EXPANDING THE REALM OF POSSIBILITY

2009 Pavement Performance Prediction Symposium

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Cost Effectiveness of Material Testing and Local Calibration

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APPLIED RESEARCH ASSOCIATES, INC.
An Employee-Owned Company

Outline

1. Local Calibration & the MEPDG; Some Results
2. Materials Testing—Is it beneficial (Rutting Example)?
3. Data Issues
4. Summary Comments

Manual of Practice for Validation-Calibration

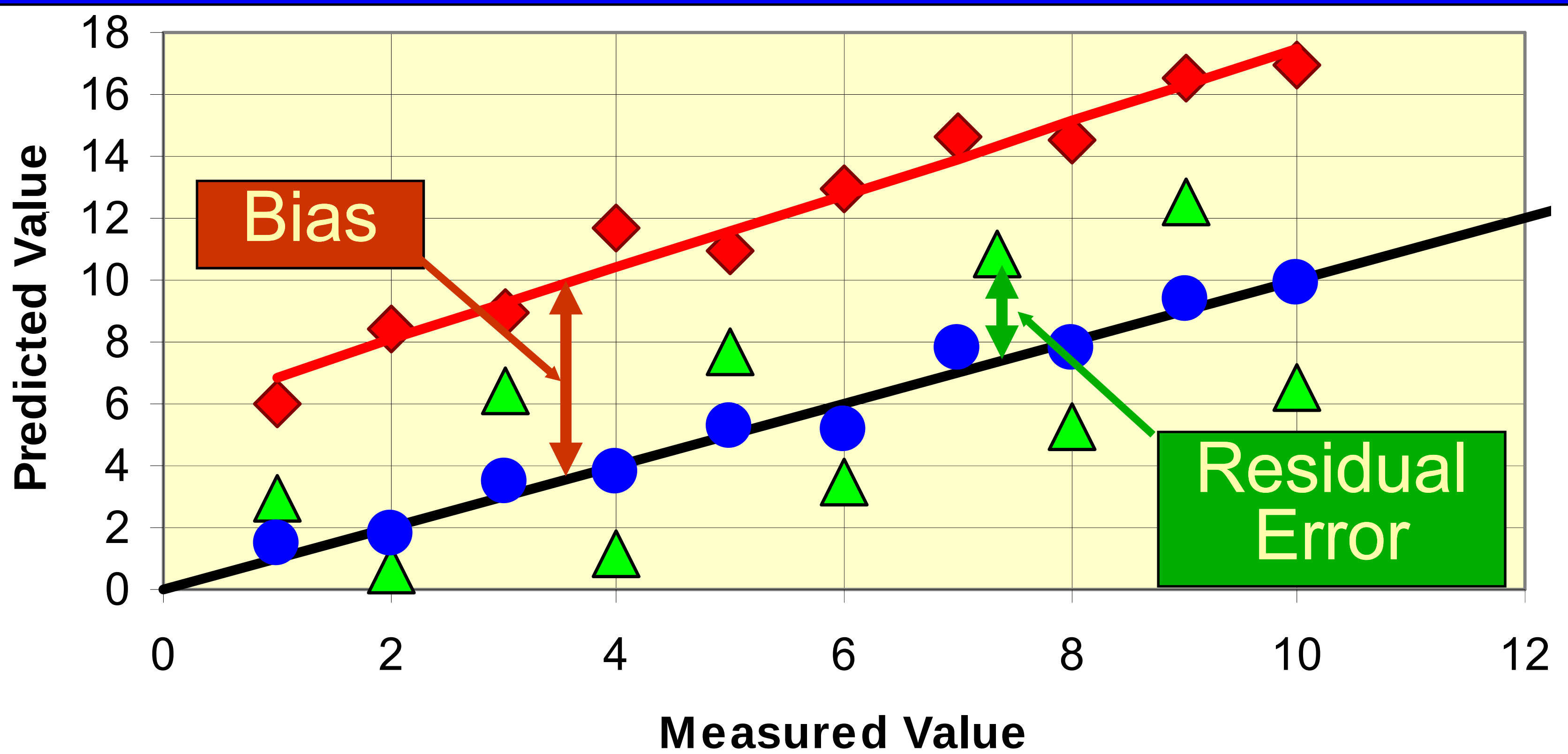
- ☑ NCHRP Project 1-40B; Guide to Local Calibration
- ☑ Three Part Demonstration Document
  1. Introduction
  2. HMA using LTPP SPS and PMS sites
  3. PCC using LTPP SPS and PMS sites

Manual of Practice for Validation-Calibration

- Mathematical models – assumed to be correct.
  - Pavement response models
  - Climatic model – ICM
  - HMA aging model
- ***Statistical or empirical models (transfer functions) may result in bias.***

Bias & Residual Error Analysis

Determine bias and error for local policies, conditions, & materials.

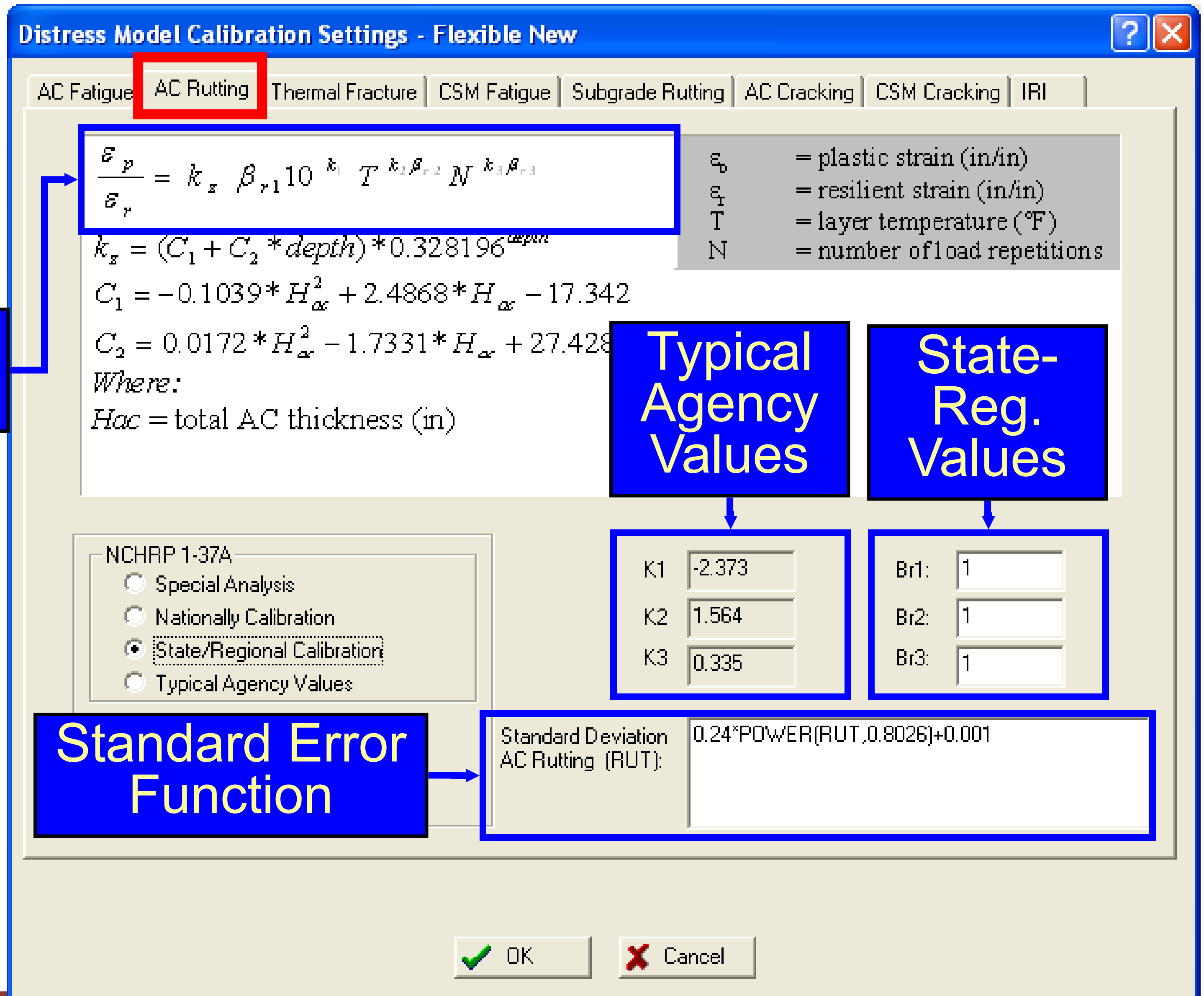


Hypothesis testing: Slope = 1 & Intercept = 0.

Local Calibration Values

HMA Rutting

Transfer Function



Standard Error Function

Sources for Some Results

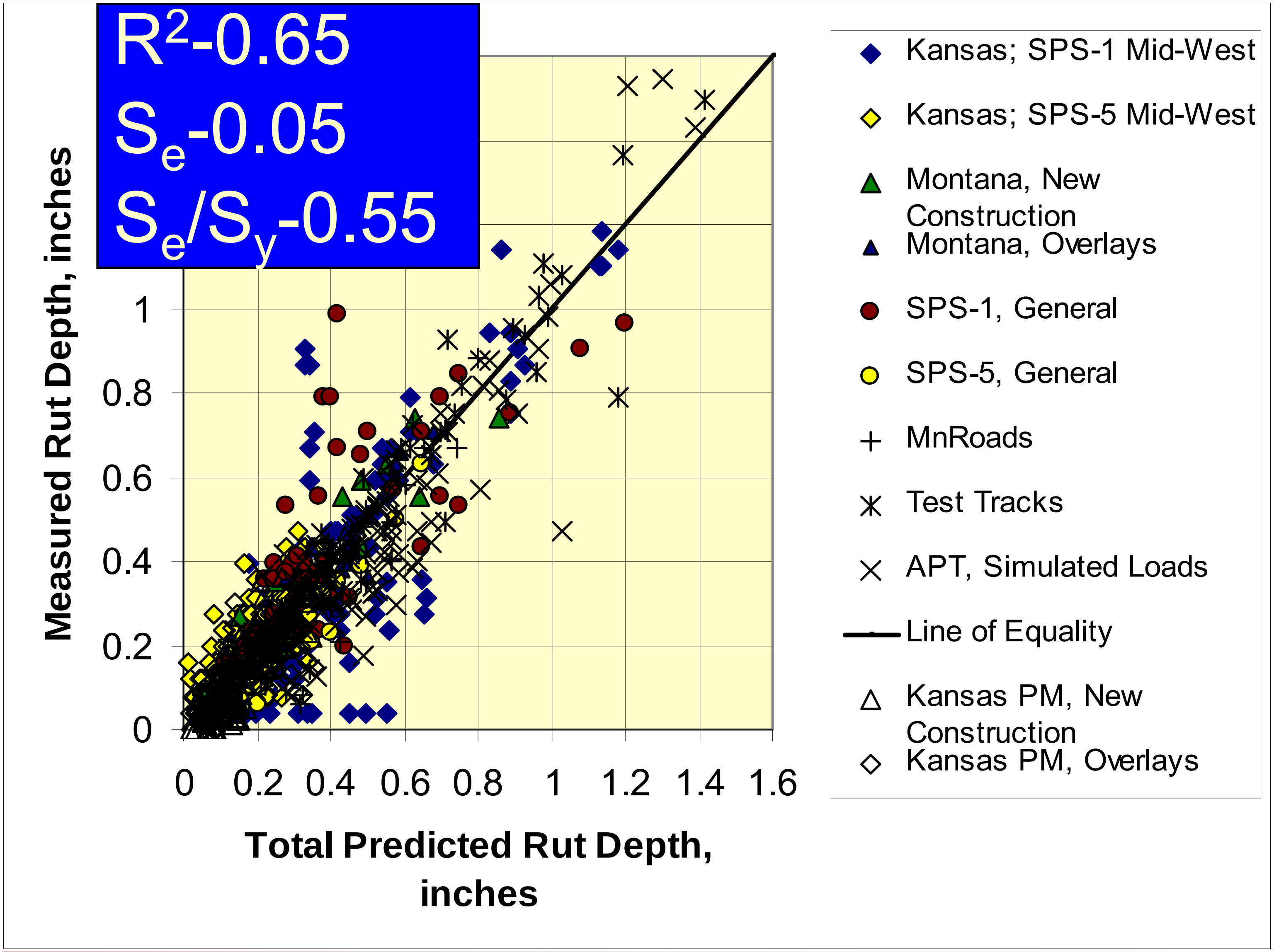
1. *APT Facilities (FHWA, FL, CA)*
2. *Test Tracks (WesTrack, NCAT, MnRoads)*
3. *LTPP SPS-1 & SPS-5 project sites.*
4. *Montana DOT experimental projects.*
5. *Northwest LTPP Projects—states adjacent to Montana.*
6. *Kansas Pavement Management Data*
7. *Mid-West LTPP Projects—states adjacent to Kansas*
8. *Missouri, Ohio, Utah, & Wisconsin*

Rut Depth Transfer Function

Local Calibration Parameter		Range	Dependent on:	Typical Value
Unbound Materials	β_{s1}	0.3 to 3.0	Water content & density	0.50
HMA	β_{r1}	0.60 to 10.0	Air voids, asphalt type & content, aggr. prop.	1.5
	β_{r3}	0.65 to 1.20		0.95
	β_{r2}	0.90 to 1.10		1.00

Includes anomalies within data set.

