Status Update: NCHRP Project 9-48
Field versus Laboratory Volumetrics and Mechanical Properties

Louay N. Mohammad
Mostafa Elseifi
Sam Cooper, III

Department of Civil and Environmental Engineering
LA Transportation Research Center
Louisiana State University

Mixture ETG Meeting
September 19, 2014
Baton Rouge, Louisiana

Research Team

Acknowledgements

- **NCHRP**
  - Dr. Ed Harrigan
  - Project Technical Review Panel
- **LADOTD and LTRC Research Staff**
- **Participating Contractors/DOTs**
  - Stark Asphalt
  - Mathy Const. Co.
  - Prairie Const. Co.
  - Barriere Const. Co.
  - Diamond B Const.
  - Community Asphalt

  Florida DOT
  Iowa DOT
  Michigan DOT
  South Dakota DOT
  Virginia DOT
  Wisconsin DOT
- **Texas Transportation Institute**
- **University of Wisconsin**

Outline

- **Objective / Scope**
- **Conduct of Experiment**
- **Preliminary Data Analysis**
  - **Evaluate the impacts of *process-based factors* on differences specimen types: Design (LL), Production (PL) and Construction (PF)**
  - **Compare mechanistic properties of three specimen types (LL, PL, PF)**
    - » **Develop shift factors for mechanistic parameters**
    - » **Affect predicted pavement performance – Pavement ME**
  - **Compare volumetric properties of three specimen types (LL, PL, PF)**
    - » **Develop tolerance recommendation**
- **Summary**

Objective

- **Determine the *cause* and *magnitude* of the differences and variances in measured volumetric and mechanical properties within and between three specimen types:**
  - **Laboratory-mixed and laboratory compacted (LL)**
    - » **Design**
  - **Plant mixed and laboratory compacted (PL)**
    - » **Production**
  - **Plant mixed and field compacted (PF)**
    - » **Construction**

Research Approach

- **Task 1: Conduct Literature Review**
- **Task 2: Conduct a Meta-Analysis of Collected Data**
- **Task 3: Submit an interim report**
- **Task 4: Conduct the experiment approved in Task 3**
- **Task 5: Prepare a recommended practice for state agencies**
- **Task 6: Prepare Final Report**

Experiment

- **Five factors**
  - **two contrasting levels -- low and high**

Factor ID	Process	Low (-)	High (+)
1	Baghouse fine	No	Yes
2	Time delay in specimen fabrication (PL)	No	Yes
3	Aggregate absorption	Low	High
4	Aggregate degradation	Soft	Hard
5	Aggregate stockpile in situ properties Moisture Content	Low	High

Experiment

- Volumetric properties
  - AV, VMA, Gmm, AC (Solvent), gradation, Gsb
  - (LL, PL, PF)
- Mechanistic properties
  - Hamburg LWT
    - (LL, PL, PF)
  - IDT Dynamic modulus
    - (LL, PL, PF)
  - Axial Dynamic Modulus
    - (LL, PL)

Experiment

- Full Factorial design
  - 2^5 factor combinations x 3 specimen types
    - » 96 test combinations
- Volumetric properties
  - 96 x 3 x 3 = 864
- Mechanistic properties
  - 96 x 4 x 3 = 1152
- Total number of samples
  - 2016

Experiment

- Quarter fractional design
  - 2^{5-2} factor combinations x 3 specimen types
    - » 24 test combinations
- Volumetric properties
  - 24 x 3 x 3 = 216
- Mechanistic properties
  - 24 x 4 x 3 = 288
- Total number of samples
  - 504

Experiment

- Fractional Factorial Design
- Only main effects will be evaluated
  - Interactions may not be quantified

Mixture ID	Baghouse Fines	Reheating	Aggregate Absorption	Aggregate Degradation	Aggregate Moisture Content
Mix 1	No	No	Low	Soft	High
Mix 2	No	No	High	Hard	Low
Mix 3	No	Yes	Low	Hard	Low
Mix 4	No	Yes	High	Soft	High
Mix 5	Yes	No	Low	Hard	High
Mix 6	Yes	No	High	Soft	Low
Mix 7	Yes	Yes	Low	Soft	Low
Mix 8	Yes	Yes	High	Hard	High

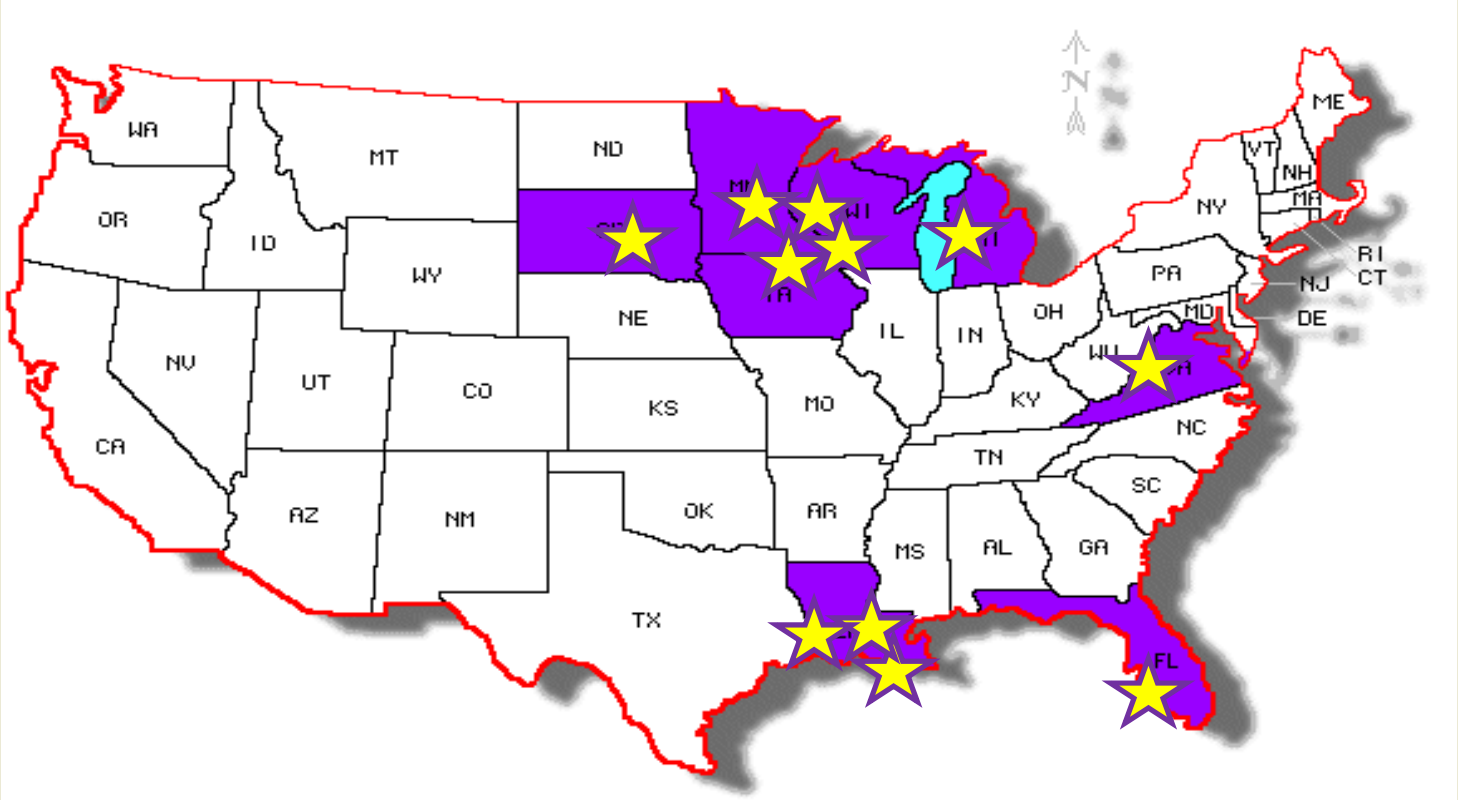
Experiment

- **Fractional Factorial Design**
- **Only main effects will be evaluated**
  - **Interactions may not be quantified**

