RPUG 2015
Road Profile Users' Group

Investigation of Curling and Warping on US 34 near Greeley, CO

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The World's Pavement Engineering Specialists

CDOT
COLORADO
Department of Transportation

Outline

- Project Background
- Data Collection
- Data Analysis
- Summary of Results
- Recommendation

Project Background

- Reconstruction of US 34 near Greeley, CO
  - Existing pavement was full-depth asphalt
- 9” JPCP over 6-8” of reclaimed asphalt base
- 15’ joint spacing (dowelled joints)
- Single pass paving (38’ wide)
- WB Construction: July 2012
- EB Construction: September 2012

Project Background

Project Background

- Initial concerns after construction of WB Lanes (July)

Contractor / CDOT Measurement Differences

Station		Contractor - Lane 1			CDOT Lane 1	Contractor - Lane 2			CDOT Lane 2
Start	*End*	*LWP*	*RWP*	*MRI*	*HRI*	*LWP*	*RWP*	*MRI*	*HRI*
554+99	549+71	62.8	59.3	61.0	89.4	61.3	63.4	62.3	103.2
549+71	544+43	61.5	54.1	57.8	77.1	59.3	54.9	57.1	96.3
544+43	539+15	55.3	43.6	49.5	74.5			3.1	87.0

> 40 in/mi difference!

Contractor Diurnal Measurement

Station		8:00 AM			1:00 PM			5:00 PM		
Start	*End*	*RWP*	*LWP*	*MRI*	*RWP*	*LWP*	*MRI*	*RWP*	*LWP*	*MRI*
554+99	549+71	109.5	99.2	104.4	80				.1	74.9
549+71	544+43	98.4	95.8	97.1	66				.8	66.8
544+43	539+15	89.9	88.5	89.2	61				.7	61.0
539+15	533+87	92.8	88.7	90.7	63.8	59.1	61.5	63.6	59.4	61.5

> 30 in/mi difference!

Project Background

- Questions to be answered:
  - What is the cause of significant differences in ride quality throughout the day?
  - What is the cause of differences in ride quality between EB (Sept) and WB (July) lanes?
- Provide recommendations for mitigation on future projects.

Data Collection

- Project Information
  - Pavement design information
  - Construction information (paving logs, equipment, etc.)

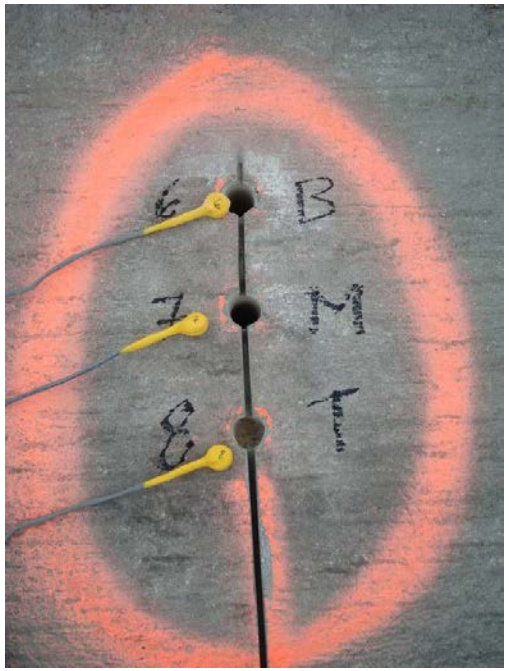
Date	Paving Day	Paving Window	Ambient High Temp (°F)	Ambient Low Temp (°F)
WB Lanes				
7/20/2012	1	7:00-19:15	102.2	62.6
7/23/2012	2	7:30-11:14	87.8	68
7/24/2012	3	7:21-19:10	98.6	66.2
7/25/2012	4	7:27-14:20	93.2	73.4
7/26/2012	5	7:20-13:58	84.2	60.8
EB Lanes				
9/13/2012	1	7:40-18:00	71.6	51.8
9/14/2012	2	7:20-11:30	69.8	44.6
9/17/2012	3	7:15-17:15	68	48.2
8/18/2012	4	7:15-18:00	80.6	42.8
9/19/2012	5	8:30-17:12	82.4	50

Data Collection

- Additional Profile Data
  - CDOT High Speed Inertial Profiler
  - Summer and Winter conditions: February & August 2014)
  - 4 Times of the day:
    - Early AM (maximum (-) slab temperature gradient)
    - Mid-AM (near-zero slab temperature gradient)
    - Early PM (maximum (+) slab temperature gradient)
    - Late PM (near-zero slab temperature gradient)

