Dowel Bar Alignment and Location
for Placement by Mechanical Dowel Bar Insertion
August 14, 2013

Scope, Background and Applicability

This guide specification is directly applicable to 18 in. (457 mm) long, round metallic dowel bars, with and without coatings, for use in jointed plain concrete pavements (JPCP) with joint sawcuts made perpendicular to the edge of pavement (e.g., non-skewed joints). The requirements herein recognize that round dowel bars must be:

1) **Aligned** such that they impose no intolerable restraint on joint opening/closing.
2) **Located** such that they provide adequate long-term load transfer and have adequate concrete cover to prevent shear failures.

The alignment of dowel bars (e.g., **horizontal skew** or **vertical tilt**) is important because significant misalignment of dowel bars in a doweled joint may prevent that joint from properly opening/closing. The occurrence of a single joint that does not open/close effectively will not necessarily result in a mid-panel crack or another pavement defect, but the risk of mid-panel cracking and joint distress increases with each successive joint with limited opening/closing capabilities (see FHWA 2007).

**Longitudinal translation** is important to ensure the proper embedment length of the dowel bar for long-term load transfer. Thus, the allowable longitudinal translation is a function of construction (e.g., location per plans and proper location of sawcut over the dowel) and the dowel bar length.

**Vertical translation** is important to ensure that there is enough concrete over the steel to resist corrosion of steel dowel bars and must be such that the concrete will not develop shear cracking or spalling above the dowels as loads are transferred across the joint. Thus, the allowable vertical translation is a function of as-constructed pavement thickness and planned dowel vertical location. Consideration must also be given for sawcut depth such that the dowels are not cut during sawing operations.

**Horizontal translation** is of concern when a dowel is located far enough from its intended location that the redistribution of joint loads negatively impacts the pavement or dowel-concrete system.

If a dowel alignment and location specification is included on a concrete paving project, it is suggested that the conditions of the specification be reviewed during a pre-paving meeting. The discussion should include a review of: 1) how the dowel bar insertion equipment will function; 2) the Accept and Requires Corrective Action Proposal (CAP) limits; 3) the dowel alignment and location testing device, its applicability to the specification, and testing and reporting protocols; and 4) acceptable corrective action scenarios.
Guide Specification

**DBAL.1 TERMINOLOGY**

Figure 1 illustrates the five types of dowel bar misalignment and mislocation and the following two sections define these misalignments and mislocations.

![Diagram of dowel bar alignment and location](image)

*Figure 1. The five types of dowel bar misalignment and mislocation (after FHWA 2007).*

**DBAL.1.1 Dowel Bar Alignment Terms**

Alignment – The degree to which a dowel bar aligns true (e.g., parallel) to the horizontal or vertical planes of the pavement.

*Horizontal Skew* – The deviation of the dowel bar from true parallel alignment from the edge of the pavement\(^iv\), measured over the entire length of the dowel bar.

*Vertical Tilt* – The deviation of the dowel bar from true parallel alignment from the surface of the pavement, measured over the entire length of the dowel bar.

*Misalignment* – Any deviation in either the horizontal or vertical plane from a true alignment condition (e.g., horizontal skew or vertical tilt).
**Single Dowel Misalignment (SDM)** – The degree of misalignment applicable to a single dowel bar, calculated as:

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

**Joint Score (JS)** – The degree of misalignment evaluated for a single transverse joint between adjacent longitudinal joint(s) and/or pavement edge(s) (i.e., a typical 12 ft [3.6 m] standard lane or up to 14 ft [4.3 m] widened lane), and calculated as:

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

where:

- \( n \) = number of dowels in the single joint
- \( W_i \) = weighting factor (Table 1) for dowel \( i \)

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

*Note to Specification Writer: A single 12 ft (3.6 m) wide transverse joint with 12 dowel bars is considered to have a moderate risk of locking when JS > 10.*

**Joint Score Trigger (JST)** – A scaling of the JS to account for the actual number of dowels in a single joint, calculated as:

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

**Maximum Allowable Locked Length (MALL)** – maximum allowable length of locked-up pavement; 60 ft (18 m), including no more than three consecutive joints with joint scores (JSs) greater than the JST.
**DBAL.1.2 Dowel Bar Location Terms**

*Horizontal Translation* – Location of dowel bar relative to the planned location from the pavement edge, nearest longitudinal joint, or nearest parallel dowel bar.

*Vertical Translation* – Location of dowel bar relative to the depth in the pavement, referenced from the nominal mid-depth of the slab thickness including tolerances for placement technique.

*Longitudinal Translation* – Location of the middle of the dowel bar length with respect to the joint saw cut created over it.

*Embedment Length* – Length of dowel bar embedded to either side of the joint saw cut.

*Mislocation* – Any deviation of a dowel bar from its planned location. Required remedial action depends on the degree of mislocation.

**DBAL.2 ALIGNMENT THRESHOLDS**

After paving, assess as-built dowel bar alignment in accordance with DBAL.4. Apply the thresholds in DBAL.2.1 and DBAL.2.2 to determine the need for additional testing or a corrective action proposal (CAP).

