Dowel Bar Alignment:
What Do We Need?
What Should We Expect?
(and a few other topics …)

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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!
Sources of Misalignment and Mislocation
Placement Factors Impacting Alignment/Location

- Baskets
  - Basket rigidity and design
    - wire sizes, leg shapes ("J" vs "A"/"V"/"U")
  - Handling
Placement Factors Impacting Alignment/Location

- **Baskets**
  - Basket rigidity and design
    - wire sizes, leg shapes (“J” vs “A”/”V”/”U”)
  - Handling
  - Basket stability - Cutting shipping wires or failure of dowel clips (FRP and other non-welded dowels) can result in basket collapse
Placement Factors Impacting Alignment/Location

- Baskets
  - Basket anchoring – pins, support layer, etc.
    - Especially a concern for concrete overlays and new construction on stabilized bases
    - See FHWA Tech Brief: Dowel Basket Anchoring Methods – May 2016

- Baskets placed relative to top of base, vertical location measured relative to top surface of pavement – indicated “mislocation”
Recommended practices for:

- Anchor types (design, length, etc.)
- Anchor locations and quantities
- Construction practices to minimize potential basket damage and movement
- Basket braces and other supplemental support systems
Placement Factors Impacting Alignment/Location

- **Dowel Bar Insertion (DBI)**
  - Dowel feed issues
  - Equipment problems (e.g., damaged insertion forks) cause systematic problems
  - Concrete mixture too stiff or too soft/consolidation around dowel bars
  - “Floating” dowels (e.g., FRP)? “Sinking” dowels?
  - Automated saw cut location marks
Sawcut Not Over Dowel Bar
Potential Impacts of Misalignment/Mislocation on Pavement Performance
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>
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<tr>
<td>Horizontal Translation</td>
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<td>Yes</td>
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Potential Dowel Misalignment Problems
Potential Dowel Misalignment Problems
"Why are we here?"

Dowel Bar Alignment and Location
Draft Version 4.2 – November 29, 2017

Preface
Developments in magnetic imaging tomography, ground-penetrating radar and ultrasonic imaging, along with associated data and image processing software, now make it relatively easy to nondestructively measure dowel positioning quickly and accurately. Furthermore, the accuracy of dowel positioning can be considered to be one indicator of construction quality, so highway agencies in the U.S. and Canada are rapidly adopting dowel imaging technology.

Because we’re here ...

Neal Peart, 1991
... and we’re here ...

- GSSI Ground-Penetrating Radar (GPR)
- MIRA – Ultrasonic tomography
  - Utilizes sound waves
  - Like GPR, can also detect other issues, such as delamination
MIT-Dowel-Scan

- Laser-guided single-person operation
- Can be used on “green” concrete
- Accurate measurements of depth, side-shift and alignment of dowels and tie bars within 1 minute of completing scan
- Still electro-magnetic pulse induction technology – 10 sensors

Source: Garry Aicken, KSE Testing Equipment
Misalignment and Mislocation Thresholds
Criteria Generally Based on Lab Tests

Some early work from the 1980s:

FIGURE 4 Single-dowel test: displacement sensors on slab surface.
Most Recent “Big” Study


- Field tests and evals
- Laboratory tests
- 3D FEM and theoretical analysis
- Pavement performance modeling
- Design and construction guidelines and recommendations for dowel alignment levels
Field Evaluation

- 35,000 dowels | 2,300 joints | 60 projects | 17 states
- Typical range of misalignment/mislocation with **no significant effect on pavement performance**:
  - Horizontal skew or vertical tilt: < 0.5 in. over 18 in. dowel
  - Longitudinal translation: ± 2 in. over 18 in. dowel
  - Vertical translation: ± 0.5 in. for 12 in. or less in thickness
Laboratory Testing

- 64 single-dowel misalignment/mislocation tests

Two-part test:
- Pull-out to simulate joint opening
- Shear test to simulate loading on damaged system

Results:
- Dowel lubrication significantly affects pullout force
- Dowel rotation as extreme as 2 in. per 18 in. dowel does not affect shear capacity
- Reduction in concrete cover from 3.25 in. to 1.25 in. causes severe reduction in ultimate shear capacity
- Reduction in dowel embedment length to 3 in. and less significantly reduces shear capacity
- Combinations of misalignment and mislocation have a compounding effect on shear performance
Effect of Embedment Length

Initial slope = shear stiffness
Max shear force = shear capacity
Effect of Embedment Length

1 in. dowel
9 in. embedment
Peak bearing stress = 2,465 psi

1 in. dowel
5 in. embedment
Peak bearing stress = 2,751 psi, (11% incr.)

