Revised Dowel Bar Tolerances for Ontario Concrete Pavements

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Abstract

Effective load transfer is a key design element for jointed plain concrete pavement and has a significant impact on long-term pavement performance. To facilitate load transfer and to allow expansion and contraction of the joints, dowel bars should be placed parallel to the vertical and horizontal planes of the pavement. In the past, it was difficult to verify the alignment of dowel bars within a concrete pavement. Recently, the Ontario Ministry of Transportation was given the opportunity to verify dowel bar alignment with an innovative non-destructive technique known as magnetic imaging tomography (MIT). The MIT scan was found to be a quick and accurate method of measuring dowel bar alignment across a transverse joint, allowing real-time, non-destructive assessment of the dowel bar alignment at joints throughout a concrete paving contract.

In Ontario, MIT scan data collection and analysis during concrete paving led to process and equipment improvements. The MIT scan was rapidly adopted both as a quality control tool for the contractor and a quality assurance tool for the ministry. Based on data collected over several paving seasons, changes were made to ministry specifications and dowel bar tolerances. The revised dowel bar tolerances for Ontario pavements are presented in this paper.

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Introduction

Effective load transfer is a key design element for jointed plain concrete pavement and has a significant impact on long-term pavement performance. To facilitate load transfer, dowel bars must be placed parallel to the vertical and horizontal planes of the pavement, to allow expansion and contraction of the joints.

In the past, the position and alignment of dowel bars within a concrete pavement has been difficult to verify. The Ministry of Transportation Ontario (MTO) utilized destructive techniques such as cut-outs and chip-outs to ensure that the position and alignment of the dowel bars met contract requirements. Recently, the ministry began to verify dowel bar alignment with an innovative non-destructive technique known as magnetic imaging tomography (MIT). The MIT scan was found to be a quick and accurate, non-destructive method of assessing dowel bar alignment across a transverse joint.

This paper outlines the introduction of the MIT scan into Ontario concrete paving contracts, the dowel bar alignment issues uncovered, and the changes to process control and equipment that resulted in improvements to dowel bar alignment.

In 2006, the ministry analysed MIT scan data collected from several large concrete paving contracts and developed a percent within limits (PWL) specification for dowel bar placement. This specification was updated in 2007 and the revisions are summarized herein.

Concrete Pavement Design in Ontario

In Ontario, concrete pavement design for heavily trafficked highways consists of doweled jointed plain concrete (JPCP) over open-graded drainage layer (OGDL) and granular base. Perpendicular transverse joints are randomly spaced at 3.7, 4.5, 4.0, 4.3 m. Epoxy coated, smooth, 32 mm x 450 mm steel dowel bars are placed at 300 mm centres across the transverse joints to provide load transfer. Longitudinal joints are tied with 15 mm x 760 mm tie bars spaced at 600 mm intervals. The pavement lanes are 3.75 m wide with a 0.5 m tied outside concrete shoulder (widened lane). Drainage collection is provided through subdrains or an urban cross-section of curb and gutter.

Position and Alignment of Dowel Bars

In JPCP design, dowel bars are required across transverse joints to provide load transfer. Dowel bars must be placed parallel to the vertical and horizontal planes of the pavement. Misalignment of dowel bars can lead to slab cracking due to locked joints, joint spalling, corner breaks and reduced load transfer (Tayabji, 2005). Insufficient embedment of the dowel bars will also result in reduced load transfer at affected joints (Tayabji, 2005). These distresses will require costly rehabilitation in the form of full- and partial-depth repairs and slab replacements, increasing the life cycle cost of the concrete pavement.

It is generally specified that dowel bars be placed, as much as is practical, parallel to the longitudinal axis and the horizontal plane of the pavement. The different types of misalignment include side shift, horizontal misalignment, vertical misalignment and depth:

