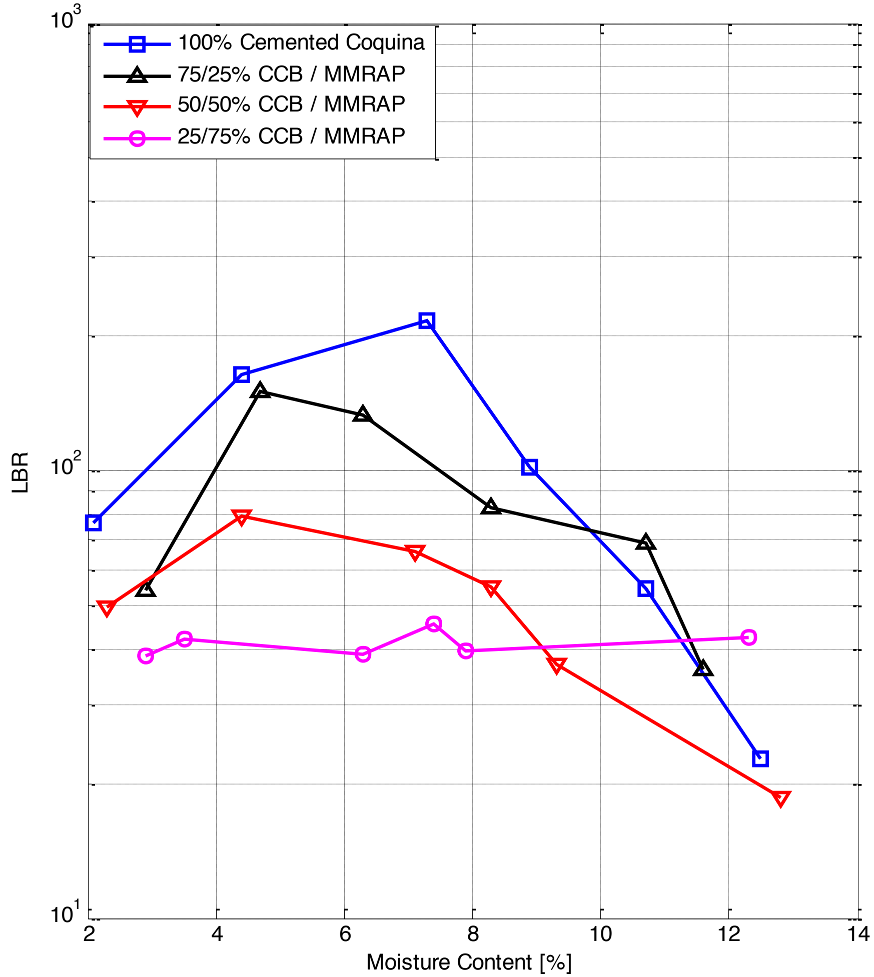
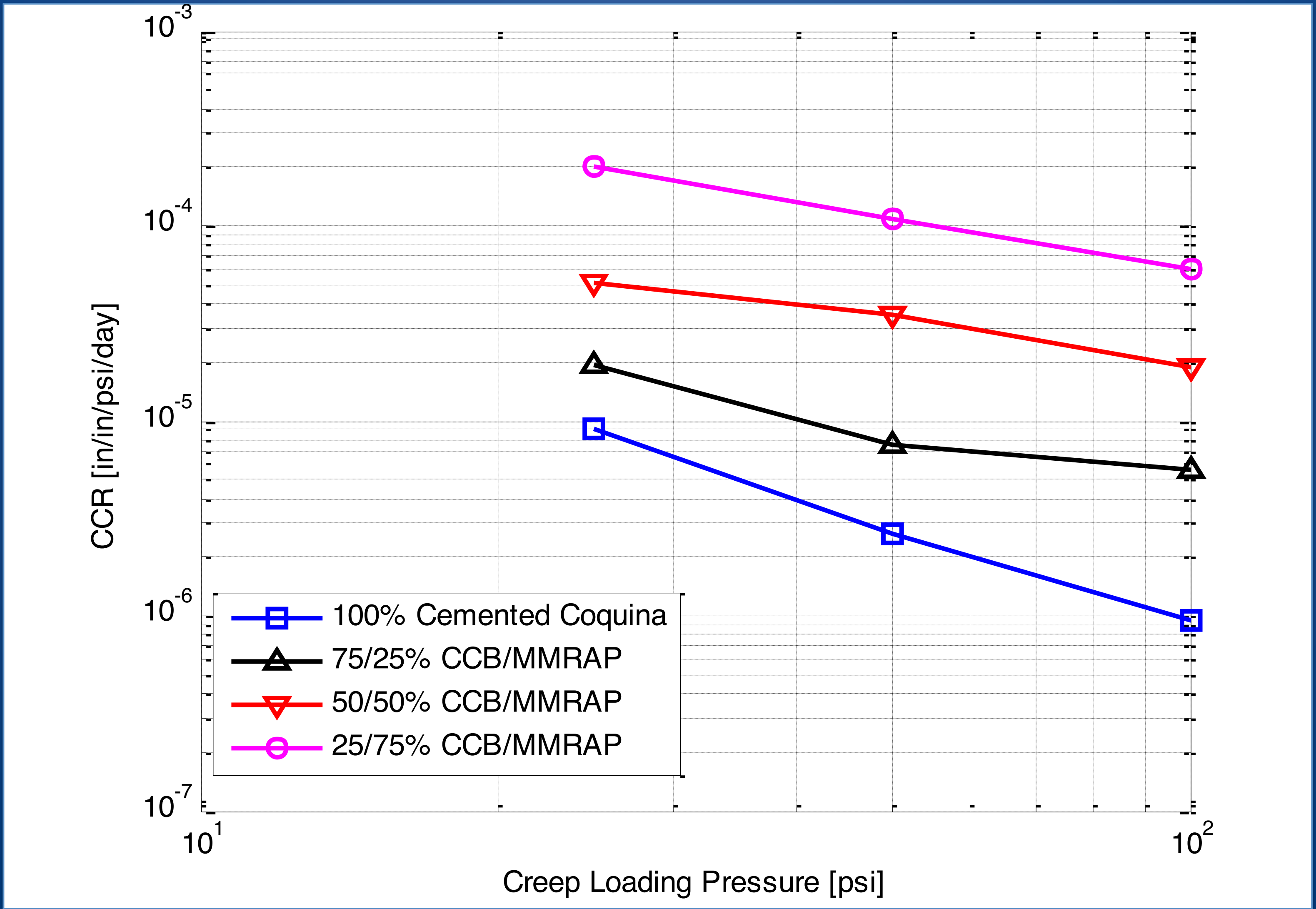
Typical Dry Density and LBR vs. Moisture Content Plots

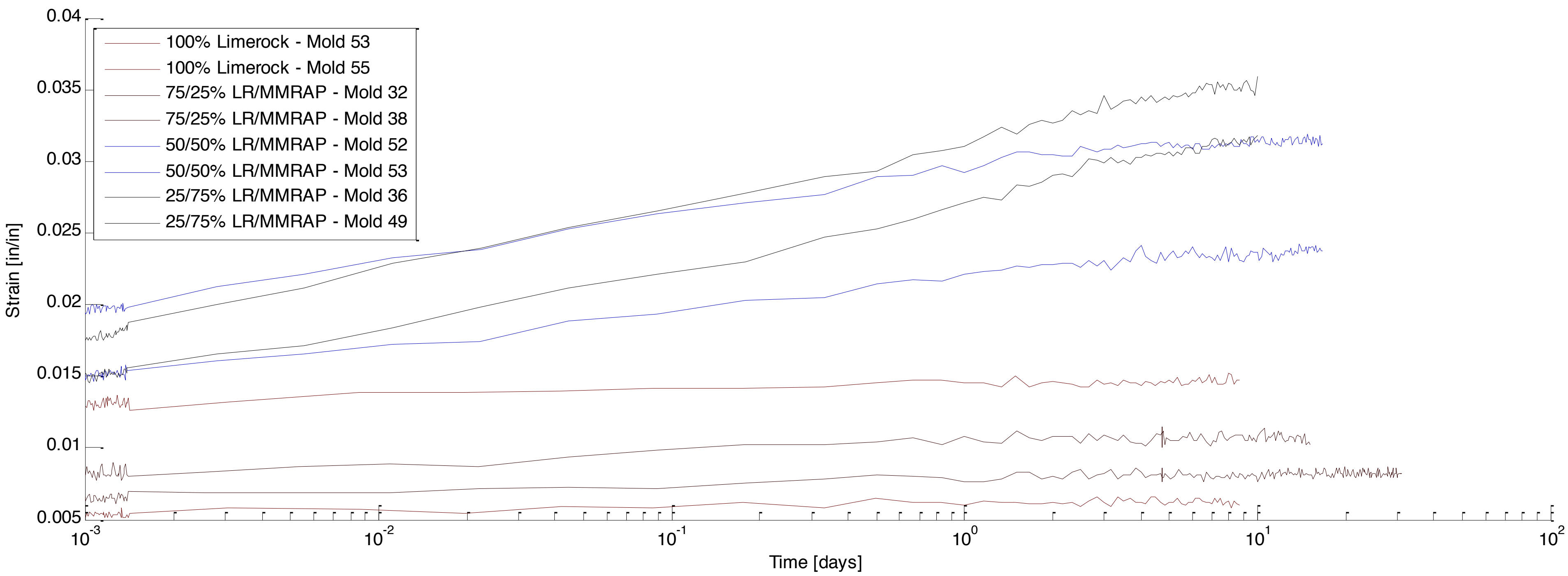




Cemented Coquina Blends CCR vs. Creep Loading Pressure



Creep Test Results Limerock 100 psi vs. Log Time



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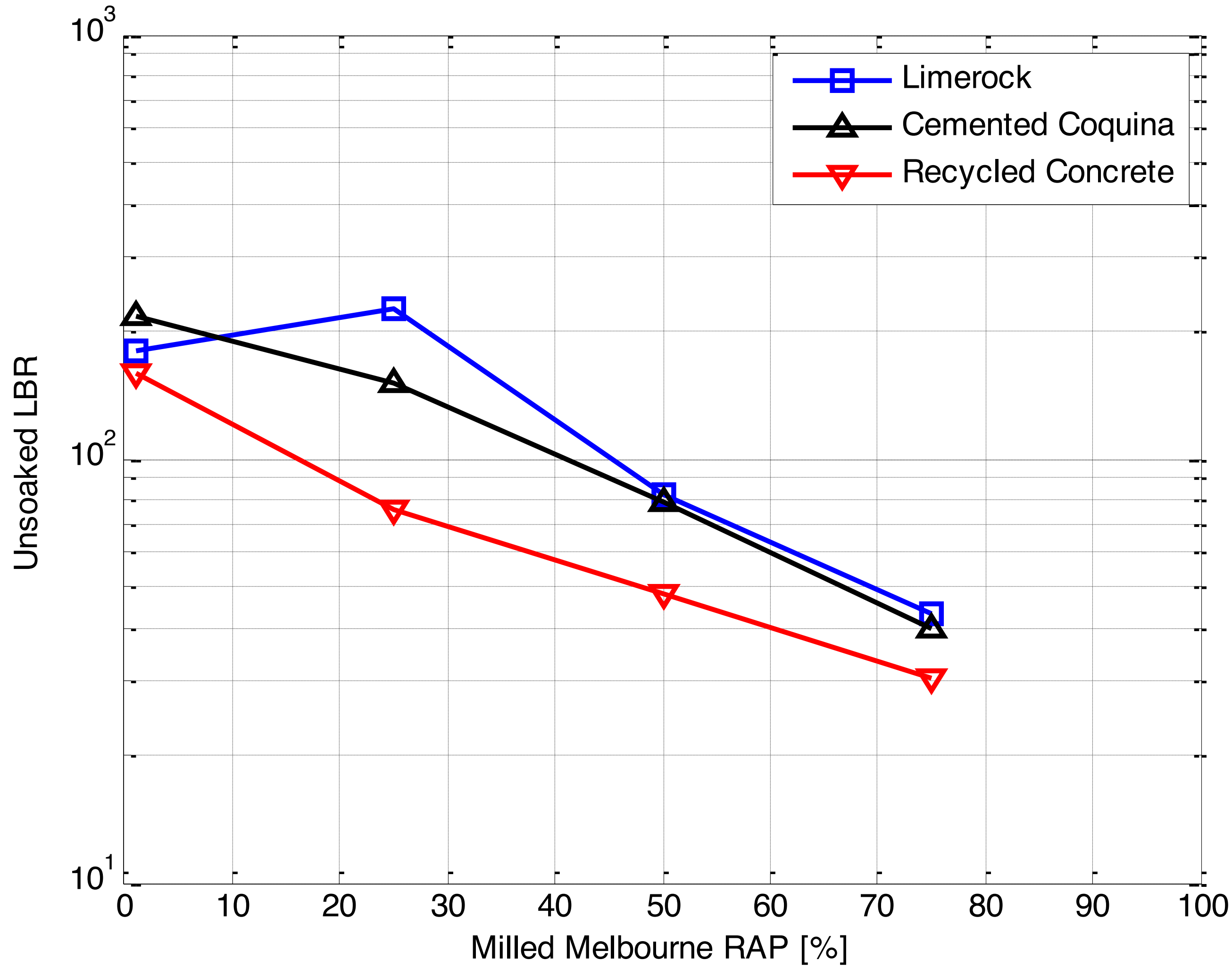
Blend Summary Unsoaked LBR vs. % Milled Melbourne RAP



