TechBrief

The Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, CPTP's primary goals are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The program was designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materials selection, mixture proportioning, and the design, construction, and rehabilitation of concrete pavements.

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U.S. Department of Transportation
Federal Highway Administration

Best Practices for Dowel Placement Tolerances

INTRODUCTION

The use of appropriately sized dowel bars is highly recommended for jointed concrete pavements that are subjected to high volumes of heavy truck traffic (FHWA 1989; AASHTO 1993). Dowel bars provide positive load transfer across pavement joints to greatly reduce critical deflections and stresses, thereby reducing the potential for pumping and faulting at joints, as well as slab cracking. However, proper placement is critical to proper functioning of the dowel bars. Improper placement may not only reduce the effectiveness of dowel bars, but may also contribute to premature distresses, including joint spalling and slab cracking.

Recognizing the importance of good dowel alignment, most highway agencies in the United States have adopted requirements for dowel placement accuracy. These requirements, however, are not enforced rigorously by most highway agencies because, until recently, there has been no practical and quick means of measuring dowel alignment. The past difficulties in measuring dowel alignment have had at least two important consequences on concrete pavement construction in the United States:

- Dowel placement tolerances that may not reflect field experience. The existing specifications are based on limited laboratory testing and analytical investigations.
- Limited use of dowel bar inserters (DBIs). Because of the concern over dowel alignment, DBIs are not widely used in the United States. Many highway agencies specifically prohibit their use, even though DBIs may offer advantages in both speed and cost of construction.

Today, dowel alignment can be measured efficiently and accurately using MIT Scan-2 (Figure 1), a state-of-the-art nondestructive testing device for measuring and recording the position and alignment of dowel bars (FHWA 2005; Yu and Khazanovich 2005). The device is easy to use, the dowel alignment can be checked within a few hours of concrete placement, and the results can be printed using the onboard printer immediately after scanning. Up to 400 or more joints can be tested by a crew of two in an 8-hr workday using MIT Scan-2.

With the availability of a practical, nondestructive means of measuring dowel alignment, questions are being raised as to the adequacy of the current standards on dowel placement tolerances. Recent investigations using MIT Scan-2 showed that many existing pavements contain at least a few significantly misaligned dowel bars, but with no apparent adverse effects on pavement performance. A national study is underway that is aimed at

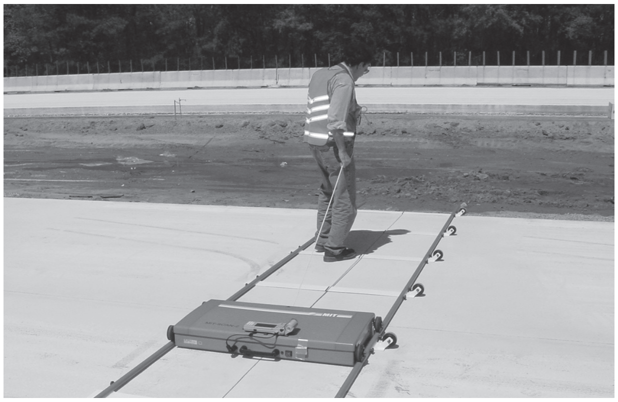

Figure 1. Dowel bar alignment testing using MIT Scan-2.

determining the dowel placement tolerance needed to ensure good pavement performance. This technical brief provides a summary of the current best practices on dowel placement tolerance, including the following key recent developments:

1. The Joint Score Rating system.
2. The percent-within-limit (PWL) specification for dowel bar tolerances developed by the Ministry of Transport, Ontario (MTO).
3. Acceptance criteria based on more in-depth consideration of pavement performance.

TYPES OF DOWEL MISALIGNMENT

Dowel bars need to be placed parallel to the pavement surface and to the longitudinal joint to enable free, uninhibited opening and closing of the joints. Temperature changes and initial drying shrinkage of concrete cause opening and closing of joints in jointed concrete pavements. The dowel bars should also be placed centered on the joint to ensure adequate embedment in both approach and leave slabs for load transfer. To ensure adequate concrete cover at slab (for both corrosion considerations and to avoid spalling), the bars should be placed near top and bottom of the mid-depth. The position of the bars along the joint is also important to ensure the bars are placed where they are needed to provide load transfer. Any deviations in dowel bar position from the ideal position may be defined as misplacement or misalignment. Figure 2 illustrates the possible types of dowel misalignments identified by Tayabji (1986).

