I-96 Case Study: Jointed Concrete Pavement Curling and Warp Presented in the Context of Pavement Asset Management

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SME

PAVEMENT ANALYSIS:
Soil-Structure Interaction Engineering

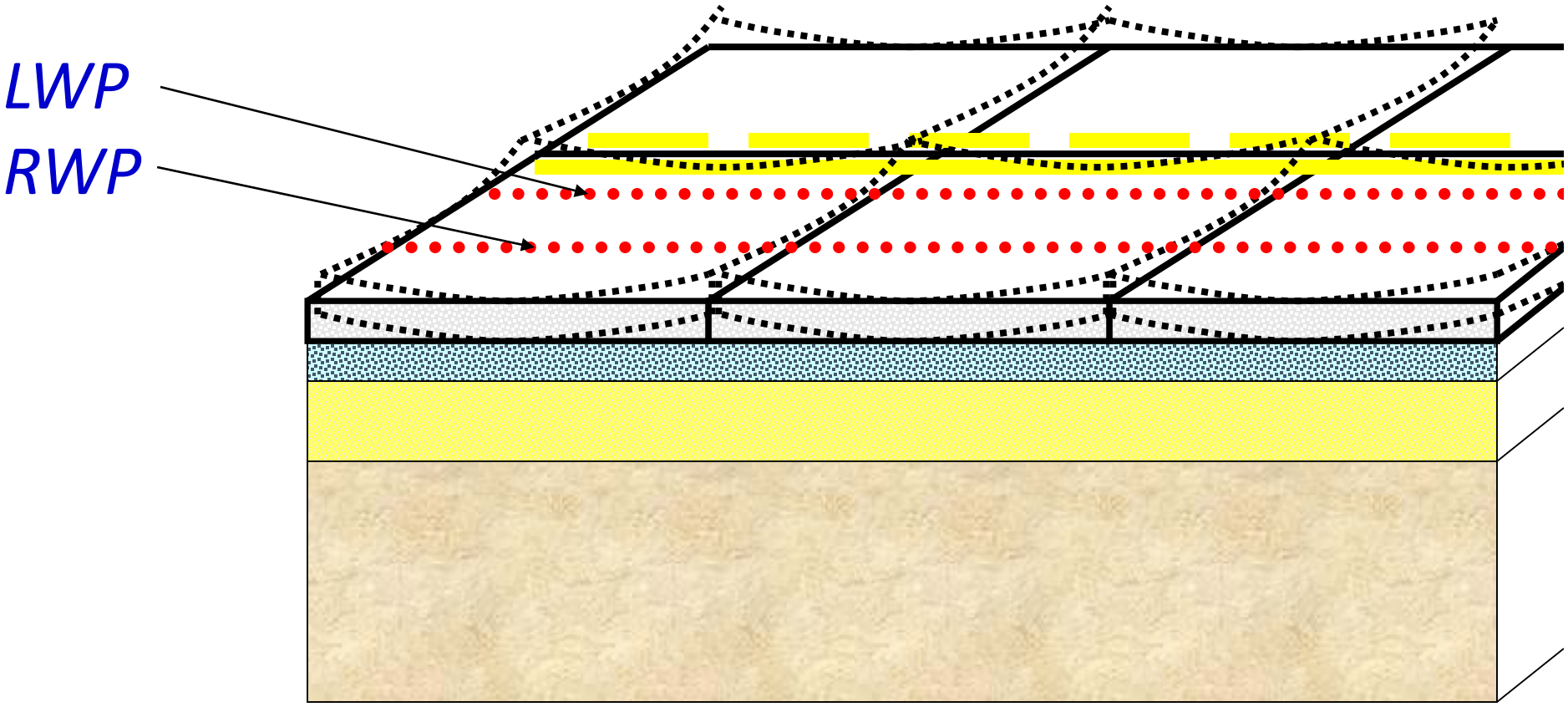
3-D Analyses:

$$M_x = \frac{Eh^3}{12(1-\mu^2)} \frac{\partial^2 z}{\partial x^2}$$

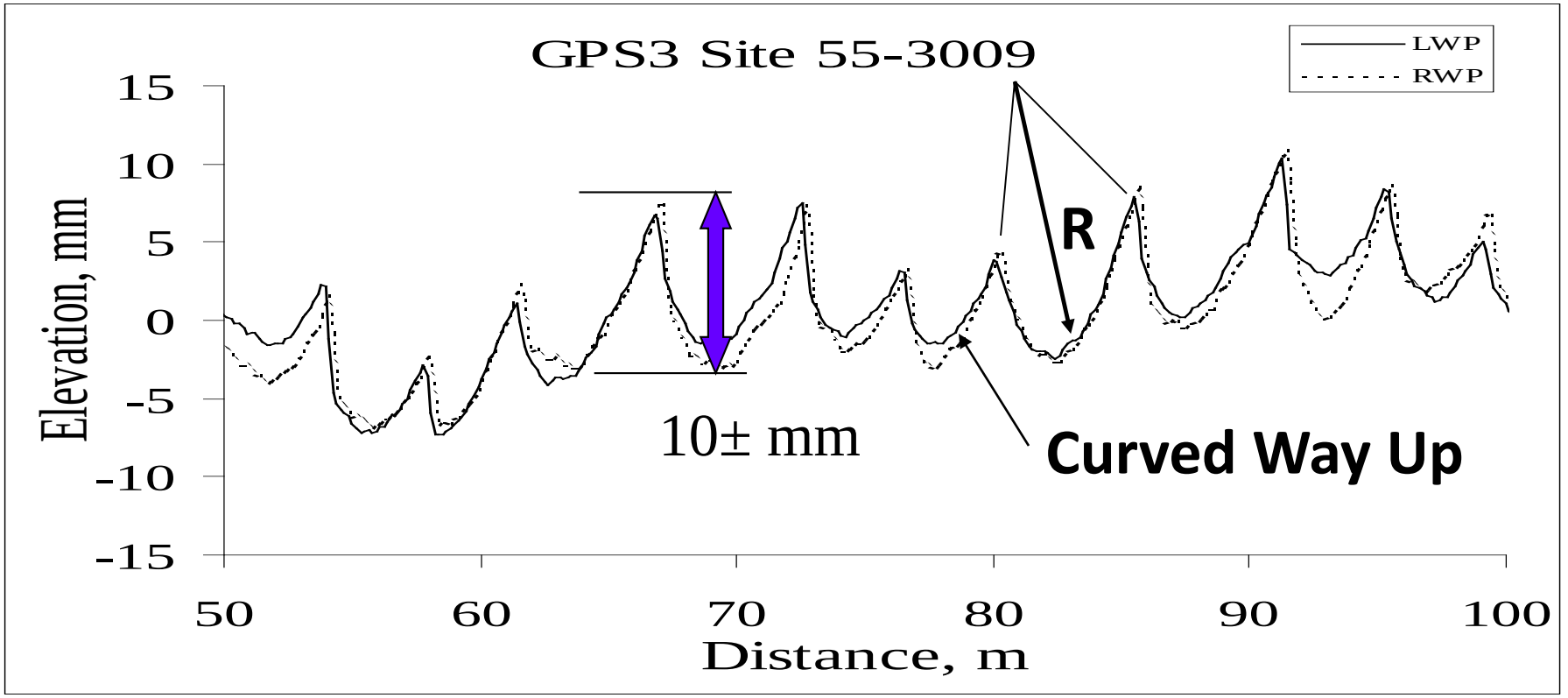
2-D Analyses:

$$M = EI \frac{d^2 z}{dx^2}$$

PAVEMENT PROFILE:
A 2-D view of a 3-D Engineering Solution



RPUG Road Profile Users' Group



Profile Date: June 19, 1992

Profile Time: 15:51:44

*** "Thermally" Curved-Down at this time of day.**

*** High Level of "Locked-In" Warp and Faulting.**

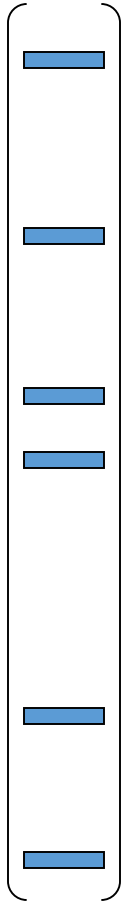
Split Profile into 2 Sub-Matrices

Raw Profile

X1	L1	R1
X2	L2	R2
X3	L3	R3
.	.	.
.	.	.
Xn	Ln	Rn

=

Discontinuities (cracks, joints...)



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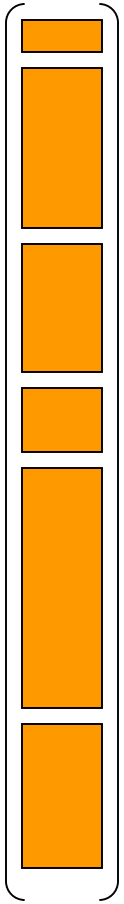
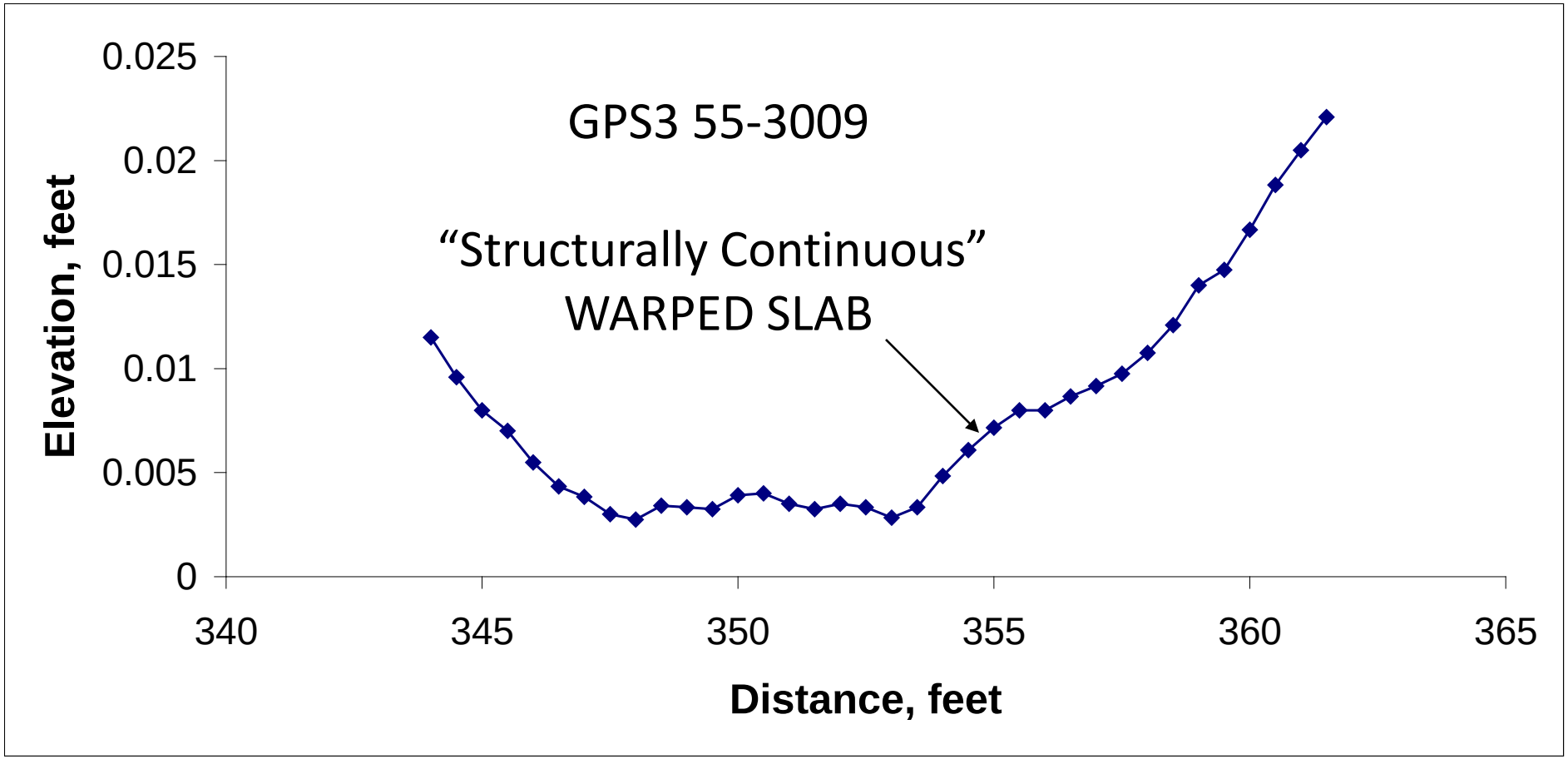
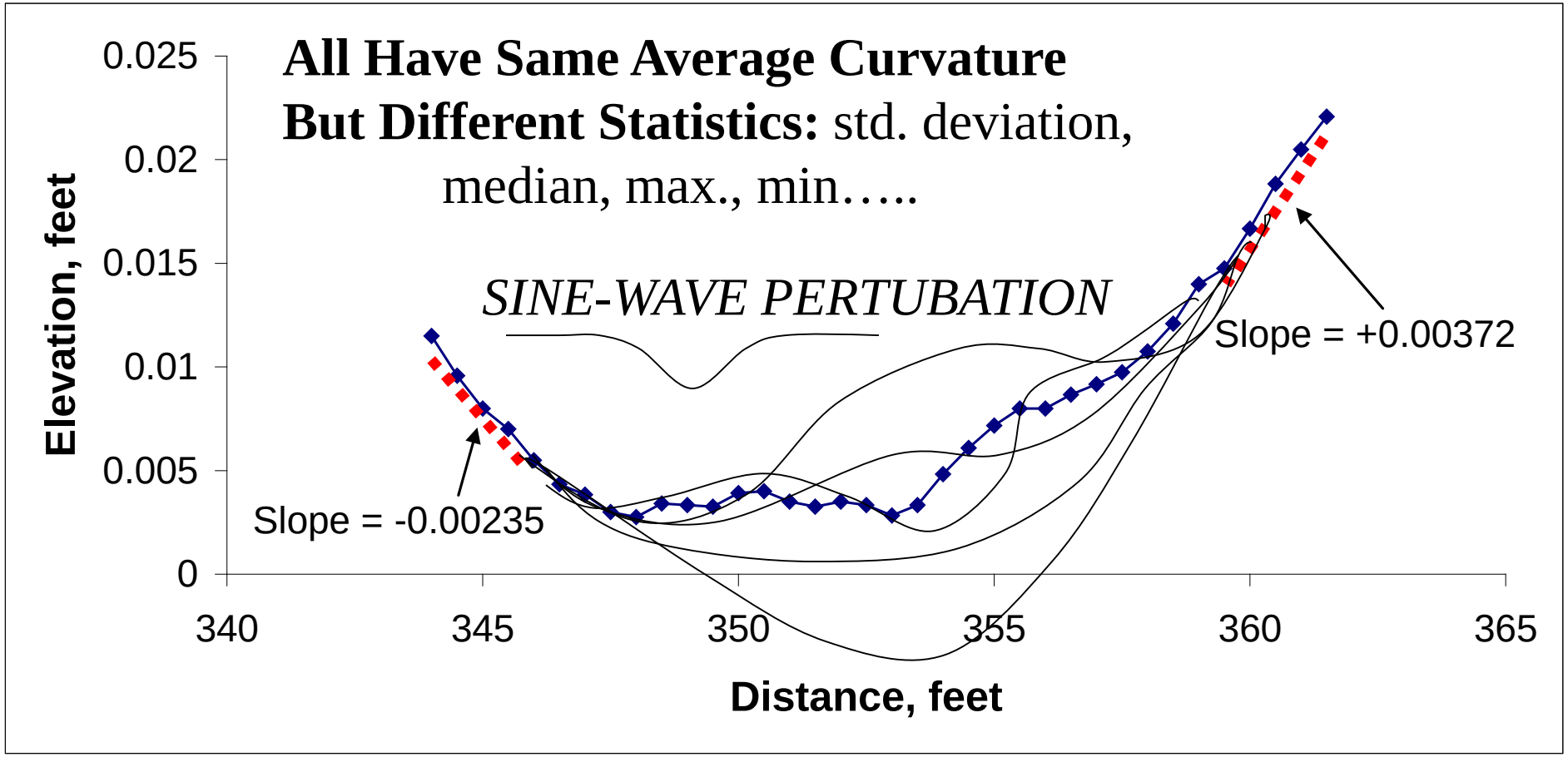
Continuous Slab Segments