Effect of Blending on LBR and Creep

Description		Unsoaked LBR	Acceptable	Soaked LBR	Acceptable	10 in base, 25 psi	
						30 Year Deformation	Acceptable
Limerock	**MRAP**						
100	0	180	Yes	162	Yes	0.08	Yes
75	25	225	Yes	99	No	0.12	Yes
50	50	82	No	55	No	0.15	Yes
25	75	43	No	NP	No	0.28	Yes
0	100	31	No	NP	No	0.56	No
Cemented Coquina	**MRAP**						
100	0	216	Yes	63	No	0.07	Yes
75	25	150	Yes	93	No	0.08	Yes
50	50	79	No	NP	No	0.17	Yes
25	75	40	No	NP	No	0.44	No
0	100	31	No	NP	No	0.56	No
Reclaimed Concrete	**MRAP**						
100	0	159	Yes	162	Yes	0.07	Yes
75	25	76	No	NP	No	0.08	Yes
50	50	48	No	NP	No	0.13	Yes
25	75	30	No	NP	No	0.43	No
0	100	31	No	NP	No	0.56	No

NP - Soaked LBR test not performed since Unsoaked LBR was below 100

Task 6b – Compaction Improvements Using Chemical Admixtures

Albert Bleakley

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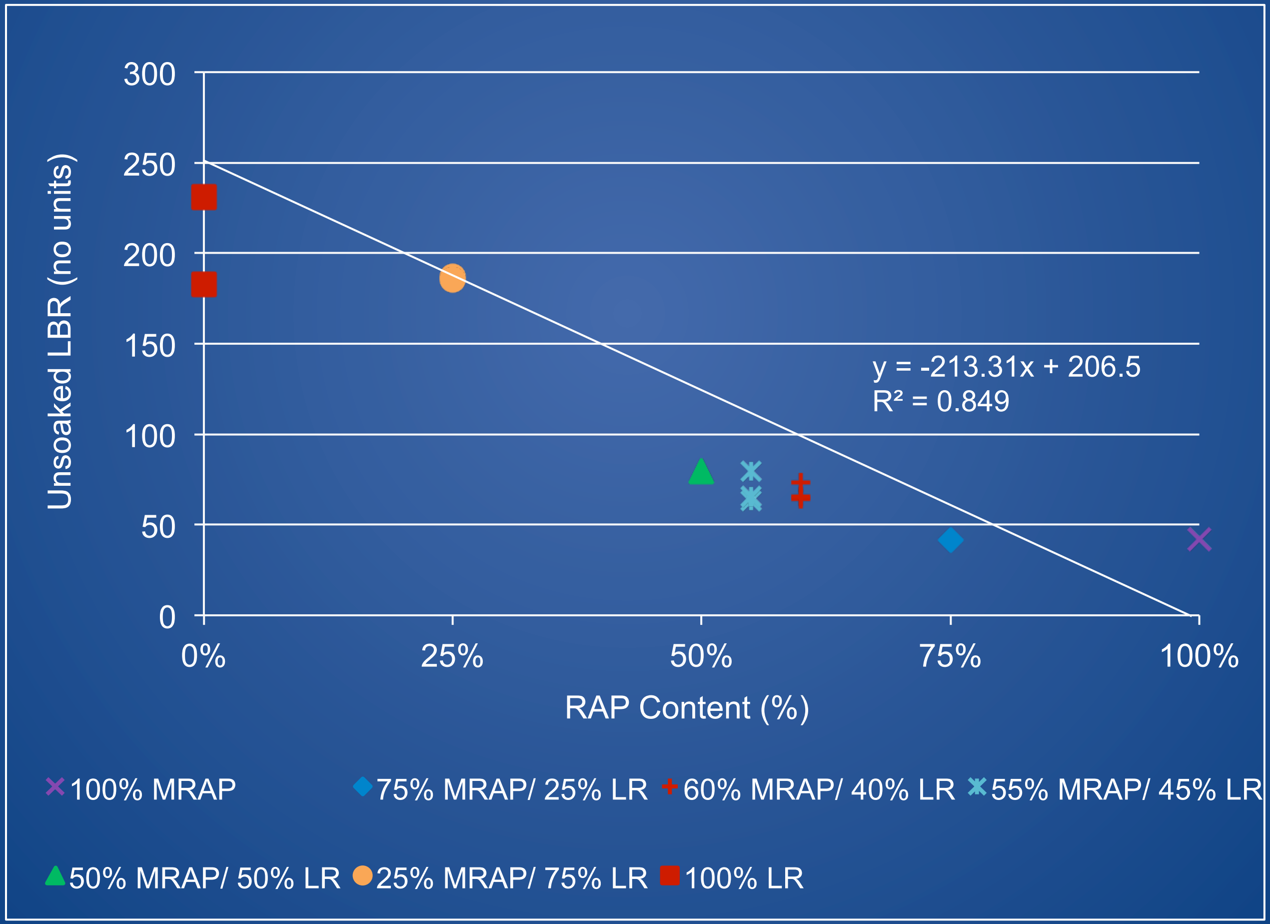
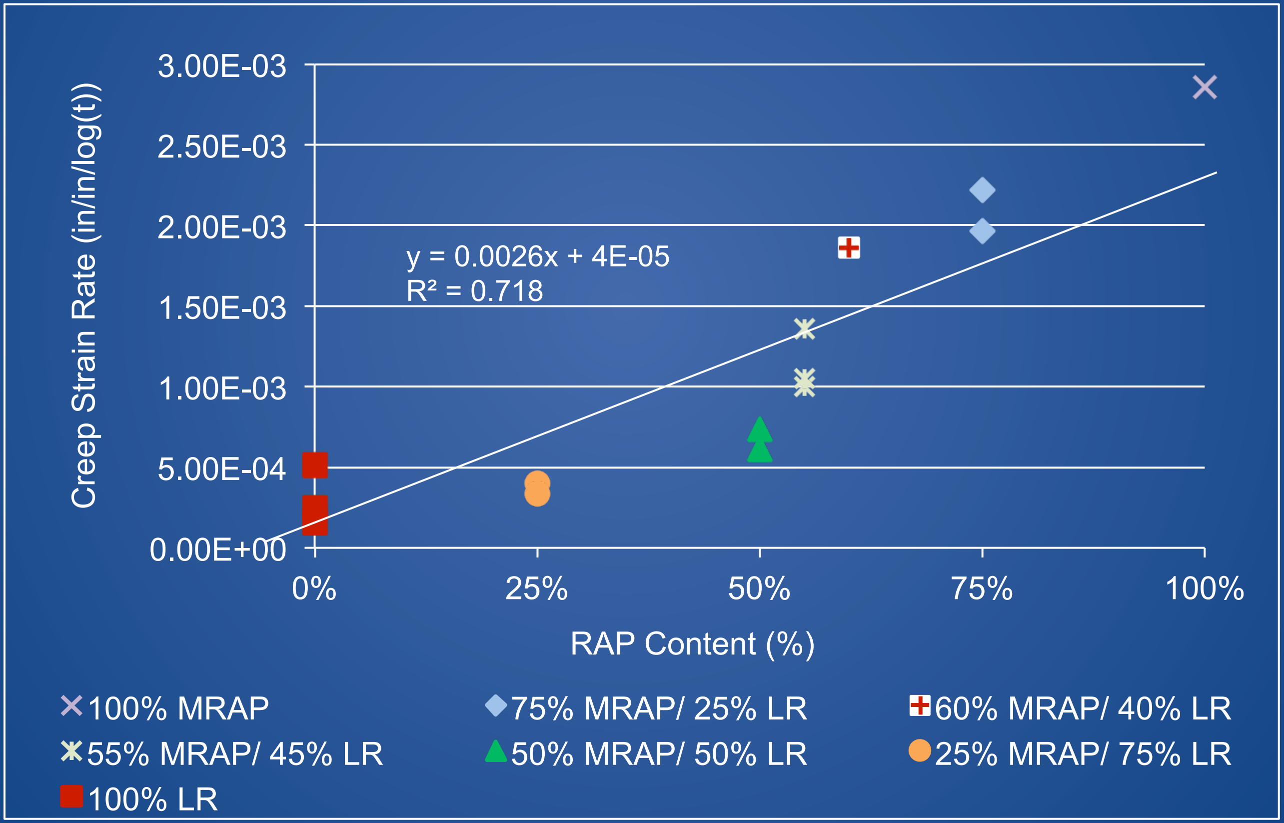
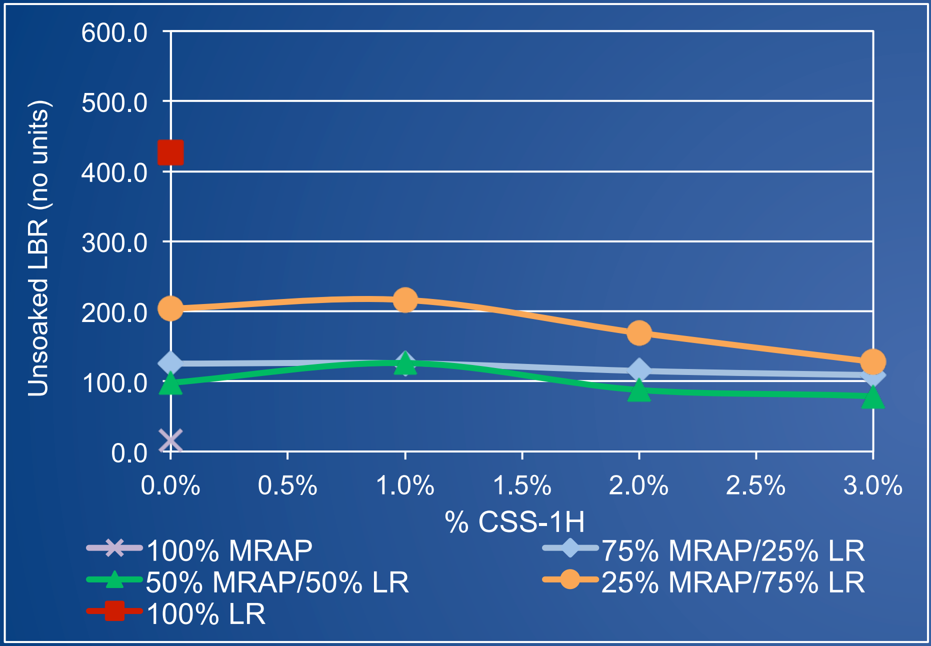
Unsoaked LBR vs RAP Content