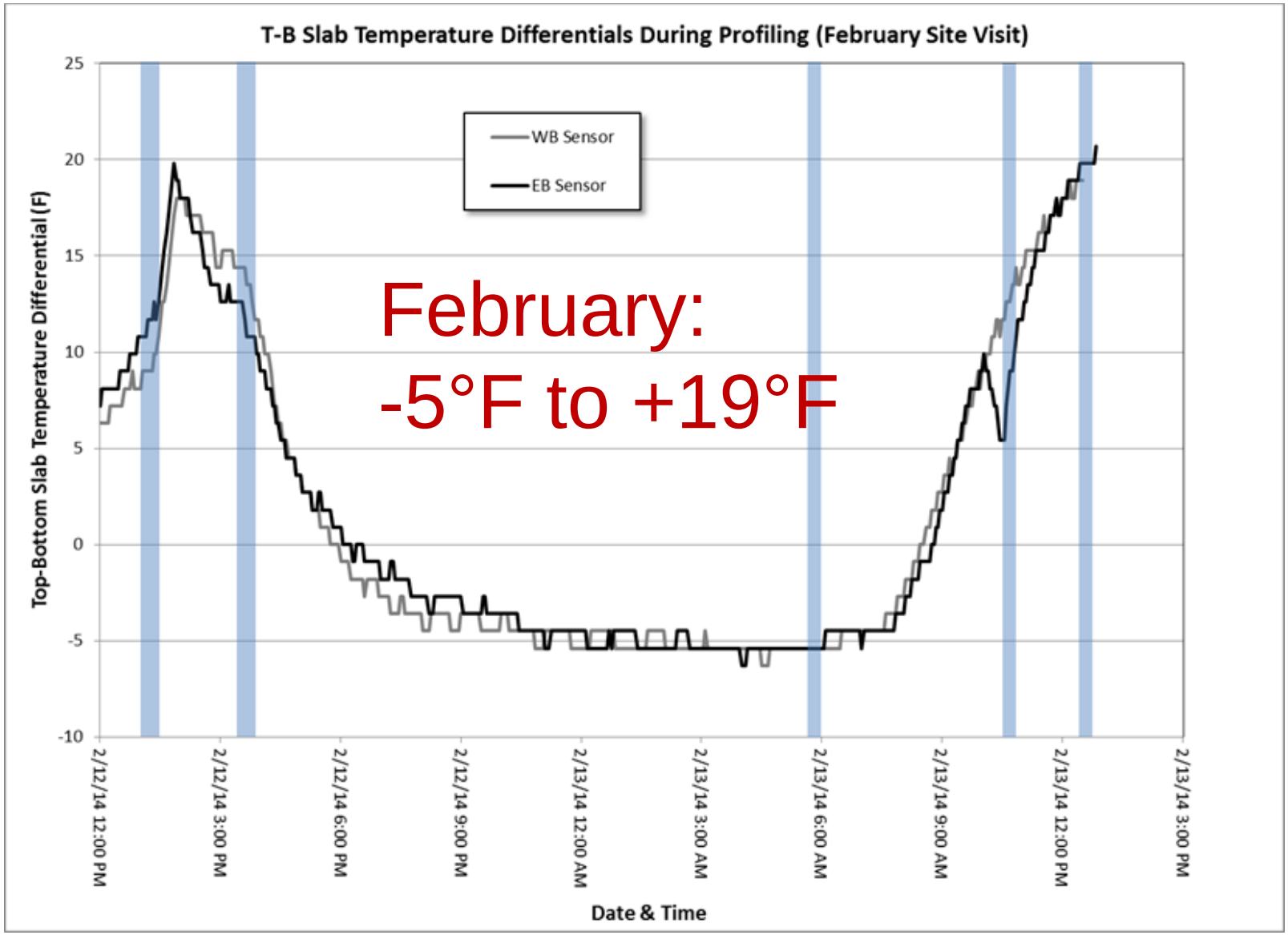
Data Collection

- Temperature Data
  - Logging sensors embedded in top, middle, bottom of slab.
  - Temperatures recorded during profiling.



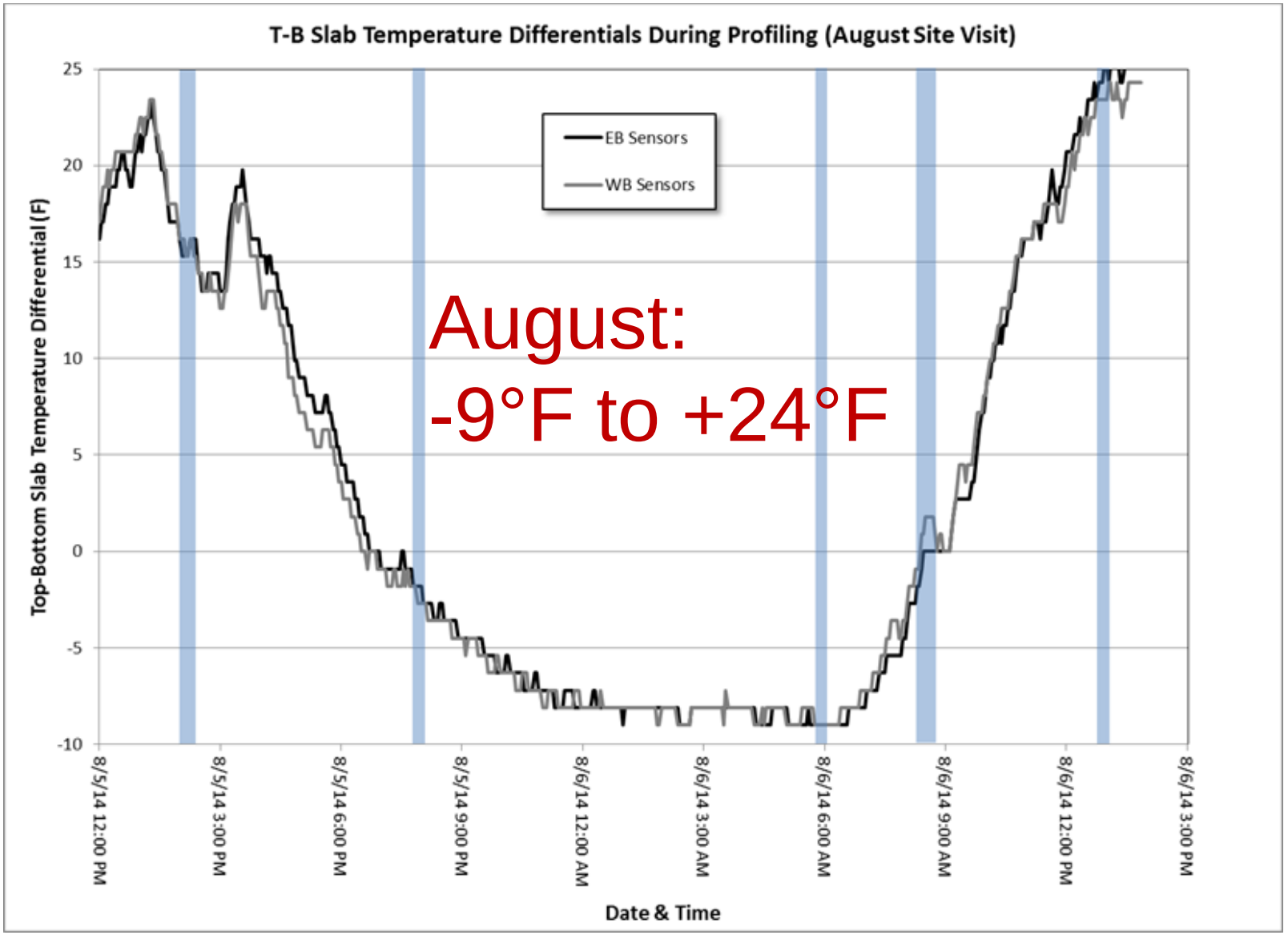
Data Collection

- Temperature Differentials During Profiling:



Data Collection

- Temperature Differentials During Profiling:



