ACPA GUIDE SPECIFICATION

Dowel Bar Alignment and Location for Placement by Mechanical Dowel Bar Insertion

January 7, 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 with joint sawcuts made perpendicular to the edge of pavement (e.g., non-skewed joints); many of the underlying principles may be applicable to round dowels with other lengths and diameters. 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 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 other pavement defect, but the risk of mid-panel cracking and joint distress increases with each successive joint with limited opening/closing capabilties (see FHWA 2007).

Longitudinal translation (see DBAL.1) 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.

Control of vertical translation (see DBAL.1) 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.[1] Consideration must also be given for sawcut depth such that the dowels are not cut during sawing operations.

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

Horizontal translation (see DBAL.1) is of concern[2] 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, QA Trigger, and Requires Action 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.

The following documents were used in preparation of this specification:

- ACPA 2006, *Evaluating and Optimizing Dowel Bar Alignment*, American Concrete Pavement Association, SR999P.

- FHWA 2005a, *TechBrief: Use of Magnetic Tomography Technology to Evaluate Dowel Bar Placement*, Federal Highway Administration, FHWA-IF-06-002, http://www.fhwa.dot.gov/pavement/pccp/pubs/06002/index.cfm.

- FHWA 2005b, *Use of Magnetic Tomography Technology to Evaluate Dowel Bar Placement*, Federal Highway Administration, FHWA-IF-06-006, http://www.fhwa.dot.gov/pavement/concrete/mitreport/.

- FHWA 2007, *Best Practices for Dowel Placement Tolerances*, Federal Highway Administration, FHWA-HIF-07-021, http://www.fhwa.dot.gov/pavement/concrete/pubs/07021/.

- NCC 2011, *Recommendations for Standardization of Dowel Load Transfer Systems for Jointed Concrete Roadway Pavements*, National Concrete Consortium, http://www.cptechcenter.org/publications/dowel_techbrief_Sept2011.pdf.

- NCHRP 2009, *Guidelines for Dowel Alignment in Concrete Pavements*, National Cooperative Highway Research Program, Report 637, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_637.pdf.

- NCPTC 2011, *Guide to Dowel Load Transfer Systems for Jointed Concrete Roadways Pavements*, National Concrete Pavement Technology Center, http://www.cptechcenter.org/publications/DowelLoadGuide.pdf.

[2] 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 steel optimization standpoints. Horizontal translation may become of concern if alternate, non-uniform dowel spacings are used in the future.

Guide Specification

DBAL.1 TERMINOLOGY

Figure 1 illustrates the five types of dowel bar misalignment and mislocation: horizontal skew, vertical tilt, horizontal translation, longitudinal translation, and vertical translation.

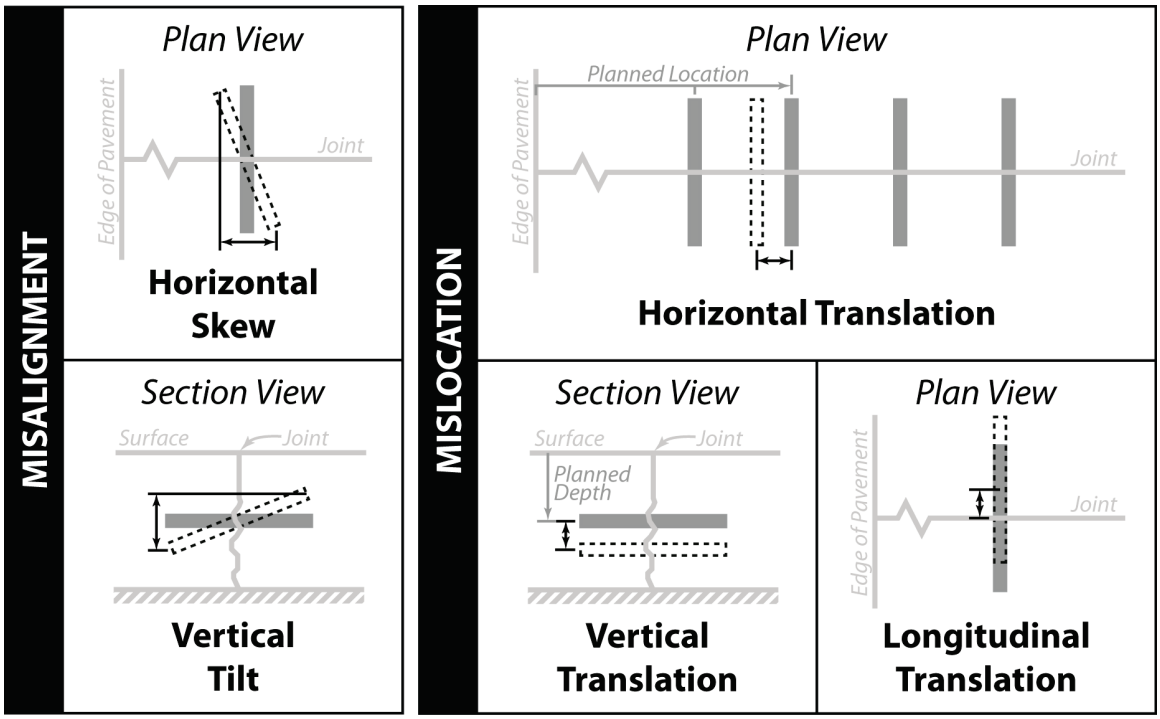

Figure 1. The 5 types of dowel bar misalignment and mislocation (after FHWA 2007).

