Dowel Bars and Misalignment Tolerances

Concrete Pavement Innovation & Technology Transfer Workshop
June 25, 2015

Robert Rodden, P.E.
Previously: Senior Director of Pavement Technology @ ACPA
Currently: Executive Director @ ISCP
Overview

- How we image hardened concrete
- The sources of misalignment and mislocation during construction
- The magnitude of acceptable misalignment or mislocation
- Guidance on specifications

... but let’s focus on the story...
Acknowledgements

- FHWA ACPT Task Force on Dowel Bar Alignment Testing – Kickoff Meeting Presenters
  - Shiraz Tayabji – Fugro
  - Glenn Eder – Dayton Superior
  - Ron Guntert – Guntert & Zimmerman
  - Brad Rister – Univ of KY
  - Jagan Gudimettla – FHWA
  - Dan Ye – Fugro
  - Shreenath Rao – ARA
  - Mark Snyder – ACPA PA
- Tom Yu – FHWA
- Bil Vavrik – ARA
- Mark Snyder – ACPA PA
pavement imaging

... is like an x-ray
Ground Penetrating Radar (GPR)
Ultrasonic Shear Wave Tomography (MIRA)

Magnetic Imaging

THICKNESS

DOWEL BARS
MIT Scan 2

- Robust and easy to use
- Accurate and reliable (± 5 mm)
- Efficient (1-2 min per joint)
  - Test 400 or more joints in an 8-hr workday
  - Test up to 3 lanes/pass
Real-Time Results

- Immediate results
- Automated data analysis
Some Application Issues Exist

Basket not cut

Basket cut

Interference from Tiebar
Results Are Telling!

Typical Joint  Basket Opened  Anchoring Issue  Missing Dowels
Results Are Telling!

Missed Sawcut
Sources of Misalignment and Mislocation
The Goal

- Dowels that are:
  - **Aligned** such that they impose no intolerable restraint on joint opening/closing
  - **Located** such that they provide adequate long-term load transfer
    - Are not so close to the surface or subbase as to cause shear failures
    - Have the required embedment depth
    - Are not too far or close to each other or pavement edge
Misalignment

- Any deviation in either the horizontal or vertical plane from a true alignment condition (e.g., horizontal skew or vertical tilt).
Mislocation

- Any deviation of a dowel bar from its planned location. DOES NOT LOCK THE JOINT!
Challenges in Placement

Baskets

Dowel Bar Insertion (DBI)
Sawcut Mislocation = Dowel Mislocation
Contractors Are Getting Proactive!!

- Locate edge dowels BEFORE sawing...
Misalignment and Mislocation Thresholds
What’s the Concern?

<table>
<thead>
<tr>
<th></th>
<th>Spalling</th>
<th>Cracking</th>
<th>Load Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Skew</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertical Tilt</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Horizontal Translation</td>
<td>–</td>
<td>–</td>
<td>Yes</td>
</tr>
<tr>
<td>Longitudinal Translation</td>
<td>–</td>
<td>–</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertical Translation</td>
<td>Yes</td>
<td>–</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Joint Locking?
ACPA and PCA Documents

- **PCA 2005 – R&D 2894, “Dowel Bar Alignments of Typical In-Service Pavements”**

All of these resources are in the Google Drive.
FHWA Guidance

- FHWA 2005 – FHWA-IF-06-002, “Use of Magnetic Tomography Technology to Evaluate Dowel Bar Placement” (full report is FHWA-IF-06-006)
Most Recent BIG Study

- **NCHRP 2009** – Report 637, “Guidelines for Dowel Alignment in Concrete Pavements”
  - Field: 35,000 dowels | 2,300 joints | 60 projects | 17 states
  - Lab: misaligned/mislocated dowels in a load frame
  - Computer: finite element analyses
NCPTC 2011 – “Guide to Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements”
Dowel Placement Specs

- Ideally, dowel bars should be placed without any placement error.
- Stringent, but constructible, requirements should be specified, and allowance should be made for tolerable errors.
- Improved guidelines are needed on dowel placement tolerance.
ACPA Guide Spec

- Reviewed refs and NY, OH, MTO, etc. specs
- Latest version 8/2013
- Dowels that are:
  - Inserted with DBI
  - 18 in. (457 mm) long
  - Round
  - Metallic
  - With & without coatings
- JPCP with joints sawed perpendicular to edge
- Includes source summary
Alignment Tolerances
3 levels defined for each misalignment/mislocation type

Accept – Placement causes no potential problems and indicates that the processes are well-controlled

QA Trigger – Placement has a low risk of causing problems, but the processes should be adjusted to achieve “Accept” level

