ASTM Kummer Lecture 2007

Quantifying the Impact of JCP Curling and Warping on Pavement Roughness

Presented by
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Transtec Group

THE TRANSTEC GROUP

FHWA Curl/Warp Study

- Impact of Curling and Warping on JCP Performance

Major Findings

- New, robust profile synchronization and joint identification techniques
- Invention of 2GCI to better characterize slab curvature
- New, effective slab curvature analysis framework
- RoCK System to assess curvature's impact on roughness

Major Findings (cont'd)

- New technique to evaluate joint hinge functionality
- New system to classify joint edge geometry
- Robust procedure to estimate joint faulting

Today, We'll Cover….

- Curl/Warp Measurement
- Profile Synchronization and Joint ID
- 2GCI Curvature Index
- RoCK System for curvature-impact on roughness

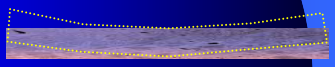
About Curl/Warp 101

Outlines

- **Curl/Warp Measurement**
- Profile Synchronization and Joint ID
- 2GCI Curvature Index
- RoCK System for Curvature-Impact-Roughess Analysis

Curl/Warp Measurement

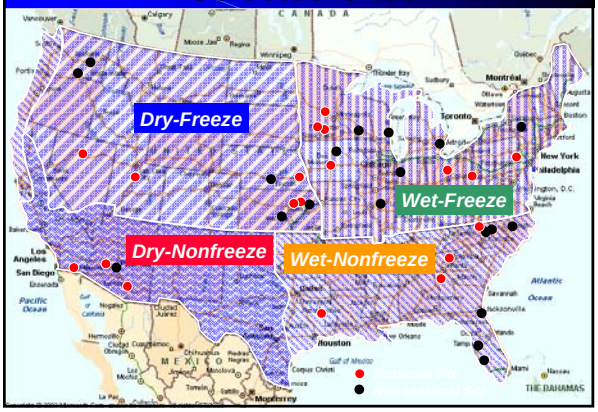
- What to be measured?
  - Site Selection
  - Data Collection
- How to measure?
  - Profiling
  - Temperature
  - Others



Site Categories

- FHWA LTPP: 11 Sites
- FHWA RIPPER: 1 Site
- FHWA HIPERPAV: 4 Sites
- FHWA Curling/Warping Study: 3 Sites
- Ohio Test Road (also Curling/Warping Study and LTPP site)
- Mn/ROAD (also Curling/Warping Study site)
- Kansas DOT/Kansas State University: 1 Site

Selected Sites



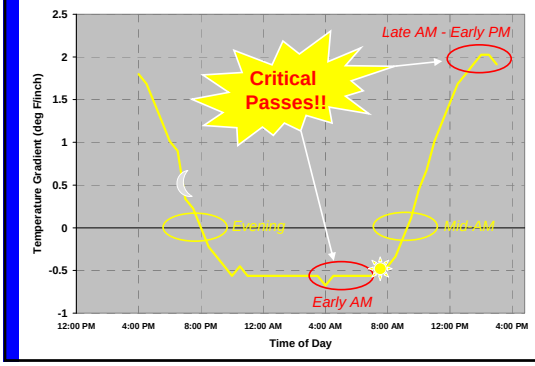
Data Collection

- Inertial profile and image log data
- Slab temperature data
- Visual distress survey
- FWD deflection
- Construction records
- Weather data

Diurnal Profiling

- Early Morning → Max (-) Temp. Gradient
- Mid-morning → ~ Zero Temp. Gradient
- Noon → Max (+) Temp. Gradient
- Evening → ~ Zero Temp. Gradient

Diurnal Profiling



Seasonal Profiling

- "Seasons"
  - Spring: March-June
  - Summer: June-September
  - Fall: September-December
  - Winter: December-March
- Minimum 15~20ºF difference in average ambient temperature between seasonal visits
- Minimum 2 months between seasonal visits

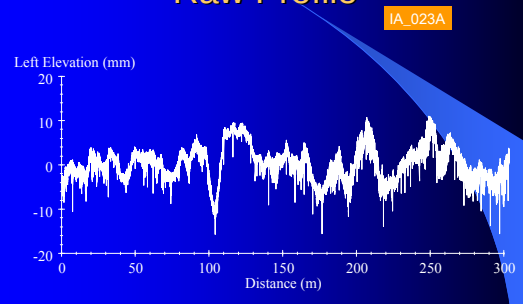
Data Collected

- 95 site visits over 38 test sites
- 96,000 miles traveled
- 19 different States
- 125 gigabytes electronic raw data
- 6,000 profile runs
- 400,000 slabs (within sections of detailed analyses) analyzed