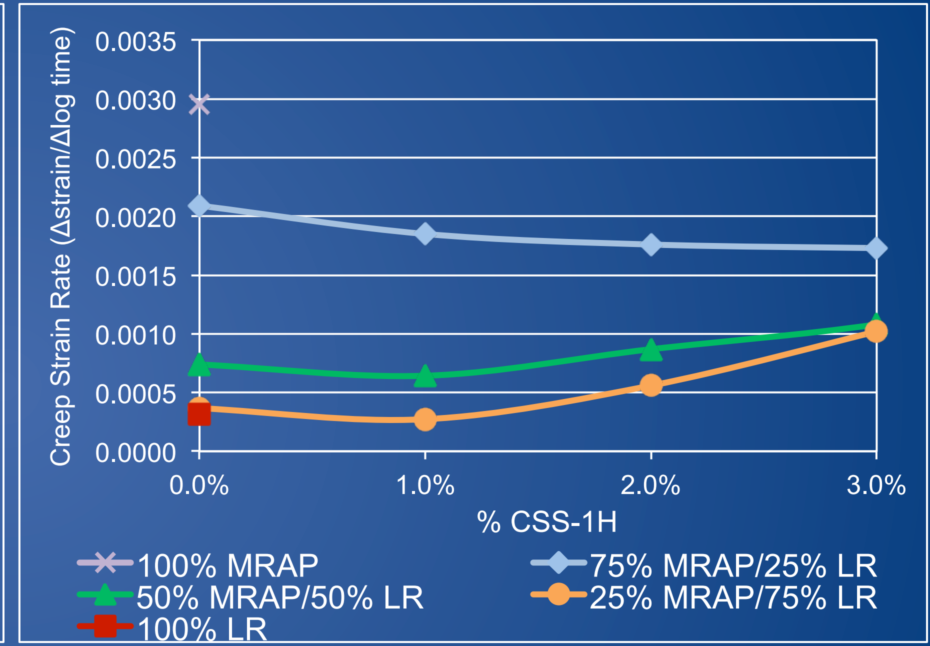


Creep Strain Rate vs RAP Content



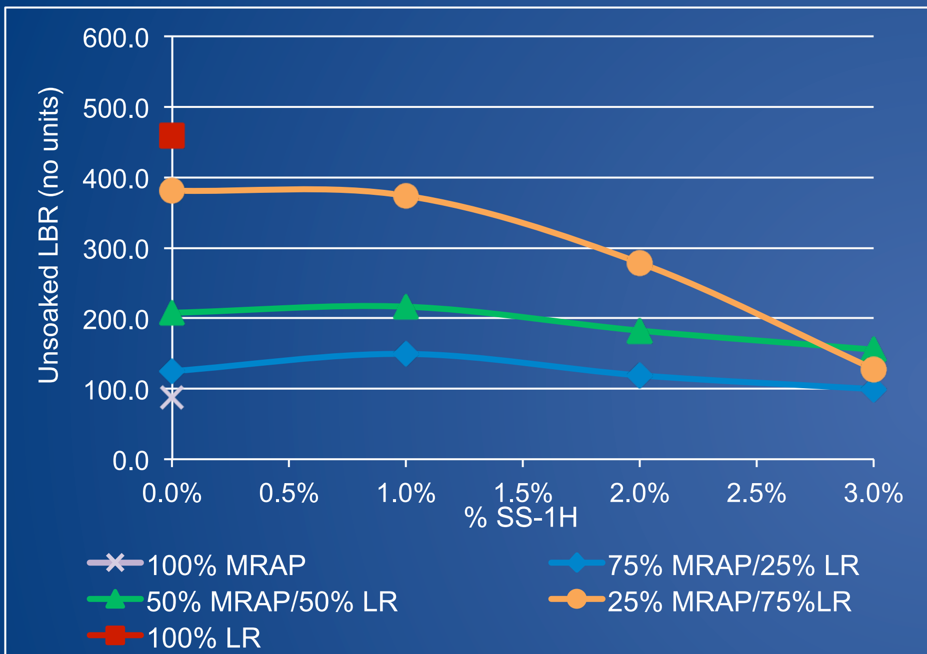
CSS-1H Stabilized MRAP/Limerock Blends

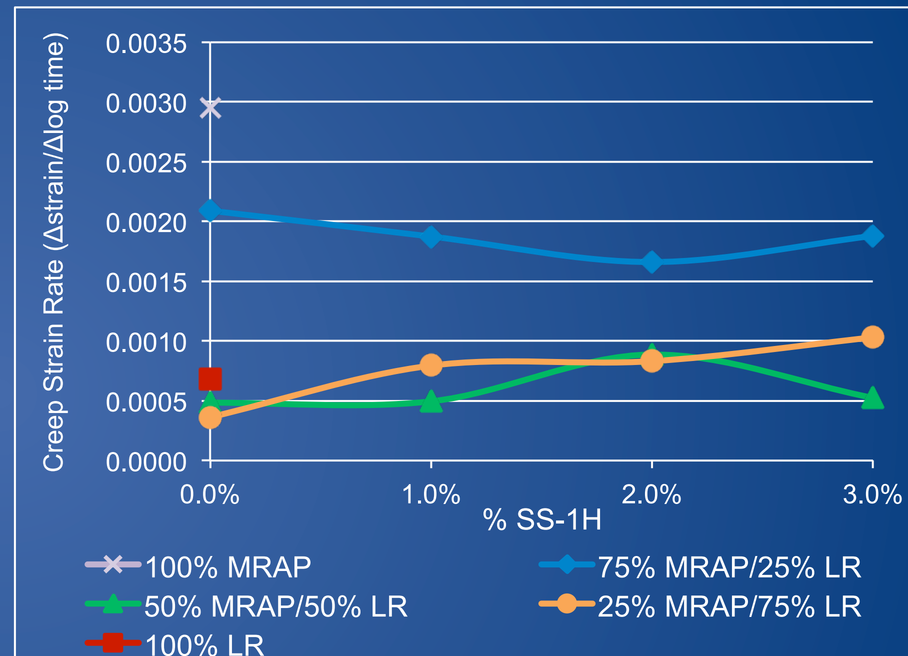




- Large LBR improvement from blending (6x – 12x)
- 10% - 20% LBR improvement from 1% CSS-1H
- Large creep reduction from blending (.7x - .1x)
- 10% - 20% creep improvement from 1% CSS-1H

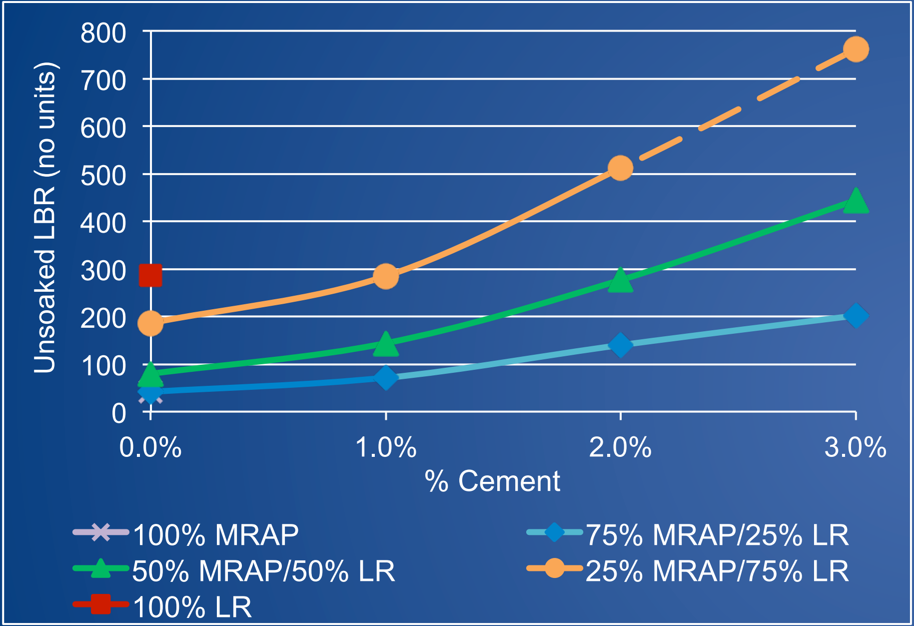
SS-1H stabilized MRAP/limerock (48 hr oven)

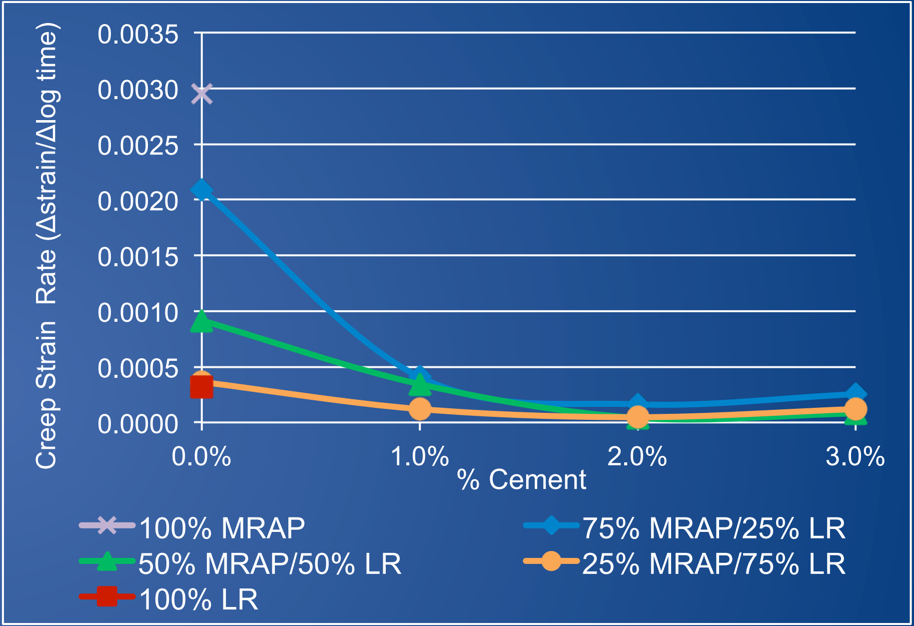




- Large LBR improvement from blending (1.5x – 4x)
- 10% - 20% LBR improvement from 1% SS-1H
- Large creep reduction from blending (.7x - .1x)
- Mixed creep improvement from 1% SS-1H

Cement Stabilized MRAP/Limerock Blends





- Large LBR improvement from blending (1.5x – 4x)
- 20% - 40% LBR improvement from 1% cement
- Large creep reduction from blending (.7x – .1x)
- 30% - 90% creep reduction from 1% cement

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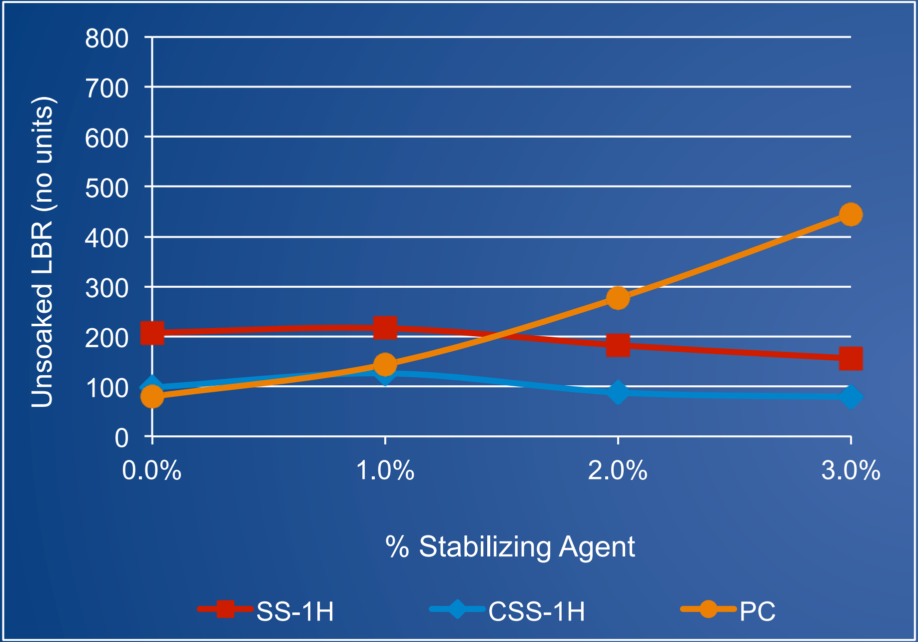
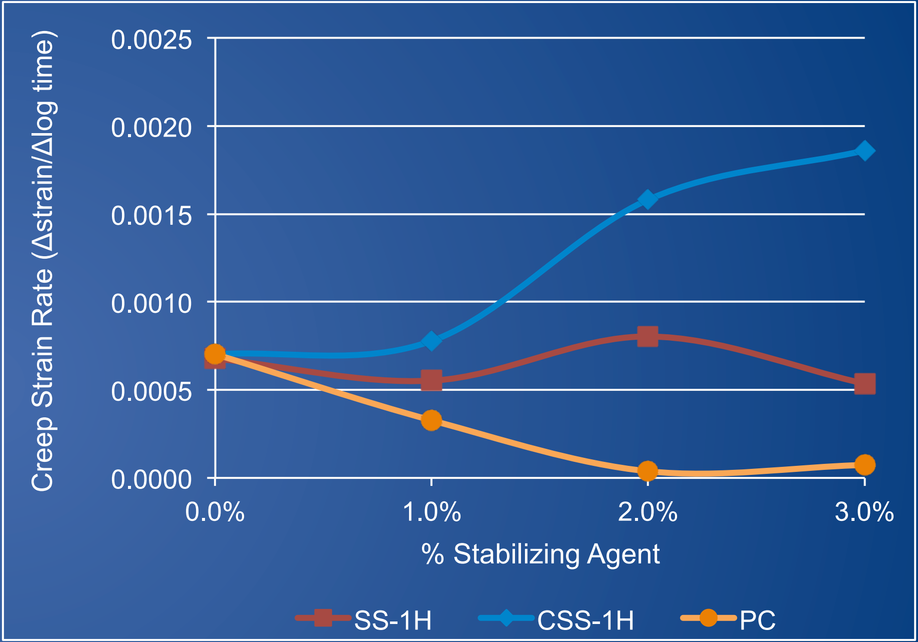
Summary of Stabilized 50% RAP/LR Blends





