



# EFFECT OF RAP ON MIXTURE PROPERTIES

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## CONVENTIONAL WISDOM

- RAP contains old, hardened binder that will stiffen the mix
- This will help reduce rutting
- May increase cracking tendencies
- There is research and experience to support conventional wisdom



# POSSIBLE EFFECTS OF RAP BINDER



RAP aggregate  
with oxidized  
binder film



# POSSIBLE EFFECTS OF RAP BINDER



RAP aggregate  
with oxidized  
binder film  
plus virgin  
binder film



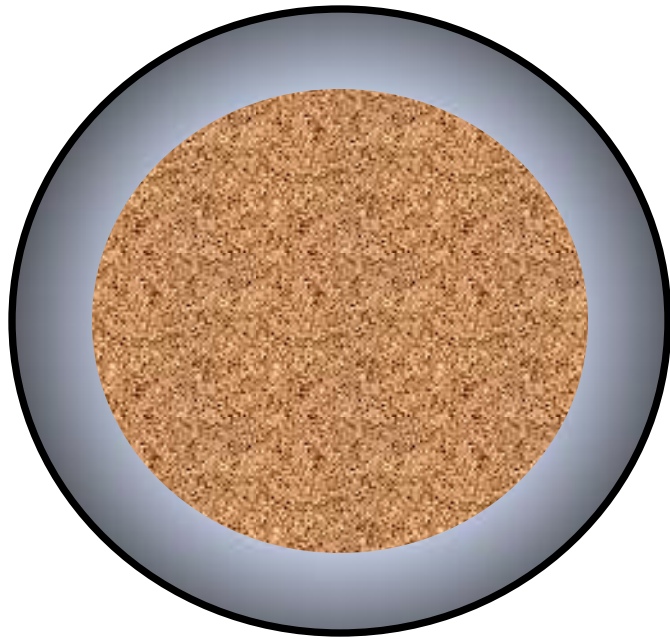
# POSSIBLE EFFECTS OF RAP BINDER



If RAP and virgin binders do not blend, effective binder properties will be those of the virgin binder only.



# POSSIBLE EFFECTS OF RAP BINDER



If RAP and virgin binders blend or merge, effective binder properties will be determined by the amount of blending that occurs.



# IMPACTS OF BLENDING ON PERFORMANCE

- If we assume there is blending and there isn't, virgin binder grade may be softer than desired.
  - Increased chance for rutting
  - Decreased chance for cracking
- If we assume there is no blending and there is, effective binder grade may be stiffer than desired.
  - Decreased chance for rutting



# RISKS OF FALSE ASSUMPTIONS

- Assuming there is blending may be more conservative.
  - Shouldn't rely on binder to control rutting
  - Increased cracking can have performance and economic impacts
- Current guidelines are a starting point, but not the definitive answer





# CURRENT AASHTO TIERS

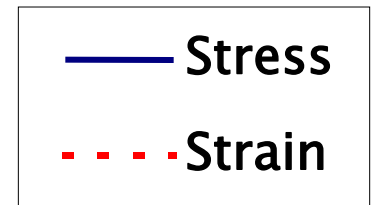
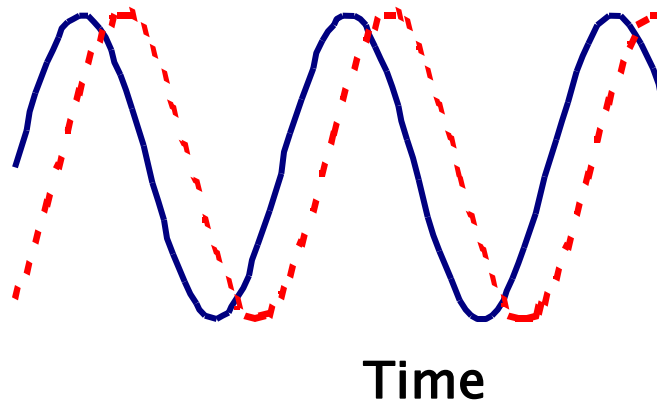
- Up to 15% RAP, no change in binder grade.
- 16–25% RAP, lower binder grade by one increment.
- More than 25%, create blending charts.
  - Assumes linear blending
  - Extract, recover and test RAP binder
  - High, low and intermediate temperatures

# AGGREGATE EFFECTS ON MIX

- RAP Aggregate also has an effect, of course
- Fineness of some RAPs can limit use
- Fractionating can help
- RAP aggregate should meet virgin shape requirements
- RAP aggregate effects on friction?
- *Mixes with and without RAP should be held to same standards.*