In general, rotational misalignments (skew/tilt) impact the free joint movements, while translational misalignments (or misplacements) impact the effectiveness of individual dowel bars in performing the intended function (i.e., provide load transfer). The critical level of rotational misalignment is the level at which the joint may lock or the concrete around the bar may spall. The critical level of translational misalignment is the level at which the load transfer effectiveness of the dowel bar is adversely affected. In the case of depth error, the critical level is the acceptable minimum cover. In general, the margin for placement error is much greater on translational misalignments than on rotational misalignments. For example, the typical specification in the United States for longitudinal translation (or side shift) and vertical translation is 25 mm (1 in.), whereas the requirement on horizontal skew or vertical tilt misalignments is 6 to 10 mm (0.25 to 0.375 in.) for 450-mm (18-in.) dowel bars.

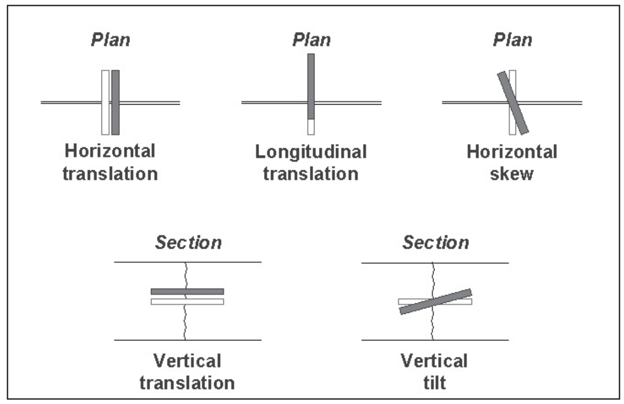

Figure 2. Types of dowel bar misalignment (Tayabji 1986).

EFFECTS OF DOWEL MISALIGNMENT

Dowel alignment has been of concern as early as the 1930s. During the late 1960s and 1970s, there was a moratorium on the use of the dowel bar implanters (an older version that used J-hooks) because of concern with excessive misalignment of dowel bars using these devices. The moratorium was exercised because of concerns with slab cracking as a result of misaligned dowels. During the mid-1980s, the new version of the implanters (now referred to as inserters) was introduced. Limited testing using the ground-penetrating radar device and coring at several projects during the late 1980s indicated that the inserters were capable of placing dowel bars generally within specified placement tolerances and that the inserter placement was comparable to basket placement.

Horizontal and vertical skew misalignments affect free joint movements. Consequently, dowel misalignment is often cited as the suspected cause when premature cracking or spalling occurs. While there are reported cases of extreme dowel misalignments causing failures shortly after construction, there are also many in-service pavements with poor dowel alignment that have not developed any visible distresses (Fowler and Gulden 1983; Yu 2005).

In laboratory studies, spalling and cracking have been produced, but the distresses developed only at displacements several times the magnitude of joint movements that typically occur in the field. The typical joint movement for 4.6-m (15-ft) slabs is 2–3 mm (0.08–0.12 in.), even in colder areas. In a recent study conducted by Michigan State University (Prabhu et al. 2006), displacements in excess of 17 mm (0.67 in.) were needed to produce spalling or cracking. The findings from the Michigan State University study (Prabhu et al. 2006) verified that the number of misaligned bars affects the pull-out force: the greater the number of misaligned bars present, the higher the force (per bar) needed to open the joint. The findings of laboratory studies suggest that both the magnitude of misalignment and the number of misaligned bars present at a joint may affect the potential for joint locking (as indicated by increased pull-out force).

Joint locking is certainly not desirable, but the performance of in-service pavements indicates that the presence of occasional, isolated, locked joints does not have any adverse effects on pavement performance (Yu 2005). Field performance also indicates that one consequence of very poor dowel alignment can be poor faulting performance. Severe dowel misalignment can cause stress concentrations, which can lead to socketing (funneling) with consequent loss in load transfer capacity.

