Effects of Reclaimed Asphalt Pavement Content and Virgin Binder Grade on Properties of Plant Produced Mixtures

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Growing Interest in RAP Use

- Economic and environmental benefits.
- Higher RAP contents in more mixtures.
- More fractionating.

Conventional Wisdom

- RAP will stiffen mix.
- More RAP will stiffen mix more.
- Improves rut resistance at high temperatures.
- May reduce fatigue resistance.
- May worsen thermal cracking.
- Need soft virgin binder to compensate.

Current US (AASHTO) Guidelines

- Account for RAP binder
  - 0 to 15% RAP, no binder grade change
  - 16-25% RAP, decrease virgin binder grade
  - Over 25% RAP, test RAP binder to determine virgin grade (or allowable RAP content)
- Based on
  - Mixture testing
  - Percentage by weight of RAP in the mixture
  - Non-fractionated mixes
  - 5% binder in RAP and new mix
- Many states have modified these.

Questions

- At what RAP content do you need to change grades?
- Effect of RAP on low temperature cracking? High temperature stiffness? Intermediate fatigue?
- Are things different when plant mixes are tested?

Approach

- Evaluated 5 sets of plant-produced mixes
  - 4 from Indiana, 1 from Michigan
- Compared
  - Dynamic modulus
  - Low temperature properties and cracking
  - Fatigue (TFHRC) (not presented today)
  - Extracted/recovered and virgin binders

Five Contractors

	RAP Content*			
Binder Grade	**0%**	**15%**	**25%**	**40%**
PG 64-22	**X**	**X**	**X**	**X**
PG 58-28			**X**	**X**

*By mass of mix

Mix Designs

- Contractors designed 9.5 mm mixes
  - Two coarse, three fine
- Full mix design on one mixture
- Adjust for changes in RAP content
- Keep gradations consistent while using existing stockpiles
  - Generally within 3% on any sieve
- Typically one point verification
  - Substantial spec compliance

Mix Production

- Routine processing and production
- RAP crushed and screened
  - Four used 12.5 mm screen
  - One used 15.9 mm (5/8 in.) screen
- Plant types – parallel and counter-flow drums, double drum, and aggregate dryer with separate mixing drum
- Sampled from one truck at plant – loose mix and gyratory samples

Mix Volumetrics

- Variations in mixes did occur
  - NCSC results → apparent low air voids
  - Low VMA for one set and one other mix
  - Binder contents almost all within ±0.3%
- Most within tolerances for single sample
- 3 contractors' QC results
  - Higher G_{mm} → higher air voids and VMA
  - Samples reheated and no dryback at NCSC