DBAL.1.1 Dowel Bar Alignment Terms

Horizontal Skew – The deviation of the dowel bar from true parallel alignment from the edge of the pavement[3], 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.

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

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

[3] COMMENT: 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).

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)[4] – 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 1. Weighting Factors[5] *in Joint Score (JS) Determination*

Single Dowel Misalignment (SDM)	W, Weighting Factor
SDM ≤ 0.6 in. (15 mm)	0
0.6 in. (15 mm) < SDM ≤ 0.8 in. (20 mm)	2
0.8 in. (20 mm) < SDM ≤ 1 in. (25 mm)	4
1 in. (25 mm) < SDM ≤ 1.5 in. (38 mm)	5
1.5 in. (38 mm) < SDM	10

The potential for locking of a single joint (e.g., transverse joint between adjacent longitudinal joint(s) and/or pavement edge(s)) as represented by the JS is as follows:

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

Joint Score Trigger (JST) – A scaling[6] of the Joint Score risk value to account for the actual number of dowels per a single joint, calculated as:

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

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.

[4] COMMENT: See *Dowel Bar Alignment Calculator* (apps.acpa.org) for a JS calculator.
[5] COMMENT: 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.
[6] COMMENT: Scaling the Joint Score risk value is necessary because the value was developed based on 12 ft (3.6 m) wide single joints with 12 dowel bars.

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 TOLERANCES

Dowel alignment tolerances are summarized in Table A.1. in Appendix A.

DBAL.2.1 Alignment Tolerances for an Individual Dowel Bar

Install dowel bars within the following *alignment tolerances for individual dowel bars,* based on a combination of horizontal skew and/or vertical tilt criteria and the dowel's single dowel misalignment (SDM):

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

DBAL.2.2 Alignment Tolerances for a Single Joint

Install dowel bars within the following *alignment tolerances for a single joint*, based on the Joint Score (JS):

JS ≤ JST[7]	Accept
JS > JST	QA Trigger
JS > JST for all doweled joints over MALL	Requires Action

[7] COMMENT: The Joint Score Trigger (JST) equals 10 for the standard case of 12 dowel bars across a 12 ft (3.6 m) wide joint but this value must be scaled if the joint has more dowels (e.g., widened lane) or less dowels.

DBAL.3 LOCATION TOLERANCES FOR AN INDIVIDUAL DOWEL BAR

Dowel location tolerances are summarized in Table A.1. in Appendix A.

Install individual dowel bars within the following *longitudinal translation tolerances*[8]:

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

Install individual dowel bars within the following *vertical translation tolerances*[9]:

<u>Vertical translation above nominal mid-depth:</u>	
Vertical Translation ≤ 1 in. (25 mm)	| Accept
Vertical Translation > 1 in. (25 mm)	| QA Trigger
Concrete Cover[10] < 2.5 in. (64 mm)	| Requires Action

AND

Provide ≥ 0.5 in. (12 mm) Between Top of Bar and Bottom of Joint Saw Cut	| Accept
Provide < 0.5 in. (12 mm) Between Top of Bar and Bottom of Joint Saw Cut	| QA Trigger
Provide < 0.25 in. (6 mm) Between Top of Bar and Bottom of Joint Saw Cut	| Requires Action

<u>Vertical translation below nominal mid-depth:</u>	
Vertical Translation ≤ 1 in. (25 mm)	| Accept
Vertical Translation > 1 in. (25 mm)	| QA Trigger
Concrete Below Bar < 2.5 in. (64 mm)	| Requires Action

Install individual dowel bars within the following *horizontal translation tolerances*:

Horizontal Translation ≤ 2 in. (50 mm)	| Accept
Horizontal Translation > 2 in. (50 mm)	| QA Trigger
Horizontal Translation > 3 in. (75 mm)	| Requires Action

[8] COMMENT: These limits 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 Accept and QA Trigger limits were 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 Action limit 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 tolerances for other dowel bar lengths.

[9] COMMENT: 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.

[10] COMMENT: Concrete cover is impacted by both vertical translation and vertical tilt and should be considered as the minimum distance between the dowel bar and the concrete surface or base, which is not necessarily located at the joint.

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 test section can be the start of production paving at the contractor's discretion. The process will be considered acceptable with approval of the Engineer if each Joint Score (JS) is less than the JST (per DBAL.2.2) AND ninety percent (90%) of the dowel bars are within the Accept limit and none of the dowel bars exceed the Requires Action limits in DBAL.2.1 and DBAL.3. Use the data to refine the paving process and reduce/eliminate misalignments and mislocations.

