

Dowel Bar Alignment and Location

November 2018

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 measure embedded dowel positioning quickly and accurately without damaging pavement joints. 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 increasingly adopting dowel imaging technology as part of their quality assurance testing programs for jointed concrete pavements.

Of critical importance is the impact of dowel alignment on pavement performance, which may be considered for individual dowels, single joints or multiple, consecutive joints. Since dowel imaging technology is relatively new, there has been a lack of practical guidance on how to effectively implement the technology in concrete paving specifications. There has been a particular need for improved understanding of the levels of dowel misalignment and mislocation that represent good construction practices (i.e., "acceptable" levels), levels that may contribute to future performance problems (i.e., "rejectable" levels), and those that fall in between these two thresholds and require process improvements without necessarily requiring corrective actions for the dowels themselves. These needs spurred the American Concrete Pavement Association to develop this guide specification based on performance studies and the experience and input of agencies and contractors throughout the U.S. and Canada.

It is emphasized that this guide specification is intended as a starting point for the revision of existing specifications/provisions, or for the development of new technically-informed specifications to meet the specific conditions and needs of an owner/agency. It was developed to be used as a complete specification system that will ensure quality paving (protecting Agency interests) through dowel placement tolerances that can be achieved with reasonable construction practices. With careful consideration, sections of this specification may be deleted or modified, or other sections may be added, as appropriate for specific project requirements. However, great care must be taken in customizing this specification to avoid creating an unreasonably tight specification (e.g., requiring greater placement precision and consistency than is easily achieved or required for good performance). Owners/agencies and contractors are strongly encouraged to work together through ACPA chapters and local state paving association affiliates in the development or revision of their specifications.

Background

Pavement dowel bars are smooth-surfaced mechanical devices that are commonly inserted or installed at transverse joint locations in concrete pavements to provide reliable transfer of vehicle loads across joints between slabs. The mechanical connection provided by dowels

reduces pavement joint deflections and slab stresses, thereby improving pavement performance and service life. Properly designed and adequately installed pavement dowels are essential to ensuring the achievement of the pavement design life.

Typical pavement dowels are fabricated from cylindrical carbon steel stock and range in diameter from 1 to 1.5 inches [25 – 38 mm], are 18 inches [457 mm] long, and are epoxy-coated. However, innovations in load transfer system design are leading to the use of an ever-broadening variety of dowel materials, shapes, lengths and corrosion-resistant coatings. Regardless of the dowel materials and dimensions, they must be installed within reasonable tolerances at the intended locations and must be aligned within the pavement in a manner that does not overly restrain slab expansion and contraction at the doweled joints.

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

It is important to limit **“side shift” or longitudinal translation** to ensure enough dowel embedment length exists for long-term load transfer. The allowable amount of longitudinal translation is a function of dowel length, dowel section properties and dowel material. Note that longitudinal translation is a function of both dowel position during placement and where the sawing crew cuts the joint with respect to the dowel location.

Depth deviation or vertical translation must be limited to ensure that there is enough concrete over the steel to prevent the development of shear cracking or spalling above the dowels as loads are transferred across the joint and (for corrosion-susceptible metallic dowels) to protect uncoated dowels (or coated dowels with coating defects) from corrosion. Thus, the allowable vertical translation is a function of as-constructed pavement thickness and planned dowel vertical location. Consideration must also be given for saw cut depth so that the dowels and their protective coatings are not cut during sawing operations.

Lateral or Horizontal translation is of concern when a dowel is located far enough from its intended location that loads are redistributed and joint performance may be affected. In the worst case, the omission of dowels near a panel corner may increase load-related stresses and cause loss of support. Conversely, the placement of dowels too close to a panel corner (mislocation) may induce significant corner restraint and possible corner spalling or cracking.

In cases where non-cylindrical dowels are used (e.g., elliptical or plate dowels), **axial rotation** of the dowel is also a concern. The use of non-cylindrical dowels in street, road, highway and airfield paving is currently not common in the U.S., and the accurate measurement of axial rotation is beyond the capability of most commonly used detection devices at this time. Therefore this aspect of dowel positioning is not currently considered in this guide specification.

This guide specification was developed with the recognition that 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.

Applicability for Different Methods

Measuring Equipment – This guide specification was developed around the MIT-SCAN2-BT magnetic imaging tomography equipment because it is commonly used and most agency specifications have been developed with this device in mind. However, the principles and concepts presented in this guide specification are applicable to other dowel position measuring equipment. The guide specification identifies where measuring equipment tolerances and other limitations must be considered for developing an effective specification for use with other types of dowel position measuring equipment.