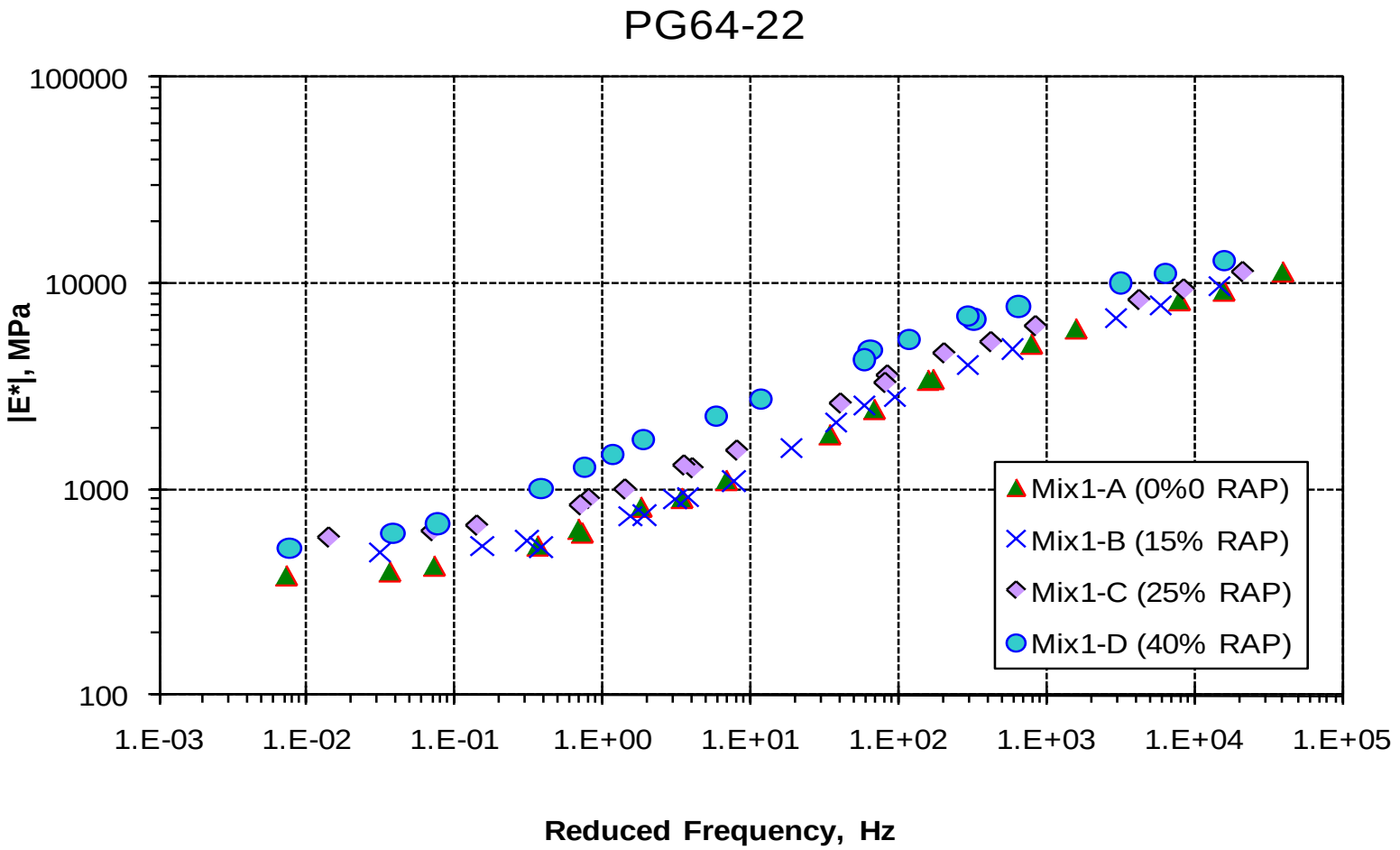
Binder Testing

- Virgin binders met specified grades
- Recovered RAP binders graded at 80 to 89°C and -9 to -20°C
- Compared to virgin binder true grade, binders recovered from mixes showed:
  - High temp grades increased ~8°C for PG64-22 and 12°C for PG58-28
    - Virgin mix was ~7°C higher
  - Low temp grades ~4°C warmer than PG64-22 and ~5°C for PG58-28
  - Increasing RAP from 0 to 25% with no grade change increased LT grade ~2°C