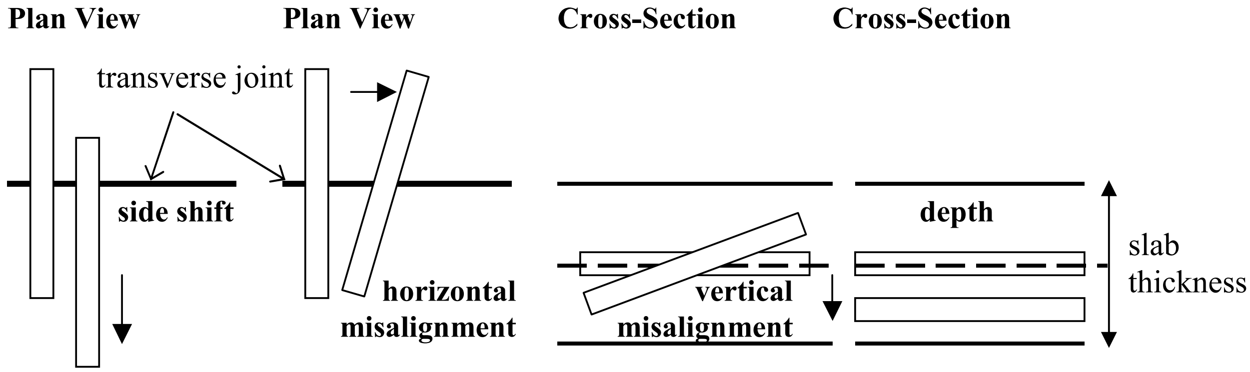


Figure 1. Types of misalignment of dowel bars in concrete pavement.

Several conditions during the concrete paving operation may result in incorrect positioning of dowel bars, including:

- concrete mix design, fluctuating consistency or density of concrete,
- contact with vibrators during consolidation,
- technical problems with the dowel bar inserter or finisher,
- poorly marked or placed joint sawcut locations.

In order to ensure high-quality concrete pavement, inspection of dowel bar alignment is recommended during production, rather than evaluating the finished work to ensure that it is in compliance with the contract requirements.

In the past, the position and alignment of dowel bars within a concrete pavement was difficult to verify. MTO required joint cut-outs 2 m x full paver width to ensure that the placement and alignment of the dowel bars met contract requirements. This type of destructive verification was only carried out at the beginning of concrete placement. In 2003-2005, the ministry was given the opportunity to verify dowel bar alignment with a non-destructive technique known as magnetic imaging tomography (MIT). The MIT scan was found to be a quick and accurate method of assessing dowel bar alignment across a transverse joint.

Evaluation of MIT Scan for Use in Ontario

As part of an effort to determine dowel bar placement accuracy in JPCP, the ministry initiated a project to evaluate the use of the MIT scan technology specifically for measuring dowel and tie bar alignment in concrete pavements (Ponniah, 2003).

The MIT-Scan-2 device functions according to the principles of pulse-induction. The transmitter sends a pulsating magnetic signal that induces eddy currents in dowels. These currents induce transient magnetic response signals, which are measured by receivers in the testing device. The methods of magnetic tomography are then used to determine the location of the dowel and tie bars (MIT GmbH, 2002). The manufacturer's published measurement accuracy and repeatability are: depth ±4 mm, vertical/ horizontal misalignment ±4 mm, side shift ±8 mm and repeatability ±2 mm.

The system computer provides a preliminary analysis of the recorded data. It provides accurate results only if dowel bars are installed within the following limits:

- Depth 150±40 mm
- Maximum vertical misalignment ±20 mm
- Maximum horizontal misalignment ±75 mm

More accurate and comprehensive analysis of the recorded data may be performed using MagnoProof software installed on an external computer. It can accurately determine dowel position regardless of alignment, expressed in Cartesian coordinates.

Dowel Bar Tolerances in Ontario

In 1991, the MTO specification for concrete pavement required that dowel bars be placed mid-depth of slab, within a tolerance of ±6 mm in the vertical and horizontal planes of the pavement. At that time, load transfer assemblies were commonly used, however automatic dowel bar inserters were permitted if the contractor could demonstrate that bars could be placed to meet the specification. The specification also required that joints be placed within ±6 mm from the centre of the dowel bars.

By the mid 1990's, all of the mainline concrete paving in Ontario was being done by slip-forming paving with automatic dowel bar inserters (DBI). In 1998, the specification was updated to require that when a DBI was used, the Contractor must remove a 2 m x full paver width section of concrete pavement within the first days paving to verify dowel bar alignment. Additional removals were required if the Contractor's operation failed to conform to the specification. Dowel bar tolerances were unchanged from the 1991 specification however, joints were to be sawcut within a tolerance of ± 15 mm from the position and alignment of the centre of the dowel bars.