< Note to Specification Writer: See Appendix A and B respectively for a summary and source of these thresholds. >

**DBAL.2.1 Alignment Thresholds for an Individual Dowel Bar**

Alignment thresholds for individual dowel bars, based on a combination of horizontal skew and/or vertical tilt criteria and the dowel’s single dowel misalignment (SDM), are as follows:

- Horizontal Skew and Vertical Tilt $\geq 0.6$ in. (15 mm) $\ldots$ | Requires More Testing
- SDM $> 1.5$ in. (38 mm) $\ldots$ | Requires CAP

**DBAL.2.2 Alignment Thresholds for a Single Joint**

Alignment thresholds for transverse joints, based on the Joint Score (JS), are as follows:

- JS $> JST$ for a single joint $\ldots$ | Requires More Testing
- JS $> JST$ for all doweled joints over MALL $\ldots$ | Requires CAP
DBAL.3 LOCATION THRESHOLDS

After paving, assess as-built dowel bar location in accordance with DBAL.4. Apply the thresholds in DBAL.3.1, DBAL.3.2 and DBAL.3.3 to determine the need for additional testing or a corrective action proposal (CAP).

< Note to Specification Writer: See Appendix A and B respectively for a summary and source of these tolerances. >

DBAL.3.1 Longitudinal Translation Thresholds for an Individual Dowel Bar

Longitudinal translation thresholds for individual dowel bars are as follows:

- Longitudinal Translation > 2 in. (50 mm) | Requires More Testing
- Longitudinal Translation > 5 in. (125 mm) | Requires CAP

DBAL.3.2 Vertical Translation Thresholds for an Individual Dowel Bar

Vertical translation thresholds for individual dowel bars are as follows:

- Vertical Translation > 1 in. (25 mm) from mid-depth and < 0.5 in. (12 mm) between top of bar and bottom of saw cut | Requires More Testing
- Concrete Cover (Top or Bottom) < 2.5 in. (64 mm) or < 0.25 in. (6 mm) between top of bar and bottom of saw cut | Requires CAP

DBAL.3.3 Horizontal Translation Thresholds for an Individual Dowel Bar

Horizontal translation thresholds for individual dowel bars are as follows:

- Horizontal Translation > 2 in. (50 mm) | Requires More Testing
- Horizontal Translation > 3 in. (75 mm) | Requires CAP

DBAL.4 FIELD MEASUREMENT PROCEDURES

DBAL.4.1 Trial Section

Measure the alignment and location of each dowel bar in the first 50 joints as a trial section; this trial section can be the start of production paving at the contractor’s discretion. The process is considered acceptable if:

1. Each JS is less than or equal to the JST per DBAL.2.2,
2. Ninety percent (90%) of the dowel bars are below thresholds requiring additional testing per DBAL.2.1 and DBAL.3, and
3. None of the dowel bars exceed the threshold requiring a CAP per DBAL.2 and DBAL.3.
Additional trial sections and appropriate corrective actions per DBAL.6 shall be required at the contractor’s expense if:

1. The construction method is not accepted by the Engineer after assessing the initial trial section,
2. Paving operations are suspended for more than 15 days, or
3. The concrete mixture or dowel installation method and/or equipment setup changes during production after approval to proceed.

**DBAL.4.2 Process Control Measurements**

Measure dowel bar alignment and location as follows during paving production:

1. Measure the alignment and location for every 10th joint.
2. If all misalignments, mislocations, and JSs are below thresholds requiring additional testing per DBAL.2 and DBAL.3, use the data to refine the paving process and reduce/eliminate misalignments and mislocations.
3. If any misalignments, mislocations, or JSs exceed a thresholds requiring additional testing per DBAL.2 or DBAL.3, further evaluate per requirements of DBAL.4.3.
4. The Engineer shall consider the dowel alignment process to be under satisfactory control when all misalignments, mislocations, and JSs are below thresholds requiring additional testing for two consecutive production days or over a paving distance specified by the Engineer prior to construction. Upon establishing satisfactory control, measure and evaluate every 20th joint thereafter. If any single dowel alignment or location or single joint JS exceeds a threshold requiring additional testing per DBAL.2 or DBAL.3, the frequency of testing will resume to every 10th joint until control is re-established.

**DBAL.4.3 Quality Assurance (QA) Evaluation Measurements**

Measure dowel bar alignment and location and propose corrective actions as follows:

1. If any misalignments, mislocations, or JSs exceeds thresholds requiring additional testing per DBAL.2 or DBAL.3, measure the joints on each side of the dowel bar or joint that exceeds the threshold, as directed by the Engineer, until five (5) consecutive joints are found to be below the threshold.
2. Propose corrective actions per DBAL.6 on any individual dowel bar that exceeds the threshold requiring a Corrective Action Proposal (CAP) per DBAL.2.1 or DBAL.3.
3. Propose corrective actions per DBAL.6 if successive joints having JSs greater than the JST indicate potential to lock up a section of pavement longer than the MALL (see DBAL.2.2).

**DBAL.4.4 Dowel Location Measurement Equipment**

Provide an operator who is properly trained to operate the measurement device. Measure the dowel location using a device with the following capabilities and degree of accuracy:
1. An operating temperature range within the range of ambient temperatures anticipated at the time of testing.

