

Effect of Dowel Bar Embedment Length on Joint Load Transfer Efficiency of MnROAD Concrete Pavement Test Cells

Thomas R. Burnham, P.E.

Abstract

It is well understood that for heavily loaded concrete pavements, the use of dowel bars across transverse joints can significantly improve their performance. To function effectively, dowel bars must be properly aligned and have sufficient embedment length to transfer load to the surrounding concrete. The use of new high accuracy dowel bar location equipment has brought renewed interest toward understanding reasonable construction tolerances for dowel bar alignment. The thirteen-year history of pavement performance data from the Minnesota Road Research (MnROAD) facility provides a unique opportunity to examine the effects of dowel bar alignment on joint performance. Specifically, this study investigated the effects of dowel bar embedment length on joint load transfer efficiency. Results of the analysis show that most test cells demonstrate little effect on the overall level and variability of LTE from dowel embedment lengths as low as 10 cm (4 in). Findings of this study could lead to important changes in construction specifications for dowel bar embedment length.

Introduction

It is well understood that for heavily loaded concrete pavements, the use of dowel bars across transverse joints can significantly improve their performance. Proper positioning of the dowel bars in relation to the transverse joint is paramount to that performance. Only with correct alignment and sufficient embedment length can a dowel bar transfer load to the surrounding concrete without causing damage. The final positioning of the dowels bars is determined both by the placement of the dowels during construction, and the creation of the transverse joint.

One method of measuring the performance of transverse joints in concrete pavements is by tracking the long term load transfer efficiency of the joints. Joint load transfer efficiency (LTE) is simply the measurement of how a tire load is transferred across a joint. Jointed concrete pavements typically begin life with very high load transfer efficiency values, and then as the pavement shrinks and experiences heavy vehicle loads, the load transfer efficiency gradually declines. Load transfer efficiency is affected by parameters such as slab shape and thickness, joint opening (available aggregate interlock), dowel bar size and alignment, and seasonal base layer support.

The Minnesota Road Research (MnROAD) facility was constructed in the early 1990's to study concrete and asphalt pavement performance (Minnesota Department of Transportation 2007). Long term monitoring and testing of the test sections at the facility has created a useful database of information about modern pavement performance, including load transfer efficiency trends for jointed concrete pavements. Readily available access to the test sections at the MnROAD facility provides unique opportunities to determine the physical aspects of each test section in detail. The measurement of dowel bar alignment is one example.

Many studies have examined the effects of the misalignment of dowel bars on concrete pavement performance (Burnham 1999, FHWA 2007, Lechner 2005, Teller and Cashell 1958, Weaver and Clark 1970). Most of the studies focused on the effects caused by vertical translation or rotational misalignment of the dowel bars. Much less emphasis has been placed on understanding the effects of dowel bar embedment lengths. Transverse joint performance can be reduced as a result of low dowel bar embedment length, which may be a result of dowel bar movement during paving, or by misalignment of the joint formation (sawing) in relation to the dowel bars.

An earlier study (Burnham 1999) on a pavement in Fergus Falls, Minnesota, revealed that dowel embedment lengths could be as low as 6.3 cm (2.5 in) and still maintain reasonable load transfer efficiency across a transverse joint. Similar results from laboratory testing of specimens with a 6.8 cm (2.6 in) dowel embedment length have been reported (Freudenstein 2001). Most transportation organizations, however, specify a minimum dowel embedment length of 7 inches for an 18 inch long dowel bar (Lane and Kazmierowski 2006). The Minnesota Department of Transportation has no specified criteria for minimum dowel embedment length, but has an available dowel bar embedment length of 190 mm (7.5 inches) for its standard 380 mm (15 inch) long dowel bars.

There can be many causes for low dowel embedment length in the field. Sawing of the transverse joints is often done at night, where it can be difficult to see the alignment marks painted on the grade adjacent to the new slabs. The baskets that the dowel bars are installed on are also prone to shifting during the paving process. While the current standard for Minnesota concrete pavement is the use of perpendicular (to traffic flow) transverse joints, the old standard (used at MnROAD) was skewed transverse joints. Informal investigations of other Minnesota concrete pavements with skewed transverse joints demonstrated that it was easy to find at least a few transverse joints on each project where the dowel embedment length ranged from low to nonexistent. Current standards of sawing perpendicular transverse joints should inherently decrease the frequency of lower dowel bar embedment lengths.

The thirteen-year history of pavement performance data from the MnROAD facility provides a unique opportunity to examine the effect of dowel bar embedment length on joint load transfer efficiency. This study focuses on six of the MnROAD interstate design concrete pavement test sections.

Research Significance

The recent availability and increasing use of new high accuracy dowel bar location equipment is bringing renewed interest toward understanding reasonable construction tolerances for dowel bar alignment. This study focuses on one aspect of dowel bar alignment, namely the minimum required embedment length for satisfactory long term joint performance. Findings of this study could lead to important changes in construction specifications for dowel bar embedment length.

Data Acquisition

MnROAD Test Sections

The data used in this study came from six of the jointed concrete pavement test sections at the MnROAD facility. The test sections are designated as Cells 6, 7, 9, 10, 12, and 13, and have been loaded by interstate traffic since August 1994. Design details for the

selected test sections are shown in FIGURE 1. Note that dowel bar diameters in the test sections range from 25 mm (1 in) to 38 mm (1.5 in), panel lengths vary from 4.6 m (15 ft) to 6.1 m (20 ft), and driving lane widths vary from 3.6 m (12 ft) to 4.3 m (14 ft). The transverse joints in each test cell are skewed 0.6 meters (2 ft) forward (near the shoulder, in the direction of traffic) for each 3.6 m (12 ft) of lane width.

As previously described, the test sections in this study have been open to interstate traffic and Minnesota's extreme climate since August 1994. The driving lane of these test sections has been loaded by over 11 million concrete pavement equivalent single axle loads (ESALs).