- Large LBR improvement from blending
- Emulsions show LBR peak at 1%; cement does not
- Emulsions show mixed creep results at 1%; cement decreases creep

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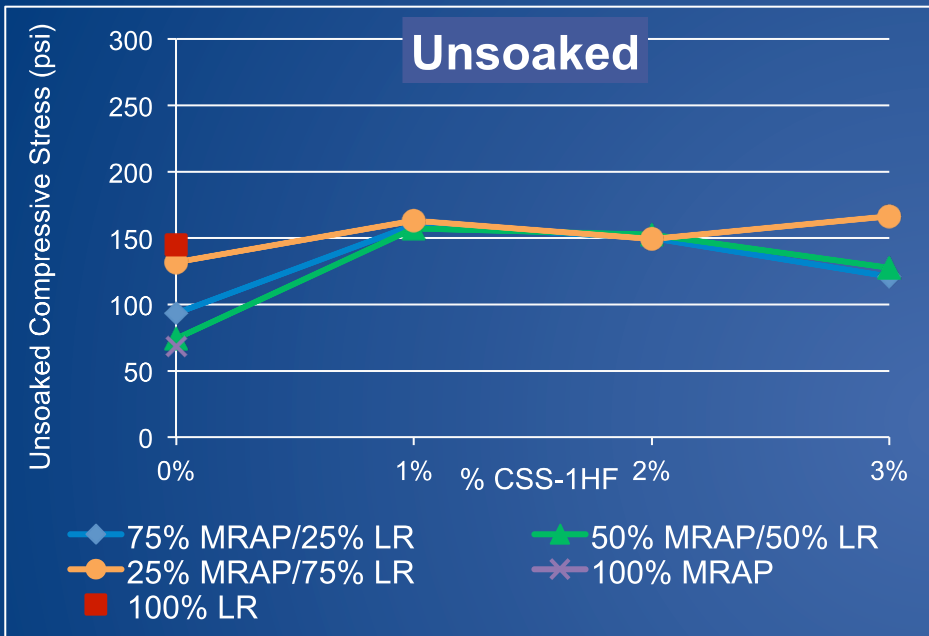
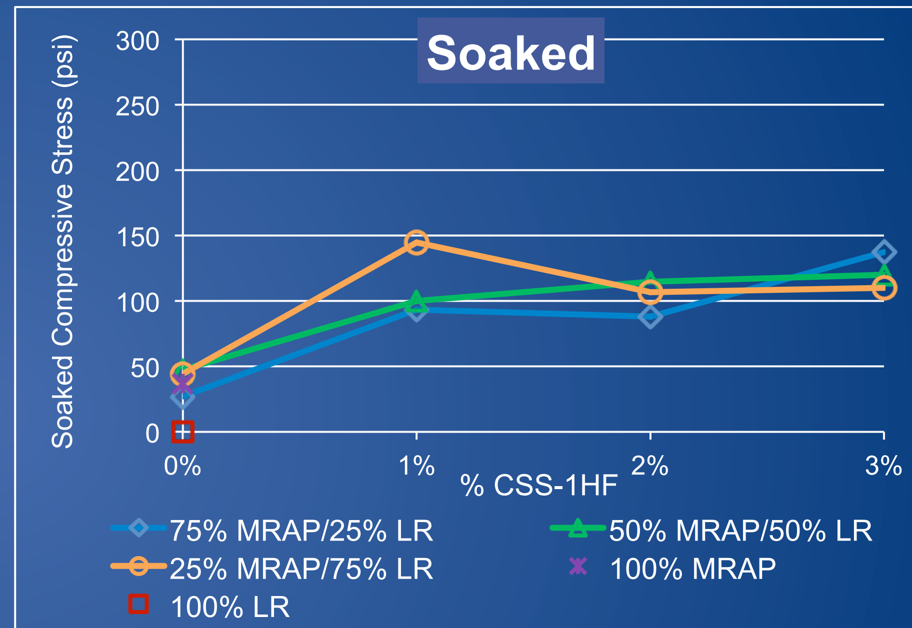
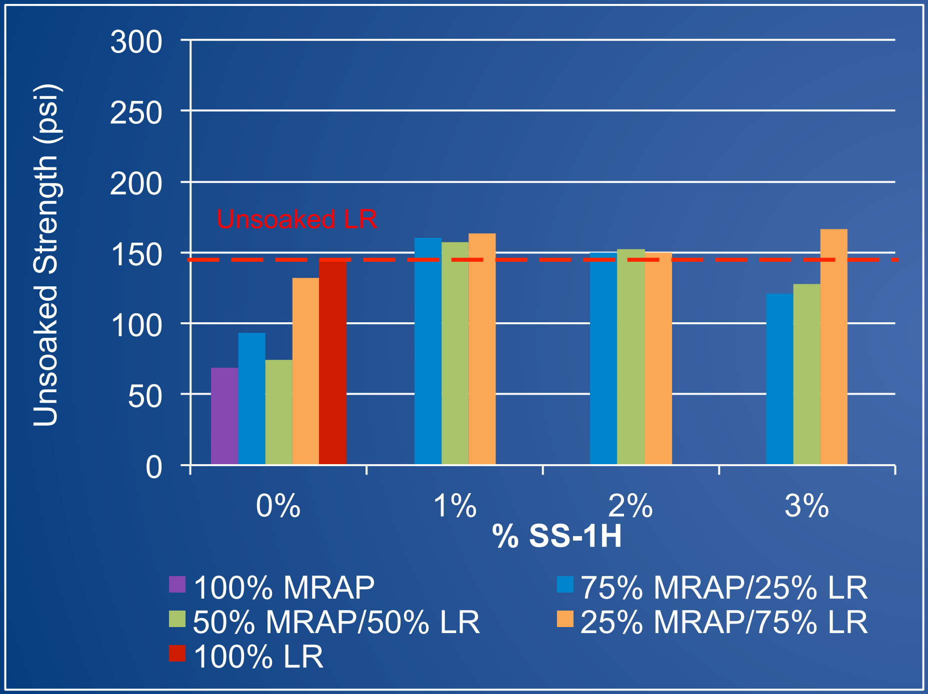
Unconfined Compression Blends with CSS-1H

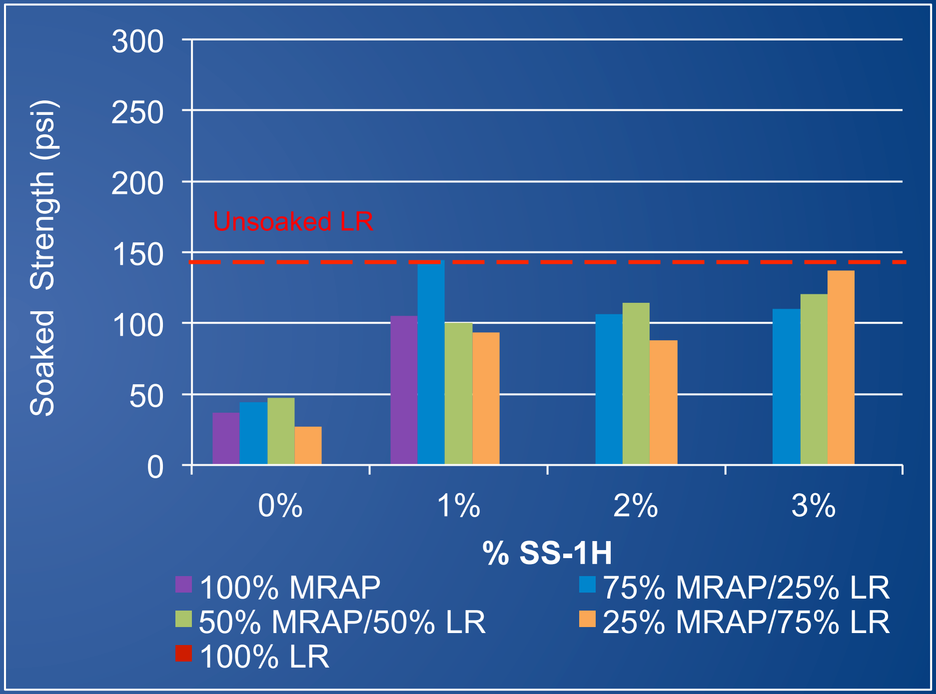




- Blending increased UCC strength 10% - 90%
- UCC strength increased 2.5x – 3.5x with 1% CSS-1H
- Blending decreased peak displacement 10% - 40%
- Peak displacement increased with CSS-1H content

Unconfined Compression Blends with CSS-1H





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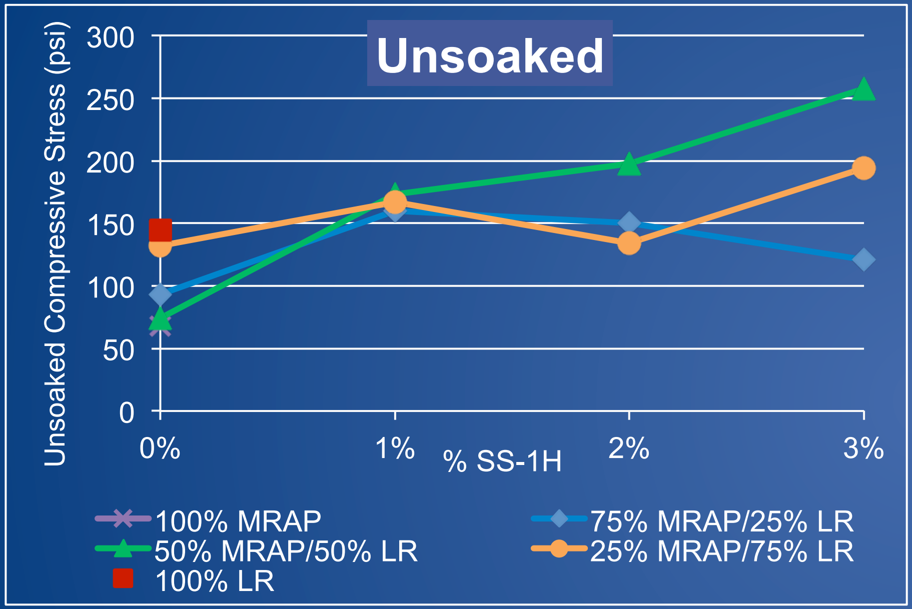
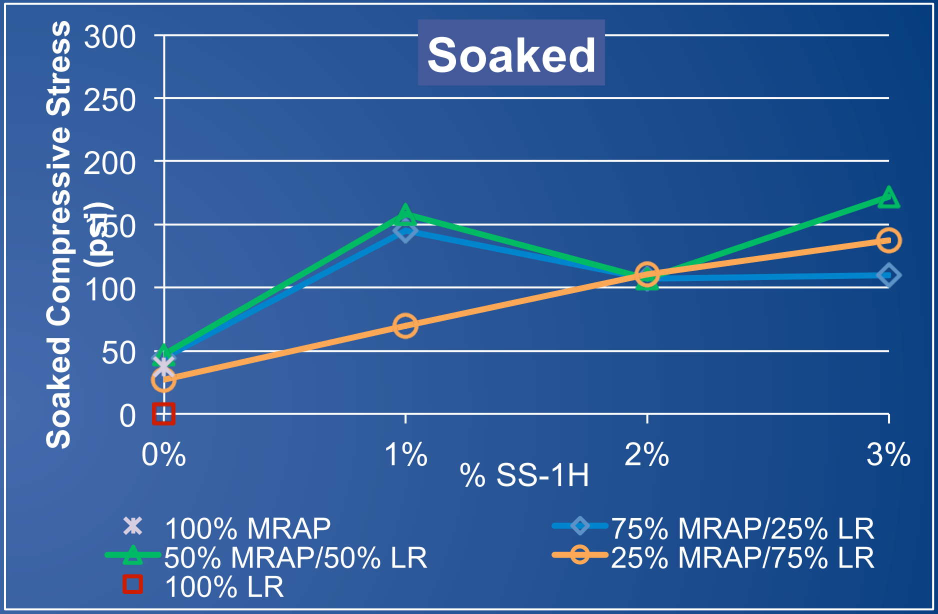
Unconfined Compression Blends with SS-1H





- Blending increased UCC strength 10% - 90%
- UCC strength increased 1.1x - 4x with 1% SS-1H
- Blending decreased peak displacement 0% - 30%
- Peak displacement increased with SS-1H content

