

Field Investigation of Dowel Misalignment and Potential for Joint Lock-Up

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Abstract

A field investigation was performed to determine the impact of dowel misalignment on joint movements and potential for joint lockup on a section of a newly constructed concrete pavement in Florida. This section of the pavement exhibited various types and degrees of dowel misalignment. Lacking a widely accepted rejection criteria, the joint score methodology published by the Federal Highway Administration (FHWA) was used to identify joints that were considered problematic. Joint scores were computed for each of the joints as indicated in the procedure. The scores generally ranged from 1 to 40 with a joint score of 1 indicating perfectly aligned dowel bars at a joint and 40 indicating a joint with a high degree of misalignment in multiple bars. The rejection criteria were initially planned to be based on the Joint Scores, however, based on a meeting between the owner, the designer, and the builder, a novel approach to arriving at the criteria based on direct measurements of the joint movements in the field was followed. This approach included measuring movements of joints with severely misaligned dowels and well-aligned dowels over a 48-hour period. The resulting data showed unexpected but conclusive evidence that suggested that more work needs to be done in establishing rejection criteria and corrective actions when dowel misalignment is detected in the field.

Introduction

Joints are essential features of jointed plain concrete pavements (JPCP) that help relieve thermal and moisture induced stresses. At the same time, they are the weakest links in concrete pavement performance, experiencing higher stresses and deflections when compared to the interior parts of the slab for the same loading conditions. Modern JPCP design calls for dowel bars to be placed across transverse joints to allow for traffic wheel load (moment) transfer across slabs while at the same time allowing for unrestricted slab expansion and contraction due to the prevailing temperature and moisture conditions. The improved load transfer also reduces slab corner deflections relative to undoweled joints. These beneficial effects provided by dowel bars help increase pavement life by reducing the potential for pumping, base erosion and faulting, and providing greater smoothness over the lifetime of the pavement. These benefits have been demonstrated time and again by many pavement studies (e.g., American Association of State Highway Officials [AASHO] Road Test and the Long Term Pavement Performance [LTPP] studies) to the extent that some consider the pumping and joint faulting issues as being completely resolved if properly sized dowel bars are incorporated into the pavement structure.

To realize their potential benefits, it is generally agreed upon that dowels must be parallel to both the centerline and the surface of the pavement, and also be centered across the transverse joint. Any deviation from such an orientation is termed as dowel misalignment. The potential adverse effects of poor dowel placements include:

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- Poor load transfer efficiency (LTE) and poor long-term faulting performance (if displaced towards bottom of slab or out of joint).
- Joint spalling (from excessive steel/concrete bearing stresses).
- Slab cracking (from joint lockup or restraint).

The following major categories of dowel misalignment were identified by Tayabji (1986) (see figure 1):

- Horizontal translation.
- Longitudinal translation.
- Vertical translation.
- Horizontal skew.
- Vertical tilt.

Most agencies have fairly strict tolerances on dowel alignment (typically less than 1/4 in end-to-end horizontal skew or vertical tilt), but those standards are based on limited laboratory and field data. In some cases, the manufacturing tolerances for dowel baskets are adopted directly as the dowel placement tolerance (ACPA 2006). However, the magnitude of dowel placement inaccuracy, particularly dowel horizontal skews and vertical tilts inaccuracy at which it affects joint movements and hence pavement performance is not well known.

Dowels are placed in concrete using dowel baskets or dowel bar inserters (DBIs). Dowel baskets are carriages designed to support or link dowel bars and to hold them in the desired alignment during concreting operations. DBIs insert dowel bars into the fresh concrete as part of the paving operation, thus eliminating the need for manually placing dowel bar baskets. However, because of apparent concerns over dowel alignment and positioning, DBIs are not as widely used in the U.S. as baskets. Some highway agencies specifically prohibit their use, although DBI can offer significant advantage in construction cost and speed. The lack of a practical means of verifying the alignment and position of the DBI installed dowel bars to allay the apparent concerns has prevented the wider use of these devices. However, the advent of the MIT Scan device to detect the alignment of in place dowels has helped in this regard. The use of DBIs for dowel bar installation as well as that of the MIT Scan device to detect dowel alignment has become more prevalent.