Rut Depth Transfer Function

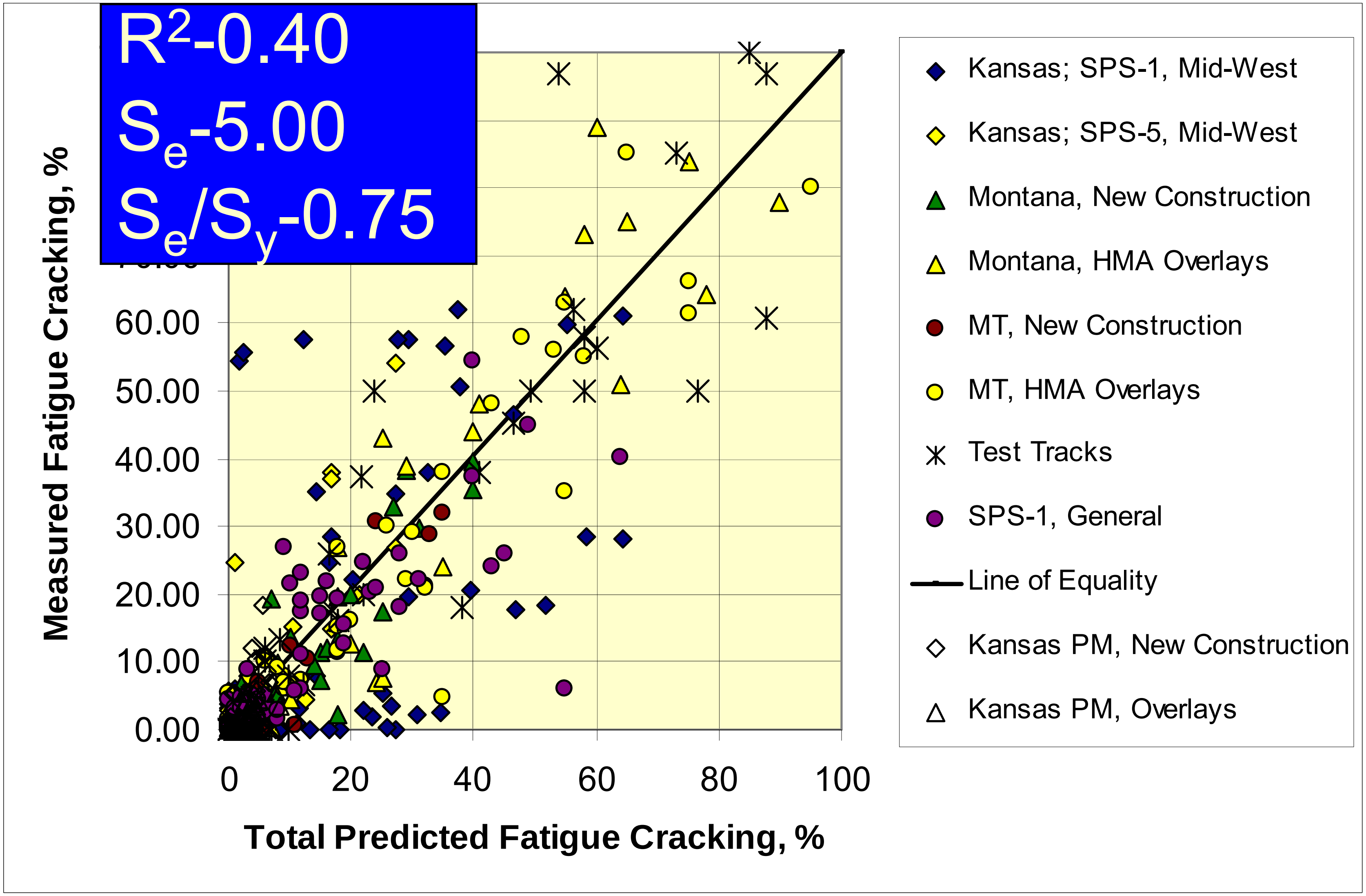


Alligator Cracking Transfer Function

Local Calibration Parameter		Range	Dependent on:	Typical Value
HMA	B_{f1}	0.0005 to 13.21	VFA, gradation, asphalt type	1.0
	B_{f3}	0.70 to 1.35		1.0
	B_{f2}	---		1.0
	C_2	1.0 to 4.0		1.0

Includes anomalies within data set.

Alligator Cracking Transfer Function

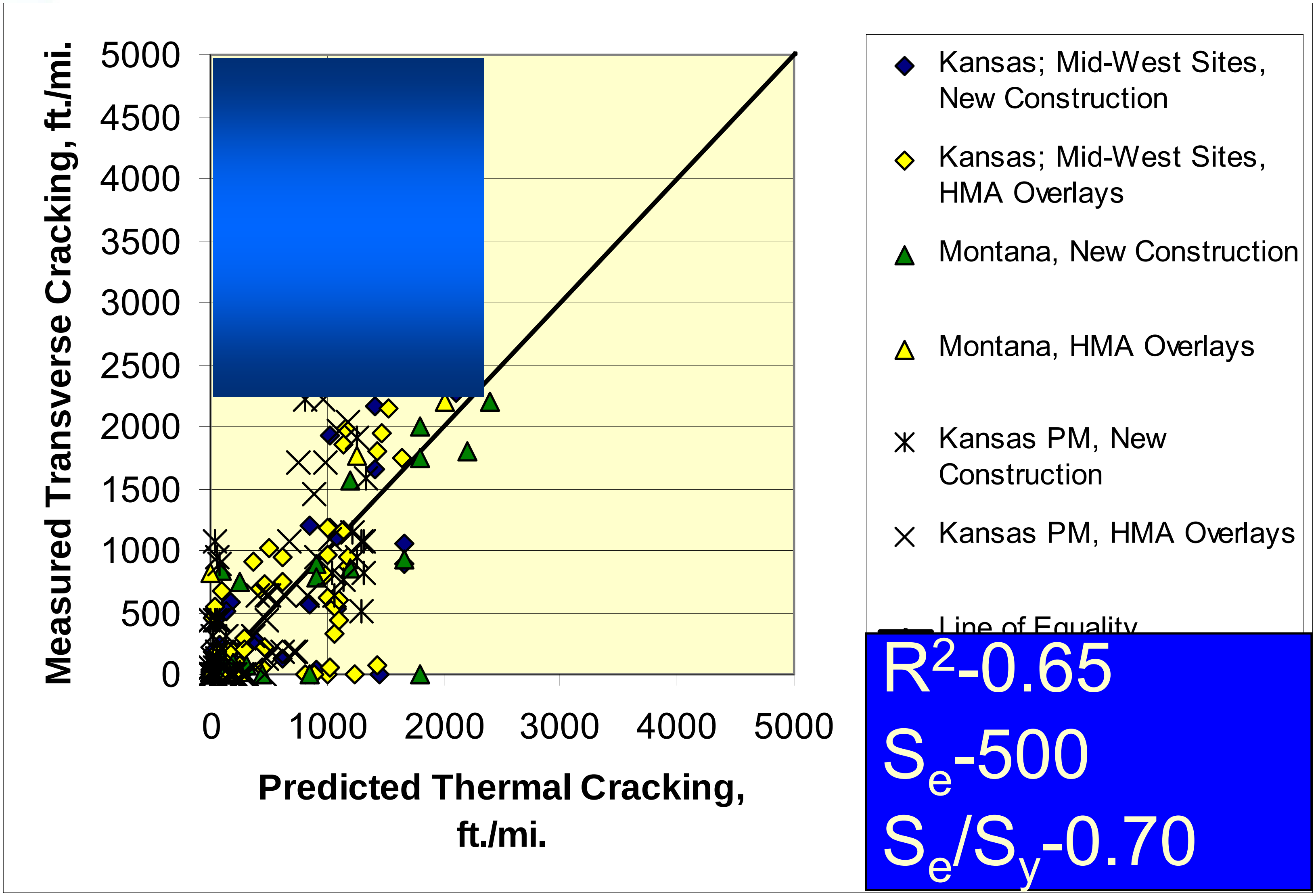


Thermal Cracking Transfer Function

Local Calibration Parameter		Range	Dependent on:	Typical Value
HMA	β_{t1}	---	---	---
	β_{t2}	---	---	---
	β_{t3}	0.25 to 20.0	Air void, asphalt content, & asphalt hardening	2.0

Includes anomalies within data set.

Thermal Cracking Transfer Function



What can help explain the large variations in the local calibration parameters?