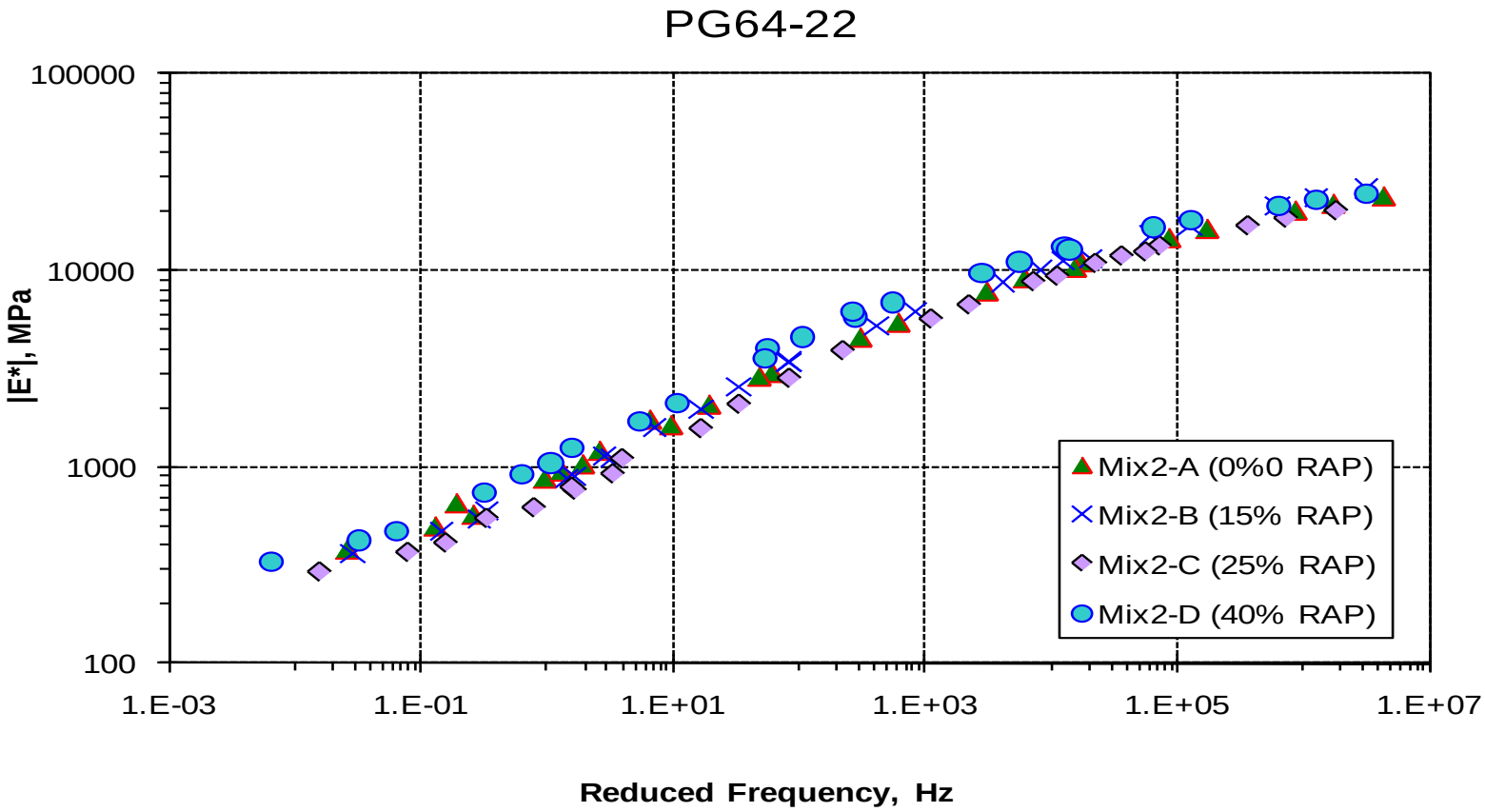
Dynamic Modulus – PG64-22

- In general, as RAP content increased, mix modulus, |E*|, did increase
- But, in most cases, modulus was not substantially greater than control for up to 25% RAP
- 40% RAP mixes tended to be stiffer than or comparable to control

