Dowel Bar and Slab Size Recommendations Based on the Mechanistic-Empirical Pavement Design Guide

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Abstract

This paper provides guidelines on two major concrete pavement design features: dowel bars and slab size. The analysis of dowel bars focused on low volume roads and streets (LVRS), whereas heavier loaded pavements were considered for the analysis of slab size effect. Design charts are recommended based on the newly released NCHRP 1-37A Mechanistic-Empirical Pavement Design Guide (M-E PDG). The dowel design charts allow the user to determine if dowel bars are necessary for LVRS, based on four climatic regions, two base erodibility indexes, and the selected slab thickness. In this analysis, the number of one-way average annual daily truck traffic (AADTT) was limited to 100. In contrast, the analysis of slab size was presented for traffic levels up to AADTT of 7,000 and slab thickness up to 40.6 cm (16 in). In addition, two climatic conditions (dry and wet) were analyzed. Dowel and slab size performance data also are presented. The slab size performance data are based on numerous existing studies in the literature. Although the amount of studies on dowel performance is not as extensive as slab-size effect studies, some very informative studies have been conducted especially on dowel bar misalignment. Dowel bar misalignment tolerances for LVRS are suggested based on these studies.

Introduction

The performance of portland cement concrete (PCC) pavement for low volume roads and streets (LVRS) depends on their design and construction. LVRS, by most definitions, carry up to 500 vehicles per day (Federal Highway Administration, 1992). For the purposes of this document, a LVRS is one that carries up to 100 trucks and buses per day in one direction based on the Federal Highway Administration (FHWA) class 4 classification or greater. The two most important aspects of concrete pavement design are slab thickness and jointing. In the past, while thickness was always designed for the project, joint spacing was relegated to a standard drawing, where the same joint spacing was used regardless of any other design condition. This has led to a number of early cracking problems that have required increased maintenance and premature rehabilitation since an inadequate joint design nearly always leads to poor performance. Regardless of the other pavement features, slabs that are too long will

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lead to transverse cracking in jointed plain concrete pavement (JPCP) due to excessive tensile stresses. Joint spacing has now come to be known as one of the most important design features for JPCP. It must be considered directly even when other key design features (e.g., slab thickness, joint load transfer devices, shoulder type) are addressed properly. As a result, proper joint design for PCC pavements requires a holistic treatment of the site and design factors for a given project.

Need for Load Transfer at Joints and Slab Size Control

Transverse joints are required in unreinforced jointed concrete pavements to prevent uncontrolled slab cracking. They provide relief from excessive stress build-up due to temperature and moisture gradients through the PCC slab and the imposed traffic loadings. Transverse joint spacing for LVRS pavements may vary depending upon slab thickness, from about 3.7 m (12 ft) for 15.2 cm (6 in) slabs to 4.6 m (15 ft) for thicker slabs. Thus, a joint is placed every 3.7 to 4.6 m (12 to 15 ft) to control cracking. This joint then becomes the most critical location in the slab. Much higher stresses and deflections occur at the joints than at the slab interior when heavy truck axle loads pass over the pavement. However, an advantage of providing planned joints (which are actually induced cracks) is that load transfer mechanisms can be provided, as needed, to reduce high stresses and deflections. Good load transfer reduces faulting, in addition to providing better ride quality and lower maintenance cost.

Effect of Dowel Bar on Load Transfer and Faulting

Concrete pavements built on LVRS typically rely on aggregate interlock to provide the necessary load transfer efficiency (LTE). A nondoweled joint provides LTE through shear forces developed at the rough joint interface due to aggregate interlock provided by the shape, size, and hardness of the coarse aggregate. As a result, joint opening highly affects LTE based on aggregate interlocking. That is why LTE of joints with aggregate interlock is highly dependent on temperature (Rufino *et al.*, 2004): it is only high during warm weather when the joint is tightly closed (small joint opening). In contrast, the load transfer mechanism of dowel bars does not rely on warm weather or closed joints to transfer load across the joint. As a result, doweled joints are effective throughout the entire year. Khazanovich and Gotlif (2003) performed a comprehensive analysis of LTE data from the Long-Term Pavement Performance (LTPP) program. They showed that doweled joints have much higher LTE than nondoweled joints.

Several field performance studies from the 1970's through the 1990's, including Highway Research Board (1962), Darter *et al.* (1985), Smith *et al.* (1998), Smith *et al.* (1990), Darter (1977), FHWA (1989), and Khazanovich *et al.* (1998), found that slabs without dowels at the joints showed substantially more faulting than doweled ones at the same location. In addition, some of these studies also concluded that dowels prevent corner breaks or diagonal cracks. Darter (1977) considered faulting "the most serious distress" because it had a significant effect on ride quality when it developed to a significant level requiring maintenance. The importance of dowel bars is further underscored when one considers what was discovered for one improperly constructed transverse joint at the AASHO Road Test, where all joints were doweled. A Special Pavement Research Report about the AASHO Road Test from the Highway Research Board (1962) states the following:

"Faulting at joints was notably absent throughout the project. One transverse joint faulted seriously, but the investigation showed that the joint had been accidentally sawed at some distance beyond the end of the dowels intended to protect it. Over the 2-yr period of the test there were no other cases of measurable faulting at joints, all of each were doweled."

Figure 1 presents a hypothetical scenario of what might have happened at the Road Test if some of the pavements within a given loop were left nondoweled and others doweled. This analysis was performed using the M-E PDG (ARA, 2004) and assuming the cross-section, traffic, climate, and materials information from the Road Test. It is noted that nondoweled joints could have had up to seven times more faulting than doweled ones. The AASHO Road test is one of the few studies that addressed the joint performance of LVRS pavements. The vast majority of field performance studies are based on highways with relatively high truck volumes and thicker pavement sections.