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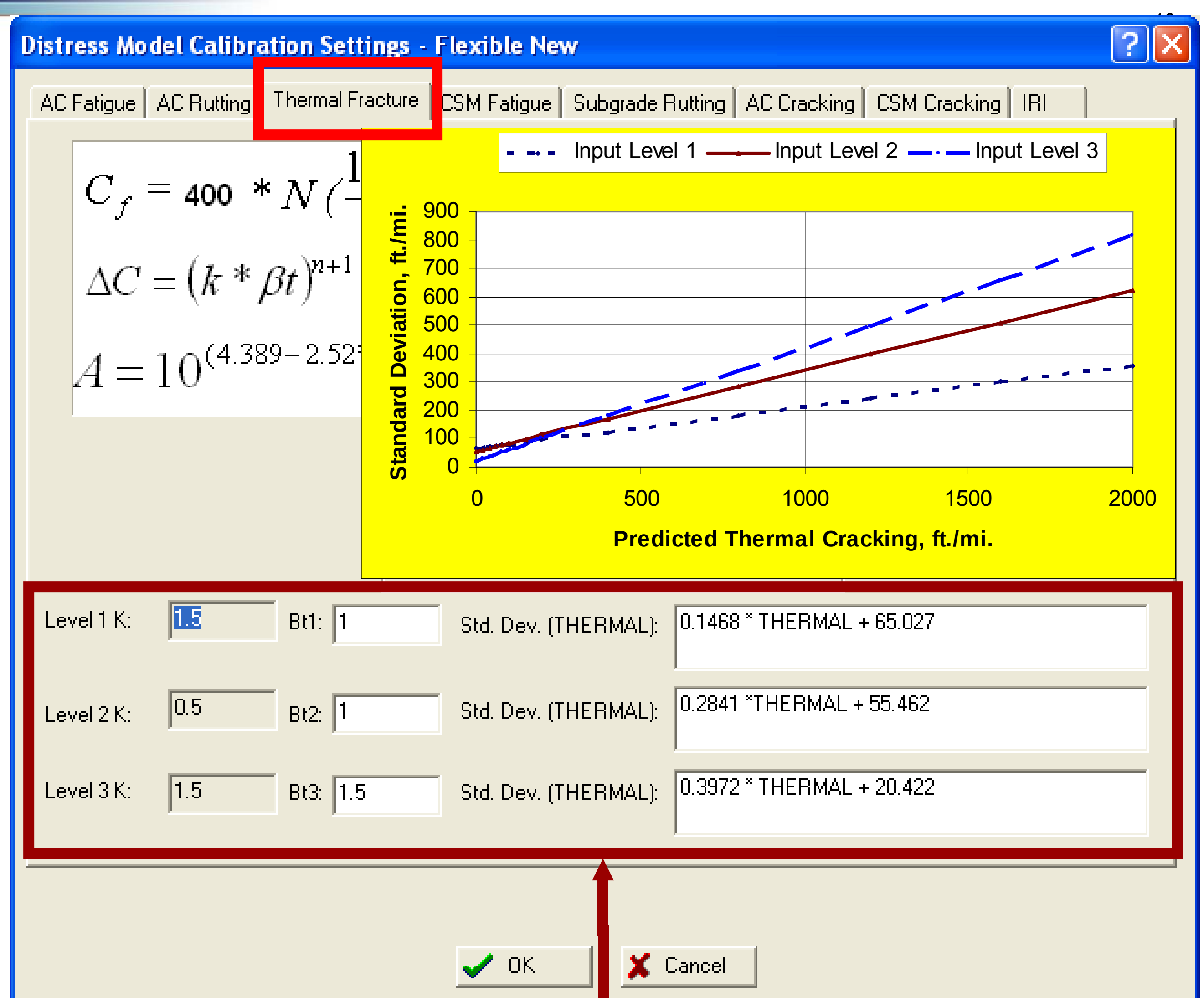
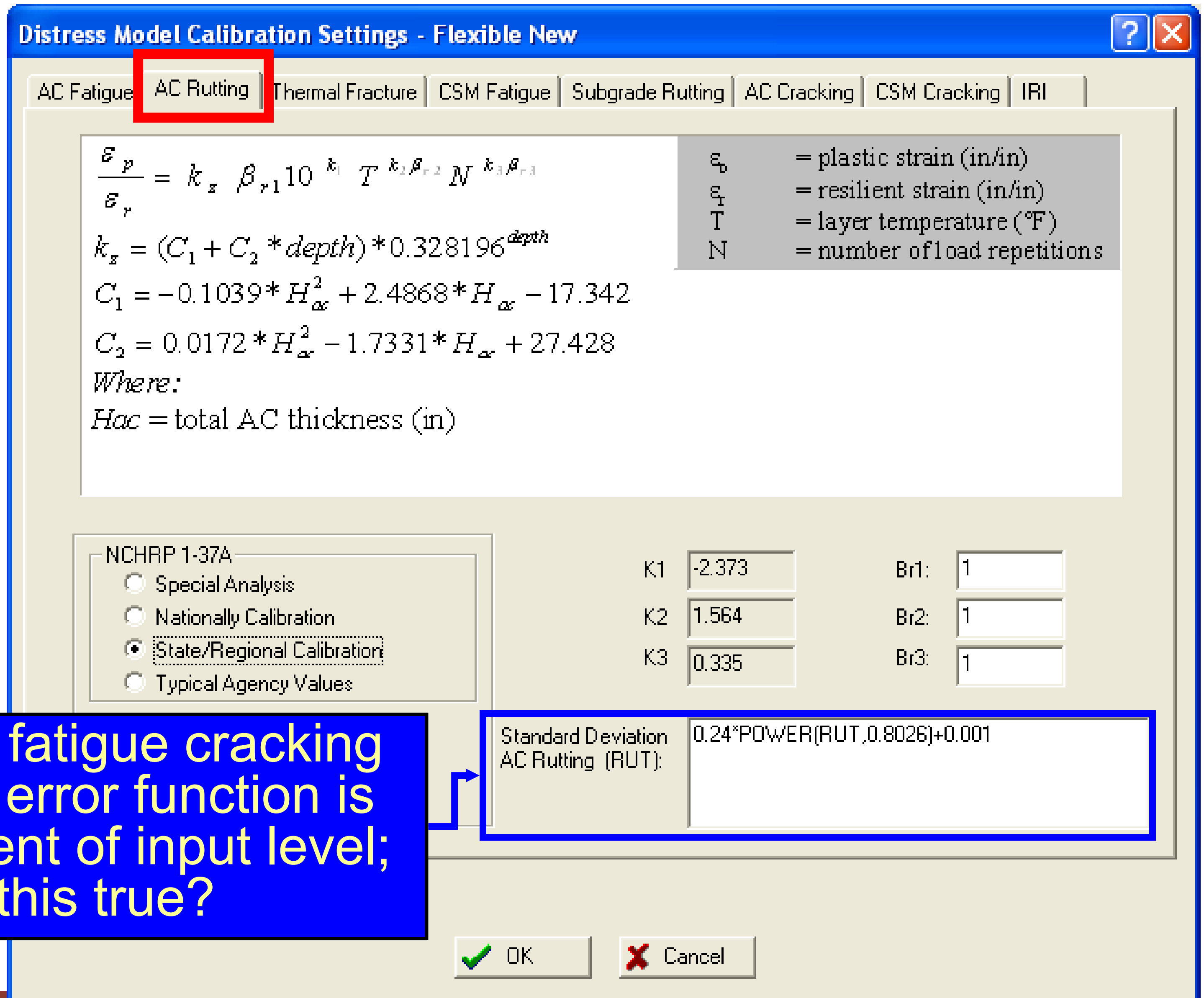
Initial Calibration Hypothesis: Input level does impact precision?



Thermal fracture—The only distress where standard error is dependent on input level.

Input Level & Standard Error



$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} 10^{k_1} T^{k_2 \beta_{r2}} N^{k_3 \beta_{r3}}$$

$$k_z = (C_1 + C_2 * depth) * 0.328196^{depth}$$

$$C_1 = -0.1039 * H_{ac}^2 + 2.4868 * H_{ac} - 17.342$$

$$C_2 = 0.0172 * H_{ac}^2 - 1.7331 * H_{ac} + 27.428$$

Rutting & fatigue cracking standard error function is independent of input level; is this true?

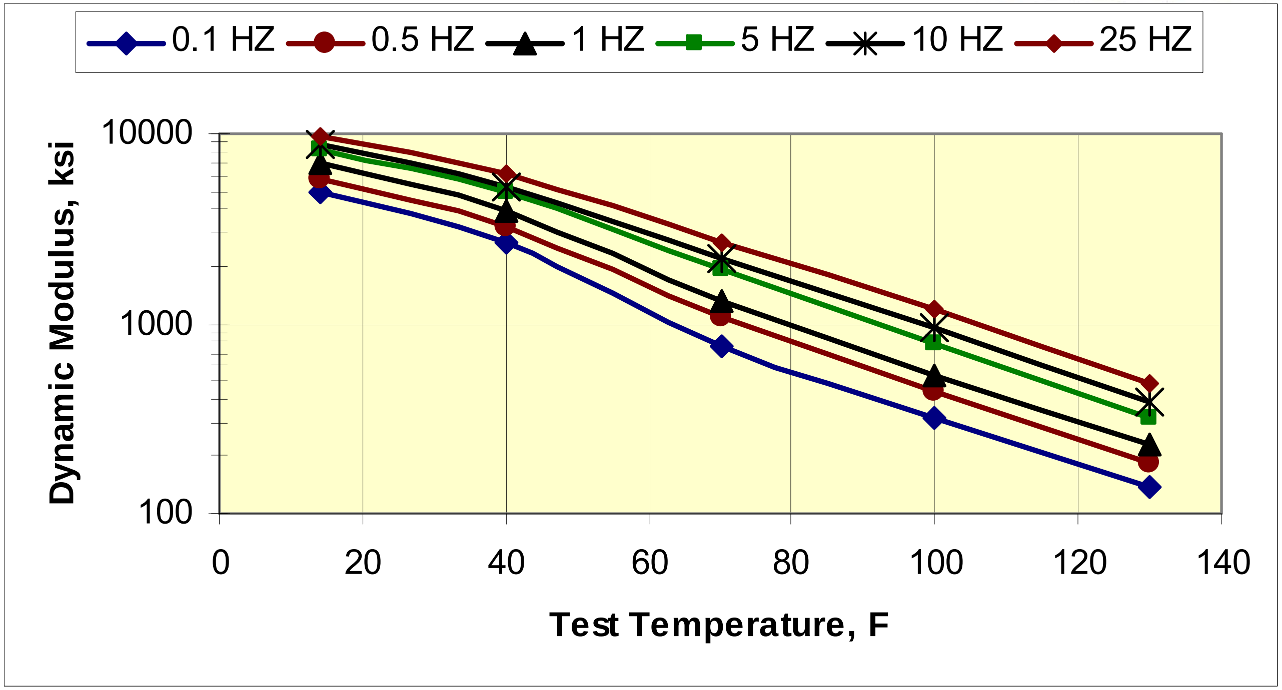
MEPDG Inputs for HMA Mixtures: Input level 1 versus 3

Input Level 3:

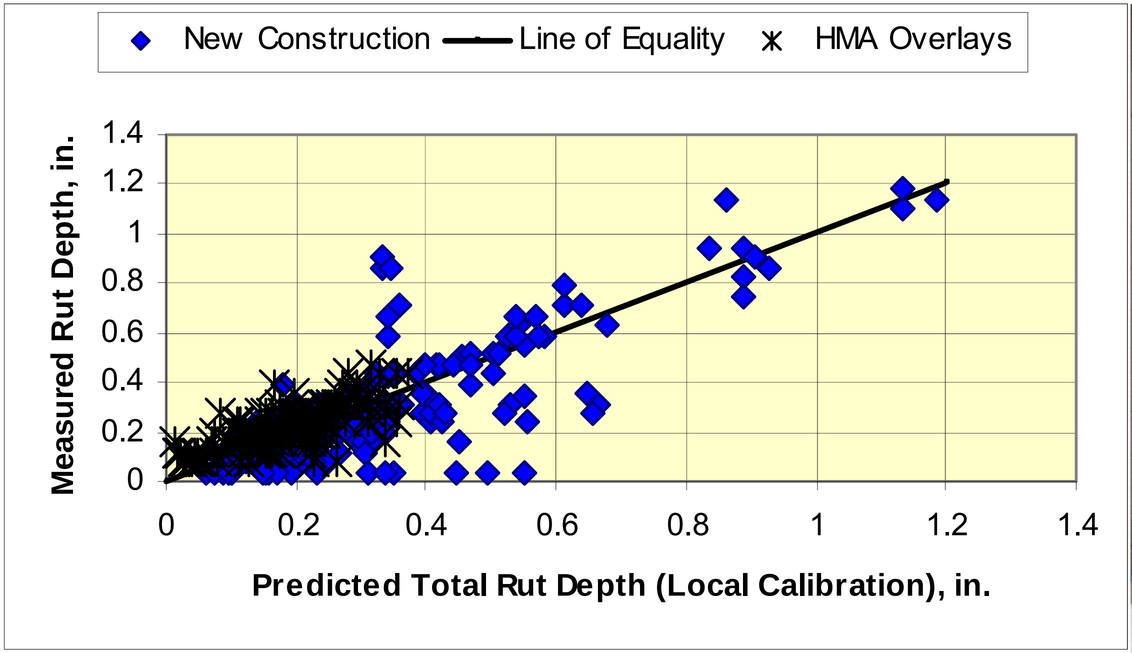
- Air voids @ construction
- Effective asphalt content by volume
- Gradation
- Density
- Asphalt grade
- Poisson's ratio

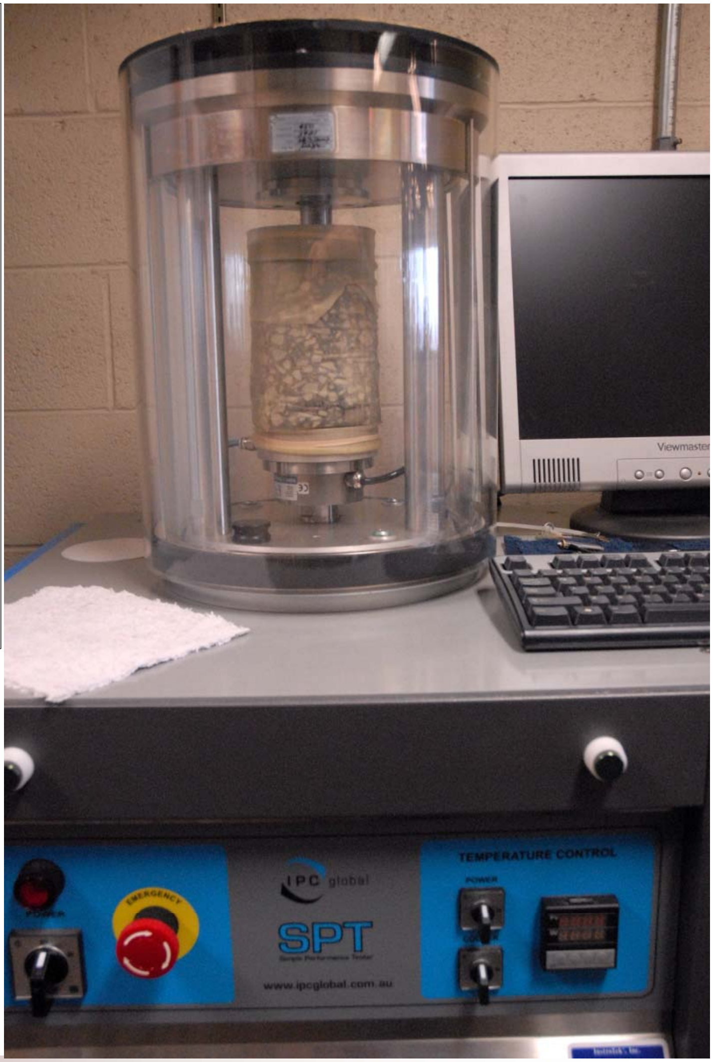
Input Level 1:

- Asphalt properties
- Dynamic modulus



Input Level 1 HMA Mix Testing; Dynamic Modulus





NCHRP 9-30 Study:

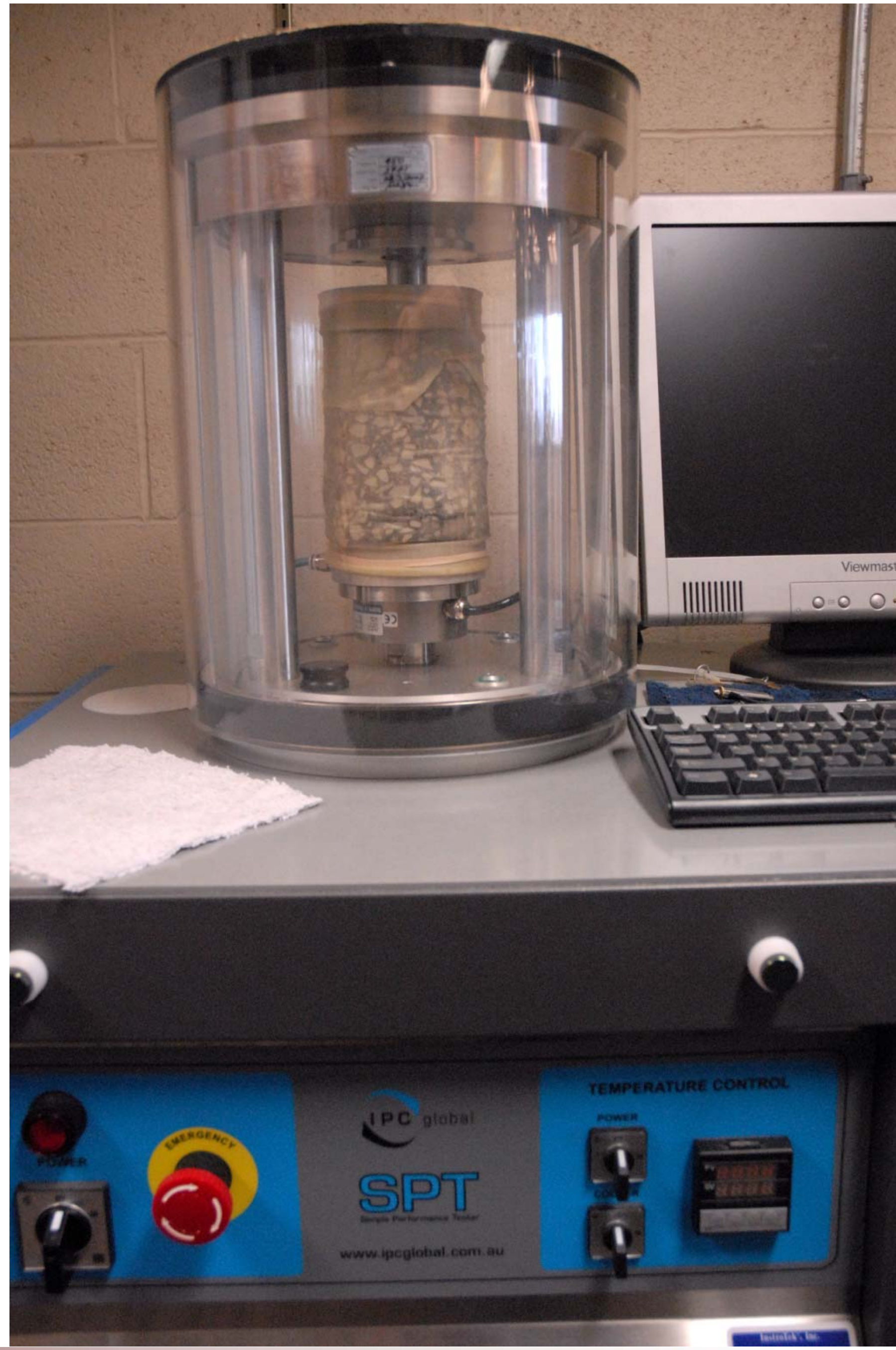
Predicted versus measured rut depths; No significant reduction in standard error term.

HMA Mix Characterization

NCHRP 9-30A:

- Dynamic Modulus
- Repeated Load Permanent Deformation Test
- Repeated Shear Constant Height Test

Loaded Wheel Test

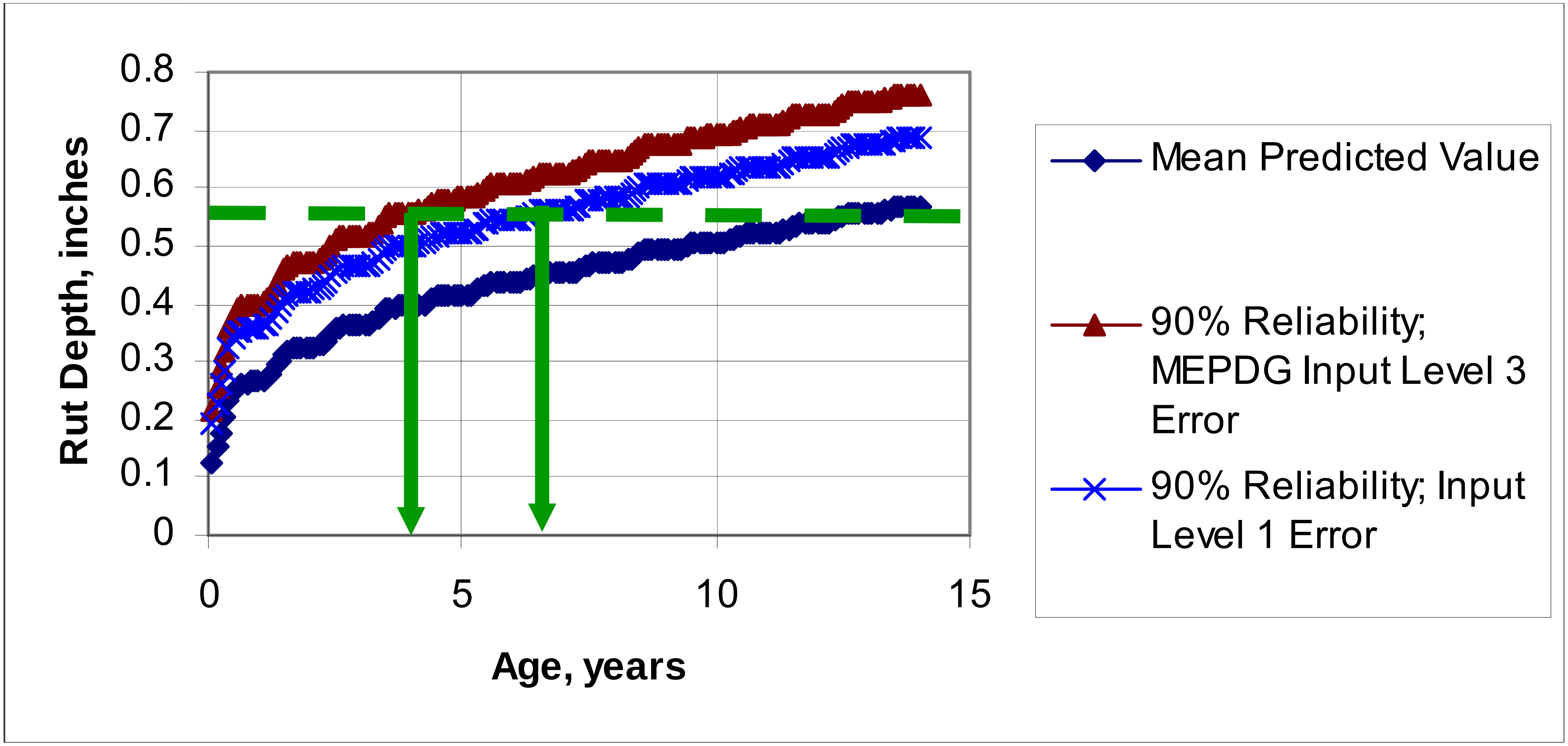


Comparison of Standard Errors for Rutting

Threshold Rut Depth, in.	Input Level 3, Local Standard Error, in.	Input Level 1 Standard Error, in.
0.25	0.09	0.07
0.50	0.14	0.09
0.75	0.17	0.10

There is a benefit; but is that benefit cost effective?

Benefit/Cost Ratio Analysis



Does the lower life cycle costs offset the higher laboratory cost of testing?

B/C Ratio Preliminary Results

<table>
<tr><th rowspan="2">Design Value, in.</th><th rowspan="2">Reliability Level</th><th colspan="3">HMA Overlay</th></tr>
<tr><th>Small Project; <$1M</th><th>Moderate Project</th><th>Large Project; >$5M</th></tr>
<tr><td rowspan="3">0.25</td><td>75</td><td colspan="3" rowspan="3">Not Cost Effective</td></tr>
<tr><td>85</td></tr>
<tr><td>95</td></tr>
<tr><td rowspan="3">0.50</td><td>75</td><td colspan="2" rowspan="2">Not Cost Effective.</td><td rowspan="3">Cost of testing is beneficial.</td></tr>
<tr><td>85</td></tr>
<tr><td>95</td><td>Not Cost Effective.</td><td>B/C>1.0 at 90% reliability.</td></tr>
<tr><td rowspan="3">0.75</td><td>75</td><td rowspan="2">Not Cost Effective</td><td>Not Cost Effective</td><td rowspan="3">Cost of testing is beneficial.</td></tr>
<tr><td>85</td><td rowspan="2">B/C>1.0 at 80% reliability.</td></tr>
<tr><td>95</td><td>B/C >1.0</td></tr>
</table>

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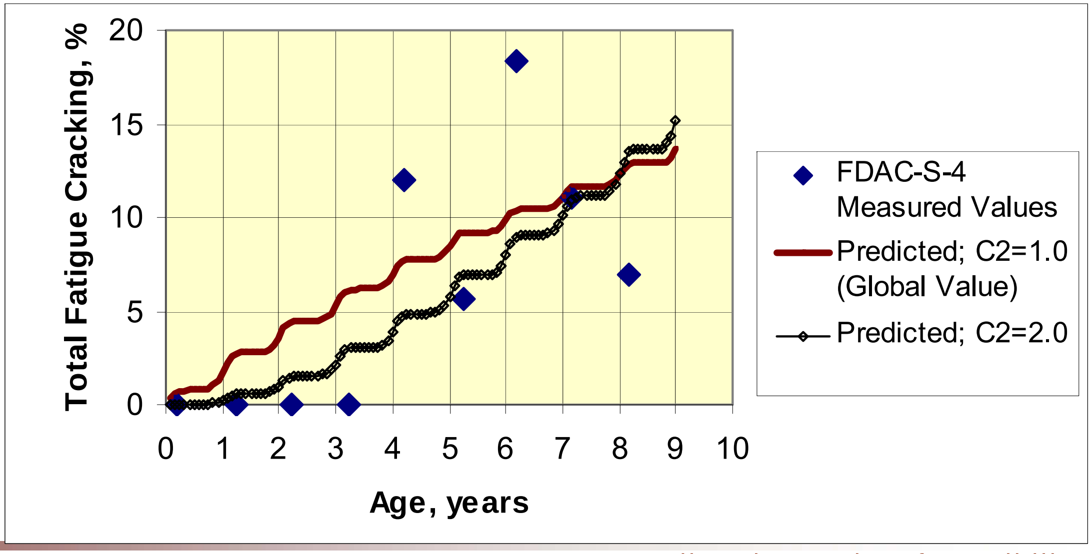
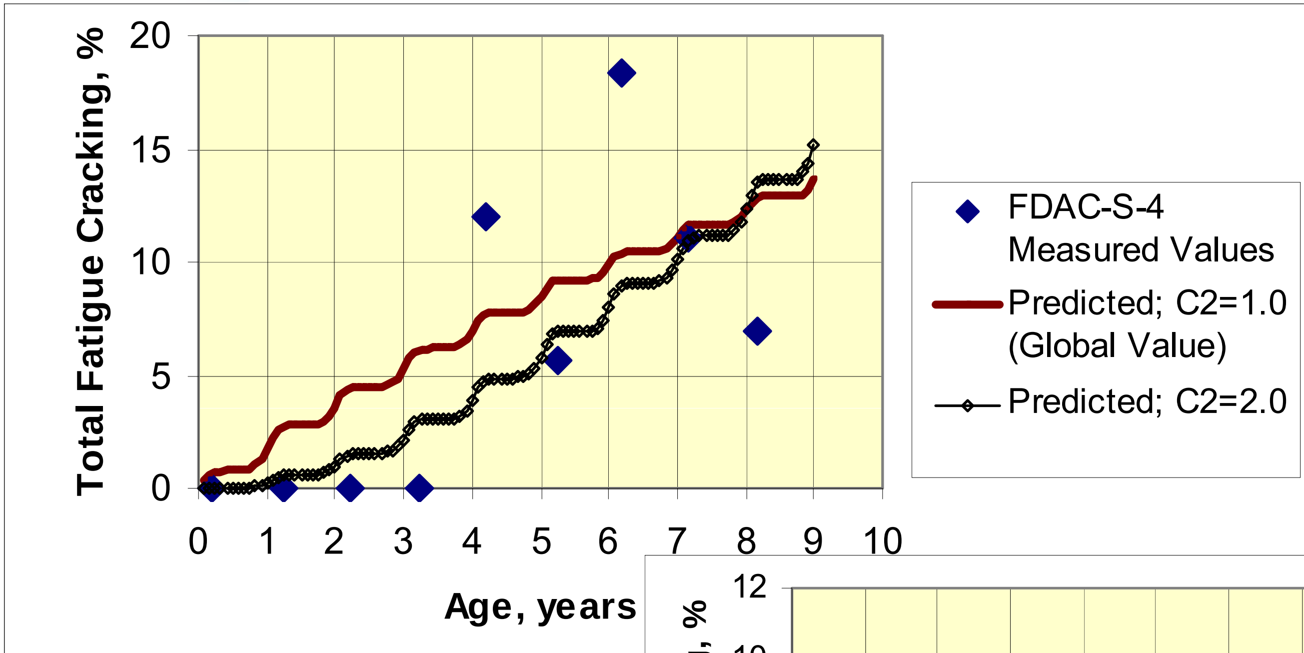
Local Calibration: The Issues