...but what is limit on bearing stress?
3-D Finite Element Modeling Results

- Rotated (especially non-uniformly rotated) dowels cause damage to the concrete around dowels due to temperature expansion and contraction, causing a reduction in joint load transfer efficiency.
  - **Dowel misalignment alone**, unless extreme rotation (e.g., > 3 in./18 in dowel), does not cause joint lockup.

- Significant dowel misalignment reduces the effectiveness of dowels.
  - Dowel misalignment has the same apparent effect on joint performance as a reduction in dowel diameter.

- **Dowel-concrete friction and bond overshadows the effect of misalignment on joint lockup.**

- Reduction in embedment length or cover reduces shear capacity.
Back to Talking about Thresholds...

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Diagram showing Plan View and Section View of pavement with labels for Horizontal Skew, Vertical Tilt, Horizontal Translation, Longitudinal Translation, and Vertical Translation.
Two thresholds to consider for each positioning measure:

Develop TH1 (Acceptance) values based on what is reasonably achieved with good practices.

Develop TH2 (Rejection) values based on what causes distress or other performance issues.
ACPA and PCA Documents

- **ACPA 2006** – SR999P, “Evaluating and Optimizing Dowel Bar Alignment”
- **PCA 2005** – R&D 2894, “Dowel Bar Alignments of Typical In-Service Pavements”
NCPTC 2011 – “Guide to Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements”
FHWA Guidance

- **FHWA (2018?)** – “Dowel Alignment Testing and Tolerances” – new tech brief, currently in review
Longitudinal Translation (18 in. bar)

- **FHWA 2007:**
  - **Accept:** < 2 in.
  - **Reject:** any joints with < three bars with a minimum embedment length of 6 in. in each wheel path

- **MTO (Canada) 2007:**
  - **Accept:** < 50 mm [2 in.]
  - **Reject:** >75mm [3 in.]

- **NCHRP 2009:** **Accept:** < 2.1 in.

- **CPTech 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

- **ACPA 2018:**
  - **Accept:** < 2 in.
  - **Reject:** > 5 in.
Vertical Translation

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

**MTO (Canada) 2007:**
- 200mm slab: mid-depth +/- 6mm (R/R +/- 10mm)
- 225mm slab: mid-depth +15mm/-12mm (R/R +23mm/-17mm)
- 250mm slab: mid-depth +25mm/-15mm (R/R +35mm/-25mm)

**NCHRP 2009:**
- **Accept:** ± 0.5 in. for T ≤ 12 in. or ± 1 in. for T > 12 in.
- **Reject:** concrete cover ≤ 2 in. or sawcut depth

**CPTech 2011:** Notes that NCHRP 2009 showed no difference between dowels at mid-depth and those located more than 1 in. closer to surface

**ACPA 2018:**
- **Accept:** ± 1/2 in.
- **Reject:** concrete cover < 2 in. or <1/4” clear to bottom of saw cut
Dowels Do Not Need to be at Mid-Depth

- **Dowel requires only adequate cover (concrete shear capacity) and to avoid conflict with saw cut**

- **NCC 2011** – provides recommendations for standardization, for example:
  - For Slab Thickness 10-12 in.
    - Dowel diameter: 1.5 in.
    - Height to dowel center: 5 in.
Horizontal Translation

- **NCHRP 2009:**
  - Accept: ± 1 in.
  - This is fixed with baskets
  - 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
Alignment of *Individual* Dowel (18 in.)

- **NCHRP 2009:** Dowel rotations up to 2 in. have a negligible effect on pullout and shear performance.
  - **Accept:** component misalign < 0.5 in.
  - **Reject:** SDM > 3 in.

- Acceptance is slightly less than FHWA recommendation and reject is 2x FHWA.

- A combination of low concrete cover and low embedment length has a more adverse effect on dowel performance than either of the two misalignments.
Alignment of *Individual* Dowel (18 in.)

Single Dowel Misalignment (SDM) = \[ \sqrt{(Horizontal Skew)^2 + (Vertical Tilt)^2} \]

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

- **MTO 2007:**
  - **Accept:** component misalignment < 15mm [0.6 in.]
  - **Reject:** component misalignment >38mm [1.5 in]

- **ACPA 2018:**
  - **Accept:** SDM < 0.75 in.
  - **Reject:** SDM > 2 in
Considering *All Dowels in a Joint*

- **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 \( i \)
Excessive Misalignment = “Lock”

