DOWEL BAR ALIGNMENT IN CONCRETE PAVEMENTS – 21ST CENTURY STANDARDS AND METHODS

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Paper prepared for presentation at the
"Innovations in Pavement Management, Engineering and Technologies" session
of the 2020 TAC Conference & Exhibition

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ABSTRACT

Dowel bars are used in the construction of jointed concrete pavements to provide load transfer, which is vital to long performance. Misaligned or improperly placed dowels may cause poor joint performance, resulting in pavement distresses, such as cracking, spalling or faulting. Dowel bar misalignment can be classified into five general categories: horizontal translation, vertical translation, side shift, horizontal rotation and vertical rotation. Depending on the type of misalignment, the impact can be a reduction in individual dowel bar effectiveness or restrained global free joint movement.

Different agencies have adopted different standards with regards to dowel bar alignment tolerances and methods of quality assurance verification. Dowel bar alignment in concrete pavement joints can be measured using a variety of methods, both destructive and non-destructive. The MIT-SCAN, a portable device using the principles of magnetic imaging tomography, has become of one of the more widely adopted devices for measuring the position and alignment of dowel bars for quality assurance purposes.

This paper provides an overview of the principles of dowel bars in jointed concrete pavements, a review of current dowel bar tolerance standards for a sampling of Canadian and U.S. jurisdictions and a detailed description of the state-of-the-practice for dowel bar alignment evaluation in Ontario.

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1. INTRODUCTION

Most modern-day concrete pavements are jointed, i.e. sawcut contraction joints are introduced at regular intervals to prevent uncontrolled cracking from temperature and moisture variations in the slab. However, these joints create a discontinuity, which may reduce their load carrying capacity. The performance of jointed concrete pavements is greatly impacted by the quality of load transfer across the joints between consecutive slabs.

Dowel bars are typically used at transverse joints to assist in providing load transfer and prevent faulting, except in low volume, light traffic scenarios. The dowels reduce the deflections at the joints, thereby by minimizing the slab stresses at the critical corner locations. The provision of effective load transfer is a key design element for jointed concrete pavement and proper dowel bar placement is an important factor in ensuring good performance. One component of good pavement performance is proper dowel bar alignment.

2. JOINTING IN CONCRETE PAVEMENTS

To control the magnitude of stresses at the joints, joint design considers parameters including dowel diameter, embedment length and spacing of dowels. According to the Federal Highway Administration (FHWA), the standard practice is to install round steel dowel bars spaced at 300 mm intervals along the length of the joint. The general rule of thumb is to use dowel bars with a diameter equal to 1/8th the slab thickness (usually 32-38 mm for highways) and a length of 450 mm (FHWA 2019). Some agencies are trialing alternative joint designs, e.g. shorter dowels, concentrating dowel placement in the wheelpath where load transfer is most important and using alternative dowel shapes to reduce bearing stresses, e.g. flat plate or elliptical dowels.

There are two main methods of dowel bar installation during construction: the use of dowel basket assemblies or the dowel bar inserter (DBI). Dowel baskets are simple steel truss structures used to hold dowel bars at the appropriate height before concrete placement. Dowel baskets typically span a full lane width and are fabricated from thick wire. The dowel baskets are laid out and firmly anchored to the base course prior to being paved over. An example of a dowel basket assembly is shown in Figure 1.

Figure 1: Dowel Basket Assembly

The dowel bar inserter is a device mounted on a slipform paver. At each joint location, the DBI automatically inserts the dowels into the fresh concrete along the length of the joint. The DBI pushes the dowels to the appropriate depth and then reconsolidates the concrete around the dowel locations using vibrating forks. An example of a dowel bar inserter is shown in Figure 2.

Figure 2: Dowel Bar Inserter on Slipform Paver

It is expected that dowel bars are installed parallel to the vertical and horizontal planes of the pavement to provide the expect degree of load transfer. The bars should be placed at the mid-depth of the slab and centered longitudinally along the sawcut. Improper placement may not only reduce the effectiveness of dowel bars, but may also contribute to premature distress formation, including joint spalling and slab cracking.

3. DOWEL BAR MISALIGNMENT

Any deviations in dowel bar position from the ideal position may be defined as misalignment. Dowel bar misalignments can be grouped into five generalized categories (Tayabji 1986):

- horizontal translation;
- vertical translation;
- longitudinal translation (side shift),
- horizontal skew (rotation); and

- vertical tilt (rotation).