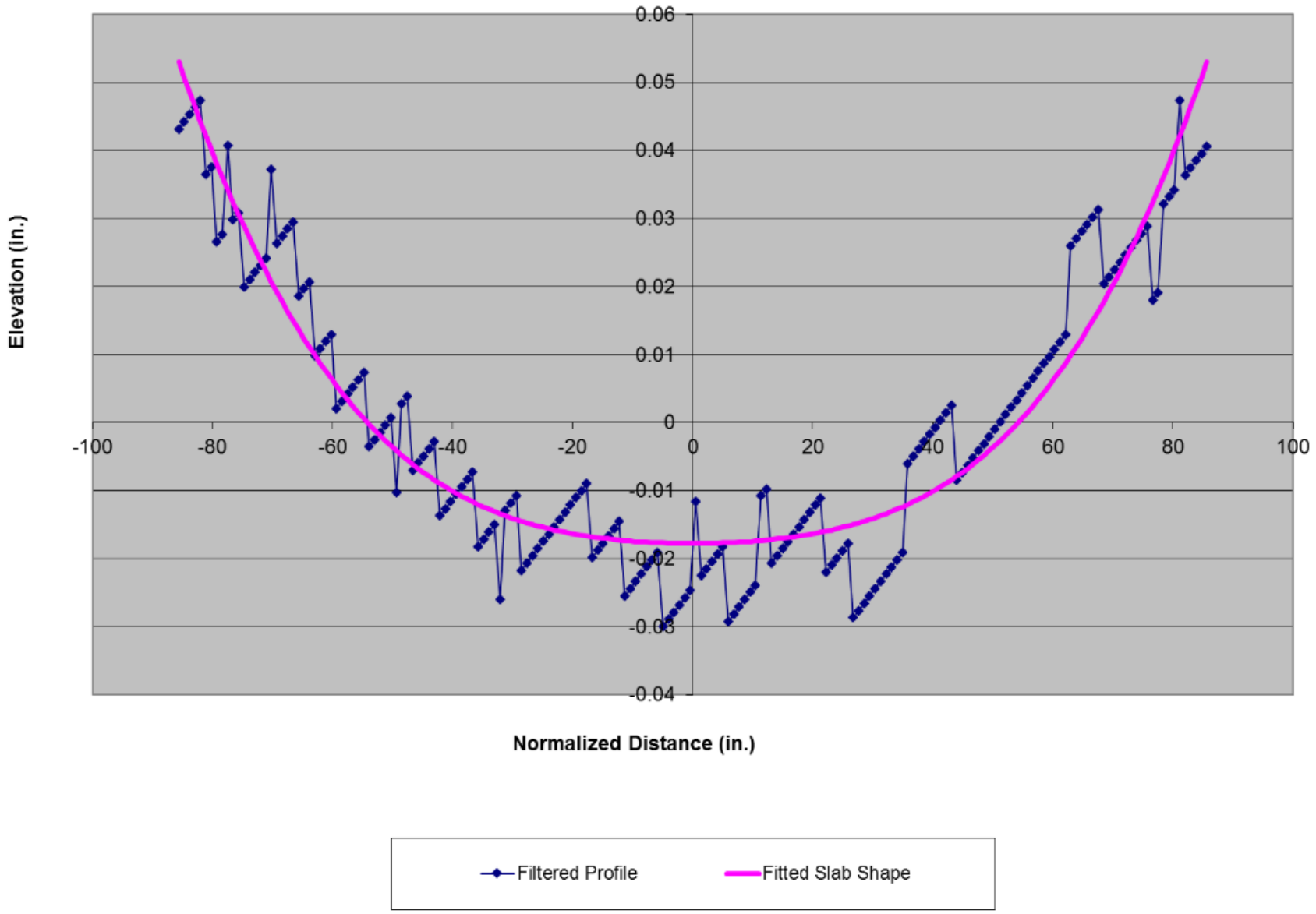
Data Analyses

- Ride Quality Analysis
  - By Lane
  - By Wheelpath
  - By Side of Bridge
  - By Paving Day
- HIPERPAV Analysis
  - Predict slab temperature differentials at set time.
  - Evaluate alternate scenarios.

Analyses

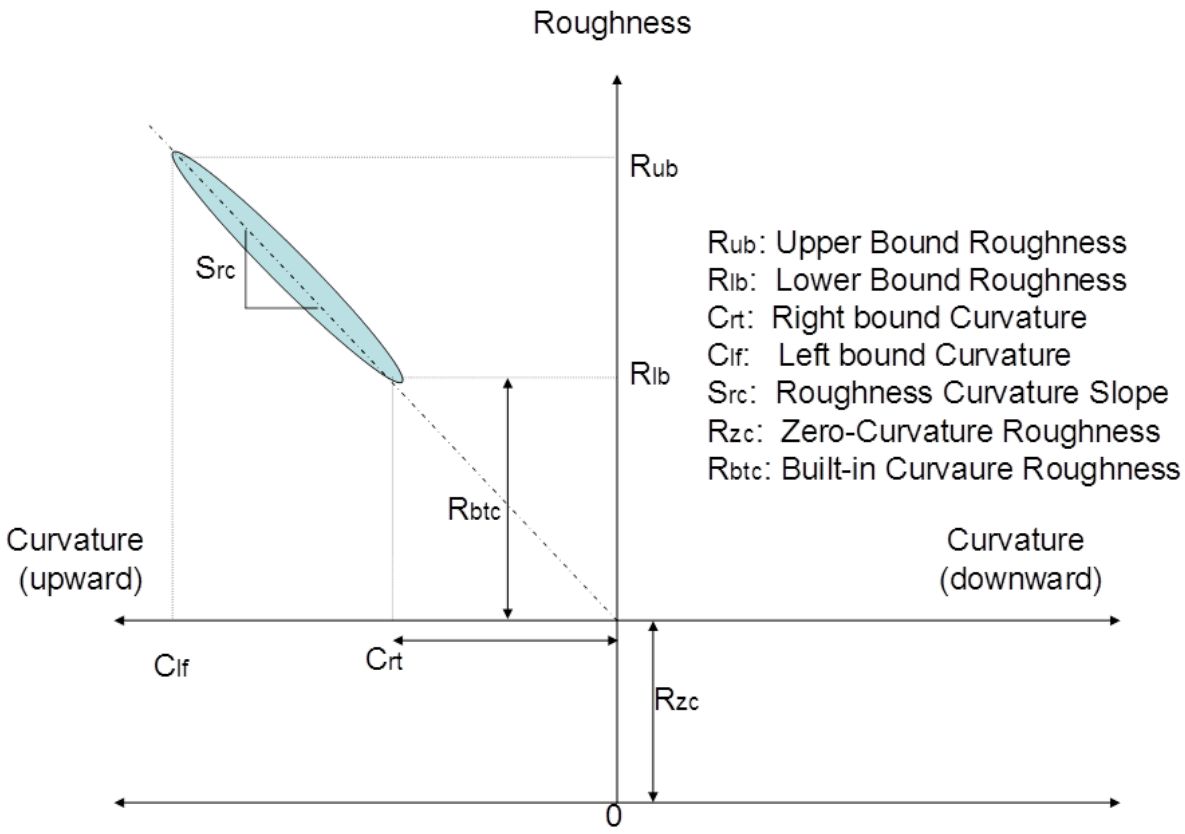
- Slab Curvature Analysis
  - Curve-fitting of slab shape based on profile data.
  - Computation of **Second Generation Curvature Index (2GCI).**
  - Over **21,000** slabs profiles analyzed!