NMAS (mm)	Mixture ID	Baghouse Fines	Time Delay	Aggregate Water Absorption (%)	Aggregate Degradation (Mic.D/LA Abr.)	Stockpile Moisture Content
12.5	Mix 1	No	No	~ 1.0	> 30 / > 40	High
	Mix 2	No	No	~ 4.0	< 20 / < 20	Low
	Mix 3	No	Yes	~ 1.0	< 20 / < 20	Low
	Mix 4	No	Yes	~ 4.0	> 30 / > 40	High
	Mix 5[a,b,c,d,e,f]	Yes	No	~ 1.0	< 20 / < 20	High
	Mix 6	Yes	No	~ 4.0	> 30 / > 40	Low
	Mix 7	Yes	Yes	~ 1.0	> 30 / > 40	Low
	Mix 8	Yes	Yes	~ 4.0	< 20 / < 20	High

Experiment – Field Project

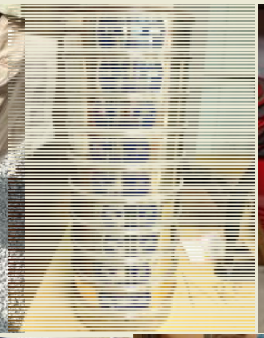
- **Survey**
- **DOTs**
- **Contractors**
- **On-going NCHRP Projects**



Experiment

- **LL Specimen Fabrication**
  - **Approximately 120 kg of loose mixture required**







Experiment

- **PL Specimen Fabrication**
  - **Approximately 120 kg of loose mixture required**

Experiment

- **PF Specimen Collection**

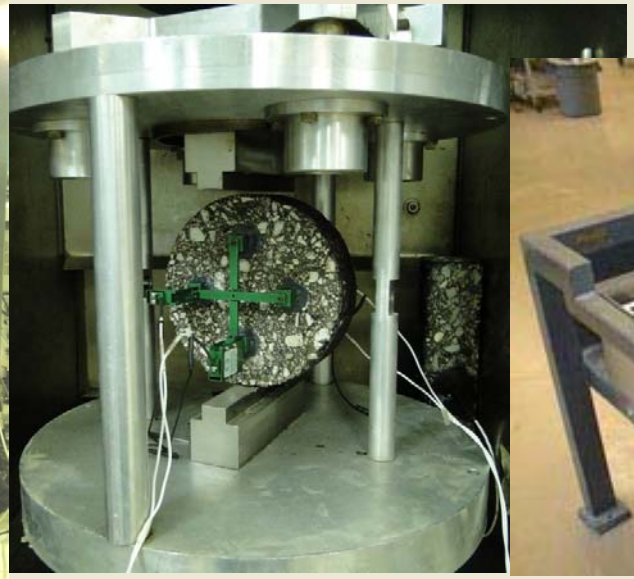
- **Roadway cores collected prior to trafficking**
- **Each core is trimmed to required specimen size for testing**

Experiment – Volumetric Properties

Volumetric Property	Test Method
G_{mm}	AASHTO T 209
G_{mb}/Air Voids	AASHTO T 166 AASHTO T 269
Asphalt Content (Extraction)	AASHTO T 164
Aggregate Gradation	AASHTO T 30
Aggregate Bulk Specific Gravity/Absorption	AASHTO T 84 AASHTO T 85

Experiment – Mechanistic Properties

Mechanistic Property	Test Method
Rut Depth (LWT)	AASHTO T 324
Axial Dynamic Modulus	AASHTO T 342
Indirect Tension Dynamic Modulus	Kim et al. (2004)