2. Minimum measurement range:
   a. Dowel bar depth measurement as necessary to accurately locate dowel bars for the pavement thickness
   b. Horizontal and vertical misalignment to at least 1.5 in. (38 mm)
   c. Horizontal translation to at least the Requires CAP level defined in DBAL.3.3

3. Maximum measurement tolerances:
   a. Repeatability: 0.125 in. (3 mm)
   b. Horizontal and vertical alignment: ±0.25 in. (±6 mm)
   c. Horizontal translation: ±0.5 in. (±12 mm)
   d. Longitudinal translation: ±0.5 in. (±12 mm)
   e. Depth (cover): ±0.25 in. (±6 mm)

Calibrate the measurement device per the recommendations of the device manufacturer for the project conditions (including dowel bar size, material, and spacing; and testing environment), and provide calibration documentation to the Engineer prior to construction. Recalibrate the measurement device and/or validate readings as required by the Engineer.

**DBAL.4.4.1 Measurement Equipment and Interference**

Prior to paving, review the measurement equipment applicability for the project conditions with the Engineer, including: ambient moisture conditions, dowel material, metallic concrete aggregate and potential contributors to magnetic interference (presence of tiebars, reinforcing steel or other embedded or underlying steel items that may affect measurement accuracy). Establish how the measurement device can meet the project conditions.

To account for magnetic interference from embedded tiebars, exclude from JS calculations any dowel bar(s) closer than 12 in. (300 mm) in any direction to tiebars in the longitudinal joint(s) due to magnetic interference. Establish the location of excluded dowels by another equivalent non-destructive method or by manual probing.

**DBAL.4.5 Reporting**

Prepare and submit to the Engineer no later than 48 hours after each day’s production a report including at least the following:

1. **General Details:** Contract number, placement date, highway number or country-route-section, direction of traffic, scan date, contractor, and name of operator.
2. **Measuring Device Data and Printouts:** Provide all data in the manufacturer’s native file format, including all calibration files. Provide the standard report generated from the on-board printer of the imaging technology used for every dowel and joint measured.
3. **Dowel Details:** For every dowel measured, provide the joint ID number, lane number and station, dowel bar number or x-location, direction of testing and reference joint location/edge location, dowel misalignment (e.g., horizontal skew, vertical tilt, and
single dowel misalignment [SDM]) and dowel mislocation (e.g., longitudinal translation, vertical translation, and horizontal translation).

4. **Misalignment and Mislocation Identification:** Identify each dowel bar with a misalignment or mislocation that exceeds an Accept limit for each alignment and location parameter listed in DBAL.2.1 and DBAL.3, accounting for the precision/bias of the measurement equipment.\(^{xvii}\)

5. **Joint Score Details:** Provide the joint ID number, lane number, station, and calculated JS for every joint measured.

6. **Locked Joint Identification:** Identify each joint with a JS greater than the JST, per DBAL 2.2. Again, account for the precision/bias of the measurement equipment.

All printouts/reports submitted by the Contractor shall remain the property of the Owner.

**DBAL.5 EXCLUSIONS**

Exclude the following from dowel location and alignment measurement:

- Transverse construction joints (headers).
- Dowels within 24 in. (609 mm) of metallic manholes, inlets and other in-pavement utility castings or other reinforced objects.

**DBAL.6 CORRECTIVE ACTION PROPOSAL (CAP)**

Submit a corrective action proposal to the Engineer for each case of actionable (e.g., exceeds a Requires CAP threshold) single dowel misalignment, single dowel mislocation, and/or JSs > JST over MALL identified by process control or quality assurance testing. Do not proceed with corrective action until the Engineer approves the proposed method of correction. As a minimum, the corrective action proposal shall include the following:

1. Actionable dowel misalignment and mislocation identification information.
2. Locked joints identification information.
3. Proposed method of remediation for each unique identified case (see Appendix C), including supporting documentation of the effectiveness of the means of proposed remediation.
Bibliography

The following documents were used in preparation of this guide specification:


Appendix A.
Summary of Dowel Bar Alignment and Location Thresholds and Their Potential Impact on Pavement Performance

Table A.1 provides a summary of the dowel bar alignment and location thresholds presented in this guide specification and Table A.2 provides a summary of the potential impact each misalignment or mislocation might have on pavement performance.

Table A.1. Summary of Dowel Bar Alignment and Location Thresholds

<table>
<thead>
<tr>
<th>Alignment Thresholds</th>
<th>Requires More Testing</th>
<th>Requires CAP</th>
<th>Requires CAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Skew of a Dowel</td>
<td>≥ 0.6 in. (15 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Tilt of a Dowel</td>
<td>≥ 0.6 in. (15 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDM of a Dowel</td>
<td></td>
<td>&gt; 1.5 in. (38 mm)</td>
<td></td>
</tr>
<tr>
<td>Joint Score of a Joint</td>
<td>&gt; JST</td>
<td>&gt; JST for all joints over MALL</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location Thresholds</th>
<th>Requires More Testing</th>
<th>Requires CAP</th>
<th>Requires CAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal Translation of a Dowel</td>
<td>&gt; 2 in. (50 mm)</td>
<td>&gt; 5 in. (125 mm)</td>
<td></td>
</tr>
<tr>
<td>Vertical Translation of a Dowel</td>
<td>&gt; 1 in. (25 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Concrete Cover Over/Under Dowel</td>
<td>&lt; 2.5 in. (64 mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dowel Depth Below Saw Cut</td>
<td>&lt; 0.5 in. (12 mm)</td>
<td>&lt; 0.25 in. (6 mm)</td>
<td></td>
</tr>
<tr>
<td>Horizontal Translation of a Dowel</td>
<td>&gt; 2 in. (50 mm)</td>
<td>&gt; 3 in. (75 mm)</td>
<td></td>
</tr>
</tbody>
</table>