Analyses


Elevation (In.)
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-100
-80
-60
-40
-20
0
20
40
60
80
100
Normalized Distance (in.)
Filtered Profile
Fitted Slab Shape

Analyses

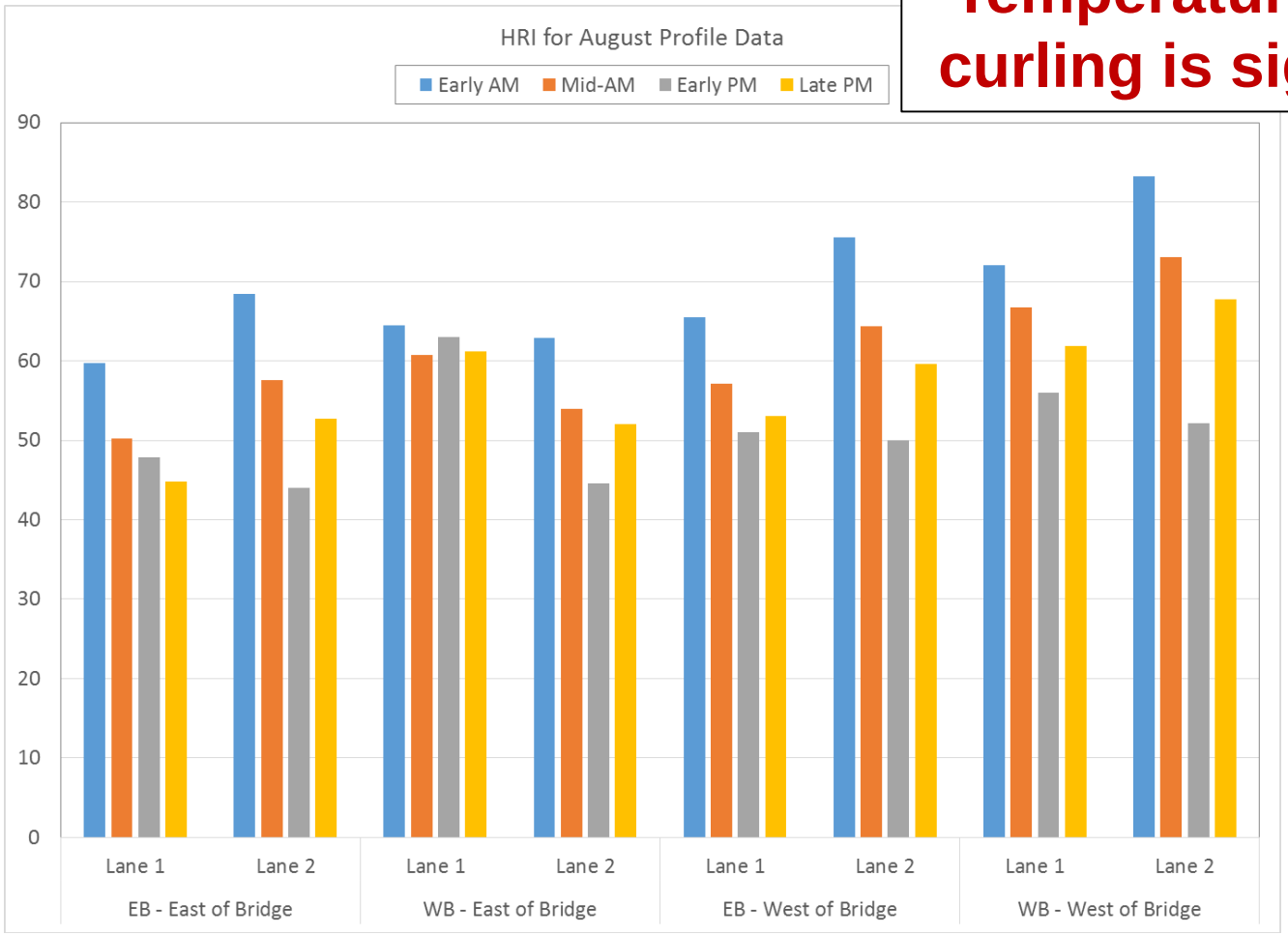
- Slab Curvature Analysis
  - Slab curvature (2GCI) vs. roughness



Summary of Results: Ride Quality

- Diurnal difference in HRI, max: 31 in/mi, avg: 14.1 in/mi

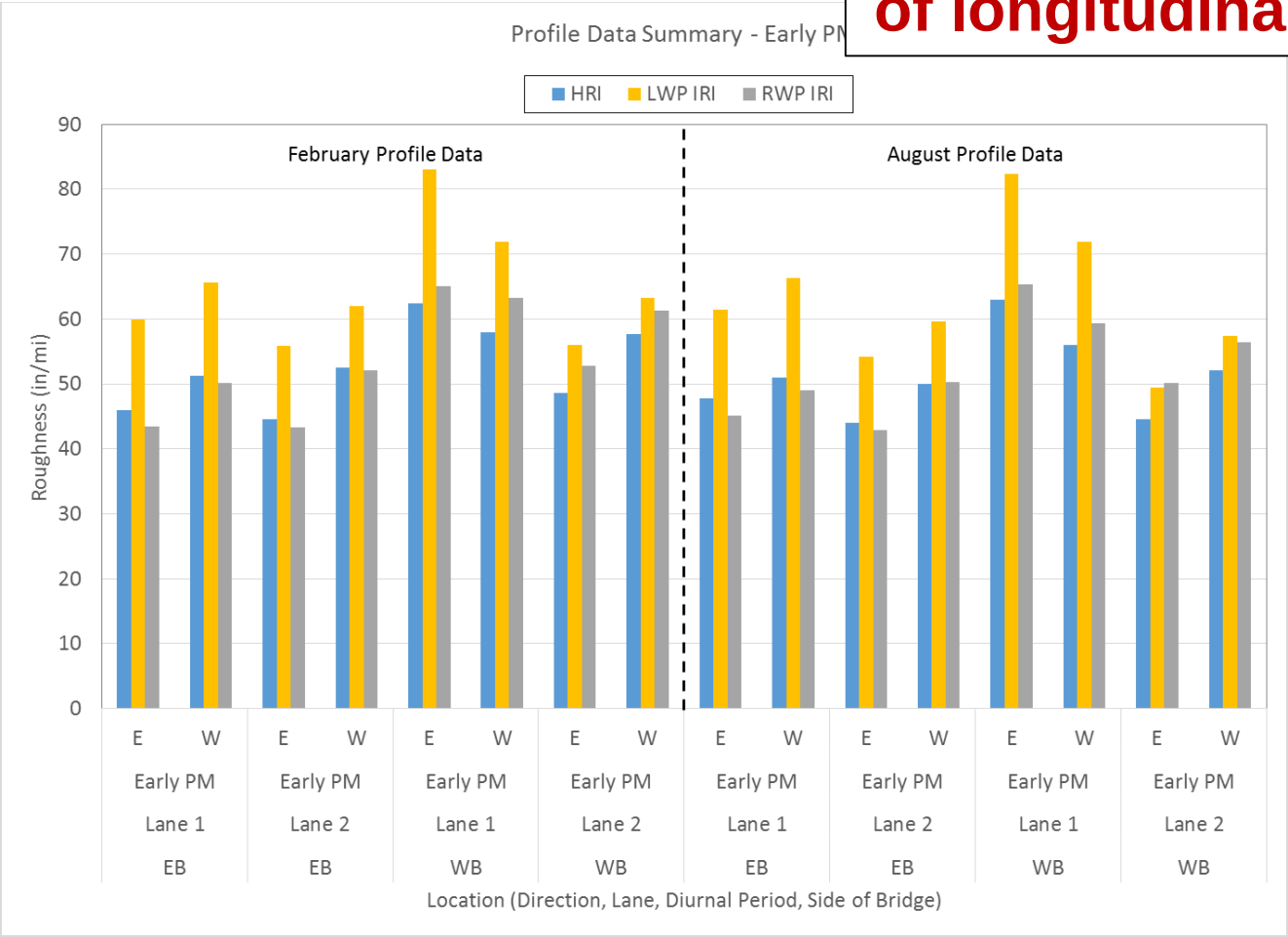
Temperature-related curling is significant!