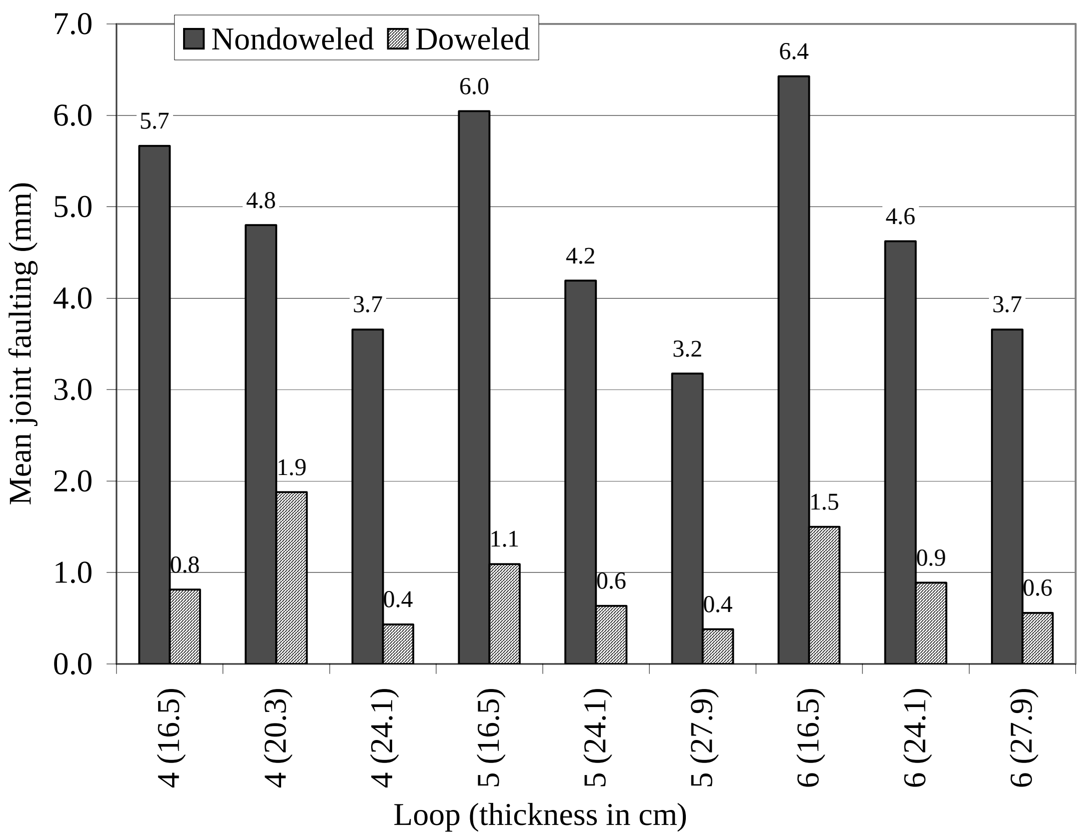

Figure 1. Predicted joint faulting of AASHO Road Test pavements after 1 million axle loads using the M-E PDG.

Effect of Slab Size on Cracking

Several transverse cracking models have been developed over the years for JPCP (Yu *et al.*, 1996; ARA, 2004) based on hundreds of field projects. A sensitivity analysis of these models shows that fatigue cracking decreases rapidly as pavement thickness increases and joint spacing decreases. Another parameter that highly affects transverse cracking is an increase in the concrete coefficient of thermal expansion (CTE). As a result, the PCC materials, particularly the coarse aggregate types, should be selected very cautiously for design purposes. Cracking is also affected by climatic conditions: nonfreeze zones tend to develop more cracks because of higher temperature gradients. Assuming a given thickness design and PCC materials, transverse cracking can be controlled through the selection of appropriate joint spacing. As cracking increases significantly with slab size, it is crucial that the designer selects appropriate joint spacing to reduce cracking to an acceptable level. In addition, if any of the design and construction parameters that also affect cracking are not estimated correctly, the actual slab cracking can be much higher than predicted in the design. The use of short joint spacing also adds some safety to pavement design in case design parameters are not estimated properly. The design of shorter slabs also results in better load transfer efficiency since they have smaller joint openings.

Many performance studies have demonstrated the beneficial effect of short transverse joint spacing on reducing transverse fatigue cracking and consequently increasing pavement life. Darter (1977) was among the first to evaluate the effect t of slab length on cracking performance. Based on the study of pavement sections in Minnesota and Michigan, he concluded the effect of joint spacing on cracking followed a S-shape function with cracking highly increasing when joint spacing increased from 4.6 to 7.6 m (15 to 25 ft). Smith *et al.* (1990) inspected many slabs on several major research projects throughout the United States and indicated that as slabs length increases, the likelihood of transverse cracking always increases. For instance, where random joint spacing exists, the longer series of slabs exhibit more cracking than the shorter slabs. Similar results were also obtained based on the analysis of 21 projects with random joint spacing in California, where longer slabs (5.5-5.8 m or 18-19 ft) had a higher percentage of cracking than shorter slabs (3.7-4.0 m or 12-13 ft): the average percentage of cracking in long slabs was more than three times higher than in shorter slabs.

As a result, long slabs are more prone to transverse cracking, but very short slabs may also result in corner and longitudinal cracking if no dowels are used. The optimum joint spacing should be the maximum slab length that reduces transverse cracking to acceptable levels during the design period. It was a concern that the increase in joints due to decrease in joint spacing would tend to decrease smoothness, but field surveys (Smith *et al.*, 1998) have concluded that joint spacing does not affect roughness as much as anticipated. Figure 2 shows that slab length also affects faulting, although the effect on faulting is not as pronounced as on cracking. This figure was obtained using the design procedure developed under the NCHRP project 1-37A (ARA, 2004). It is clearly observed that the effect of slab length on faulting is linear and highly non-linear for cracking.

As demonstrated in this paper, the most prominent advantage of using dowels is reduction in faulting, and consequently, maintaining smoothness. To illustrate these effects using the M-E PDG, Figure 5 shows predicted joint faulting at 75 percent reliability versus initial year AADTT for doweled and nondoweled joints, whereas Figure 6 shows the same analysis focusing on smoothness. These figures can also be used to determine the amount of traffic that the pavement can carry before a given performance parameter is reached. The use of 2.54-cm (1-in) diameter dowel bars greatly reduces faulting, especially for traffic higher than 50 trucks per day, assuming the selected thickness. The use of 3.17-cm (1.25-in) dowels further reduces faulting, and the additional increase in diameter does not provide much benefit for the design conditions considered herein. Similarly, concrete pavement ride (smoothness) is enhanced with the use of dowel bars. This improvement can be up to 1.26 m/km (80 in/mi) for the selected conditions.

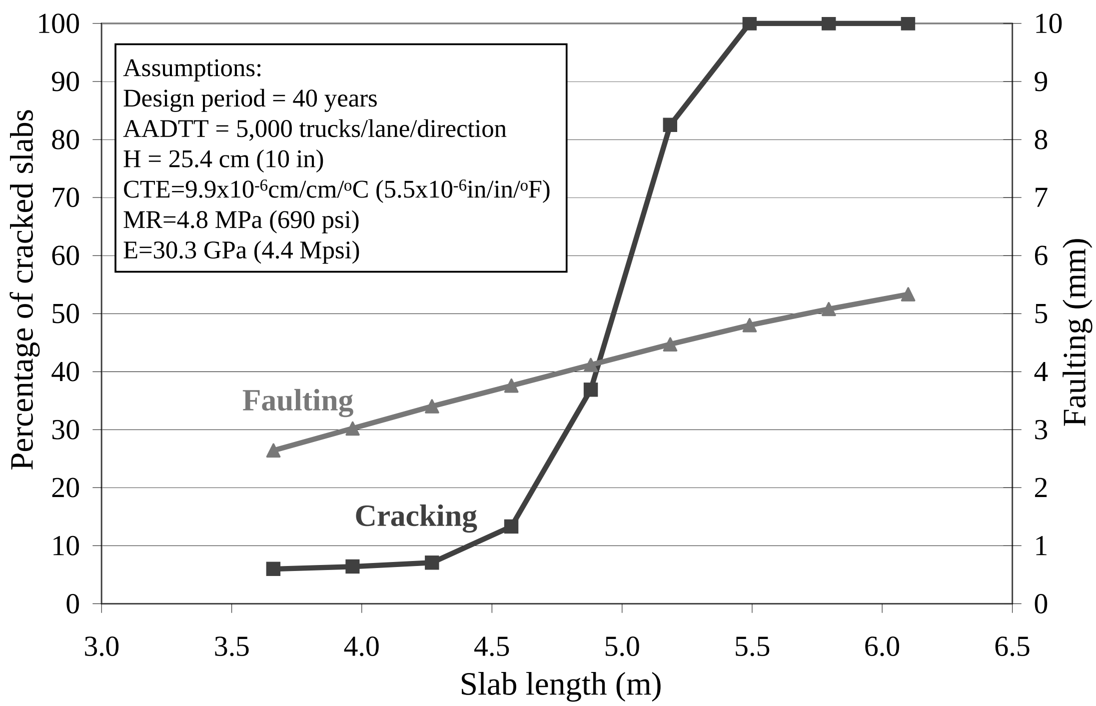

Figure 2. Effect of slab length on cracking and faulting using the M-E PDG.