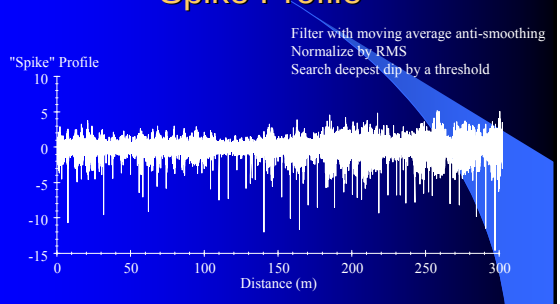
Outlines

- Curl/Warp Measurement
- **Profile Synchronization and Joint ID**
- 2GCI Curvature Index
- RoCK System for Curvature-Impact-Roughess Analysis

Raw Profile

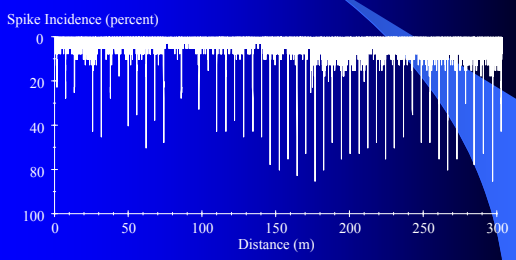


Spike Profile



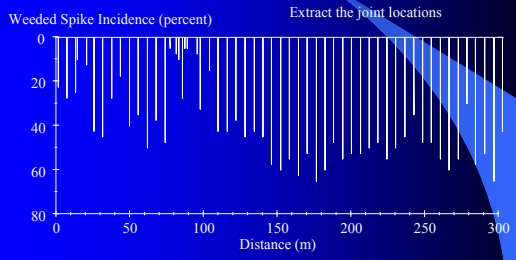
Spike Incidence

Assemble the dip count across the data set



Weeded Spike Incidence

Weed/clear false hits
Extract the joint locations



Outlines

- Curl/Warp Measurement
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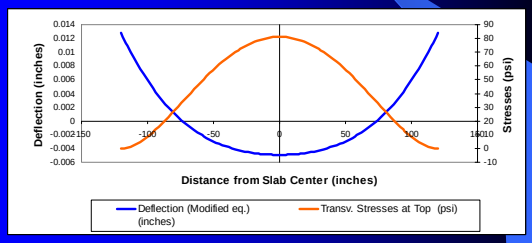
- **2GCI Curvature Index**
- RoCK System for Curvature-Impact-Roughess Analysis

Westergaard Curling Formula

$$z = -z_o \frac{2\cos\lambda\cosh\lambda}{\sin 2\lambda - \sinh 2\lambda}\left[(-\tan\lambda + \tanh\lambda)\cos\frac{x}{l\sqrt{2}}\cosh\frac{x}{l\sqrt{2}} + (\tan\lambda + \tanh\lambda)\sin\frac{x}{l\sqrt{2}}\sinh\frac{x}{l\sqrt{2}}\right]$$



Westergaard Curling Parameters

- Radius of relative stiffness
  A fixed (theoretically known) quantity, and is a function of the slab thickness, modulus of elasticity, Poisson's ratio, and the modulus of reaction for the slab support.
- Strain gradient
  A linear approximation of the combined thermal- and moisture-induced strains in the concrete slab per unit thickness. If slab geometry, materials, and support parameters are all known, this parameter alone could serve as a suitable curvature index.

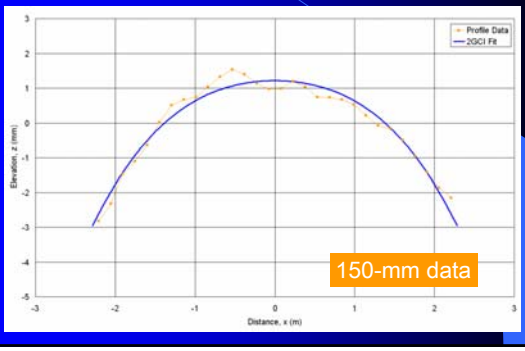
Adjusted Westergaard Curling Parameters

- Adjusted to overcome Westergaard assumptions
- Fit to actual slab deformation
- More fundamental than an arbitrary geometric function
- Fitted parameters:
  - Pseudo-radius of relative stiffness
  - Pseudo-strain gradient

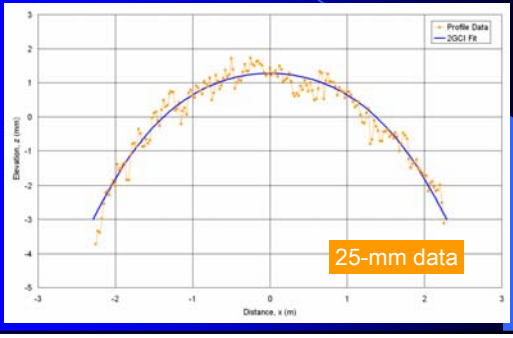
2GCI Computation Steps

- Isolate the individual slab segments
- Pre-process isolated segments
- Mask joints (optional)
- Define model parameters
- Perform nonlinear curve fitting based on Westergaard curling formula
- Parse and report the curvature indices