Dowel Baskets or Dowel Insertion Methods – The principles and concepts that are the basis of this guide specification are applicable to dowels of all types, whether mechanically inserted or installed in baskets. However, shipping wires on dowel baskets are known to cause significant interference when using magnetic imaging tomography equipment (e.g., MIT-SCAN2-BT). This happens because the shipping wires create a circuit that distorts the magnetic imaging.

With proper anchoring of well-made dowel basket assemblies, dowel bar alignment and positioning should be adequately maintained throughout the paving process, but this is predicated on an assumption of adequate basket rigidity. ACPA recommends that dowel basket spacer/tie wires are not cut after basket placement and prior to paving. The wires serve to brace and stiffen the baskets during paving and help to prevent basket movement as the paver passes. Engineering analyses show that the shipping wires will not lock up transverse joints; the wire will yield or the welds will break before the wires could cause the joint to lock up (See ACPA R&T 6.01).

Despite this recommendation, some agencies require cutting dowel basket tie wires prior to paving. The proponents of cutting the wires express concern that magnetic imaging tomography equipment will not function as well if the wires are not cut. This poses a dilemma of competing interests. By “not” cutting basket tie wires one can mitigate a major cause of a potential alignment issues – less stable baskets. However, by cutting the tie wires to facilitate scanning for dowel location, this destabilizes the basket assembly for the purpose of good dowel placement/alignment measurement.

Although uncut shipping wires on baskets likely will have significant impact on the quantitative results produced by magnetic imaging equipment, useful information will still be available from the device. In most cases, the numerical results may only be useful for making general conclusions about the dowel bar configuration, and will not be useful for quantitative comparisons to required tolerances. However, the visual map that MIT-SCAN2-BT software produces will still be useful for showing the presence of dowel bars, general horizontal alignment, and longitudinal translation relative to the center line of the test. It will also show any dowel bars that slip out of the basket, either partially or completely.

Another factor to consider for basket rigidity, especially if shipping tie wires are cut, is the style of basket legs. Baskets with “A”, “V”, or “U” style legs provide 24 more welds and approximately 12 ft (4 m) more wire in the frame than baskets designed with “J” legs. The additional welds and wire add stability to the frame during the concrete placing process and help to maintain dowel bar alignment.

Recommendations for Project-Specific Implementation

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 (if used) will function;
- 2) The “acceptance” and “rejection” 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

1.0 SCOPE

This guide specification is directly applicable to 18-inch [457-mm] long, cylindrical dowel bars, with or without coatings, that are inserted or installed in conventional jointed plain (unreinforced) concrete pavements (JPCP), in either travel lanes or shoulder pavements, with sawed joint cuts made perpendicular to the edge of pavement (i.e., non-skewed joints).¹

2.0 REFERENCED DOCUMENTS

ASTM E3013 / E3013M – 17 Standard Test Method for Evaluating Concrete Pavement Dowel Bar Alignment Using Magnetic Pulse Induction

3.0 TERMINOLOGY

Figure 1 illustrates the five principal types of dowel bar misalignment and mislocation (or position error) and the following two sections define these misalignments and mislocations.