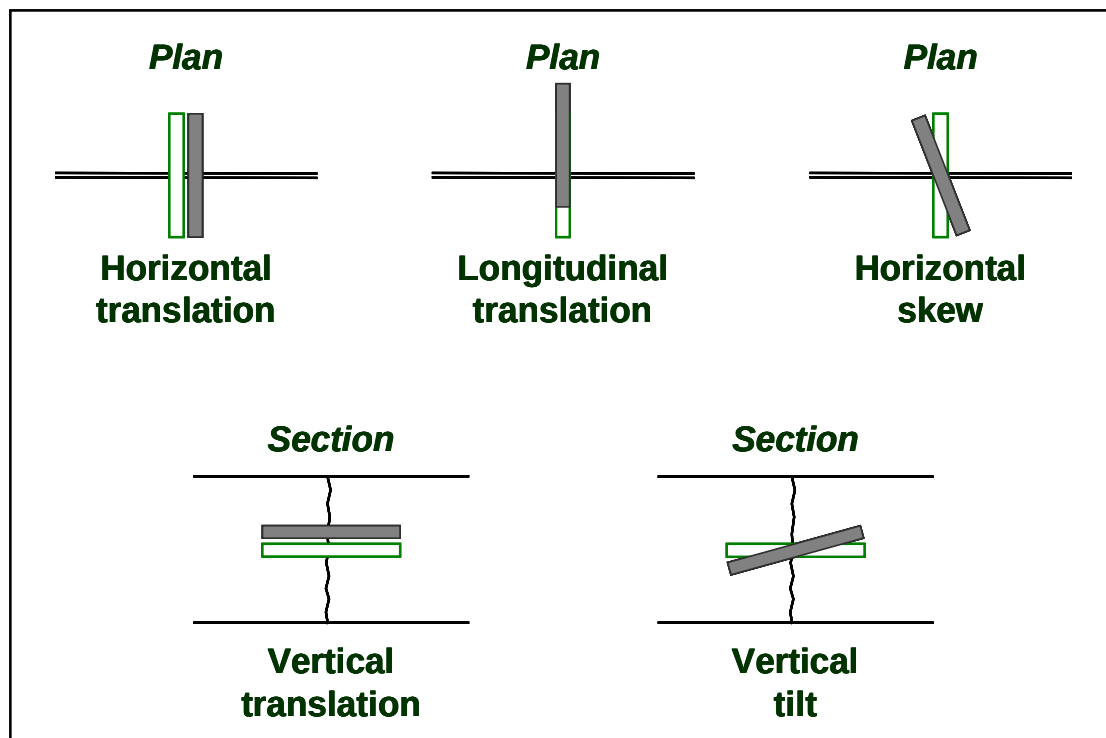


Figure 1. Types of dowel misalignment (from Tayabji, 1986).

In recent years, the MIT Scan has been increasingly used by various highway agencies and paving contractors for evaluating dowel alignment in JPCP. Numerous evaluations of the accuracy of MIT Scan have shown the device to be a reliable tool for locating dowels with high accuracy for dowels inserted with dowel baskets with cut transport tie wires or DBIs (Yu and Khazanovich 2005). The accuracy of the device was confirmed in studies by Hossain and Elfinio (2006) in Virginia as well as Leong et al. (2006) in Ontario. The efficiency and ease of use of the device was also found to be robust for application to investigations that require large amounts of measurements in a wide range of environments (FHWA 2007). The robustness of the device prompted the Federal Highway Administration's (FHWA's) Concrete Pavement Technology Program (CPTP) to initiate a loan program encouraging implementation of this technology. The device has been identified by the FHWA as a practical, implementation-ready product that has the potential to improve quality of concrete pavements (FHWA 2005).