One Example – Mix |E*|



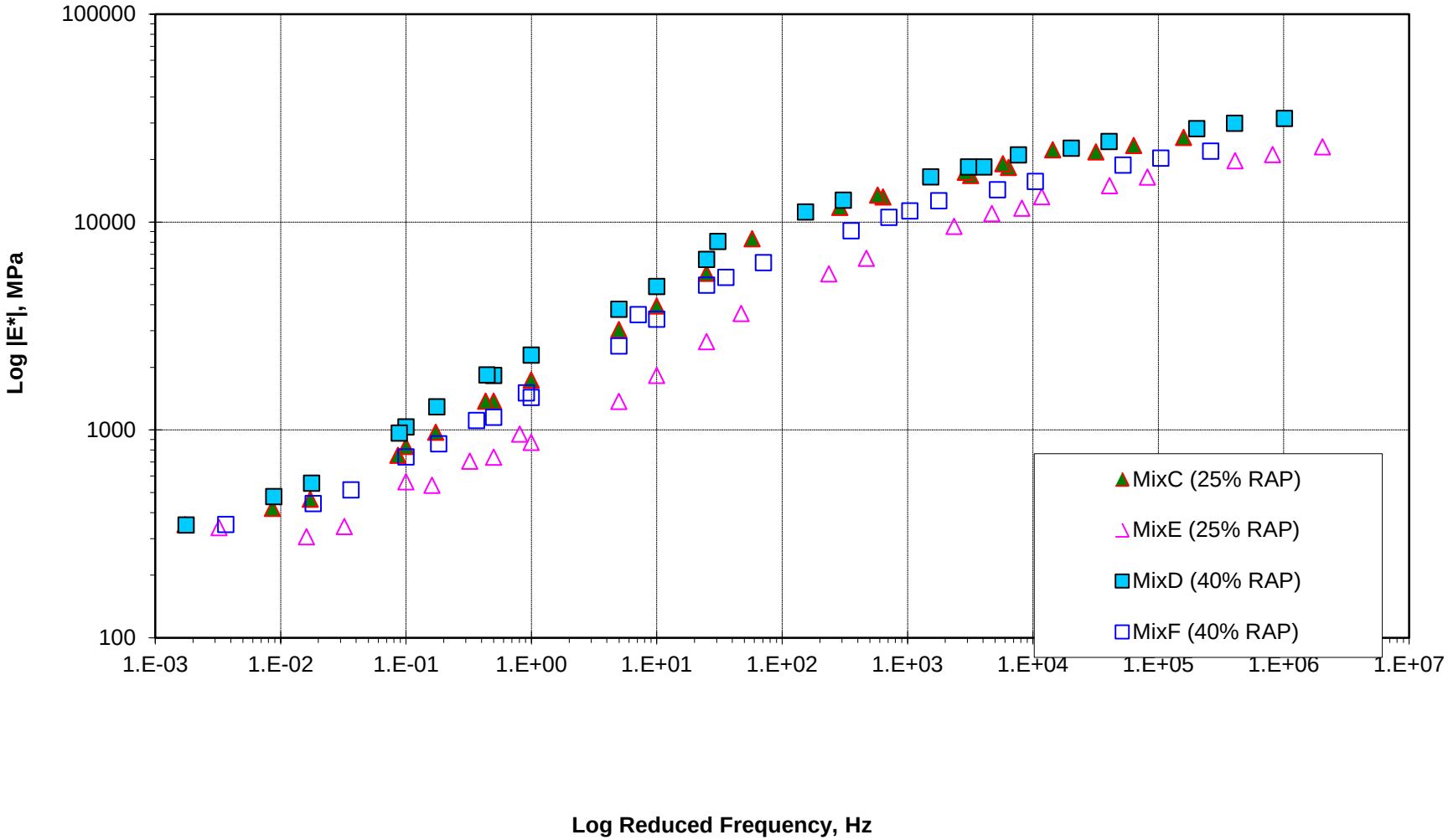
Another Example – Mix |E*|



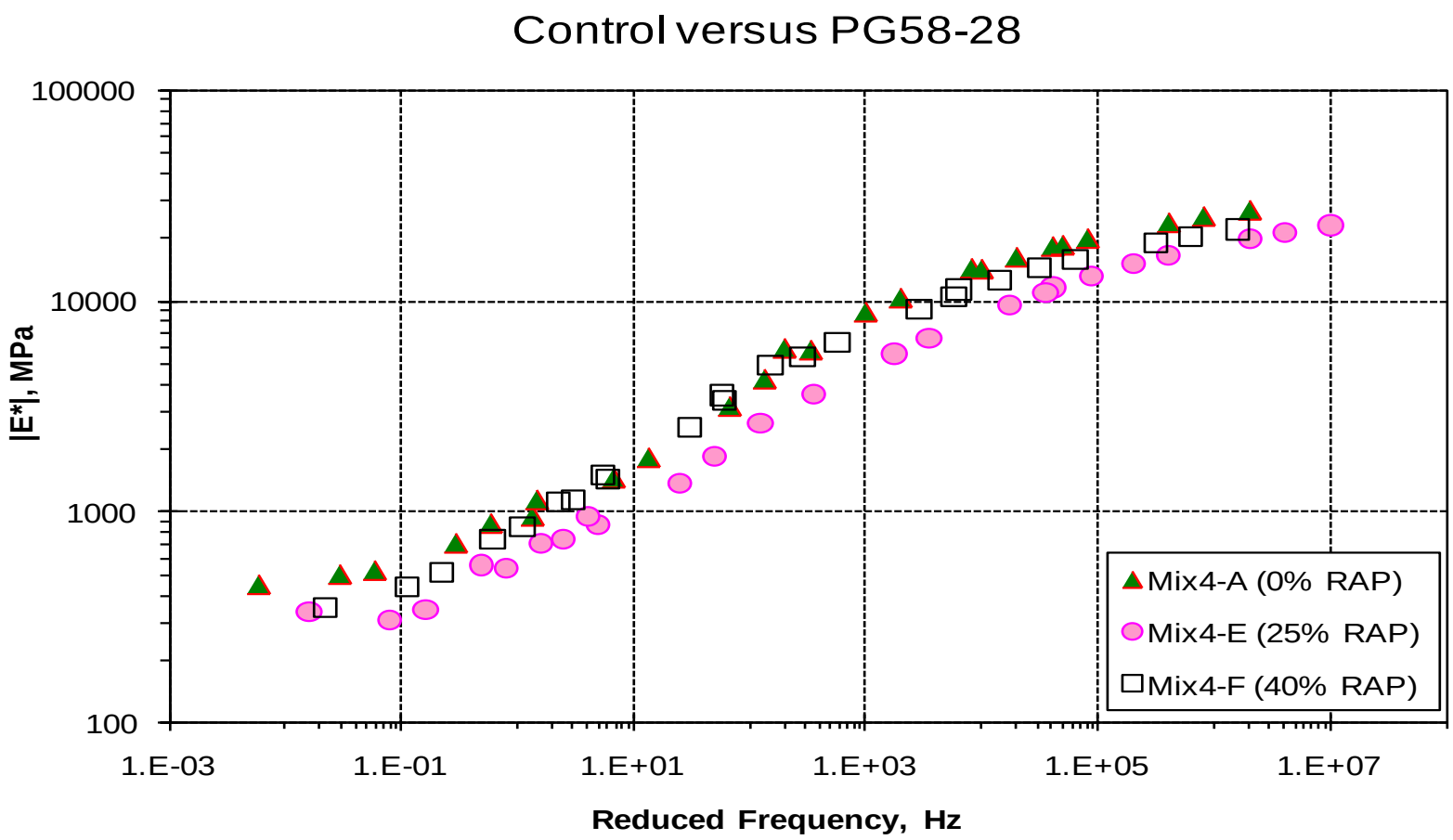
Modulus with PG58-28

- Use of PG58-28 generally reduced