If the dowel bar installation method is not accepted by the Engineer after assessing the trial section, if paving operations have been suspended for more than 15 days, or if the concrete mixture or dowel installation method or equipment setup changes during production after approval to proceed, additional trial sections and appropriate corrective action (see DBAL.6) shall be required at the contractor's expense.

DBAL.4.2 Quality Control (QC) Measurements

Measure dowel bar alignment and location as follows for Quality Control (QC):

1. Measure the alignment and location for every 10th joint.
2. If ALL misalignments, mislocations, AND Joint Scores (JSs) are within the Accept limits in 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 Joint Scores (JSs) exceed a QA Trigger limit in DBAL.2 and DBAL.3, perform Quality Assurance (QA) measurements per the direction of the Engineer (see DBAL.4.3).
4. The Engineer shall consider the dowel alignment process to be under satisfactory control when ALL misalignments, mislocations, AND JSs are within the Accept limits 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. If the alignment or location of any individual dowel bar or the Joint Score (JS) of the joint exceed the QA Trigger limits in DBAL.2 and DBAL.3, the frequency of testing will resume to every 10th joint until control is re-established.

DBAL.4.3 Quality Assurance (QA) Measurements

Measure dowel bar alignment and location and take corrective actions as follows for Quality Assurance (QA):

1. If the alignment or location of any individual dowel bar or the Joint Score (JS) of a joint is found to exceed a QA Trigger limit per the tolerances in DBAL.2 and DBAL.3, measure the joints on each side of the QA Trigger exceeding dowel bar or joint that exceeds the QA Trigger, as directed by the Engineer, until five (5) consecutive joints are found within the Accept limits. In exceptional cases with apparent systematic misalignment and/or mislocation, the Engineer may opt to measure and assess all dowels/joints from a single day's production.

2. Take corrective actions per DBAL.6 on any individual dowel bar that exceeds a Requires Action limit per the tolerances in DBAL.2 and DBAL.3.
3. Take corrective actions per DBAL.6 if successive joints having Joint Scores (JSs) greater than the JST indicate potential to lock up a section of pavement longer than the maximum allowable locked length (MALL) (see DBAL.3).

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[11] measurement as necessary to accurately locate dowel bars for the pavement thickness
    b. Horizontal and vertical misalignment[12] to at least 1.5 in. (38 mm)
    c. Horizontal translation to at least the Requires Action level defined in DBAL.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.

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.

---

[11] COMMENT: 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. In that case, to meet a minimum cover of 3 in. (75 mm), a depth at which dowel bars are considered acceptable, a device must capable of measuring to as deep as 9.25 in. (235 mm) (FHWA 2007).

[12] COMMENT: Skewed joints need special consideration for testing. (FHWA 2005b).

To account for magnetic interference from embedded tiebars, exclude from Joint Score (JS) calculation any dowel bar(s) closer than 12 in. (300 mm) in any direction[13] to tiebars in the longitudinal joint(s) due to magnetic interference. At the Engineer's discretion, establish the location of excluded dowels by another equivalent non-destructive method or by 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 greater than the individual dowel bar QA trigger for each alignment and location parameter listed in DBAL.3 and DBAL.4.
5. *Joint Score Details:* Provide the joint ID number, lane number, station, and calculated Joint Score (JS) for every joint measured.
6. *Locked Joint Identification:* Identify and highlight in red each joint with a Joint Score (JS) greater than the JST.

All printouts and 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.

[13] COMMENT: Interference from nearby tiebars and other embedded metal objects is a known issue with MIT-Scan and MIT-Scan II.

DBAL.6 CORRECTIVE ACTION

Submit a proposal for corrective action to the Engineer for each case of actionable (.e.g, exceeds a Requires Action limit) single dowel misalignment, single dowel mislocation, and/or joint scores identified by quality 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 joint identification information.
3. Proposed method of remediation for each unique identified case, including supporting documentation of the effectiveness of the means of proposed remediation.

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[14] 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[8] 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).

[14] COMMENT: 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.

    - 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 A. Summary of Dowel Bar Alignment and Location Tolerances

Table A.1 provides a summary of the dowel bar alignment and location tolerances presented in this guide specification.

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

Alignment Tolerances	QA Trigger	Requires Action
Dowel Horizontal Skew	≥ 0.6 in. (15 mm)	
Dowel Vertical Tilt	≥ 0.6 in. (15 mm)	
Dowel SDM		> 1.5 in. (38 mm)
Joint JS	> JST	> JST for all dowels over MALL

Location Tolerances	QA Trigger	Requires Action
Dowel Longitudinal Translation	> 2 in. (50 mm)	> 5 in. (125 mm)
Dowel Vertical Translation	> 1 in. (25 mm)	
Vertical Concrete Cover Over/Under Dowel		< 2.5 in. (64 mm)
Dowel Depth Below Saw Cut	< 0.5 in. (12 mm)	< 0.25 in. (6 mm)
Dowel Horizontal Translation	> 2 in. (50 mm)	> 3 in. (75 mm)