### Restraint

<table>
<thead>
<tr>
<th>Single Dowel Misalignment (SDM)</th>
<th>W, Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDM ≤ 0.6 in. (15 mm)</td>
<td>0</td>
</tr>
<tr>
<td>0.6 in. (15 mm) &lt; SDM ≤ 0.8 in. (20 mm)</td>
<td>2</td>
</tr>
<tr>
<td>0.8 in. (20 mm) &lt; SDM ≤ 1 in. (25 mm)</td>
<td>4</td>
</tr>
<tr>
<td>1 in. (25 mm) &lt; SDM ≤ 1.5 in. (38 mm)</td>
<td>5</td>
</tr>
<tr>
<td>1.5 in. (38 mm) &lt; SDM</td>
<td>10</td>
</tr>
</tbody>
</table>

The potential for restraining 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**
Alignment of Single Joint

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

MISALIGNMENT OF ANY DOWEL WILL CONTRIBUTE TO THE JOINT SCORE

\text{JS} < \text{JST} \quad \text{Accept}
Joint Scores for a Basket Placement in IN
5 years old
Joint Scores for a 30-year old Section in GA
30-yr old GA section with extremely poor dowel alignment
Findings from the ACPA Study

- Dowel alignments are generally very good, but
  - Almost all projects contained at least a few significantly misaligned bars
  - None of the sections surveyed exhibited distress related to misalignment
- 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 comparable
Considering Measurement Accuracy of Equipment in Spec Limits

Very important to understand measurement accuracy of devices – different measurement accuracy may mean different testing spec limits!

Example:
- Longitudinal Offset (Side Shift) Acceptance = 2 inches
- Longitudinal Offset (Side Shift) Rejection = 5 inches
- Device A accuracy = +/- ¼ inch
  - Accept values less than 2.25 inches (protects contractor)?
  - Reject values exceeding 4.75 inches (protects owner)?
- Device B accuracy = +/- ½ inch
  - Accept values less than 2.50 inches (protects contractor)?
  - Reject values exceeding 4.50 inches (protects owner)?
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
<th>Limit Adjustments for Alternative Equip Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Misalignment</td>
<td>0 in.</td>
<td>0.75 in. [19mm]/18 in. [450mm]</td>
<td>Decrease upper limit by (rot. accuracy – 0.25 in [6mm])</td>
</tr>
<tr>
<td>Side Shift (Longitudinal Translation)</td>
<td>-2 in. [-50mm]</td>
<td>2 in. [50mm]</td>
<td>Increase lower limit and decrease upper limit by (long. trans. accuracy – 0.5 in [12mm])</td>
</tr>
<tr>
<td>Horizontal Translation</td>
<td>N/A*</td>
<td>N/A*</td>
<td>N/A*</td>
</tr>
<tr>
<td>Depth (Distance from Pavement Surface to Dowel Centroid)</td>
<td>Nominal Slab Thickness/2 - ½ in [13mm]</td>
<td>Nominal Slab Thickness/2 + ½ in [13mm]</td>
<td>Increase lower limit and decrease upper limit by (depth accuracy – 0.25in [6mm])</td>
</tr>
<tr>
<td>Joint Score</td>
<td>0</td>
<td>15</td>
<td>Adjust weighting factors, not JS limit.</td>
</tr>
</tbody>
</table>
## ACPA Guide Spec Rejection Limits

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Rejection Levels</th>
<th>Limit Adjustments for Alternative Equip Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Composite Misalignment</strong></td>
<td>$&gt; 2$ in. [50mm]</td>
<td>Decrease by (rot. accuracy – 0.25 in [6mm])</td>
</tr>
<tr>
<td><strong>Side Shift (Longitudinal Translation)</strong></td>
<td>$</td>
<td>\text{Side Shift}</td>
</tr>
<tr>
<td><strong>Horizontal Translation</strong></td>
<td>N/A*</td>
<td>N/A*</td>
</tr>
<tr>
<td><strong>Depth (Distance from Pavement Surface to Dowel Centroid)</strong></td>
<td>$&lt; \text{Saw Cut Depth} + \frac{1}{4}$ in [6mm] + dowel diameter/2 or $&gt; \text{Slab Thickness} – (2$ inches [50mm] +dowel diameter/2)**</td>
<td>Decrease upper limit by (depth accuracy – 0.25in [6mm])</td>
</tr>
<tr>
<td><strong>Joint Score</strong></td>
<td>Effective Panel Length $&gt; 60$ ft [20 m]</td>
<td>Adjust weighting factors, not JS limit.</td>
</tr>
</tbody>
</table>
Overtime ...