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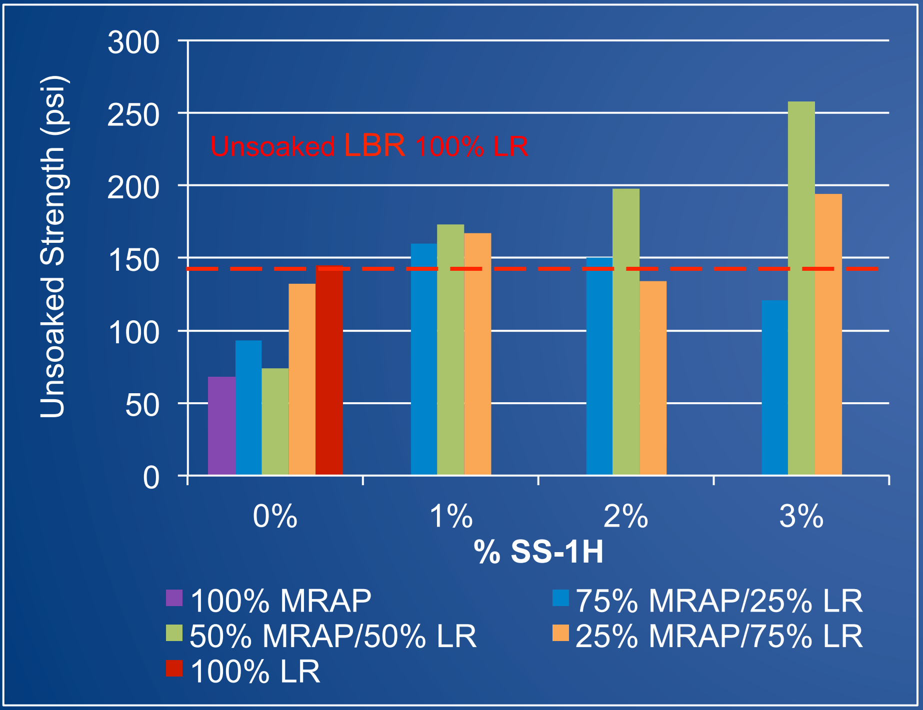
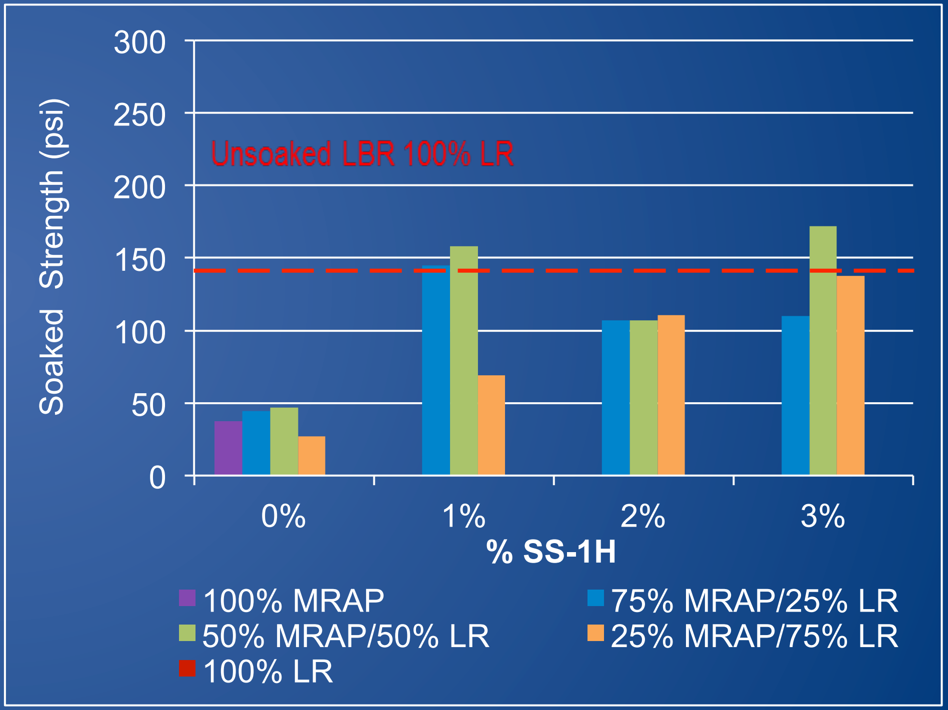
Unconfined Compression Blends with SS-1H





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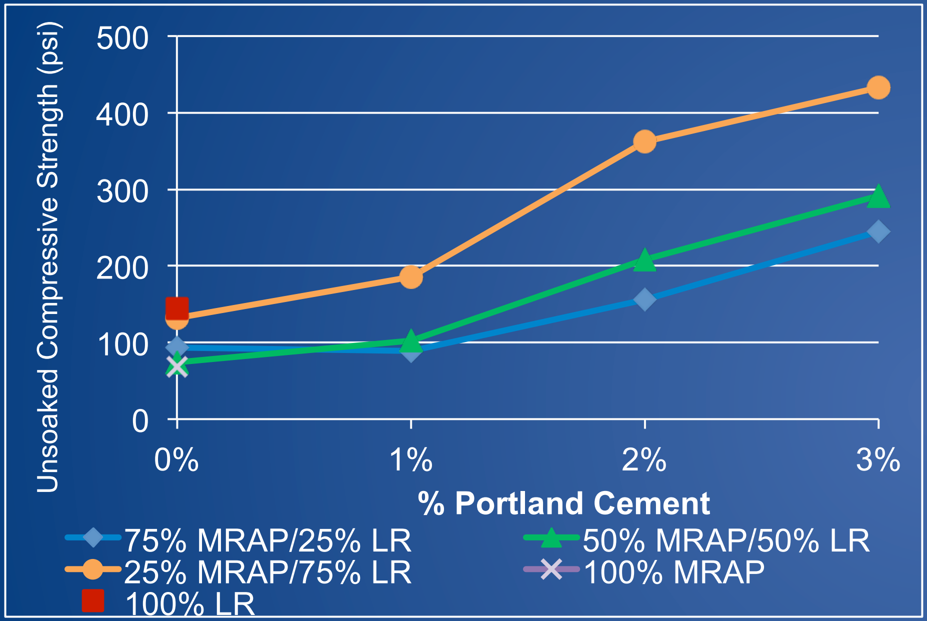
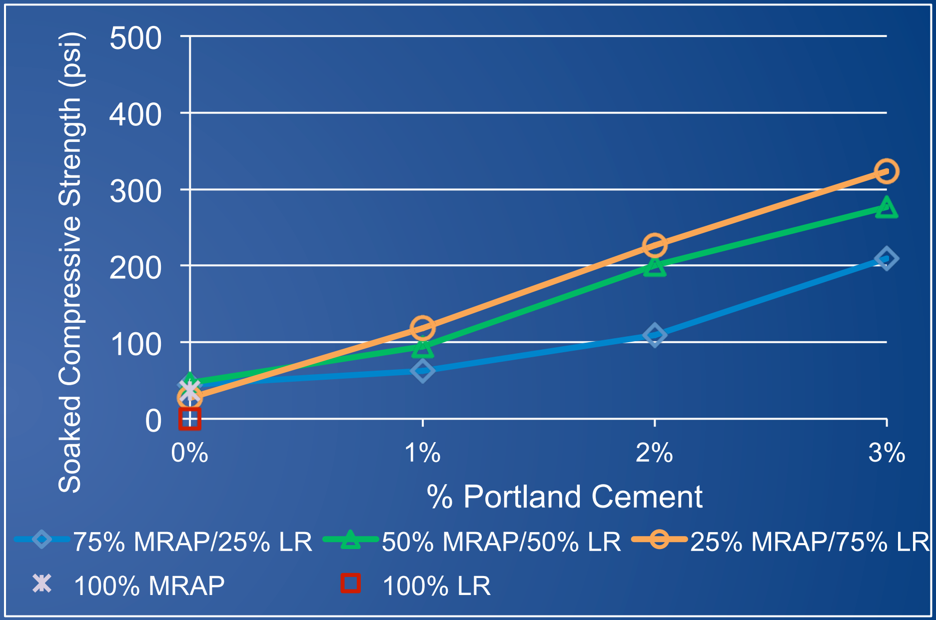
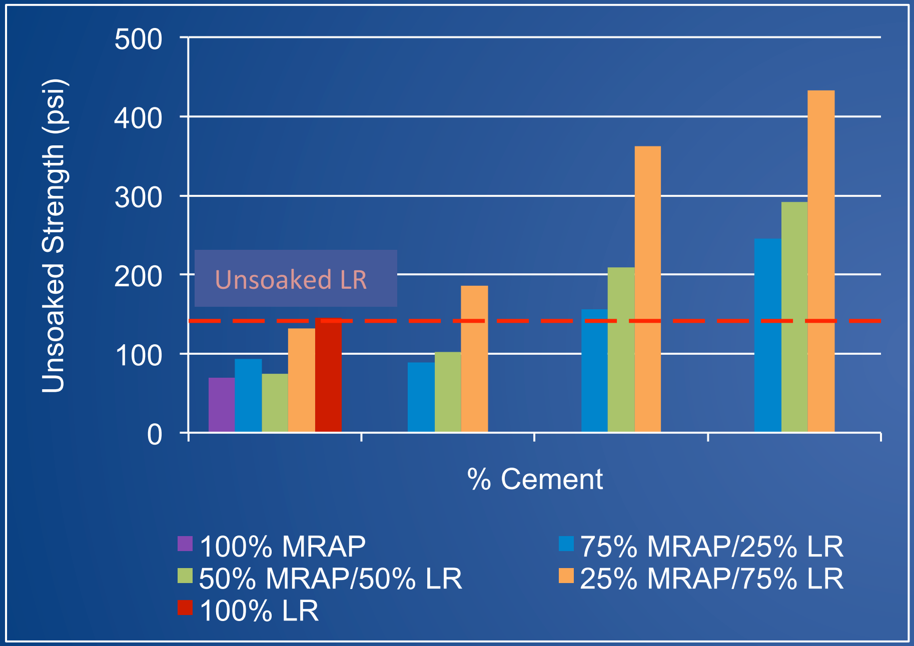
Unconfined Compression Blends with Portland Cement

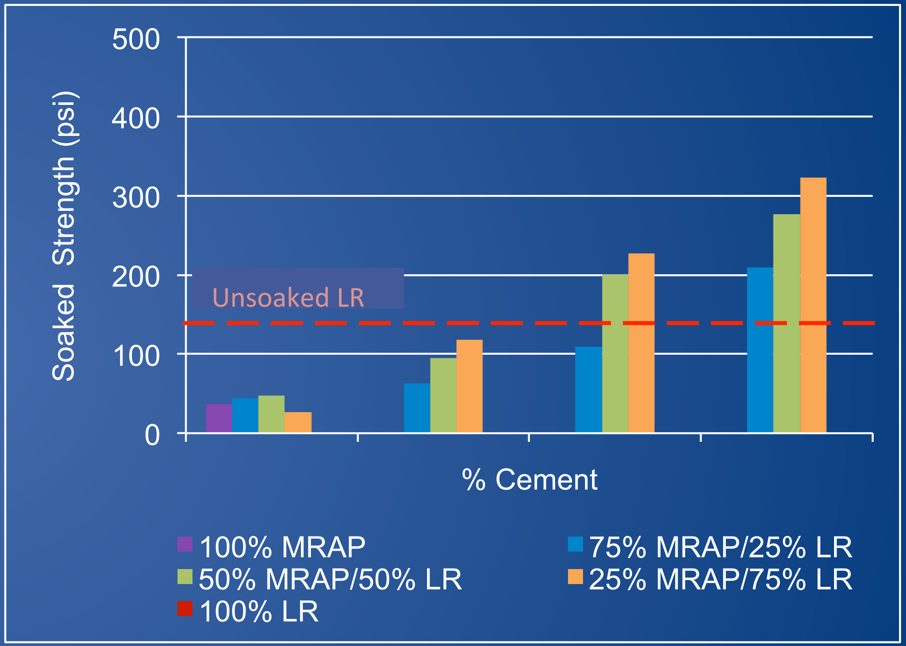




- Blending increased unsoaked UCC strength 10% - 90%
- Blending decreased peak displacement 0% - 30%
- Peak displacement unchanged with cement content

Unconfined Compression Portland Cement





- UCC unsoaked strength increased 10% - 30% with 1% cement
- UCC soaked strength increased 50% - 400% with 1% cement

