Quantifying the Impact of Jointed Concrete Pavement Curling and Warping on Pavement Unevenness

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Portorož, Slovenia
US FHWA Curl/Warp Study

- Impact of Curling and Warping on JCP Performance
Outlines

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

- **What to be measured?**
  - Site Selection
  - Data Collection

- **How to measure?**
  - Profiling
  - Temperature
  - Others
Diurnal Profiling

- Critical Passes!!

Temperature Gradient (deg F/inch)

12:00 PM 4:00 PM 8:00 PM 12:00 AM 4:00 AM 8:00 AM 12:00 PM 4:00 PM

Early AM

Mid-AM

Evening

Late AM - Early PM
Outlines

- Curl/Warp Measurement
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Raw Profile

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Distance (m)

Left Elevation (mm)
Spike Profile

- Filter with moving average anti-smoothing
- Normalize by RMS
- Search deepest dip by a threshold

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Spike Incidence

Assemble the dip count across the data set

Spike Incidence (percent)

Distance (m)

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Weeded Spike Incidence

Weed/clear false hits
Extract the joint locations

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Outlines

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Westergaard Curling Formula

\[
\begin{align*}
\text{Deflection (Modified eq.)} & \quad \text{Transv. Stresses at Top (psi)} \\
\end{align*}
\]

\[
\begin{align*}
\text{Distance from Slab Center (inches)} & \\
\end{align*}
\]

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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 Fit – Curled Down Slab

25-mm data
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

![Graph showing Pseudo Gradient (με/cm) vs Slab Number]

- Slab Number
- Pseudo Gradient (με/cm)

Legend:
- Early AM
- Mid AM
- Noon
- Late PM

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2GCI Analysis

AZ_001am - winter

Graph showing pseudo-gradient distribution (μɛ/cm) for different time periods: Early AM, Mid AM, Noon, Late PM. The graph includes quartiles, minimum, median, maximum, and quartile 3 data points. The x-axis represents the time periods, and the y-axis represents the pseudo-gradient distribution values.
2GCI Analysis

MN_046a - summer

Pseudo Gradient (με/см)

Slab Number

- Early AM
- Mid AM
- Noon
- Late PM
2GCI Analysis

MN_046a - summer
Mean Curvatures

Pseudo-gradients ($\mu$e/cm)
Outlines

- Curl/Warp Measurement
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2GCI vs Roughness

Mean Pseudo-Gradient (με/cm)

Time

-16
-14
-12
-10
-8
-6
-4
-2
0

0:00 4:48 9:36 14:24 19:12 0:00

Spring
Summer
Fall
Winter

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The RoCK Chart

Roughness

Curvature (upward)

Clf  Crt  0  Portorož, Slovenia

Curvature (downward)

Rlb

Rzc

Rub
Roughness Decomposition

Curvature-related Roughness

Non Curvature-related Roughness

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TYPE I-A Sites

Curled up
Curvature dominates roughness

Src < 0
Rbtc > 0

Curvature (upward)
Curvature (downward)
Portorož, Slovenia

Roughness

Src < 0
Rbtc ~ 0

Curled up mildly
Curvature affects roughness

TYPE I-B Sites

Curvature (upward)
Curvature (downward)

Clf
Crt

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TYPE II Sites

Curled up and down
Curvature affects
Roughness mildly

Src < 0
Rbtc ~ 0

Src > 0
Rbtc > 0

Curvature (upward)
Curvature (downward)

Clf
Crt

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TYPE III-A Sites

Curled down
Curvature dominates roughness

Curvature (upward)

Curvature (downward)

Src > 0
Rbtc > 0
Rlb CrtClf

Rubic

Rzr

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TYPE III-B Sites

Curled down mildly
Curvature affects roughness

Roughness

Surf 2008

Src > 0
Rbtc ~ 0

Clf Crf

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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
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Effect of curling and loading-current geometry

Stresses (Kpa)

- Legal limit load only
- Loading on 28 Ton tandem only
- Curling + legal load
- Curling + load on 28 ton tandem
- Curling + load on 20 Ton simple axle

Strength
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
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