OTHER TOPICS
“Optimized” Dowel Spacing

- Trend toward reducing standard dowel installations from 12 dowels per 12-ft lane to 11
- Increase distance from lane edge to outside dowels to reduce incidence of paver-induced misalignment
- Can also use shorter dowels (MN), especially in repairs and precast (NY, HI, others)

Minneapolis DOT Standard and Practice
“Optimized” Dowel Spacing

Concentrated dowels in wheel paths

- Common in repairs and dowel bar retrofit
- Increasingly in new construction

MN TH59: 2 lanes, 6 dowels
Illinois Tollway: 5 dowels/wheel path
Precast Panels: 4-5 dowels/wheel path
Utah DOT Design Standard
"Optimized" Dowel Designs
(alternate shapes and materials)

- Reduce bearing stress while holding cross-sectional area constant (or reducing it)
- Examples:
  - Hollow Dowels (fill or use end caps)
  - Elliptical Dowels
  - Plate Dowels

(Photos: Greenstreak, PNA Construction Technologies, Glen Eder, O-Dowel)
Traditional Epoxy Coatings

- Typical product: AASHTO M254/ASTM 775 (green, “flexible”)  
- ASTM 934 (purple/grey, “nonflexible”) has been suggested
  - Perception of improved abrasion resistance (but green meets same spec requirement)
  - Mancio et al. (2008) found no difference in corrosion protection

What is needed:
- Durability, resistance to damage in transport, handling, service
- Standardized coating thickness
Epoxy Coatings for Dowels: Better Stuff is Available!

Simplex Supply Armour Coat – 2-layer fusion-bonded system
Dowel Corrosion Solutions: Corrosion-Resistant/Noncorroding Materials

- Stainless Steel (Solid, Tubes)
  - Expensive (solid bars and, to a less extent, grout-filled tubes)
  - Deformation and slab cracking concerns (hollow tubes only)

- "Microcomposite" Steel
  - Sufficient corrosion resistance?

- GFRP Products
  - Not yet widely adopted
  - Concerns over behavior, durability
Dowel Corrosion Solutions: Barrier/Cathodic Protection

- Galvanic (Sacrificial)
  - Inexpensive and self-regulating
  - Appears well-suited for pavement dowel applications (zinc cladding or sleeve)
Composite Protection: Epoxy plus Galvanizing (Tubular Dowel)

- High-strength, Grade 60 structural steel tubing
- Heavy wall-to-outside diameter ratio
- G40 galvanized coating with epoxy
- Epoxy-coated to state requirements
- End plugs limit intrusion

O-Dowel 2-layer Epoxy-Galvanized tubular dowel system
Comparing Solid Metal, Tubular Metal and Solid FRP

<table>
<thead>
<tr>
<th>Dowel Type</th>
<th>Diameter (in)</th>
<th>Dowel Modulus, E (psi)</th>
<th>Applied Shear Force (lbs)</th>
<th>Dowel Deflection at Joint Face (in)</th>
<th>Bearing Stress (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metallic</td>
<td>1.50</td>
<td>29,000,000</td>
<td>1940 (12-in spacing)</td>
<td>0.0009</td>
<td>1405</td>
</tr>
<tr>
<td>Sch 40 Pipe</td>
<td>1.66</td>
<td>29,000,000</td>
<td>1940 (12-in spacing)</td>
<td>0.0009</td>
<td>1421</td>
</tr>
<tr>
<td>FRP</td>
<td>1.50</td>
<td>5,600,000</td>
<td>1940 (12-in spacing)</td>
<td><strong>0.0015</strong></td>
<td><strong>2185</strong></td>
</tr>
<tr>
<td>FRP</td>
<td><strong>1.93</strong></td>
<td>5,600,000</td>
<td>1940 (12-in spacing)</td>
<td>0.0009</td>
<td>1393</td>
</tr>
<tr>
<td>FRP</td>
<td>1.50</td>
<td>5,600,000</td>
<td><strong>1293 (8-in spacing)</strong></td>
<td>0.0010</td>
<td>1456</td>
</tr>
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</table>

... but field performance to date suggests FRP may be used with same diameter and spacing without apparent impact on service life.
Discussion Topics:

- Is it more cost-effective to build pavement thicker with no dowels and plan to grind?
- How many times can you grind concrete pavement?
Acknowledgments

- Garry Aicken – KSE Testing Equipment
- Glenn Eder – Simplex Supply and Manufacturing
- Jagan Gudimetta – FHWA
- Ron Guntert – Guntert & Zimmerman
- Dale Harrington – CP Tech Center
- Kyle Hoegh, Minnesota DOT
- Tom Kazmierowski – Golder Associates
- Lev Khazanovich, University of Pittsburgh
- Becca Lane – Ministry of Transportation – Ontario
- Mitzi McIntyre – CTS Cement
- Brad Rister – Univ of KY
- Robert Rodden, PNA (formerly ACPA)
- Chris Schenk – Schenk Industrial Marketing
- Shiraz Tayabji – Advanced Concrete Pavement Consultancy, LLC
- Jerry Voigt and Eric Ferrebee, ACPA
- Tom Yu – FHWA
- Matt Zeller – Concrete Paving Association of MN
Discussion/Questions?

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