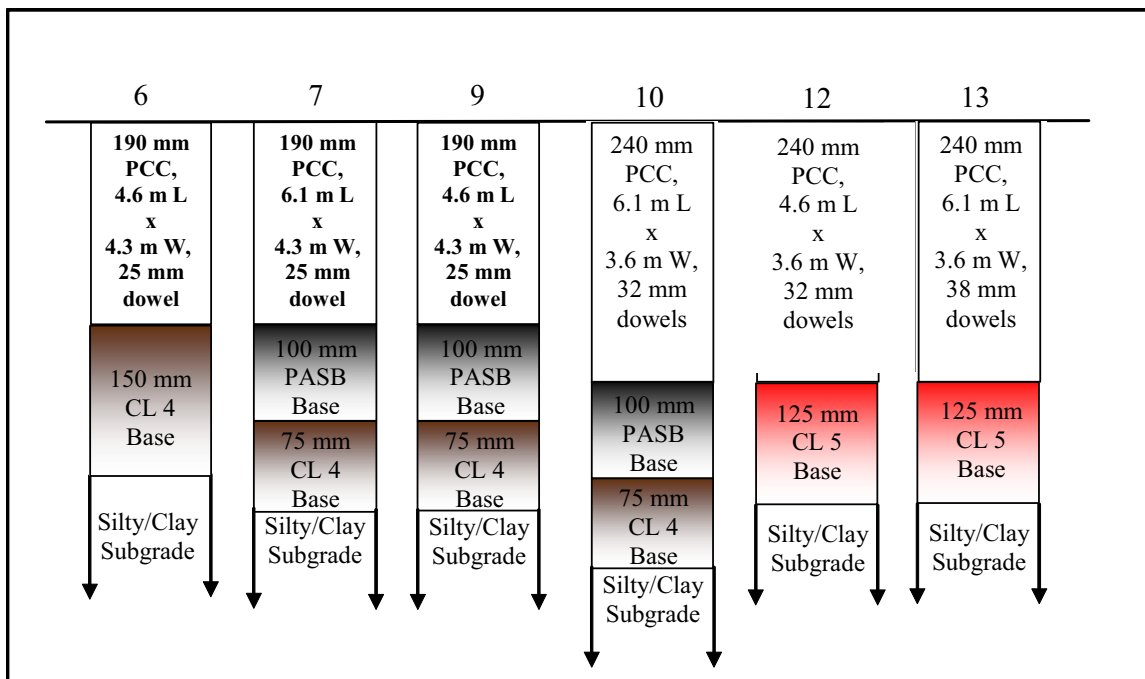


FIGURE 1 MnROAD concrete pavement test cell design details.

Dowel Bar Location Measurements

Measurement of the location of dowel bars in the MnROAD concrete test cells (in this study) took place in 1998. All of the dowel bars are epoxy-coated steel and have a length of 380 mm (15 in). See FIGURE 2 for information showing dowel bar details and slab identification.

To locate the dowel bars, a pulse induction metal location device was used to closely estimate the lateral and longitudinal locations of at least 4 dowels (per lane) within each transverse joint. Longitudinal dowel bar embedment length measurements were referenced to the approach panel side of the joint. Vertical and horizontal rotation of the dowels was not measured, but significant rotation was not noted (or expected) during the location process, as the dowels are mechanically secured to support baskets.

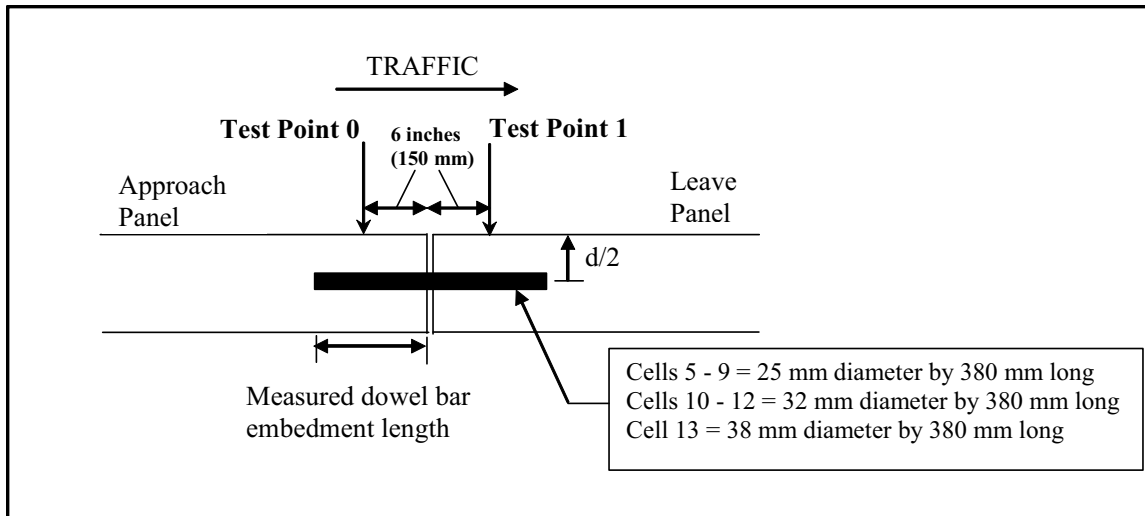


FIGURE 2 Dowel bar and slab testing details for study.

Load Transfer Efficiency Testing

Since 1994, all MnROAD concrete pavement test cells have been periodically tested for transverse joint load transfer efficiency using a Falling Weight Deflectometer (FWD) device. Within each test cell, five transverse joints in each lane were selected as routine test locations. Additional test points identified as having lower dowel embedment lengths were also tested several times in 1998-2000, and again in 2007.

To determine joint load transfer efficiency, FWD testing was conducted at test points located 150 mm (6 in) on either side of the joint in the outside wheelpath of each lane. See FIGURE 2 for identification and location of the LTE test points. The FWD loading pattern consisted of three drops at each load level load of 26.6 kN, 40 kN, and 66.7 kN (6000, 9000, 15000 lbs). A 12-inch diameter FWD load plate was used. During the testing, air and pavement surface temperatures were captured by infrared sensors on the FWD device. Internal slab temperature data from embedded thermocouple sensors was also collected for each test cell, and were used to verify and supplement the FWD readings. Testing was typically done at temperatures conducive to load transfer efficiency testing [recommended by AASHTO to be less than 26° C (80° F)(AASHTO 1993)], however LTE testing also occurred at higher slab temperature conditions, which often resulted in artificially elevated LTE values.

Data Analysis

Embedment Length

As previously mentioned, an individual dowel bar embedment length depends on a number of factors, mostly determined during the construction process. Dowel bars can shift within a support basket, a support basket can move due to poor anchorage, or the joint sawing operation can cause longitudinal misalignment.