# DYNAMIC MODULUS TEST

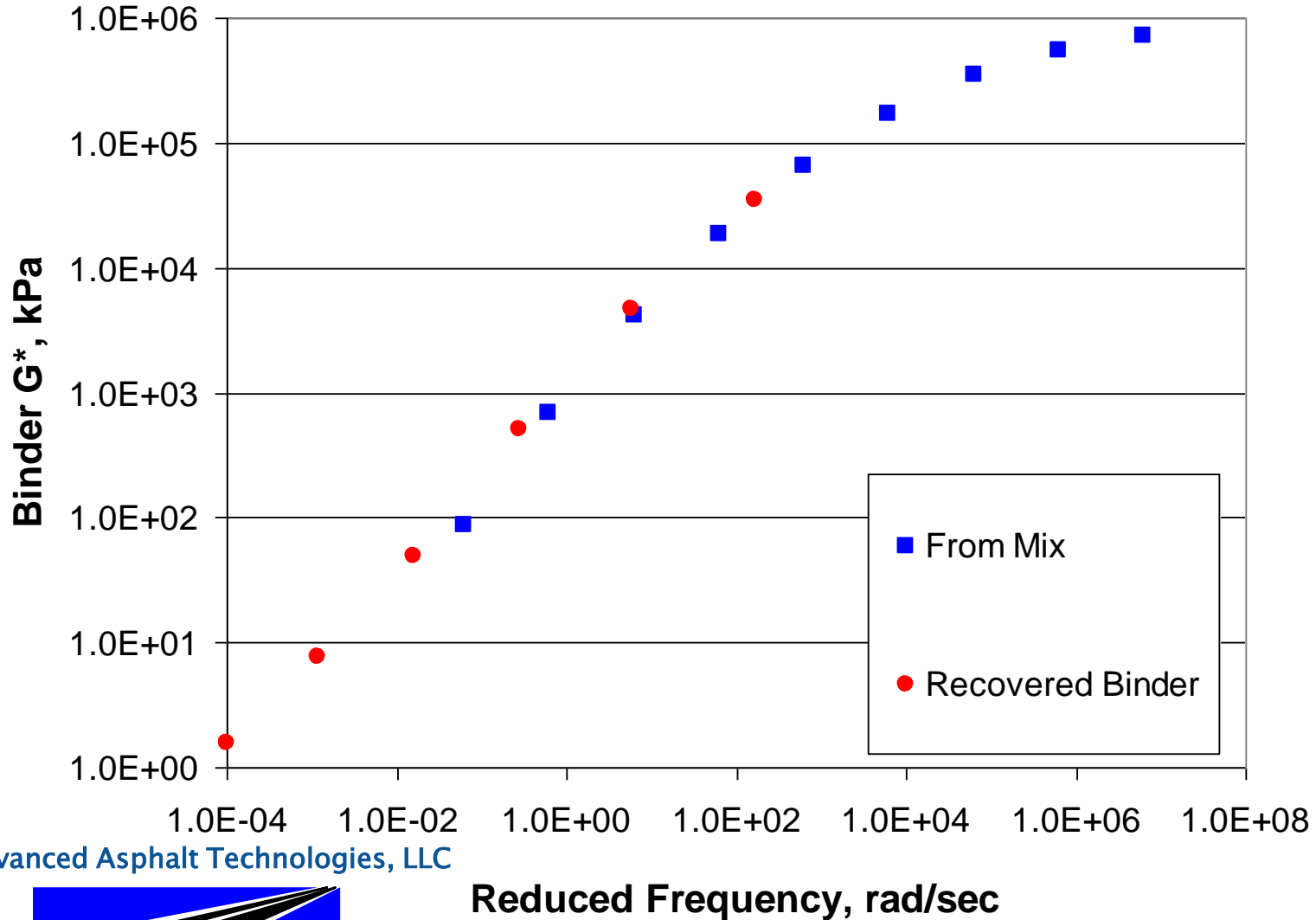


$$|E^*| = \frac{\sigma_0}{\epsilon_0}$$

- Rutting
- Fatigue Cracking



# 9.5 MM WITH PG 64-22, BATCH PLANT



Advanced Asphalt Technologies, LLC

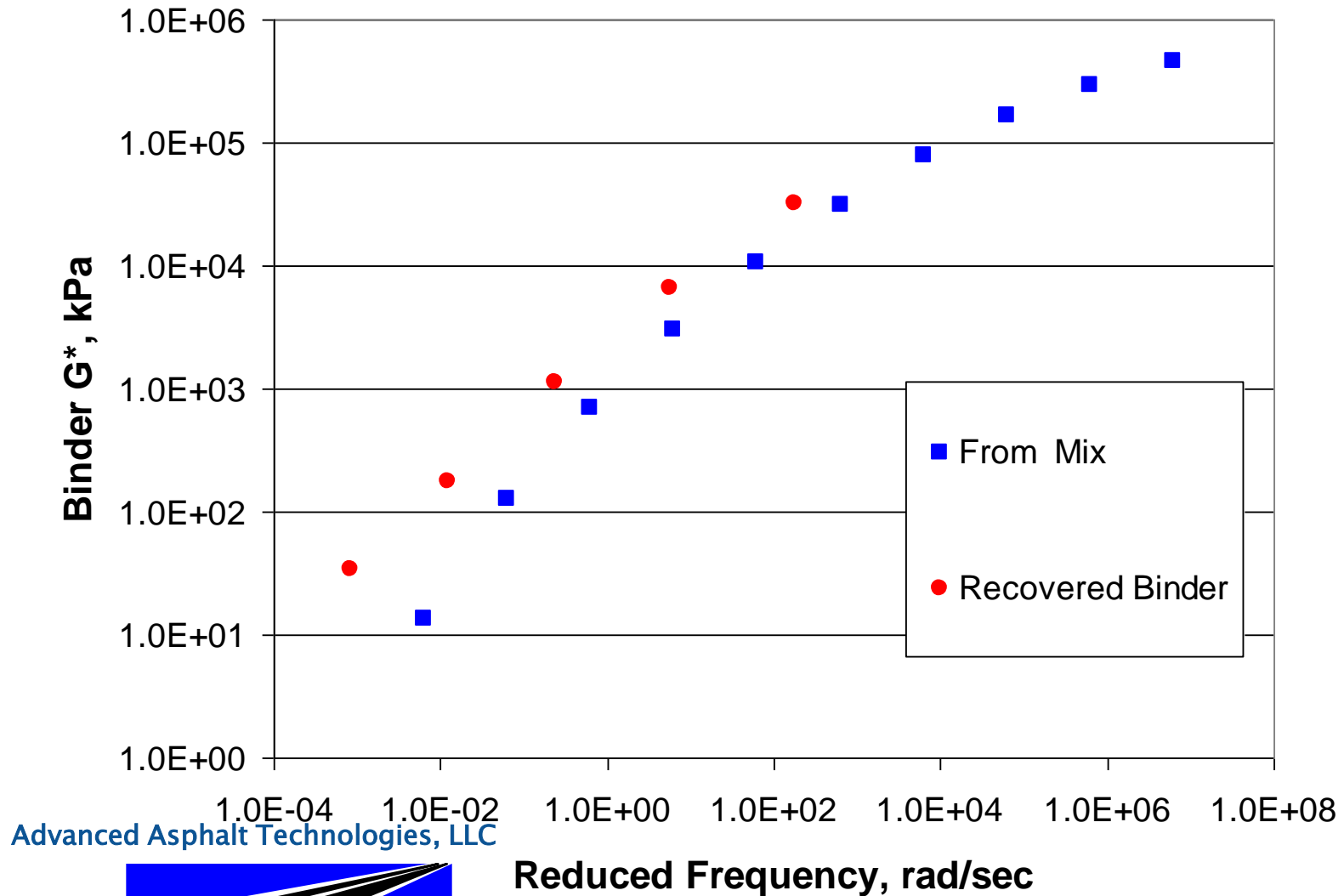


Reduced Frequency, rad/sec



*"Engineering Services for the Asphalt Industry"*

# 9.5 MM WITH PG 64-22 + 5% RAS, BATCH PLANT



Advanced Asphalt Technologies, LLC

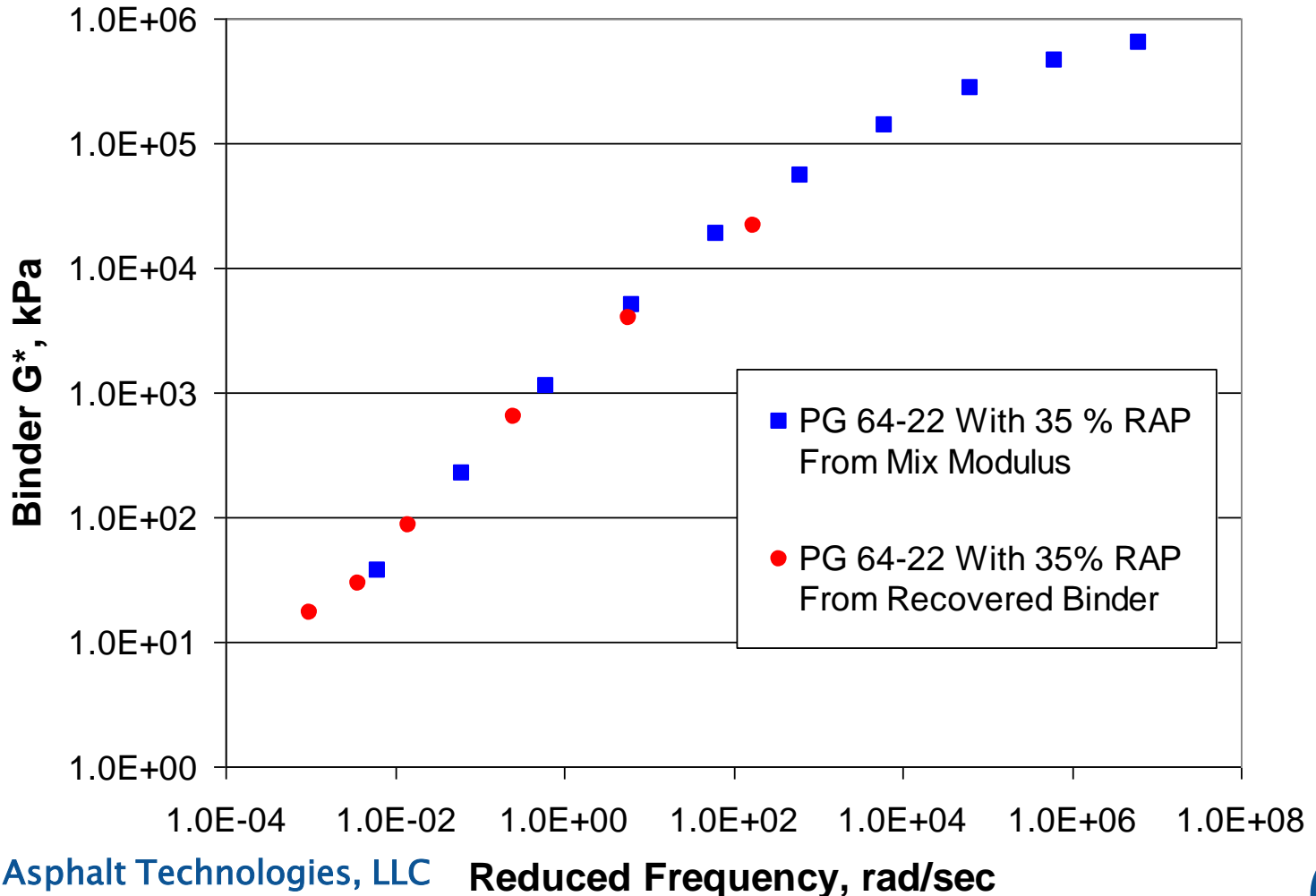


*"Engineering Services for the Asphalt Industry"*

Reduced Frequency, rad/sec



# 9.5 MM WITH PG 64-22 + 35 % FRAP, DOUBLE BARREL



Advanced Asphalt Technologies, LLC

Reduced Frequency, rad/sec



*"Engineering Services for the Asphalt Industry"*



# BONAQUIST APPROACH

- Advantage – allows assessment of production variables
  - RAP processing
  - Production rates and temperatures
  - Additives
  - Storage time, etc.
- More information *Hot Mix Asphalt Technology*, September/October 2007.



# NCSC STUDY

## *Low-Temperature Performance Properties of Hot Mix Asphalt Containing RAP, Phase 2*

- 2006 -- Evaluated plant-produced mixes with up to 40% RAP and two virgin binder grades
- Results suggested 25% RAP did not need grade change
- 2007 -- Expanded - four more contractors
- FHWA funded