With the arrival of the MIT scan on MTO contracts it became apparent that these existing dowel bar tolerances were not being met by the province's concrete paving contractors. A decision was made to investigate what tolerances are required to ensure long term performance of concrete pavements, while at the same time gathering MIT scan data from numerous concrete paving contracts to determine what tolerances are achievable.

Impact of Dowel Bar Alignment on Pavement Performance

To address the impact of dowel bar alignment on pavement performance, the ministry hired an expert to summarize the work in this field to date and to provide recommendations to the ministry for future modifications to MTO specifications. The consultant report concluded that the primary concern with dowel bar misalignment is the risk of premature failures within 10 to 15 years. With high levels of dowel misalignment, failures may occur earlier at joints/slabs. The findings of the report (Tayabji, 2005) were as follows:

Horizontal and Vertical Misalignment

Horizontal and vertical misalignment of dowel bars can introduce sufficient restraint at the joint to cause transverse cracking at mid-slab. A series of frozen/locked joints can induce random cracking in pavement slabs. Misalignment of the outside four dowels in the driving lane can also lead to corner breaks. Dowel misalignment can cause excessive PCC stresses in the area surrounding dowels, resulting in spalling and looseness around dowel bars, which can seriously impact the load transfer capability of the critical outside dowel bars and lead to higher rates of faulting. When misalignment exceeds 25 mm, the potential for spalling around the dowel bar is high. Greater variations in PCC temperatures cause wider joint openings and increase the effect of dowel misalignment.

Side Shift

Load transfer can be compromised if the dowel embedment is not sufficient. A minimum of embedment of 175 mm is recommended. If the embedment length is compromised, higher concrete bearing stresses develop and under repeated application of traffic loading, may lead to dowel looseness or spalling around the dowel bar, affecting the load transfer capability of the critical dowel bars and leading to faulting.

Depth

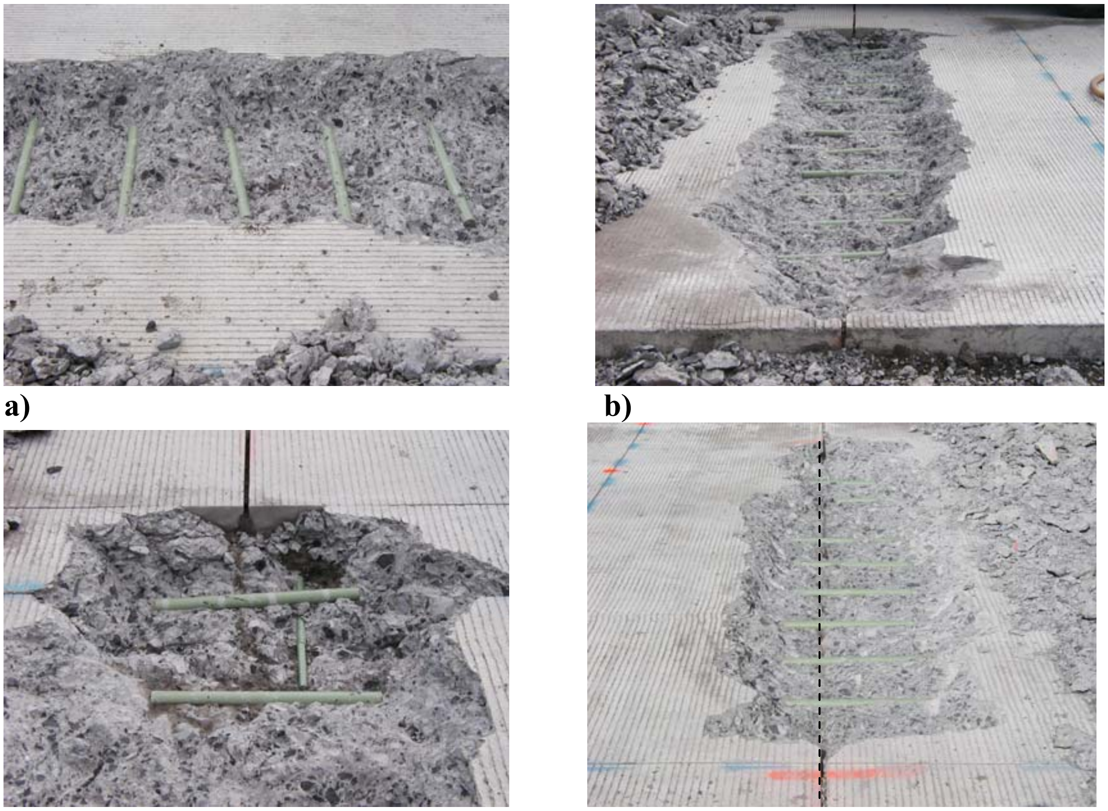
Dowel depth must be monitored to ensure that the bars are not being placed in higher stress zones where they could be deformed or cause de-bonding or bearing stress failures (punch-outs) in the PCC. Load transfer can be compromised if dowel cover is not sufficient. Joint spalling at the slab bottom under wheel path locations may result due to reduced cover around the dowel bar. A minimum cover of 75 mm is recommended. Shallow dowel bars, placed in the top third of the slab, risk being cut during the joint sawing operation.