Before the effect of dowel bar embedment length on LTE is examined, it is useful to understand the typical variation in embedment length. FIGURE 3 shows a histogram of dowel bar embedment lengths for transverse joints in the MnROAD test cells considered in this study. With a Mn/DOT design embedment length of 19.1 cm (7.5 in),

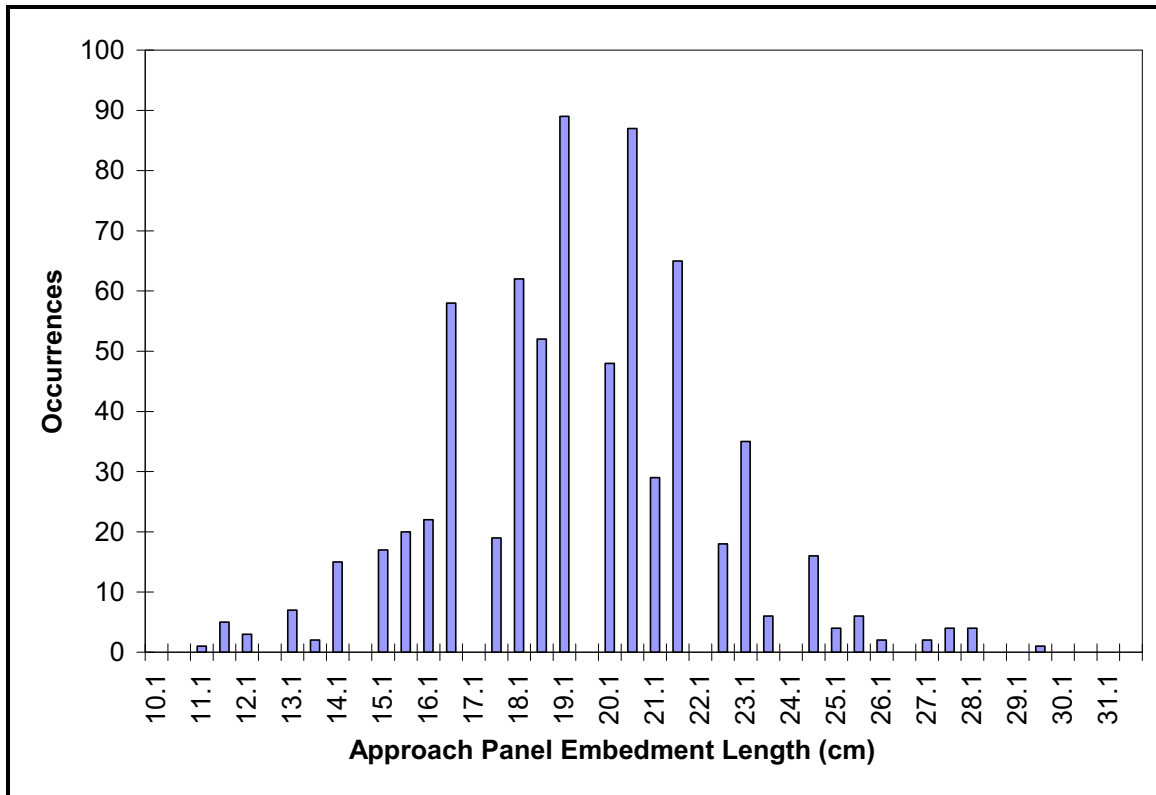


FIGURE 3 Distribution of dowel bar embedment lengths (into approach panel) for MnROAD test cells 6, 7, 9, 10, 12 and 13. Mn/DOT design embedment length is 19.1 cm (7.5 in). (1 inch = 2.54 cm)

the statistical distribution appears approximately normal. For this study, embedment lengths less than 16.5 cm (6.5 in) were categorized as “low embedment.” The lowest embedment length measured in the test cells for this study was 11 cm (4.3 in).

LTE Calculations

Joint load transfer efficiency (LTE) values in this study were determined using the method outlined in Section 3.5.4 of the *1993 AASHTO Guide for Design of Pavement Structures* (AASHTO 1993). Equation 1 was used for the analysis,

$$d_{je} = \frac{d_u}{d_l} \times 100 \quad (1)$$

where d_{je} is the load transfer efficiency in percent, d_u is the deflection near the joint of the unloaded slab, and d_l is the deflection near the joint of the loaded slab. Slab bending and panel warp and curl correction factors were neglected during the analysis. Only the right (or driving) lane LTE trends were examined in this study.

Data for this study came from 2 sources. The first source was five routine testing locations (2 test points at each joint) within each test cell, with a LTE history going back to 1994. The second source was additional joints tested periodically since 1999. The additional test points included joints with dowel bars embedded to the design specified length, as well as joints with lower dowel bar embedment lengths.

During the analysis, LTE data was first determined for individual test locations and test points. For each test point 0 and 1 near each joint tested, EQUATION 1 was then used to calculate the LTE using the average of three measured FWD deflection basins for a 40 kN (9000 lb) load sequence. Once the LTE calculations were complete, the data were plotted to observe overall trends. FIGURES 4 and 5 demonstrate the change in LTE with time for test cells 6, 7, 9 and test cells 10, 12, 13, respectively. The data shown in the figures is for 40 kN (9000 lbs) loading on the approach panel side of joints and dowel bar embedment lengths near the specified design length of 19 cm (7.5 in). Expecting a decline of LTE with time, it is readily apparent from FIGURES 4 and 5 that many LTE tests were conducted when slabs were experiencing expansion due to high internal temperatures and/or moisture, therefore leading to artificially elevated LTE values. This led to the decision to more closely examine the LTE trends and behavior during fall time periods, when temperatures and moisture in the slabs are lower and more consistent from year to year. In fact, supplemental testing was carried out in the fall of 2007 to gather additional data that would best represent the current level of LTE within the joints. LTE data from fall testing periods was extracted from the overall data and plotted in FIGURES 6 and 7.