Table A.2. Summary of the Potential Impact of Dowel Bar Mislocation/Misalignment on Pavement Performance (after FHWA 2005a)

<table>
<thead>
<tr>
<th>Spalling</th>
<th>Cracking</th>
<th>Load Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Skew of a Dowel</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Vertical Tilt of a Dowel</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Longitudinal Translation of a Dowel</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Vertical Translation of a Dowel</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Horizontal Translation of a Dowel</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Appendix B.
Source or Justification of Joint Score (JS) Weighting Factors and Moderate Risk of Locking Value, Maximum Allowable Locked Length (MALL), and Dowel Bar Alignment and Location Thresholds

DBAL.B.1 Weighting Factors in JS Determination (Table 1 in DBAL.1.1)

The values suggested as weighting factors in JS calculations were first proposed by ARA 2005:

<table>
<thead>
<tr>
<th>Range of misalignment</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm &lt; d ≤ 15 mm (0.4 in &lt; d ≤ 0.6 in.)</td>
<td>0</td>
</tr>
<tr>
<td>15 mm &lt; d ≤ 20 mm (0.6 in &lt; d ≤ 0.8 in.)</td>
<td>2</td>
</tr>
<tr>
<td>20 mm &lt; d ≤ 25 mm (0.8 in &lt; d ≤ 1 in.)</td>
<td>4</td>
</tr>
<tr>
<td>25 mm &lt; d ≤ 38 mm (1 in &lt; d ≤ 1.5 in.)</td>
<td>5</td>
</tr>
<tr>
<td>38 mm &lt; d (1.5 in &lt; d)</td>
<td>10</td>
</tr>
</tbody>
</table>

The same JS weighting factors are presented in ACPA 2006 and FHWA 2007.

DBAL.B.2 JS Moderate Risk of Locking Value (DBAL.1.1)

The JS value suggested for a moderate risk of locking was first proposed by ARA 2005:

<table>
<thead>
<tr>
<th>Joint Score s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>s &lt; 5</td>
<td>Very low risk of joint locking</td>
</tr>
<tr>
<td>5 ≤ s ≤ 10</td>
<td>Low risk of joint locking</td>
</tr>
<tr>
<td>10 ≤ s ≤ 15</td>
<td>Moderate risk of joint locking</td>
</tr>
<tr>
<td>s &gt; 15</td>
<td>High risk of joint locking</td>
</tr>
</tbody>
</table>

The same value is presented in ACPA 2006, and FHWA 2007 states, “A Joint Score of 10 is the critical level, above which the risk of joint locking is considered high.”

DBAL.B.3 Maximum Allowable Locked Length (MALL) (DBAL.1.1)

A limit of 60 ft (18 m) of restrained pavement is supported by industry experience with jointed reinforced concrete pavements (JRCP) and hinge jointed pavements.

It was once common practice in the US to build JRCP with a transverse joint spacing of 60-100 ft (18-30 m) and expect intermediate cracks to form at about 15-20 ft (4.5-6 m) intervals. The relatively small amount of reinforcing steel in the JRCP would hold the intermediate cracks
tightly together, and the pavements performed well until the reinforcing corroded and the cracks faulted and deteriorated. This deterioration is not expected in a transverse joint with dowel bars that have some increased risk of restraint, because the dowels in a JPCP provide significantly better load transfer than the reinforcing steel in a JRCP.

A similar concept called a hinge joint design was investigated by the Illinois DOT. In a hinge joint design, 3 to 4 panels are tied (see Figure 6 from excerpt below) in a design that might be best characterized as strategically-reinforced JRCP, where steel is placed at a known crack (e.g., sawcut joint) and not in throughout each concrete slab. The follow excerpted from FHWA\(^1\) details the approach:

In accordance with IDOT practices at the time, the jointed concrete pavement was constructed as a hinge-joint design, in which conventional doweled transverse joints are spaced at 13.7-m (45-ft) intervals and intermediate "hinge" joints containing tie bars are placed at 4.6-m (15-ft) intervals between the doweled joints (see Figure 6); this pavement is essentially a jointed reinforced design with the reinforcing steel concentrated at locations where the pavement is expected to crack. The hinge joints contain number 6 epoxy-coated tie bars, 900-mm (36-in.) long and placed at 450-mm (18-in.) intervals across the joint (Gawedzinski 2000). Preformed compression seals (32-mm [1.25-in.] wide) are placed in the doweled transverse joints and a hot-pour joint seal placed in the tied hinge joints (Gawedzinski 2000).

![Figure 6. Illinois DOT hinge joint design (IDOT 1989).](image)


\(^1\) Source: [http://www.fhwa.dot.gov/pavement/concrete/hpcp/hpcp05.cfm](http://www.fhwa.dot.gov/pavement/concrete/hpcp/hpcp05.cfm)
Another approach to determining an acceptable MALL is to consider how multiple tied concrete lanes are used on roadway projects when the roadway is more than one lane wide. Assuming that each joint is effectively locked over the MALL because misaligned dowel bars, the joints might best be modeled as tied joints and a tool such as ACPA’s Mechanistic-Empirical (M-E) Tiebar Designer, a new tie bar design method developed by ARA, might be useful in determining how many slabs might reasonably be tied together: [http://apps.acpa.org/apps/METiebar.aspx](http://apps.acpa.org/apps/METiebar.aspx). While this M-E Tiebar Designer will provide a much more accurate prediction of how many lanes can be tied together for a given set of site and design conditions, field experience has shown that tying of four slabs/lanes generally is acceptable. Four slabs at the conventional maximum joint spacing of 15 ft (4.6 m) results in a MALL of 60 ft (18 m). Note, also, that if four slabs are effectively tied together, neither end is considered pinned, so the shrinkage stresses are expected to develop over only ½ the tied length, or 30 ft (9 m).