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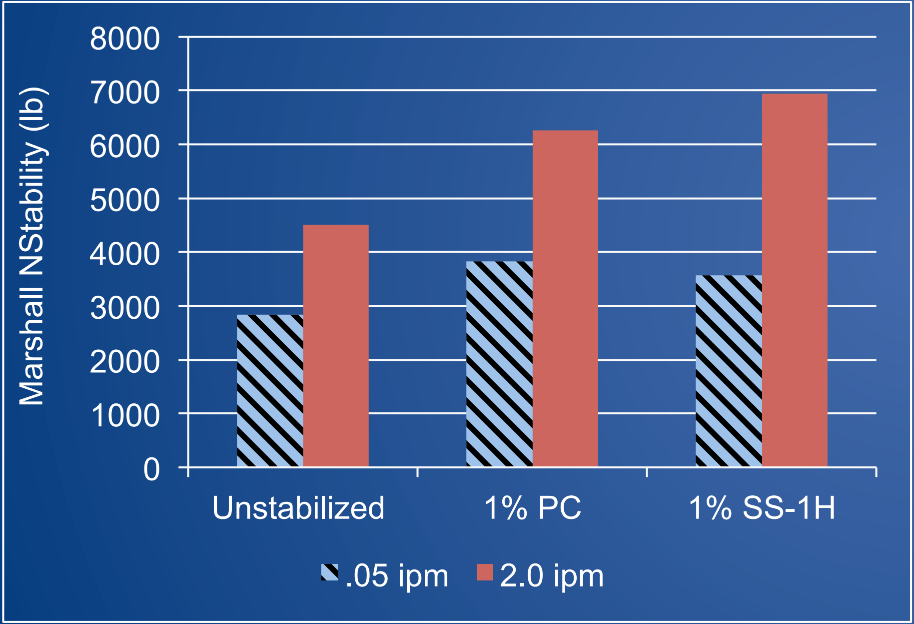
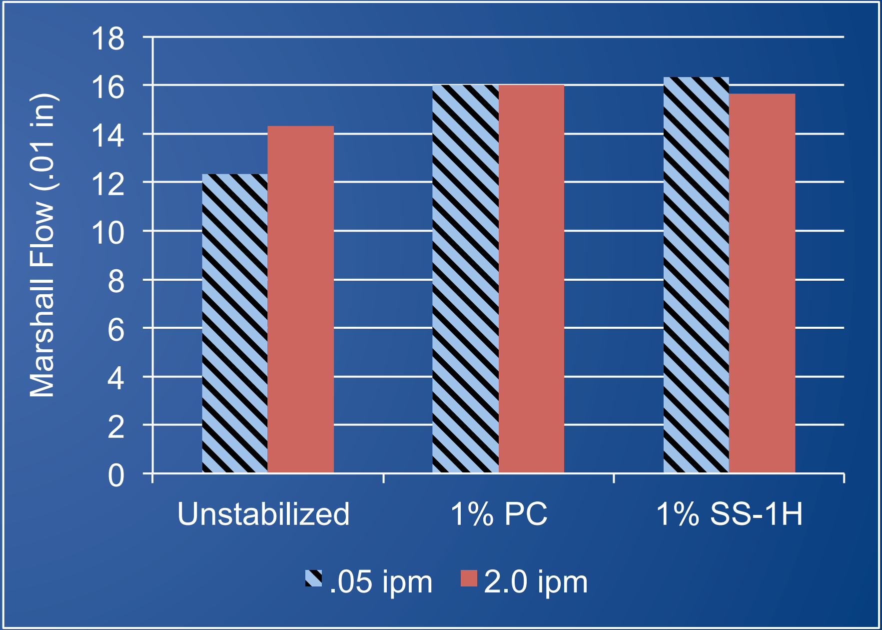
Modified Marshall .05 ipm vs 2.0 ipm





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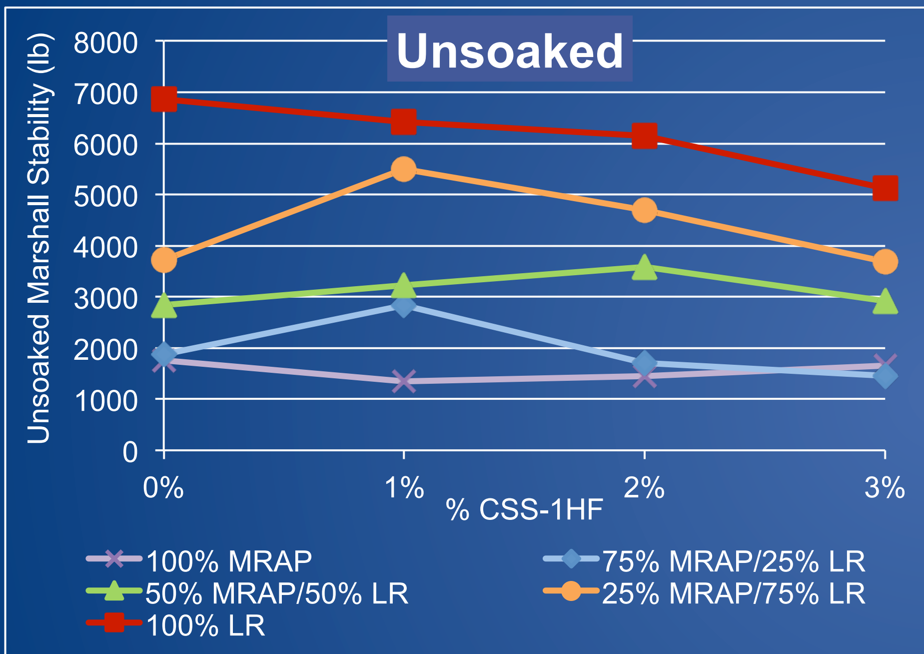
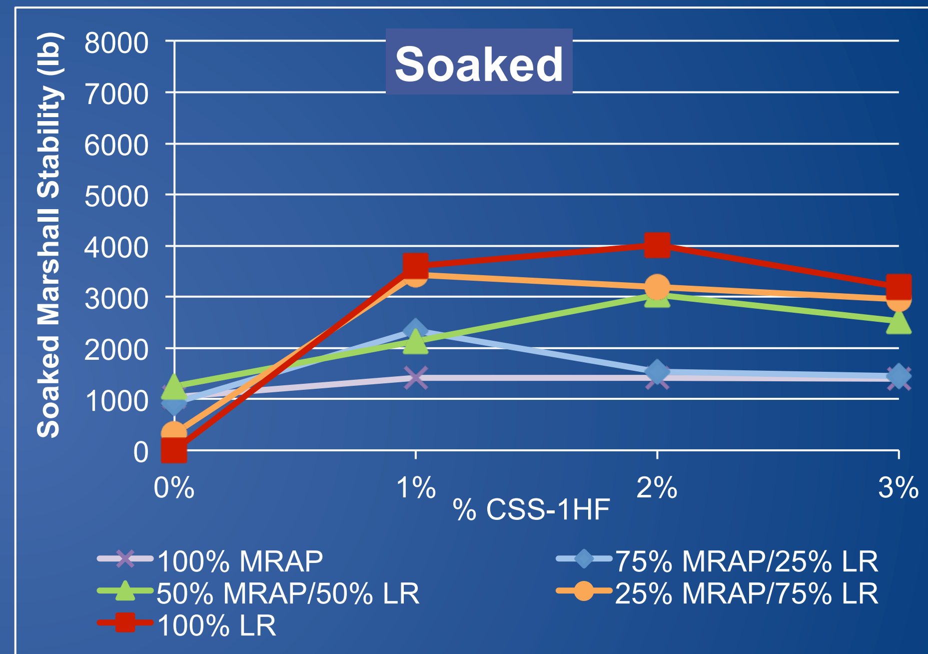
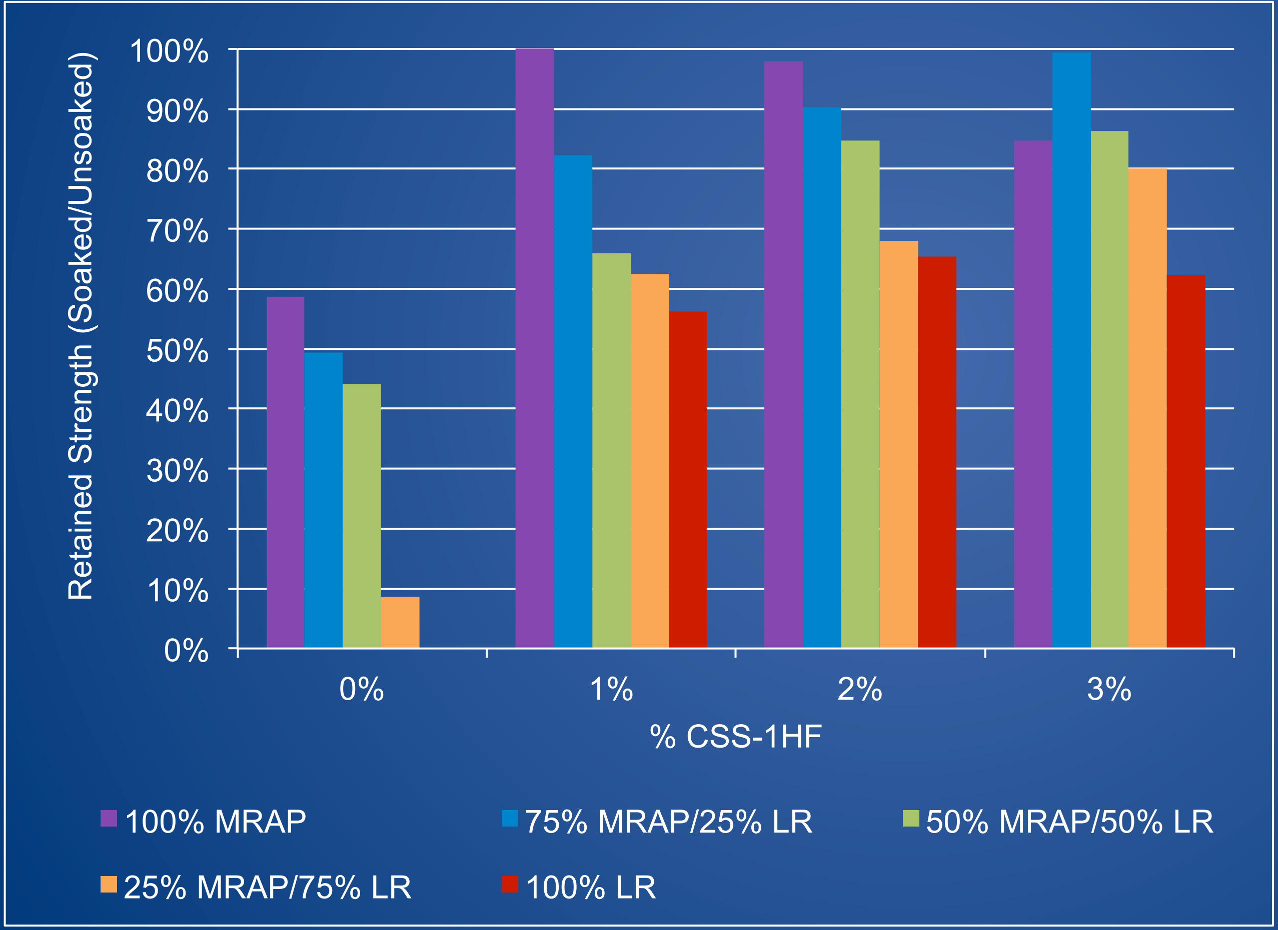
Modified Marshall Blends with CSS-1H





- All blends peaked between 1% and 2% CSS-1H
- Marshall flow (not shown) increased with increasing CSS-1H