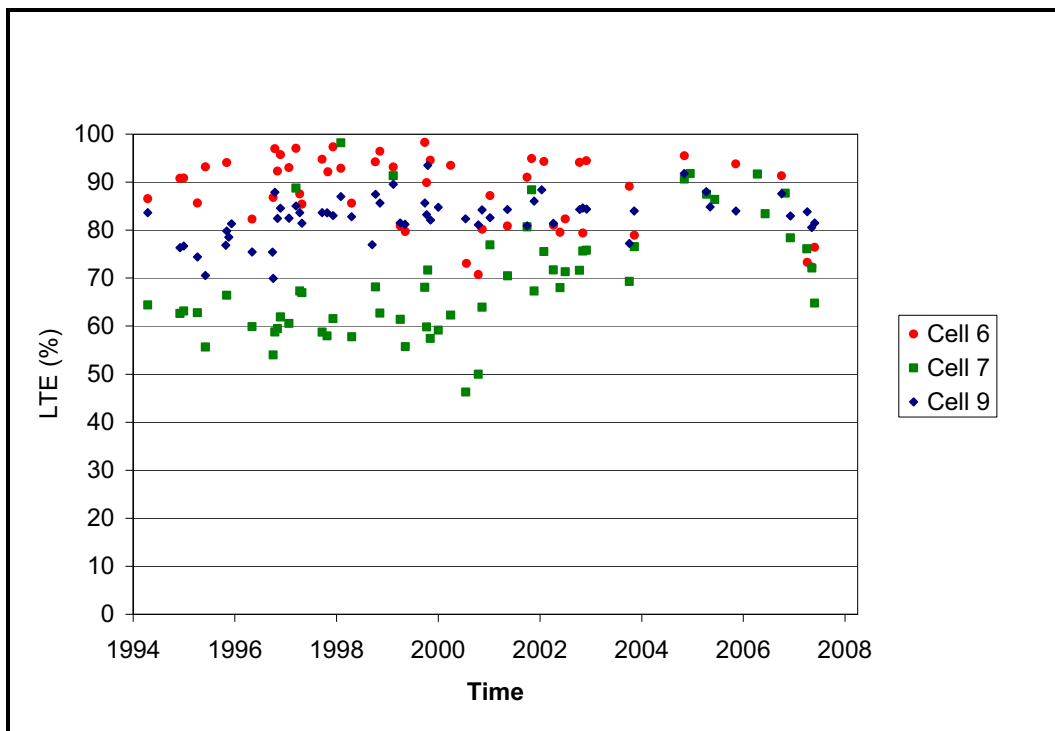


FIGURE 4 History of LTE for MnROAD test cells 6, 7, 9. Data for test point 0, FWD load=40 kN (9000 lbs), design (19 cm) dowel embedment.

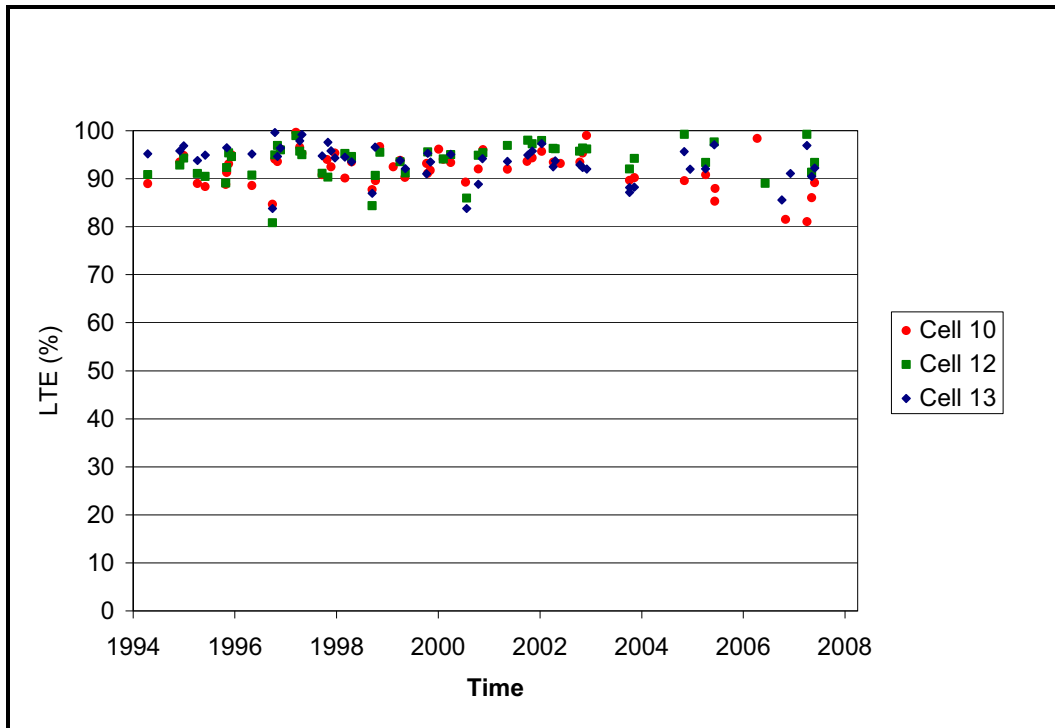


FIGURE 5 History of LTE for MnROAD test cells 10, 12, 13. Data for test point 0, FWD load=40 kN (9000 lbs), design (19 cm) dowel embedment.

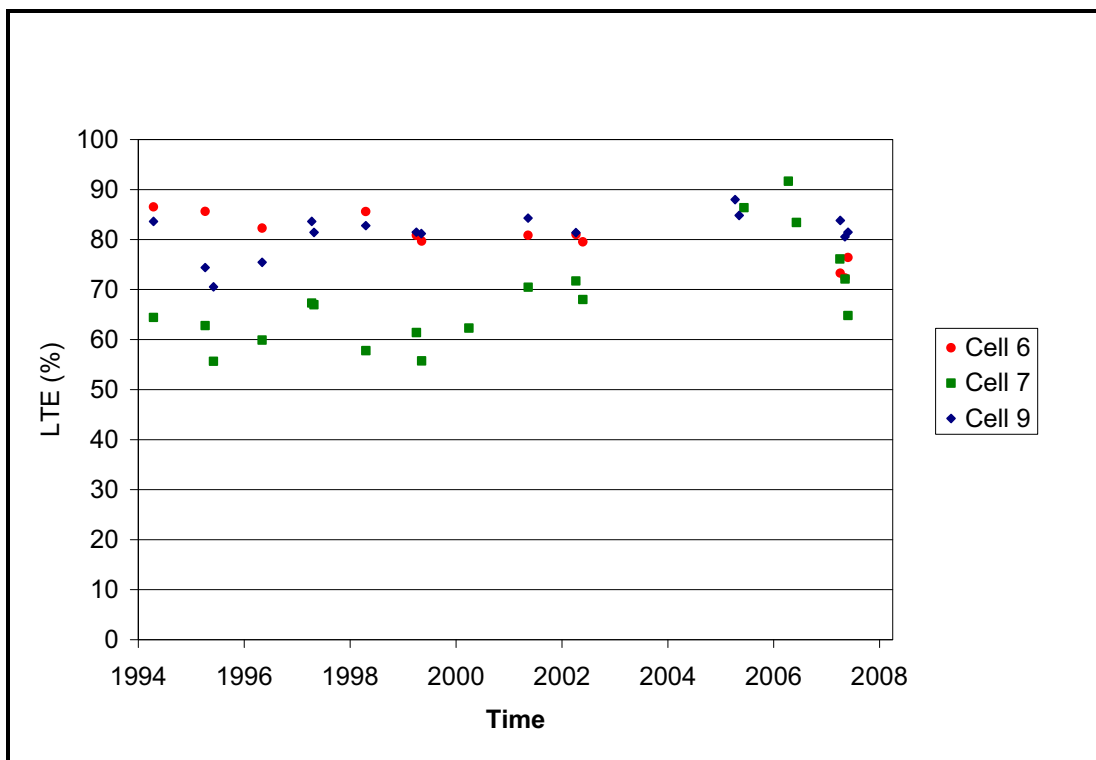


FIGURE 6 LTE data during fall time periods for test cells 6, 7, 9.