mix modulus compared to PG64-22
- Mixes with 40% RAP were usually much stiffer than with 25% RAP
- In some cases, mix with 25% RAP and PG58-28 was much less stiff than control

EXAMPLE – PG64-22 VS PG58-28



EXAMPLE – CONTROL VS PG58-28



Statistical Analysis

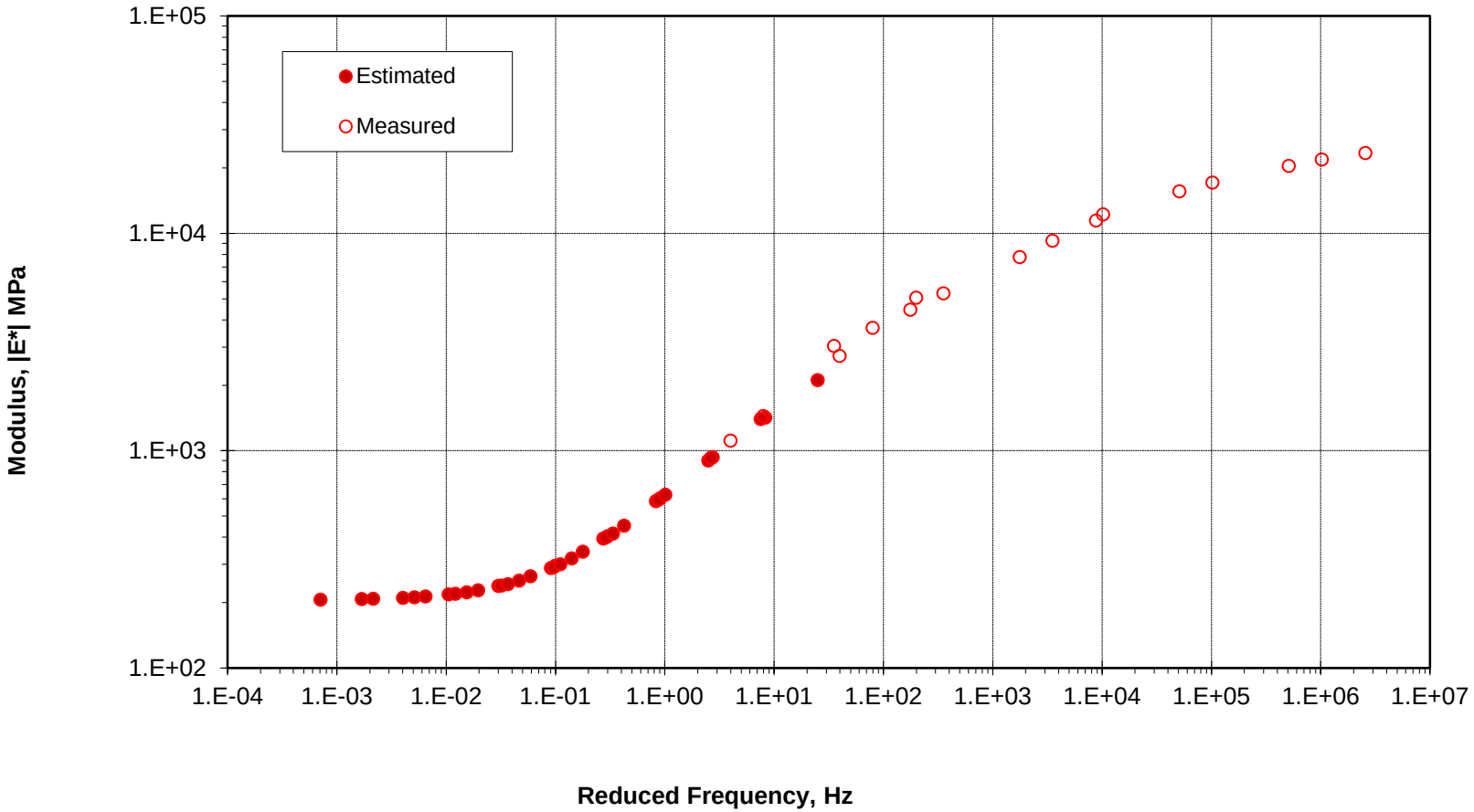
ANOVA and comparison of means test at different temperatures (4 to 54.4°C) showed:

- Mixes with PG64-22 either
  - not significantly different OR
  - 40% RAP mix was different from the others
- Mixes with PG58-28 were sometimes different from each other

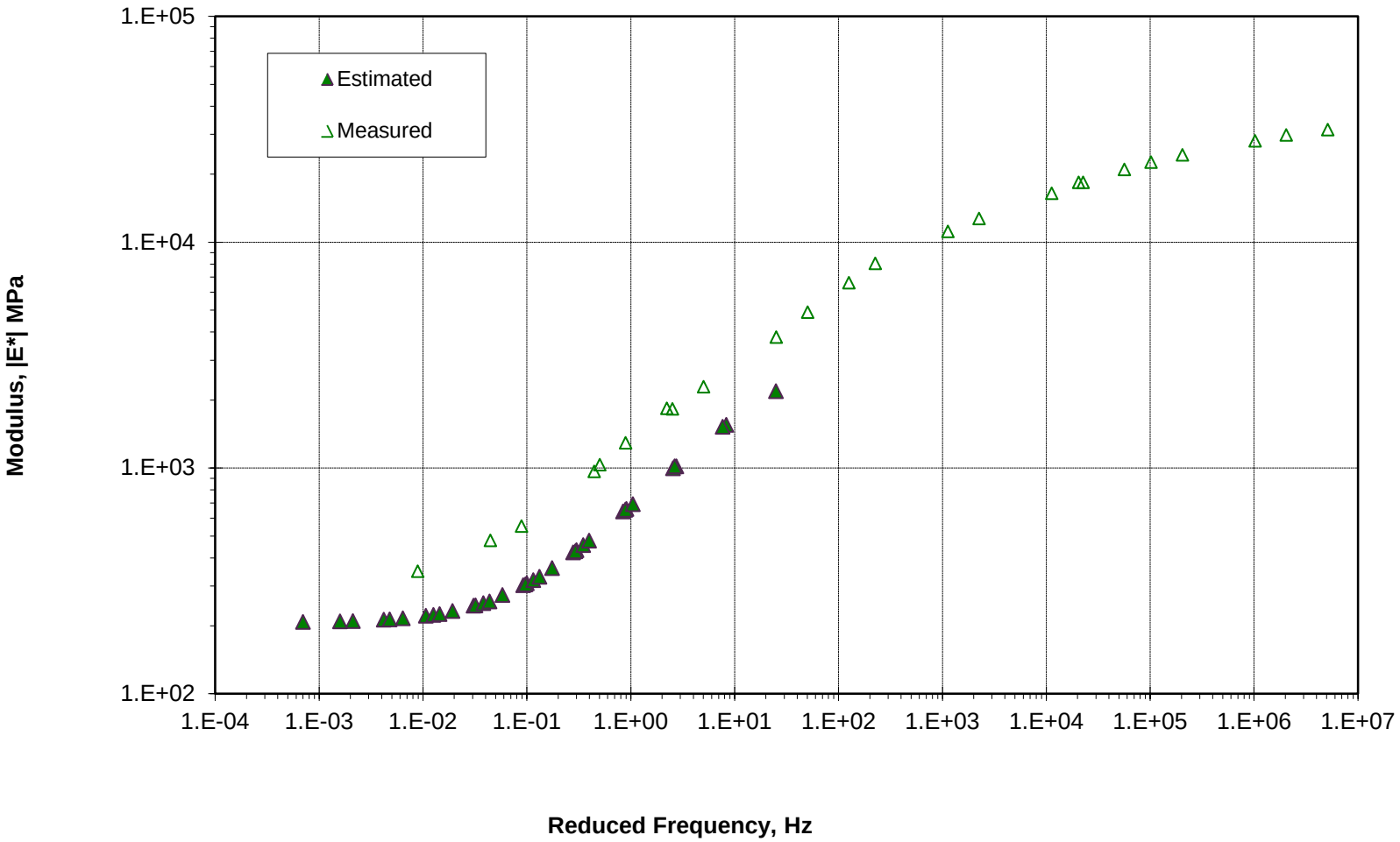
Bonaquist Analysis

- Compare measured mix modulus to estimated modulus
  - Hirsch model using recovered binder (blended) and mix volumetrics
- Suggests how the combination of binders is behaving in the mix
  - Does the mix act as if the binders mixed or not?

Thorough Mixing



Poor Mixing


1.E+05
1.E+04
1.E+03
1.E+02
Estimated
Measured
Modulus, |E*| MPa
1.E-04
1.E-03
1.E-02
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Reduced Frequency, Hz

Summary of Mixing

	Mix A	Mix B	Mix C	Mix D	Mix E	Mix F
RAP %	0	15	25	40	25	40
PG	64-22	64-22	64-22	64-22	58-28	58-28
Contractor 2	Good	Good	Good	Poor	Good	Good
Contractor 3	Good	Partial	Good	Good	Good	Good
Contractor 4	Good	Good	Poor	Poor	Good	Good
Contractor 5	Good	Good	Good	Good	Good	Good

Low Temperature Mix Tests

- IDT Creep Compliance and Strength
  - Calculated critical cracking temperature, T_c
- With PG64-22
  - 15 to 25% RAP changed T_c by ~2°C (warmer)
  - 40% RAP changed T_c by ~4°C
- With PG58-28
  - 25% RAP was comparable to control
  - 40% RAP mix was ~1°C warmer than control

Critical Cracking Temperatures

- Assume -22 needed to resist thermal cracking
- 12 of 29 mixes had T_c warmer than -22 ("failed")
- 3 of 5 virgin mixes "failed"
- Same for PG64-22 with 15 and 25% RAP
- With PG58-28, 1 of 5 "failed" at both RAP contents
- So, softer binder did improve failure rate but PG64-22 + RAP mixes performed comparably to virgin mixes

Observations and Conclusions

Recovered Asphalt Binder

- As RAP increased, high temp grade increased 1 to 3°C
- Low temp grade increased 1 to 2°C
- Both increased, but less than expected
- PG58-28 decreased high and low grades about half a grade (3°C)

Observations and Conclusions

Mixture Stiffness

- As RAP increased, E* increased, especially at intermediate and high temps
  - Not in all cases
- No significant difference for mixes with PG64-22 and 0 to 25% RAP
  - Significant difference for some at 40%
- PG58-28 typically did reduce mix stiffness
  - Usually significant difference between 25 and 40% RAP

Observations and Conclusions

Low Temperature Properties

- T_c increased 1°C for PG64-22 with up to 25% RAP
- T_c increased 4°C for PG64-22 with 40% RAP compared to virgin mix
  - T_c ~ -19 to -22°C – OK for the area
- T_c with PG58-28 only 1 to 3°C lower than with PG64-22

Observations and Conclusions

- Findings suggest no grade change needed for RAP contents $\leq$25%
- Binder grade should be one grade softer for 40% RAP mixes
- Applicable to these materials and conditions; not necessarily true elsewhere
- Review your typical materials, especially typical RAPs, to explore applicability

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QUESTIONS?

Full Report

http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/11058/