Use of Mit Scan Data to Revise Dowel Bar Tolerances

Based on the consultant report (Tayabji, 2005), which found that dowel bar misalignment can result in locked joints, slab cracking, joint spalling, poor load transfer across the joints and corner breaks, the ministry concluded that appropriate dowel bar tolerances are required to ensure the long-term performance of concrete pavements. However, the ministry also needed to evaluate what dowel bar tolerances the owner could realistically specify, given the practical limitations of equipment, workmanship, concrete mix design and consistency. Analysis was carried out on MIT data from large concrete paving contracts collected during the 2004-2007 construction seasons.

Case Study #1: Highway 417, east of Ottawa

In September 2004, 36 km of 2-lane concrete paving began on Highway 417 east of Ottawa. Full width paving (3.75m + 4.25m, 200 mm thick) began using a four-track slipform paver with rear mounted automatic dowel bar inserter (DBI) and automatic tie-bar inserter. It soon became evident that the DBI was malfunctioning. MIT scanning carried out on the newly placed concrete pavement indicated a variety of dowel bar misalignment problems, including: dowel bars horizontally and vertically misaligned; tie bars intersecting dowel bars at the longitudinal joint; dowel bars placed deeper than the mid-depth of the slab; dowel bars were missing; and joint sawcuts not centered over the dowel bars (Figure 2).



a) b)

c) d)

Figure 2. (a) and (b) Horizontally and vertically misaligned dowel bars. (c) Tie bars intersecting dowel bars. (d) Joint sawcut not centered over dowel bars.

Since concrete paving had continued for at least 1200 m with the malfunctioning DBI, the ministry was looking at a significant problem. The first step was to use the MIT scan to identify the extent of the problem, scanning the work before and after the equipment breakdown, with random scanning throughout the contract. In order to be allowed to continue with the work, the ministry required a corrective action plan from the contractor. The contractor completely over-hauled and upgraded the DBI equipment, staff were sent for training and an improved quality control (QC) plan was put in place. A saw cutting rolling template (guide) was devised for cutting of transverse and longitudinal joints. The contractor also agreed to use the MIT scan on the next two stages of work.

During construction of the next two stages, the contractor used the MIT scan results to make further improvements to process and equipment. Dowel bar alignment improved significantly from the initial stage (placed with a malfunctioning DBI in Sept 2004), to stage 2 (placed July-Aug 2005), to stage 3 (placed Aug-Sept 2005).

Case Study #2 - Hwy 401, east of Windsor

In the 2005 construction season, 10 km of six-lane concrete pavement was placed on Hwy 401 east of Windsor. Concrete pavement was placed in two separate passes: the two inside lanes together (3.5 m and 3.75 m), then the driving lane (3.75 m lanes plus 0.5 m tied concrete shoulder). The contractor used a new four-track paver with in-the-pan dowel bar inserter. The concrete pavement design consisted of 260 mm JPCP over an open graded drainage layer.

This contract was experiencing some problems with high slump and variable concrete consistency. MIT scan results suggest that this resulted in higher values of horizontal and vertical misalignment.

MIT scan data also highlighted a problem with the outside lane. The transverse joints in lane 1 and 2 did not match precisely with lane 3, which was placed separately. The joint sawcutting operation in lane 3 simply followed the sawcut in lanes 1 and 2, resulting in side shift issues. Detecting this problem early on allowed the contractor to make adjustments to the operation to ensure precise joint placement.