$$e_{Total} = e_{Lack-of-Fit} + e_{Measurement} + e_{Input} + e_{Pure}$$

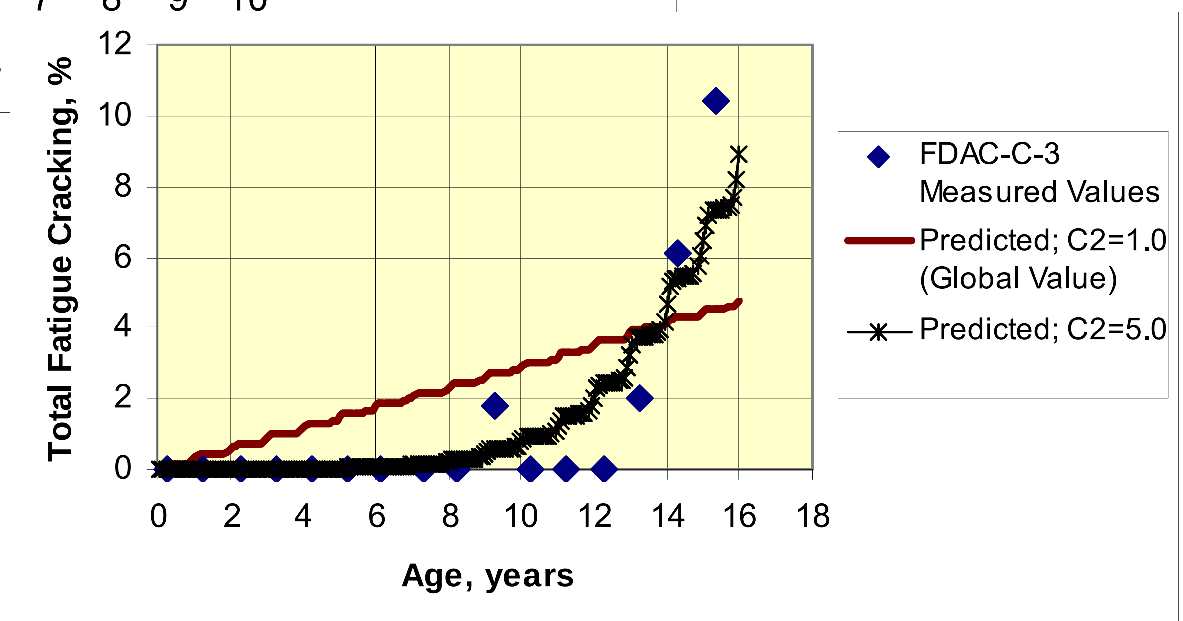
Quantifying the prediction error & model precision to determine why the errors are so large.



Important Errors

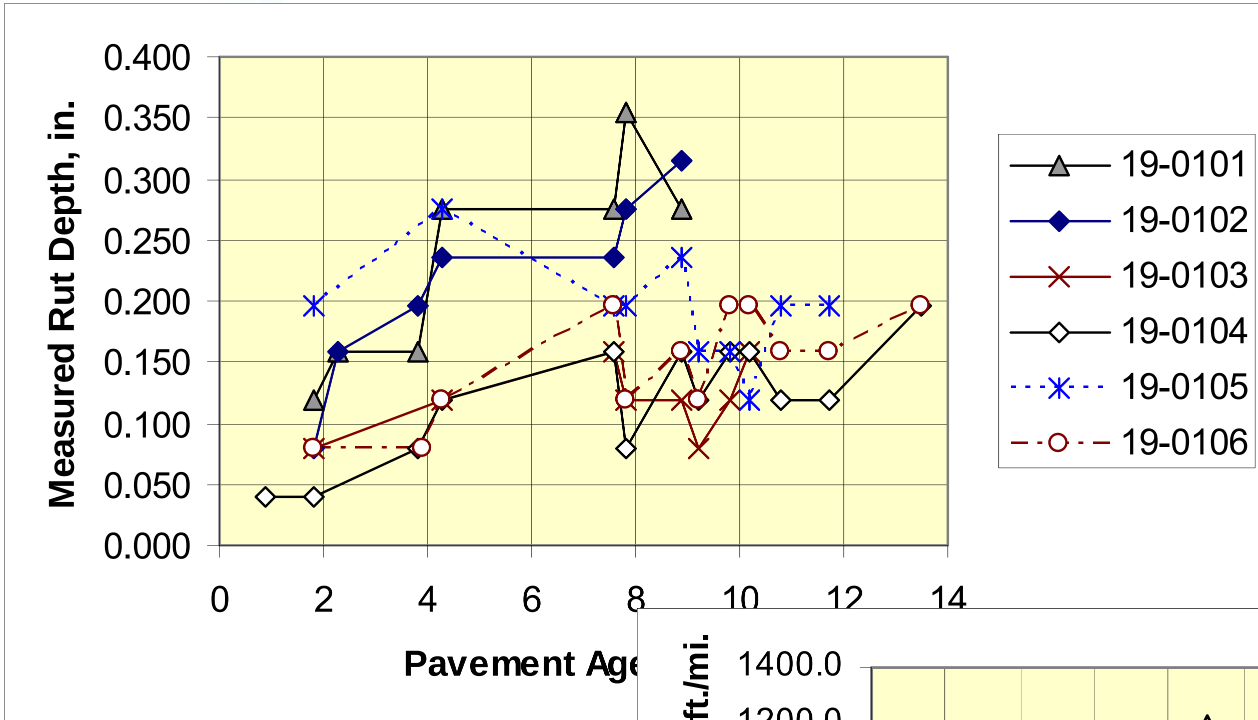


Measure. Error

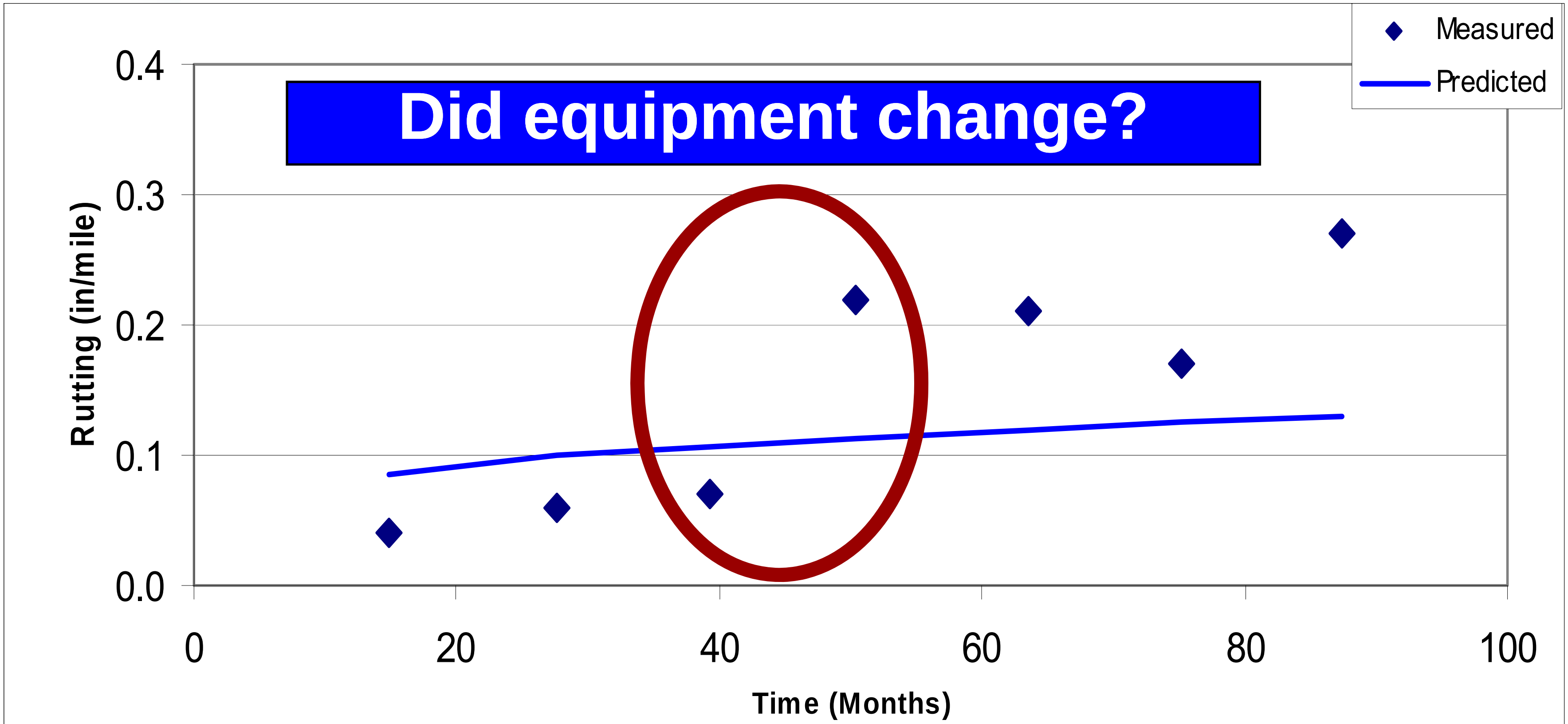


Lack-of-Fit Error

Measurement Error

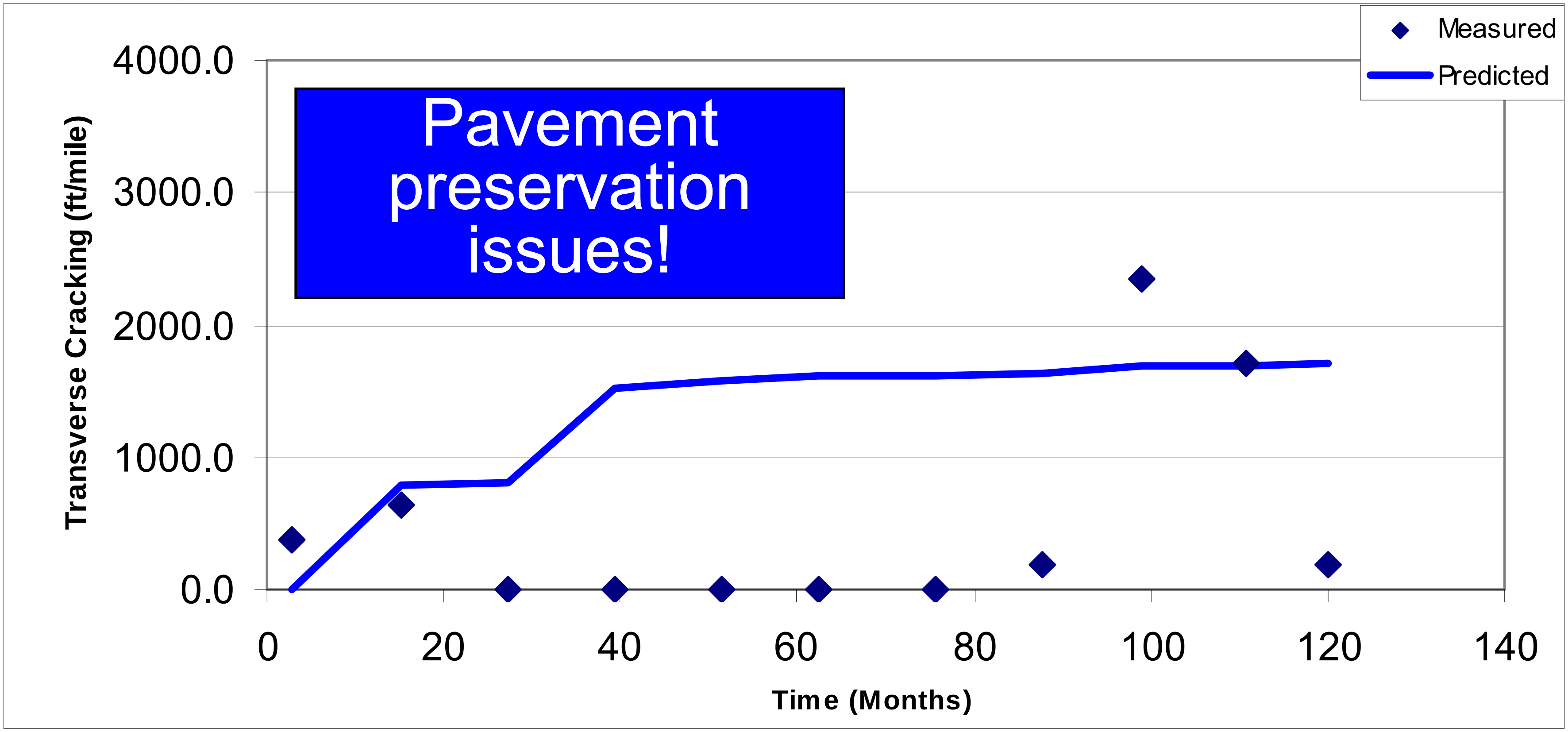


Measurement Error?