**DBAL.B.4 Horizontal Skew and Vertical Tilt Thresholds (DBAL.2.1)**

The values suggested as thresholds for horizontal skew and vertical tilt are from FHWA 2007, which contains the following language:

**Acceptance Criteria**
- Horizontal or vertical rotational alignment:
  - <15 mm (0.6 in) over 450 mm (18.0 in.).

**Rejection Criteria**
- Reject any bars with misalignment greater than 38 mm (1.5 in.).

NCPTC 2011 notes the following:

**Dowel Alignment Requirements**

Most highway agencies have fairly close tolerances on dowel bar placement and alignment. A report by ARA (2005) noted that most states have adopted the Federal Highway Administration-recommended limits on dowel rotation (horizontal skew or vertical rotation) of 1/4 in. per ft of dowel bar length or two percent (FHWA 1990). It also noted that there was no evidence that this level of tolerance was required to ensure good field performance.

And NCHRP 2009 suggests the following, generally more relaxed, thresholds:

- Dowel rotations of up to 2 in. over 18 in. [51 mm over 457 mm] length have a negligible effect on pullout and shear performance measures.
Establish constructible acceptance criteria. Establishing a relatively tight (but constructible) placement tolerance will promote the placement of properly aligned dowel bars and eliminate the need for further evaluation or remedial actions. Examples of such tolerances may include the following:

- Horizontal or vertical rotational alignment: 0.5 in. [13 mm] over 18.0 in. [457 mm].

Establish rejection criteria. Rejection criteria should be established on the basis of measured, predicted, or expected pavement performance or behavior. For example, remedial action may be required due to inadequate depth of placement (considering concrete cover requirements and saw cut depth), inability to achieve specified performance thresholds (e.g., predicted faulting or IRI), or obvious placement flaws (e.g., interference from misplaced tie bars). For example, a dowel, joint, or section may be rejected if any of the following conditions occur:

- Rotational misalignment is 3 in. [75 mm] or more per 18 in. [457 mm] dowel length.

DBAL.B.5 Longitudinal Translation Thresholds (DBAL.3.1)

The values suggested as thresholds for longitudinal translation were calculated to ensure at least 4 in. (100 mm) of embedment length on either side of the joint saw cut (see NCPTC 2011). The Requires More Testing threshold was calculated as (18 in. [450 mm] dowel bar length - 2* 4 in. [100 mm] of embedment)/2 - 3 in. [75 mm] as a safety factor = 2 in. [50 mm]. The Requires CAP threshold was calculated as (18 in. [450 mm] dowel bar length - 2* 4 in. [100 mm] of embedment)/2 = 5 in. [125 mm]. Similar calculations can be conducted to determine allowable horizontal translation thresholds for other dowel bar lengths.

This Requires More Testing threshold is consistent with that suggested by FHWA 2007:

Acceptance Criteria

- Longitudinal (side) shift: <50 mm (2 in.) for 450-mm-long (18 in.) bars.

And NCHRP 2009 suggests the following threshold for acceptance:

- Longitudinal translation: 2.1 in. [55 mm] over 18-in. [457 mm] dowels.
The recommended Requires CAP threshold, however, is based on a required embedment depth of 4 in. (100 mm), whereas previous recommendations for a required embedment depth have been more on the order of 6 in. (150 mm). For example, FHWA 2007 suggests the following rejection threshold:

- Longitudinal (side) shift—
- Reject any joints with fewer than three bars with a minimum embedment length of 150 mm (6 in.) under each wheel path.

The 4 in. (100 mm) of required embedment depth is based on the results of the NCHRP 2009 study; as summarized by NCPTC 2011 (Note: Khazanovich et al. is NCHRP 2009):

In laboratory shear pull tests of dowels with varying amounts of embedment, Khazanovich et al. found no significant loss of shear capacity until embedment length fell to 4 in., and embedment lengths of as little as 2 in. provided shear capacity of more than 5,000 lb, which is more than sufficient for the critical dowel under typical highway design conditions (Figures 8 and 9). It should be noted, however, that the initial stiffness of the dowel-concrete system decreased by 60 percent or more when dowel embedment decreased to 3 in. or less, which would result in higher differential deflections and increased potential for pumping and faulting.

![Graph showing effect of embedment length on shear force and displacement for 1.25 in. diameter steel dowels](image-url)
DBAL.B.6 Vertical Translation Thresholds (DBAL.3.2)

The Requires More Testing threshold for vertical translation from mid-depth is based primarily on field experience and what is achievable under typical construction conditions with well-controlled processes. For example, FHWA 2007 suggests the same acceptance criteria:

Acceptance Criteria
• Depth: mid-depth + 25 mm (1 in.).