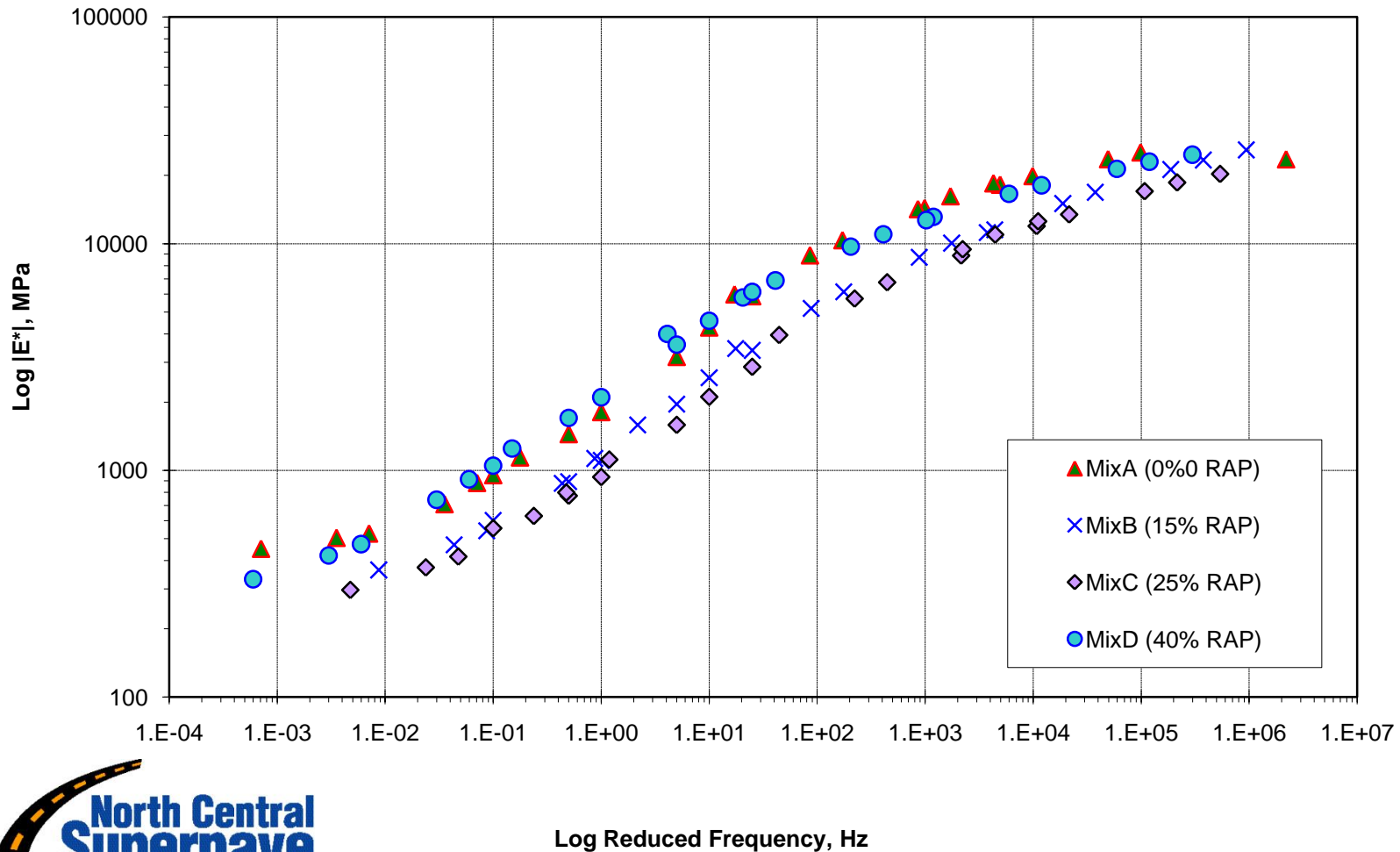
# EXPERIMENTAL DESIGN

Reclaimed Asphalt Pavement				
Binder Grade	0%	15%	25%	40%
PG 58-28			X	X
PG 64-22	X	X	<b>X</b>	X