The increased use of MIT Scan has, however, also brought into focus the issue of how much misalignment is acceptable for agencies. Agency dowel alignment tolerances set prior to a good understanding of field achievable tolerances and the "real world" realization of misalignment on pavement performance are being scrutinized since they were being used for acceptance. This has launched a renewed interest into dowel misalignment research including laboratory and field studies. Some examples include NCHRP Report 637 (Khazanovich et al. 2009), Leong et al (2006), Milind et al. (2006), and ACPA (2006). These studies have contributed a significant amount of understanding on how dowel alignments impact joint movements through laboratory or analytical work and the impact of misalignment on long-term field performance of pavements (e.g., faulting, cracking, and spalling).

Past Research on Dowel Misalignment

Field studies (ACPA 2006, Khazanovich et al. 2009) have shown that slab or joint distress may not always occur as a result of dowel rotations (horizontal skews and vertical tilts). Khazanovich et al. (2009) observed that within the non-extreme limits of dowel rotations measured in their study, there were no differences in the amounts of transverse cracking and joint spalling observed as a result of dowel rotations. The ACPA study (2006) observed that projects with a significant number of misaligned bars performed well without showing any signs of distress after 8 or more years of service under heavy traffic suggesting that a limited amount of misaligned bars in concrete pavement joints may be tolerable. One project constructed in 1977 on I-20 in Georgia, and surveyed and cored by Fowler and Gulden (1983) has performed well for over 25 years despite the prevalence of significantly rotated dowel bars.

Laboratory investigations in the form of slab pullout tests were conducted by some researchers (e.g., Khazanovich et al. (2009), Prabhu et al., (2006) and Tayabji (1986)) to model the effects of severely misaligned dowel bars on joint behaviour during joint movement. Although the exact test configuration varied, multiple bars were tested together in all cases to represent a joint. The general observations from these tests were that the force required displacing the dowel increased with increasing misalignment. When the bars were misaligned non-uniformly, a greater amount of pullout force was required and showed greater amount of cracking as compared to joints with bars that were uniformly misaligned. Slabs developed cracking only at significant misalignment levels (over $\frac{3}{4}$ in) when the alignment of dowels along the joint was non-uniform and when excessive levels of joint opening were present (over $\frac{1}{2}$ in). Minor spalling around dowels was observed in slabs with significant misalignment. Further, Khazanovich et al. (2009) observed that dowel rotations of up to 2 in (end-to-end) length have a negligible effect on pullout and shear performance measures.

However, despite the laboratory and field studies completed to date, there is still a significant dearth of guidance, especially on setting up effective construction specifications, on how to resolve specification non-compliance when dowel misalignment is encountered in the field. Practical questions such as the ones noted below are still unanswered.

- Do one or two severely misaligned bars at a joint have the same impact as several bars with minor misalignment?
- Do misaligned bars in the wheel path have the same impact as those outside the wheel path?
- Does one out-of-compliance joint warrant corrective action? As a corollary, how many consecutive joints need to be misaligned before joint distress is evident?
- What is the best corrective action in the when misalignment is detected? Is slab removal and replacement always the appropriate solution?

The Federal Highway Administration's (FHWA's) Technical Brief FHWA-HIF-07-021 (FHWA 2007) provides some guidance in this regard. It proposes the use of a Joint Score which 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 empirically assigned to each degree of misalignment from experience (see Table 1) and the number of bars in each misalignment category and adding 1 (FHWA 2007; Yu 2005).

The Joint Score gives an indication of locked joints and an evaluation on this basis is a step in the right direction. However, it does not provide a conclusive proof that the joints are indeed locked. Hence a more direct method to investigate if a joint is locked or not is needed before corrective action can be taken.

Table 1. Weighting factors used to determine Joint Score (from Yu 2005).

Range of Misalignment*	Weight
0.4 in < d < 0.6 in	0
0.6 in < d < 0.8 in	2
0.8 in < d < 1 in	4
1.0 in < d < 1.5 in	5
d = deviation	
*Resultant misalignment (square root of the sum of squares of horizontal and vertical misalignments).	