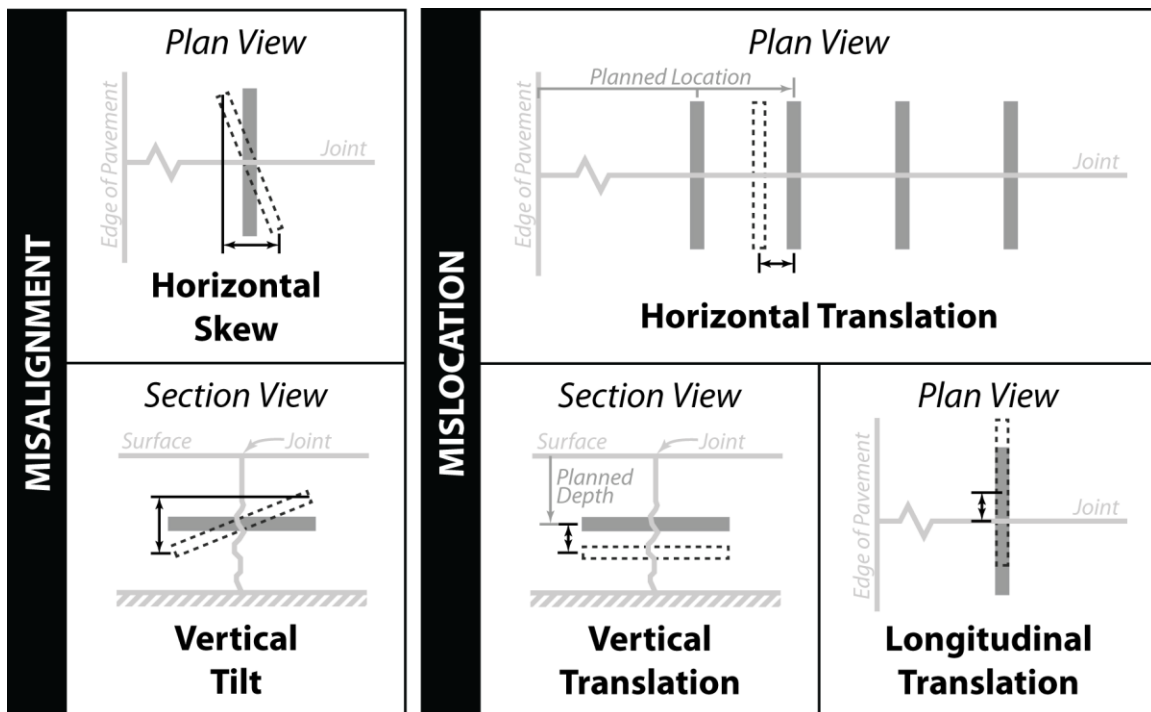


Figure 1. The five types of dowel bar misalignment and mislocation (after FHWA 2007).

3.1 Dowel Bar Alignment Terms

Alignment – The degree to which a dowel bar is oriented parallel to the pavement surface and to the primary direction of pavement expansion/contraction or joint opening/closing.

¹ This specification was developed around the MIT-SCAN2-BT magnetic imaging tomography equipment because that equipment is commonly available and most agency specifications have been developed with this device in mind. However, the principles and concepts presented herein may be modified for use with any type of dowel position measuring equipment.

Misalignment – Any deviation in the horizontal plane (e.g., horizontal skew), the vertical plane (e.g., vertical tilt), or both, from an aligned condition, as described above.

Horizontal Misalignment or Skew – The amount of horizontal rotation in a dowel bar about its center point when viewed from directly above the dowel. (Note: Rotation in a counter-clockwise direction is assigned a negative value and the value is given as the horizontal distance between the ends of the dowel bar, as shown in Figure 1.)

Vertical Misalignment or Tilt – “The amount of vertical rotation in a dowel bar about its center point when viewed from the edge of pavement or lane where the test was initiated.” (ASTM 2015) (Note: Rotation in a counter-clockwise direction is assigned a negative value and the value is given as the vertical distance between the ends of the dowel bar.)

Side Shift & Alignment Orientation

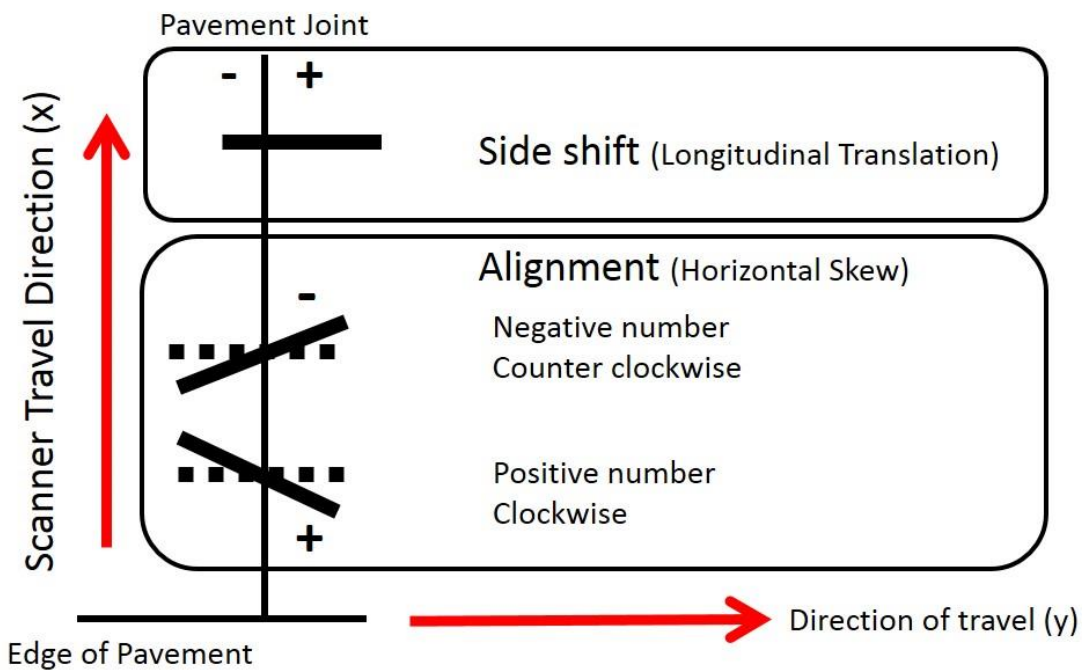


Figure 2. Illustration of standard side shift and horizontal alignment sign conventions (source: ASTM E3013.3013M-17).