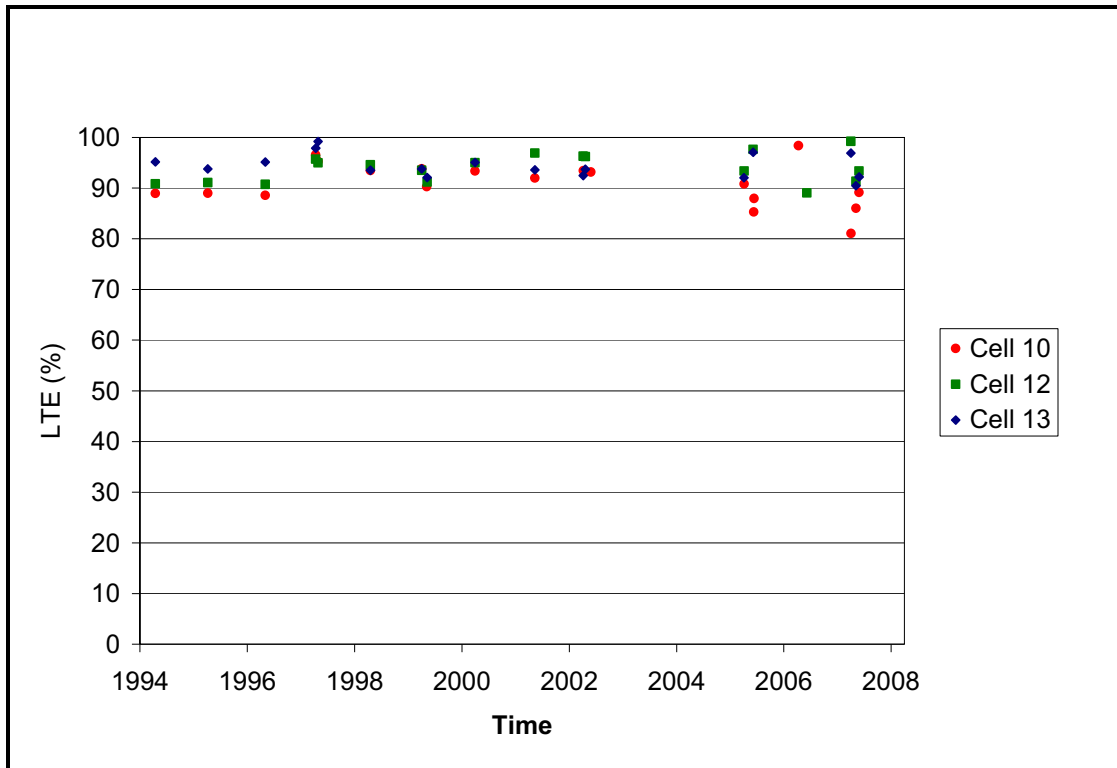


FIGURE 7 LTE data during fall time periods for test cells 10, 12, 13.

One interesting trend in LTE was demonstrated by test Cell 7. While other test cells exhibited higher LTE values early in life, followed by a decline in LTE with time, test cell 7 began with fairly low LTE values. Test cell 7 then exhibited a more constant, if not cyclic, behavior in LTE with what appears to be an increase in LTE with time. Initial thoughts are that the behavior may be influenced by panel length or base type, although test cell 9 has the same base type (but a different panel length). Future forensic investigations of test cell 7 may reveal some answers on whether the condition of the PASB (permeable asphalt stabilized base) has changed with time and is influencing transverse joint LTE behavior. Despite the lower levels of LTE exhibited in test cell 7, joint faulting still remains at very low levels, as in most other MnROAD interstate traffic loaded test cells.

As shown in FIGURE 7, the LTE trends for test cell 10 also stand out from similar thickness test cells 12 and 13. Similar to test cell 7, test cell 10 exhibited slightly lower LTE throughout its life (compared to cells 12 and 13). More recently however, the trend in test cell 10 shows signs of a more rapid decline in LTE with time. Both test cells 7 and 10 have a PASB base layer and 20 foot panel lengths. More evidence will be gathered in the future to determine if these physical parameters are affecting LTE behavior, or whether it is coincidental.

Embedment Length vs. LTE

Utilizing joint load transfer efficiency values from LTE testing performed in September, October and November 2007, the effect of dowel bar embedment length on LTE was examined. FIGURES 8-13 show the results from LTE testing with a 40 kN (9000 lbs) FWD load. In each figure, the solid vertical line indicates the design specified

embedment length of 19.1 cm (7.5 in). The dashed lines indicate the ± 25 mm (± 1 in) longitudinal misalignment tolerances, below (and above, depending on which side of the joint is loaded) which this study defines as “low embedment.”

Before the trends shown in the figures are discussed, it must be noted that the observations stated are strictly empirical, as it was determined there was insufficient data to perform statistical analyses, and the scope of this study did not include the development of a LTE versus dowel bar embedment length model.