2GCI Fit – Curled Down Slab



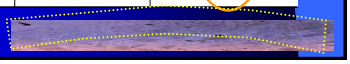
2GCI Fit – Curled Down Slab



2GCI Fit – Curled Down Slab

Positive values

Profile Data Interval mm	2GCI Type	Pseudo-Radius (m)	Pseudo-Gradient (με/cm)
150	2-parameter	0.947	28.2
150	1-parameter	0.965 (fixed)	27.0
25	2-parameter	0.988	26.2
25	1-parameter	0.965 (fixed)	27.8

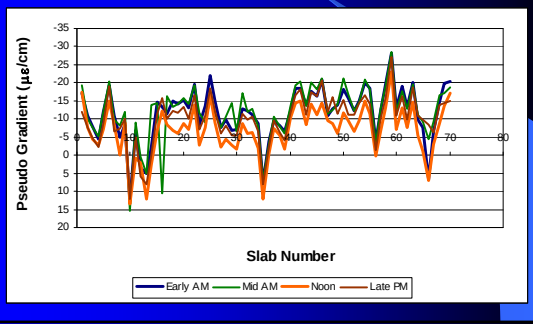


2GCI Computation

- Isolate the individual slab segments
- De-trend and de-mean the profile segment
- Mask joints
- Define model parameters
- Perform nonlinear curve fitting

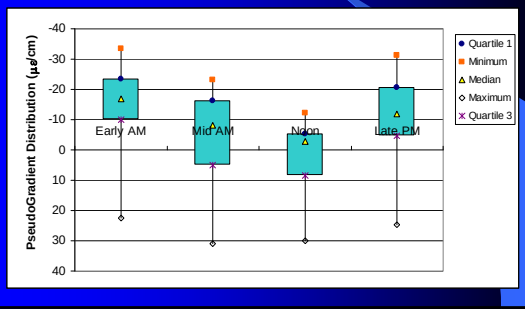
2GCI Analysis

AZ_001am - winter



2GCI Analysis

AZ_001am - winter



2GCI Analysis

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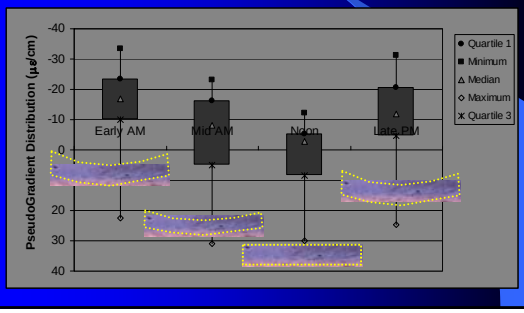
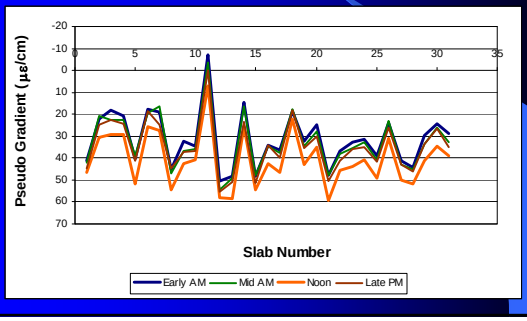