Revisions to MTO Concrete Pavement Specification, 2006-2007

MIT scan data collection and analysis led contractors to process and equipment improvements and the ministry to re-evaluate dowel bar tolerances. In 2006, the ministry used MIT scan data collected from ministry contracts to develop an end result specification with percent within limits (PWL) payment adjustment based on dowel bar tolerances. This specification was updated in 2007.

Revisions to Dowel Bar Tolerances

MTO criteria for revised dowel bar tolerances were based on findings in the literature (Tayabji, 2005) and in a CPTP Technical Brief entitled "Best Practices for Dowel Placement Tolerances":

1. **Vertical and horizontal misalignment:** When vertical/horizontal misalignment exceeds 38 mm, the potential for spalling around the dowel bar is high. The current MTO specification requires that dowel bars be placed parallel to the longitudinal axis and horizontal plane of the pavement within a tolerance of ±15 mm along the length of the dowel bar. The tolerance for horizontal and vertical alignment was revised from ±6 mm in 1991 and 1998, and ±12 mm in 2005, to ±15 mm in 2006 and 2007. The rejection criteria was revised from 25 mm in 2006 to 38 mm in 2007.
2. **Side shift:** A minimum embedment length of 175 mm is recommended for load transfer. The current MTO specification requires that transverse joints be sawcut within a tolerance of ±50 mm from the centre of the dowel bars. The tolerance was revised from ±6 mm in 1991, ±15 mm in 1998, and ±40 mm in 2006. The rejection criteria was revised from 50 mm in 2006 to 75 mm in 2007.
3. **Depth:** A minimum cover of 75 mm is recommended around dowel bars. Shallow dowel bars, placed in the top third of the slab, risk being cut during the joint sawing operation. The current MTO specification requires that dowel bars be placed mid-depth of the specified slab thickness within the following tolerances:
    a. For a 200 mm slab thickness, lower limit = - 6 mm, upper limit = + 6 mm
    b. For a 225 mm slab thickness, lower limit = -12 mm, upper limit = +15 mm
    c. For a 250 mm slab thickness, lower limit = -15 mm, upper limit = +25 mm
    d. For a 260 mm slab thickness, lower limit = -15 mm, upper limit = +25 mm

The depth tolerance was revised from ±6 mm in 1991 and 1998. The rejection criteria are based on a requirement for 75 mm cover at the bottom of the slab and a sawcut depth of one-third slab thickness. This will vary as follows:

e. For a 200 mm slab thickness, rejection criteria are <90 mm or >110 mm
f. For a 225 mm slab thickness, rejection criteria are <95 mm or >135 mm
g. For a 250 mm slab thickness, rejection criteria are <100 mm or >160 mm
h. For a 260 mm slab thickness, rejection criteria are <105 mm or >170 mm.

Requirements for a Trial Section

At the beginning of construction, the contractor is required to place a trial section to verify that the equipment can place the dowel bars in accordance with the requirements of the specification. The MIT-Scan-2 is then used to verify the position and alignment of the dowel bars for every joint within the trial section.

Quality Control During Production

During production, the position and alignment of the dowel bars in every 10^{th} transverse joint are measured using the MIT-Scan-2. Testing is carried out at the start of the next day's production or within 24 h of each day's production. If the position and alignment of any of the dowel bars is found to be rejectable, the remainder of the joints within that day's production are scanned.

Acceptance Criteria for Position and Alignment of Dowel Bars

A lot consists of the total quantity of concrete pavement on the contract. 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. Absolute values are used to calculating means.

The percent within limits (PWL) is calculated for vertical alignment, horizontal alignment, side shift and depth according to LS-101 (MTO, 1998). 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.

For calculation of PWL, the upper limit and lower limits for each attribute are as specified in Table 1.