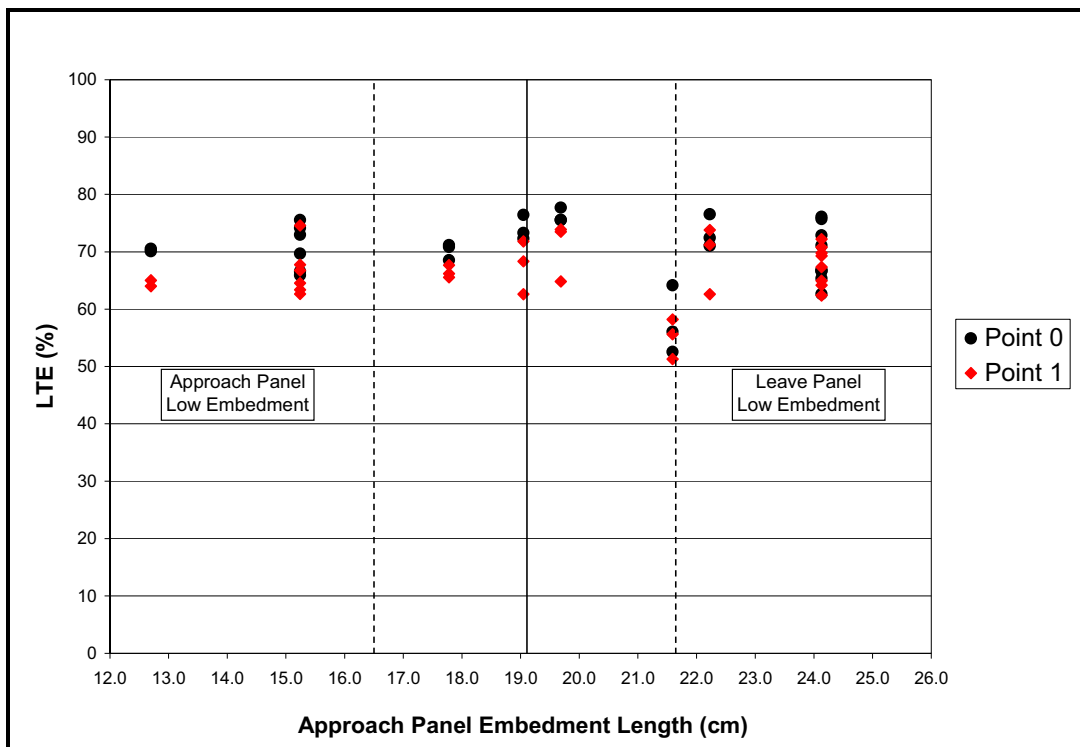


FIGURE 8 LTE for various dowel bar embedment lengths (into approach panel) as measured on MnROAD test cell 6 during the fall of 2007. Specified design embedment length is 19.1 cm.

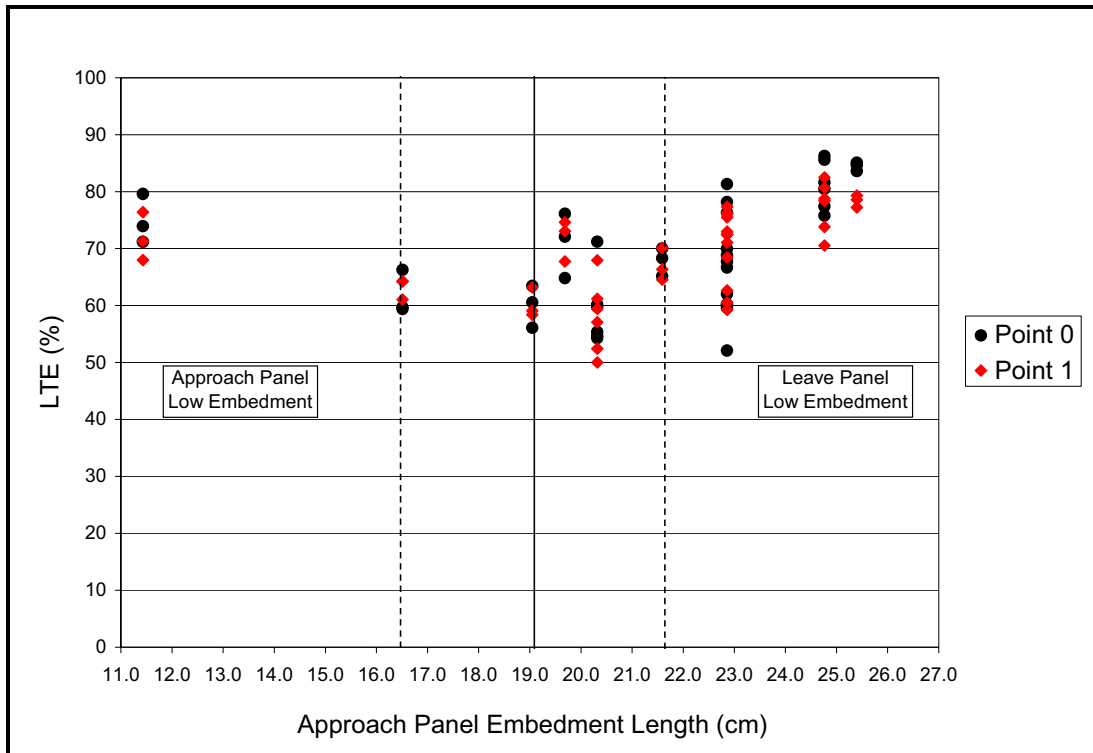


FIGURE 9 LTE for various dowel bar embedment lengths (into approach panel) as measured on MnROAD test cell 7 during the fall of 2007.