Depending on the type of misalignment, the impact can affect individual dowel bar effectiveness or globally affect free joint movement. The five types of bar misalignment are shown in Figure 3.

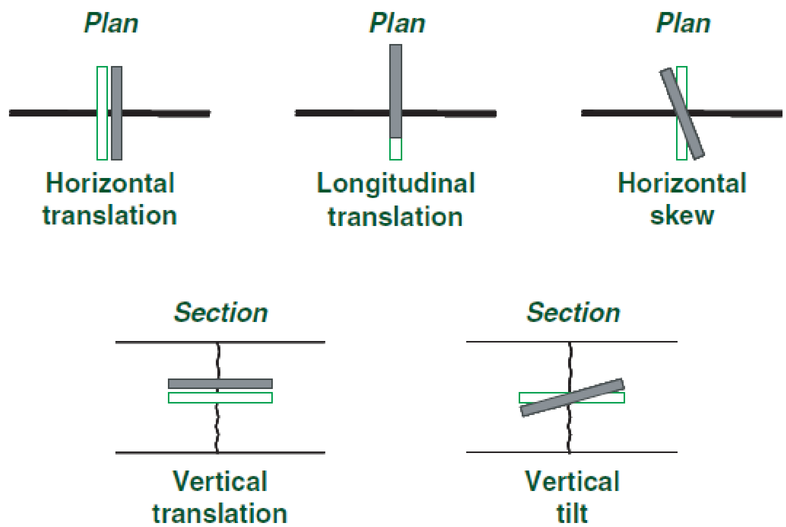

Figure 3: Types of Dowel Bar Misalignment (after Tayabji 1986)

In general, rotational misalignments, i.e. skew or tilt, impact the free movement of joints, while translational misalignments impact the effectiveness of individual dowel bars in providing load transfer.

3.1. <u>Horizontal Skew and Vertical Tilt</u>

The horizontal and vertical misalignment of dowel bars can introduce sufficient restraint at the joint to cause transverse cracking. A locked joint (or series of locked joints) can cause random cracking in pavement slabs. Misalignment of the dowels closest to the slab edges can also lead to corner breaks. Dowel rotation can also cause excessive stresses in the area surrounding dowels, resulting in spalling and looseness, which can decrease the load transfer capability, leading to pavement faulting (ACPA 2018).

3.2. <u>Longitudinal Translation</u>

Load transfer is influenced by the embedment length of the dowel bars. If the embedment length is not sufficient, higher bearing stresses develop. Under repeated traffic loadings, dowel looseness or spalling around the dowel bar may develop. The resulting consequences are diminished load transfer efficiency and faulting (ACPA 2018).

3.3. <u>Vertical Translation</u>

Dowels are ideally placed at mid-depth of the slab. Bars that are too shallow or too deep may not have sufficient concrete cover. Insufficient cover can cause higher concrete stresses, resulting in spalling or dowel punch-outs. Load transfer properties will be diminished. Adequate cover is also necessary for preventing bar corrosion. Very shallow dowel bars also risk being cut during the joint sawcutting operation (ACPA 2018).

However, not all dowel misalignment necessarily results in the development of pavement distress, e.g. slab cracking and spalling. A critical degree of misalignment is needed for performance to be impacted. Rotational misalignments should not exceed the critical level where the joint may lock or where the concrete may spall. Translational misalignment should be limited such that an acceptable degree of load transfer is provided. Variation in depth should be limited to provide the minimum level of cover (top and bottom). Research efforts have been undertaken to develop allowable tolerances.

4. CAUSES OF DOWEL BAR MISALIGNMENT

Bar misalignments can occur for a number of reasons during construction. These reasons may be related to materials, equipment or workmanship.

When using dowel baskets, factors that may result in dowel misalignment include:

1. Insufficient basket rigidity;
2. Poor quality control during basket fabrication, e.g. loose welds or improper heights;
3. Damage during basket transportation and placement;
4. Improper basket anchoring;
5. Inaccurate placement of sawcuts over the basket (Tayabji 1986).

The following factors may result in dowel misalignment when using a DBI for insertion:

1. Improper or poorly tuned DBI operation (technical problems);
2. Poor strike-off after dowel placement;
3. Insufficient consolidation (vibration) after dowel placement;
4. Inaccurate placement of sawcuts over the inserted dowels;
5. Improper concrete mix design or fluctuating consistency or density, e.g. segregated mix, or excessive slump (Tayabji 1986).