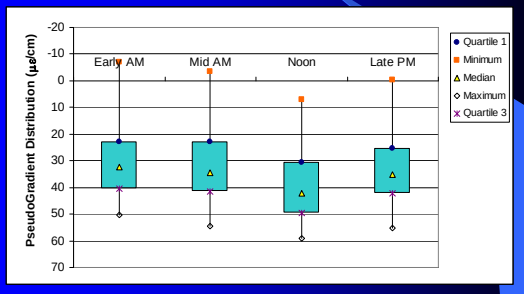
2GCI Analysis

MN_046a - summer



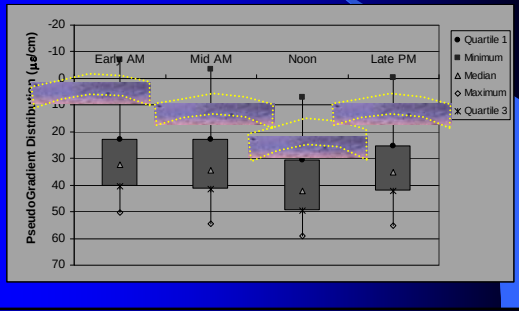
2GCI Analysis

MN_046a - summer

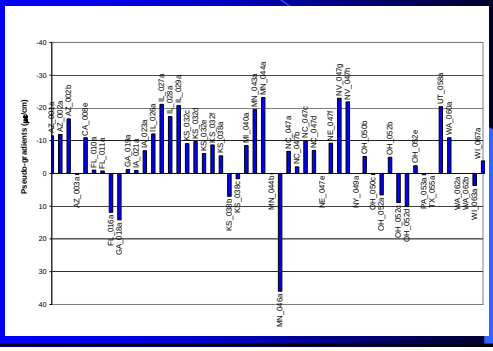


2GCI Analysis

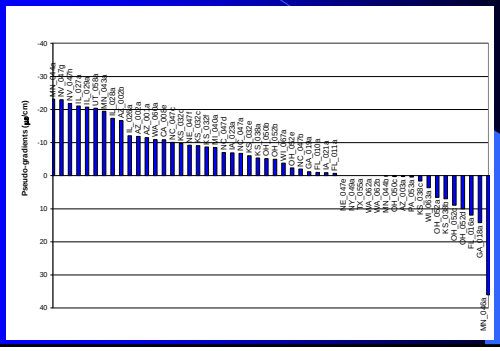
MN_046a - summer



Mean Curvatures



Mean Curvatures

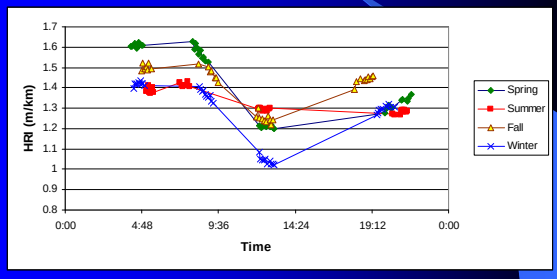


Outlines

- Curl/Warp Measurement
- Profile Synchronization and Joint ID
- 2GCI Curvature Index
- **RoCK System for Curvature-Impact-Roughness Analysis**