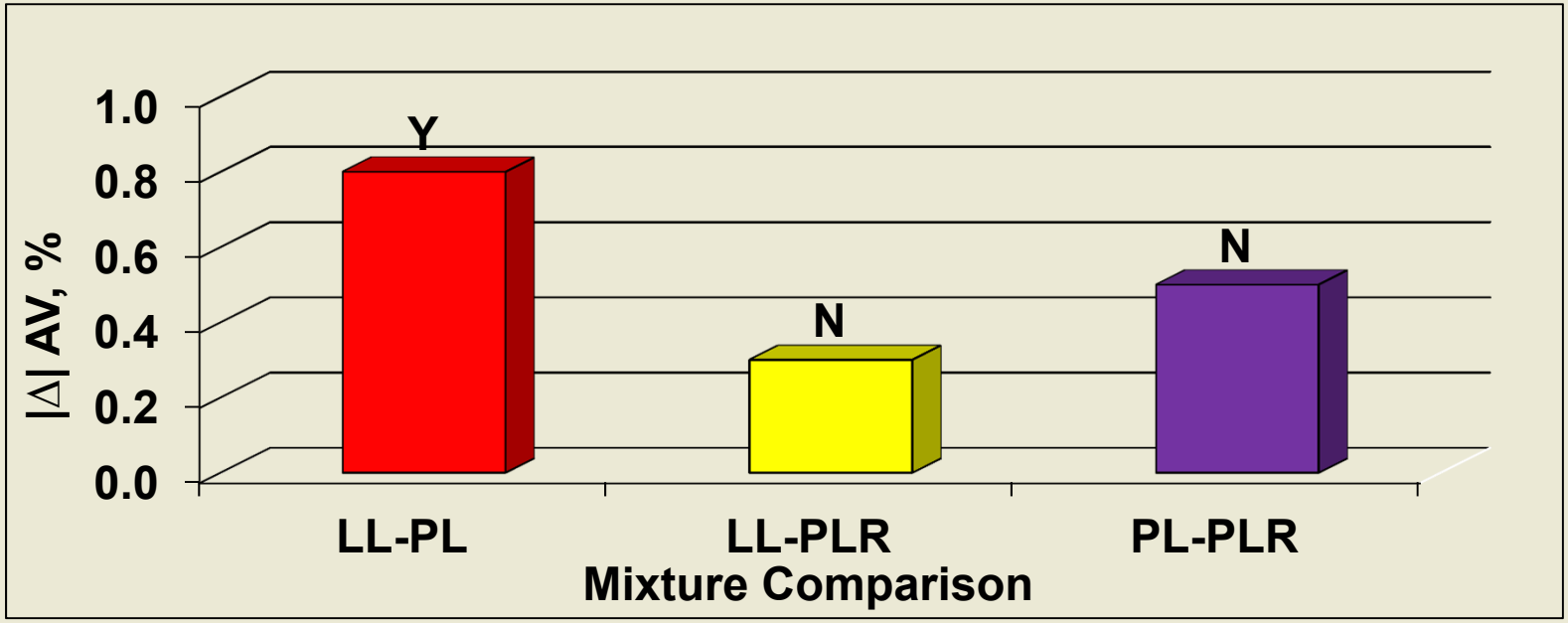


Effect of Specimen Type: Air Voids

Mix 1 -- WI

Specimen Type	AVG	ST.Dev
LL	4.2	0.6
PL	3.4	0.3
PLR	3.9	0.2

AV – Delta Summary, %		
LL - PL	LL - PLR	PL - PLR
0.8	0.3	-0.5

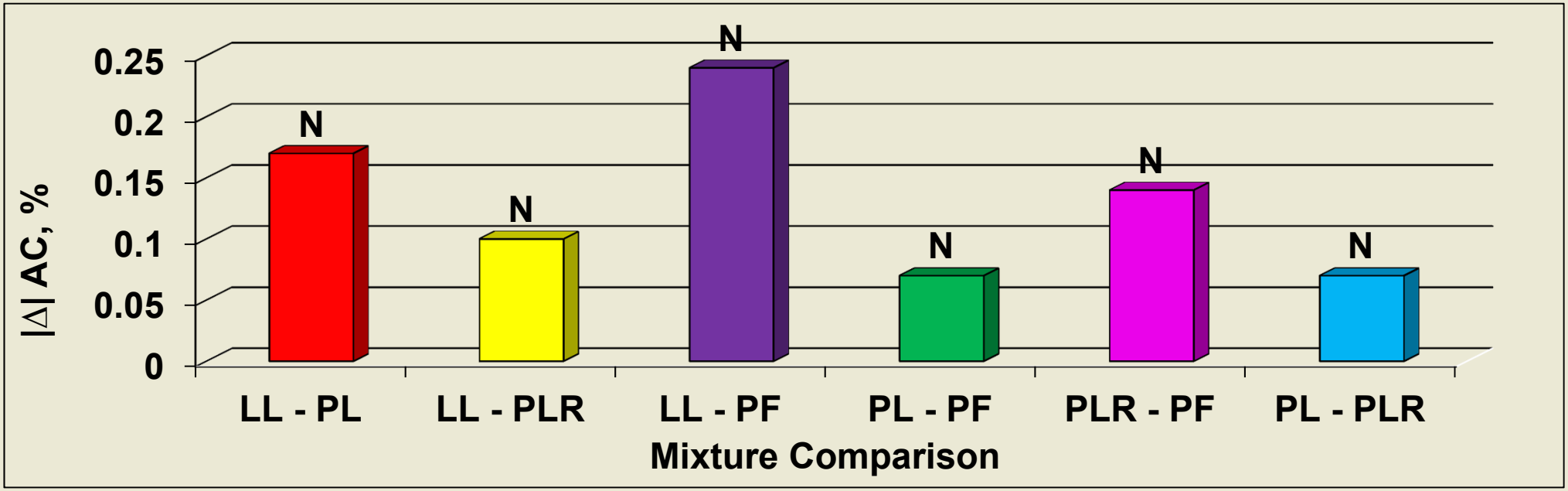


Effect of Specimen Type: Asphalt Content

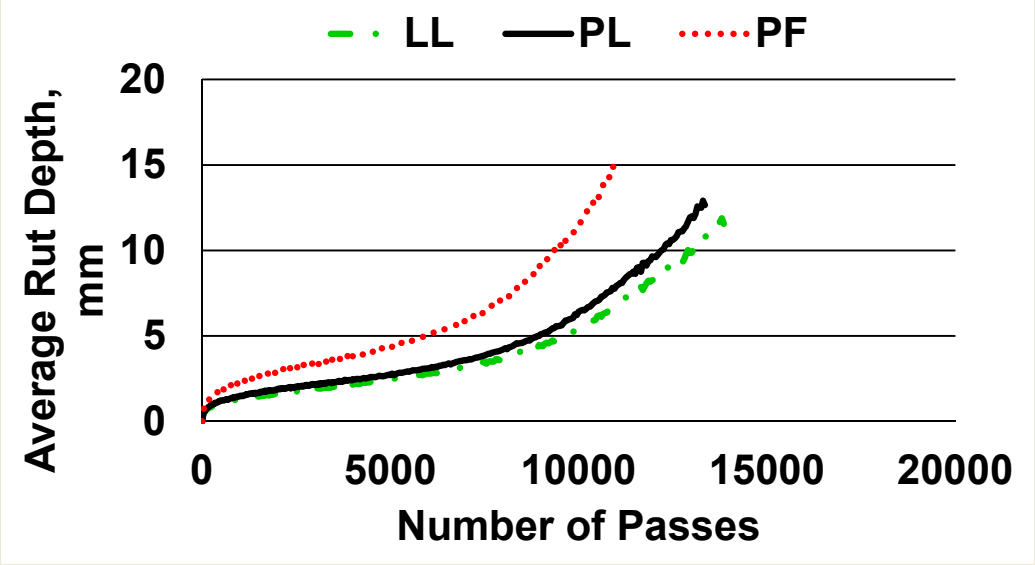
Mix 1 -- WI

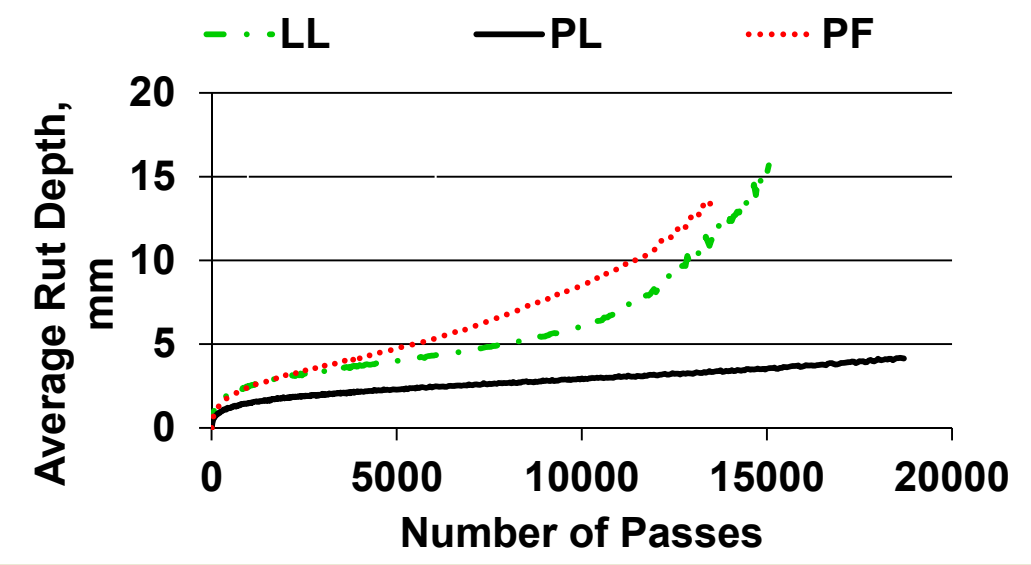
Specimen Type	AVG	ST.Dev
LL	5.40	0.03
PL	5.57	0.07
PLR	5.50	0.10
PF	5.64	0.23

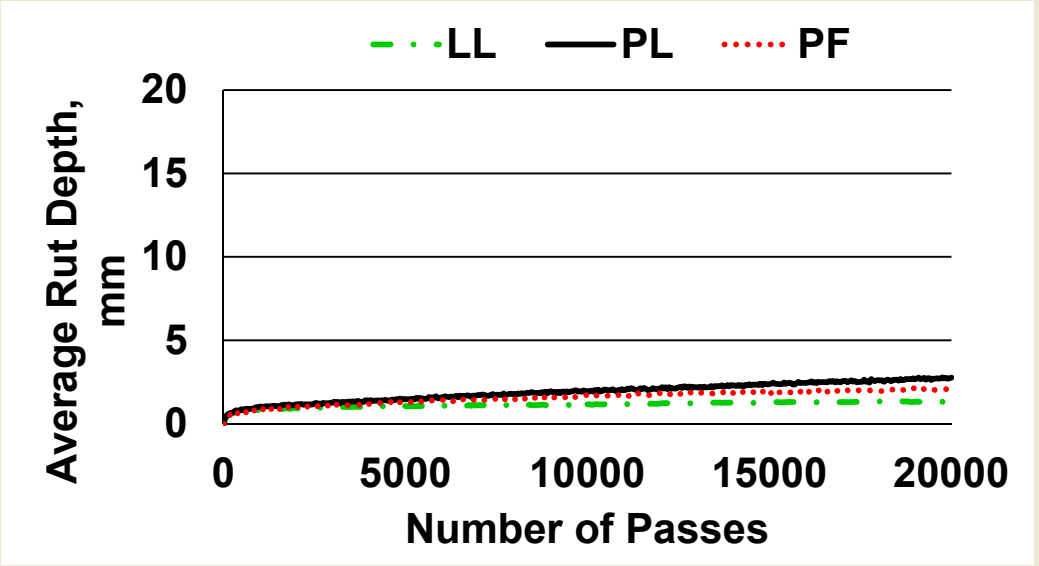
AC– Delta Summary, %					
LL - PL	LL - PLR	LL - PF	PL - PF	PLR - PF	PL - PLR
-0.17	-0.10	-0.24	-0.07	-0.14	0.07