Proper quality control and quality assurance at the time of construction can help avoid dowel bar alignment and the associated future performance issues.

5. DOWEL BAR ALIGNMENT SPECIFICATIONS

While the perfect alignment of each and every dowel bar is desirable, practical limitations in construction processes do exist. Some degree of misalignment can be acceptable as the detrimental effects of misalignment are not likely to occur.

To prevent distresses from excessive dowel bar misalignment, appropriate dowel bar tolerances are required to ensure the long-term performance of concrete pavements. Dowel bar tolerances must consider the critical levels of misalignment, i.e. the level likely to cause distress, but also the practical limitations of equipment, workmanship and concrete mix properties.

Guidelines for allowable dowel misalignment vary from agency to agency. Despite more than 30 years of research, no consensus exists on dowel bar tolerances. Dowel bar misalignment has been known to be a pavement performance issue for more than half a century. However, no easy means of evaluating misalignment have been available until the introduction of non-destructive equipment, such as the MIT-SCAN (discussed in the next section).

Due to a lack of information on what deviations actually impact pavement performance, most agencies set conservative tolerances on dowel bar alignment. A large number of U.S. states have adopted limits on dowel rotation (horizontal skew or vertical tilt), recommended by the Federal Highway Administration (FHWA), of 1/4 inch per foot of dowel bar length or two percent (FHWA 1990). These specifications were developed based on very limited data from field and laboratory performance studies.

However, many agencies have begun re-evaluating and relaxing decades-old dowel bar tolerance limits based on more recent studies. An overview of current tolerances in use, as detailed in the National Cooperative Highway Research Program (NCHRP) Report 637: Guidelines for Dowel Alignment in Concrete Pavements, is summarized in Table 1.

Table 1: Dowel Bar Tolerances from Various Jurisdictions (Khazanovich et al, 2009)

<table>
<tr><th rowspan="2">Agency</th><th>Vertical Tilt</th><th>Horizontal Skew</th><th>Longitudinal Translation</th><th>Vertical Translation</th></tr>
<tr><th>mm per 457 mm</th><th>mm per 457 mm</th><th>mm per 457 mm</th><th>mm per 457 mm</th></tr>
<tr><td>Arkansas</td><td rowspan="13">6</td><td rowspan="13">6</td><td rowspan="13">N/A</td><td rowspan="13">N/A</td></tr>
<tr><td>Connecticut</td></tr>
<tr><td>Federal Aviation Administration</td></tr>
<tr><td>Hawaii</td></tr>
<tr><td>Idaho</td></tr>
<tr><td>Kentucky</td></tr>
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<tr><td>Wisconsin</td></tr>
<tr><td>Nebraska</td></tr>
<tr><td>Iowa</td></tr>
<tr><td>Michigan</td></tr>
<tr><td>Montana</td><td>6</td><td>6</td><td>13</td><td>13</td></tr>
<tr><td>North Dakota</td><td rowspan="2">6</td><td rowspan="2">6</td><td rowspan="2">13</td><td rowspan="2">13</td></tr>
<tr><td>Tennessee</td></tr>
<tr><td>Ontario</td><td>6</td><td>6</td><td>15</td><td>15</td></tr>
<tr><td>Nevada</td><td>13</td><td>13</td><td>N/A</td><td>N/A</td></tr>
</table>

Agency	Vertical Tilt	Horizontal Skew	Longitudinal Translation	Vertical Translation
	mm per 457 mm	mm per 457 mm	mm per 457 mm	mm per 457 mm
Missouri	13	13	13	25
Kansas	10	10	N/A	1/10 Pavement Depth
Indiana	10	10	N/A	N/A
North Carolina				
Illinois	5	5	N/A	N/A
Delaware				
South Carolina	14	14	76	19
Georgia	14	14	N/A	N/A
Germany	19	19	50	N/A
Alabama	6	6	N/A	N/A
Great Britain	10	10	N/A	N/A
New York	N/A	4	6	7
Ohio	N/A	N/A	13	13
Pennsylvania	6	6	25	25

Based on the findings of dowel alignment research studies and the experience of numerous North American agencies and contractors, the American Concrete Pavement Association (ACPA) has published a "Dowel Bar Alignment and Location" guideline specification. This specification includes acceptance and rejection tolerances from a number of alignment and location parameters. ACPA's recommended tolerances for 457 mm (18 inch) dowels are summarized in Table 2 and Table 3 (ACPA 2018). Percent within limits (PWL) is calculated for each criterion using the acceptance limits. PWL greater than or equal to 90% for any lot receives full payment. PWL greater than or equal to 50% and less than 90% receives a pay adjustment. Lots with PWL less than 50% are rejectable.