And NCHRP 2009 suggests the following acceptance criteria:

• Vertical translation: ± 0.5 in. [13 mm] for pavements 12 in. [305 mm] or less in thickness; ± 1.0 in. [25 mm] for pavements greater than 12 in. [305 mm] in thickness.

The following excerpts from NCPTC 2011 discuss how it is now known that locating dowel bars exactly at mid-depth is not necessary for structural reasons and that the primary concern is sufficient cover depth such that the concrete will not develop shear cracking or spalling above the dowels as loads are transferred across the joint (Note: Khazanovich et al. is NCHRP 2009):
Khazanovich et al. (2009) analyzed field performance data to compare faulting and load transfer efficiency (LTE) at joints with dowels centered within 1/4 in. of slab mid-depth with those of joints with dowels that were more than 1 in. closer to the pavement surface. They found no statistically-significant differences in faulting and LTE between the two groups.

They also performed laboratory tests of single dowels and conducted finite element analyses to examine the effects of concrete cover (which is affected by vertical translation) and dowel diameter on the shear capacity of the dowel-concrete system. Figure 6 summarizes the results of these studies and shows that the shear capacity of the system exceeds 5,000 lb when the cover over either 1.25 in. or 1.5 in. dowels is greater than 2 in. Recalling the maximum design shear loads in the critical dowel, it is clear that significant vertical dowel translation (up to the point where less than 2 in. of cover are provided) will still provide sufficient shear capacity for typical design load conditions. Khazanovich et al. further suggest that concrete cover exceeding 3.5 times the dowel diameter (i.e., 3.5 in. for a 1 in. dowel, 4.375 in. for a 1.25 in. dowel, or 5.25 in. for a 1.5 in. dowel) provides no significant increase in shear capacity.
Based on this evidence, NCHRP suggests the following rejection criterion:

- Concrete cover at any end of the dowel is 2 in. [51 mm] or less from the top surface.

The other concern with cover depth is to ensure enough concrete over the steel to resist corrosion of steel dowel bars. ACI 318 suggests a minimum cover of 3 in. (75 mm) for cast-in-place concrete (nonprestressed) that is cast against and permanently exposed to earth and 2 in. (50 mm) or less for concrete exposed to earth or weather but not against earth. FHWA 2008 suggests the following, similar, rejection criteria with regard to concrete cover:
Rejection Criteria

- Depth—
  - Reject any bar with the concrete cover above the bar less than 75 mm (3 in.) or the saw-cut depth.

Corrosion protection for dowel bars in concrete pavements is, however, generally addressed through dowel material or coating selection because it is assumed that some water will reach the dowel bars through the joint. In any case, the acceptance threshold suggested for concrete cover thickness at 2.5 in. (64 mm) is based primarily off of the NCHRP 2009 results, with consideration for concrete cover to resist corrosion.

The other concern raised by the FHWA rejection criteria is the sawcut depth. NCHRP 2009 suggests the same rejection criterion:

- Concrete cover from the dowel to the top surface is less than the sawcut depth.

Because the as-constructed sawcut depth might vary from the plan sawcut depth, the suggested Requires More Testing and Requires CAP thresholds with respect to sawcut depth are set slightly conservative to the NCHRP 2009 and FHWA 2007 rejection criteria.

DBAL.B.7 Horizontal Translation Thresholds (DBAL.3.3)

The values suggested as thresholds for horizontal translation are based primarily on engineering judgment of ACPA staff engineers. NCHRP 2009 suggests a horizontal translation tolerance of ± 1 in. (25 mm). Several documents (e.g., FHWA 2007) identify horizontal translation as a concern but do not provide guidance on allowable tolerances, suggesting that while it is of concern it is not critical to pavement performance in the range of mislocations encountered in the field. This has lead many agencies (e.g., NYSDOT and MTO) to omit a horizontal translation tolerance from their specifications. Cover depth with respect to the pavement edge is a key concern, but the typical dowel bar spacing of 12 in. (300 mm) on-center is a very conservative design and there is generally at least 6 in. (150 mm) of clearance from the edge dowels and edge of pavement for constructability reasons. Also, alternate dowel bar arrangements using less than 12 dowel bars on 12 ft (3.7 m) wide slab can reduce stresses and strains in the pavement relative to using 12 dowels at 12 in. (300 mm) on-center (see ACPA’s DowelCAD software: http://acpa.org/dowelcad/). Thus, the evidence suggests that while horizontal translation likely is not a critical tolerance with regard to pavement performance, the suggested thresholds are assumed at reasonable values based on field experience and performance.
Appendix C.
Corrective Actions to Consider

Note on Incentives/Disincentives: Because dowel bars typically are not an itemized pay item (e.g., dowel bars typically are included in the square yard [meter] pricing of the placed concrete pavement) and because of complexities with determining an appropriate basis on which to pay an incentive (e.g., the target of any DBI operation is perfect location and alignment of the dowel bars and joint sawcut over the dowel bars, making improvements beyond that impossible), ACPA does not offer an incentive/disincentive proposal on dowel bar alignment and location at this time.