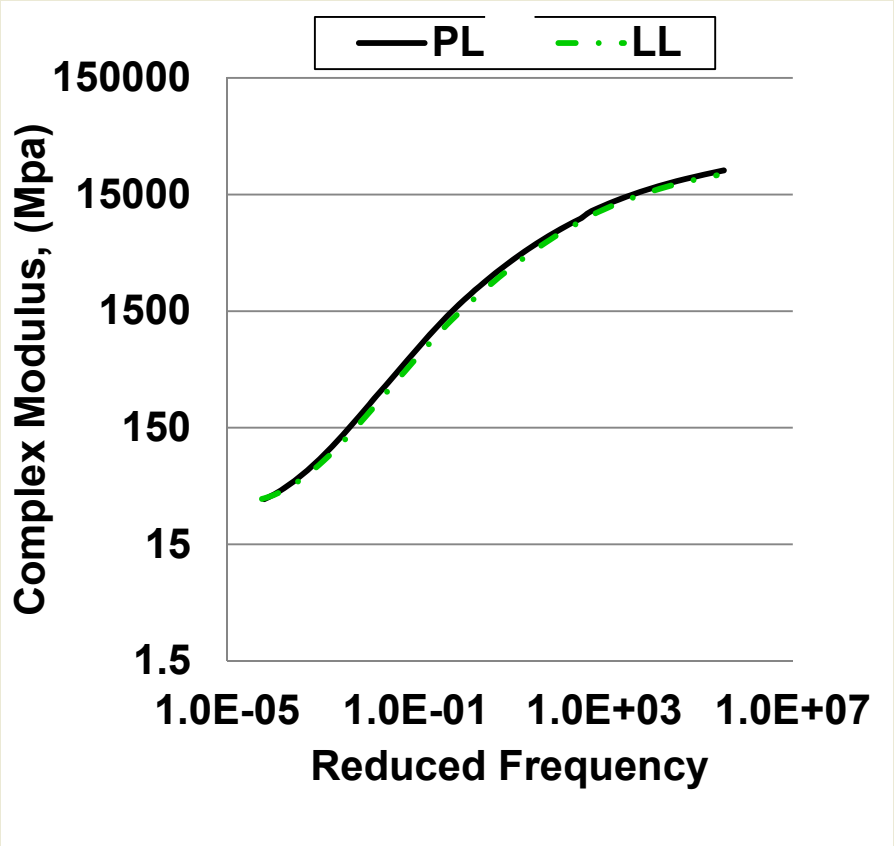
Effect of Specimen Type: LWT Test



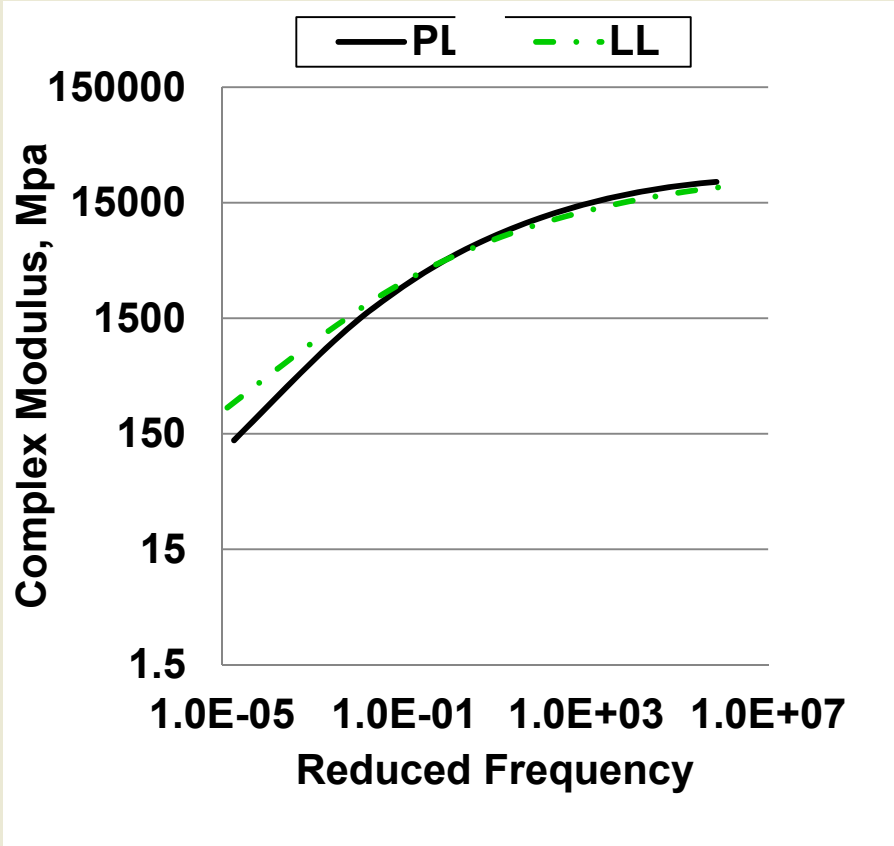




Effect of Specimen Type:
Axial Dynamic Modulus

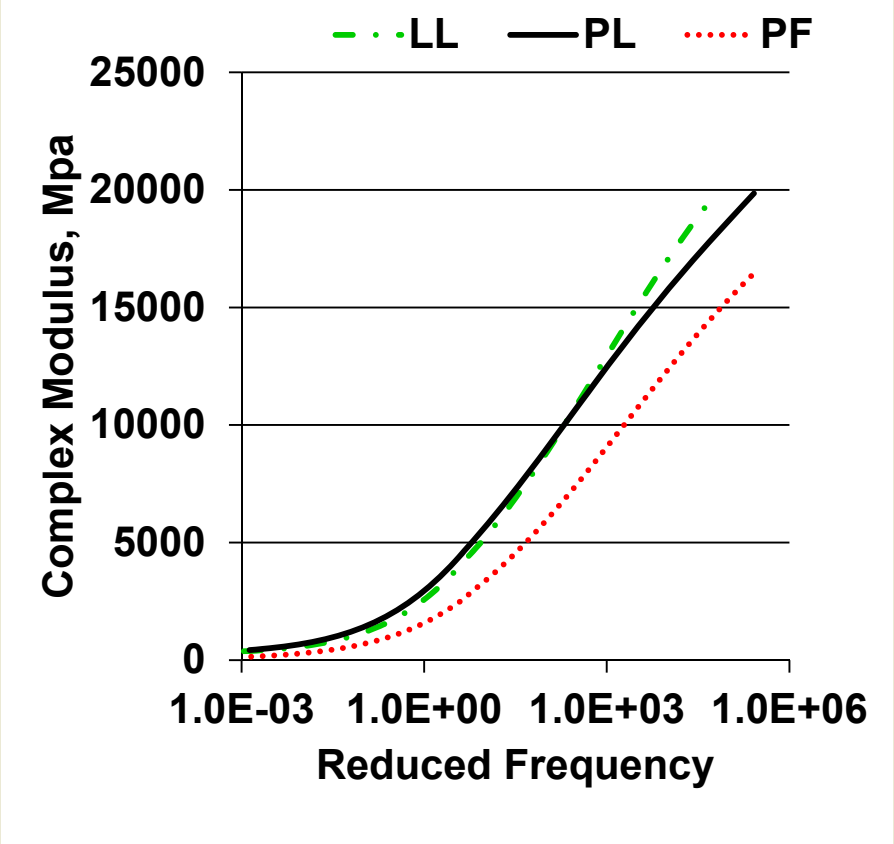


Mix 5 SD

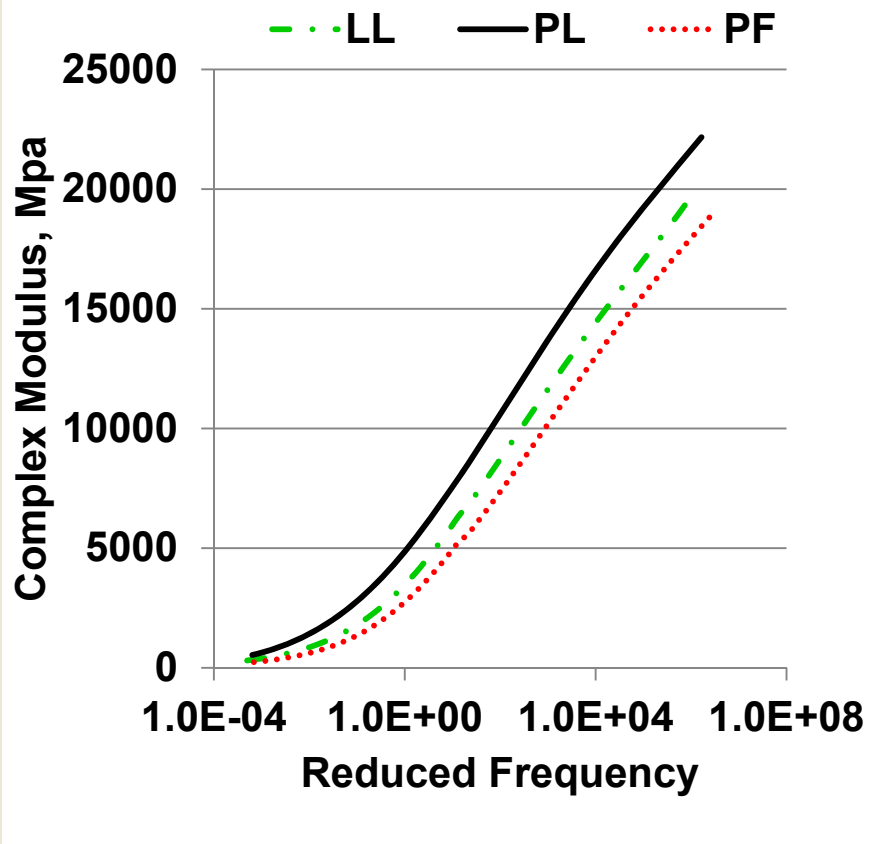


Mix 8 LA

Effect of Specimen Type:
IDT Dynamic Modulus



Mix 3MN



Mix 5VA

Summary of Differences Among Specimen Types
Design (LL), Production (PL), Construction (PF),

- **Volumetric Parameters**

Comparison	AirVoids	VMA	VFA	Gmm	AC	Gsb
Design vs Construction	----			45%	9%	18%
Design vs Production	64%	27%	73%	64%	18%	36%
Production vs Construction	----			27%	9%	9%

- **Mechanistic Parameters**

Comparison	LWT	Axial E*	IDT E*
Design vs Construction	38%	----	57%
Design vs Production	18%	55%	29%
Production vs Construction	52%	----	61%

Experiment

NMAS (mm)	Mixture ID	Baghouse Fines	Time Delay	Aggregate Water Absorption (%)	Aggregate Degradation (Mic.D/LA Abr.)	Stockpile Moisture Content
12.5	Mix 1	No	No	~ 1.0	> 30 / > 40	High
	Mix 2	No	No	~ 4.0	< 20 / < 20	Low
	Mix 3	No	Yes	~ 1.0	< 20 / < 20	Low
	Mix 4	No	Yes	~ 4.0	> 30 / > 40	High
	Mix 5[a,b,c,d,e,f]	Yes	No	~ 1.0	< 20 / < 20	High
	Mix 6	Yes	No	~ 4.0	> 30 / > 40	Low
	Mix 7	Yes	Yes	~ 1.0	> 30 / > 40	Low
	Mix 8	Yes	Yes	~ 4.0	< 20 / < 20	High

Effect of Process-Based Factors
Design (LL), Production (PL), Construction (PF),