Composite Misalignment (CM) – The composite misalignment is the total spatial deviation of the dowel axis from the design orientation and is computed as:

$$\text{Composite Misalignment (CM)} = \sqrt{(\text{Horizontal Skew})^2 + (\text{Vertical Tilt})^2}$$

Joint Score (JS) – A value that represents the impact of all misaligned dowels in a single transverse joint between adjacent longitudinal joint(s) and/or pavement edge(s) (i.e., a typical 12-ft [3.6m] standard lane or a widened lane up to 14 ft [4.3 m] in width) on the ability of that joint to open and close properly. Joint Score is computed as:

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

where:

W_i = weighting factor (Table 1) for dowel i

x = number of dowels in a single joint

n = number of dowels excluded from calculation of JS (e.g., due to measurement interference, etc.)

Note on Joint Score Calculation: When calculating Joint Score using data obtained from magnetic pulse induction (MPI) devices, exclude from the calculation any alignment data for dowel bar(s) located much closer than 12 in [300 mm] in any direction to tiebars in the longitudinal joint(s) (absolutely no closer than 9 inches away), as well as dowel bars within approximately 24 in [600 mm] of metallic manholes, inlets and other in-pavement utility castings or other reinforced objects or metal features that may cause magnetic interference. Alternatively, employ a different but equivalent non-destructive method or manual probing, and then include the previously excluded bars in the JS calculation.

Table 1. Weighting Factors in Joint Score (JS) Determination

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

* For dowel position measurement systems with reduced measurement accuracy, reduce CM values in Table 1 by 1.414*(rotational measurement accuracy of the selected equipment – 0.25 inches [6mm])

Critical Joint Score (JS_{CRITICAL}) – A value of the Joint Score above which the joint has a high probability of restraining joint opening and closing to an extent that may impair long-term pavement performance. This value increases with the distance between adjacent longitudinal joints and varies with the additional restraint of slab movement at the slab-subbase interface (i.e., slab-subbase "friction" or interlock). Critical Joint Score does not vary with the number of dowels in the joint. It is calculated as:

$$Critical\ Joint\ Score\ (JS_{critical}) = C * 15 * \frac{Joint\ Width\ (ft)}{12}$$

where:

C = Optional adjustment factor for local conditions (e.g., climate, panel length, slab-subbase restraint, local experience, etc.), that can reflect how much more or less joints are expected to move and induce higher or lower slab stress (from panel length, annual temperature range, frictional restraint, etc.) compared to a standard section. Choose C=1.0 for standard case; refer to Table 2. for applying this adjustment for specific project applications². (Standard case is a design with typical 15-ft panels constructed on a stabilized base with moderate frictional restraint in a climate with a moderate range of annual temperatures.)

Table 2. Guidance for Selecting Joint Score C Factors.

Panel Length (ft)		<13		13 – 17		>17	
Material below Slab		Unbound	Stabilized	Unbound	Stabilized	Unbound	Stabilized
Climate	Mild ($\Delta T^* < 40$)	1.7	1.5	1.5	1.3	1.3	1.1
	Moderate ($\Delta T^* = 40 - 70$)	1.4	1.2	1.2	1.0	1.0	0.8
	Severe ($\Delta T^* > 70$)	1.2	1.0	1.0	0.8	0.8	0.6

* ΔT = Highest average monthly high temperature – Lowest average monthly low temperature, °F (e.g., Average July High Temp – Average January Low Temp)

Maximum Effective Panel Length (MEPL) – maximum allowable length of pavement that includes consecutive joints with JS values exceeding $JS_{CRITICAL}$. $MEPL \leq 60$ ft (18 m) and should include no more than three consecutive joints with joint scores (JS) greater than the $JS_{CRITICAL}$.

3.2 Dowel Bar Location (Positioning) Terms

Mislocation or Positioning Error – Any deviation in the position of the center point of a dowel bar (vertically, horizontally or laterally) from its planned position as referenced to the saw cut location and as-constructed thickness of the slab.

Horizontal Translation – Positioning of the center of the dowel at some distance away from the intended position along the centerline of the associated transverse joint. (Note: Positioning is referenced to the starting point of the measurement, which should coincide with the pavement edge or longitudinal saw cut; positive values are expressed for positions that are further than planned from the starting point of the test measurement.)