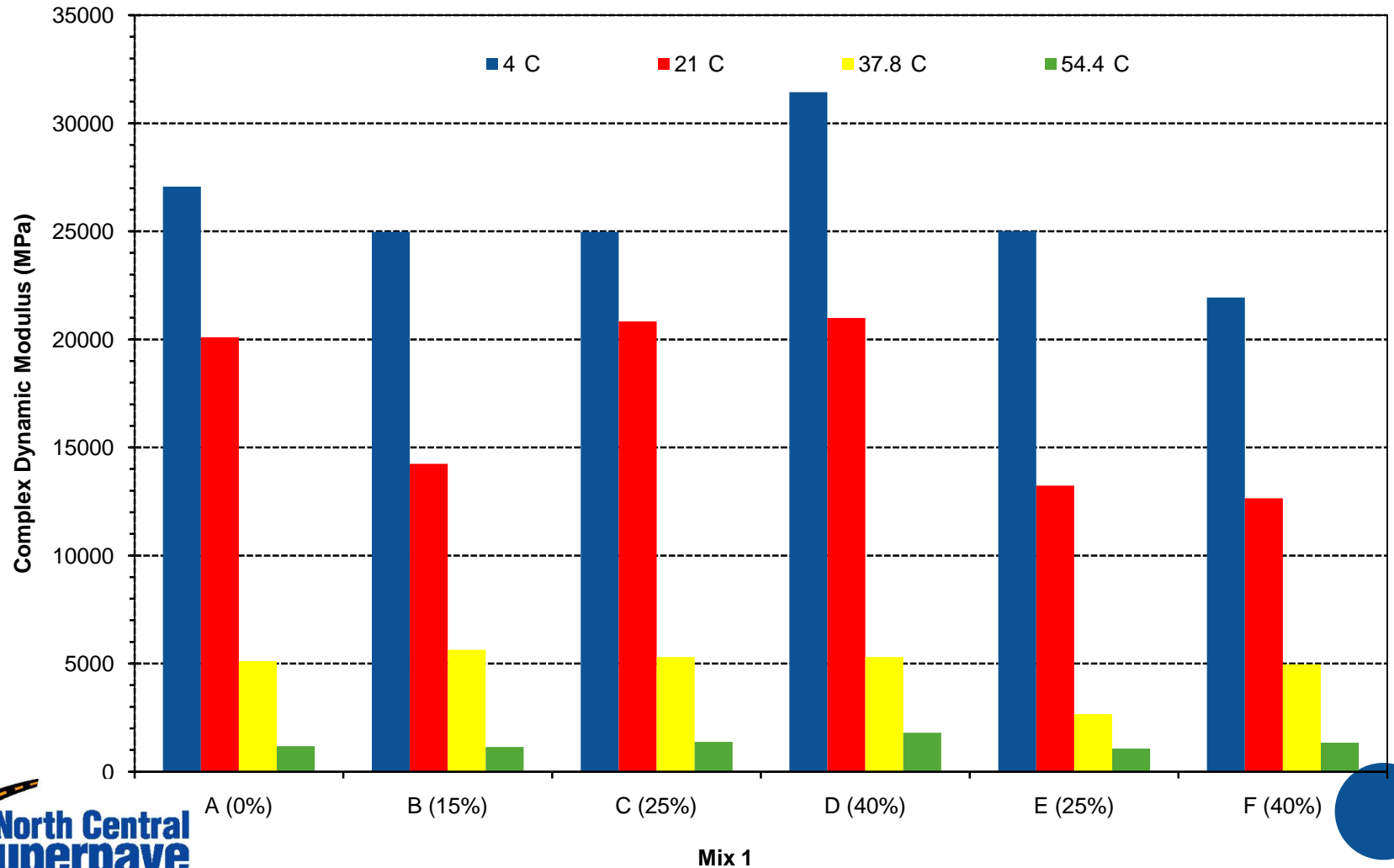


# COMPARISON OF RAP CONTENTS

PG64-22

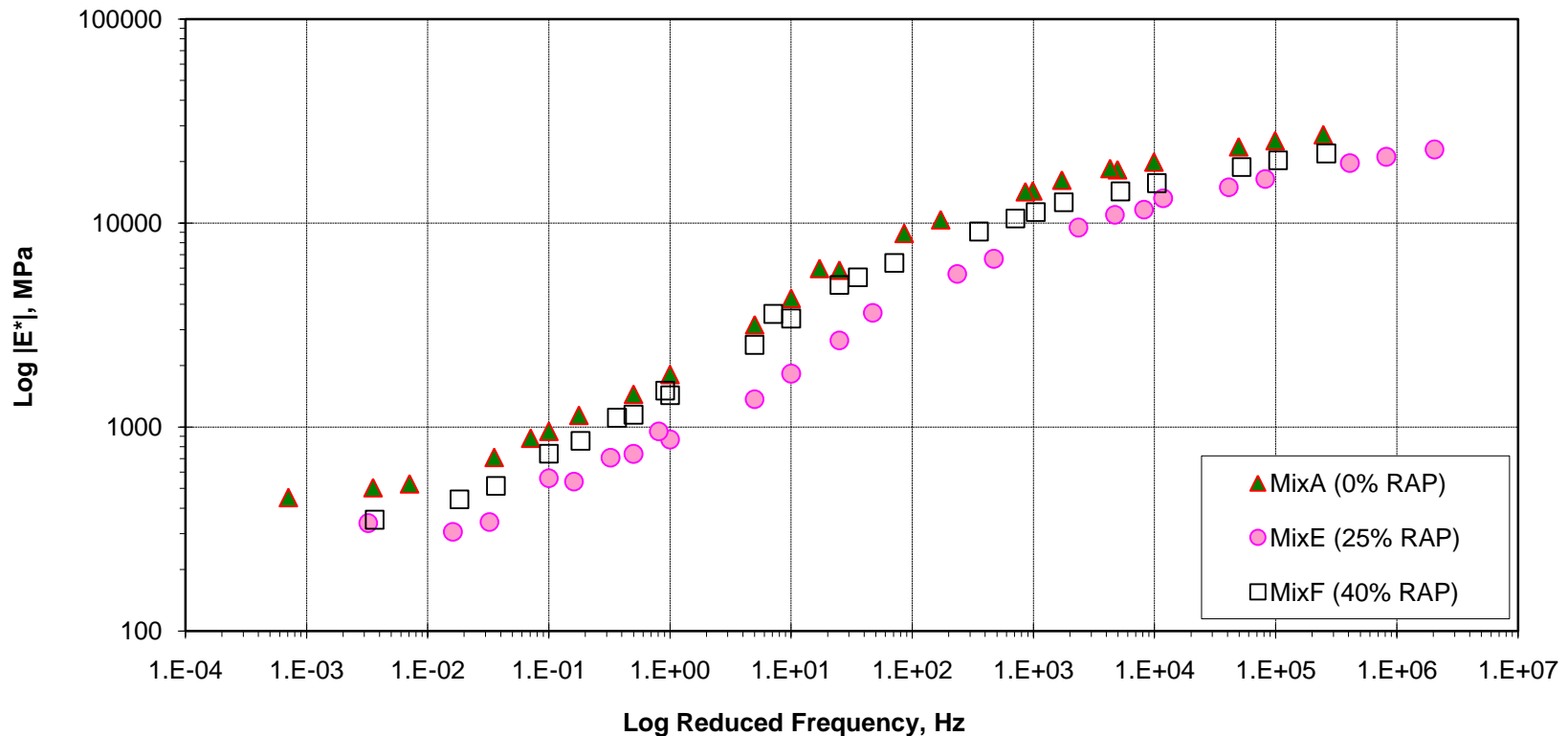


# DRAFT, UNFILTERED DATA, MIX 1



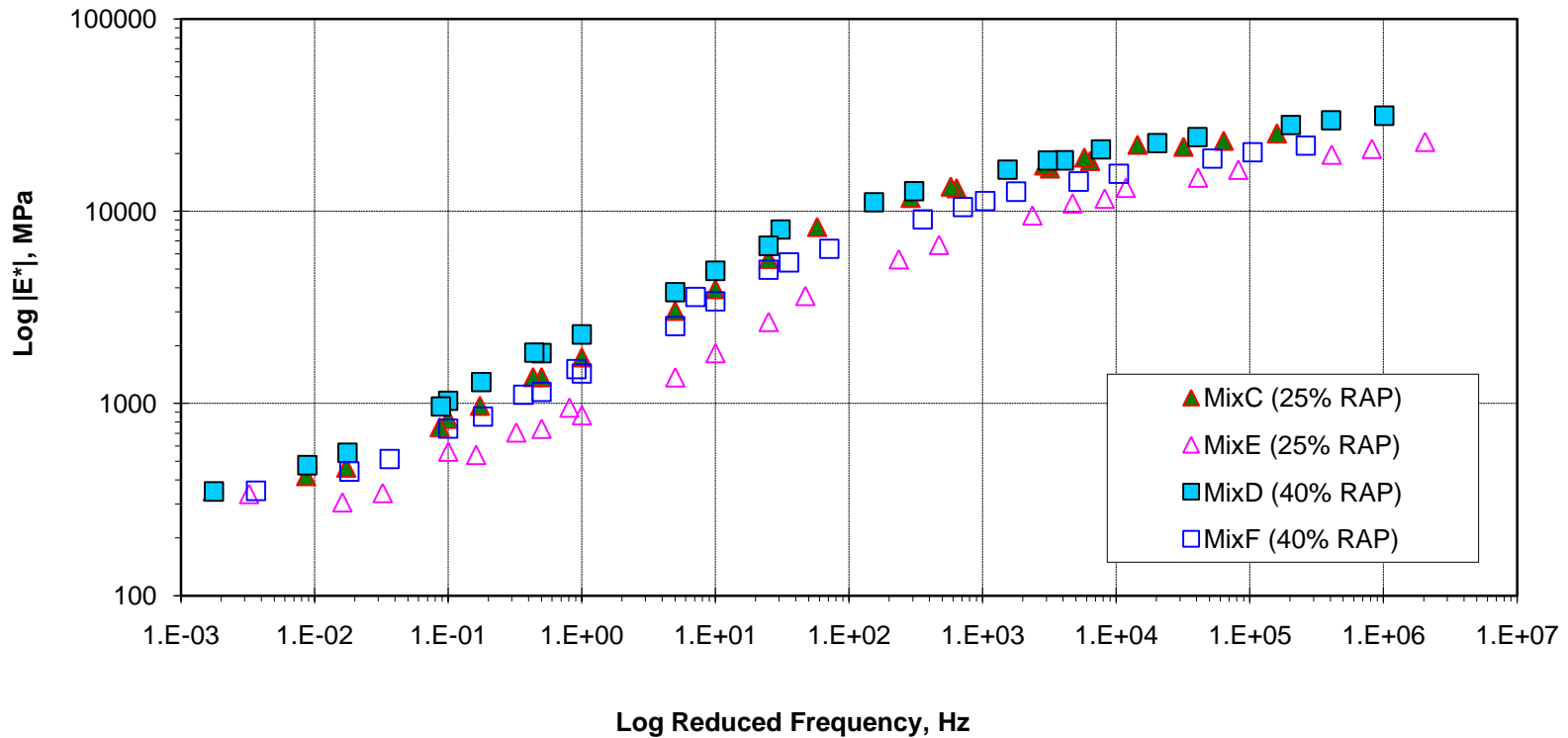
# ONE EXAMPLE – MIX |E\*|

Control versus PG58-28

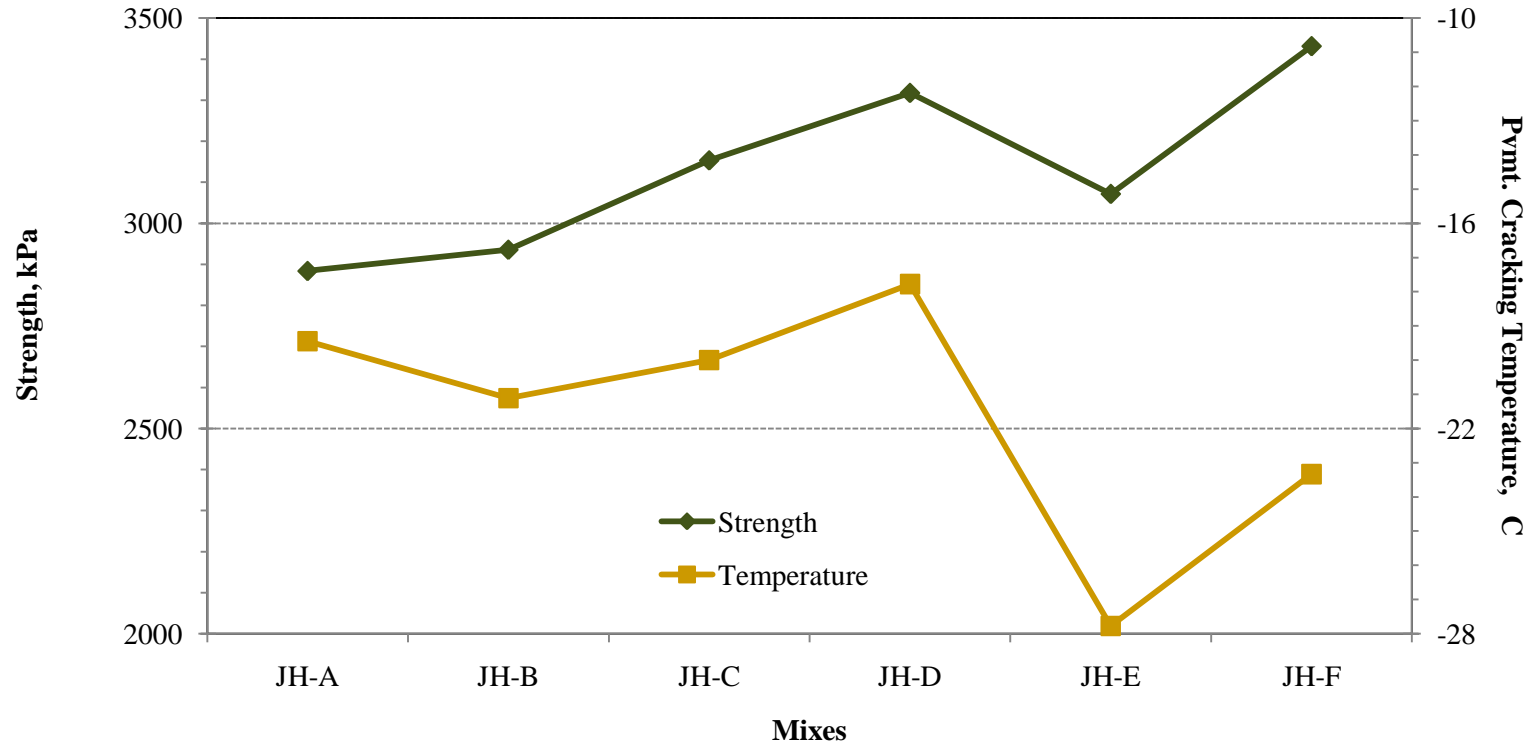