Requires Action – Placement has significant risk of causing problems; corrective action should be considered and the processes should be adjusted as required
ACPA: Location of Individual Dowel

**Longitudinal Translation**

- ≤ 2 in. (50 mm) | Accept
- > 2 in. (50 mm) | QA Trigger
- > 5 in. (125 mm) | Requires Action

The **Accept** and **QA Trigger** limits:

\[
\text{Accept and QA Trigger limits: } \frac{18 \text{ in. length} - 2 \times 4 \text{ in. of embedment}}{2} - 3 \text{ in. safety factor} = 2 \text{ in.}
\]

The **Requires Action** limit:

\[
\text{Requires Action limit: } \frac{18 \text{ in. length} - 2 \times 4 \text{ in. of embedment}}{2} = 5 \text{ in.}
\]

**NOTE:** 4 in. of embedment based on NCHRP 2009 and NCPTC 2011
NCHRP 2009: **Accept:** < 2.1 in.

FHWA 2007:

- **Accept:** < 2 in.
- **Reject:** any joints with < three bars with a minimum embedment length of 6 in. under each wheelpath

NCPTC 2011: Notes that NCHRP 2009 showed no significant loss of shear capacity until embedment length < 4 in.; embedment length as low as 2 in. provided shear capacity of 5,000 lb, more than sufficient for critical dowels in highways
MnDOT Experience

Tom Burnham identified a section with low embedment length due to mislocated sawcut and has monitored field performance, concluding:

“... a minimum dowel bar embedment length of 64 mm (2.5 in.) is needed to prevent significant faulting and maintain reasonable load transfer efficiency across a joint.”

Section is now 15 yrs+ old and still performing

ACPA: Location of Individual Dowel

**Vertical Translation**

- Dowel **above** mid-depth
  - \( \leq 1 \text{ in. (25 mm)} \) | Accept
  - \( > 1 \text{ in. (25 mm)} \) | QA Trigger
  - Cover \( < 2.5 \text{ in. (64 mm)} \) | Requires Action

AND

Distance between top of dowel and bottom of sawcut:

- \( \geq 0.5 \text{ in. (12 mm)} \) | Accept
- \( < 0.5 \text{ in. (12 mm)} \) | QA Trigger
- \( < 0.25 \text{ in. (6 mm)} \) | Requires Action

Do we know if sawcut to correct depth?!?
ACPA: Location of Individual Dowel

- **Vertical Translation**
  - Dowel **below** mid-depth
    - \( \leq 1 \text{ in. (25 mm)} \) | Accept
    - \( > 1 \text{ in. (25 mm)} \) | QA Trigger
    - Cover < 2.5 in. (64 mm) | Requires Action
NCHRP 2009:
- **Accept:** ± 0.5 in. for \( T \leq 12 \) in. or ± 1 in. for \( T > 12 \) in.
- **Reject:** concrete cover \( \leq 2 \) in. or sawcut depth

FHWA 2007:
- **Accept:** ± 1 in.
- **Reject:** concrete cover < 3 in. or sawcut depth

NCPTC 2011: Notes that NCHRP 2009 showed no difference between dowels at mid-depth and those located more than 1 in. closer to surface
... No Need for Dowel at Mid-Depth

- **NCC 2011** – recs for standardization, for example:
  - Dowel diameter: 1.5 in.
  - Height to dowel center: 5 in.
  - Slab Thickness: >10-12 in.

- **Dowel only needs to be in the middle 1/3 of slab; concerns are cover depth and sawcut depth**
ACPA: Location of Individual Dowel

**Horizontal Translation**

- ≤ 2 in. (50 mm) | Accept
- > 2 in. (50 mm) | QA Trigger
- > 3 in. (75 mm) | Requires Action
NCHRP 2009:

Accept: ± 1 in.

This is set with a basket

Many documents (e.g., FHWA 2007) identify horizontal translation as a concern but do not provide guidance on allowable magnitude

Many state agency specs omit a tolerance

Cover depth with edge of pavement is key

Dowels @ 12 in. o.c. is VERY conservative
ACPA: Alignment of *Individual* Dowel

Horizontal Skew **AND** Vertical Tilt < 0.6 in. (15 mm) | Accept
Horizontal Skew **OR** Vertical Tilt ≥ 0.6 in. (15 mm) | QA Trigger
SDM > 1.5 in. (38 mm) | Requires Action

*Single Dowel Misalignment (SDM) =*

\[
\sqrt{(\text{Horizontal Skew})^2 + (\text{Vertical Tilt})^2}
\]
Refs: Align. of Individual Dowel (18 in.)

- **FHWA 2007:**
  - **Accept:** component misalignment < 0.6 in.
  - **Reject:** SDM > 1.5 in.