² **Note Specification Writer:** For example, select C=1.0 for designs with typical 15-ft panels that are constructed on stabilized base in a climate with a moderate range of annual temperatures. Select C=1.2 to 1.7 (resulting in higher values of critical joint score) for panels with the same or shorter length that are constructed on unbound base materials or in milder climates. Finally, select C=0.6 to 0.9, resulting in lower critical joint score values, when panels lengths are longer and are constructed on stabilized bases or in severe climates. Table 2 provides general guidance for establishing C factors; further research and calibration are recommended to establish a more rigorous basis for establishing C factors where multiple pavement designs and climate conditions exists within the specification writer’s territory.

Side Shift (Longitudinal Translation) – Positioning of the center of the dowel at some distance longitudinally (i.e., in the direction of vehicle travel) from the centerline of the associated transverse joint. (Note: Positioning is referenced to the transverse saw cut; values are expressed as positive for positioning to the right of the joint when viewed from the starting point of the test measurement at the outside edge of the lane.)

Depth – “The measured position of the centroid of the dowel from the surface of the concrete pavement ...” (ASTM 2017). Note that height above base is more relevant than depth below surface for dowels placed in baskets, especially in areas of superelevation. Placement thresholds and tolerances for vertical placement must be specified with consideration of dowel placement method. For example, dowels that are placed using dowel bar insertion (DBI) equipment are inserted to depths relative to the pavement surface, which is also the reference plane for magnetic, ultrasonic and ground-penetrating radar-based position measurement equipment. Placement tolerances in this case can be expected to be tighter than when dowels are placed using basket assemblies that position the dowels with respect to the bottom of the pavement slab while measurements are performed from the top surface, especially in areas of superelevation or where the elevation or thickness of the base layer is not well-controlled.

Depth Deviation or Vertical Translation – “The difference in specified or design depth of the dowel bar [relative to] the measured depth at the centroid of the dowel bar.” (Note: “Values are expressed either positive for additional depth or negative for less depth.”) (ASTM 2017)

Embedment Length – Length of dowel bar embedded on either side of the joint saw cut. (Note: the critical embedment length for any given dowel will be measured on the side of the joint with less embedment.)

4.0 EQUIPMENT FOR DETECTING DOWEL LOCATION AND ALIGNMENT

4.1 Magnetic Pulse Induction (MPI) Equipment Requirements

Use MPI dowel alignment and location measurement equipment that complies with ASTM E3013/E3013-17 for Magnetic Pulse Induction (MPI) systems.

In addition, use MPI equipment with the following capabilities:

1. Minimum measurement range:
 - a. Dowel bar depth measurement as necessary to accurately locate dowel bars for the project pavement thickness
 - b. Horizontal and vertical misalignment to at least 2.0 in. [50 mm]
 - c. Depth deviation (vertical translation) and side shift (longitudinal translation) to at least the rejection levels described in Section 7.0.
2. 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 + $\frac{1}{2}$ dowel diameter): ± 0.25 in. [± 6 mm]
 - f. If the measurement system measurement tolerances exceed those presented here, specification acceptance and rejection limits must be modified using the guidance presented in Tables 2 and 3 in Sections 6 and 7.
3. An operating temperature range that includes the range of ambient temperatures anticipated at the time of testing.
 4. Output of single- and multiple-joint reports (also called batch or project reports) containing, as a minimum, the information described in section 13 of ASTM E3013/3013M-17.

4.2 Non-MPI Equipment Requirements

Obtain the Engineer's approval before using detection equipment that does not employ magnetic pulse induction technology (e.g., such as ground-penetrating radar or ultrasonic equipment). Ensure that the non-MPI dowel alignment and location measurement equipment provides non-destructive dowel location measurement capabilities similar to those described in ASTM E3013/E3013-17 for MPI systems, and to those listed in Section 4.1 above. When measurement tolerances vary significantly from those required for MPI measurement equipment, adjust specification acceptance and rejection limits in Sections 6.0 and 7.0 based on the non-MPI equipment measurement capabilities. Obtain the Engineer's approval for adjusted measurement tolerances compatible with the non-MPI equipment.

4.3 Calibration of Detection Equipment

4.3.1 MPI Equipment Calibration – Calibrate³ MPI Equipment, in accordance with ASTM E3013/3013M-17, to the specific dowel size(s), material type(s) and length(s) being used on the project. Use the calibration data file developed by the manufacturer for each device and bar type.

4.3.2 Non-MPI system calibration – Calibrate non-MPI equipment in accordance with the manufacturer's instructions for all factors that affect the equipment's ability to characterize dowel positions in the anticipated testing environment (i.e., anticipated temperature and moisture conditions, dowel material and size, and/or any other relevant variables).