TABLE 1: Specification Limits for Position and Alignment of Dowel Bars

Attribute	Lower Limit	Upper Limit
Horizontal alignment (mm)	-15	15
Vertical alignment (mm)	-15	15
Side shift (mm)	-50	50
Depth Tolerance (for specified slab thickness):		
200 mm (mid depth - 6 mm/+6 mm)	94	106
225 mm (mid depth -12 mm/+15 mm)	100	127
250 mm (mid depth -15 mm/+25 mm)	110	150
260 mm (mid depth -15mm/+25 mm)	115	155

Repair Criteria

Any sublot is rejectable if it is found to contain an individual dowel bar which exceeds any of the criteria identified in Table 2 or 3:

TABLE 2: Rejection Criteria for Vertical / Horizontal Alignment and Side Shift

	Vertical Alignment	**Horizontal Alignment**	**Side shift** (Measurement taken from transverse sawcut)
	(Measurement along length of the dowel bar)		
Reject - Remove & Replace	<-38 mm or >38 mm	<-38 mm or >38 mm	<-75 mm or >75 mm

TABLE 3: Rejection Criteria for Depth of Dowel Bars

	Depth of Dowel Bar (mm) (Measurement taken from top of concrete surface to centre of dowel bar)			
Specified Slab Thickness	**200 (mm)**	**225 (mm)**	**250 (mm)**	**260 (mm)**
Reject–Remove & Replace	<90 or >110	<95 or >135	<100 or >160	<105 or >170

Payment Adjustment for Position and Alignment of Dowel Bars

The Pay Factor for position and alignment of dowel bars is based on the following formula:

$$\mathbf{PF_{dowel\ bars} = PF_{horizontal} + PF_{vertical} + PF_{sideshift} + PF_{depth} - 3}$$

Where: $PF_{horizontal}$ = Pay factor for horizontal misalignment
$PF_{vertical}$ = Pay factor for vertical misalignment
$PF_{sideshift}$ = Pay factor for sideshift
PF_{depth} = Pay factor for depth

The pay factors of the dowel bars for horizontal, vertical, sideshift and depth are each calculated using the equations in Table 4 to the nearest 0.01.

TABLE 4: Payment Factors

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

Conclusions

During the life of a concrete pavement, full- and partial-depth repairs and slab replacements may be expected due to spalled joints and cracked slabs. A literature review has shown that effective load transfer has a significant impact on long-term performance of jointed plain concrete pavements. To facilitate load transfer, dowel bars must be placed parallel to the vertical and horizontal planes of the pavement. Misalignment of dowel bars can lead to slab cracking, locked joints, joint spalling, corner breaks and reduced load transfer. Misplaced saw-cutting of joints, resulting in insufficient embedment of the dowel bars, can also result in reduced load transfer.

In the past, MTO specified that dowel bars be placed mid-depth of slab, aligned within a tolerance of ±6 mm. During construction, verification of dowel bar alignment was through cut-outs and chip-outs carried out at the beginning of concrete placement. This destructive testing method discouraged further evaluation during production. With the introduction of the MIT scan, the owner and the contractor now have readily available data on dowel bar alignment. The MIT scan is a quick and accurate method of assessing dowel bar alignment, allowing real-time, non-destructive assessment of the dowel bar alignment at joints throughout a concrete paving contract.

In order to ensure long term concrete pavement performance, it is recommended that inspection of dowel and tie bar alignment be carried out during production, rather than evaluating the finished work. The MIT scan provides a check that all aspects of the contractor's paving operation are under control and allows for timely corrective action when any aspect of the paving operation is out of control.

The MIT scan was rapidly adopted as both a quality control tool for the contractor and a quality assurance tool for the ministry. MIT scan data collection and analysis led contractors to process and equipment improvements, and the ministry to a re-evaluation of specified dowel bar tolerances.

Using MIT scan data collected from several ministry contracts, a percent within limits (PWL) specification was developed for dowel bar placement. The 2007 specification requires that dowel bars be placed within the following tolerances: vertical/horizontal misalignment shall be no more than ±15 mm along the length of the bar, with a rejection criteria of > 38 mm; transverse joints shall be sawcut within a tolerance of ±50 mm from the centre of the dowel bars, with a rejection criteria of > 75 mm; and dowel bars shall be placed mid-depth of the specified slab thickness within 94-106 mm for a 200 mm slab, 100-127 mm for a 225 mm slab, 110-150 mm for a 250 mm slab and 115-155 mm for a 260 mm slab. The rejection criteria for depth are based on 75 mm cover at the bottom of the slab, and a sawcut depth of one-third slab thickness. Adoption of these revised tolerances has resulted in a significant reduction in dowel bar rejection for misalignment, side shift, and depth.

Use of the MIT scan in Ontario led to improvements in contractor equipment and processes, and to the development of achievable dowel bar tolerances in the ministry's concrete pavement specification.

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