Current Joint Design Practice

Most design recommendations on the selection of joint type are based solely on pavement thickness. As most LVRS thickness designs do not exceed 20.3 cm (8 in), the description of current design practices will be limited to that value. As a rule of thumb, the American Concrete Pavement Association (ACPA) suggests the use of dowel bars for slabs 20.3-cm (8-in) thick or more. However, depending on the combination of other design and site factors (e.g., base type, precipitation, design life), pavements thinner than 20.3 cm (8 in) may also need dowels to prevent premature faulting of joints. McGhee (1995) indicated that most States required dowel bars. For those that did not, faulting was primarily the cause of concrete pavement failure. Currently, dowels are used in almost all States in the U.S. and also in some cities and counties. In fact, several States are performing dowel bar retrofitting on projects where dowels were not originally placed, to prevent faulting after diamond grinding. This has shown to be very effective in controlling joint faulting and prolonging the life of pavements.

Similarly to the selection of joint type, most traditional slab size recommendations used to be based solely on slab thickness. The 1993 American Association of State Highway and Transportation Officials (AASHTO) design guide (AASHTO, 1993) limited the joint spacing (in feet) to twice the slab thickness (in inches), which is a very common used rule of thumb. As a result, a 30.5-cm (12-in) thick slab should have a slab length of 7.3 m (24 ft). However, the adoption of such a criterion is risky because the real world is far more complicated and can result in many failures. Today, most States use a maximum transverse joint spacing of 4.6 m (15 ft) regardless of thickness (ACPA, 2004a). The most recent revised ACPA joint spacing guideline (ACPA, 1991) recommended joint spacings between 3.7 m (12 ft) and 6.1 m (20 ft), depending on slab thickness and subbase type. Shorter slab lengths are recommended for stabilized subbases. In contrast, the FHWA Technical Advisory (FHWA, 1990) recommends a maximum joint spacing of 4.6 m (15 ft) for JPCP. Currently, 4.6 m (15 ft) is the most common joint spacing in use.

Dowel Design

The design of dowel bars consists of specifying their length, diameter, and spacing. Dowel diameter is certainly the most important aspect of dowel design, since length and spacing recommendations usually do not vary. As a general guideline, AASHTO (1993) suggests that the dowel diameter should be equal to 1/8 of the slab thickness. This was used for all slab thicknesses at the AASHO Road Test. For instance, an 8.9-cm (3.5-in) slab used 1.27-cm (0.5-in) dowels, 12.7-cm (5-in) used 1.59-cm (0.625-in), 16.5-cm (6.5-in) used 2.22-cm (0.875-in), 20.3-cm (8-in) used 2.54-cm (1.00-in), and so on. All joints at the AASHO Road Test included dowels properly sized for the loadings, and none of these joints exhibited faulting within 1 million axle loadings. In addition, based on the analysis of extended AASHO Road Test pavements that were in service an additional 12 years and subjected to many additional heavy traffic loadings on I-80, it was found that an increase in dowel diameter has a major effect on controlling faulting. FHWA (1990) also recommends this guideline but limits the dowel diameter to a minimum of 3.18 cm (1.25 in) for highways. Similarly, the ACPA (1991) recommends the use of 3.17-cm (1.25-in) dowel diameter for slabs thinner than 24.5 cm (10 in). Other dowel diameter recommendations are based on the traffic level. According to an ACPA survey (ACPA, 2004a), the average dowel bar diameter is 3.17 cm (1.25 in). Another survey performed in 1992 (McGhee, 1995) indicated that most State highway agencies used a dowel diameter of at least 2.54 cm (1 in). Since slab thickness on LVRS generally does not exceed 20.3 cm (8 in), 2.54-cm (1-in) diameter dowel bars or the small elliptical dowel bars are recommended. As elliptical dowels reduce the bearing stresses compared to round dowels for the same cross sectional area, smaller elliptical bars can be used to keep the same bearing stress as round ones. As the stress concentration occurs at the top and bottom of the dowels, their sides do not assist in the distribution of load. Elliptical bars are placed at the mid-depth of the slab with their major axis parallel to the ground. As a result, elliptical bars provide more bearing area for stress distribution.

Common dowel length and spacing are 47.5 cm (18 in) and 30.5 cm (12 in), respectively. This is recommended in the AASHTO (1993) pavement design guide, as well as in a recent joint design guide by Ambroz *et al.* (1996). These dimensions are by far the most used ones according to a database of State highway agency practices compiled by ACPA (2004a). A study conducted in the late 1950's concluded that the dowel embedment length required to provide full load transfer was five or more times the bar diameter (Teller, 1959). Based on this study, 2.54-cm (1-in) diameter bars would need a minimum embedded length of 12.7 cm (5 in). A recent study by the Minnesota DOT (Burnham, 1999) indicated that an embedded length of only 6.35 cm (2.5 in) is sufficient to keep faulting at an acceptable level of 0.63 cm (0.25 in) and provide an LTE with less variability. This study has led Minnesota to the use of dowels 38.1-cm (15-in) long. Based on these studies, dowels 38.1-cm (15-in) long spaced at 30.5-cm (12-in) intervals are adequate for LVRS.

Another important aspect of dowel performance is to control dowel bar misalignment. A reasonable rotational alignment is crucial to avoid joint lock-up and potential cracking. Dowel bar translation beyond the joint, on the other hand, would result in a nondoweled joint. As a result, specification tolerances must be established to limit dowel bar misalignment. The major dowel alignments that must be controlled are vertical and horizontal rotation, which are usually measured from the end of the dowels, as illustrated in Figure 3. Vertical and longitudinal translations should be controlled as well. The importance of controlling longitudinal translation is to guarantee appropriate dowel embedment length and unrestricted adequate opening and closing of the joint.

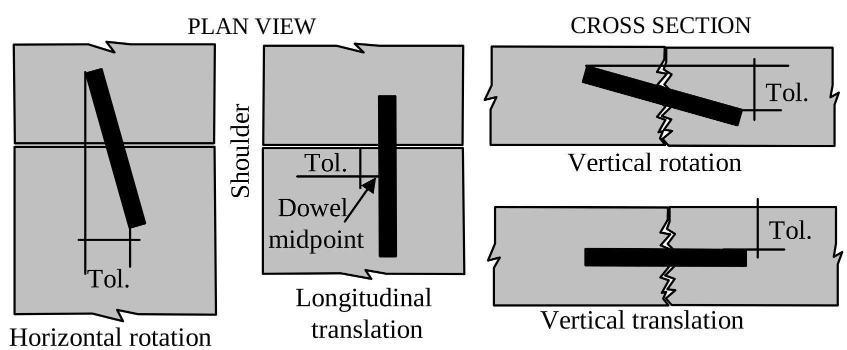

Figure 3. Diagram of how to measure dowel bar misalignment.