As noted in NCHRP 2009, “the combined effect of low concrete cover and low embedment length is greater than the effect of either one of the two misalignments.” Thus, determining the necessary corrective action is not as simple as identifying each dowel or joint with a Require CAP threshold surpassed because some synergies might also exist. In any case, there are three potential actions to consider when mislocated or misaligned dowel bars or locked joints are determined to exist on a project are:

1. Do nothing.
2. Estimate performance loss and assess a penalty.
3. Conduct a destructive corrective action.

The appropriate corrective action for a misaligned or mislocated dowel or locked joint also is dependent on a number of factors that extend beyond the alignment and location tolerances, including but not limited to:

- **Dowel Location** – If the dowel is in a non-critical location (e.g., middle of lane, between wheelpaths), sawing of that dowel without re-establishment of load transfer at that location might be considered.
- **Support System** – If the pavement has a strong support system, long-term differential deflection at the joint should be less dependent on the dowel bars. Also, the MALL might be considered to be shorter on a stabilized subbase than on an unstabilized subbase.

NCHRP 2009 presents an equivalent dowel diameter concept in which a concrete pavement performance modeling software (e.g., AASHTOWare Pavement ME) can be used to estimate the long-term performance change that will occur as a result of the mislocations and/or misalignments on a specific project. This procedure effectively reduces the dowel bar diameter to an equivalent effective diameter based on the magnitude of misalignment and/or mislocation present on representative sublots within a project. The Contractor may opt to have such an analysis conducted by a qualified professional to estimate the long-term performance impact such that a pay reduction penalty might be negotiated with the Owner in-lieu of repairs that might ultimately cause more harm than good.
Consider the following corrective actions for actionable individual dowel bars:

- For misalignment due to horizontal skew or vertical tilt, assess the potential of the dowel bar to cause slab or joint damage, or locking of the joint by the joint score:
  - Where JS < JST and an individual misaligned dowel is not likely to cause pavement damage or complete joint restrain, do nothing.
  - Saw through actionable dowel bar to reduce opening/closing restraint.
  - Saw through actionable dowel bar(s) to reduce restraint and retrofit dowel bar(s) at appropriate location(s).
  - Place full-depth repair to remove joint with actionable dowel bar(s).
  - Replace full slabs to remove joint with actionable dowel bar(s).

- For mislocation due to longitudinal translation of individual dowel bar(s), assess the potential of the dowel bar to cause slab or joint damage, or locking of the joint by the joint score:
  - Where JS < JST and an individual misaligned dowel is not likely to cause pavement damage or complete joint restrain, do nothing.
  - Retrofit dowel bars using DBR between\textsuperscript{ex} or over/through actionable dowel bar(s).
  - Place full-depth repair to remove joint with actionable dowel bar(s).
  - Replace full slabs to remove joint with actionable dowel bar(s).

- For mislocation due to longitudinal translation caused by an errant saw cut:
  - Do nothing if the damage potential is minimal.
  - If the joint has not activated, saw new joint at the proper location and epoxy and/or cross-stitch the mislocated saw cut.
  - If the joint has activated, retrofit dowel bars using DBR between\textsuperscript{ex} or over/through actionable dowel bar(s).

- For mislocation due to vertical translation toward pavement surface:
  - Do nothing if the damage potential is minimal.
  - Saw through actionable dowel bar(s) to remove shearing restraint.
  - Retrofit dowel bars using DBR through actionable dowel bar(s).
  - Place full-depth repair to remove joint with actionable dowel bar(s).
  - Replace full slabs to remove joint with actionable dowel bar(s).

- For mislocation due to vertical translation toward pavement base:
  - Do nothing if the damage potential is minimal.
  - Saw through actionable dowel bar to remove potential for shear failure.
  - Place full-depth repair to remove joint with actionable dowel bar(s).
  - Replace full slabs to remove joint with actionable dowel bar(s).

- For mislocation due to horizontal translation:
  - Do nothing if the damage potential is minimal.
  - Retrofit dowel bars using DBR where dowel bar(s) are missing.
  - Place full-depth repair to remove joint with actionable dowel bar(s).
  - Replace full slabs to remove joint with actionable dowel bar(s).
Consider the following corrective actions for **consecutive joints** with actionable Joint Scores (JSs):

- Saw through actionable dowel bar(s) to remove opening/closing restraint and retrofit dowel bars using DBR in enough joints to meet the requirements of the maximum allowable locked length (MALL).
- Place full-depth repair(s) to remove joint(s) with actionable dowel bar(s) and to meet the requirements of the maximum allowable locked length (MALL).
- Replace full slabs to remove joint(s) with actionable dowel bar(s) and to meet the requirements of the maximum allowable locked length (MALL).
Appendix D. Commentary

While many of the underlying principles presented in this guide specification may be applicable to round dowels with lengths and diameters different that those for which this guide specification was developed, thresholds and other details within the specification might require adjustments for alternate dowel bar sizes, shapes, materials, coatings, etc.

See NCC 2011 for details on planned dowel vertical locations that do not necessarily place dowel bars at the mid-depth of the pavement.

Software such as DowelCAD (see acpa.org/dowelcad) and the performance of dowel bar retrofit (DBR) installations illustrate that current doweling practices with dowel bars spaced uniformly at approximately 12 in. (300 mm) on-center are overly conservative and that alternate dowel arrangements with less dowels per joint may prove beneficial from both a stress/strain/deflection response and a steel optimization standpoint. Horizontal translation may become of concern if alternate, non-uniform dowel spacings are used in the future.

Horizontal skew measurements are erroneous if the testing device is not oriented perpendicular to the edge of the pavement (e.g., if the device references a skewed joint).