Study Objectives

This paper presents the results of a field investigation performed to determine the impact of misalignment on joint movements and potential for joint lock-up on a section of newly-constructed concrete pavement on I-95 near Cocoa Beach in Florida that had not yet been open to traffic. This section of the pavement exhibited various types and degrees of dowel misalignment as determined by the MIT Scan device. Some of the joints in this pavement section exhibited dowel misalignments that were greater than Florida Department of Transportation's (FDOT's) specification limits. FDOT specifications currently allow for maximum end-to-end alignment tolerance of 13 mm (0.5 in) in both the horizontal skew and the vertical tilt. Lacking clear national consensus on the corrective measures to be applied, FDOT and the contractor agreed to not just rely on Joint Scores for remedial action but go forth with a unique field test to investigate the joint openings of the various affected joints to understand the impact of the problem and to help arrive at potential resolution to the issue. The uniqueness of the approach embarked upon is that, while several other parameters were evaluated to understand the impact of dowel misalignment on joint and pavement performance, to the best of the authors' knowledge, there has not been a direct field experiment that attempts to relate different types of dowel misalignment with joint opening. Joint opening measurement is relatively simple to conduct and can be used during construction to balance the risk between the owner and contractor. It also provides an insight into potential long-term problems.

Evaluation Plan

The section of the pavement under investigation was a 13-in thick jointed plain concrete pavement (JPCP) being constructed as part of a design-build project. DBIs were used on this project to insert 1.5-in diameter 18-in long greased epoxy-coated dowel bars. Joint Scores were computed for each of the joints as indicated in the procedure outlined in FHWA-HIF-07-021 (FHWA 2007). The scores generally ranged from 1 to 40 with a joint score of 1 indicating a perfectly aligned joint and 40 indicating a joint with a high degree of misalignment in multiple bars.

At a meeting held on March 31, 2008, at the contractor's offices, the owner, owner's representative, the designer, and builder discussed the issue of joint scores and their potential impacts on joint movements to see if high joint scores necessarily cause joint lock-up. It was agreed upon at this meeting that joint movements would be measured on a representative set of joints of the affected pavement over a 24-hour

cycle to establish the impact of various types of dowel misalignments on joint movements. The following sections document the methodology used to determine joint movements.

Test Methodology. Joint movements were measured in general compliance with the methodology used by the LTPP Seasonal Monitoring Program's *Instrumentation Installation and Data Collection Guidelines*. This is a well established procedure which used to measure movements at transverse joints across various concrete pavement sections in the country as part of the LTPP program. Data from this program can be found in a table named MON_JOINT_GAGE_DATA of the LTPP database published by the Federal Highway Administration (FHWA).

The procedure begins with drilling $\frac{1}{2}$ in diameter holes with approximately a $\frac{1}{2}$ in recess on both sides of a transverse joint at mid-panel length and near the corners of the slab. One-half inch brass snap rings are then inserted into the drilled holes so that they are situated approximately, 0.375 in below the pavement surface. Figure 2, taken from the LTPP guidelines, and shows the typical snap ring installation.