Table 2: ACPA Guideline Specification Acceptance Limits (adapted from ACPA 2018)

Criterion	Lower Limit	Upper Limit
Composite Misalignment	0 mm	19 mm
Side Shift (Long. Translation)	-50 mm	50 mm
Horizontal Translation	N/A	N/A
Depth Deviation	Mid-depth + 13 mm	Mid-depth - 13 mm
Joint Score	0	15

Note:

i) Composite Misalignment (CM) = square root of the sum of the squares of the Horizontal Skew and the Vertical Tilt for a single dowel

ii) Joint Score (JS) = a value that represents the impact of all misaligned dowels in a single transverse joint, based on CM values for individual bars, where:

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

where:
W_i = weighting factor (ranging from 0 to 10, depending on CM magnitude) for dowel *i*
x = number of dowels in a single joint
n = number of dowels excluded from calculation of JS (due to measurement interference, proximity to tie bars, etc.)
Joint Scores greater than 10 indicate a moderate risk of restraint and joint scores greater than 15 indicate probable joint lock-up.

Table 3: ACPA Guideline Specification Rejection Limits (adapted from ACPA 2018)

Location Tolerances	**Rejection Level**
Composite Misalignment	> 50 mm
Side Shift (Long. Translation)	± 125 mm
Horizontal Translation	N/A
Depth	< 6 mm from bottom of sawcut or concrete cover < 50 mm
Joint Score	Effective Panel Length (due to consecutive restrained joints) < 18 m

The Ontario Ministry of Transportation (MTO) dowel alignment specification also establishes different acceptance and rejection criteria for various dowel alignment parameters along with lot-based percent within limits (PWL) pay adjustments to encourage better construction practices. Ontario's specification is discussed in greater detail in Section 7.

Based on a study of 60 pavement sections in 17 U.S. states allowing for a broad range of design, construction, climate, and traffic variables, Rao et. al. (2009) determined that the following specification tolerances are easily constructible, but also have no significant effect on pavement performance:

- Horizontal skew or vertical tilt: <13 mm over a 457 mm dowel
- Longitudinal translation: ± 50 mm over a 457 mm dowel
- Vertical translation: ± 13 mm for pavements 305 mm or less in thickness.

6. METHODS OF EVALUATING DOWEL BAR ALIGNMENT

Various methods exist for the evaluation of dowel bar alignment. Until recently, only destructive methods were available to verify bar alignment. For this reason, the measurement of the position of dowel bars embedded in concrete was a difficult and costly task, and thus, was performed infrequently. However, non-destructive methods have been gaining popularity in the last twenty years. These methods allow for the measurement of dowel bar position with ease and high accuracy.

6.1. Destructive Methods

The primary destructive methods of dowel bar alignment verification include joint chip-out and coring. Chipping out a joint consists of exposing the embedded dowel bars using a jackhammer. The positions of each dowel bar in a joint, e.g. their rotation and translation, can subsequently be measured by hand. Bar alignment could be also be verified by coring. A single core provides minimal information, generally limited to bar depth. However, by coring at the anticipated location of both ends of the bar, a greater degree of information could be obtained, such as an estimate of the degree of rotation. However, unless performed extensively, coring only provide a sampling of bar alignment at any given joint. Adjacent bars may have greatly different positions. Figure 4 and Figure 5 show examples of dowel bar alignment verification using coring and chip-out methods, respectively.

Figure 4: Cored Dowel Bar Ends with Representative Bar to Show 3D Bar Alignment (Yu 2005)

Figure 5: Chipped Out Transverse Joint with Dowel Bars Exposed

These methods are slow and comparatively expensive. For these reasons, the measurement of dowel bar alignment by chipping out or coring has been performed relatively infrequently on concrete paving contracts. These reasons did not provide agencies with much incentive to monitor dowel bar alignment and position on an ongoing basis throughout the contract. Dowel bar tolerances were often not enforced as it was not possible to quickly and accurately measure alignment. The Ontario Ministry of Transportation (MTO), as an example, would typically only carry out this type of destructive verification only at the beginning of concrete paving on any given contract.