Fowler and Gulden (1983) studied the effect of dowel bar misalignment on PCC pavement performance for Georgia DOT. At that time, Georgia DOT had a tolerance of ± 2.54 cm (1 in) for both vertical and horizontal translational alignment. Fowler and Gulden (1983) verified that more than half of the bars had longitudinal misalignment more than the specified value. In fact, some dowels were completely out of the joint. As the recommended dowel length is 38.1 cm (15 in) and the required embedded length is approximately five times of the dowel diameter, the acceptable horizontal translational misalignment is ±6.35 cm (2.5 in). The vertical translational misalignment should be at most ± 2.54 cm (1.0 in).

In the early 1980's, the vertical and horizontal rotation tolerances in Georgia were 3.13 and 6.25 cm/m (0.375 and 0.75 in/ft), respectively (Fowler and Gulden, 1983). They measured maximum vertical and horizontal rotations of 8.33 and 19.17 (1.0 and 2.3 in/ft), respectively, which were still working as designed. Currently, Georgia's specification calls for 3.13 cm/m (0.375 in/ft) regardless the direction (Khazanovich *et al.*, 2001). Parry (1989) performed a study in the late 1980's for Wisconsin that found 90 percent of the tested dowels were within their rotation tolerance of 2.75 cm/m (0.33 in/ft). In Missouri, a recent study performed by Donahue (2003) found average vertical and horizontal rotations of 1.42 and 2.50 cm/m (0.17 and 0.30 in/ft), respectively. Based on pullout tests performed in the laboratory, Tayabji (1986) concluded that pullout loads were relatively low if the misalignment of two opposite dowels was kept below 5.58 cm/m (0.67 in/ft) and maximum joint opening kept to 0.64 cm (0.25 in). A theoretical analysis of rotational misalignment (Khazanovich *et al.* 2001) concluded that dowel misalignment of 1.42 cm/m (0.17 in/ft) or less did not cause significant restraint, which is about 25 percent of the acceptable level suggested by Tayabji (1986). According to Fowler and Gulden (1983), a study performed by the Alabama Highway Department in 1967 that concluded that misalignment up to 2.08 cm/m (0.25 in/ft), regardless the type, was not a concern for good pavement performance. Coincidentally, 2.08 cm/m (0.25 in/ft) was the tolerance limit established by FHWA in the late 1980's (FHWA, 1989). FHWA has considered relaxing this tolerance based on State experiences. In contrast, the ACPA (2004b) recommends a tolerance limit of 3.13 cm/m (0.375 in/ft). This tolerance for rotational misalignment is feasible and within the range of suggested values for rotational misalignment; therefore, this level is appropriate for LVRS when short joint spacing is used.

Dowel and Slab Size Design Recommendations

Heavy trucks and buses represent a portion of this daily amount of vehicles, which if high enough volume, can lead to pumping, faulting, and unacceptable roughness for nondoweled joints. The question is, at what truck and bus volume should dowels be used to prevent significant faulting and roughness? Clearly, dowels are not needed on all LVRS with lower levels of truck traffic, but when the predicted truck traffic exceeds a certain level, dowels will be needed to prevent excessive joint faulting and possible slab cracking due to loss of support. The recommendations for the use of dowel bars are provided after discussing the current practice. It is based on the predicted level of truck traffic for a given slab thickness, base or soil type, and climatic zone.

The dowel analyses shown were performed assuming up to 100 heavy trucks in the design lane per day in the first year of a 30-year design period (DP). The assumed traffic distribution was comprised basically of buses and single-unit trucks. In contrast, slab size analyses were developed for much higher traffic (up to 7,000 heavy trucks in the design lane). Figure 4 can be used to convert from initial year AADTT to cumulative traffic, and vice-versa, for different design periods.

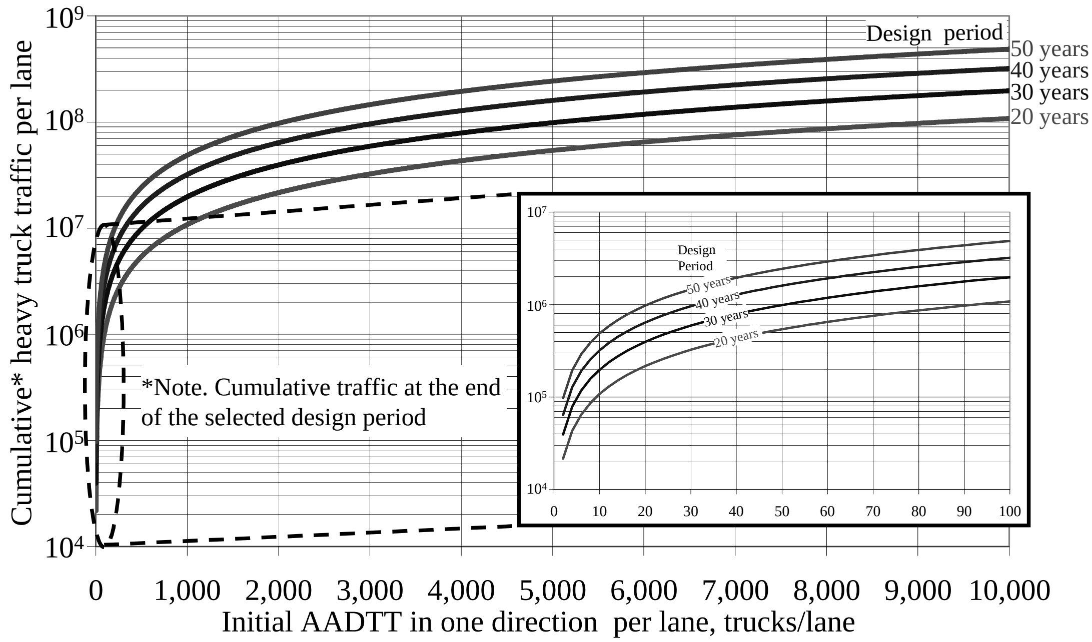

Figure 4. Cumulative traffic versus AADTT (compound traffic growth = 4%).

The design charts presented in this section can be used to decide whether dowel bars are needed in LVRS. This decision depends on the daily traffic level, slab thickness, climate, and subgrade type. The selected design criteria were based on the recommendation for LVRS in the M-E PDG (ARA, 2004). These recommendations focus on an optimized LVRS design in terms of dowels and slab size. The criteria for using dowels were based solely on faulting and smoothness, whose threshold values for acceptable designs were selected to be 0.38 cm (0.15 in) and 3.16 m/km (200 in/mi), respectively. The daily number of heavy trucks (and buses) that would lead to the selected design criteria at the end of the design period was determined for different slab thickness, subgrade conditions, and climatic zones. A range between 15.2 and 20.3 cm (6 and 8 in) was evaluated because these are typical thicknesses for LVRS. Climatic zones were divided according to the LTPP zoning criteria (Figure 7): Wet-Freeze (WF), Wet-Nonfreeze (WNF), Dry-Freeze (DF) and Dry-Nonfreeze (DNF). To account for different subgrade types, the Erodibility Index (EI) was varied from very erodible (EI=5) slab placed on fine-grained soils to erosion resistant (EI=3) good quality granular base course.