Modified Marshall Blends with CSS-1H



- Large increase in retained strength
- SS-1H gave similar results

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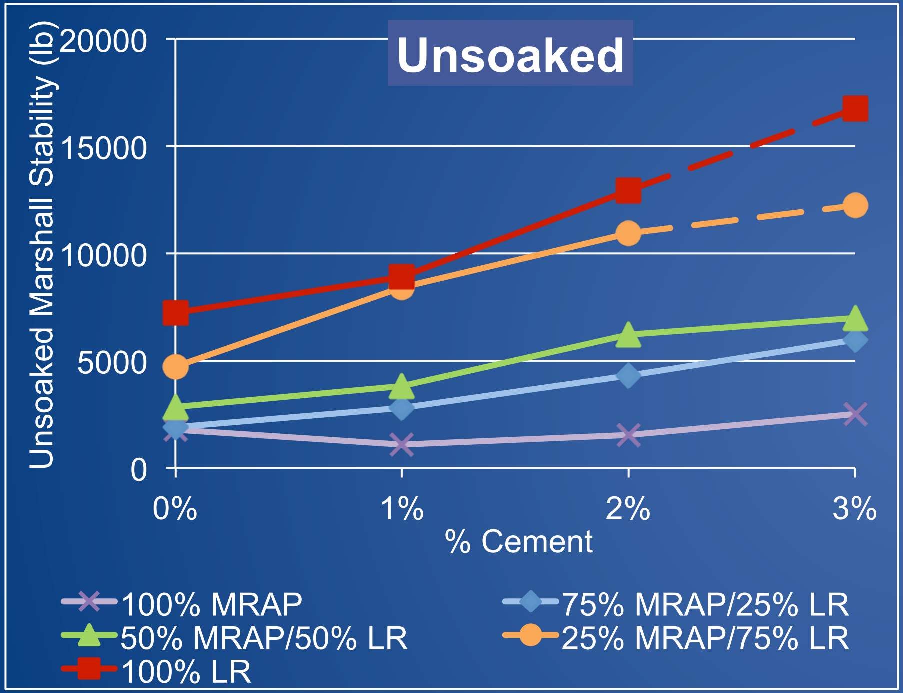
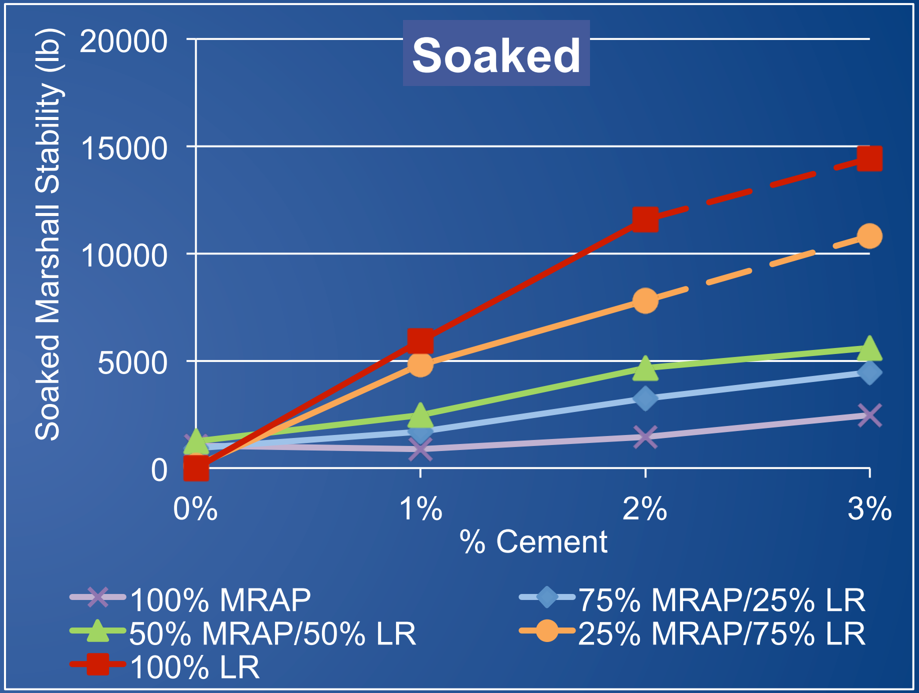
Modified Marshall Blends with Cement





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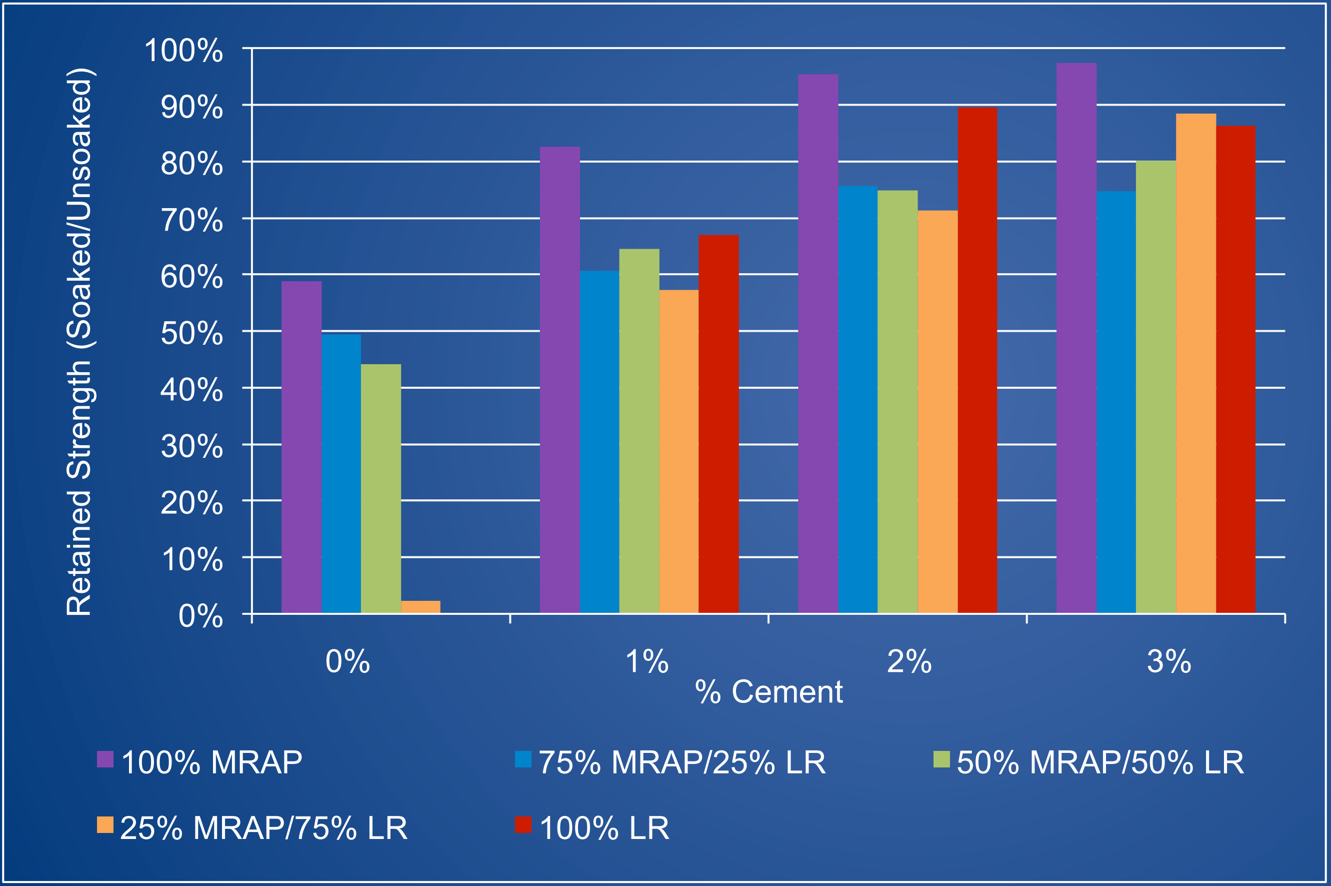
Modified Marshall Blends with Cement Retained Strength



Large increase in retained strength, particularly at high limerock contents

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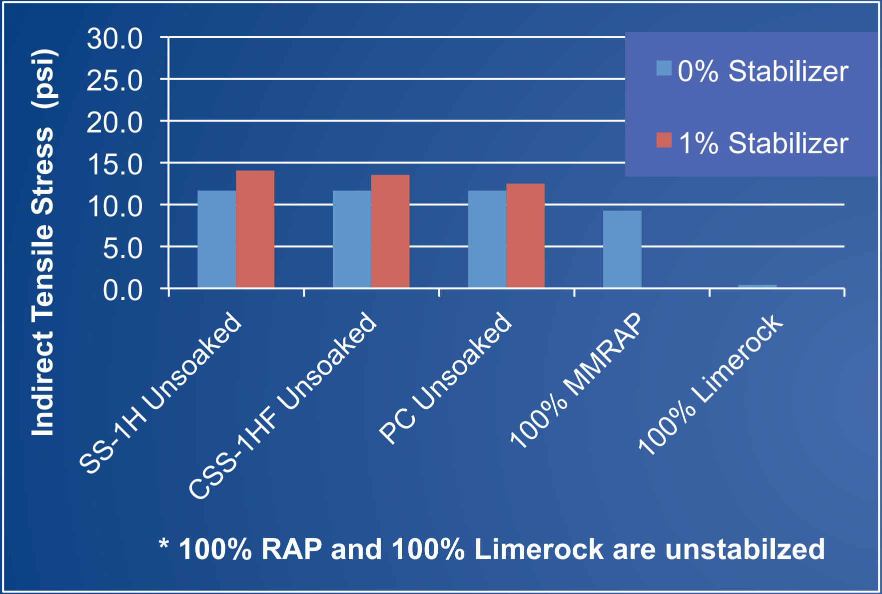
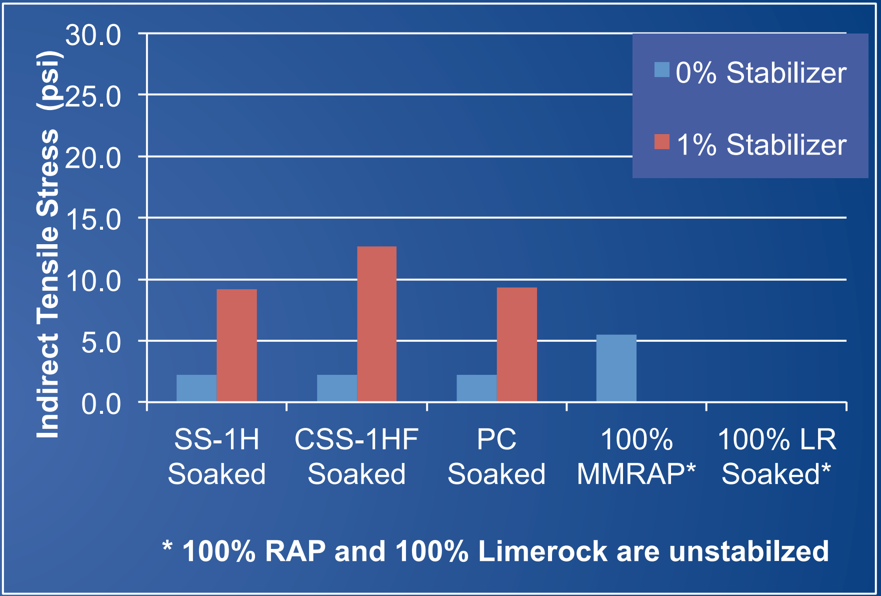
Indirect Tensile Test 50% MMRAP with Stabilizer





- Blending increased unsoaked IDT strength by 20% over 100% MRAP; 30x over 100% limerock
- 1% stabilizing agent increased unsoaked IDT by 15%
- Blending decreased soaked IDT strength by 60% compared to 100% MRAP; but >> 100% LR (IDT = 0)
- 1% stabilizing agent increased soaked IDT 4x – 6x