Summary of Results: Ride Quality

- Wheelpath difference in IRI, max. 18 in/mi
  avg: 7.7 in/mi

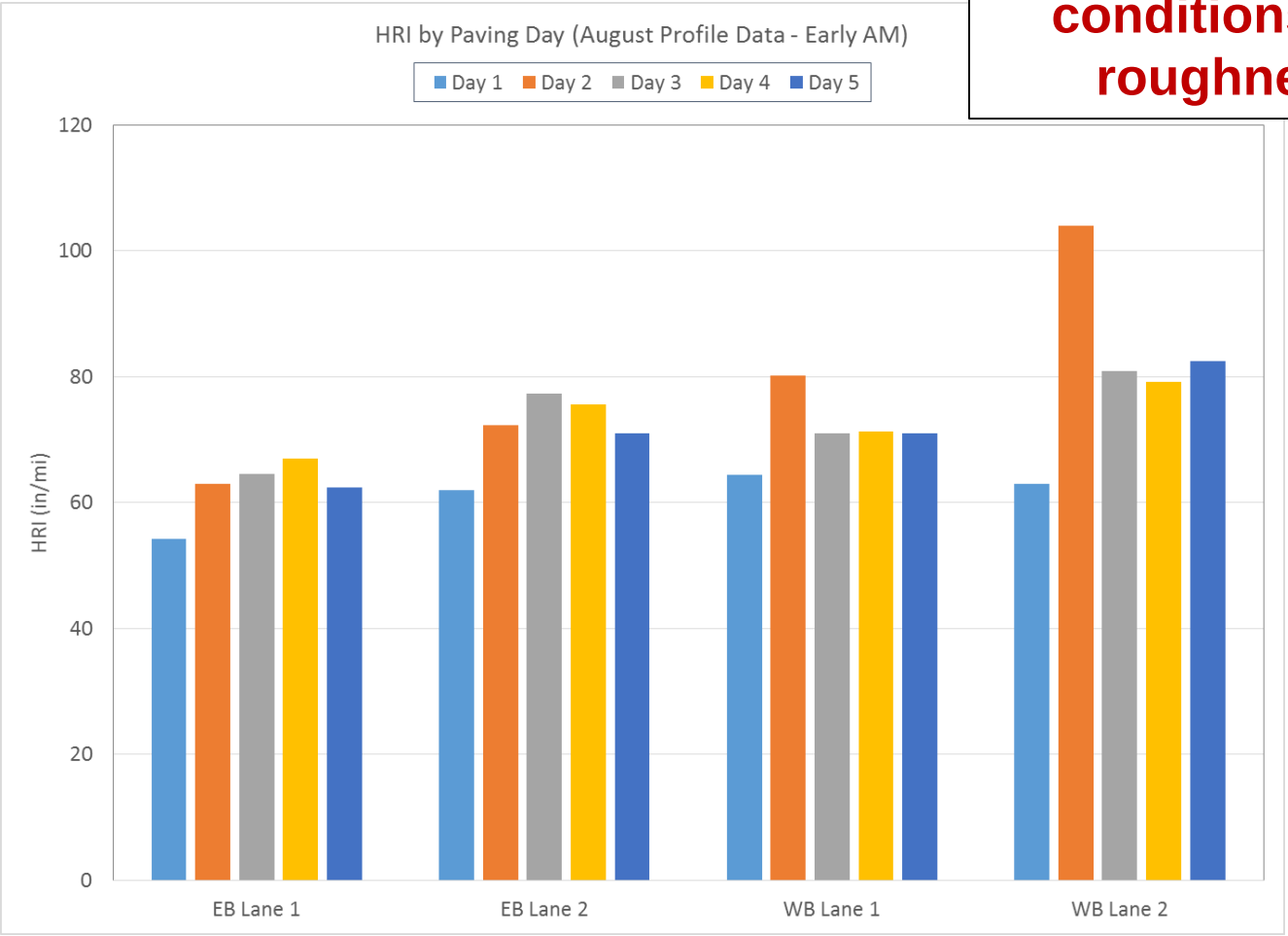
Related to formation of longitudinal joints?



Summary of Results: Ride Quality

- Ride quality by paving day

No clear correlation between paving conditions and roughness.