6.2. <u>Ground Penetrating Radar</u>

Ground Penetrating Radar (GPR) systems operate by transmitting pulses of electromagnetic energy into the ground and then recording the energy that is reflected back to the surface. The GPR signal responds to variations in the electrical properties of subsurface materials (i.e. dielectric constant and conductivity) that are a function of material type and moisture content. Where a contrast in dielectric properties exists between adjacent materials, a proportion of the electromagnetic energy will be reflected back. Subsurface structures can be mapped by measuring the properties of this reflected energy (i.e. amplitude and travel time). Figure 6 shows an example of a transverse scan of a joint using ground coupled equipment. The dowel bars are shown as hyperbola shapes.

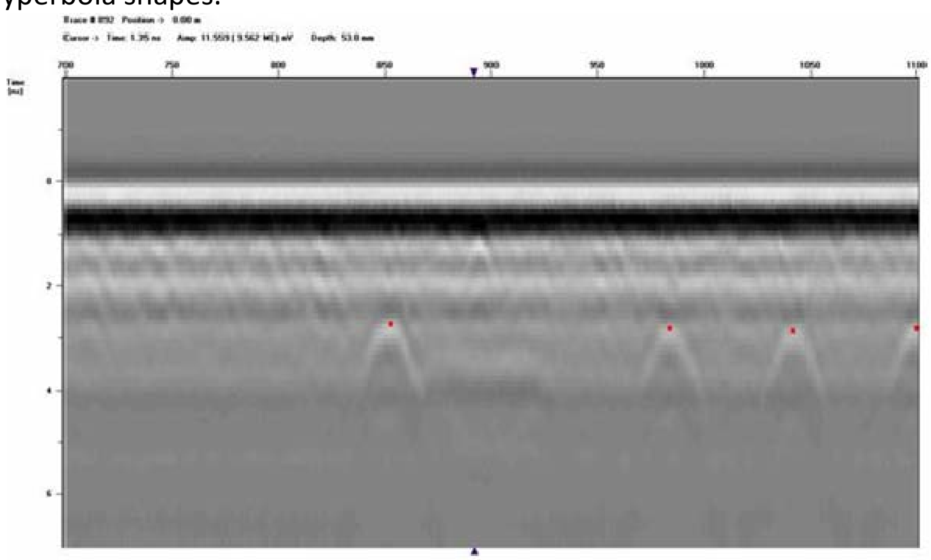

Figure 6: GPR Scan of Concrete Pavement Transverse Joint

Missouri DOT (MoDOT 2003) demonstrated that GPR can be used to assess dowel bar alignment accurately. Vertical alignment can be accurately measured within 3 mm and the accuracy of lateral dowel position is within 10 mm. However, this method of detecting dowel alignment is sensitive to the dielectric constant of concrete, which is a function of moisture content, temperature, and antenna frequency, among others. GPR data processing is a complicated activity. An experienced analyst is needed to interpret the GPR output and compute the dowel bar positions.

6.3. MIT-SCAN

While the importance of achieving good dowel alignment is widely recognized, the ability to monitor the placement accuracy of dowel bars effectively has been limited by the lack of practical means of measuring the position and orientation of dowel bars embedded in concrete.

Launched in the early 2000s by a German firm, the MIT-SCAN revolutionized the determination of dowel bar positioning and alignment. Using the principles of magnetic tomography, the MIT SCAN device emits a weak, pulsating magnetic signal and detects the induced eddy currents in the embedded dowel bars. Using sensitive detectors and sophisticated data analysis algorithms, the position of the dowels can be calculated with great accuracy (Yu and Khazanovich, 2005).

The original MIT-SCAN system (MIT-SCAN-2) consists of three main components:

- The scanner unit that emits electromagnetic pulses and detects the induced magnetic field using five sensor coils;
- An onboard computer that runs the operates the system, collects the test data, and performs the preliminary evaluation (originally wired, subsequently wireless in the Bluetooth-enabled version);
- A glass fiber-reinforced plastic rail system that guides the scanner unit along the joint.