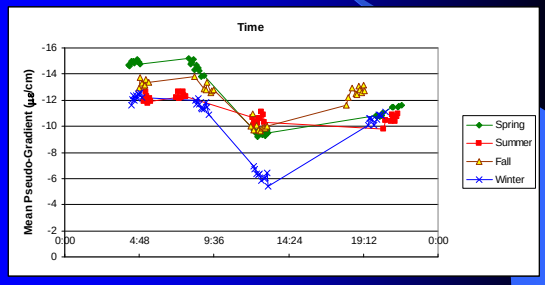
2GCI vs Roughness

AZ_001m



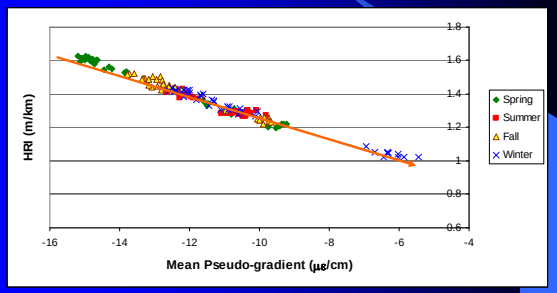
2GCI vs Roughness

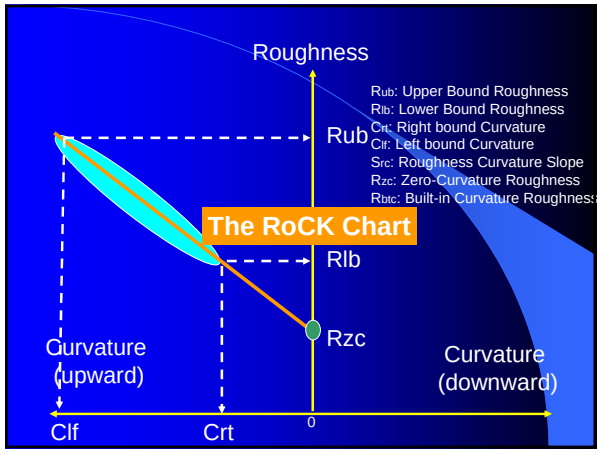
AZ_001m

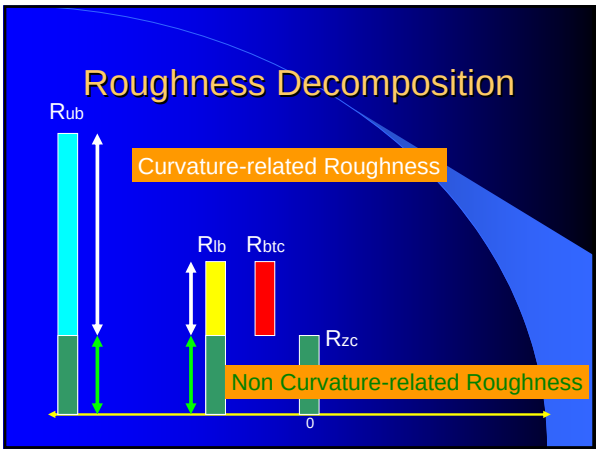


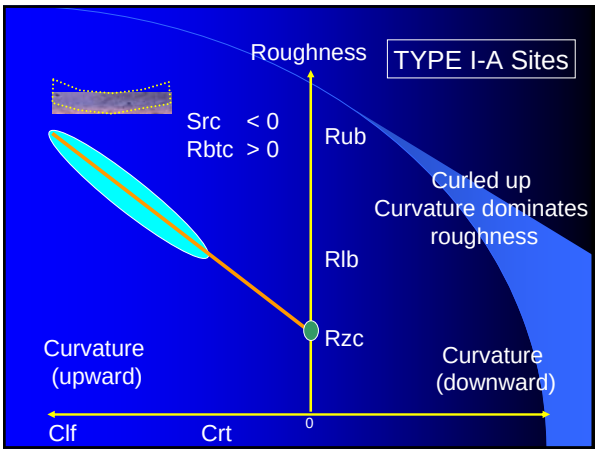
2GCI vs Roughness

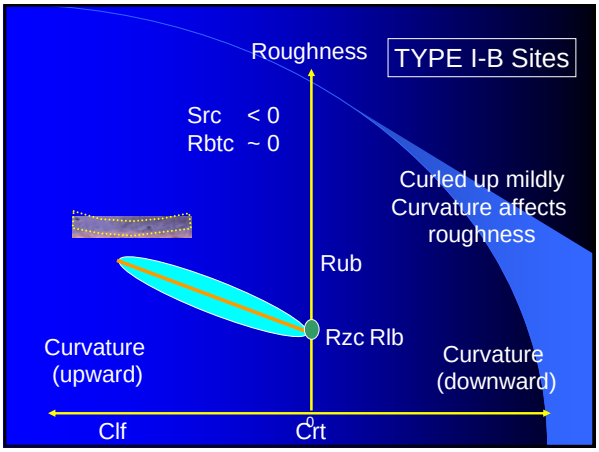
AZ_001m

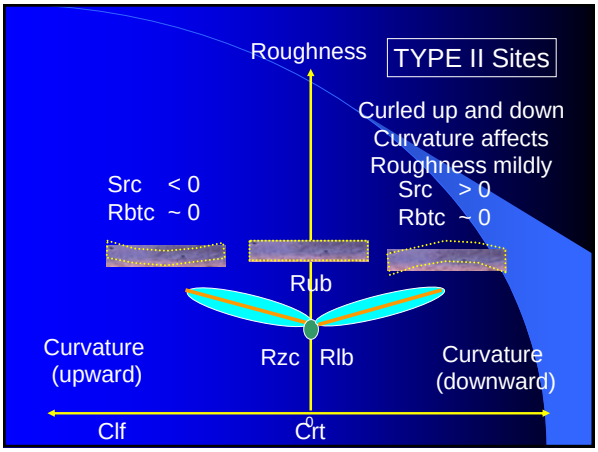


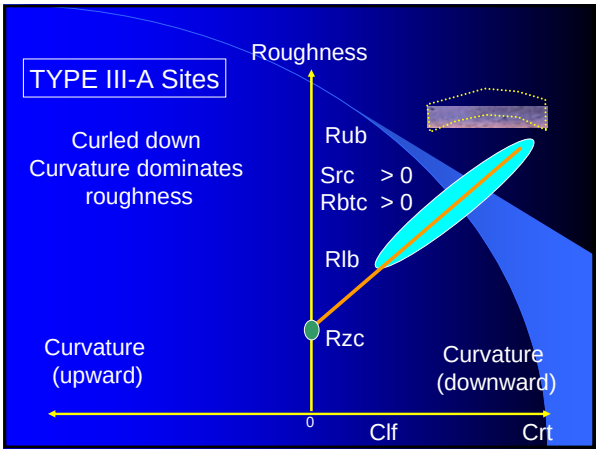


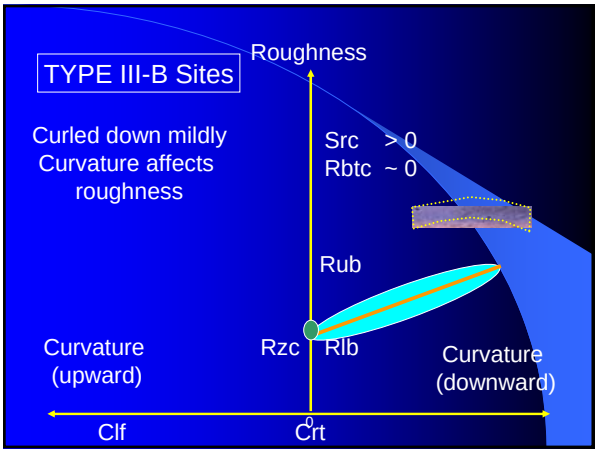

Roughness Decomposition
Rub
Curvature-related Roughness
Rlb
Rbtc
Rzc
Non Curvature-related Roughness
0


Roughness
TYPE I-A Sites
Src < 0
Rbtc > 0
Rub
Curled up
Curvature dominates
roughness
Rlb
Rzc
Curvature
(upward)
Curvature
(downward)
Clf
Crt
0