- **Analysis of Covariance**
  - **Design (LL) vs Production (PL)**
    - » **Volumetric:**
      - **Stockpile Moisture:**
        - Air Voids
      - **Baghouse:**
        - Asphalt Content, Gradation
      - **Absorption:**
        - Asphalt Content
      - **Aggregate Hardness:**
        - Gradation
      - **Time Delay:**
        - None
    - » **Mechanistic:**
      - **No effect of process-based factors**

Effect of Process-Based Factors
Design (LL), Production (PL), Construction (PF),

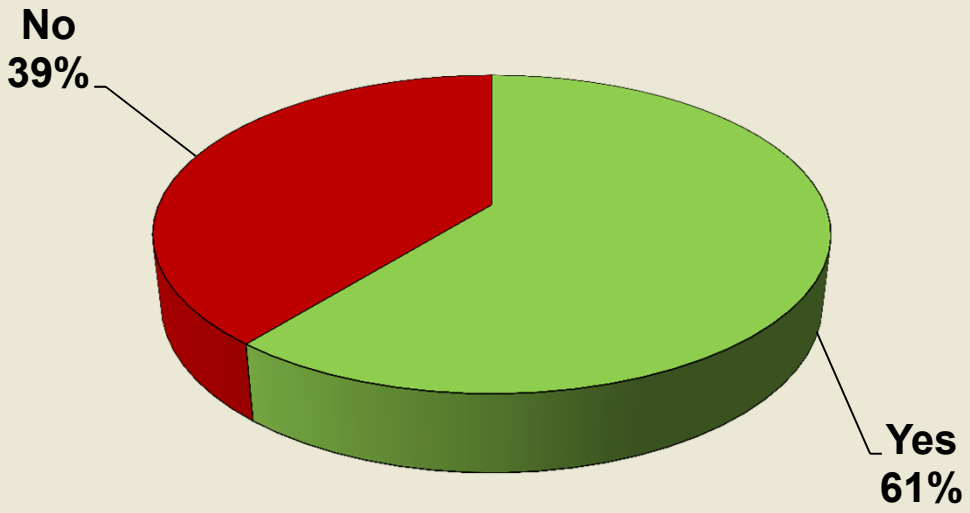
- **Analysis of Covariance**
  - **Design (LL) vs Construction (PF)**
    - » **Volumetric:**
      - **Stockpile Moisture:**
        - Gradation
      - **Baghouse:**
        - Asphalt Content, Gradation
      - **Aggregate Absorption:**
        - None
      - **Aggregate Hardness:**
        - Gradation
      - **Time Delay:**
        - None
    - » **Mechanistic:**
      - **Aggregate Hardness:**
        - IDT Dynamic Modulus

Effect of Process-Based Factors
Design (LL), Production (PL), Construction (PF),

- **Analysis of Covariance**
  - **Production (PL) vs Construction (PF)**
    - » **Volumetric:**
      - **None**
    - » **Mechanistic:**
      - **None**

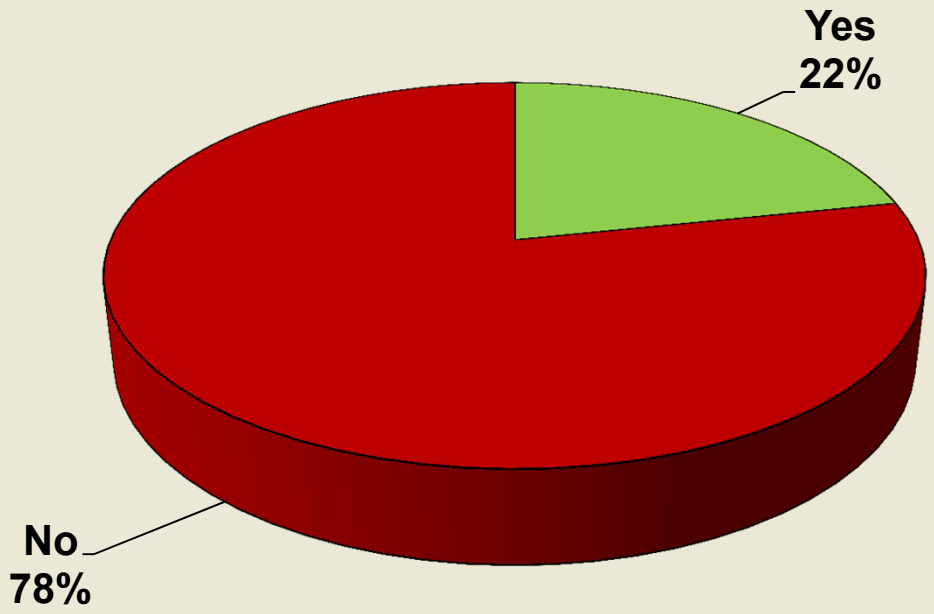
Why are factors not effecting mixture properties? – Contactor Survey