4.4 Documentation of Detection Equipment

Obtain the Engineer's approval of the dowel locating equipment prior to its use. Submit the following documentation for approval:

³ **Note to Specifier:** The calibration process involves using the specific dowel bars to develop a software file that adjusts the signal measurement received to provide accurate results for the specific bar type, as well as a correction factor for the metal content in the specific scanner being used. Unless the device is damaged, no periodic [re-] calibration is required." (ASTM 2017). Note that calibration files are device-specific and do not permit the exchange of software and scanners between MPI systems. (ASTM 2017).

- a. Validation that the detection equipment has been properly calibrated for the size of dowel bar.
- b. The manufacturer's specified measurement tolerances.
- c. The serial number of the measurement device.

4.5 Operation of Detection Equipment

Provide an operator who is properly trained to operate the measurement device. Operate the equipment in accordance with the manufacturer's recommendations and in a manner ensuring that measurements obtained are accurate to the tolerances described in section 4.1.

Prior to paving, review the measurement equipment applicability for the project conditions with the Engineer, including: ambient moisture conditions, dowel material, presence of metallic concrete aggregate and potential contributors to magnetic interference (e.g., presence of tiebars, reinforcing steel or other embedded or underlying steel items that may affect measurement accuracy). Develop a plan to ensure that the measurement device can be used for proper process control under project conditions.

5.0 FIELD MEASUREMENT PROCEDURES

5.1 Process Validation Testing⁴

Perform process validation testing at project start-up and whenever there has been a long-term suspension of paving operations or a change in paving equipment, concrete mixture design, construction crews or other factors that have significant potential to impact dowel positioning. Use a process validation test section no shorter than is needed to incorporate at least 25 joints at the nominal planned spacing, nor longer than needed to incorporate 50 joints. Some initial distance of paving (e.g., up to 10 joints) may be excluded from the evaluation section to avoid the inclusion of common start-up problems (e.g., atypical concrete workability, inconsistent concrete head in front of the paver, etc.) that do not represent steady-state paving conditions.

A process validation section is not required if the project has less than 500 lineal feet of paving or has no sections of continuous paving greater than 45 lineal feet.

Upon completion of the process validation section, evaluate all joints in the section using the approved dowel position measuring equipment. Provide an electronic copy of the testing report and the collected data to the Engineer within three business days of completing the Process

⁴ **Commentary:** The purpose of validation testing is to demonstrate (the contractor's perspective) or ensure (the owner's perspective) that the paving process (and especially the dowel installation process) is under control and producing an acceptable quality of pavement prior to the start of production paving. It provides an opportunity to evaluate (and adjust or correct, if necessary) any aspects of the pavement construction process that impacts the quality of paving and the positioning of the dowels – including concrete mixture components and proportions, installation of dowel baskets, concrete placement and consolidation operations, paving equipment function and laborer actions. This can be accomplished with a paving demonstration or "test strip" that is placed nearby and off of the contract paving grade, but is often performed over a limited length of the project and, if approved, becomes a part of the finished project.

Validation Section. Ensure the report includes, as a minimum, the information described in Section 13 of ASTM E3013/E3013M-17, as well as an identification of each dowel bar with a rejection-level misalignment or mislocation and each joint with a joint score that exceeds the critical joint score.

All printouts/reports submitted by the Contractor becomes the property of the Engineer/Owner.

The dowel installation process is acceptable if:

1. Each JS is less than or equal to JS_{CRITICAL} (see section 3.1);
2. Eight-five percent (85%) or more of the dowel bars meet the alignment and positioning acceptance criteria presented in section 6.0; and
3. None of the dowel bars exceed the rejection levels of misalignment and positioning described in Section 7.0.

If the results do not meet any of the above criteria, make process adjustments to correct dowel alignment and location deficiencies and construct an additional test section to validate the modified construction process. Do not begin full production paving until the construction process has been refined, acceptable results are achieved and the Engineer accepts one or more process validation test sections.

In addition, any dowels in the validation test sections with misalignment or mislocation levels that exceed rejection levels must be addressed using appropriate corrective actions at no expense to the owner/agency.

Costs associated with rejected materials or modifying equipment or processes to achieve process acceptance are the Contractor's responsibility. Project delays caused by failure to achieve an acceptable dowel installation process count against project working days, where such limits apply.