What is the Curvature of This?

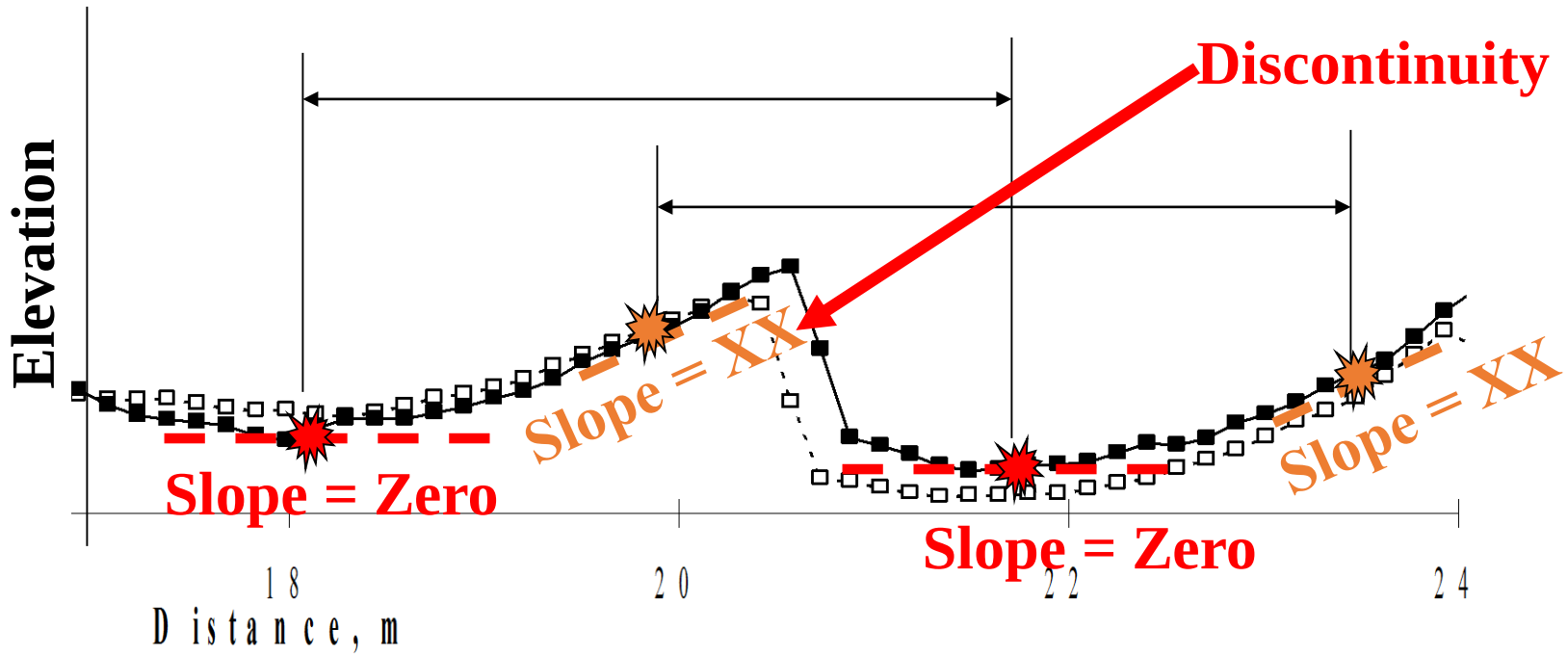


See TRB Paper# 092061: Measuring Curvature in Concrete Slabs and Connecting the Data to Slab Modeling Theory

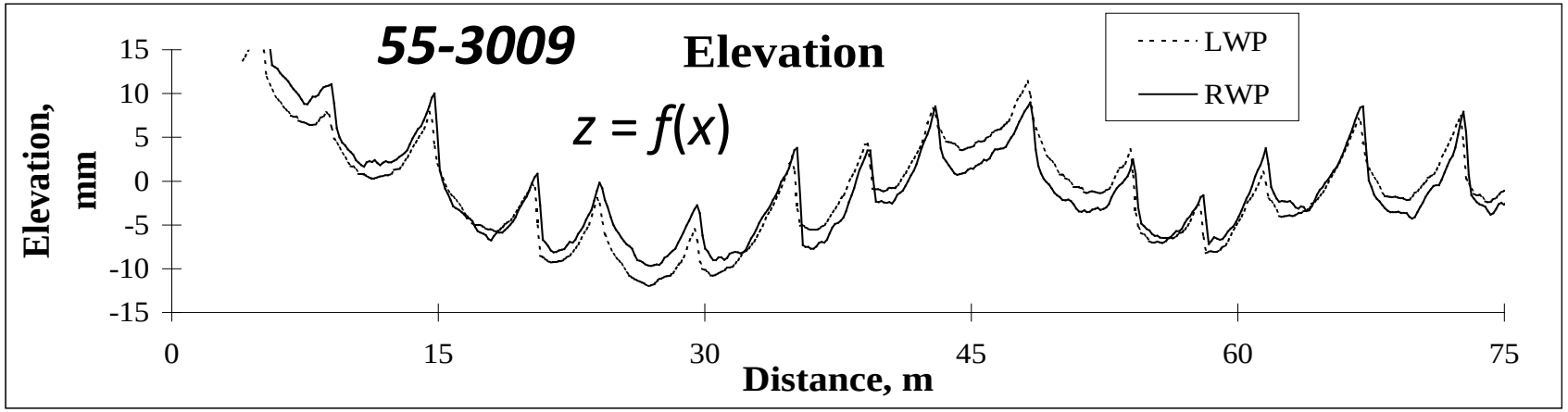


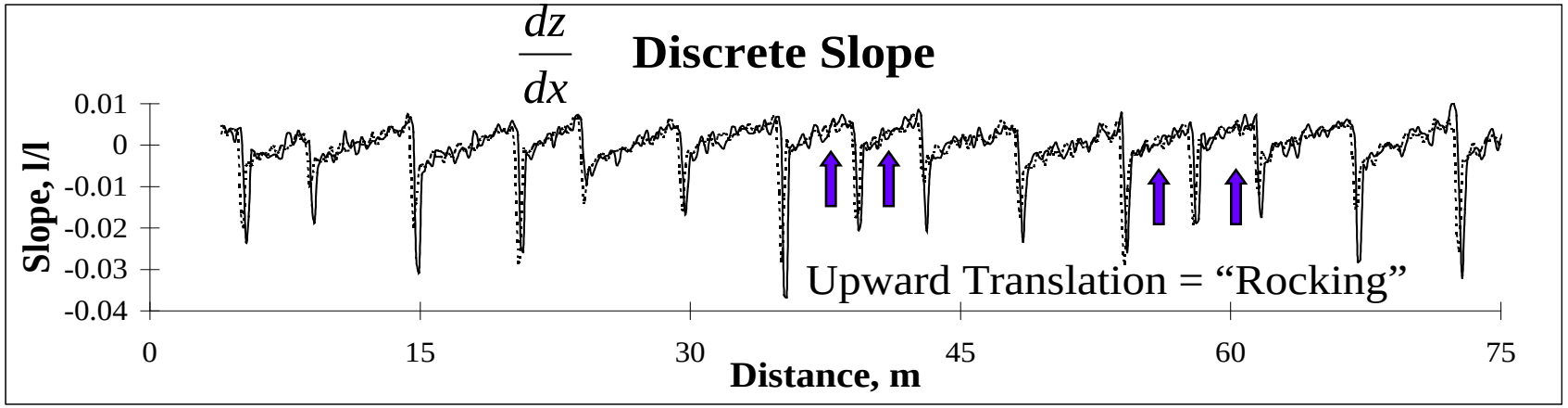
$$\kappa_{mean} = \frac{\int_0^L z''(x)dx}{L} = \frac{z'(L) - z'(0)}{L}$$

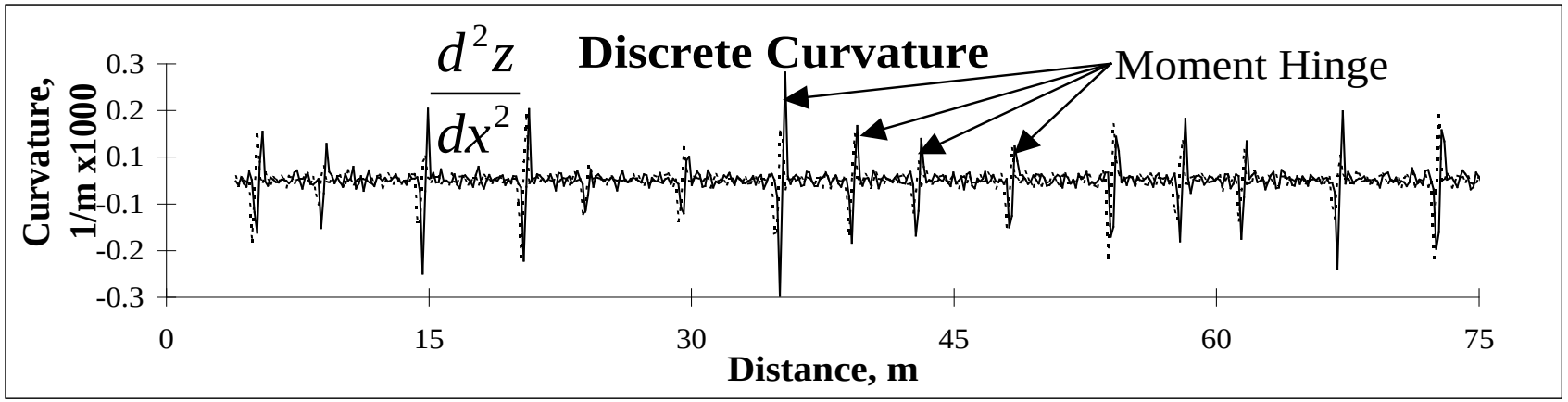
κ_{AVG} concept not valid through a working/hinging joint or crack