Roughness
TYPE I-B Sites
Src < 0
Rbtc ~ 0
Curled up mildly
Curvature affects
roughness
Rub
Rzc Rlb
Curvature
(upward)
Curvature
(downward)
Clf
Crt
0


Roughness
TYPE II Sites
Curled up and down
Curvature affects
Roughness mildly
Src < 0
Rbtc ~ 0
Src > 0
Rbtc ~ 0
Rub
Rzc
Rlb
Curvature
(upward)
Curvature
(downward)
Clf
Crt
0


TYPE III-A Sites
Roughness
Curled down
Curvature dominates
roughness
Rub
Src > 0
Rbtc > 0
Rlb
Rzc
Curvature
(upward)
Curvature
(downward)
0
Clf
Crt


TYPE III-B Sites
Roughness
Curled down mildly
Curvature affects
roughness
Src > 0
Rbtc ~ 0
Rub
Rzc
Rlb
Curvature
(upward)
Curvature
(downward)
Clf
Crt
0

Here are some applications

A Tale of 3 Test Sites

A Tale of 3 Test Sites

- AZ_001a
  - HIPERPAV AZ site, frontage road of I-10, Tucson AZ
- MN_046a
  - LTPP GPS 27-3003, TH 15, Lafayette, MZ
- PA_053a
  - LTPP GPS 42-3044, I-78, Lenhartsville, PA

AZ_001a Site

MN_046a Site

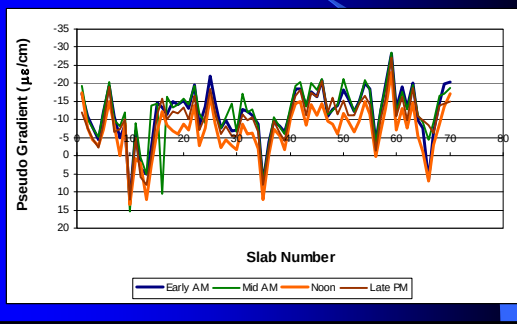
PA_053a Site

A Tale of 3 Test Sites

Site	Slab Thick mm(inch)	Base Type	Base Thick mm(inch)	Slab Width m(ft)	Joint Space mm(ft)	Dowel
AZ 001a	254 (10)	1	102 (4)	3.7 (12)	4.6 (15)	N
MN 046a	191 (7.5)	8	127 (5)	4.3 (14)	4.6 (15)	N
PA 053a	330 (13)	8	203 (8)	3.7 (12)	6.1 (20)	Y