An example of the MIT-SCAN-2 in use along a transverse joint is shown in Figure 7. The operator aligns the rail system along any transverse joint. After initiating the test on the computer, the operator pulls the wheeled scanner carriage along the length of the joint using a rope. Subsequently, the on-board computer, running the MagnoNorm software, will generate the measurement results in the field (bar depth, side shift, and horizontal and vertical misalignments) for most joints without excessive misalignment.

Figure 7: MIT-SCAN-2 Device in Use

More accurate and comprehensive analysis of the data can be performed using the MagnoProof software. Using the higher computing power of Windows-based systems, MagnoProof can calculate the positions of bars in more complicated measuring situation, e.g. greater degrees of misalignment or the influence of foreign metal. The MagnoProof software also produces graphic outputs, of which an example is shown in Figure 8.

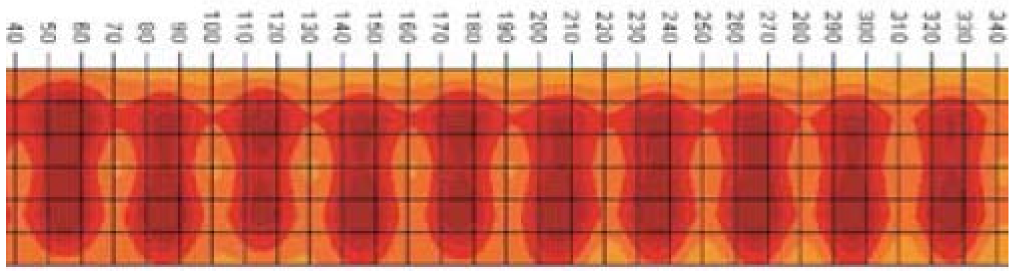

Figure 8: Example Graphical Output from MagnoProof showing Dowel Bars

The MIT-SCAN works on fresh or hardened concrete. A single joint scan takes about 1 minute. Two hundred or more joints can be scanned in a workday, with up to three lanes tested in a single pass. Measurements can be performed in most weather conditions.

Each MIT-SCAN is individually calibrated to each type of dowel bar that will be scanned using the device to provide very accurate results. Calibrations take into consideration bar material, diameter and length.

While the device was designed for scanning dowel bars placed using a dowel bar inserter (DBI), it can also be used to scan bars placed in dowel baskets with reasonable accuracy if the transport tie wires on the basket are cut.

Numerous studies have demonstrated the accuracy and repeatability of the MIT-SCAN system. The manufacturer's published measurement accuracy and repeatability are summarized below :

- Depth: ±4 mm;
- Vertical/ horizontal misalignment: ±4 mm;
- Side shift: ±8 mm;
- Repeatability: ±2 mm (Yu and Khazanovich, 2005).

While traditional methods for dowel bar alignment verification slow and damaging, the MIT-SCAN technology makes it possible to evaluate every joint in a concrete pavement. This allows for the ongoing monitoring of paving performance and the ability to catch any issues with dowel bar alignment in a timely fashion, benefitting both the contractor and the owner.

6.3.1. Newest Iteration – MIT-DOWEL-SCAN

The manufacturer, MIT Mess- und Prüftechnik GmbH, has been working to improve their technology. The newest design, known as the MIT-DOWEL-SCAN, was recently released. This system is now rail-free, which allows for faster scanning as there are no rails to assemble or move. A small laser is used to guide the scanner along the joint being scanned, which is now pushed from behind. The laser automatically maintains alignment of the scanner cart so that no steering by the operator is needed. The MIT-DOWEL-SCAN now includes 10 sensors for increased resolution.

The MIT-DOWEL-SCAN device is shown in Figure 9. Figure 10 shows the MIT-DOWEL-SCAN lined up on joint to scan with the guidance laser in the foreground.

Figure 9: New MIT-DOWEL-SCAN Device (MIT Mess- und Prüftechnik GmbH, n.d.)

Figure 10: MIT-DOWEL-SCAN Device with Guidance Laser in the Foreground (Aicken 2018)

7. CASE STUDY: STATE-OF-THE-PRACTICE IN ONTARIO

7.1. Background

In recent years, the Ontario Ministry of Transportation (MTO) has been building concrete pavements on heavily trafficked provincial highways as part of expansion or reconstruction projects. The pavement design generally comprises doweled jointed plain concrete pavement over an asphalt treated open-graded drainage layer (OGDL) and a granular subbase. Transverse joints are sawcut on a repeating random joint spacing pattern of 3.7, 4.5, 4.0 and 4.3 m (OPSD 551.010, 2017). Smooth, epoxy coated steel dowel bars (32 mm diameter x 450 mm long) are placed at the transverse joints at 300 mm spacings to provide load transfer (OPSD 552.010, 2017).