Average Curvature Over These Spans = Zero







See TRB Paper No. 06-0711
For how to evaluate slab tilt and pumping from profile slope data

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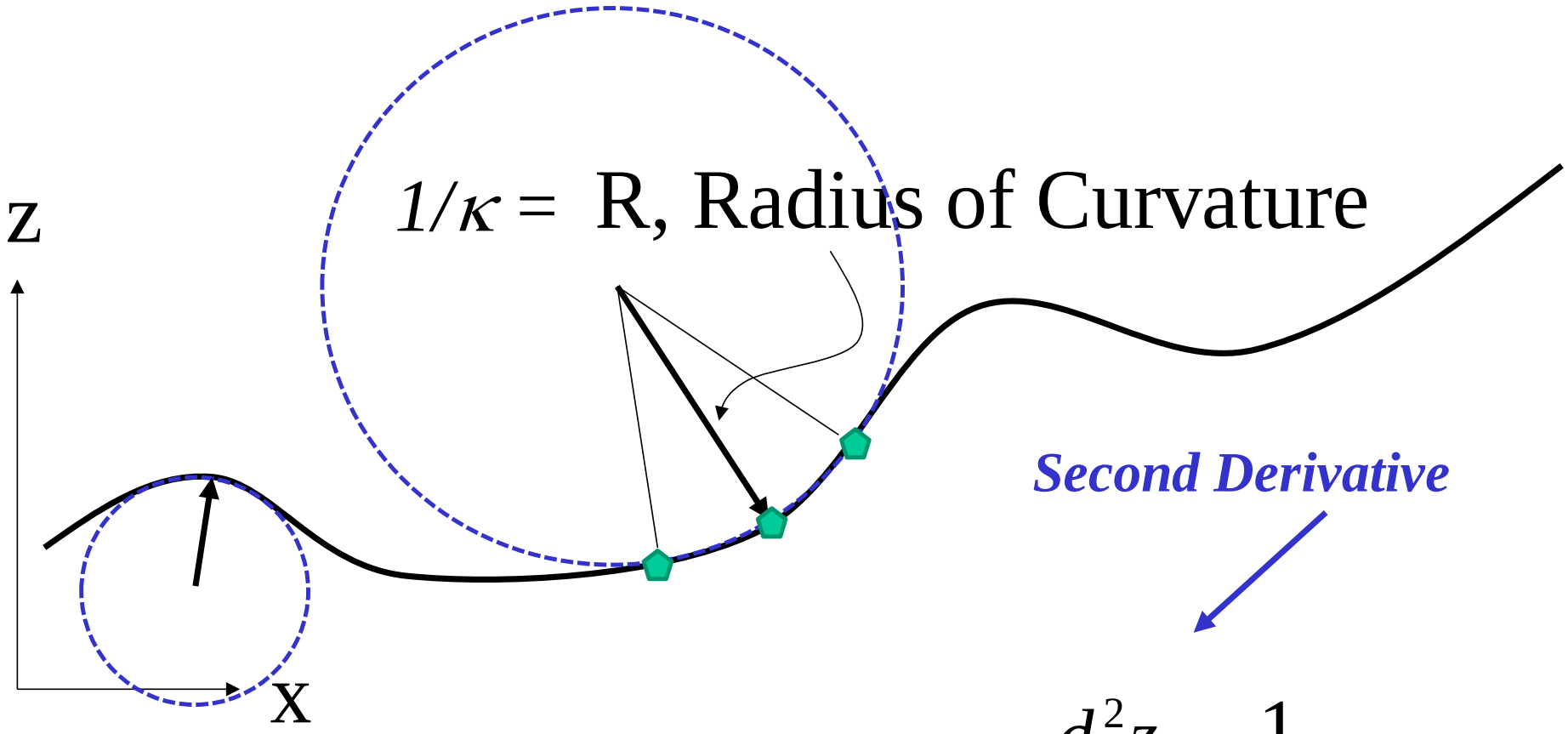
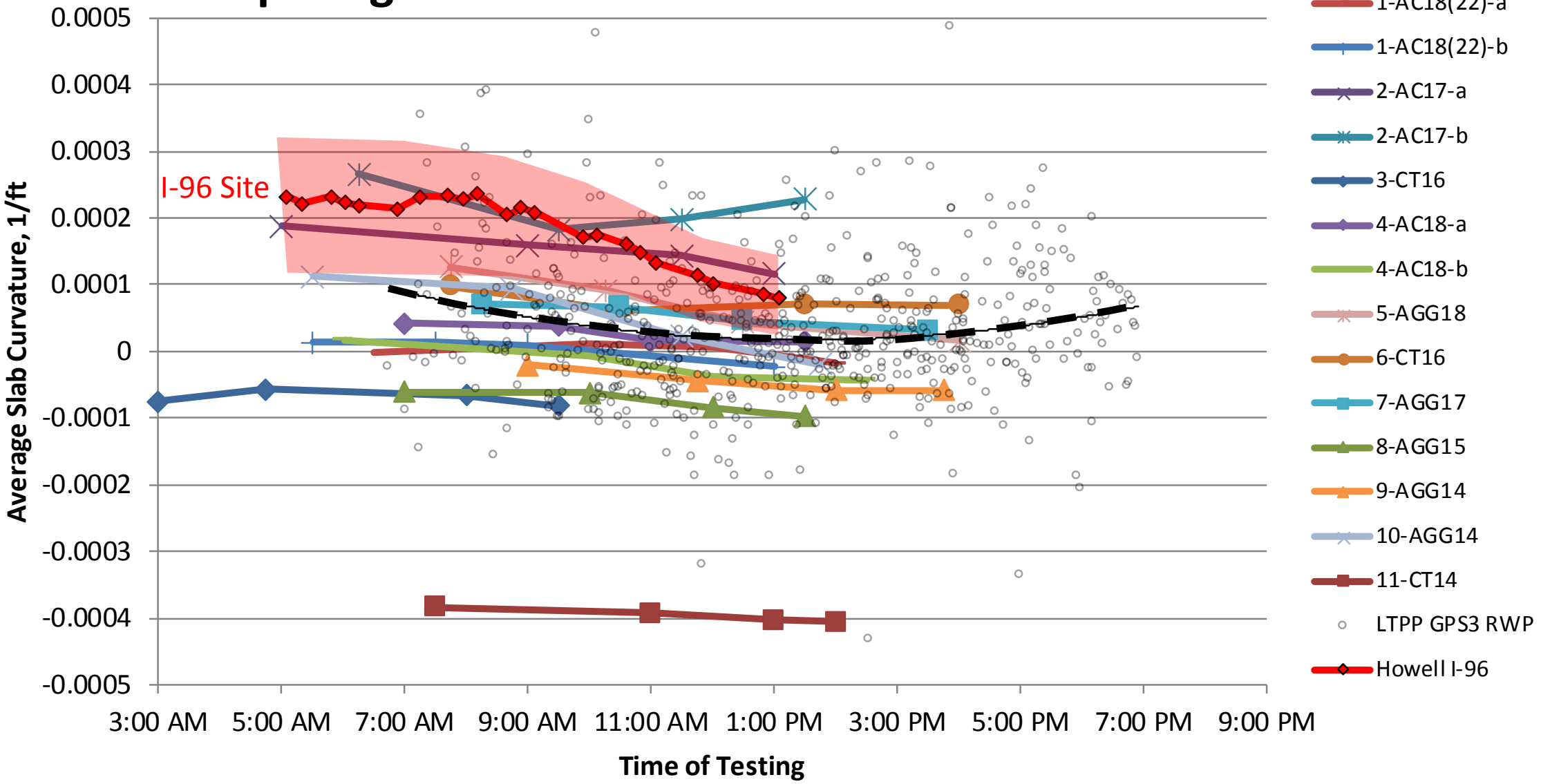


$$\textbf{\textit{CURVATURE}} \text{ of } f(x) = \kappa \approx \frac{d^2z}{dx^2} \quad \frac{1}{R}$$

Comparing to National Database



Search “IPRF Joint Load Transfer” for Final Report describing airfield test sites shown

30 years on the Road To Progressively Better Data

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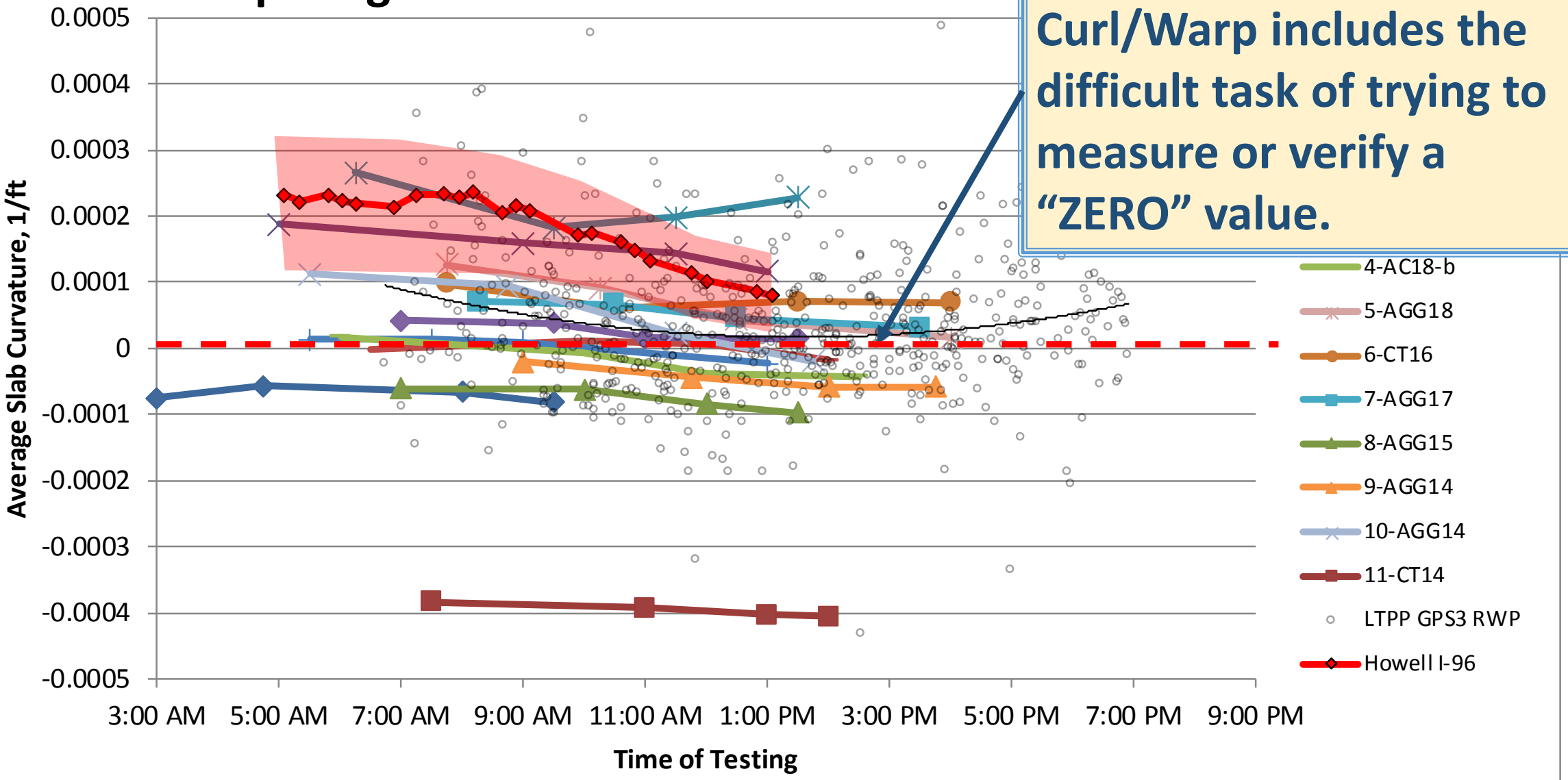
Comparing to National Database



Trying to Measure Curl/Warp includes the difficult task of trying to measure or verify a "ZERO" value.

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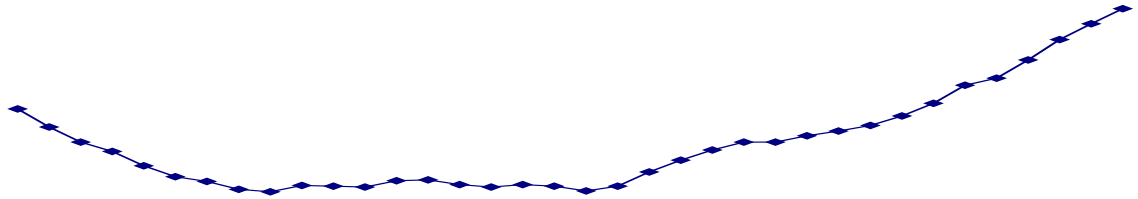
OK, ***Zero*** +/- How Much ????

How precise is your method?