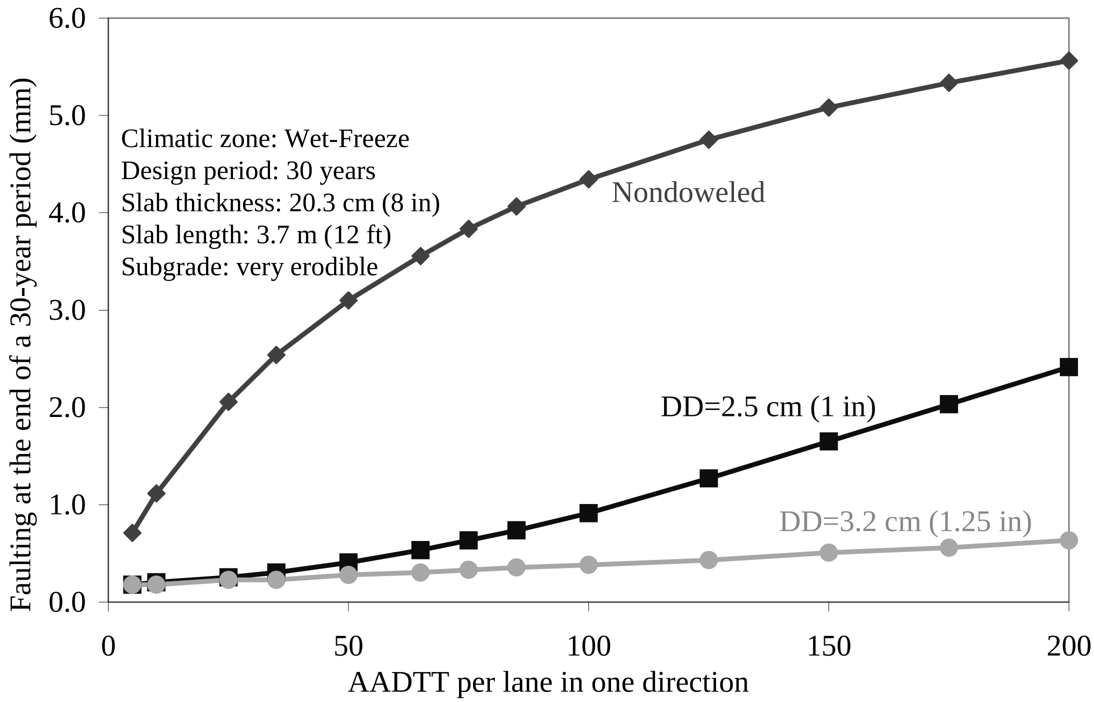

Figure 5. Effect of dowels on faulting.

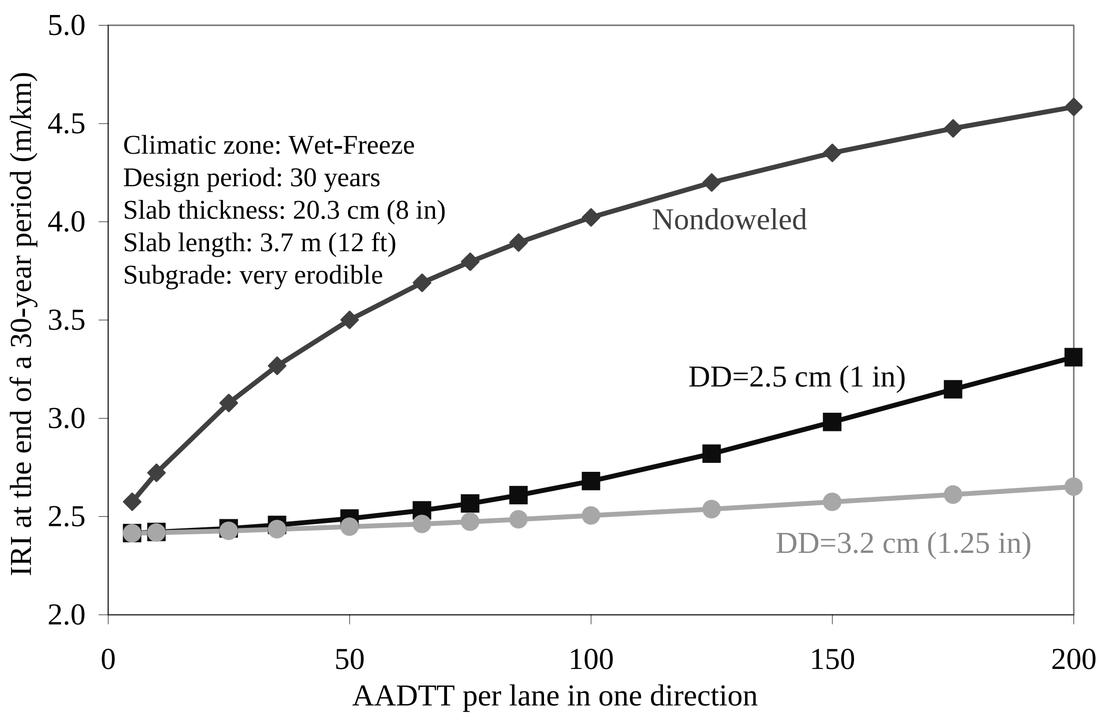

Figure 6. Effect of dowels on smoothness.