7.2. Concrete Paving Specification

MTO first trialed the MIT-SCAN equipment in 2003. Following several trial projects where data was collected, the concrete paving specification was updated in 2006 with the adoption of the MIT-SCAN equipment for quality control. MIT-SCAN data collection and analysis lead contractors to implement process improvements, and the ministry re-evaluated their specified dowel bar tolerances (Lane and Kazmierowski, 2008).

MTO evaluates four parameters as part of the dowel bar alignment verification: depth, side shift, horizontal misalignment and vertical misalignment. A specification limit and a rejection limit are established for each parameter (OPSS, 2018). Current limits are shown in Table 4 and Table 5.

The total quantity of concrete pavement placed on the contract is considered a lot. Each transverse joint is considered a sublot. Acceptance of the dowel bar alignment for the lot is based on the mean and standard deviation of the lot measurements for vertical alignment, horizontal alignment, side shift and depth. The dowel bar closest to the longitudinal joint shall be removed from the analysis due to possible interference of the tie bar.

The percent within limits (PWL) for the lot is calculated for vertical alignment, horizontal alignment, side shift and depth using the specification limits. If the lot PWL is greater than or equal to 90%, the lot is acceptable. If the lot PWL is less than 90% and greater than or equal to 50%, the lot is accepted with a price adjustment. If the lot PWL is less than 50%, the lot is rejectable and subject to repair and reassessment.

Table 4: Ontario Specification Limits for Position and Alignment of Dowel Bars

Attribute		Lower Limit	Upper Limit
Horizontal Misalignment		-15	15
Vertical Misalignment		-15	15
Side Shift		-50	50
Depth	Slab Thickness <215 mm	Mid-depth - 6	Mid-depth + 6
	Slab Thickness 215-229 mm	Mid-depth - 12	Mid-depth + 15
	Slab Thickness ≥ 230 mm	Mid-depth - 15	Mid-depth + 25

Table 5: Ontario Rejection Criteria for Position and Alignment of Dowel Bars

Attribute		Lower Limit	Upper Limit
Horizontal Misalignment		-38	38
Vertical Misalignment		-38	38
Side Shift		-75	75
Depth	Slab Thickness <215 mm	Mid-depth - 10	Mid-depth + 10
	Slab Thickness 215-229 mm	Mid-depth - 18	Mid-depth + 23
	Slab Thickness 230-259 mm	Mid-depth - 25	Mid-depth + 35
	Slab Thickness ≥ 260 mm	Mid-depth - 25	Mid-depth + 40

7.3. Procedures

7.3.1. Trial Section

At the beginning of construction, the contractor places a trial section to verify that the equipment can place the dowel bars in accordance with the specification requirements. Every joint is scanned using the MIT-SCAN by a representative of the owner to verify the position and alignment of the dowel bars.

7.3.2. Joint Cut-Out

At the commencement of paving, the first joint is chipped out after being evaluated with the MIT-SCAN. The Contract Administrator inspects the joint and measures and records the depth, side shift, vertical and horizontal alignment of all the dowel bars. These measurements are compared to the MIT-SCAN results to verify accuracy.

7.3.3. Quality Assurance during Production

During paving, one joint for every 10 joints is randomly selected and the position and alignment of the dowel bars of are measured using the MIT-SCAN by a representative of the owner. If the position and alignment of any of the dowel bars is found to be rejectable, joints on either side of the unacceptable joint will be scanned, until five consecutive joints on each side are found with no rejectable bars. Any joints with rejectable bars are removed and replaced.

8. CONCLUSIONS

Dowel bar alignment is a key performance indicator for concrete pavements. Advances in non-destructive measurement have allowed for the widespread evaluation of in-situ dowel bar positioning, something that was not previously possible. Improved dowel bar alignment data have allowed for the refinement of concrete paving specifications to balance quality and constructability. To ensure high-quality concrete pavements, many agencies are choosing to monitor dowel bar alignment on an ongoing basis to ensure that it is in compliance with the contract requirements so that good long-term pavement performance can be achieved.

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