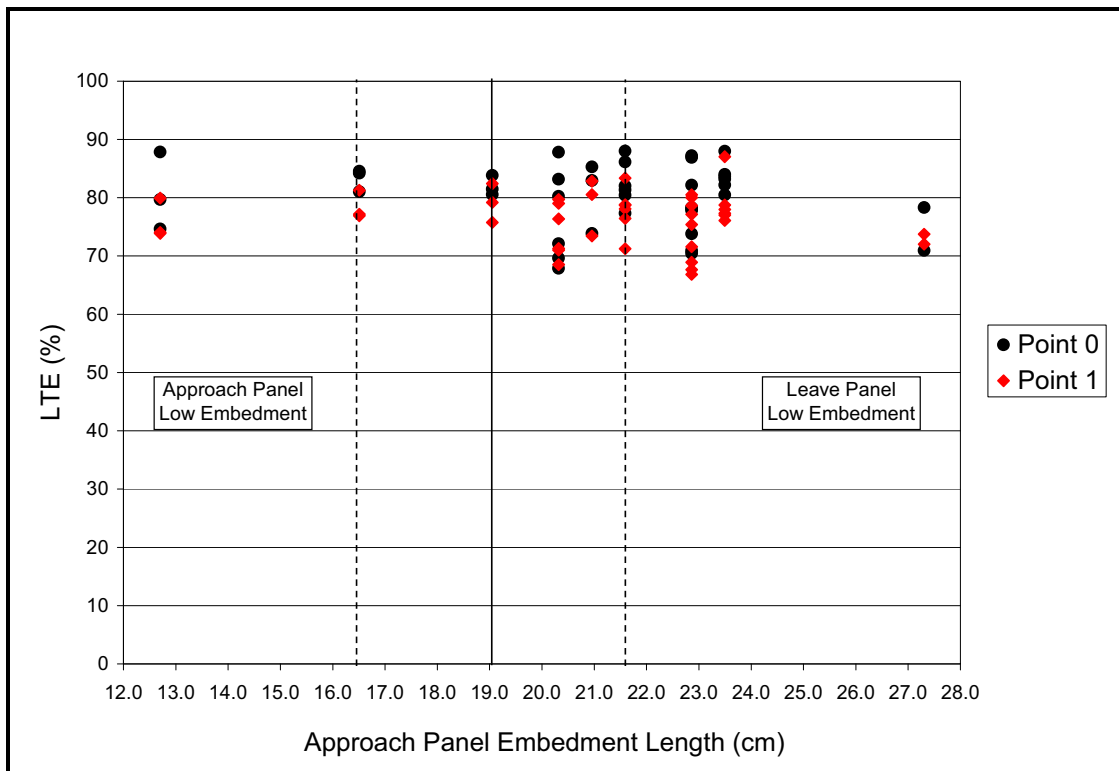


FIGURE 10 LTE for various dowel bar embedment lengths (into approach panel) as measured on MnROAD test cell 9 during the fall of 2007.

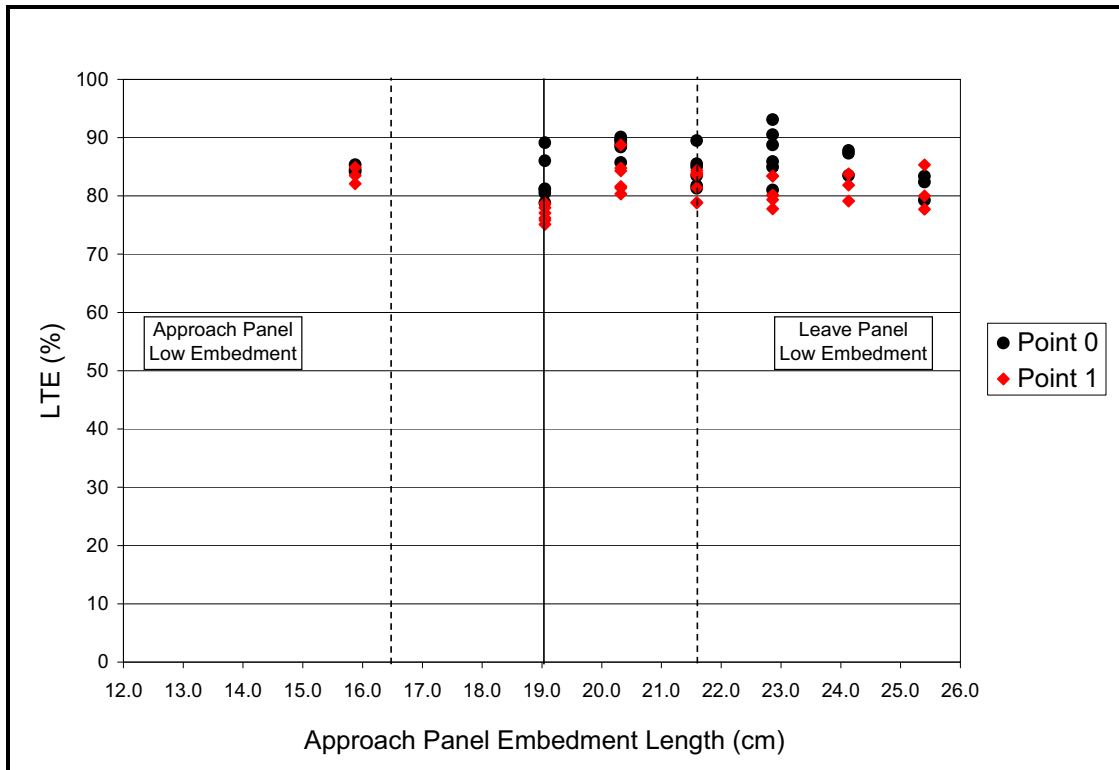


FIGURE 11 LTE for various dowel bar embedment lengths (into approach panel) as measured on MnROAD test cell 10 during the fall of 2007.

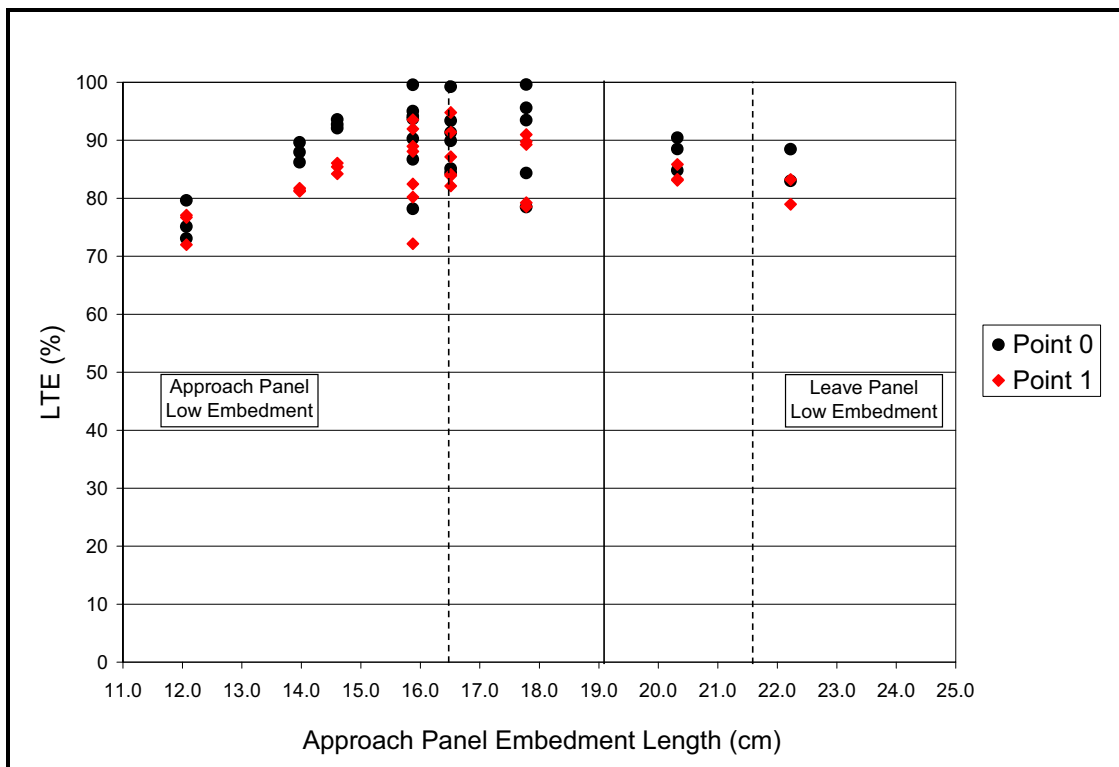


FIGURE 12 LTE for various dowel bar embedment lengths (into approach panel) as measured on MnROAD test cell 12 during the fall of 2007.