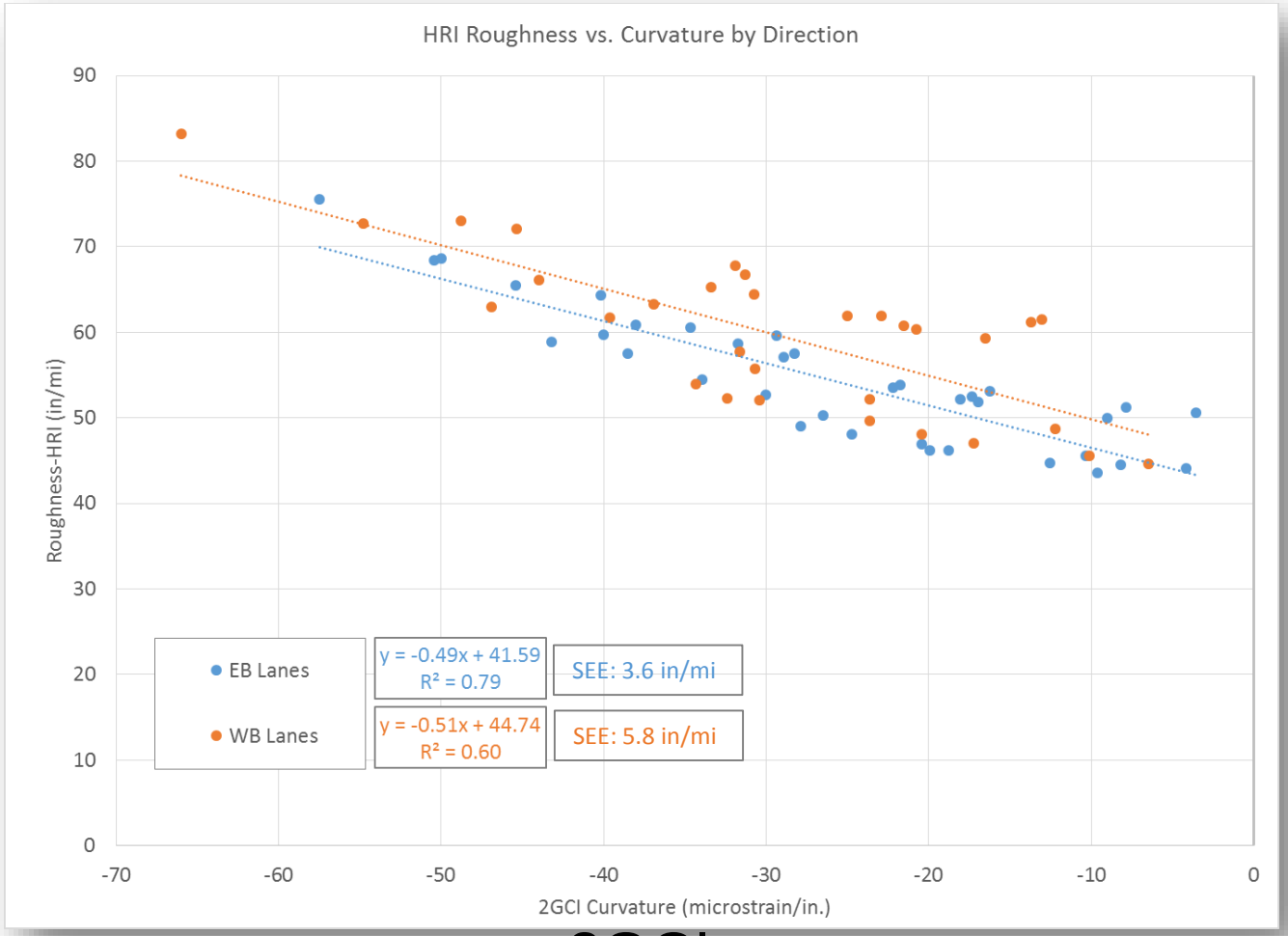


Summary of Results: Slab Curvature

- Most curled up slabs (negative 2GCI).
- No substantial difference between EB and WB lanes.

Summary of Results: Slab Curvature

- Roughness vs. Curvature by Direction



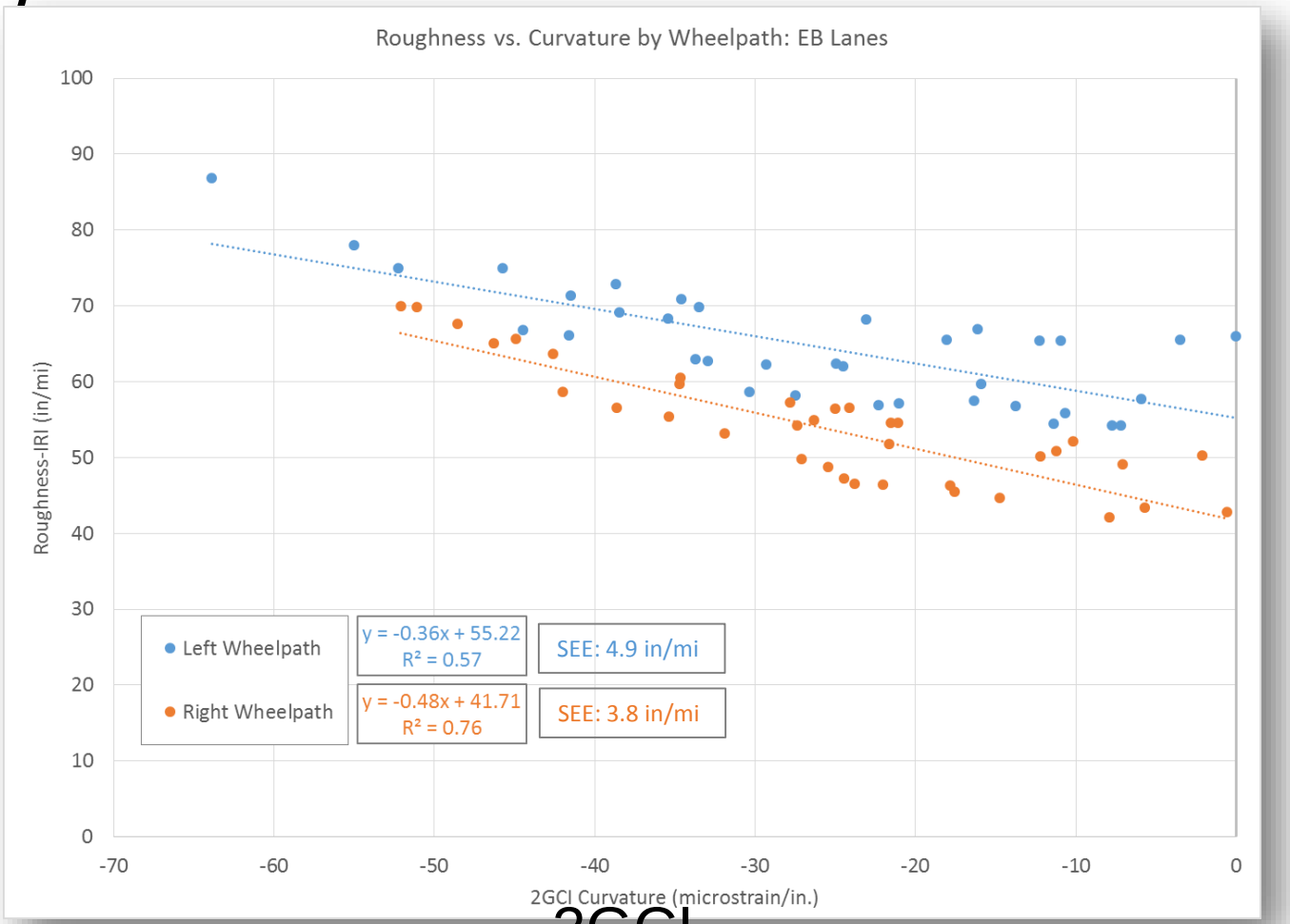
HRI

2GCI

Summary of Results: Slab Curvature

- Roughness vs. Curvature by Wheelpath (EB)