Precision mostly related to texture size

For a single 18-ft slab we get:



Arc lengths = 8’ 7’ 6’ 5’ 4’ 3’ 2’ 1’

# of arcs = 20+22+24+26+28+30+32+34 Arc Values

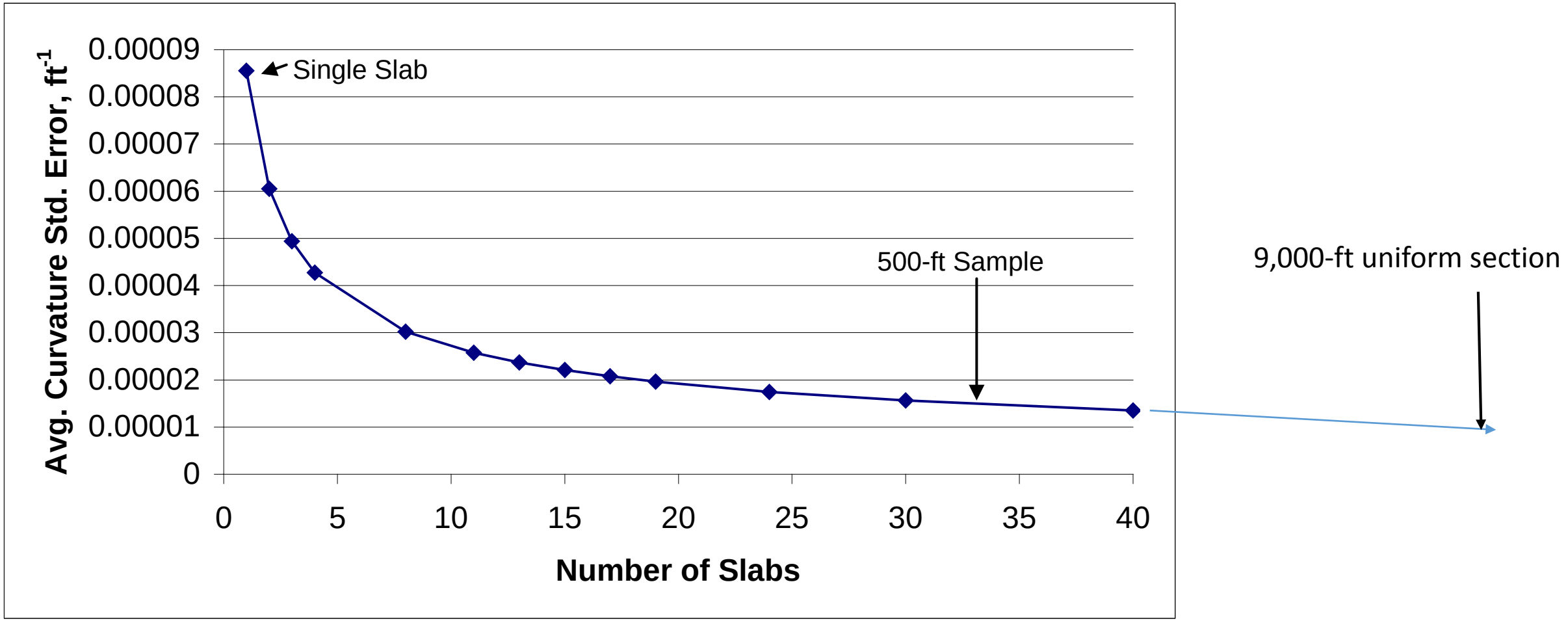
= **216 Arc Values from 18-ft Slab LWP**

2 Wheel Paths = 432 arcs, 32 end slopes, 16 κ-strings

Report: Curvature Frequency Distribution
Number of Arcs
Standard Deviation of Arc Curvatures
Median, Avg, Max, Min Curvature
Average Continuous Segment Length
Fault Sizes.....many other indices

The Central Limit Theorem- For any large population having finite standard deviation, the mean of sample size, *n*, approaches the mean of the population as *n* becomes large.

Standard Error for Predicted Mean Curvature = $\frac{\sigma_{\kappa}}{\sqrt{n}}$



Standard error values are most related to the size of pavement surface texture and surface finishing/flaw features.

Curvature analysis summary output table.

Software calculates the curvature statistics for the raw data arcs, and then does the same arc calculations on cubic splines fit at 2.5-ft intervals through the raw data. Standard error is reduced using a spline fitting technique.

0.0072/sqrt(18) = 0.0017 ?

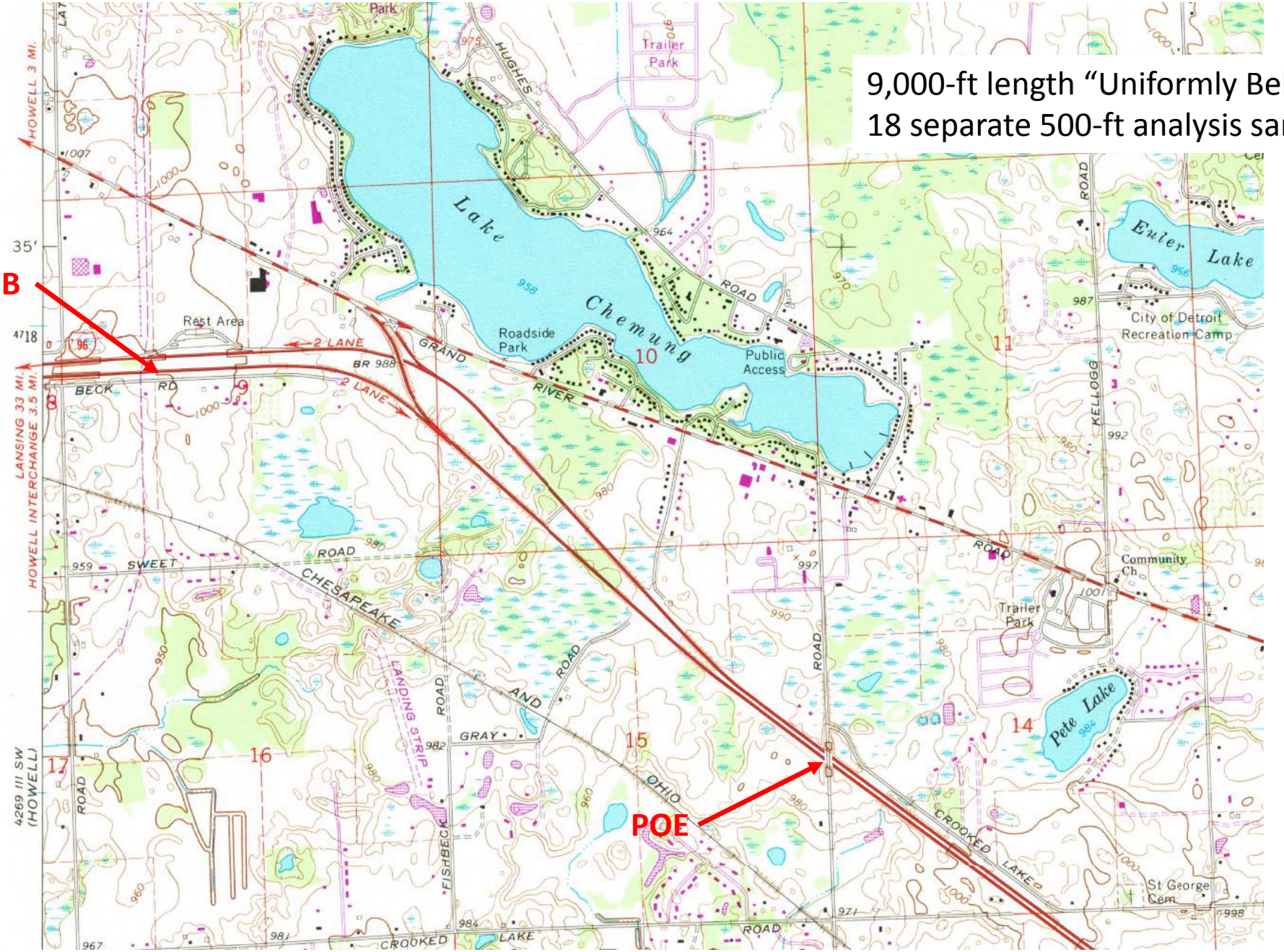
Site: R10 Middle Lane, 5500-6000
Profile Date: 10/23/15
ProfileTime: 8:11 AM

Curvature Summary

Avg. hinge spacing = 11.9

Curvature Index	Value	Sample Size	StdDev	Std Error of Mean
Leave Slab Arcs	0.27	1228	2.41	0.069
Approach Slab Arcs	0.30	518	2.50	0.110
6" Arcs	0.25	1380	2.43	0.065
12" Arcs	0.29	1029	1.06	0.033
18" Arcs	0.29	874	0.63	0.021
24" Arcs	0.30	735	0.44	0.016
30" Arcs	0.30	617	0.34	0.014
36" Arcs	0.30	512	0.29	0.013
42" Arcs	0.29	415	0.26	0.013
48" Arcs	0.29	330	0.24	0.013
6" Spline Arcs	0.25	1380	0.65	0.018
12" Spline Arcs	0.31	1031	0.42	0.013
18" Spline Arcs	0.32	875	0.34	0.012
24" Spline Arcs	0.31	735	0.29	0.011
30" Spline Arcs	0.31	617	0.27	0.011
36" Spline Arcs	0.29	512	0.26	0.012
42" Spline Arcs	0.26	415	0.26	0.013
48" Spline Arcs	0.30	330	0.22	0.012
All Arc Average	0.28	7638	1.33	0.015
All Arc Mean	0.31	7638	1.33	0.015
All Arc Median	0.33	7638	1.33	0.015
Spline Average	0.29	5895	0.42	0.006
Spline Trim Mean	0.32	5895	0.42	0.006
Spline Median	0.32	5895	0.42	0.006
Leave Slab Splines	0.30	1228	0.56	0.016
Approach Slab Splines	0.26	518	0.64	0.028
Short Slab Index	0.33	3283	1.71	0.030
Old Byrum CI (1999)	0.2816	5	0.0219	0.010
Current Byrum CI	**0.2872**	**15279**	**0.89**	**0.0072**

Curvature Units = ft^{-1} x 1000



30 years on the Road To Progressively Better Data

RPUG Road Profile Users' Group

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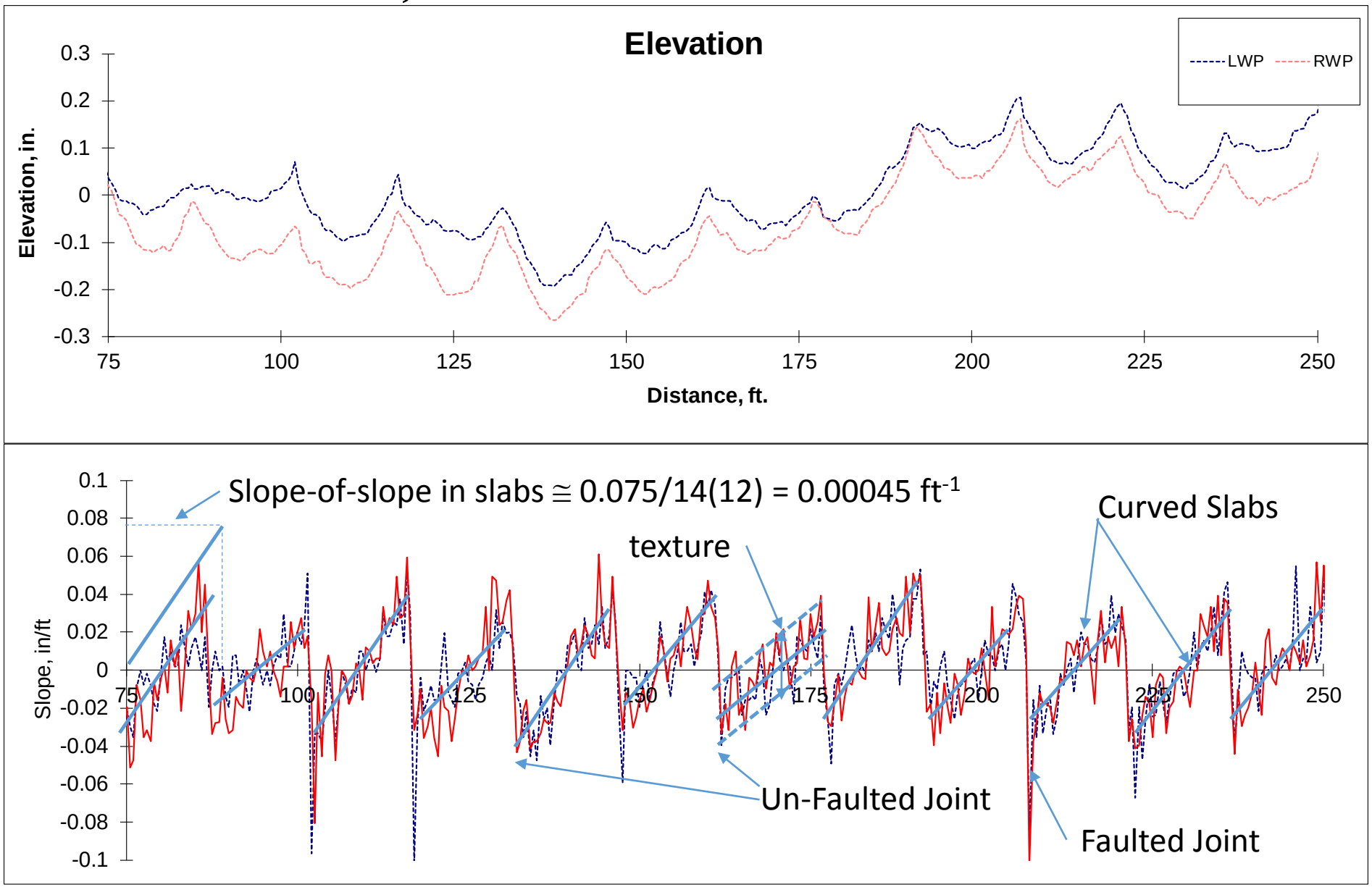
R10 Middle Lane, 5500-6000 23-Oct-15 8:11:00