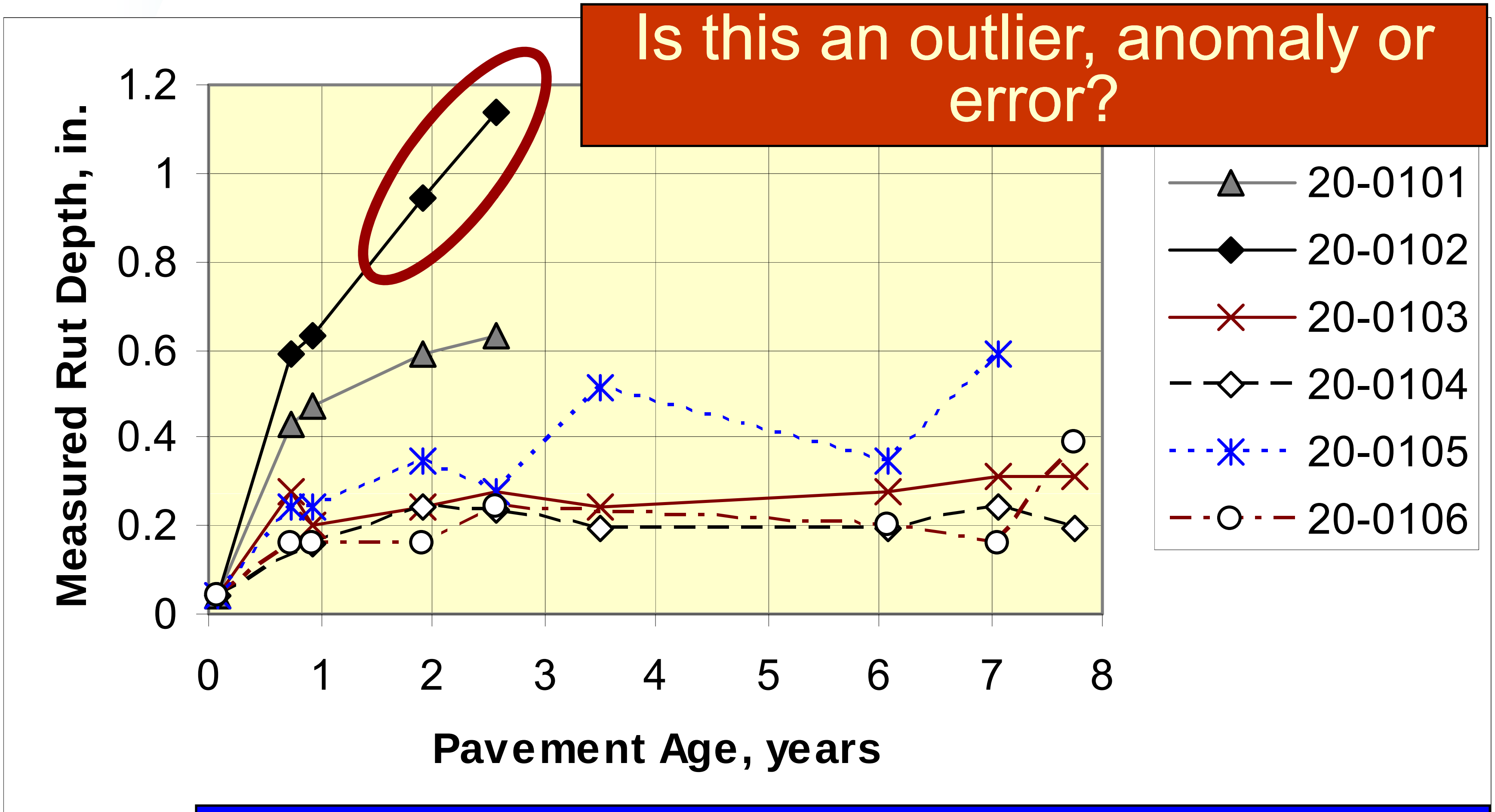
Data measurement errors represent the higher component of the total error term.

Policy—Lack-of-Fit Error?



Why are transverse cracking values so diverse?

Data Anomaly?

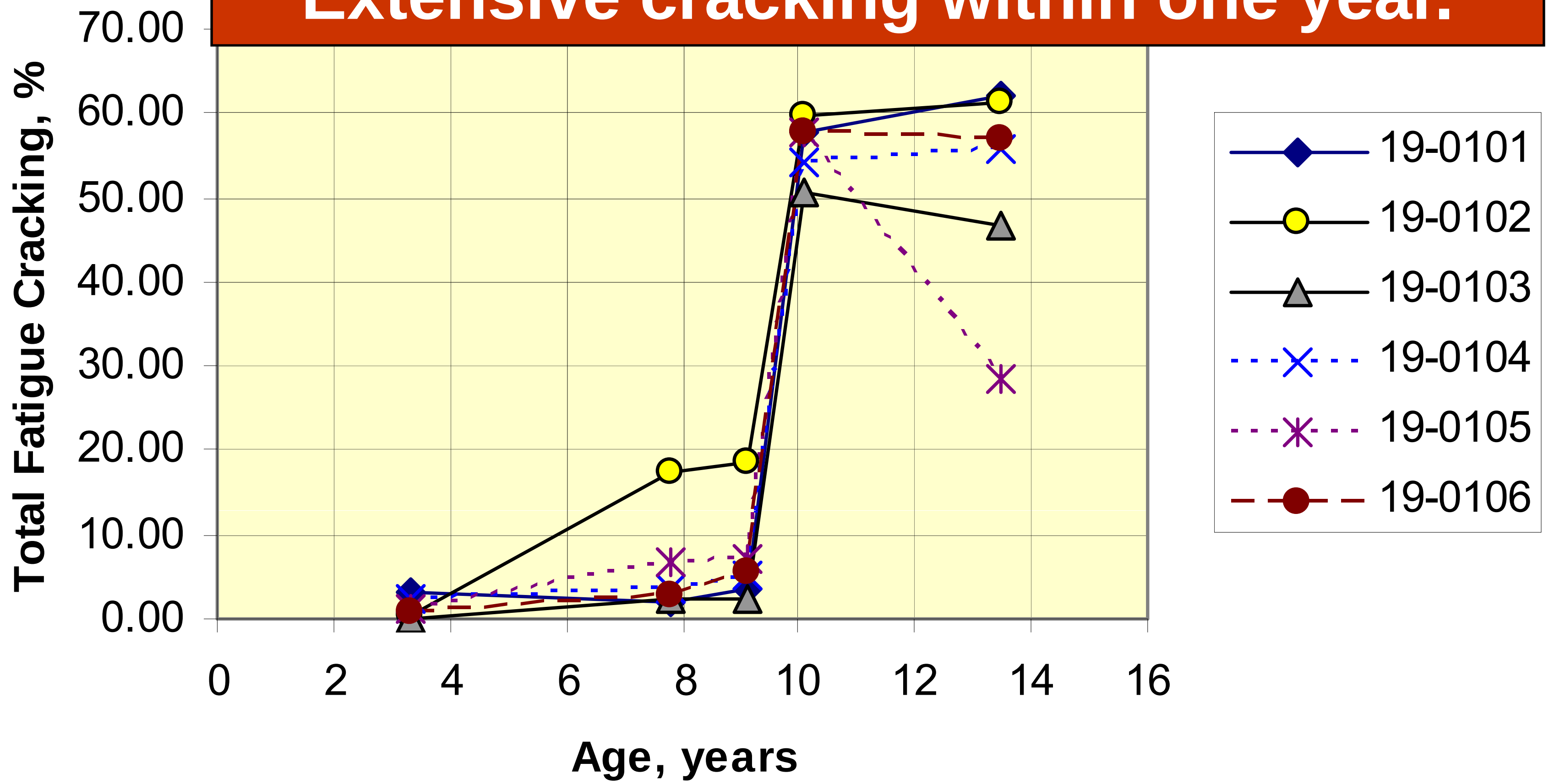


Is this an outlier, anomaly or error?

Construction problems & weather delays.
Weak unbound layers.

Data Anomaly?

Extensive cracking within one year.



Loss of bond between HMA layers
Stripping of HMA Mixtures

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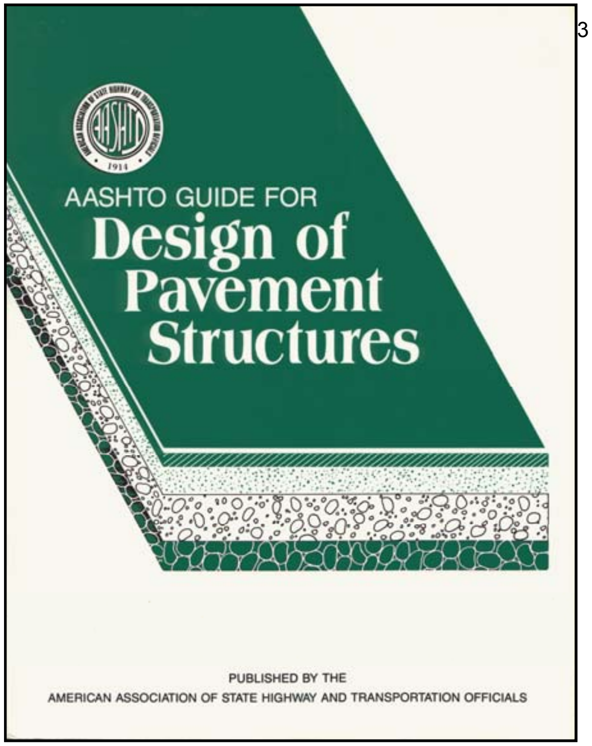
Remember where we are coming from, as you use the MEPDG!

- Assumptions used in the Design Guides?
- Calibration of both Design Guides?
- Error in the service life predictions of both Design Guides?



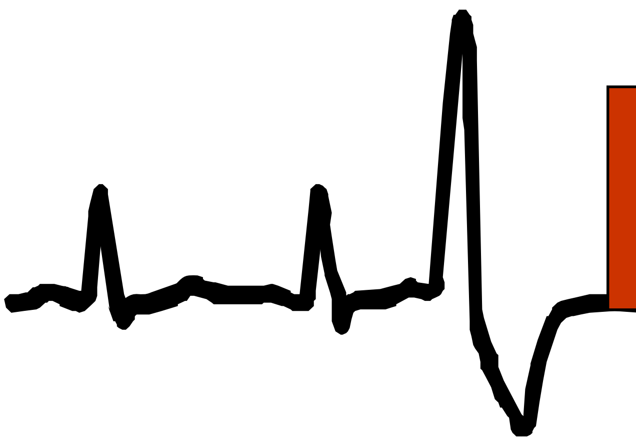
Should we wait until its *PERFECT?*

- If we wait until there are no more changes, *we will never use it*.
- If we wait for perfection, *it will be impractical and cost will restrict its use*.

There is ***NO*** perfect procedure & it will never be perfect!