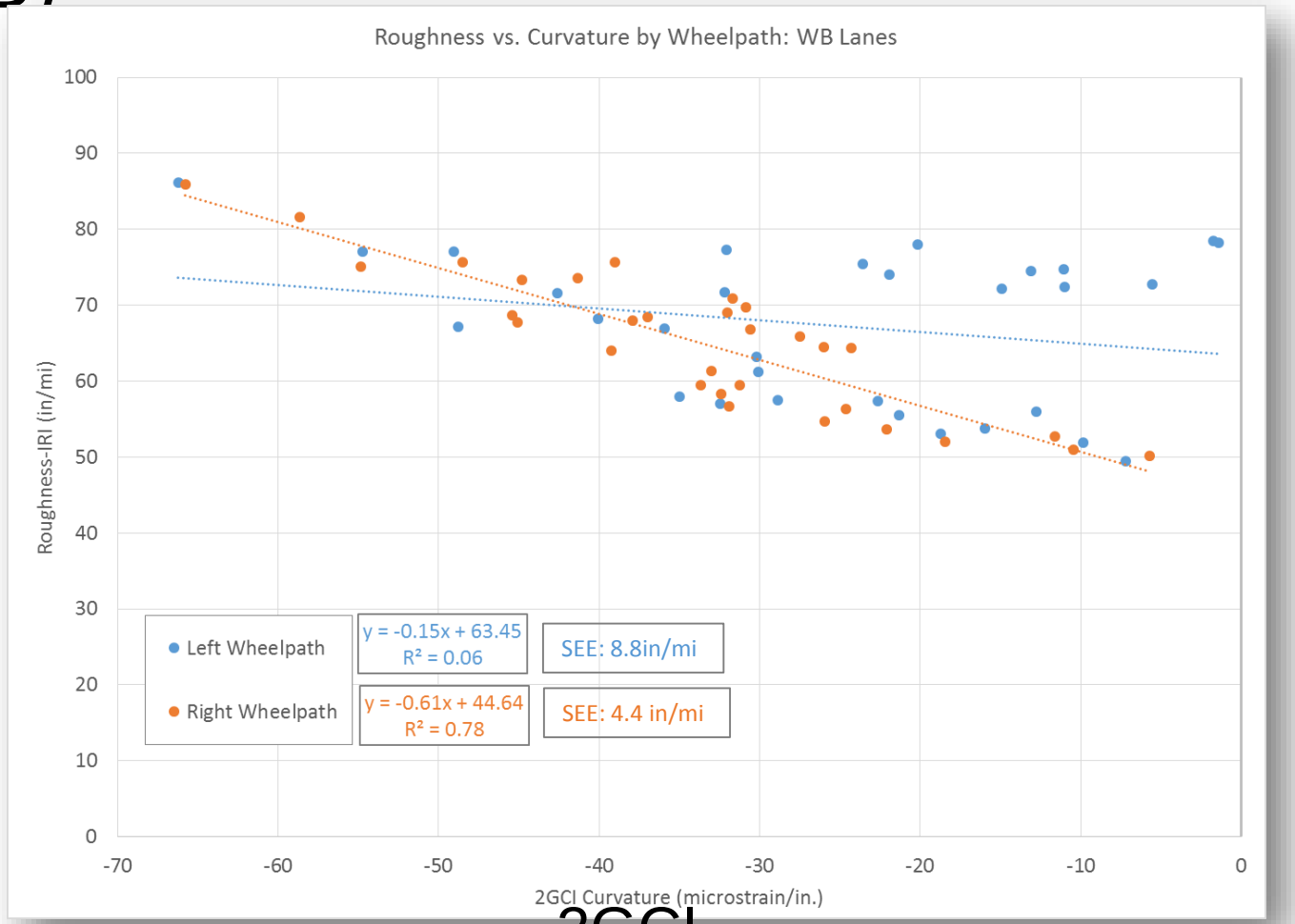
IRI



2GCI

Summary of Results: Slab Curvature

- Roughness vs. Curvature by Wheelpath (WB)



IRI

2GCI

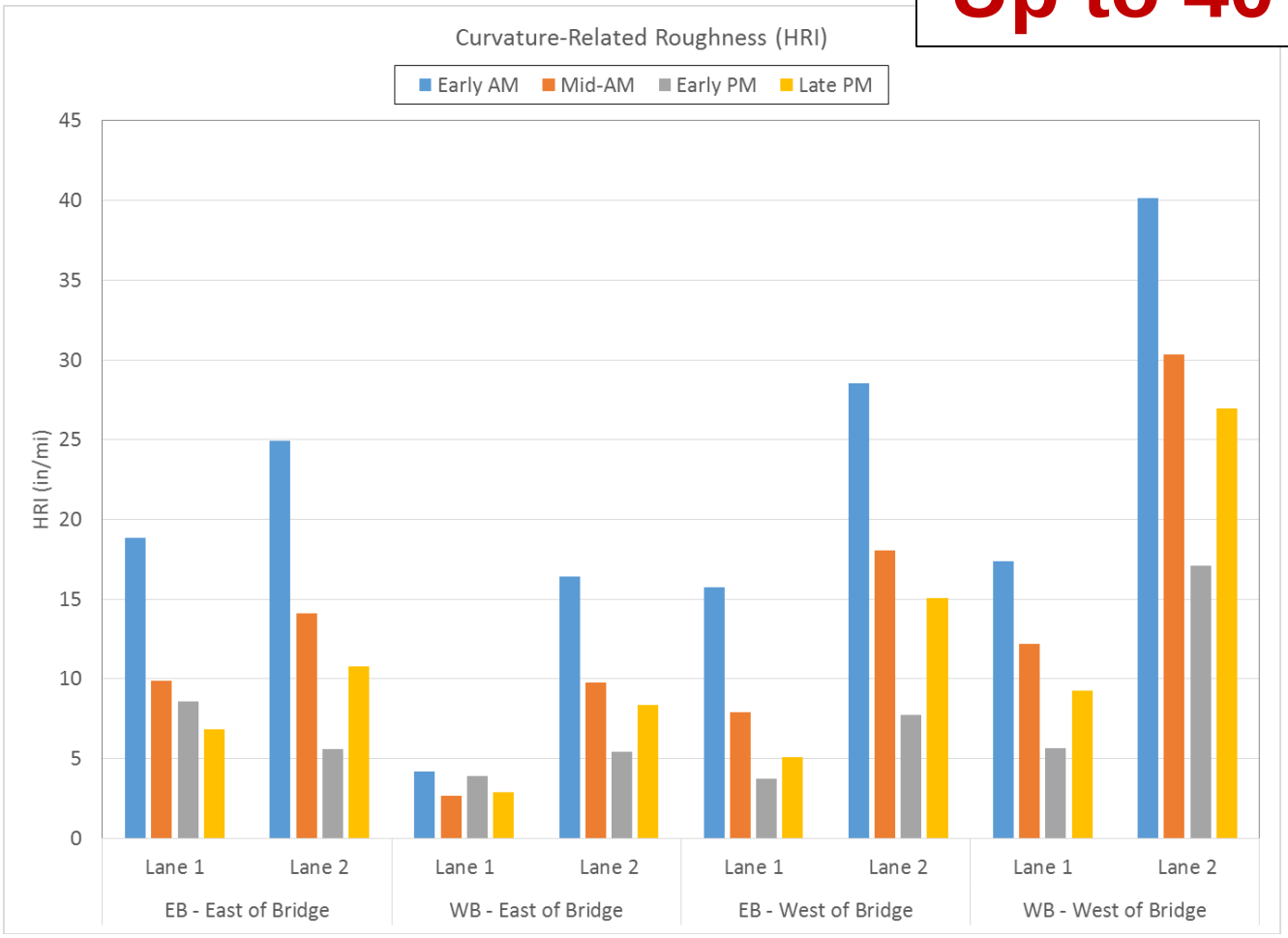
Summary of Results: Slab Curvature

- Estimate Zero-Curvature Roughness.
  - EB Lanes (HRI): 41.6 in/mi
  - WB Lanes (HRI): 44.7 in/mi
- Separation of curvature vs. non-curvature related roughness