JOINT SCORE RATING OF ROTATIONAL (SKEW) MISALIGNMENT

One limitation of existing specifications on dowel placement tolerances is that they do not fully consider the effects of dowel rotational misalignment on pavement behavior. The rotational misalignments govern joint movements. As such, a joint-by-joint evaluation is important in evaluating the potential impact of rotational misalignments on pavement performance. On short-jointed pavements, free joint movement is not necessary at every joint. In fact, pavement designs incorporating so-called "hinge joints" have been used on experimental pavements, with dowelled joints at every second or third transverse joint (Smith et al. 1997). Field studies have also shown that occasional locked joints have no adverse effects on pavement performance. However, many consecutive locked joints are not desirable, because of the potential for the buildup of restraint stresses in the locked group of slabs and excessive joint movements at the first working joint.

In one recent study, a simple, weighted-score system was used to conduct a joint-by-joint evaluation of dowel alignments (Yu 2005). The Joint Score, as defined in this evaluation, is a measure of the combined effects of misaligned dowel bars at a joint. Joint Score is determined by summing the product of the weights (given in Table 1) and the number of bars in each misalignment category and adding 1. For example, if a joint has four misaligned bars in the range of 15 to 20 mm (0.6 to 0.8 in.), the Joint Score is 9; if a joint has one misaligned bar in the range of 15 to 20 mm (0.6 to 0.8 in.) and one bar in the range of 25 to 38 mm (1.0 to 1.5 in.), the score is 8. A Joint Score of 10 is the critical level, above which the risk of joint locking is considered high.

Table 1. Weighting Factors Used to Determine Joint Score (Yu 2005)

Range of Misalignment*	Weight
10 mm < d < 15 mm (0.4 in. < d < 0.6 in.)	0
15 mm < d < 20 mm (0.6 in. < d < 0.8 in.)	2
20 mm < d < 25 mm (0.8 in. < d < 1 in.)	4
25 mm < d < 38 mm (1.0 in. < d < 1.5 in.)	5

d = deviation
*Resultant misalignment (square root of the sum of squares of horizontal and vertical misalignments).

ONTARIO'S DOWEL ALIGNMENT SPECIFICATION

As a result of poor dowel bar placement on a project during 2003, the MTO performed a review of their dowel bar alignment specification and conducted field testing to determine the dowel alignment levels being achieved in the field. During 2006, the MTO established a new set of requirements for dowel bar alignment (Lane and Kazmierowski 2006), as summarized below for 450-mm-long (18 in.) dowel bars.

Horizontal and vertical rotational alignments:
- Acceptable level: < 15 mm (0.6 in.)
- Rejection criterion: > 25 mm (1.0 in.)

Longitudinal shift:
- Acceptable level: < 40 mm (1.6 in.)
- Rejection criterion: > 50 mm (2.0 in.)

Depth:
- Acceptable levels:
  - 94 to 106 mm (3.70 to 4.17 in.) for 200-mm (8-in.) slab
  - 106 to 127 mm (4.17 to 5.00 in.) for 225-mm (9-in.) slab
  - 113 to 153 mm (4.45 to 6.02 in.) for 250-mm (10-in.) slab
- Rejection criterion: The rejection criterion is based on 75-mm (3-in.) concrete cover at the slab bottom and top and saw-cut depth that is typically one-third of slab thickness.

In addition to the acceptable and rejectable dowel bar alignment levels, the MTO also introduced the PWL provision to adjust the price paid on a lot basis. The PWL is computed for vertical and horizontal rotational alignments, longitudinal shift, and depth. The payment for each lot is based on the PWL. Also, irrespective of the PWL values, if any dowel bar is rejectable based on the above criteria, the entire transverse joint is removed and replaced using the full-depth repair procedure.