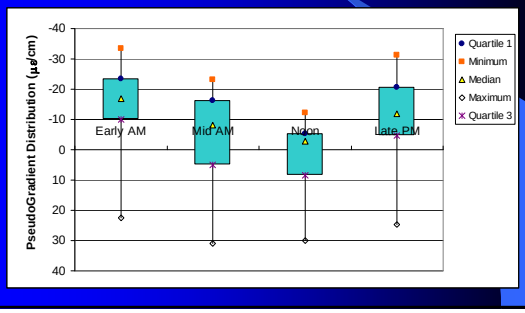
2GCI Analysis

AZ_001am - winter

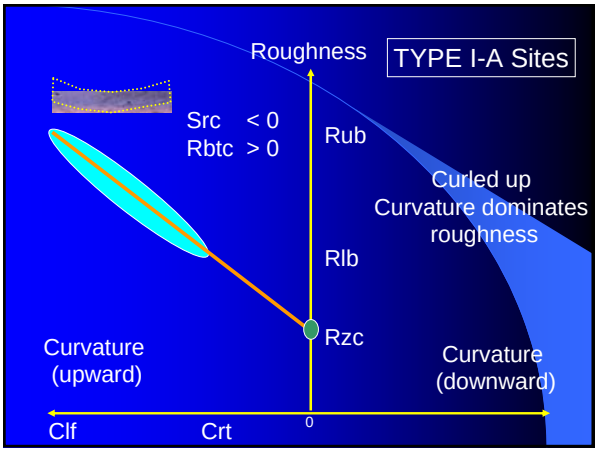


2GCI Analysis

AZ_001am - winter

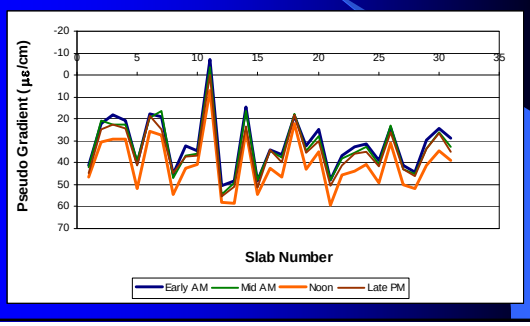


TYPE I-A Sites



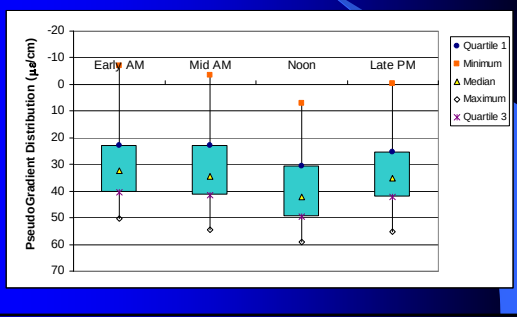
2GCI Analysis

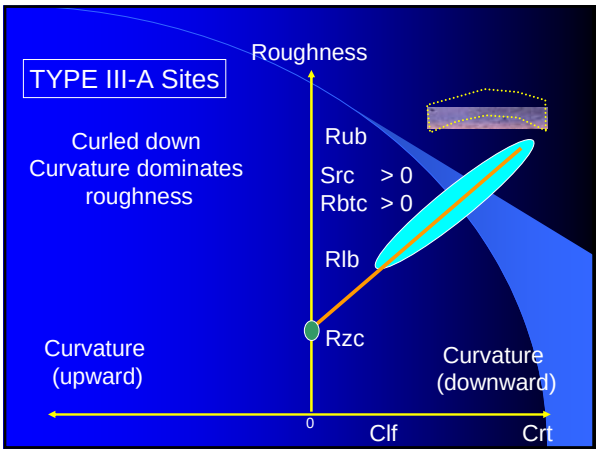
MN_046a - summer

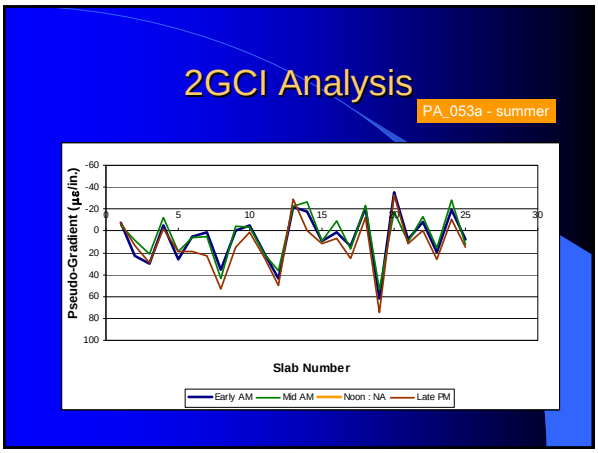


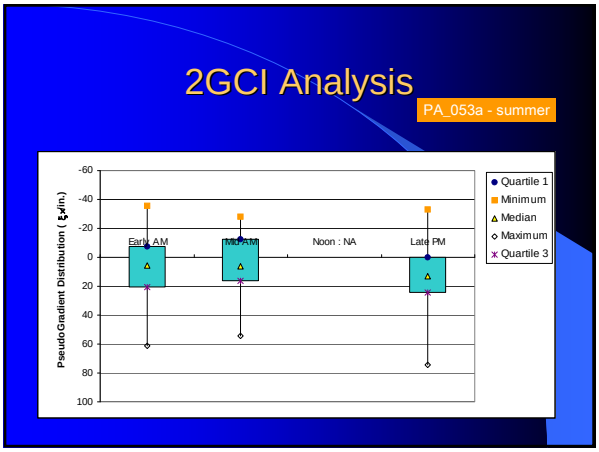
2GCI Analysis

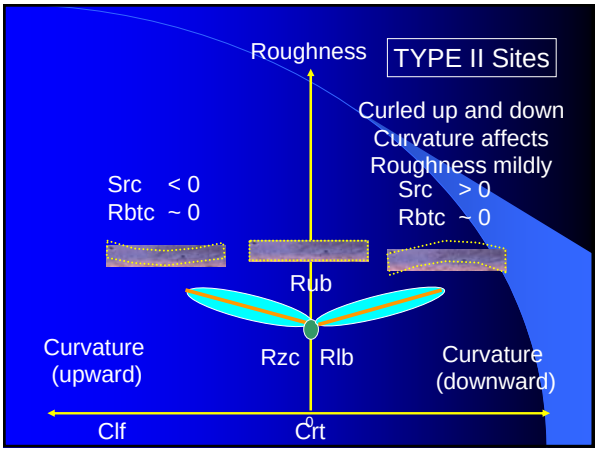
MN_046a - summer











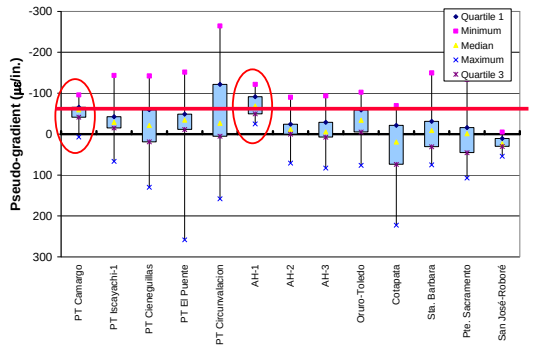
Bolivian Project

- Two-lane undivided JCP
- Mountainous terrain with moderate fills and cuts
- 24-ft wide, 12-ft joint spacing
- 8-inch slab on 6-inch granular base
- Local climate is arid with rains from December to March
- Drastic overnight temperature drops