- **Do you observe VMA collapse in the HMA production at your plant prior to fine-tuning?**
  - **Cause: Aggregate Breakdown and increased fines.**



Why are factors not effecting mixture properties? – Contactor Survey

- **Do you observe VMA collapse in the HMA production at your plant after fine-tuning?**



Mechanistic Properties Comparison

- Compare mechanistic properties of three specimen types
  - LL, PL, and PF
- Develop Shift Factors
  - Loaded Wheel Tracking Test
  - Axial Dynamic Modulus
  - IDT Dynamic Modulus

Mechanistic Properties Comparison

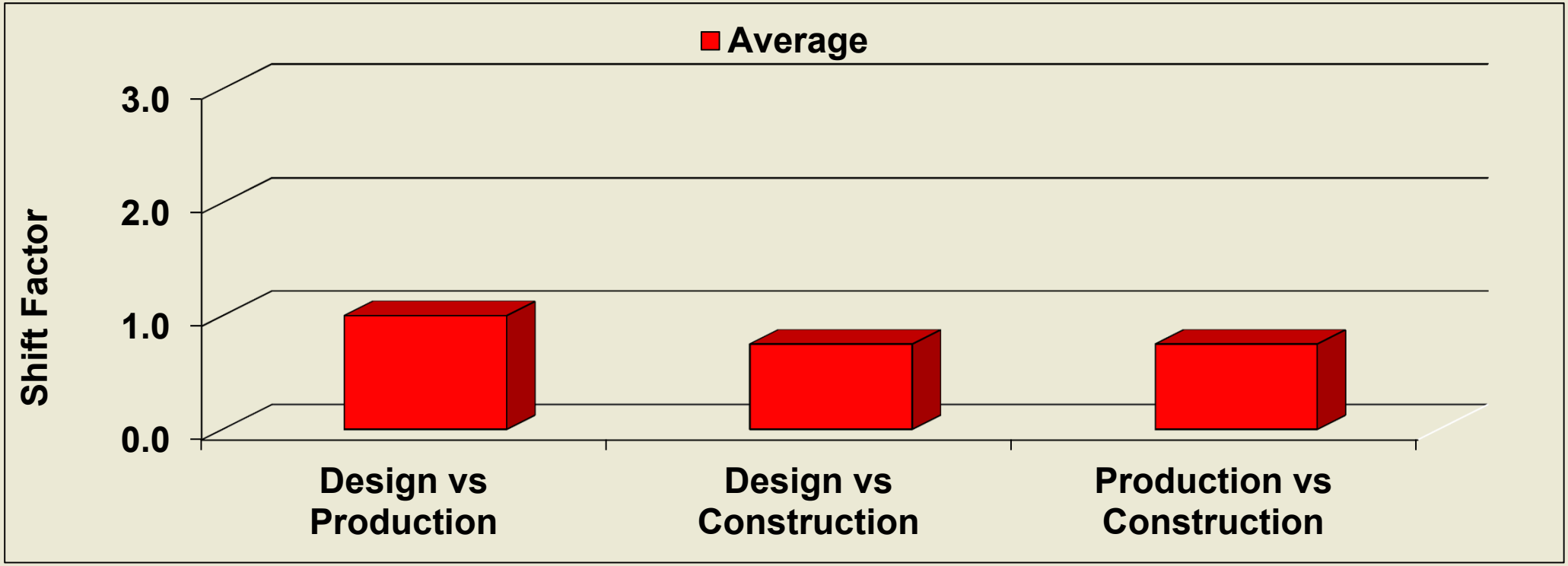
Shift Factors – LWT

- Recommended Shift
  - Design to Production: 1.0
  - Design to Construction : 0.75
  - Production to Construction: 0.75

Comparison	No. of Passes	Average Shift
Design / Production	1000	1.0
	5000	1.0
	10000	1.0
	15000	0.8
	20000	0.8
	Avg.	1.0
Design / Construction	1000	0.8
	5000	0.8
	10000	0.7
	15000	0.7
	20000	0.7
	Avg.	0.75
Production / Construction	1000	0.8
	5000	0.7
	10000	0.7
	15000	0.7
	20000	0.9
	Avg.	0.75

Mechanistic Properties Comparison

Shift Factors – LWT



Mechanistic Properties Comparison

Shift Factors – Axial Dynamic Modulus

- **Recommended Shift**
  - **Shift may need to be utilized at higher temperatures**
    - **May relate to binder oxidation in plant produced mixtures**

Comparison	Temperature, °C	Average Shift	Shift Range	
			Minimum	Maximum
Design / Production	-10.0	1.0	0.7	1.1
	4.4	1.0	0.7	1.1
	25.0	0.9	0.6	1.1
	37.8	0.8	0.5	1.1
	54.4	0.8	0.5	1.2

Mechanistic Properties Comparison

Shift Factors – IDT Dynamic Modulus

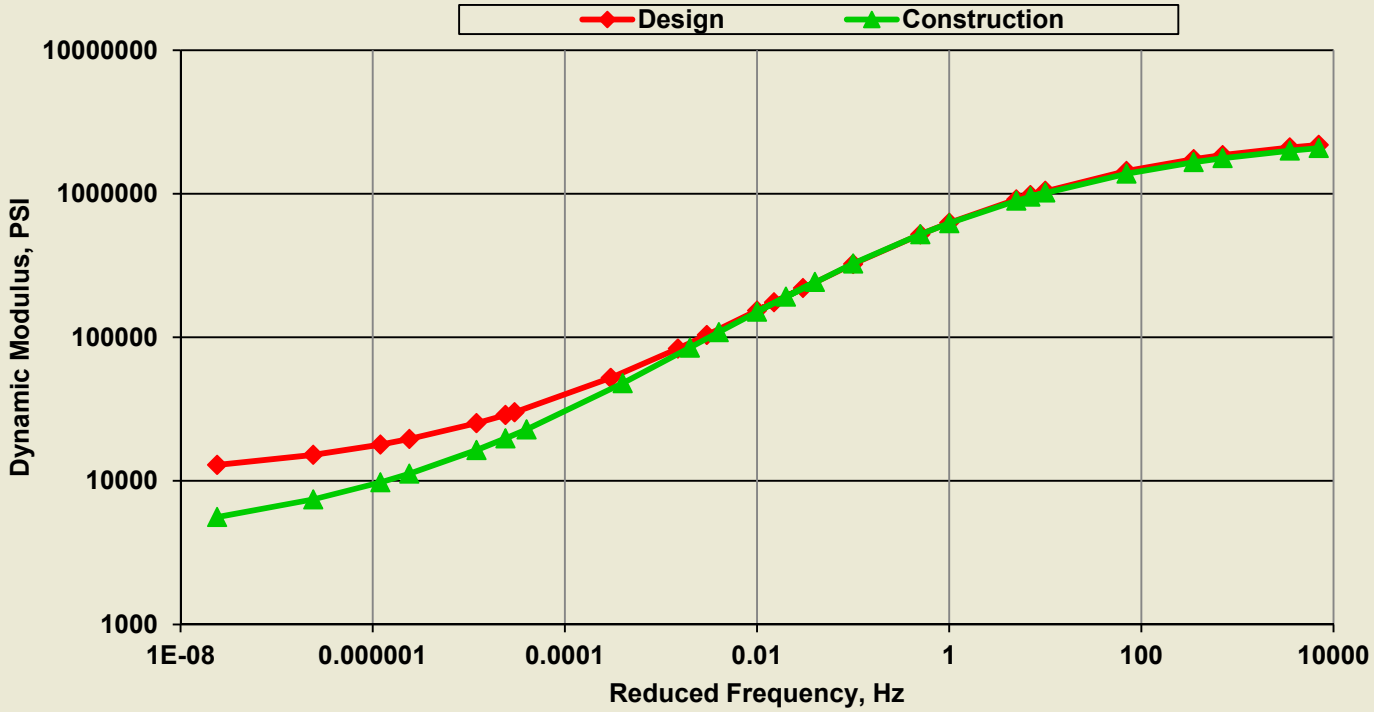
- **Recommended Shift**
  - **Need for shift increase with test temperature.**
    - » **IDT Dynamic modulus is highly sensitive to binder properties and aggregate orientation at elevated temperatures**