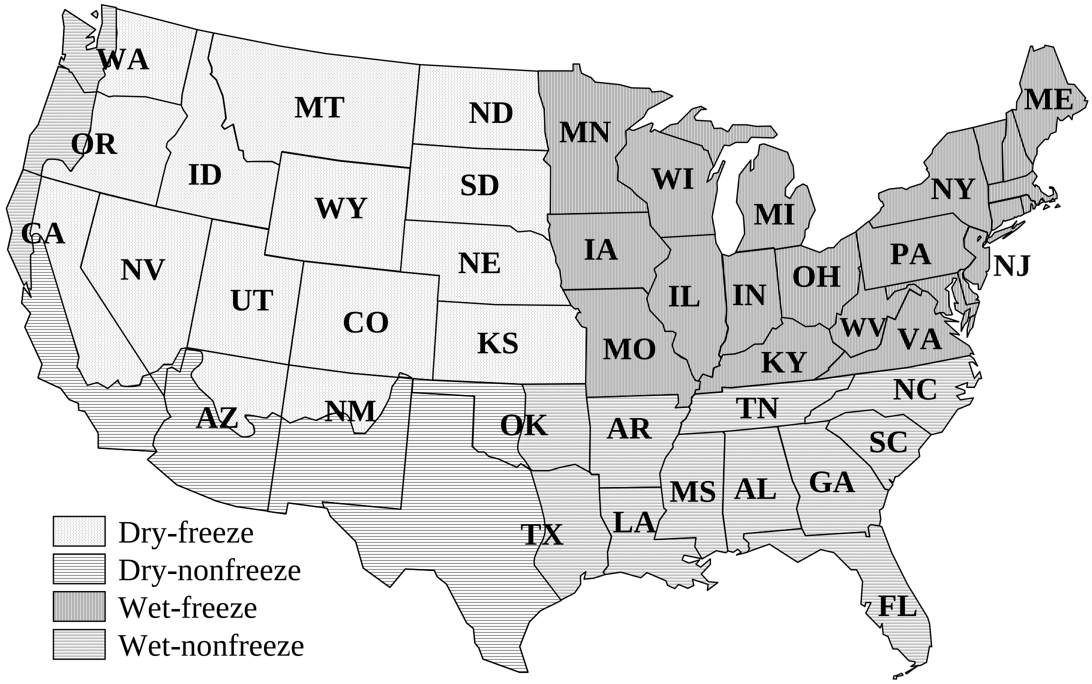

Figure 7. LTPP climatic zone map.

Figure 8 shows the recommendation of dowel bar use for very erodible subgrade (fine-grained soil), assuming a reliability level of 75 percent. A similar analysis for erosion resistant subgrade (coarse-grained soil) is shown in Figure 9. Examples illustrating how to use these design charts are discussed in this paragraph. The number at the top of each shaded area shows the maximum number of AADTT that nondoweled slabs can carry before reaching faulting level in excess of 0.15 in at the end of 30 years. Consider the local streets in central Illinois cities (WF), where the slab on compacted subgrade is standard practice. A study by ERES Consultants (1994) showed that urban streets in the area carry the following number of heavy vehicles per lane per day in one direction: 36 (bus route with 17.8-cm or 7-in slab) and 11 (not a bus route with 15.2-cm or 6-in slab). For collector routes (15.2-cm or 7-in slab), these numbers are 53 (bus route) and 28 (not a bus route). Assuming the slab is placed directly on a very erodible subgrade (e.g., silty clay), Figure 8 shows that dowels are not needed on non-bus route but are required on bus routes to carry 30 years of traffic. Similar conclusion is also obtained for collector streets. If the same conditions were applied to the Atlanta climate (WNF), dowels would not be required for local or collector routes for a 30-year design life, regardless is it was or not a bus route. This example illustrates the importance of accounting for climatic area when designing pavement to prevent faulting. Another example is a rural road in western Kansas (DF) that has an initial truck volume of 8 per day and a 15.2-cm (7-in) slab placed on a fine-grain compacted subgrade. Figure 8 indicates that no dowels are required over a 30-year life. However, it is likely that an industrial plant will soon be constructed along the road and that this will increase truck traffic to 25 trucks per day. Figure 8 shows that this would definitely require dowel bars to control faulting and roughness over 30 years.

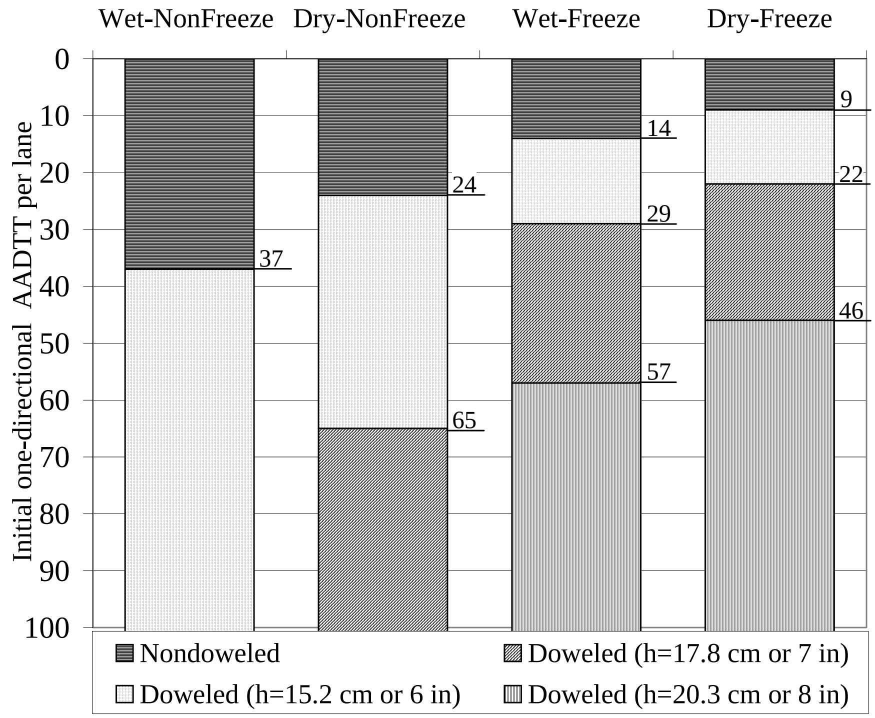

Figure 8. Dowel use recommendation for very erodible subgrade (design period = 30 years).

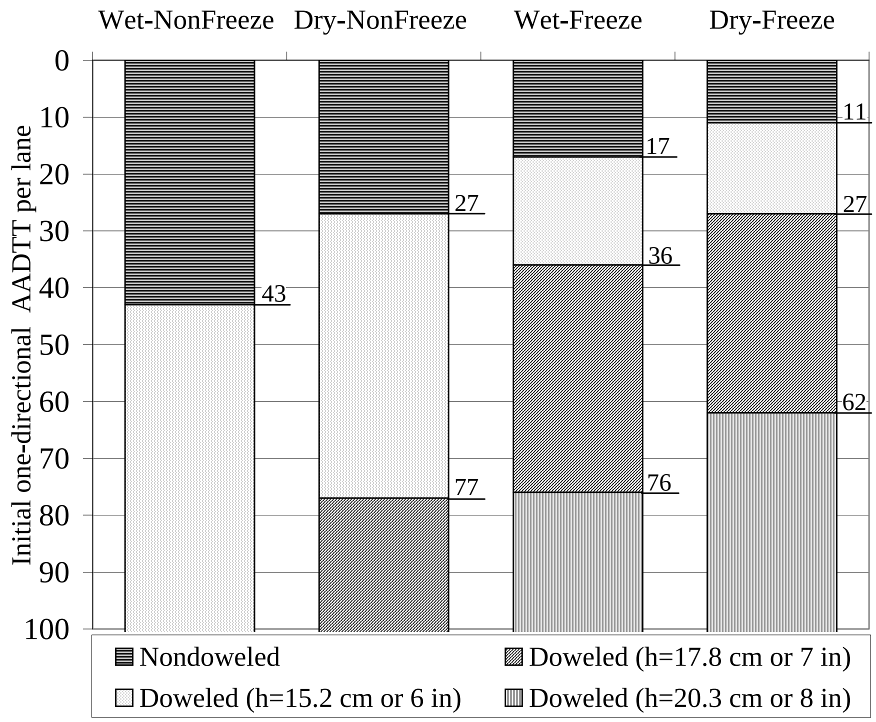

Figure 9. Dowel use recommendation for erosion resistant subgrade (design period = 30 years).