5.2 Process Control Measurements and Actions

5.2.1 Frequency of Measurement During Production Paving

1. Initially, measure dowel bar alignment and location at one randomly selected joint from every group of 10 consecutive joints during paving production. The Engineer shall consider the dowel alignment process to be under satisfactory control when all alignment, positioning and joint score acceptance criteria are met—percent within limits (PWL) is greater than or equal to 90 percent—for two consecutive production days or over a paving distance specified by the Engineer prior to construction.
2. Upon establishing satisfactory control, measure and evaluate one randomly selected joint from every group of 20 consecutive joints thereafter.
3. If the PWL for any single dowel alignment or positioning acceptance criterion falls below 90 percent, the frequency of testing will revert to every 10th joint until control is re-established.
4. If any measured Joint Score (JS) exceeds JS_{CRITICAL} , measure the alignment of dowels in adjacent joints to determine the Effective Panel Length (EPL).

5. Exclude from measurement operations all dowels in transverse construction joint headers.

5.2.2 Use of Process Control Measurements

1. If all misalignments, mislocations, and JSs are below acceptance thresholds, use the data to refine the paving process¹ and further reduce or eliminate misalignments and mislocations.
2. If any misalignments, mislocations, or JSs exceed acceptance thresholds listed in section 6:
 - a. 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.
 - b. Propose corrective actions for any individual dowel bar that exceeds the rejection thresholds presented in section 7.
 - c. Propose corrective actions per section 7 if more than 3 consecutive joints have joint scores (JS) greater than the critical joint score (JS_{CRITICAL}).

5.3 Reporting

Provide the Engineer with an electronic report of the measurements obtained for each week's production prior to beginning paving on the first day of the following week. Ensure the report includes, as a minimum, the information described in Section 13 of ASTM E3013/E3013M, as well as an identification of each dowel bar with a rejection-level misalignment or mislocation and each joint with a joint score that exceeds the critical joint score.

All printouts/reports submitted to the Engineer shall remain the property of the Owner.

6.0 ACCEPTANCE CRITERIA FOR DOWEL ALIGNMENT, DOWEL POSITION AND JOINT SCORE

6.1 Lot Size

A lot shall consist of all travel lane or shoulder paving placed by any given paving machine or operation on any given day. Each lane-transverse joint shall be considered to be a subplot.

6.2 Acceptance Criteria for Inserted Dowel Bars

Acceptance of dowel alignment and position is based on the mean and standard deviation of the lot measurements for individual dowel composite alignment, side shift (longitudinal translation) and depth, as well as for joint score. When using MPI measurement devices, remove data for any dowels located within 12 inches of tie bars at longitudinal joints from the analyses due to possible interference of the tie bars with dowel location and alignment measurements.

The Engineer will calculate the PWL for each criterion. If the lot PWL is greater than or equal to 90% for any given criterion, the lot is acceptable for that criterion. If the lot PWL is less than

90% and greater than or equal to 50% for any given criterion, the lot is acceptable for that criterion with a price adjustment. If the lot PWL is less than 50% for any single criterion, the lot is rejectable and is subject to corrective action and reassessment, or can be accepted with a price adjustment at the Engineer's/Agency's option.

For calculation of the PWL, the upper and lower limits of each acceptance criterion⁵ are listed in Table 3.

Table 3. Specification Acceptance Limits for Position and Alignment of Individual Dowels, and Joint Score

Criterion	Lower Limit	Upper Limit	Limit Adjustments for Alternative Equip Tolerances
Composite Misalignment	0 in.	0.75 in. [19mm]/18 in. [450mm]	Increase upper limit by (rot. accuracy – 0.25 in [6mm])
Side Shift (Longitudinal Translation)	-2 in. [-50mm]	2 in. [50mm]	Decrease lower limit and increase upper limit by (long. trans. accuracy – 0.5 in [12mm])
Horizontal Translation	N/A*	N/A*	N/A*
Depth (Distance from Pavement Surface to Dowel Centroid)	Nominal Slab Thickness/2 + ½ in [13mm]	Nominal Slab Thickness/2 - ½ in [13mm]	Increase lower limit and decrease upper limit by (depth accuracy – 0.25in [6mm])
Joint Score	0	15	Adjust weighting factors, not JS limit.

*Studies to date have found that significant horizontal translation is rare and that it has not been associated with any definitive pavement distress.

⁵ **Commentary:** The values presented generally represent commonly achieved values (less than 30 percent of measurements fell outside of these limits) based on broad-based national studies of dowel alignment and position (NCHRP 2009, ARA 2005, ACPA 2006).