See Dowel Bar Alignment Calculator (apps.acpa.org) for a web-based JS calculator.

Weighting factors may vary with dowel materials, dowel coating type and thickness and embedded dowel length. The weighting factor values presented in Table 1 were developed for 18 in. (457 mm) round metallic dowel bars with and without epoxy coating.

From ARA 2005, the research report that developed the Joint Scoring system:

In general, a Joint Score of 10 or higher indicates a significant potential for joint locking. The Joint Score reflects the risk of joint locking, which in turn may be closely correlated to pavement performance. The MIT Scan-2 testing results strongly suggest that many in-service pavements have at least a few joints that are very likely locked, even though those pavements exhibit no signs of any distress due to the potentially locked joints. Note that not all joints crack through and become working joints during the first few years of the pavement life. The only known adverse effect of the uncracked joints is wide opening of adjacent joints.

Scaling the JS risk value is necessary if the joint has more dowels (e.g., widened lane) or less dowels because the moderate risk of locking JS value of 10 was developed based on 12 ft (3.6 m) wide single joints with 12 dowel bars.
While vertical translation defines the vertical mislocation of a dowel bar, the vertical translation actionable conditions are written in terms of concrete cover depth (both top and bottom) and sawcut depth to normalize the specification for varying concrete pavement thicknesses. See DBAL.B.6 for more details.

An agency might typically require the contractor to propose a process or quality control (QC) plan. Because of the simplicity of the proposed process control procedure and its integration into other portions of the specification, ACPA recommends that the process control plan be included in the specification for dowel bar alignment testing. The agency may, however, allow the contractor to submit requests for changes to the process control plan, as necessary and justified, or opt to exclude a process or quality control plan from their specification.

The approaches and methods that might be considered to improve control during paving operations are outside of the scope of this specification. Please see other ACPA literature or training, or contact ACPA for guidance.

A device’s depth measurement capability becomes critical for thicker pavements. For instance, measurement equipment with an upper limit of 7.5 in. (190 mm) for depth measurement may not be sufficient for testing 13 in. (330 mm) pavements. See FHWA 2007 for more discussion on this issue.

Skewed joints need special consideration for testing, especially for alignment. See FHWA 2005b for more discussion on this issue.

Because of the nature of some devices, calibration and recalibration must be completed by the measurement device manufacturer and for a given set of conditions (e.g., dowel bar diameter, length, material, coating, etc.). Regular validation (e.g., weekly, start and end of a job, etc.) of the device might also be required by the Engineer. If validation is required, validate against some known mislocation and misalignment such as a manually measured header (transverse construction joint) or dowel alignment and location validation jig.

Interference from nearby tiebars and other embedded metal objects is a known issue with MIT-Scan and MIT-Scan II. ACPA’s typically recommendation on tiebar location with respect to dowel bars is along the lines of:

If a tiebar is placed too close to a transverse joint, it may interfere with joint opening and closing and the effectiveness of the dowel bar load transfer at the joint. To keep the slab corner from being too restrained, no tiebar should be placed within 6 in. (150 mm) of the tip of the nearest dowel bar in the transverse joint. The operator may have to use a specific sequence where tiebars are omitted while paving. Depending on the joint and tiebar spacing design requirements, this may be every fourth or fifth bar.
Based on a typical tiebar length of 30 in. (750 mm), diameter of 5/8 in. (16 mm) and spacing to nearest dowel bar of 6 in. (150 mm) and also 1.5 in. (38 mm) dowel bars that are 18 (450 mm) long spaced at 12 in. (300 mm) on-center and 6 in. (150 mm) from edge of pavement, this this specification would require either exclusion or manual measurement of two dowel bars near the tied longitudinal joint:

To mitigate this issue, the tiebar-to-dowel bar spacing might instead be increased to a minimum of 12 in. (300 mm) for projects employing mechanical dowel bar insertion that will be imaged using magnetic tomography, resulting in a case where no dowel bars are excluded from the JS calculation:
Limitations of the dowel location measurement equipment must be considered when interpreting results. For example, dowel alignment and location details obtained using the MIT-Scan II device can be impacted negatively by the presence of nearby tiebars, steel-toed boots, metallic debris (e.g., nails, conduits, etc.), hand tools, vehicles, etc.; by the chemical composition of the dowel bar (e.g., carbon content); by human error in positioning the device or the rails that guide the device; by unevenness of the guide rails due to the pavement surface texture or localized roughness; and even by the flexibility of the guide rails or runout of the guide wheels on the device. Such factors can effectively increase the measurement error beyond the measurement tolerances published by the device manufacturer.

The thresholds specified in this document must be modified to account for the precision of the testing device. For example, if a specified threshold is ±1.0 in. (25 mm) and the precision of the testing device is 0.25 in. (6 mm), the effective tolerance is ±1.25 in. (31 mm).

While research into performance of misaligned and mislocated dowel bars is still ongoing, field evidence suggests that some repairs cause more harm than good and that all repairs of dowel misalignment/mislocation should be considered carefully. For example, cutting through a misaligned dowel might increase the risk of corrosion of then newly exposed and unprotected dowel face, potentially leading to spalling.

When dowel spacing becomes too close, a risk is created for a horizontal crack at the depth of the dowel bars. Thus, if dowel bar retrofits are to be constructed between the existing dowel bars, it is preferred to only provide the minimum necessary number of dowel bar retrofits.