- **NCHRP 2009:** Dowel rotations up to 2 in. have a negligible effect on pullout and shear performance
  - **Accept:** component misalignment < 0.5 in.
  - **Reject:** SDM > 3 in.
Joint Score (JS) – Means of assessing locking potential; evaluated for a single transverse joint between adjacent longitudinal joint(s) and/or pavement edge(s):

\[
\text{Joint Score (JS)} = 1 + \sum_{i=1}^{n} W_i
\]

where:

- \( n \) = number of dowels in the single joint
- \( W_i \) = weighting factor for dowel \( i \)

NOTE: Originated in **PCA 2005** and **ACPA 2006**
The potential for locking of a single joint:

- **JS ≤ 5** | very low risk of joint restraint
- **5 < JS ≤ 10** | low risk of joint restraint
- **10 < JS ≤ 15** | moderate risk of joint restraint; potentially locked
- **JS > 15** | high risk of joint restraint; joint locked

NOTE: Values identical in **FHWA 2007, PCA 2005, ACPA 2006**
ACPA: Not All Joints are 12’ Wide

Joint Score Trigger (JST) – A scaling of the Joint Score risk value to account for the actual number of dowels per a single joint:

\[
\text{Joint Score Trigger (JST)} = 10 * \frac{\text{# of Dowel Bars in Single Joint}}{12}
\]

<table>
<thead>
<tr>
<th># of Dowel Bars in Single Joint</th>
<th>JST</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8.3</td>
</tr>
<tr>
<td>11</td>
<td>9.2</td>
</tr>
<tr>
<td>12</td>
<td>10.0</td>
</tr>
<tr>
<td>13</td>
<td>10.8</td>
</tr>
<tr>
<td>14</td>
<td>11.7</td>
</tr>
</tbody>
</table>
ACPA: Alignment of Single Joint

Joint Score (JS) = 1 + \sum_{i=1}^{n} W_i

MISALIGNMENT OF ANY DOWEL WILL CONTRIBUTE TO THE JOINT SCORE

JS ≤ JST | Accept
JS > JST | QA Trigger
JS > JST for all joints over MALL | Requires Action
...But More Than 1 Joint Can Lock

**Maximum Allowable Locked Length (MALL)** – maximum allowable length of locked-up pavement; 60 ft (18 m), including no more than three consecutive joints with JS > JST.

Hinge Joint Design | Essentially JRCP with steel strategically located beneath joint.

How many lanes can you tie together?
Field Installation and the Tie to Performance
Full-Width Basket (FWB) vs DBI

Overall ACPA Special Report Data

- ACPA FWB
- ACPA DBI

<table>
<thead>
<tr>
<th>Category</th>
<th>FWB</th>
<th>DBI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.4</td>
<td>80%</td>
<td>70%</td>
</tr>
<tr>
<td>0.4 - 0.6</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>0.6 - 0.8</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>0.8 - 1.0</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>&gt; 1.0</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

(Chart showing percentage distribution for each category.)
Wheel-Path Baskets (WPB) on I-90
This is Increasingly Common

UT DOT
Standard Drawing

ID DOT
Standard Drawing

McLeod County, MN
Standard Drawing
FWB vs WPB vs DBI

Tollway I-90 Overall Dowel Alignment

- FWB
- WPB
- DBI
Impacts of Innovative Designs

Photo source: PNA Construction Technologies and MnDOT
Impacts of Innovative Designs

Photo source: Jim Thomas @ The Harper Company
Findings from the ACPA Study

- Dowel alignments are generally very good, but
  - Almost all projects contained at least a few significantly misaligned bars
- Occasional, isolated “locked joints” may have no significant effect on pavement performance
- Poor dowel alignment may cause looseness around dowels, impacting LTE but not cracking
- Dowel alignment achieved using baskets and DBI are similar; similar results on IL Tollway
JSs for a Basket Placement in IN
JSs for a DBI Placement in KS
KS, NB I-35 – 6 years old
Joint Score for a Section in GA
30-yr old GA section with extremely poor dowel alignment
... but no cracking!

So Joint Score is not the holy grail of dowel bar alignment characterization.
ARA Currently Looking Deeper

MIT scanning LTPP sections for a larger scale look at the tie to performance

www.infopave.com
ACPA Guide Spec Also Includes

- Trial Section
- Testing Procedures
  - Quality Control (QC)
  - Quality Assurance (QA)
  - Exclusions
- Measurement Equipment
- Measurement Interference
- Reporting
- Corrective Action

Next version with PWL and other enhancements...
Questions?

Robert Rodden, P.E. | Executive Director
International Society for Concrete Pavements | ISCP
www.concretepavements.org | @ConcPaveSociety