7.0 REJECTION CRITERIA FOR DOWEL ALIGNMENT, DOWEL POSITION AND JOINT SCORE

Individual dowel bars which exceed any of the criteria identified in Table 4 will be rejected.⁶

Table 4. Specification Limits for Position and Alignment of Individual Dowels, and Joint Score

Criterion	Rejection Levels	Limit Adjustments for Alternative Equip Tolerances
Composite Misalignment	> 2 in. [50mm]	Decrease by (rot. accuracy – 0.25 in [6mm])
Side Shift (Longitudinal Translation)	Side Shift > (L-8)/2 in (L = nominal dowel length)	Decrease by (long. trans. accuracy – 0.5 in [12mm])
Horizontal Translation	N/A*	N/A*
Depth (Distance from Pavement Surface to Dowel Centroid)	< Saw Cut Depth + ¼ in [6mm] + dowel diameter/2 or > Slab Thickness – (2 inches [50mm] +dowel diameter/2)**	Decrease upper limit by (depth accuracy – 0.25in [6mm])
Joint Score	EPL > 60 ft	Adjust weighting factors, not JS limit.

*Studies to date have found that significant horizontal translation is rare and that it has not been associated with any definitive pavement distress.

**Reject if distance between bottom of saw cut and top of dowel is less than ¼ in [6 mm] or if bottom of slab cover is less than 2 in [50 mm].

8.0 CORRECTIVE ACTIONS FOR INDIVIDUAL DOWELS AND JOINTS

Submit a corrective action proposal to the Engineer for each individual dowel with misalignment or positioning values that exceed the rejection levels above, and/or consecutive joints with JS > JS_{CRITICAL} over a distance that exceeds MEPL in validation sections and in production paving. As a minimum, the corrective action proposal shall include the following:

1. Identification of misaligned and mislocated dowels that are proposed for corrective action (i.e., all rejected dowels and any others that the Contractor chooses to correct to improve PWL values).
2. Identification and location of joints with JS > JS_{CRITICAL}.
3. Proposed method of remediation for each unique identified case, including supporting documentation of the effectiveness of the means of proposed remediation.

Do not implement the corrective action proposal until the Engineer approves the proposed method of correction.

⁶ The values presented in Table 4 are based on research studies that indicate significant potential for performance reductions for measures of misalignment or mislocation/positioning greater than these levels (NCHRP 2009, ARA 2005, ACPA 2006).

NOTE: Remediation methods for some misalignment and mislocation issues include "do nothing" when the affected dowel is non-critical (i.e., not in a wheel path or located within 6 inches of a longitudinal joint). Such cases can be expected to have no impact on long-term pavement performance and may be handled by a payment reduction for the individual dowel.

9.0 PAY ADJUSTMENTS FOR DOWEL ALIGNMENT AND POSITION (OPTIONAL)

9.1 Payment Adjustments for Alignment and Position for Dowel Bars

The payment adjustment for position and alignment of dowel bars in each lot will be calculated on the basis of the final lot PWL values (after corrective actions) and the originally bid unit price for the installed dowels using the following formula:

$$\text{Payment Adjustment (Reduction)} = \text{Dowel Quantity} \times \text{Unit Price (as bid)} \times (\text{PF}_{\text{dowels}} - 1.00) \times C$$

where:

$$\text{PF}_{\text{dowels}} = \text{PF}_{\text{CM}} + \text{PF}_{\text{SIDESHIFT}} + \text{PF}_{\text{DEPTH}} - 2.00$$

PF_{CM} = pay factor for composite alignment of individual dowels

$\text{PF}_{\text{SIDESHIFT}}$ = pay factor for individual dowel sideshift

PF_{DEPTH} = pay factor for depth

C = Correction factor ($0 \leq C \leq 1.00$) for specification phase-in (e.g., C = 0.6 in year 1 of alignment spec use, 0.8 in year 2, 1.0 in years 3 and beyond)

Calculate the pay factors for composite misalignment, sideshift and depth using the equations presented in Table 5, rounded to the nearest 0.01.

Table 5. Payment Factor Equations

Percent Within Limits (PWL)	Payment Factor (PF)
$90 \leq \text{PWL} \leq 100$	PF= 1.00
$50 \leq \text{PWL} < 90$	PF = 0.55 + 0.005*PWL

9.2 Additional Testing for Revised Payment Adjustments

It is recognized that the testing and payment process prescribed herein is based on a sample of all of the joints within each lot, and that it is possible that the alignment and positioning of dowels in the sample may not be representative of the alignment and positioning of dowels throughout the lot and that payment adjustments may be reduced or eliminated with additional measurements.

Therefore, if the PWL for any alignment or positioning criterion is less than 90 percent and results in a reduction in payment, the Contractor has the option to perform testing of additional randomly selected joints in the lot, up to a 100 percent sample, and to have those additional

measurements also included in the PWL calculations. All additional collected data must be used in the PWL calculations, even if it results in lower PWL values and further reductions in payment.

Bibliography and References

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

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