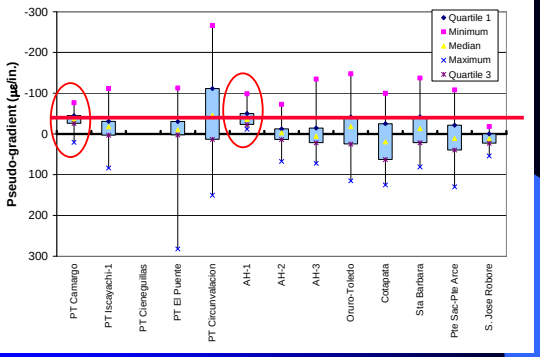
Bolivian Project

- Low relative humidity and extreme temperatures
- Mix with a relatively high water cement ratio, high CTE aggregate, and inadequate curing techniques.
- Longitudinal cracks at the center of the slab in both travel directions after the first winter

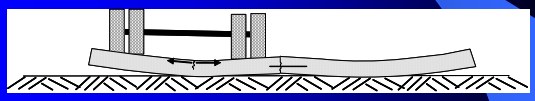
AM



PM

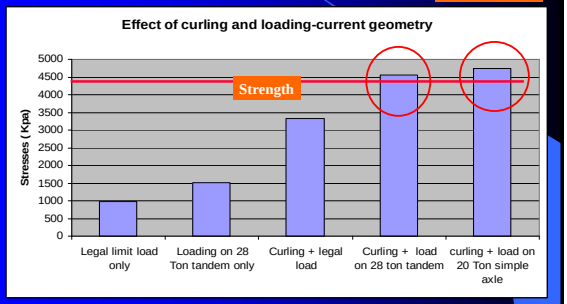


Bolivian Project



Bolivian Project

FEM Analysis

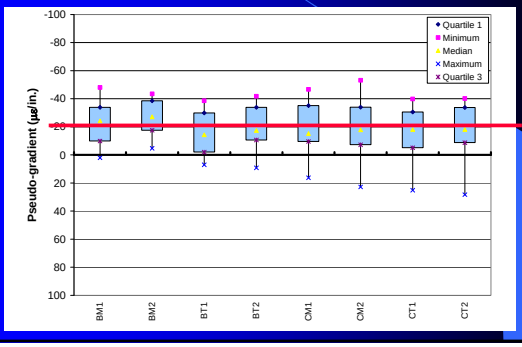


Base & Curing Study

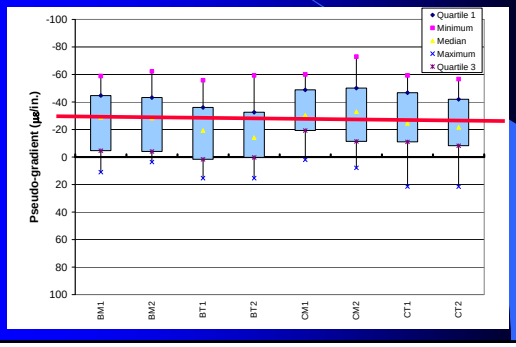
Cases	Prime Coat	Evap reducer
1	✔	
2	✔	✔
3		✔

Prime Coat w/o Evap Redu

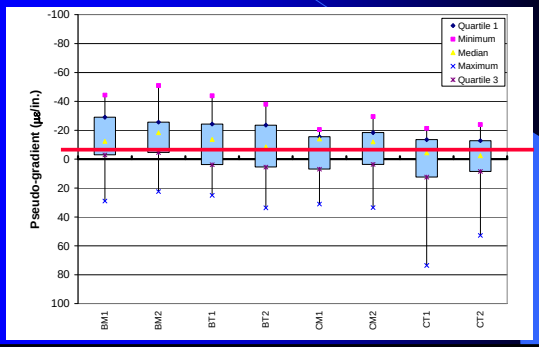
Case 1



Prime Coat w/ Evap Redu Case 2



No Prime Coat w/ Evap Redu Case 3



The Implications…

- What's timing to measure roughness for a pavement acceptance testing?
- What's the best practice to avoid curl and warp?
- What's the best time to grind the pavements to improve smoothness?

Tools you can use…

- New, robust profile synchronization and joint identification techniques
- Invention of 2GCI to better characterize slab curvature
- New, effective slab curvature analysis framework
- RoCK System to assess curvature's impact on roughness

Final Reports

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Thank You !