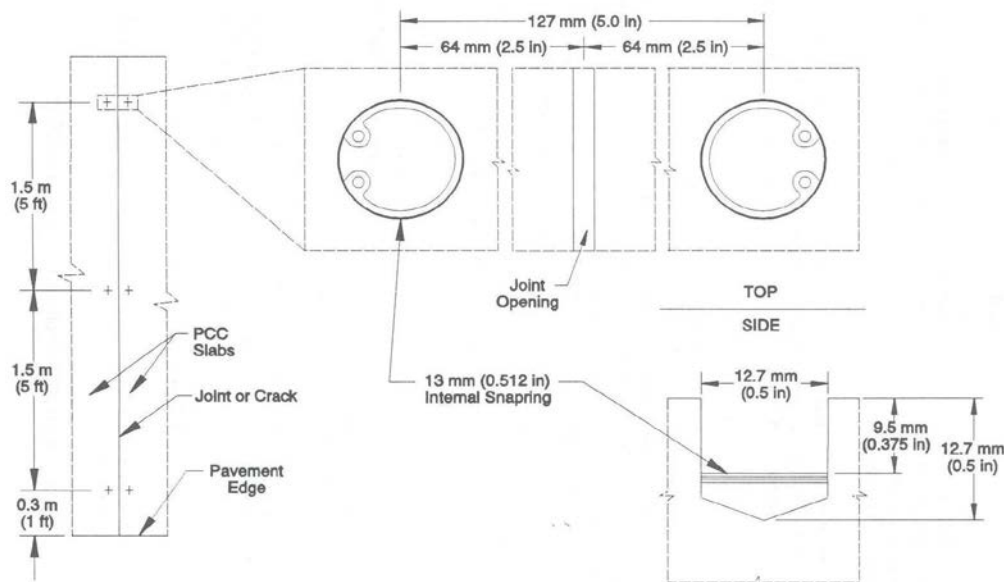


Figure 2. Snap ring placement.

Once the snap rings are installed, joint movements were measured at each location with a ± 0.01 mm precision electronic digital caliper. Snap rings improve repeatability and accuracy of joint movement measurements by providing a sharp edge for the micrometer caliper jaws to make contact with each time a measurement needs to be taken. Carbon and glass calibration standards were periodically checked with the calipers to ensure that the caliper was within calibration at all times.

Additional holes were drilled into the pavement close to each joint (approximately near the center of the PCC slab) to measure pavement temperatures that correspond to the joint movement measurements. Temperature measurement holes were drilled at 1.0 in from the pavement surface, at mid depth, and 1 in from the bottom of the slab. After drilling, the holes were cleared of dust by blowing through a small piece of plastic tubing inserted into the holes. 1.0 to 2.0 ml of mineral oil, measured with an oral syringe, was then dispensed into the holes to provide thermal

conductivity between the pavement and temperature probe. Temperature readings were taken with a ± 0.1 °C k-type digital probe to coincide as closely as possible with the times when the joint measurements were taken.

At each joint and at each location at a given joint (mid-slab, inner corner, and outer corner), five to six joint movement observations and associated temperature measurements were taken. The instrumentation and subsequent testing was conducted over 46 hour period starting mid morning on April 15th and ending in the early morning hours of Thursday April 17th in order to capture both extreme warm and cool temperature differentials. During the testing period, the daytime weather was mostly sunny to completely sunny and the nights were clear and cool; ideal conditions for joint movement testing. Each round of testing lasted 3 to 4 hours and involved walking and/or driving to each joint, recording time, temperatures, and joint movement observations.

Test Locations. Based on a review of the MIT Scan and joint score data provided by the contractor, the following categories of joint misalignment were selected for instrumentation and testing:

- Category 1 – Control Joints (Joint Score = 1): All dowel bars have excellent alignment with horizontal, vertical, and total misalignment, all less than or equal to 0.4 in (10 mm).
- Category 2 – Test Joints (Joint Score ~ 20): Many (6 or more) bars with slight/moderate vertical misalignment, none or only one bar with horizontal misalignment greater than 0.6 in (15 mm).
- Category 3 – Test Joints (Joint Score ~ 20): Many (6 or more) bars with slight/moderate vertical and/or horizontal misalignment (roughly equal contribution to joint score from horizontally and vertically misaligned bars; 3 or more bars with horizontal misalignment and 3 or more bars with vertical misalignment greater than 0.6 in [15 mm]).
- Category 4 – Test Joints (Joint Score ~ 30 to 40): Many (6 or more) bars with slight/moderate/high vertical misalignment, none or only one bar with horizontal misalignment greater than 0.8 in (20 mm).
- Category 5 – Test Joints (Joint Score ~ 30 to 40): Many (6 or more) bars with slight/moderate/high vertical and/or horizontal misalignment (roughly equal contribution to joint score from horizontally and vertically misaligned bars; 3 or more bars with horizontal misalignment and 3 or more bars with vertical misalignment greater than 0.8 in [20 mm]).

Measuring joint movements on select joints within these categories afforded a broad basis for understanding the true impact of various types and degrees of misalignment on joint performance.