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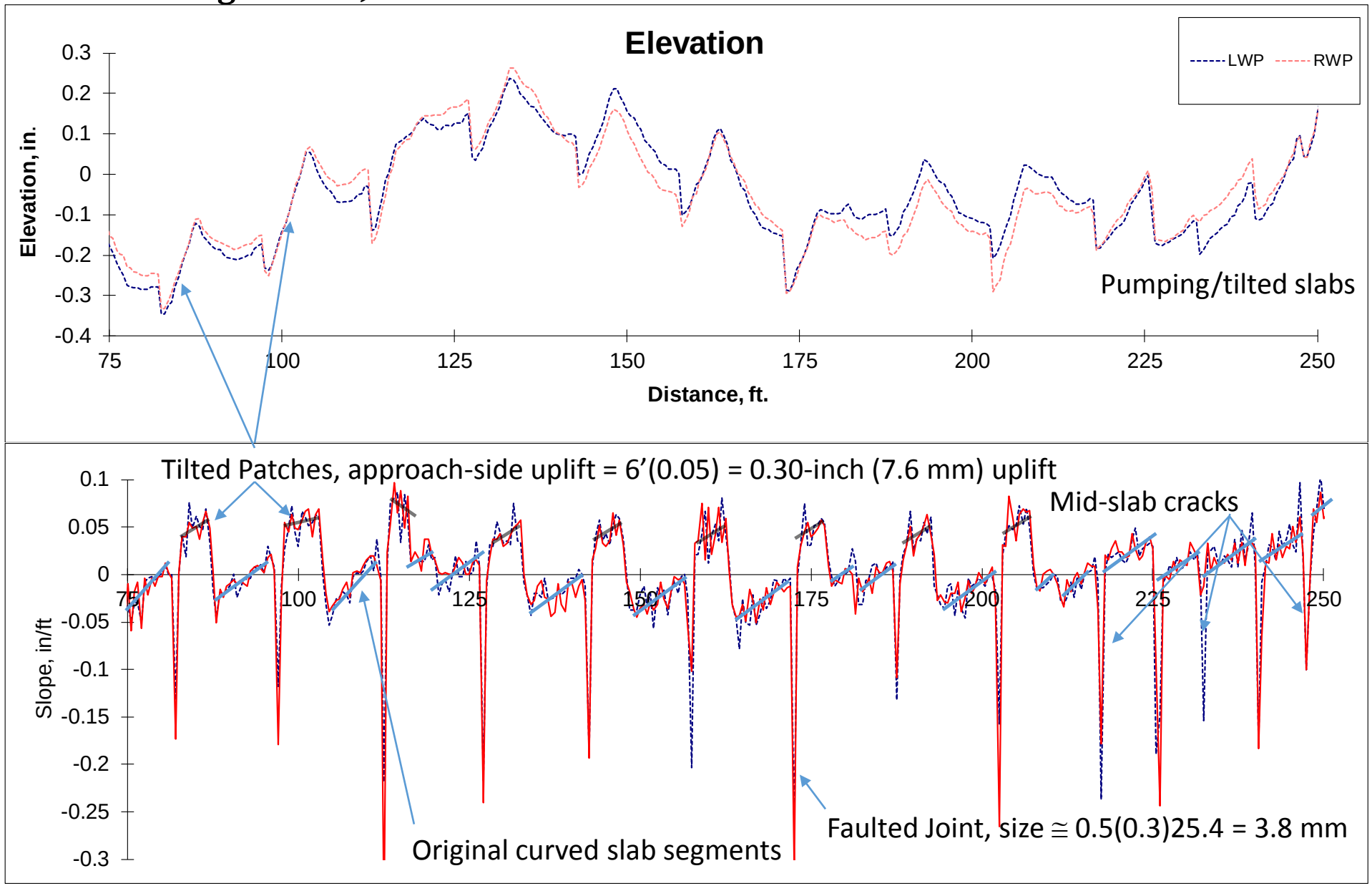
R2 Right Lane, 5000-5500 23-Oct-15 6:29:00



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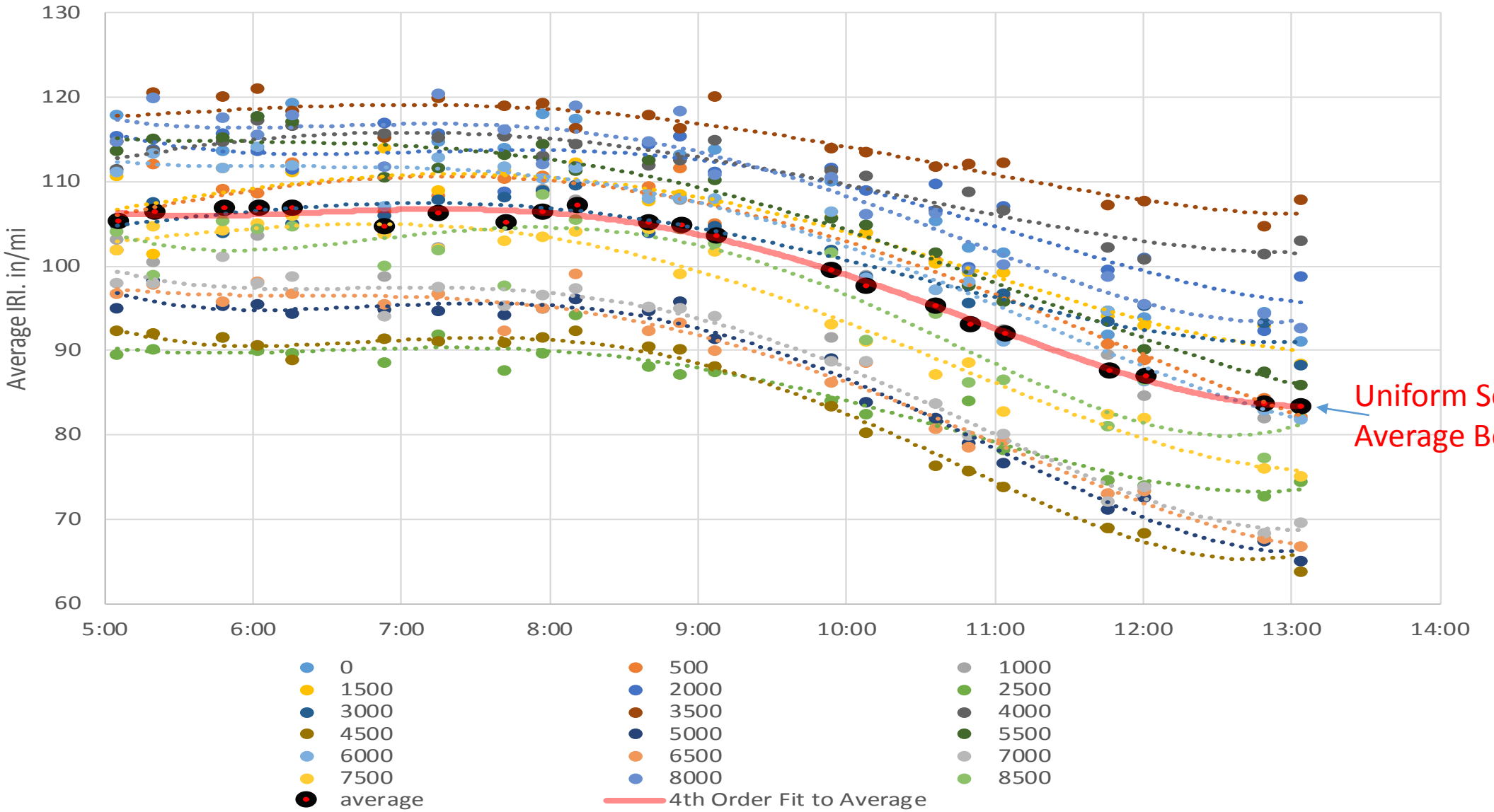
IRI trends per 500-ft segment

EB I-96 Howell

22 profiles obtained 5AM to 1PM



Uniform Segment Average Behavior

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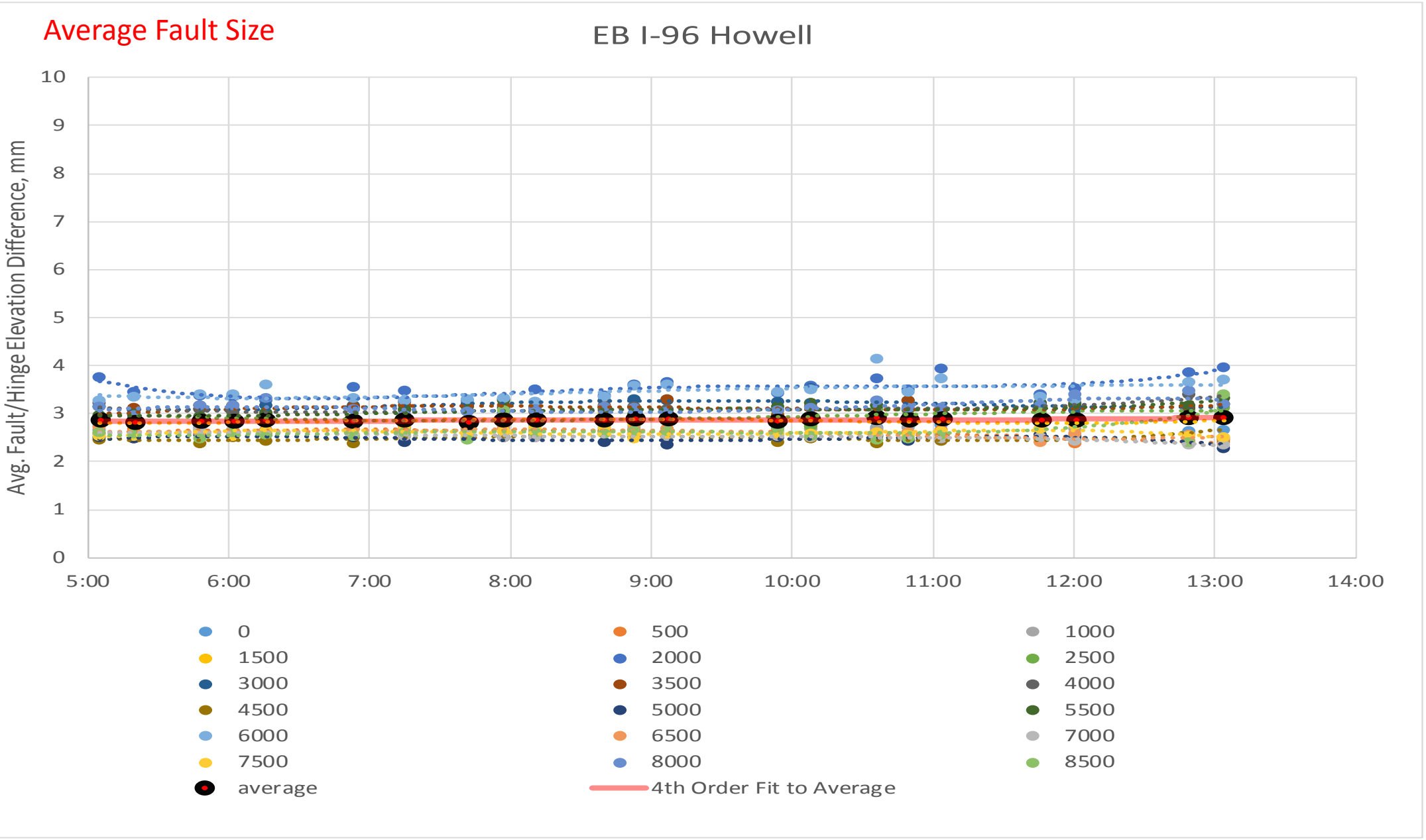
Average Fault Size