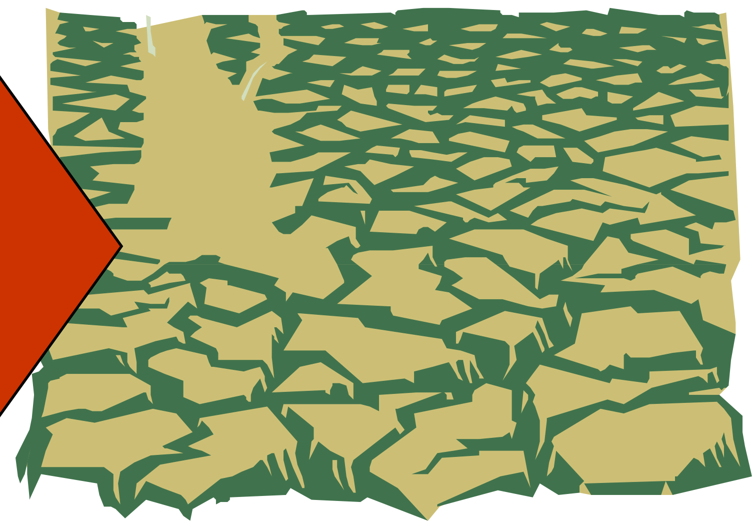
Calibration of Distress Transfer Functions

Pavement Response



TRANSFER FUNCTION

Distress



- Stresses
- Strains
- Deflections

Calibration is a key.

- Fatigue Cracks
- Rut Depths
- Transverse Cracks

Where is the error coming from?

Larger Errors:

- Measurement of distress.
- Anomalies – construction & material defects.
- Policy issues/specs. – not considered directly by the MEPDG.

Lower Correlation Cause: Anomalies Measurements

Minimal Errors:

- Truck traffic – minimal.
- Climate – minimal.
- Input level 3; E*

PM & Mid-West LTPP Sites	
Transfer Function	**S_e/S_y**
Rut Depth	0.80
Fatigue Cracking	0.90
Thermal Cracking	0.90
IRI, Smoothness	0.65

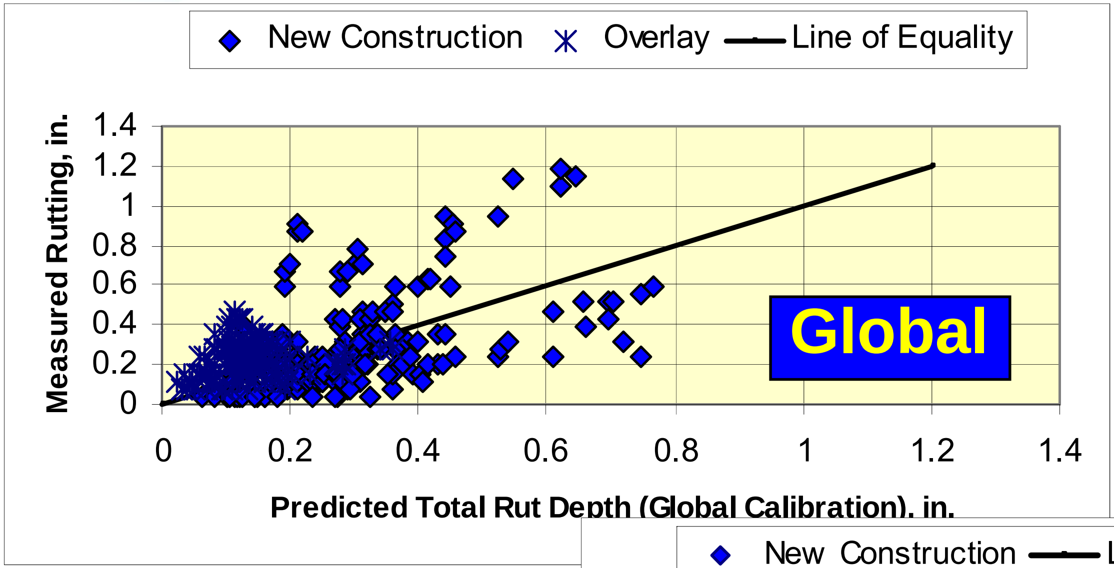
Summary Comments

- Materials testing is cost effective for some conditions – the benefit is greater than the cost.
  - Type of test?
  - Mixture properties?
- Measurement error will not be reduced by changing the model.

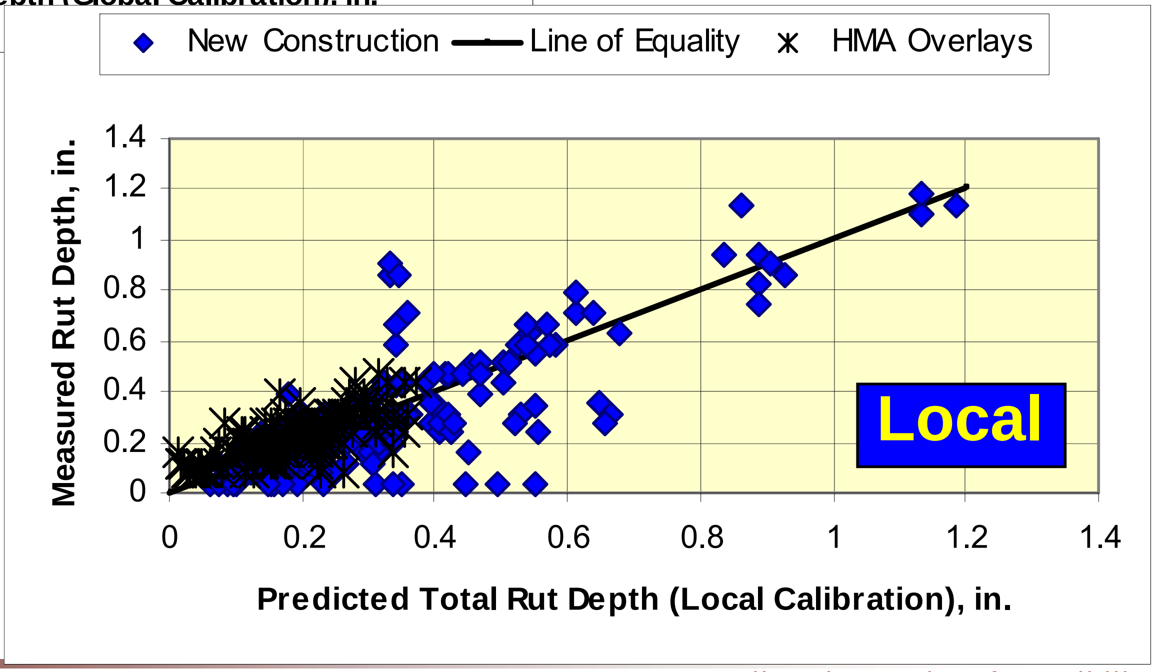
Questions!