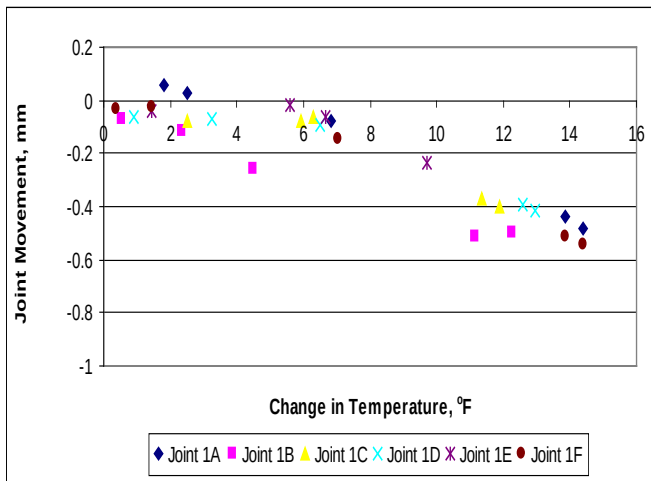
Table 2 presents the joint categories, joint designations and the exact joint scores for each joint selected for testing. As can be noted, five joints were targeted within each category along with one additional joint to overcome any measurement related issues. The test locations were spray painted on the adjacent Jersey barrier prior to the measurement.

Table .2. Joint scores of joints selected for testing.

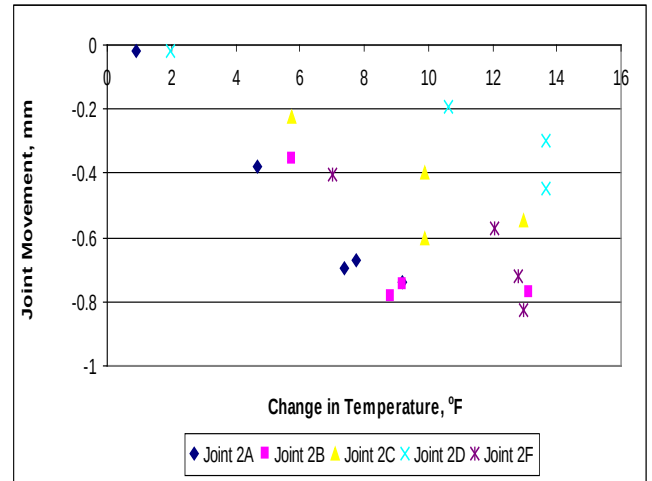
Joint Category	Joint Number	Joint Score
1 (Joint Score = 0)	1A	1
	1B	1
	1C	1
	1D	1
	1E	1
	1F	1
2 (Joint Score = 20)	2A	19
	2B	19
	2C	19
	2D	19
	2E	N/A
	2F	19
3 (Joint Score = 20)	3A	20
	3B	19
	3C	20
	3D	20
	3E	20
	3F	20
4 (Joint Score = 30 to 40)	4A	39
	4B	N/A
	4C	34
	4D	39
	4E	39
	4F	N/A
5 (Joint Score = 30 to 40)	5A	38
	5B	39
	5C	40
	5D	33
	5E	32
	5F	31

Data Analysis and Testing Observations

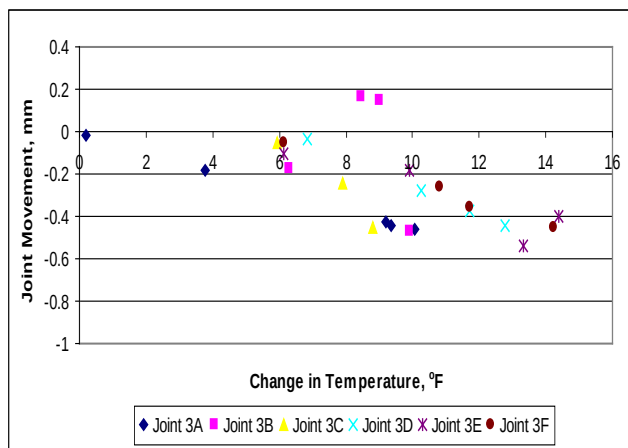
Figure 3 presents the movements recorded at various joints for each category of misalignment. Note that the average of the joint movements at each of the three test locations at a given joint (mid-slab, inside corner, outside corner) is plotted in the figures for each joint.