BEST PRACTICE

The available information on the effects of dowel misalignment suggests that dowel placement tolerances need to be re-assessed. The basic premise for the dowel bar tolerance requirements should be that while constructible requirements need to be established, the bars should be placed as accurately as possible. The dowel bars placed in accordance with the specification should not have any adverse effects on pavement performance. However, it is important to also recognize that there may be cases where even grossly misaligned dowel bars have no adverse effect on pavement performance (e.g., occasional, isolated, locked joint). In such cases, "do nothing" can be the best treatment option. These factors suggest the following approach for dowel placement specifications:

- Establish constructible acceptance criteria—No further evaluation is needed if the acceptance criteria are met. In general, dowel bars should be placed in proper alignment. This can be encouraged by establishing a relatively tight, but constructible, placement tolerance.
- Establish rejection criteria considering the effects on pavement performance—Determine the need for remedial action on joint locking based on joint-by-joint evaluation using Joint Score Rating; on embedment length, consider the location of dowel bars—additional allowance could be given for dowel bars outside the wheelpath.
- Establish either a PWL provision or a warranty program for dowel bars that do not meet the acceptance criteria but do not fall in the rejection region.

Acceptance Criteria

- Horizontal or vertical rotational alignment: <15 mm (0.6 in) over 450 mm (18.0 in.).
- Longitudinal (side) shift: <50 mm (2 in.) for 450-mm-long (18 in.) bars.
- Depth: mid-depth + 25 mm (1 in.).

Rejection Criteria

- Horizontal and vertical rotational alignment: Evaluate on joint-by-joint basis, using the Joint Score.
  - Isolated locked joints (as indicated by a Joint Score greater than 10) may be allowed, provided the adjacent joints have a Joint Score less than 10.
  - It may be permissible to allow up to two or

three consecutive locked joints (joints with Joint Scores greater than 10), depending on joint spacing and climate. Establish the maximum allowable consecutive locked joints based on maximum joint movement, not to exceed 5 mm (0.2 in.).

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

- Longitudinal (side) shift—
  - Reject any joints with fewer than three bars with a minimum embedment length of 150 mm (6 in.) under each wheelpath.
- Depth—
  - Reject any bar with the concrete cover above the bar less than 75 mm (3 in.) or the saw-cut depth.
  - Reject any joints with fewer than three bars with a minimum concrete cover below the bar of 75 mm (3 in.) in each wheelpath.
- PWL less than 50 percent—Evaluate PWL on the basis of both joints and individual bars.
  - Joints—A joint is within limit if the Joint Score is less than 10 and meets both the side-shift and depth criteria.
  - Individual bars—Individual bars are within limit if a bar satisfies the *Acceptance Criteria.*

The agency may allow the contractor to make repairs to bring the PWL above the 50 percent level. One of the factors that should be considered in determining whether the contractor may make repairs to bring the PWL above 50 percent is the acceptability of the presence of the cut ends of dowel bars (caused by repairs) that may corrode and cause spalling. Another factor is the number of retrofit dowel bars installed. An excessive number of retrofit dowel bars is not desirable on a new concrete pavement intended for a long life, especially for heavy traffic.

CORRECTIVE MEASURES

The following corrective measures may be considered for bars or joints that fail to meet the minimum standard as described by the *Rejection Criteria:*

- Horizontal or vertical misalignment.
  - Saw-cut the problem bars.
  - Retrofit dowel bars to ensure that at least three dowel bars are provided in each wheelpath that satisfy the *Acceptance Criteria.*
- Longitudinal (side) shift and missing bars.
  - Retrofit dowel bars to ensure that at least three dowel bars are provided in each wheelpath that satisfy the *Acceptance Criteria.*
- Depth error.
  - Inadequate cover over the bar—If the problem bar can be removed, remove the entire bar and retrofit replacement bars to ensure that at least three dowel bars are provided in each wheelpath that satisfy the *Acceptance Criteria.* If the problem bar cannot be removed, perform full-depth repair.
  - Inadequate cover below the bar—Retrofit dowel bars to ensure that at least three dowel bars are provided in each wheelpath that satisfy the *Acceptance Criteria.*

If PWL is less than 90 percent but greater than 50 percent, a pay adjustment or warranty of 15 or more years may be considered. Projects with PWL less than 50 percent are not acceptable according to the *Rejection Criteria.*

ONGOING RESEARCH

Many questions remain regarding the levels of dowel alignment tolerances needed to ensure good pavement performance. A comprehensive study is underway (NCHRP Project 10-69, Guidelines for Dowel Alignment in Concrete Pavements) that is aimed at answering those questions and developing improved guidelines on dowel placement tolerances. In the interim, the information provided in this technical brief may be utilized to develop practical, interim specifications.

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