# ONE EXAMPLE – MIX |E\*|

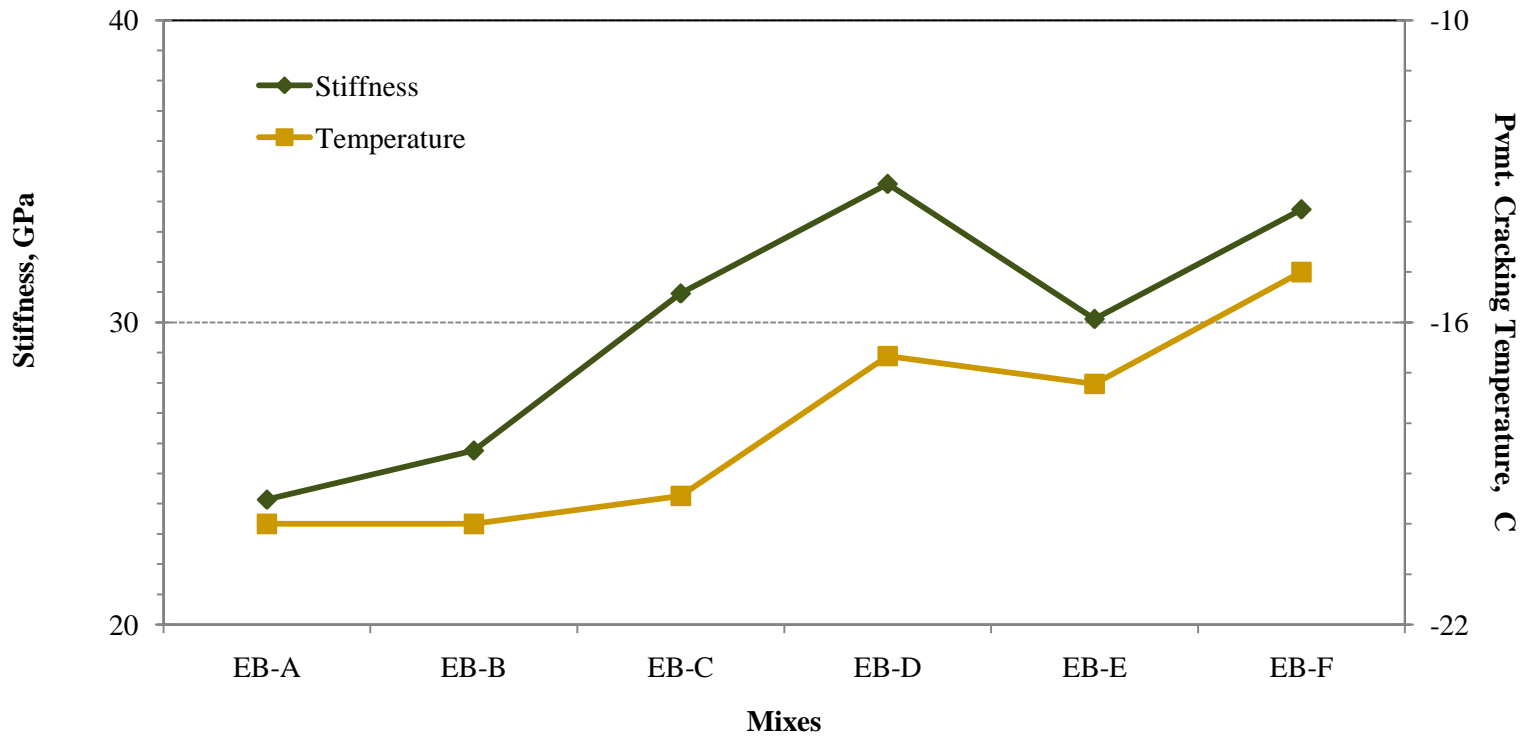
PG64-22 versus PG58-28



# IDT STRENGTH EXAMPLE 1



# IDT STIFFNESS EXAMPLE 2



# BASED ON THIS RESEARCH

- And testing RAP sources from across the state
- INDOT increased RAP contents to:
  - 25% with no change in grade
  - 40% with a grade change
- Spec change has been adopted



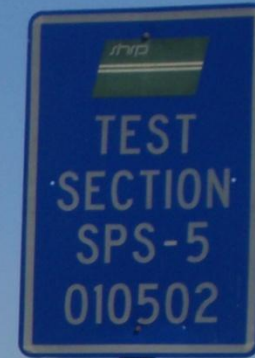


A decorative vertical bar on the left side of the slide, consisting of several thin, light blue vertical lines of varying thicknesses. To the right of these lines are several solid blue circles of different sizes, arranged in a cluster that tapers towards the bottom.