The slab size design charts can be used to determine the slab length depending on the design initial one-directional AADTT per lane and the slab thickness. The developed charts can be applied to pavements carrying up to 7,000 daily trucks per one-directional lane during a design period of 40 years. If a different design period is selected, the equivalent initial one-directional AADTT for the selected design period can be determined using Figure 4. Slab size design charts were developed for the least and most critical zones in terms of cracking: WF and DF, respectively. The selected design criterion was a maximum cracking of 15 percent at the end of the design period assuming a reliability of 90 percent. These slab size design charts presented were based solely on fatigue cracking since faulting is not as much affected by slab size as cracking. In addition, it is assumed that all joints are doweled. These charts can only be used to estimate the required slab size to limit fatigue cracking because the results were not checked against faulting. In order to use this chart for thickness design, the user still needs to verify for faulting.

Figure 10 shows the design chart of slab length for a DF zone, whereas Figure 11 shows the same analysis for a WF zone. These figures indicate that for a given set of design assumptions (structure, PCC material, pavement materials, etc.) and site factors (traffic, axle configurations, climate, and subgrade), the smaller the joint spacing, the lower the required PCC slab thicknesses. The exact impact of the reduced joint spacing on slab thickness will, however, be a function of specific design and site factors. When joint spacing is reduced to a certain practical limit from construction considerations, reducing it further will not affect the PCC slab thickness. In order to illustrate the use the slab size design charts, a practical example is provided. Consider a section of Interstate where the one-directional AADTT is about 4,500. A truck lane distribution factor of 0.9 was applied assuming two lanes in one direction (ARA, 2004), resulting in an initial one-directional AADTT per lane of about 4,000. If the design thickness is 25.4 cm (10 in), the slab length should be limited to 4.6 m (15 ft) in a WF condition. If the design thickness is 35.6 cm (14 in), the slab length should not exceed 5.5 m (18 ft), as shown in Figure 10. In contrast, shorter slab lengths would be required if the same traffic was applied in Salt Lake City (DF zone): the length of 25.4-cm (10-in) thick and 35.6-cm (14-in) thick slabs should be limited to 3.7 and 4.9 m (12 and 16 ft), respectively (Figure 11).

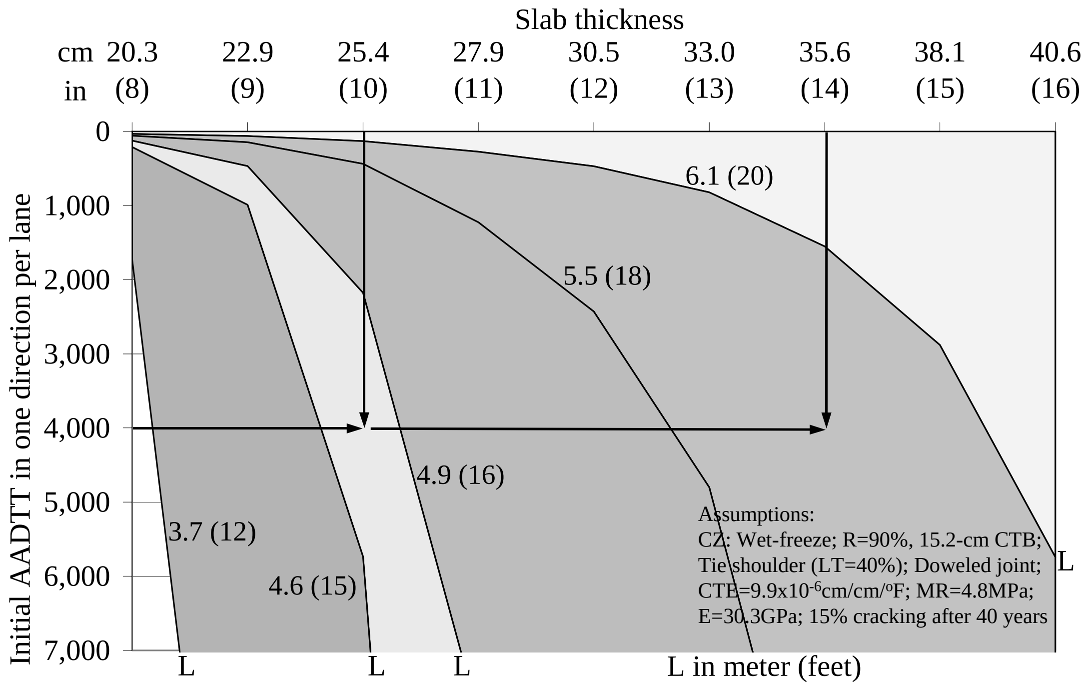

Figure 10. M-E PDG recommendation for maximum slab length in a wet-freeze (WF) zone for selected site conditions.

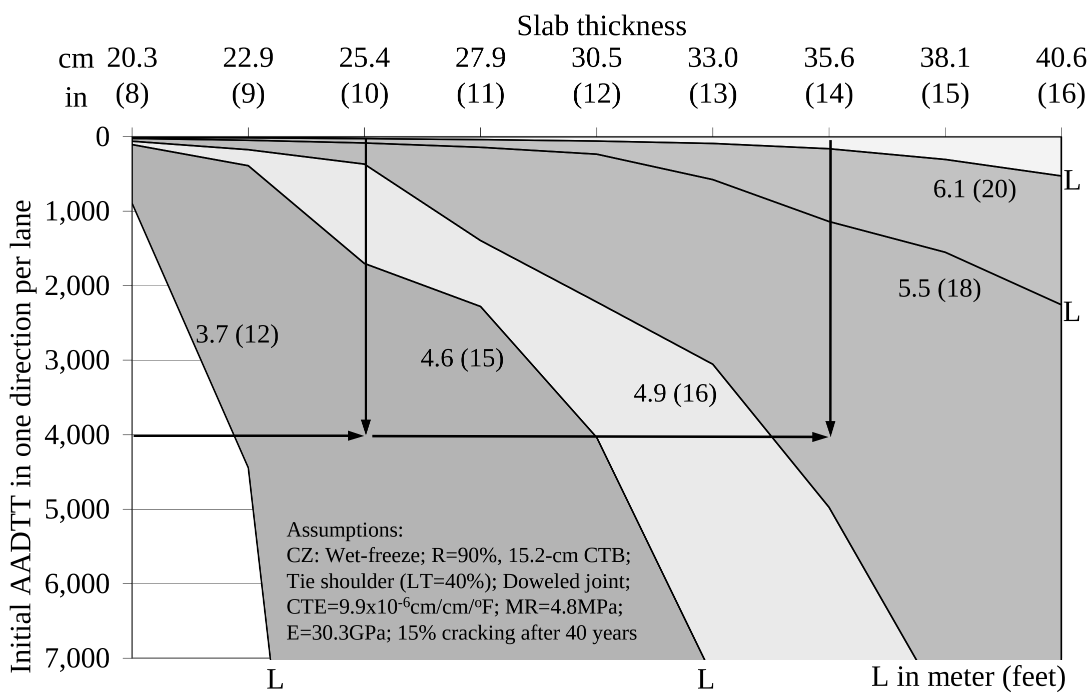

Figure 11. M-E PDG recommendation for maximum slab length in a dry-freeze (DF) zone for selected site conditions.