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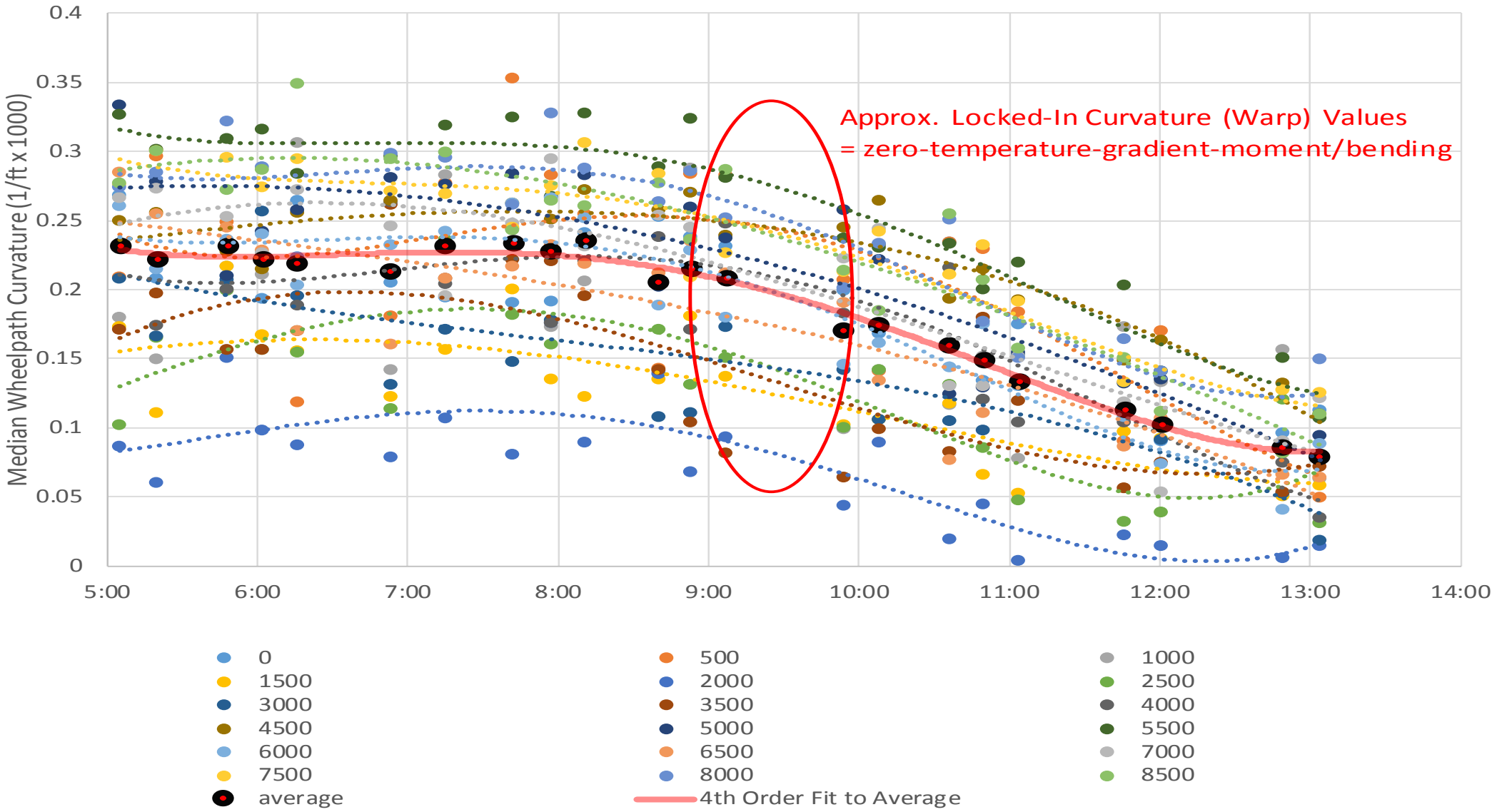
Slab Curvature Index, CI

EB I-96 Howell

22 profiles obtained 5AM to 1PM



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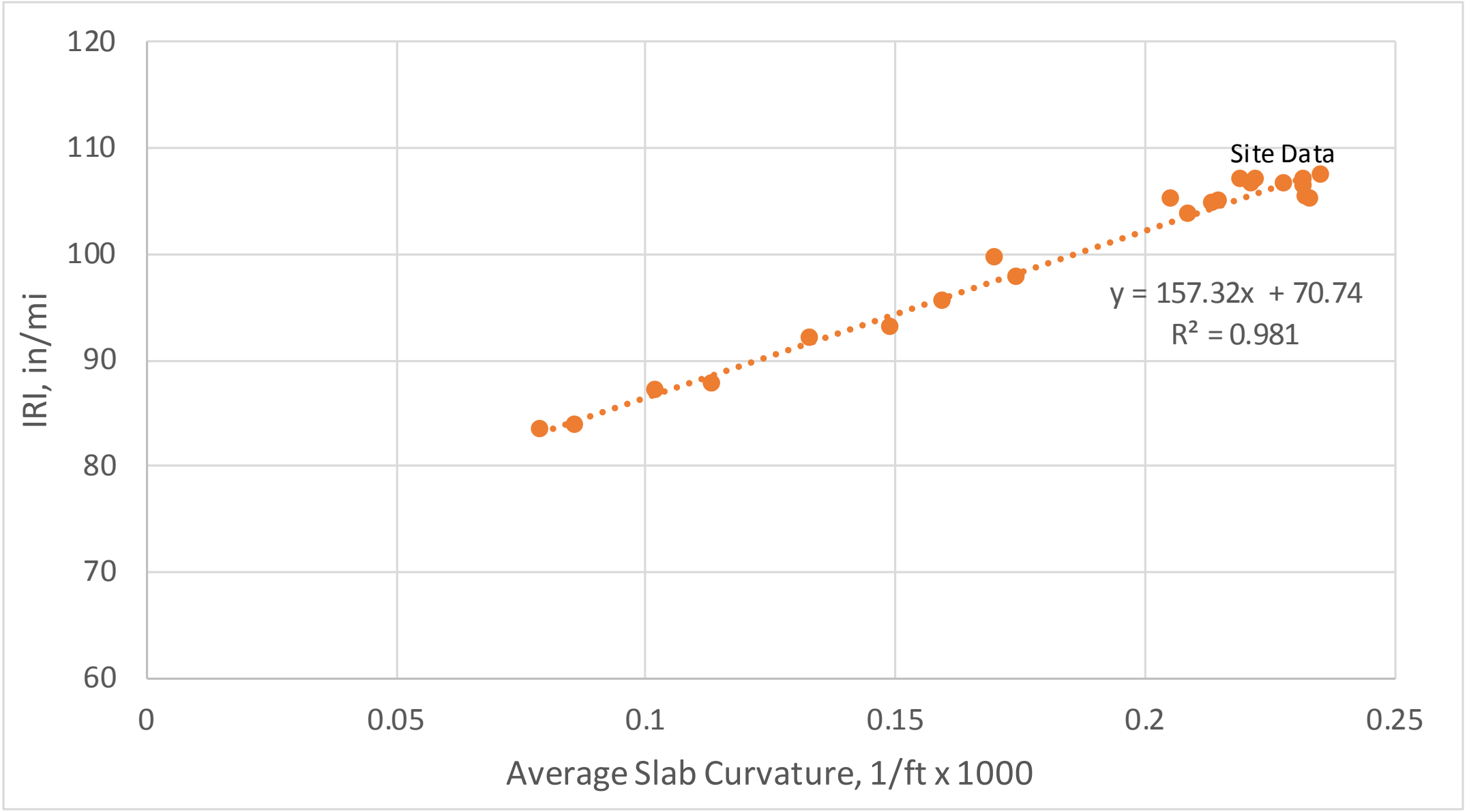
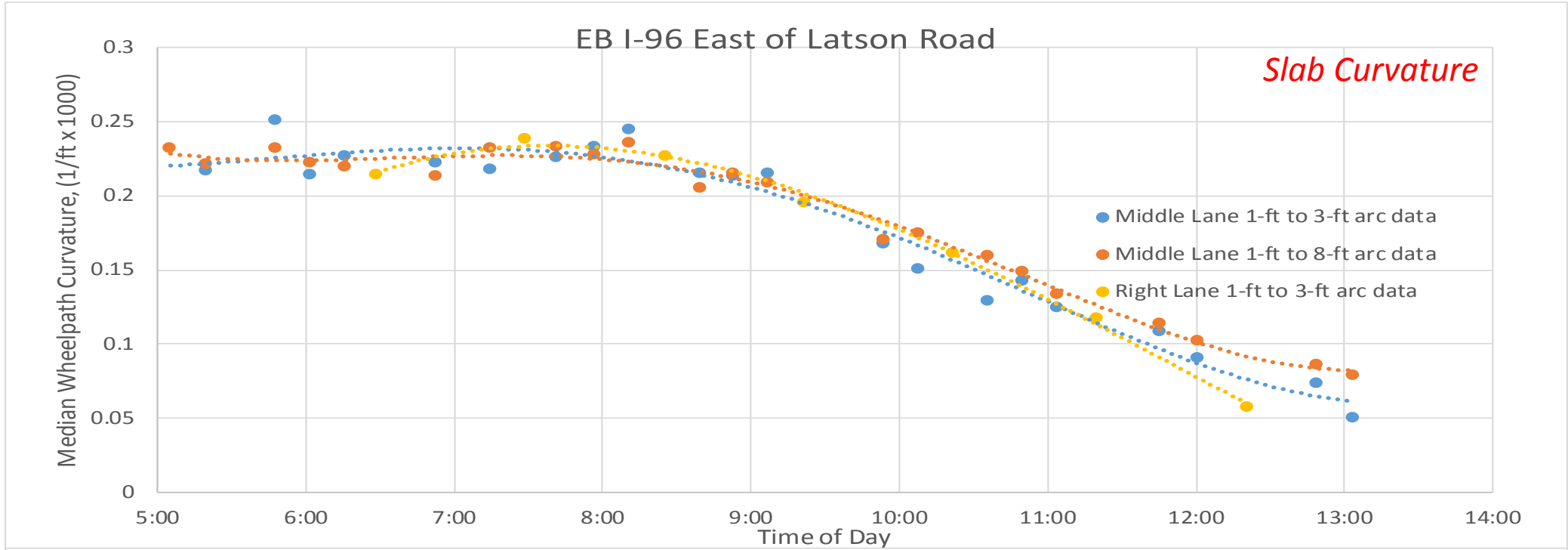
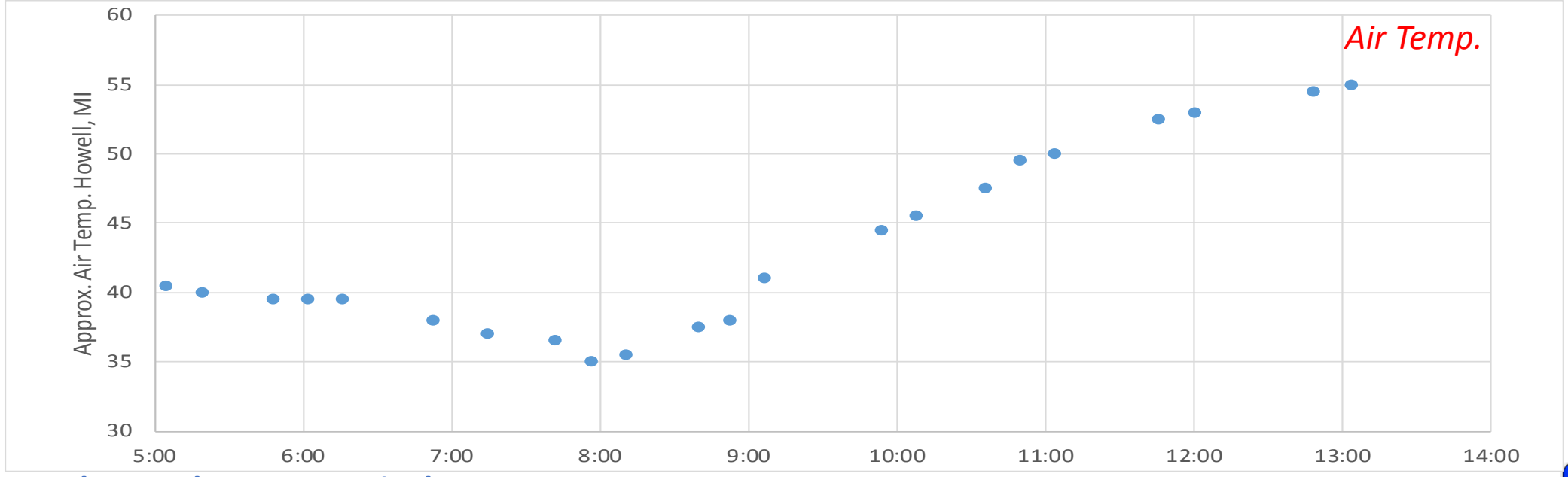
Site-Specific Curling vs. IRI trend: Sites with longer slabs would likely have steeper sloped trends