Temperature, °C	Comparison	Average Correction	Correction Range	
			Minimum	Maximum
-10	Design/Production	1.0	0.8	1.1
	Design/Core	1.0	0.9	1.3
	Production/Core	1.1	0.9	1.4
10	Design/Production	0.9	0.8	1.1
	Design/Core	1.2	0.8	1.5
	Production/Core	1.3	0.9	1.7
35	Design/Production	1.0	0.6	1.4
	Design/Core	1.4	0.9	2.1
	Production/Core	1.5	0.8	2.2

Mechanistic Properties Comparison

IDT Dynamic Modulus – Master Curve

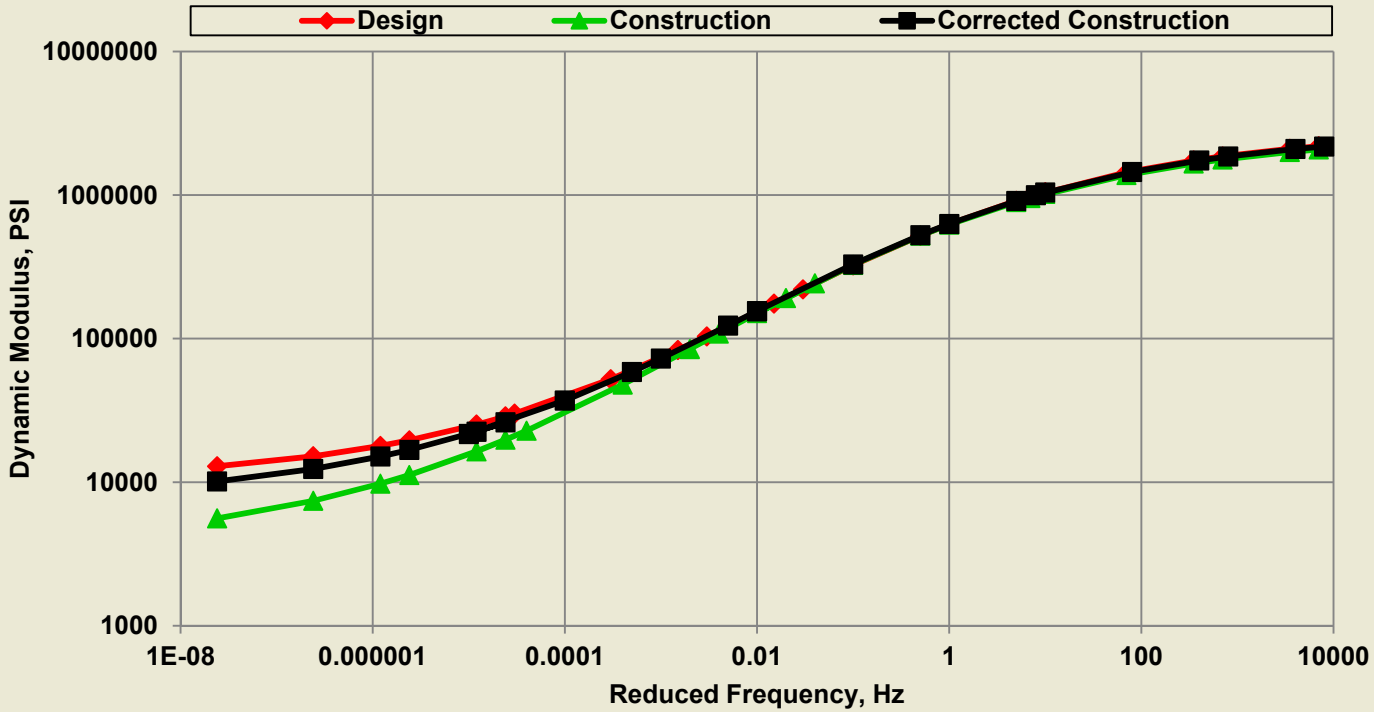
- Apply shift factor
- PF to LL



Mechanistic Properties Comparison

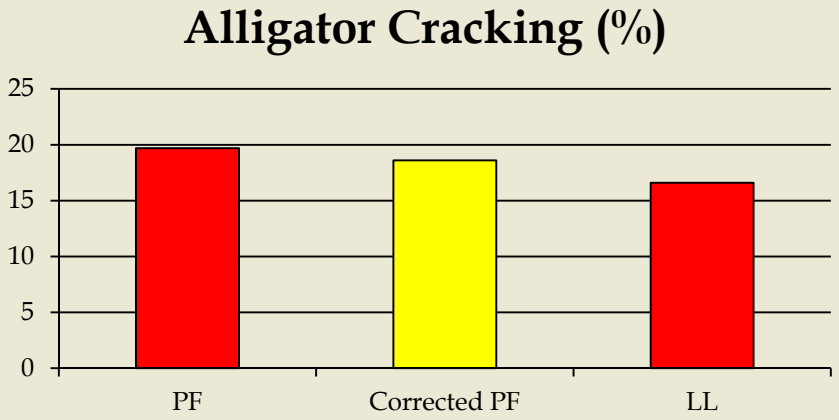
IDT Dynamic Modulus – Master Curve

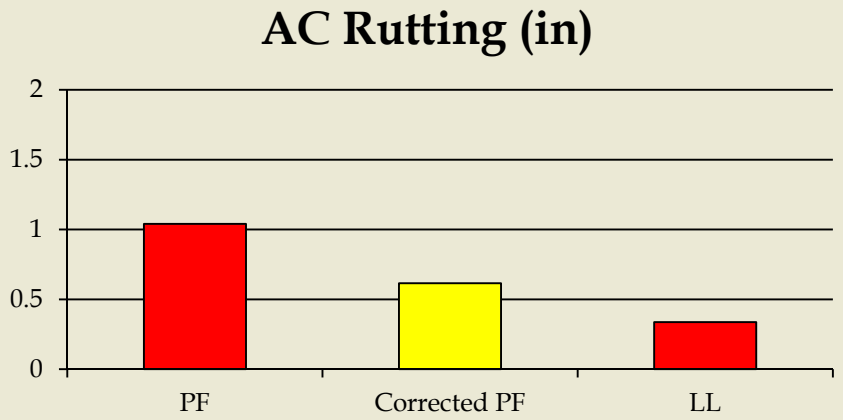
- Apply shift factor
- PF to LL

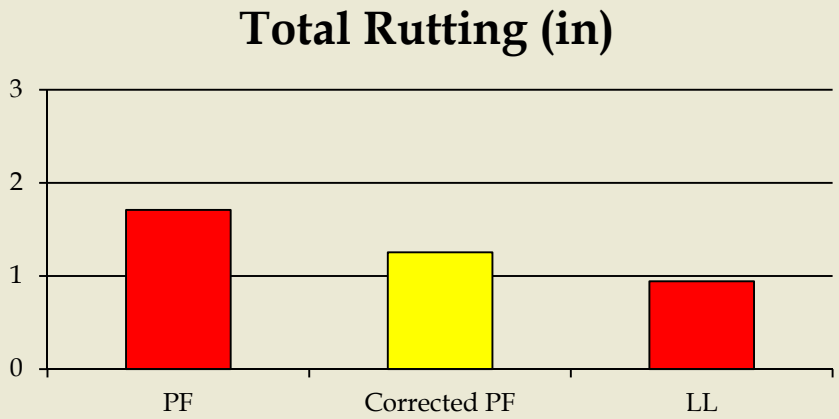


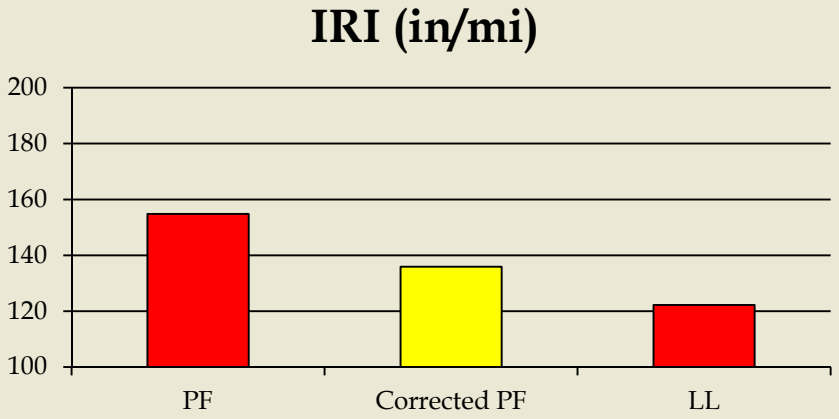
Mechanistic Properties Comparison

IDT Dynamic Modulus – Pavement ME









Volumetric Properties Comparison
Tolerance Recommendation

- **Compare volumetric properties of three specimen types**
  - **LL, PL, and PF**
- **Determine magnitude of differences among specimen types**
- **Develop tolerance recommendations**

Volumetric Properties Comparison

Tolerance Recommendation – Design vs Production

Comparison	Property	Avg	Min	Max	Confidence Limit 95%
Design - Production	AV,%	0.6	0.0	1.3	0.8
	VMA,%	0.4	0.0	2.1	1.2
	VFA,%	4.0	0.3	9.9	5.4
	AC,%	0.2	0.0	0.4	0.2
	Gmm	0.014	0.002	0.039	0.020
	Gsb	0.011	0.002	0.025	0.014
	Passing 0.075 mm, %	0.4	0.0	0.9	0.5

Volumetric Properties Comparison

Tolerance Recommendation – Design vs Construction

Comparison	Property	Avg	Min	Max	Confidence Limit
Design - Construction	AC,%	0.2	0.0	0.3	0.2
	Gmm	0.011	0.000	0.020	0.013
	Gsb	0.010	0.001	0.033	0.019
	Passing 0.075 mm, %	0.7	0.1	1.3	0.7

Volumetric Properties Comparison

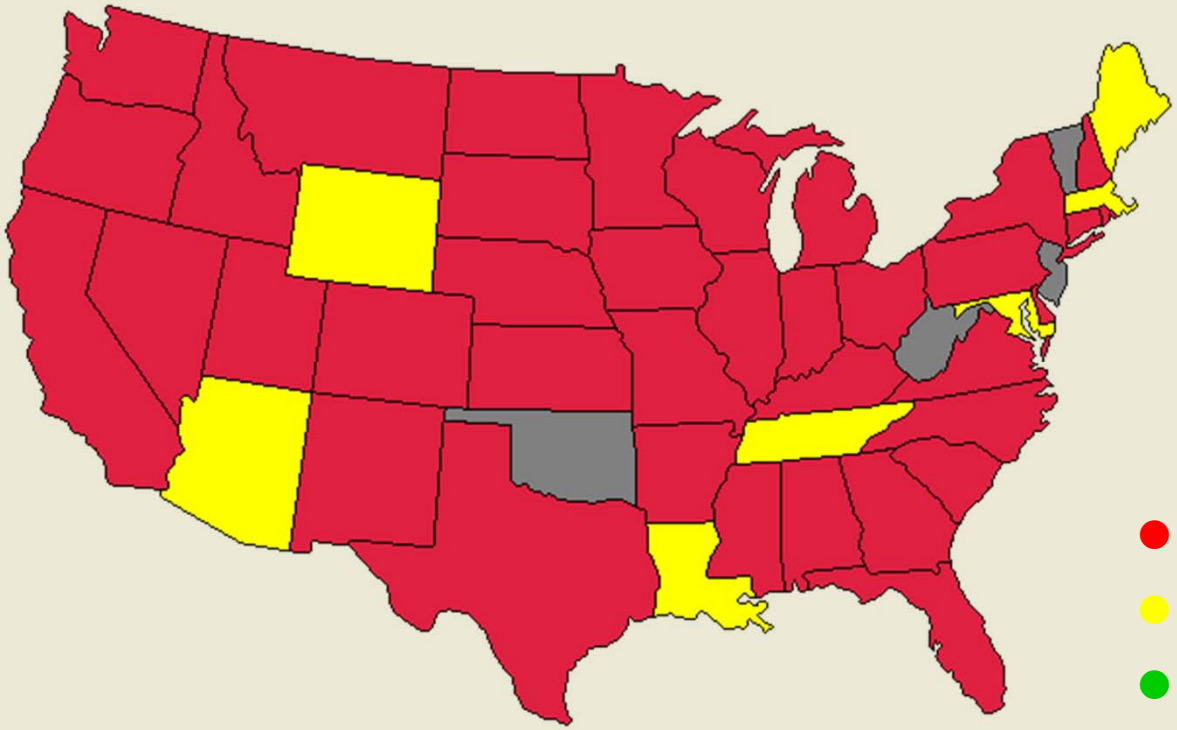