Conclusions

Based on dowel performance studies presented in the literature and using the new NCHRP 1-37A M-E PDG, it was shown that doweled joints provide high and constant LTE, control faulting, improve ride quality, and reduce corner breaks and diagonal cracks. In addition, these performance studies have concluded that dowels significantly reduce faulting. Regarding the dowel design, it was suggested to use 38.1-cm (15-in) long dowels at 30.5-cm (12-in) intervals for LVRS. The recommendation for dowel bars alignment in short jointed LVRS was the following: 3.13 cm/m (0.375 in/ft) for rotation, ± 6.35 cm (2.5 in) for horizontal translation, and ± 2.54 cm (1.0 in) for vertical translation. Dowel bars can also be elliptical, which are in fact more effective than round bars because they reduce dowel bearing stress for the same cross sectional area or result in similar bearing stresses with a smaller cross sectional area. Finally, design charts were presented to allow user to decide whether dowel bars are needed in LVRS to control faulting and roughness based on the daily traffic level, slab thickness, climate, and subgrade type.

Regarding the effect of slab size, it was concluded that the use of short joint spacing reduces fatigue cracking rapidly. The longer the joint spacing, the higher is the probability of transverse cracking. It was also found faulting was not as sensitive to the slab length as is cracking. Faulting, however, is very sensitive to dowel diameter and shape: it tends to decrease as the dowel diameter increases. It was shown that warmer climates are more critical for top-down fatigue cracking than freezing areas. This is caused by higher top of slab shrinkage and higher negative gradients. Finally, design charts were developed to estimate the slab length based on AADTT, slab thickness, slab length and two extreme climatic areas: wet-freeze and dry-freeze. These charts should be used for selection of joint spacing in conjunction with local factors, but not for thickness design purposes.

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References

Ambroz, J. K., W. J. Seiler, and M. I. Darter (1996). "Load Transfer Design and Benefits for Portland Cement Concrete Pavements," Report Number 96-128-E1, ERES Consultants, Inc.

American Association of State Highway and Transportation Officials (1993). "AASHTO Guide for Design of Pavement Structures," American Association of State Highway and Transportation Officials, Washington, D.C.

American Concrete Pavement Association (1991). "Design and Construction of Joints for Concrete Highways," Technical Brief No. TB- TB010-01P, Concrete Paving Technology, American Concrete Pavement Association, Skokie, IL.

American Concrete Pavement Association (2004a). "Database of State Department of Transportation (DOT) Concrete Pavement Practices," Downloaded from <**http://www.pavement.com**> (June 10, 2004).

American Concrete Pavement Association (2004b). "Understanding Sawed Joints and Dowel Bar Alignment," Concrete Pavement Progress, Volume 40, No. 4.

Applied Research Associates (2004). "Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures," Final Report of Project No. 1-37A, National Cooperative Highway Research Program.

Burnham, T. (1999). "A Field Study of PCC Joint Misalignment Near Fergus Fall, Minnesota," Final Report No. MN/RC-1999-29, Minnesota Department of Transportation.

Darter, M. I. (1977). "Design of Zero-Maintenance Plain Jointed Concrete Pavement," Report No. FHWA-RD-77-111, Federal Highway Administration.

Darter, M. I., J. M. Becker, M. B. Snyder, and R. E. Smith (1985). "Portland Cement Concrete Pavement Evaluation System – COPES," NCHRP Report 277, Transportation Research Board, Washington, D.C.

Donahue, J. (2003). "Investigation of Dowel Bar Placement Accuracy with a Dowel Bar Inserter," Report No. RDT03-009, Missouri Department of Transportation.

ERES Consultants (1994). "Review of Design and Construction Standards for New Subdivision Streets," Part 2, Final Report prepared for City of Champaign.

Federal Highway Administration (1989). "The Benefits of Using Dowel Bars," Technical Paper No. 89-03, Washington, D.C.

Federal Highway Administration (1990). "Concrete Pavement Joints," Technical Advisory T 5040.30, Washington, D.C.

Federal Highway Administration (1992). "Local Low-Volume Roads and Streets," Publication No. FHWA-SA-93-006, Washington, D.C.

Fowler, G., and W. Gulden (1983). "Investigation of Location of Dowel Bars Placed by Mechanical Implantation," Georgia DOT and Federal Highway Administration, Report No. FHWA/RD-82/153.

Highway Research Board (1962). "The AASHO Road Test – Report 5," Special Report 61E about Pavement Research, Publication No. 954, Division of Engineering and Industrial Research, Washington D.C.

Khazanovich, L., and A. Gotlif (2003). "Evaluation of Joint and Crack Load Transfer – Final Report," Report No. FHWA-RD-02-088, Federal Highway Administration.

Khazanovich, L., M. Darter, R. Bartlett, and T. McPeak (1998). "Common Characteristics of Good and Poorly Performing AC Pavements," Report No. FHWA-RD-97-131, Federal Highway Administration.

Khazanovich, L., N. Buch, and A. Gotlif (2001). "Evaluation of Alignment Tolerances for Dowel Bars and Their Effects on Joint Performance," Draft Report prepared for Michigan DOT.

McGhee, K. H. (1995). "Design Construction, and Maintenance of PCC Pavement Joints," Synthesis of Highway Practice 211, National Cooperative Highway Research Program, Washington, D.C.

Parry, J. (1989). "Dowel Bar Placement: Mechanical Insertion Versus Basket Assemblies," Final Report, Study No. 88-10, Wisconsin Department of Transportation.

Rufino, D., J. Roesler, and E. Barenberg (2004). "Effect of Pavement Temperature on Concrete Pavement Joint Responses," *Proceedings*, Paper No. P-29, 2004 Federal Aviation Administration Worldwide Technology Transfer Conference, Atlantic City, New Jersey, April.

Smith, K. D., D. G. Peshkin, M.I. Darter, A. L. Mueller, and S. H. Carpenter (1990). "Performance of Concrete Pavements, Volume I: Evaluation of Concrete Pavement Performance and Design Features," Report No. FHWA-RD-89-136, Federal Highway Administration.

Smith, K.D., M. J. Wade, D. G. Peshkin, L. Khazanovich, H. T. Yu, and M. I. Dater (1998). "Performance of Concrete Pavements, Volume II: Evaluation of In-Service Concrete Pavements," Report No. FHWA-RD-95-110, Federal Highway Administration.

Tayabji, S. (1986). "Dowel Placement Tolerances for Concrete Pavements," Transportation Research Record 1062, Transportation Research Board, pp. 47-54.

Teller, L. W., and H. D. Cashell (1959). "Performance of Doweled Joints Under Repetitive Loading," Bulletin 217, Highway Research Board, Washington D.C.

Yu, H.T., M.I. Darter, K.D. Smith, J. Jiang, and L. Khazanovich (1996). "Performance of Concrete Pavements: Volume III - Improving Concrete Pavement Performance," Report No. FHWA-RD-95-111, Federal Highway Administration, Washington, D.C.