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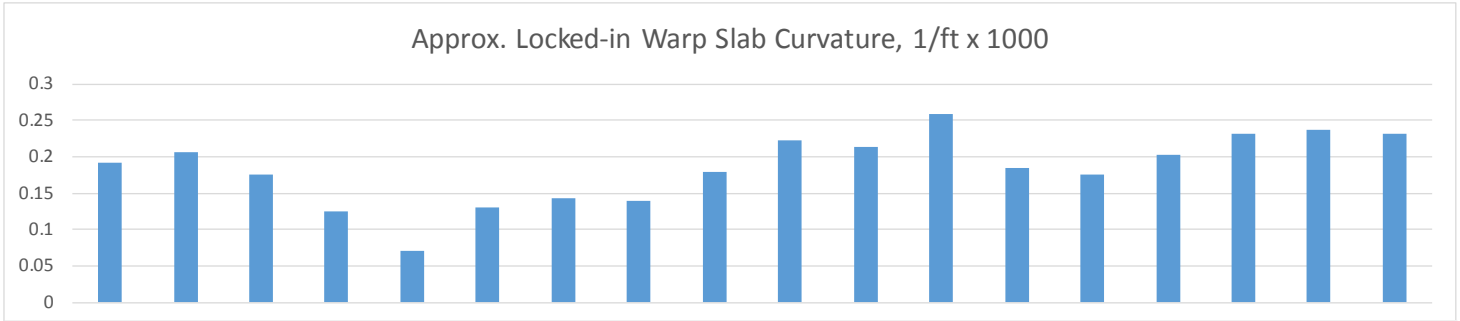
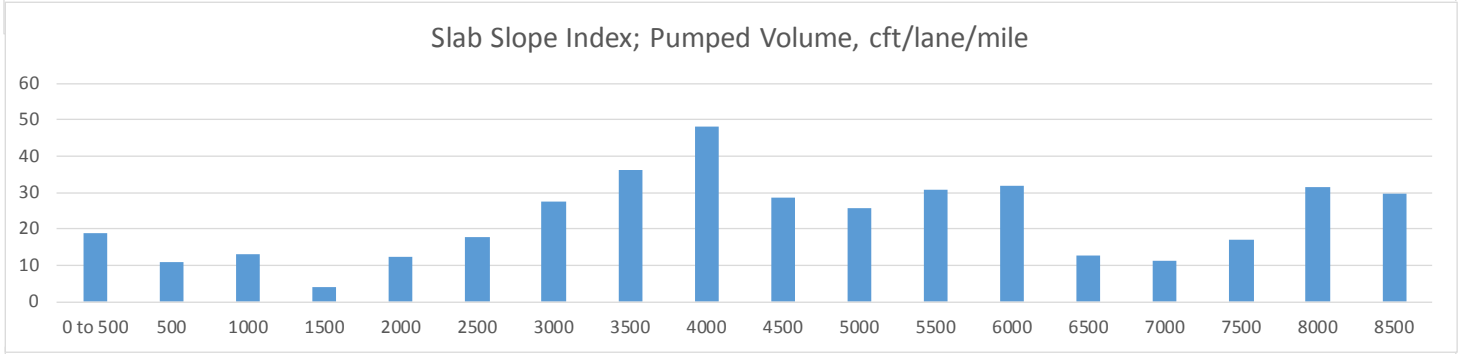
500-ft averages

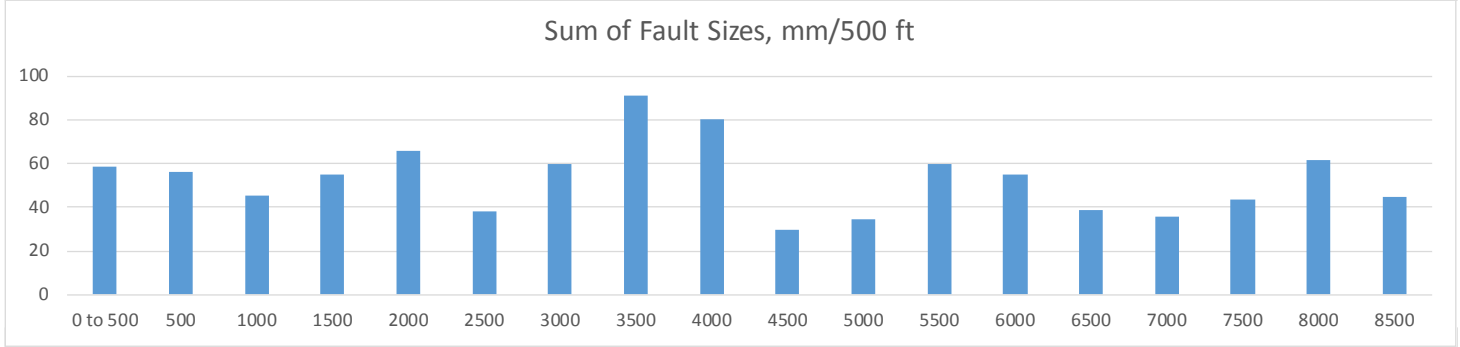
Slab Warp $\frac{d^2z}{dx^2}$



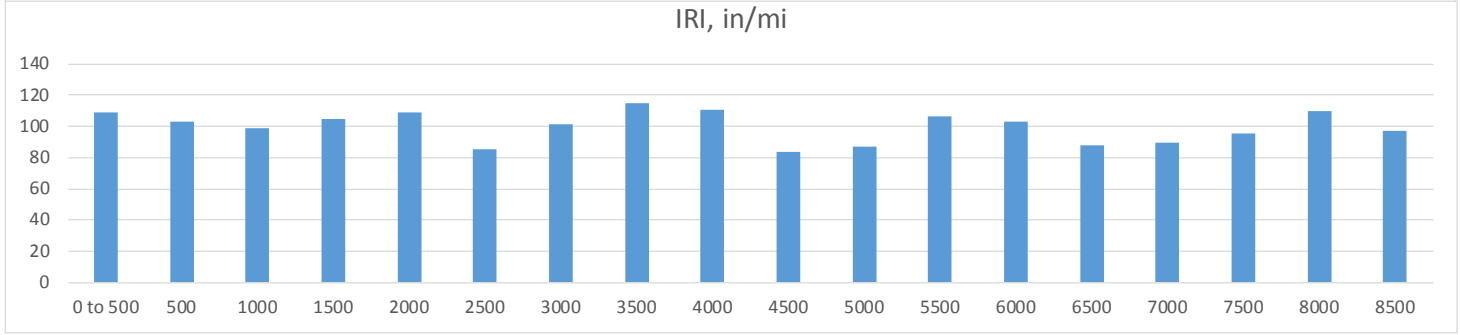
Slab Tilting/Pumping $\frac{dz}{dx}$



Discontinuities



Ride Quality Index



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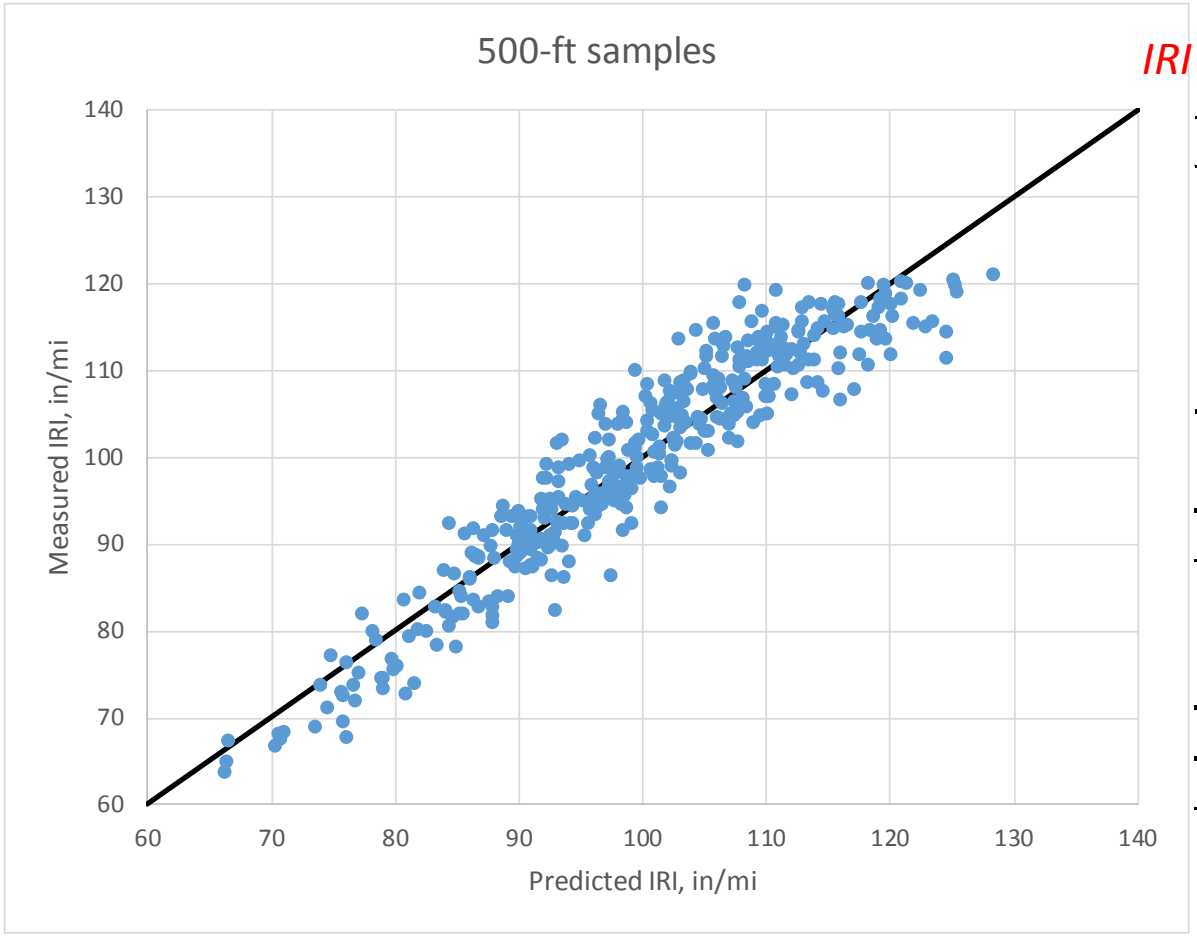


IRI Prediction from profile shape parameters: simple linear regression

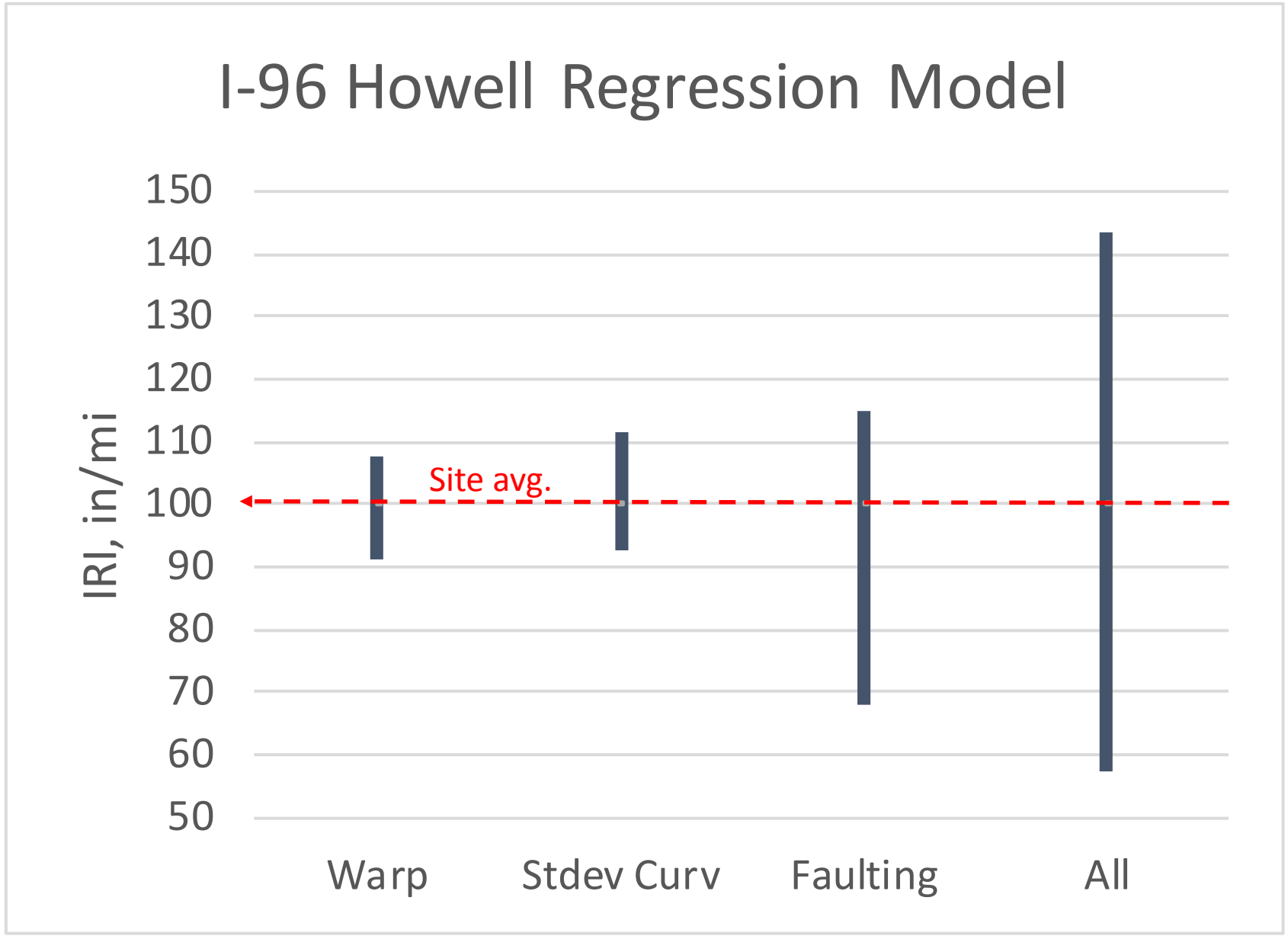
Regression Statistics	
Multiple R	0.94732273
R Square	0.89742035
Adjusted R Square	0.89583814
Standard Error	4.15170914
Observations	396