This Week Is Our 36th Wedding Anniversary

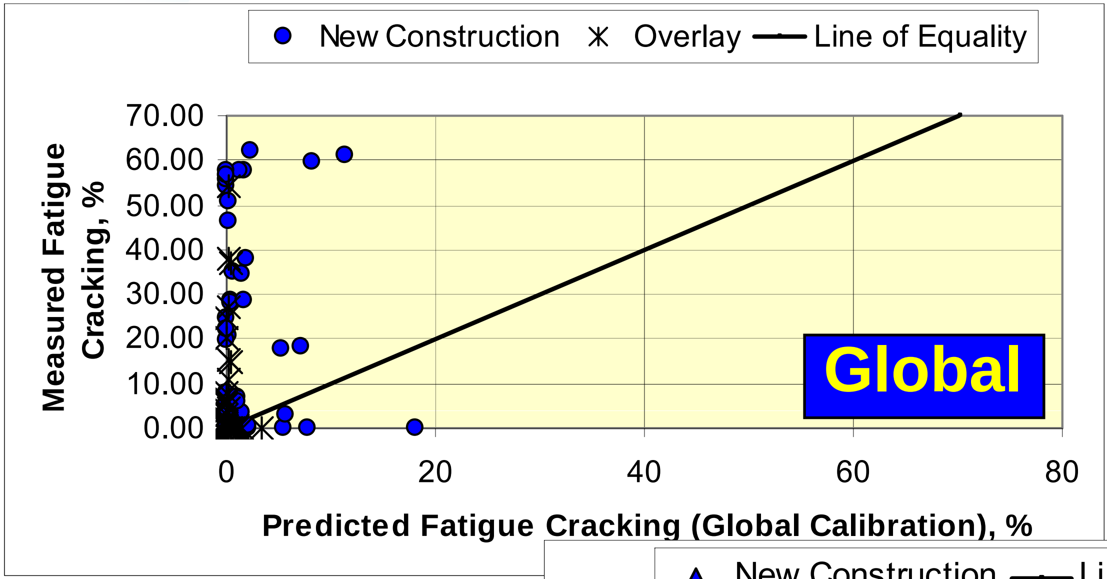
Local Calibration—Kansas



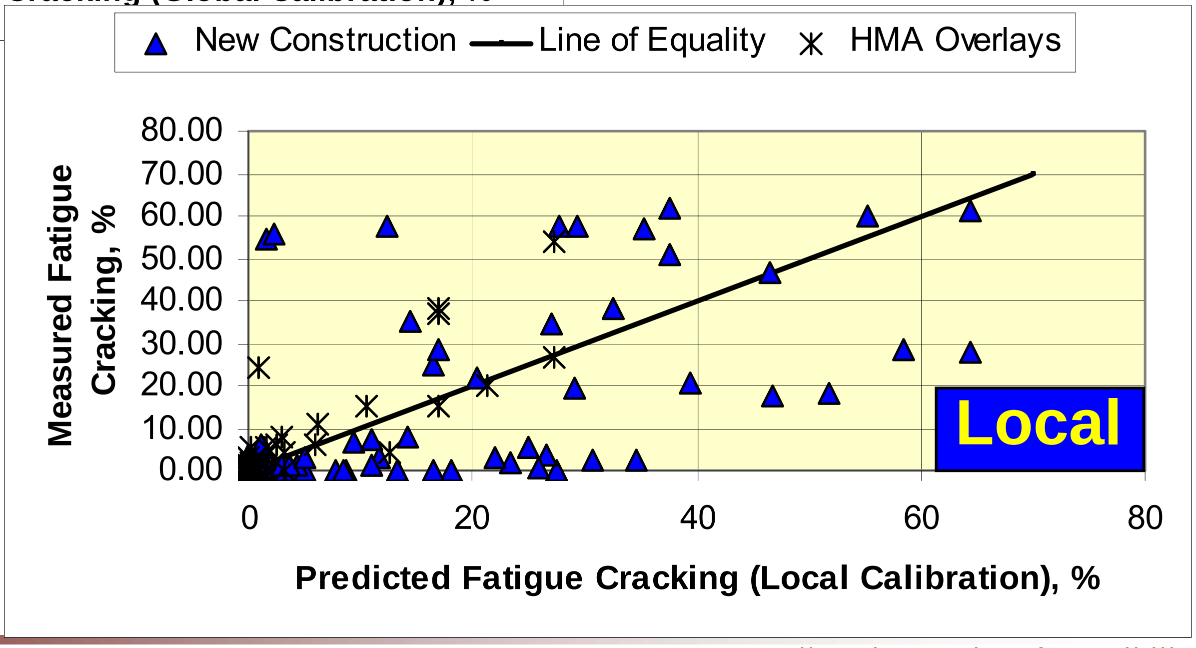
Total Rutting



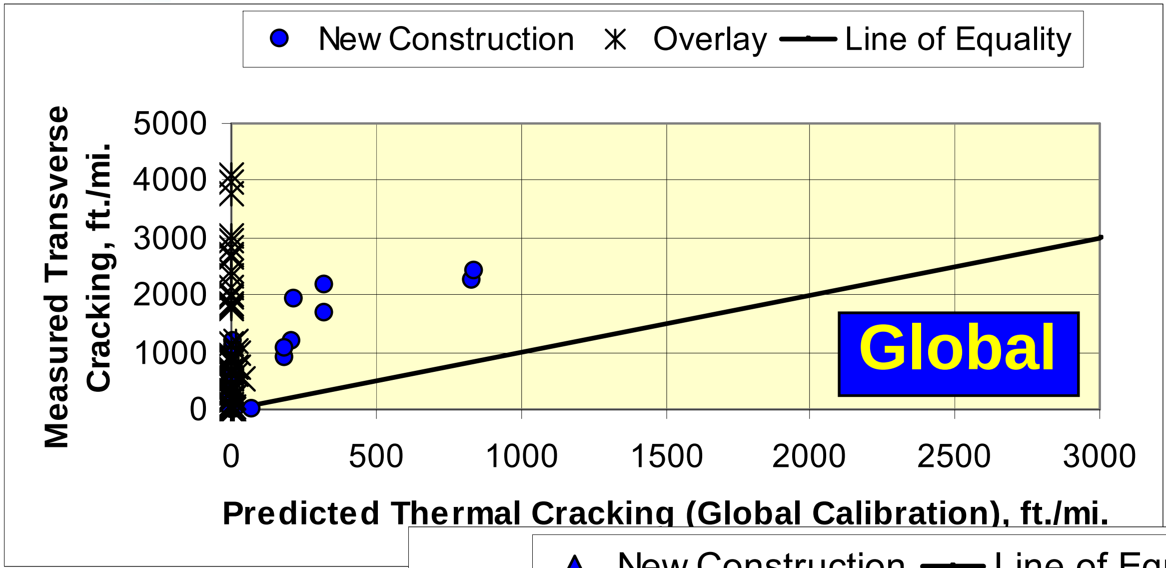
Local Calibration—Kansas



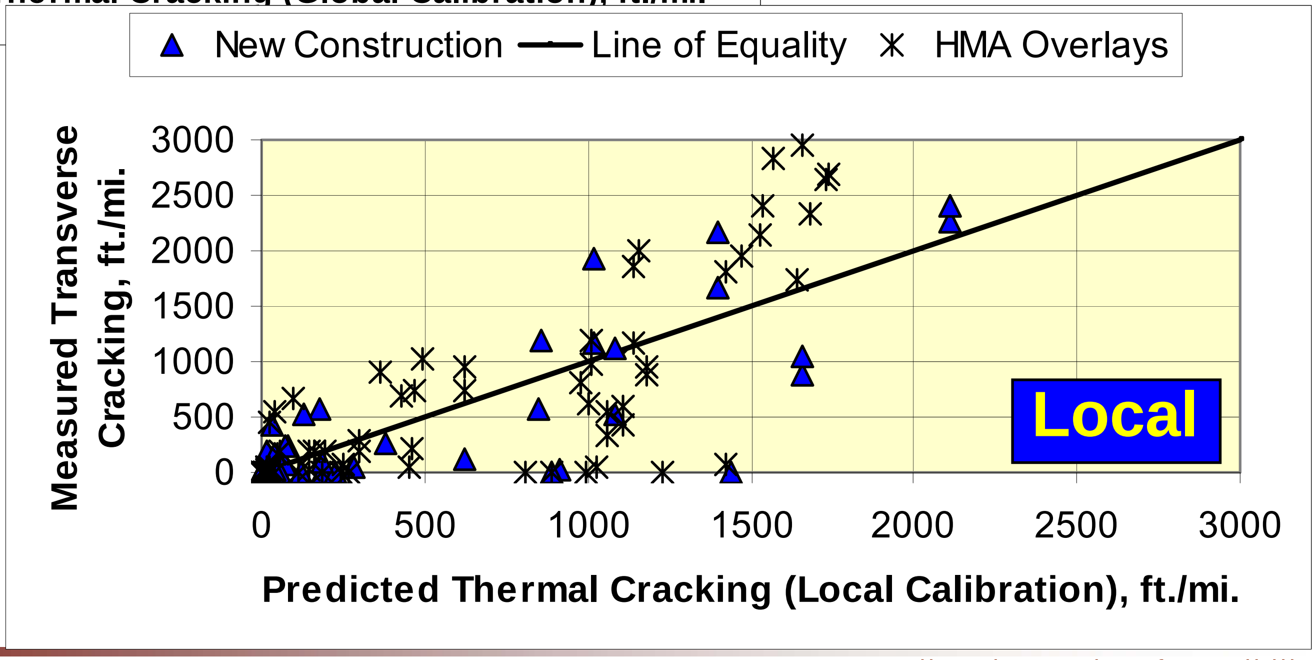
Alligator Cracking



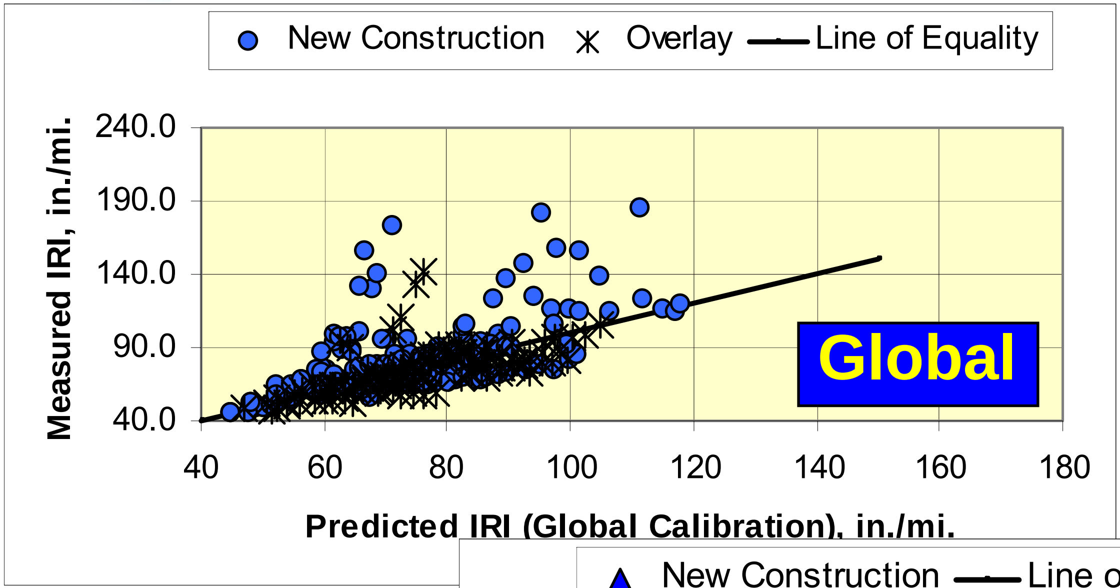
Local Calibration—Kansas



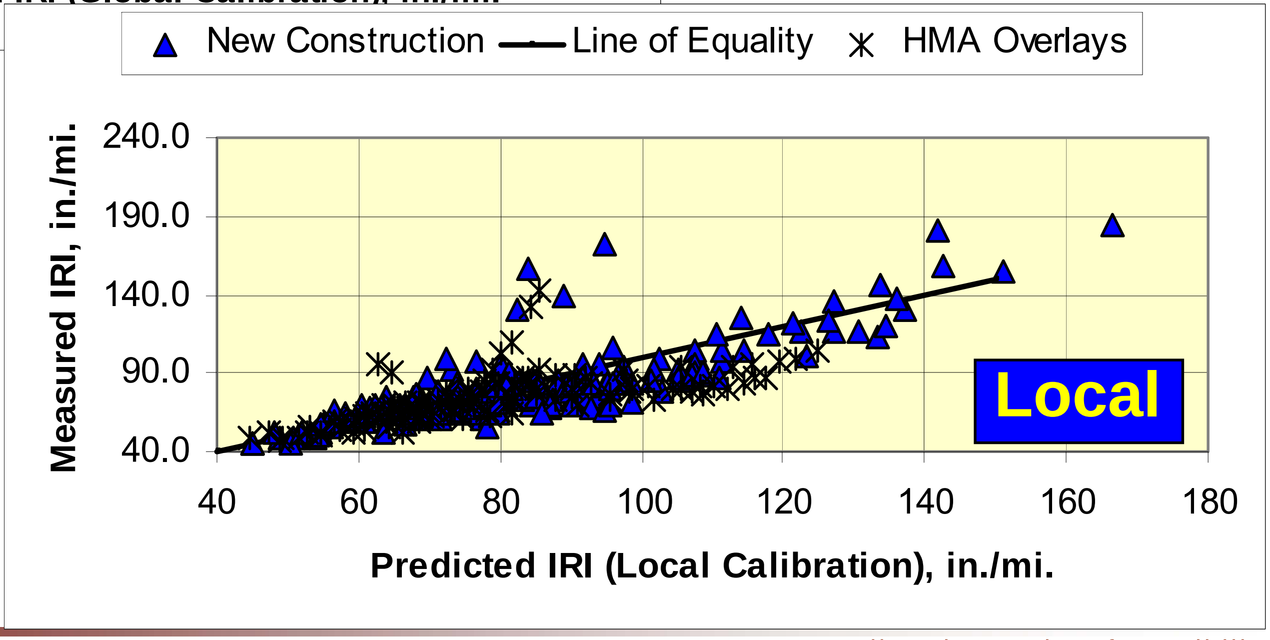
Transverse Cracking



Local Calibration—Kansas



Roughness or IRI Values

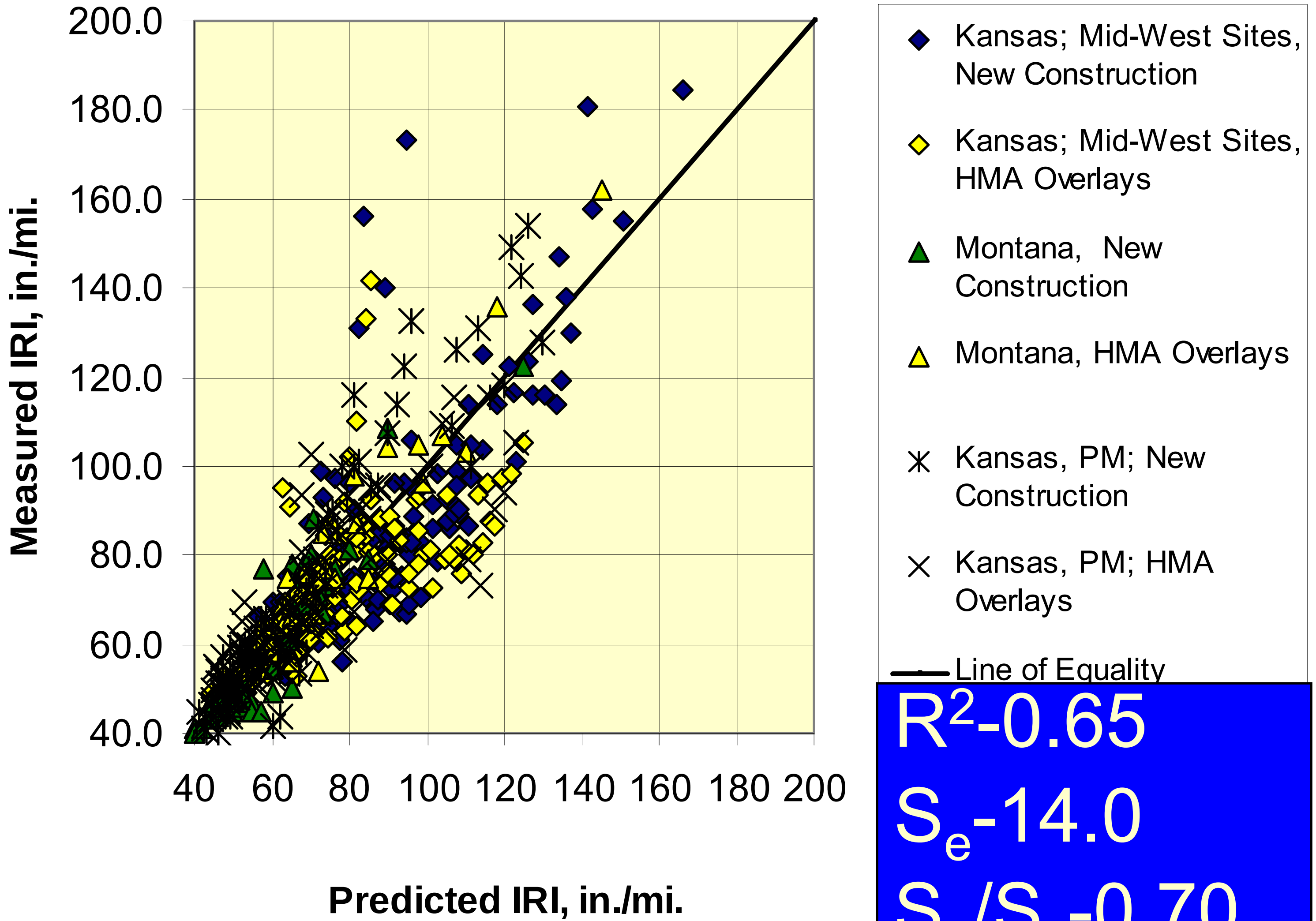


IRI Regression Equation

Calibration Parameter		Range	Dependent on:	Typical Value
HMA	C_1	---	---	1.0
	C_2	---	Individual Distresses	1.0
	C_3	---		1.0
	C_4	---		1.0

Includes anomalies within data set.

IRI Regression Equation



R^2-0.65

S_e-14.0

S_e/S_y-0.70