Tolerance Recommendation – Production vs Construction

Comparison	Property	Avg	Min	Max	Confidence Limit
Production - Construction	AC,%	0.1	0.0	0.4	0.2
	Gmm	0.009	0.001	0.027	0.018
	Gsb	0.008	0.000	0.031	0.017
	Passing 0.075 mm, %	0.5	0.1	0.8	0.5

Volumetric Properties Comparison

Tolerance Recommendation

- **Design vs Production: ± 0.2%**
- **Design vs Construction: ± 0.2%**
- **Production vs Construction: ± 0.2%**



- **Above Tolerance**
- **At Tolerance**
- **Below Tolerance**
- **Not Specified**

Summary

- Cause and magnitude of Δ in volumetric & mechanical properties within and b/w three specimen types
  - LL, PL, PF
- Eleven field project / mixture
  - Varying process-based factors
- Impacts of process-based factors
  - Volumetric and Mechanistic
    - None: PL vs PF
  - Volumetric
    - LL vs PL, and LL vs PF
  - Contractor Survey
    - Adjustment to account for the process-based factors
- Comparison of mechanistic properties of three specimen types
  - LWT (LL vs PF and PL to PF)
  - Axial E* (LL vs PL) -- >25C
  - IDT E* (LL vs PF) -- > >10C

Summary

- **Comparison of mechanistic properties of three specimen types**
  - **Recommended shift factors were developed**
  - **effects on pavement performance prediction**
  - **Use of LL or PL moduli in performance prediction would result in under-design of the pavement structure**
- **Comparison of volumetric properties of three specimen types**
  - **Tolerance Recommendation were developed**
  - **Comparison to existing State practice**
    - **Can be lowered**

What's next?

- **Task 4: Conduct of Experiment**
- **Task 5: Develop a Recommended Practice for Incorporating Variability Into Specifications**
- **Task 6: Prepare and Submit Final Report**


LSU
LOUISIANA STATE UNIVERSITY
Photo: Jim Zietz, Office of Public Affairs

THANK YOU