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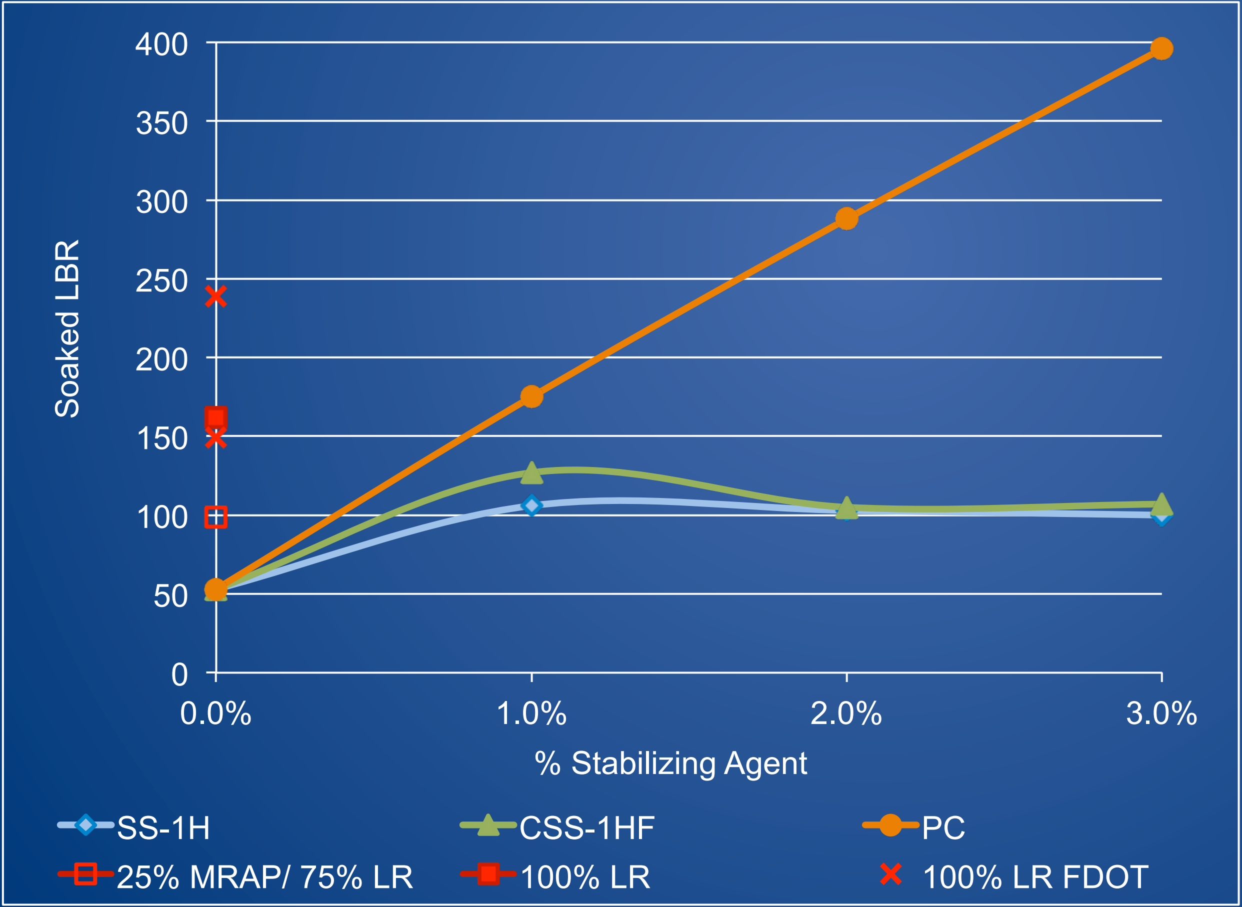
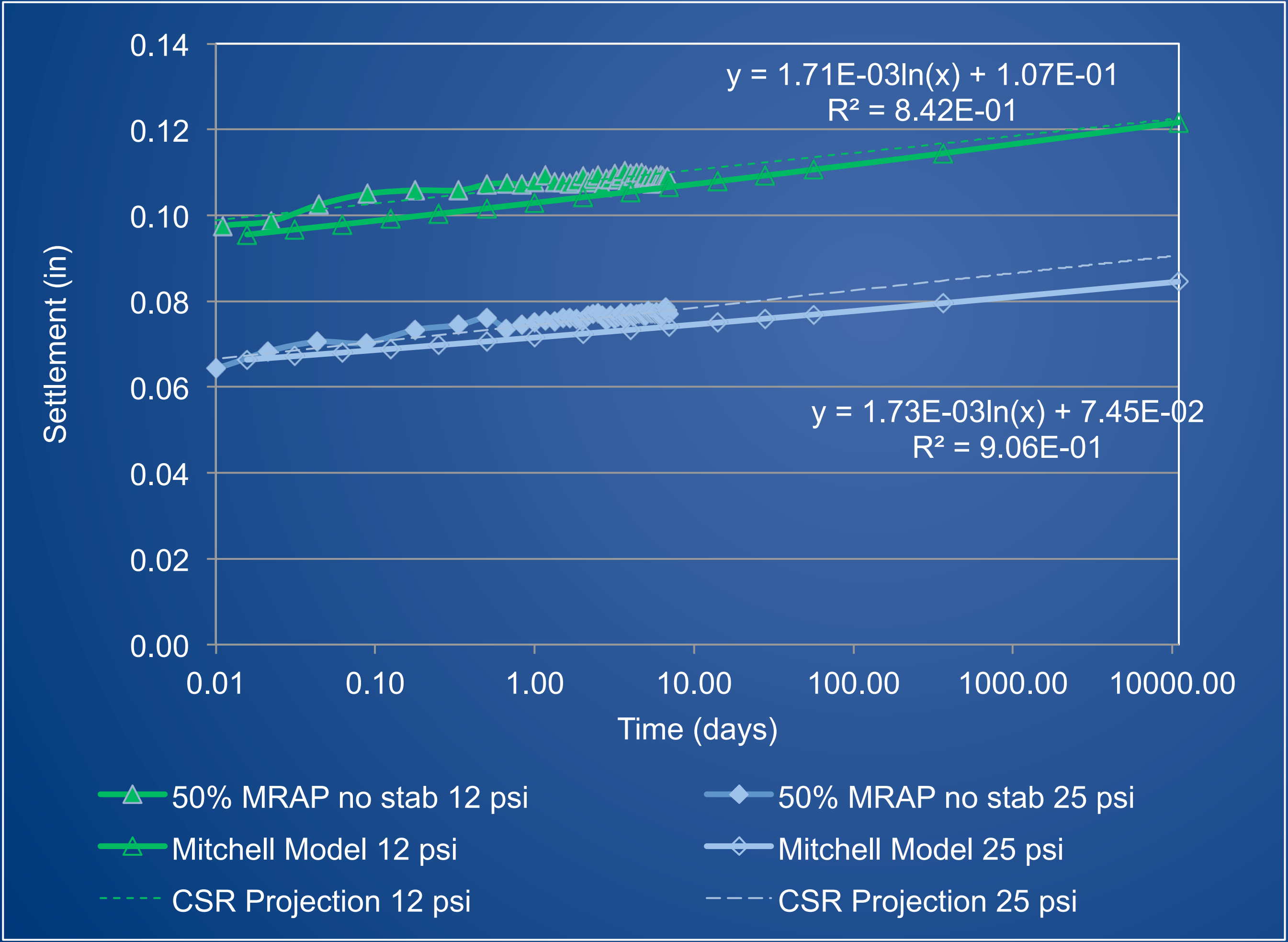
Summary of Soaked LBR of Stabilized 50% MRAP/50% LR blends



Emulsion and cement stabilized 50%/50% blends had soaked LBR over 100

Creep Models – 30 Year Creep of 10 inch Base at 25 psi Constant Stress



50% RAP/50% LR with 1% cement has acceptable creep (<3% strain (0.3 in)) in both models

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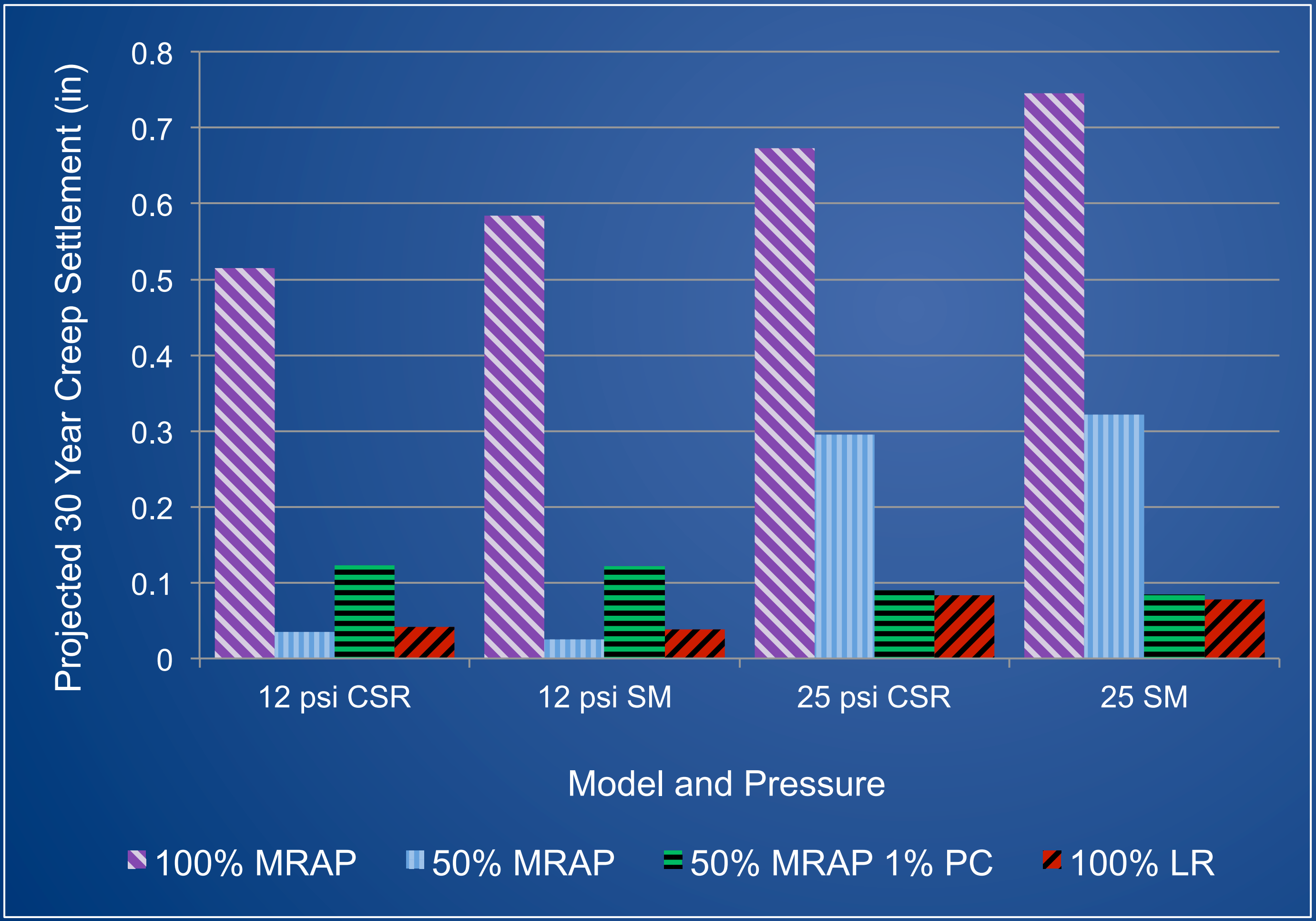
Summary of 30 Year Creep of 10 inch Base at 12 and 25 psi Constant Stress



- Unstabilized 50%/50% blends ok at 12 psi, marginal at 25 psi
- Stabilized 50%/50% blends ok at 25 psi

Conclusions

- Fractionating RAP did not improve strength or creep performance
- Laboratory gyratory compaction greatly increased strength of RAP or RAP/aggregate blends
- Blending RAP with aggregates improved permeability by 1 – 3 orders of magnitude
- Blends of 50% or less RAP behave more like a conventional aggregate with greatly reduced creep and higher strength
- Blends of RAP/A-3 sand, RAP/Cemented Coquina, and RAP/crushed concrete had LBRs < 100

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Conclusions

- 50% RAP/limerock blends without stabilizing agent achieved a soaked LBR of 53. This meets the subbase specification (40) but not the base specification (100).
- 50% RAP/limerock blends showed projected creep strain of approximately 3% over 30 years at 25 psi constant stress making them marginal for base course. Projected creep at 12 psi was under 1% making 50%/50% blends acceptable for subbase.
- 25% RAP/limerock blends without stabilization achieved a soaked LBR of 98.7 with very low creep. This blend may be acceptable for base course.

Conclusions

- Asphalt emulsion stabilized RAP/limerock blends showed a peak LBR and creep reduction at approximately 1% emulsion
- Cement stabilized RAP/limerock blends continued to increase in LBR and decrease creep with increasing cement content
- Lime stabilization of RAP/limerock blends did not appreciably improve LBR or decrease creep

Conclusions

- 50% RAP/limerock blends stabilized with either asphalt emulsion or Portland cement reached soaked LBR values over 100.
- 50% RAP/limerock blends stabilized with cement showed projected creep strain of approximately 1% over 30 years at 25 psi constant stress making them acceptable for base course.
- 50% RAP/limerock blends stabilized with asphalt emulsion showed projected creep strain under 3% over 30 years at 25 psi constant stress making them acceptable for base course.

Conclusions

- Marshall stability showed strong positive correlation to LBR strength for all stabilizing agents. Marshall flow showed strong positive correlation to creep strain rate for cement and CSS-1H but weak positive correlation for SS-1H
- Unconfined compression and indirect tensile results did not consistently correlate to LBR or creep strain rate

Conclusions

- The Creep Strain Rate method of projecting creep using a logarithmic curve fit of experimental data between 0.01 and 7 days gave similar results to the Singh and Mitchell modeling method.

Recommendations

- Do not use lime stabilization with RAP/ limerock blends
- Use blends of 50% RAP/50% limerock without stabilizing agents for subbase course
- Use blends of 50% RAP/50% limerock with asphalt emulsion or cement stabilization for base course
- Possibly use blends of 25% RAP/75% limerock without stabilizing agents for base course

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