**BUT THAT IS JUST LAB DATA**

**How do these mixes  
perform in the real world?**

# Performance Studies of Asphalt Pavements with Greater than 25% RAP



Randy C. West, NCAT  
October 7, 2009



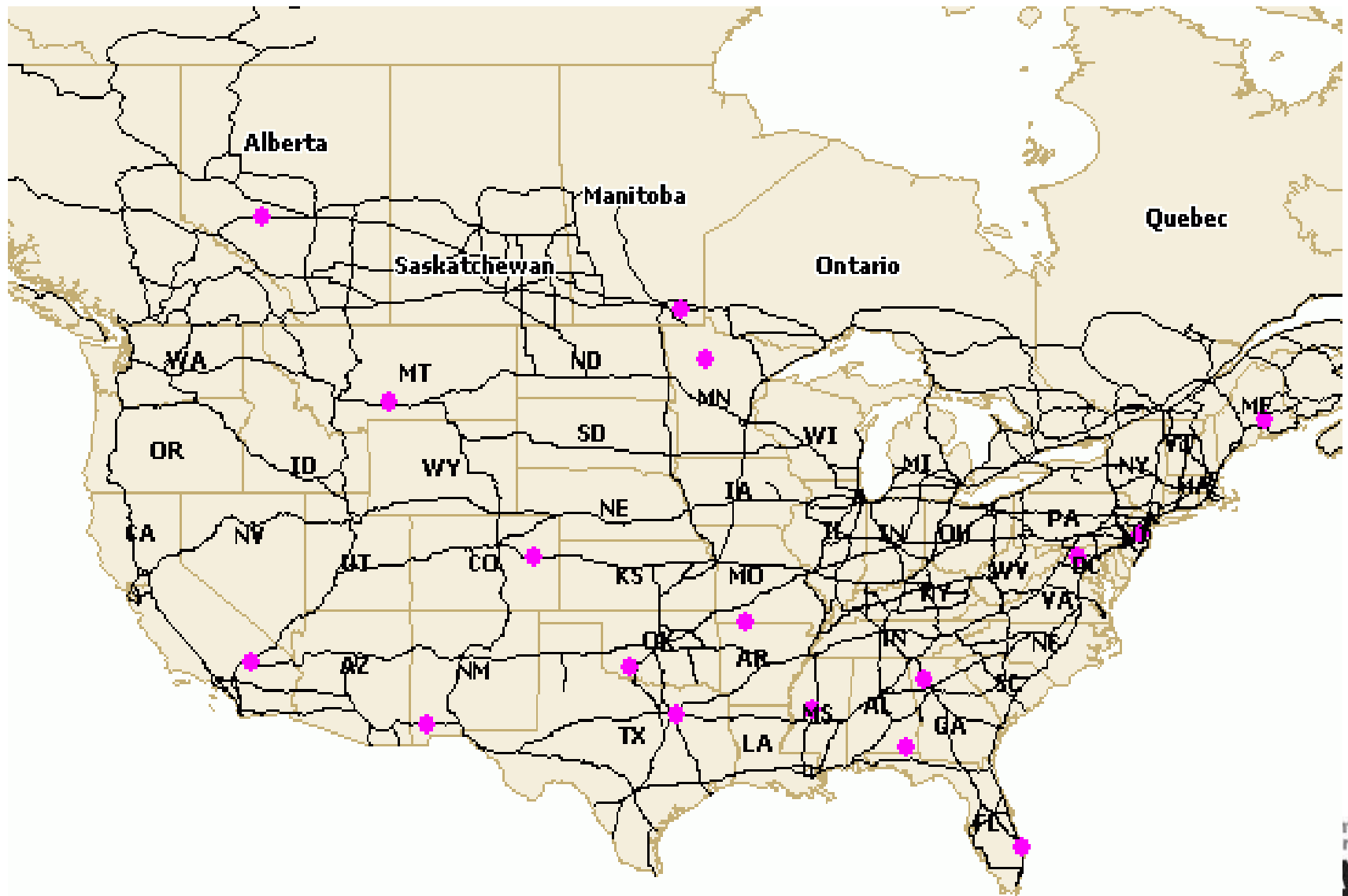
# A Performance Comparison of RAP vs. Virgin Mixes

- 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 and no mill
  - 5" overlay, no mill and no mill
- Five performance measurements (annual)
  - Rutting, mm
  - IRI, m/km
  - Fatigue cracking, m<sup>2</sup>
  - Transverse cracking, # per section
  - Longitudinal cracking, m
- 340 comparisons: graphed, tabulated differences, statistical analyses

# SPS-5 Project Locations



# General Performance

## Percentage of Sections Below General Pavement Performance Thresholds

Distress Parameter	Threshold	RAP Sections	Virgin Sections
IRI	2.0 m/km	86%	89%
Rutting	10 mm	71%	78%
Fatigue Cracking	25% of WP area	60%	72%
Longtnl. Cracking	25% of section length	79%	86%
Transverse Cracking	20 cracks per section	47%	64%
Block Cracking	10% of section area	89%	94%
Raveling	10% of section area	75%	69%

# Summary of Statistical Analyses

Distress Parameter	Virgin Performed Better than RAP	RAP Performed Better than Virgin	Insignificant Difference Between RAP and Virgin	RAP Performed Equal to or Better Than Virgin
IRI	42	39	19	58
Rutting	33	29	38	67
Fatigue Cracking	29	> 10	61	71
Longtnl. Cracking	15	10	75	85
Transverse Cracking	32	> 15	53	68
Block Cracking	3	1	96	97
Raveling	7	15	78	93

# Possible Causes of Higher Occurrence of Fatigue Cracking in RAP Mixes

- Lower effective binder content
- Binder is more brittle
- Lower in-place density
- Higher dust contents



# Possible Causes of More Fatigue Cracking in RAP Sections

State/Province	# Pairs: Rec.>Vir.	Softer Vir. Binder in Rec. Mix?	Asphalt Content		P200	
			Vir.	Rec.	Vir.	Rec.
Alabama	2	Y	4.8	5.0	4.0	√ 5.1
California	2	N	5.3	√ 3.8	4.3	√ 6.2
Mississippi	3	N	5.9	5.7	5	5
Montana	4	Y	4.8	√ 3.7	5	√ 7.8
New Jersey	2	Y	4.8	4.8	n.a.	n.a.
Alberta	4	Y	5.4	5.4	8.6	√ 10.5
Manitoba	2	N	5.9	5.9	5	√ 6

# CONCLUSIONS

Based on the long-term performance of a large number of projects across North America...

- Pavements using  $\geq 30\%$  RAP perform equal or better than virgin pavements in most cases
- Transverse and fatigue cracking were observed more often in some pavements with RAP compared to pavements with all virgin materials
- Differences in cracking performance for several locations may have been due to lower asphalt contents and/or higher dust contents

## OTHER WORK

- NCHRP 9-46, *Improved Mix Design, Evaluation and Materials Management of High RAP Content HMA (NCAT)* – completion 2010
- FHWA Funded, *Development of High RAP Content Mix Guidelines and Informational Documents* (NCAT/ NCSC/ UNH) – completion 2010
- FHWA HMA Recycling ETG – ongoing
- Other state studies ongoing
- All will offer more guidance.



# HIGHER RAP CONTENTS

- Can work – can *perform* – if properly designed, produced and constructed
- **But**, need attention to detail
- Some precautions are needed
  - Many of these are the same as for aggregate best practices



# SOME KEYS TO SUCCESS

- Processing the RAP
- Stockpiling the RAP
- Control during production





***In GOK Pile***

***After  
Processing***



# PROCESSING RAP

- Mixed RAP can be variable
  - Crushing/Screening to break up clumps
  - Processing can improve uniformity
  - Uniformity essential to meet specifications



# FRACTIONATING RAP

- Can improve uniformity (remixes)
- Allows use of different sizes to meet mix volumetrics
- Allows better control of gradation (and binder content)





# STOCKPILING PRACTICES

- Avoid segregation
- Avoid contamination
- Reduce stockpile moisture



# REDUCE STOCKPILE MOISTURE

- Reduce fuel consumption and drying costs by keeping your materials dry
- Lower moisture leads to increased production capacity
- Lower maintenance and fuel costs for loaders
- Lower paving costs



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