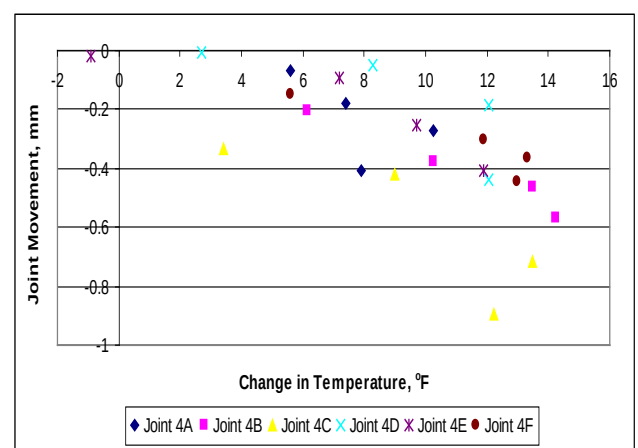
(a) Category 1 Joints.



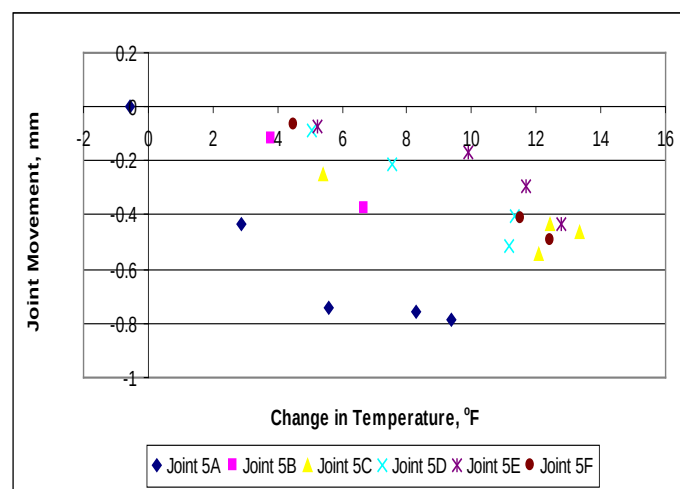
(b) Category 2 Joints.



(c) Category 3 Joints.



(d) Category 4 Joints.



(e) Category 5 Joints.

Figure 3. Joint movements recorded at the various joints tested.

The joint movements in the figures were determined as follows:

1. Establish a reference joint opening—this corresponds to the first joint opening width measured at a joint.
2. Establish a reference temperature (T_{ref})—this is the temperature corresponding to the first joint measurement.
3. Compute joint movement—all subsequent measurements of joint width are compared against this reference width to obtain joint movement.
4. Compute change in temperature—this value corresponds to the difference between the temperature at the time a given joint measurement is made (T_i) and T_{ref} for that joint.

A positive value for the change in temperature means that the temperature at the time of the observation has increased when compared to T_{ref} . This will result in a negative joint movement indicating that the joint has closed.

The following observations can be made from the figure 3:

- All the joints tested including those in category 5 (with the highest number and degree of dowel misalignment) experienced joint movements as a function of temperature change.
- The magnitudes of the joint movements in categories 2 through 5 appear to be relatively in the same order of magnitude when compared to the control category (category 1) which had perfectly aligned joints.
- Generally speaking, the trends in the joint movement as a function of the temperature are as expected for all joint categories, i.e., as the temperature rises, the joints close.
- There is a fair degree of variability in the movements experienced by joints within a given category. This appears to be true for all the joint categories.

Recommendations for Practice

This relatively small but practical study illustrates that unfavorable dowel misalignment measurements do not necessarily result in “locked” joints. While MIT Scan is a good screening test, joint movement measurement is a relatively straightforward technique that could be made a part of the overall evaluation of joints suspected to have poor dowel alignment. The results of this evaluation could be used to refine rejection criteria and to develop corrective measures. Based on the limited empirical evidence gathered from this study, those joints suspected to cause joint “lock-up” in fact did not show such behavior in the field. Hence removal and replacement of these slabs may be unwarranted, unnecessary, and expensive. Further work to evaluate the potential to use the results from this diagnostic test is recommended.

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