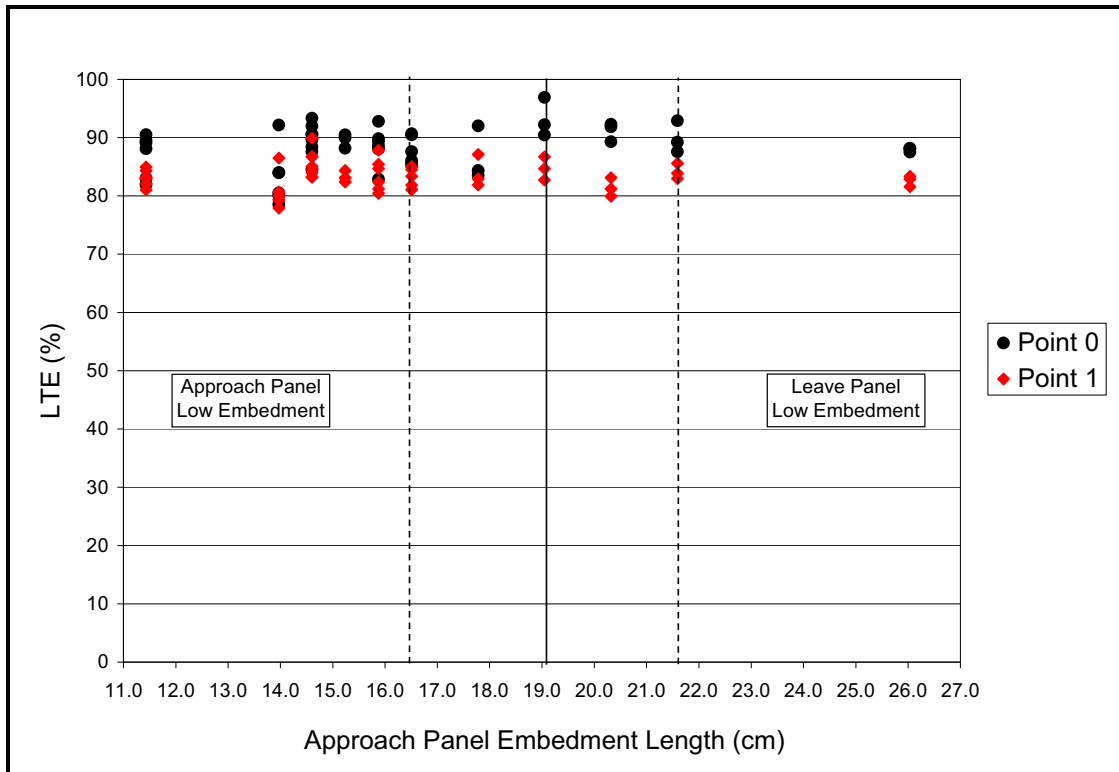


FIGURE 13 LTE for various dowel bar embedment lengths (into approach panel) as measured on MnROAD test cell 13 during the fall of 2007.

The results of the analysis show that for test cells 6, 9, 10, and 13, there is little effect on the overall level and variability of LTE from lower dowel embedment lengths alone (for the range of embedment lengths available at MnROAD). This observation is regardless of whether the load is applied on the approach or leave side of a joint.

Just as the overall trend of LTE with time for test cell 7 exhibited a different trend than other test cells (see FIGURE 6), cell 7 also showed a unique trend in LTE versus dowel bar embedment. FIGURE 9 shows that in test cell 7, LTE values actually trend higher with decreasing dowel bar embedment lengths, although there appears to be much higher variability in the LTE values than other test cells. Whether the behavior is a perhaps a function of panel size, or even built-in slab warp and curl, future research will be required to ascertain the more complex characterization that is needed to identify the causes.

Test cell 12 exhibits an opposite trend to test cell 7. As shown in FIGURE 12, the LTE in test cell 12 is noticeably lower for the approach panel embedment length of 12 cm (4.75 in). Given the variability of the LTE at other embedment lengths, particularly at 16 cm (6.25 in), it was unclear however, whether the LTE trend was consistent. The LTE values on the right side of FIGURE 12 indicate that lower dowel bar embedment lengths into the leave panel behave similarly to test cells 10 and 13.

As a side observation, for most of the test cells in this study, FWD loads applied to the leave panel (test point 1) yielded slightly lower load transfer efficiency values than for approach panel (test point 0) loading.

Conclusions and Recommendations

Data from six interstate traffic loaded MnROAD concrete pavement test cells was used to determine the effects of dowel bar embedment length on joint load transfer efficiency. Plots of LTE testing results over 13 years revealed that more consistent trends in LTE could be observed if results from fall testing periods were examined.

Utilizing joint load transfer efficiency values from LTE testing performed in September, October and November 2007, the effect of dowel bar embedment length on LTE was observed. Results of the analysis show that for the range of embedment lengths available at MnROAD, most test cells demonstrate little effect on the overall level and variability of LTE from lower dowel embedment lengths alone. Exceptions to the observed trends will need to be addressed in future related research, however may be attributed to the highly variable nature of the vertical and horizontal profile of transverse joints.

Given that the lowest measured dowel bar embedment length in this study was 11 cm (4.3 in), there is a need for more focused field research studies examining a range of dowel bar embedment lengths, especially down to the critical lengths as determined in previous studies (6 cm [2 in]). Additional LTE testing, especially during fall time periods, will continue to be performed on MnROAD test cells to support such future studies.

The recent availability and increasing use of new high accuracy dowel bar location equipment is creating a need for defining reasonable construction tolerances for dowel bar alignment. This study has shown that dowel embedment length specifications need to acknowledge the insensitivity of dowel embedment length on LTE performance, at least with embedment lengths as low as 10 cm (4 in). Of course other important parameters, such as available aggregate interlock, seasonal base support, and rotational misalignment of dowel bars, need to be examined in how they affect joint load transfer efficiency. Many studies (example: NCHRP 10-69) are currently underway to address those issues, which should further the understanding of transverse joint behavior in concrete pavement.

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Disclaimer

The contents and opinions presented in this paper are those of the author, who is responsible for the facts and accuracy of the data. The contents do not necessarily reflect the views or opinions of the Minnesota Department of Transportation.

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