ANOVA

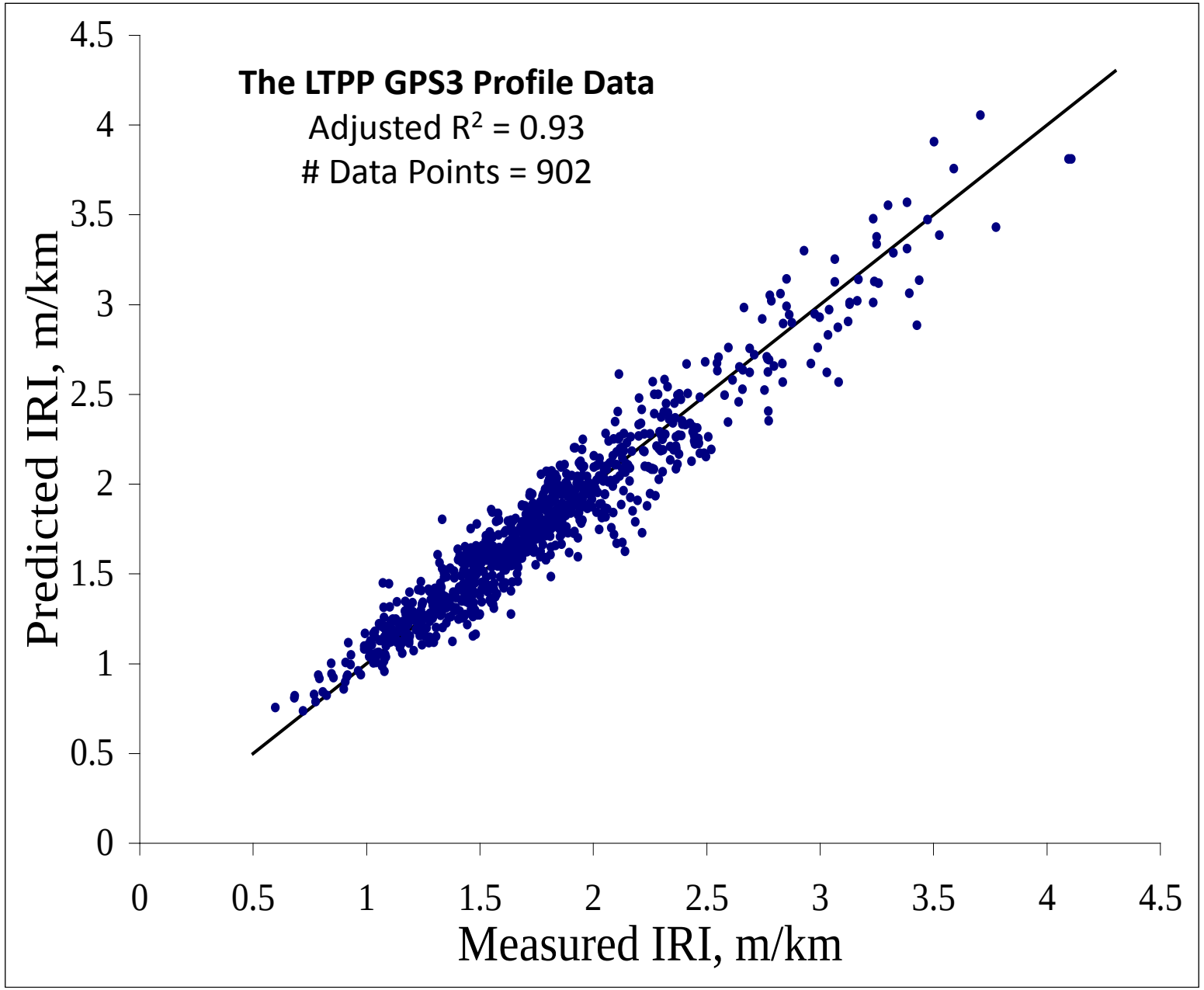
	df	*SS*	*MS*	*F*	*Significance F*
Regression	6	58659.46989	9776.578	567.1958	6.9404E-189
Residual	389	6705.071951	17.23669		
Total	395	65364.54184			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	25.9744358	4.747270717	5.471446	8.01E-08
CI_median	47.8168985	3.529127219	13.54921	1.57E-34
12StdevCI	12.1703799	3.171571857	3.837334	0.000145
36StdevCI	30.036206	3.719987784	8.074275	8.58E-15
Avg Flt Size	5.593806	1.35289643	4.134689	4.36E-05
#Faults	0.50723744	0.305084711	1.662612	0.097196
ToTFlt, mm	0.82260559	0.244979056	3.357861	0.000863

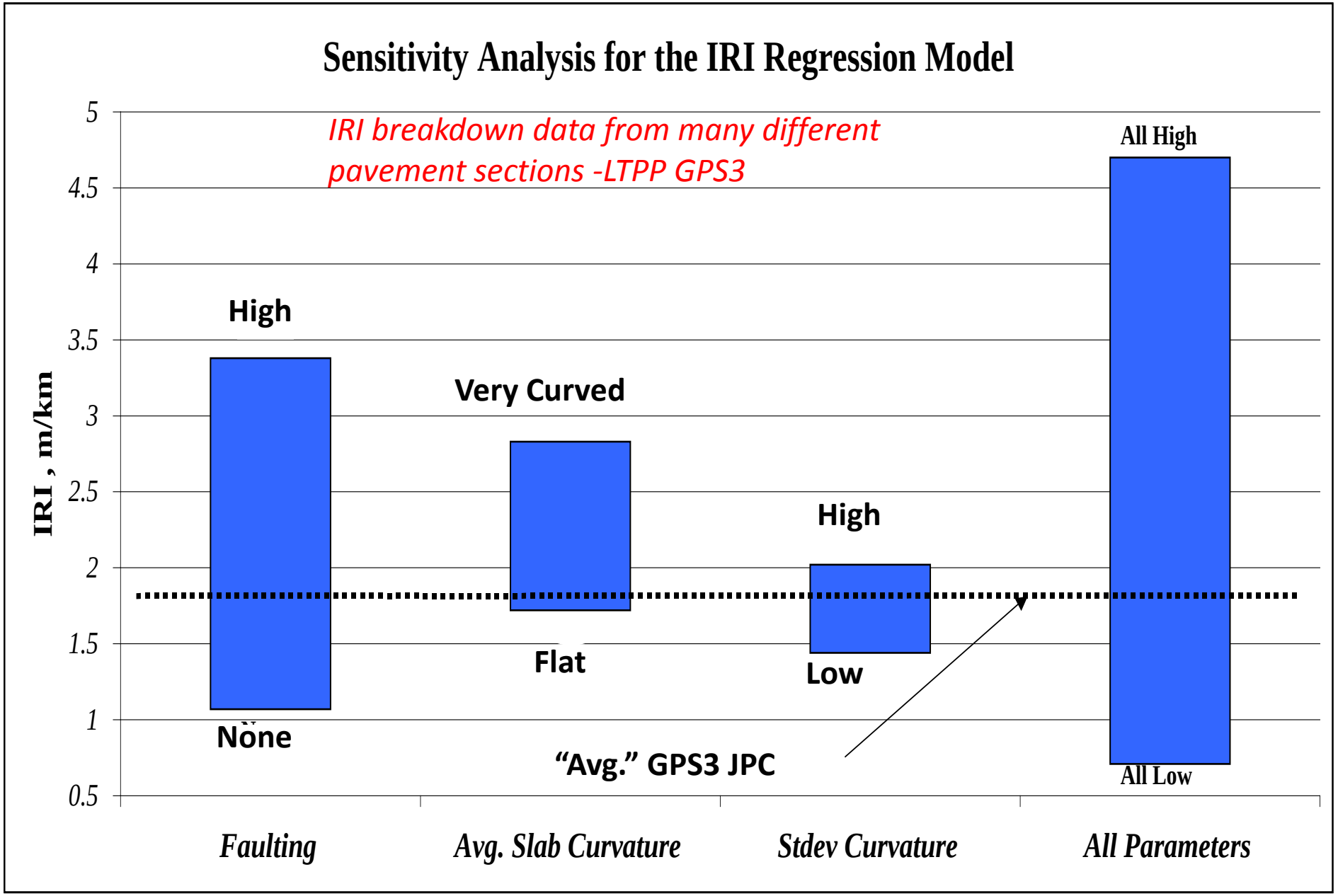
IRI breakdown data from a single uniformly behaving section



IRI breakdown data from a single uniformly behaving section



IRI breakdown data from many different pavement sections from the LTPP GPS3



≅ 115 in/mi

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TEST SITE SUMMARY

Curling = "Average Slab Curvature ***Change***" ≅ 0.00016 ft^{-1} change for a total change in air temperature of about 20 degrees Fahrenheit over a 5-hour period 8AM (min. temp) to 1PM (max. temp) for testing in October.

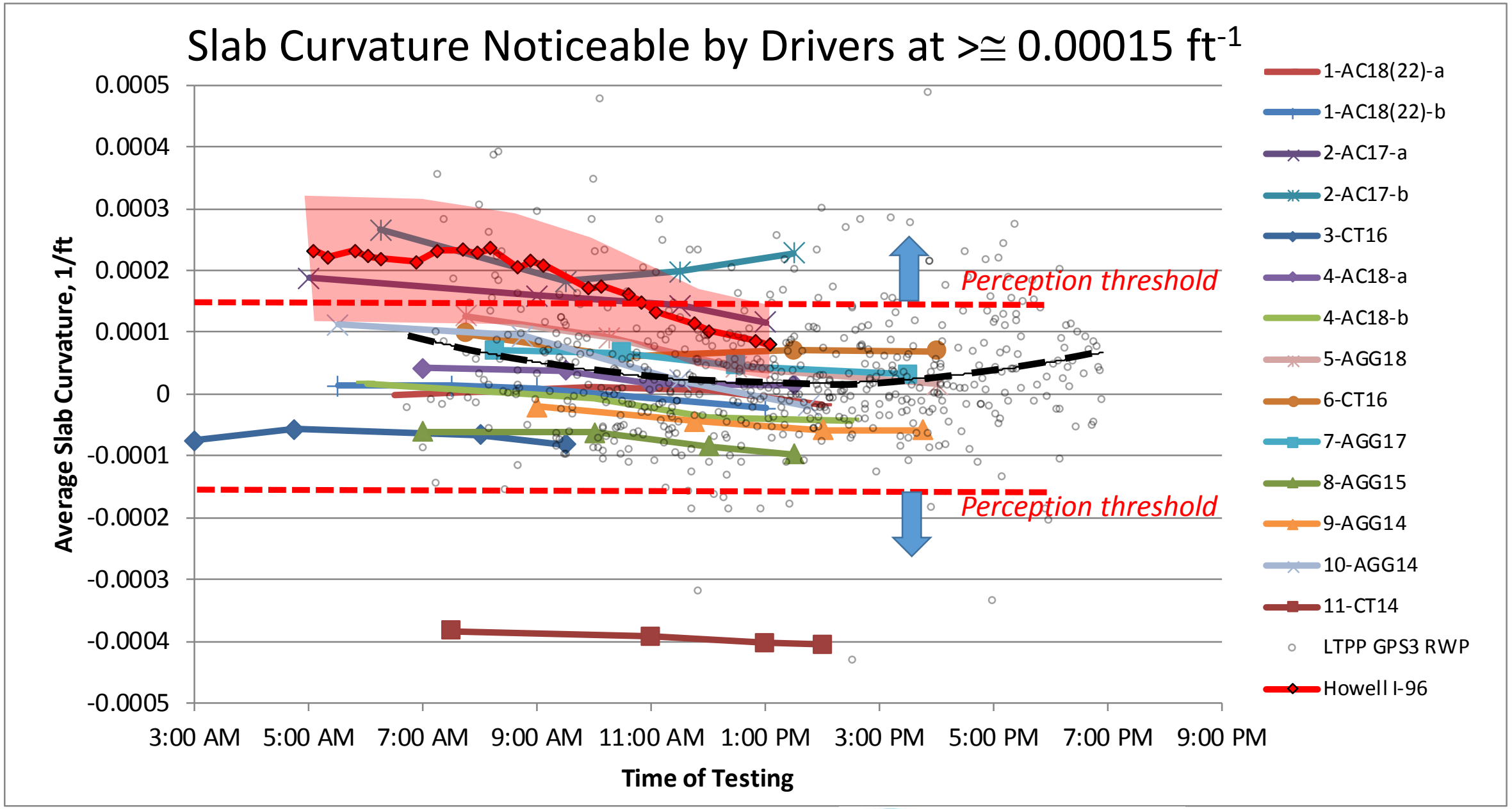
Warping = "Average Slab Curvature at/near Zero-Gradient Time" ≅ +0.00020 ft^{-1}, with apparent locked-in warp curvatures in the 500-ft samples ranging between about +0.00026 and +0.00007 ft^{-1}

Middle Lane IRI 85 to 115 in/mi average of about 100 in/mi (not failed at 21 yr)

Truck Lane IRI = 165 to 300 in/mi average of about 200 in/mi (near terminal at 21 yr)

IRI Change = 25 in/mi *change* for a slab curvature *change* (curling) of about 0.00016 ft^{-1}

LTPP GPS3 = 70 in/mi change for about 0.00050 ft^{-1} range in CI



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