Summary of Results: Slab Curvature

- Curvature-related Roughness (HRI)

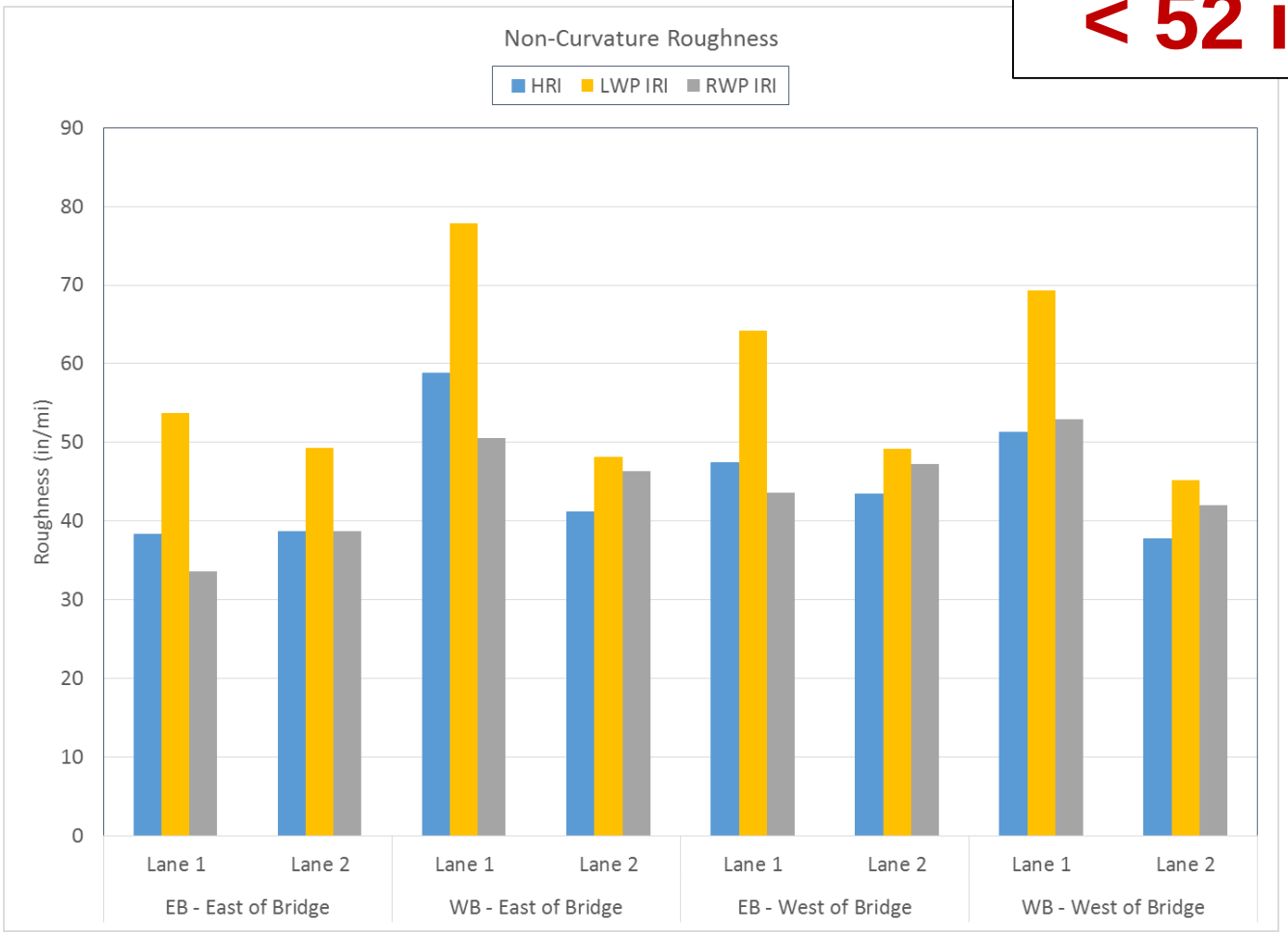
Up to 40 in/mi !



Summary of Results: Slab Curvature

- Non-curvature Roughness (HRI)

< 52 in/mi



Summary of Results: HIPERPAV

- Predicted top-bottom slab temperature differentials at final set
  - EB Lanes: +2.8F
  - WB Lanes: +15.9F
  - Both result in a negative “built-in” temperature gradient and upward slab curvature.
- Alternate scenarios
  - Night paving (7 PM vs. 7 AM start) and cooler base temperature both resulted in smaller (negative) temperature differential.

Conclusions

- Difference between EB and WB lanes was not as significant as initially thought.
- **Temperature curling** is significantly impacting ride quality.
- How to we account for this in ride quality acceptance?

Recommendations: Construction Practices

- Hot weather paving:
  - Minimize top-bottom slab temperature differential
    - Night paving or upper limit on ambient temperature for paving.
    - Upper limit on base temperature, cool it with lime slurry, curing compound, etc.
  - Consider improved curing practices
    - Double coat in hot weather
    - Poly-Alpha Methylstyrent (PAMS) curing compound

Recommendations: Smoothness Acceptance

1. Collect profile data at two times during the same day
   - Early AM and Early PM
   - Exception if weather conditions change (e.g., becomes overcast).

Recommendations: Smoothness Acceptance

1. Set acceptance thresholds based on two parameters:
   1. Average HRI for the two sets of profile data.
      - Threshold slightly higher than current threshold
   2. Maximum absolute difference in HRI between the two sets of profile data.
      - Tentatively, 15-20 in/mi maximum

Recommendations: Smoothness Acceptance

- Localized Roughness:
  - Continue use of Short Baselength (25 ft) Continuous IRI.
  - Look for ALRs that appear in both sets of profile data.
  - Require synchronization of profile data.

Recommendations: Smoothness Acceptance

- Validation using US 34 Data
  - HRI limit = 67 in/mi (current CDOT full pay limit).
  - Maximum absolute difference = 15 in/mi.

		Number of 0.1-mile Segments	Percent Passing Average HRI Criteria	Percent Passing Absolute Difference Criteria
February Profile Data				
EB	Lane 1	14	100	93
	Lane 2	14	100	43
WB	Lane 1	13	69	100
	Lane 2	13	69	62
August Profile Data				
EB	Lane 1	13	100	54
	Lane 2	13	92	8
WB	Lane 1	12	67	58
	Lane 2	12	58	0

Recommendations: Smoothness Acceptance

- Validation using US 34 Data
  - No segments passed both criteria.
  - After grinding (early AM profile) all segments pass both criteria.
- Pilot project/shadow specification implementation will help dial in appropriate thresholds for these criteria.


Thank You!
TURN 20
PIRELLI
PIRELLI
PIRELLI
PIRELLI
UBS
LG
LG
LG
LG
LG
LG
LG
LG
1:03
LAP 0
1 VET
2 HAM
3 WEB
4 RAI
5 MSC
6 HUL
7 ALO
8 GRO
9 MAL
10 SEN