Longitudinal Cracking in Alternate Jointed Plain Concrete Panel Widths in Wisconsin

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Abstract

This paper presents the results of comparative analyses of longitudinal cracking occurring in wider concrete panels (>12ft) in Wisconsin. The analysis revealed that approximately 60% of 1,008 segments involved in the study experienced longitudinal cracking. For the same pavement thickness and joint spacing, panel widths of 12ft and 14ft that exhibited higher amounts of longitudinal cracking than the larger 15-ft panel, received corresponding higher levels of truck traffic than the 15-ft panel. Pavement segments with thickness of 9in at a joint spacing of 20ft experienced higher amounts of longitudinal cracking in 14ft and 15ft wide panels than in 12ft wide panels. For a 9-in pavement thickness at a joint spacing of 16ft, the best performance may be attained by using 12ft wide panels. For a 14-ft wide panel with 9-in or 10-in thickness, the best performance may be attained using a 15-ft joint spacing. In addition, models developed showed that longitudinal cracking variations in 10-in 14-ft wide panels at 16-ft or 20-ft joint spacing is dictated by the Annual Average Daily Traffic, while percent trucks is the foremost factor that explains variations in longitudinal cracking for 12-ft and 15-ft wide panels at specific joint spacing and thickness values.

Introduction

The Wisconsin Department of Transportation (WisDOT) began the construction of widened concrete pavements in the early 1990's, using 26-foot and 30-ft wide panels, respectively, for rural four-lane divided highways and rural two-lane highways. For rural four-lane divided highways, the standard pavement section includes the outside lane paved at 14ft wide. The rationale behind these sections on mainline paving was to reduce stress and deflection at the pavement edge due to tire loads near the slab edge. Subsequent field evaluation revealed that the additional 2-3 feet paved beyond the normal traffic path was successful in meeting the intended objective and eliminated the hazard of edge drop off at the edge of the normal12-ft driving lane. Based on this evaluation, it was assumed that the widened sections would result in additional service life of the pavement and significantly reduce shoulder maintenance. While the current pavement section appeared to have been a success in reducing edge cracking and shoulder maintenance, it may have made the pavement more susceptible to other forms of distress, specifically, longitudinal cracking.

A study was initiated by WisDOT to examine the prevalence of longitudinal cracking in wider dowelled Jointed Plain Concrete Pavement (JPCP) panels and to understand the factors attributable to the cracking phenomenon. This paper presents the results of comparative analyses of longitudinal cracking in 12-, 14-, and 15-ft wide concrete panels focusing on four main factors including joint spacing, thickness, traffic, and pavement age.

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Literature Review on Cracking in Concrete Pavements

The phenomena of cracking in concrete pavements including causes, time of occurrence, and treatment methods have been widely discussed in the literature. The consensus is that cracking of concrete slabs occur when internal tensile stresses exceed tensile strength. The internal stresses have been attributed to initial moisture loss during curing, base restraint or subbase friction during longitudinal expansion and contraction from temperature changes, as well as thermal/moisture gradients between the top and bottom of the slabs (Halm et al. 1985; Richardson and Armaghani 1987; Voigt 1992; Voigt 1994; Okamoto et al. 1994; Weiss 1999; Corley-Lay and Morrison 2002; Ardani et al. 2003). The majority of longitudinal cracking tends to be random in nature and has been reported to occur in some new pavements within the first two months of construction, initially appearing at large intervals (30 to 150 ft) and forming at similar intervals over time. In situations where random cracking initially occurs and continue to develop well after paving and sawing, slab movement from grade settlement/frost heave or slab restraint from the use of stabilized subbases such as cement-treated, asphalt-treated, permeable asphalt-treated, and econocrete have been found to be the causes (Halm et al. 1985; Voigt 1992; Voigt 1994). One study in North Carolina reported the occurrence of longitudinal cracking on 80% of slabs placed on cement-treated bases compared to 7% for sections placed on crushed aggregate bases (Corley-Lay and Morrison 2002).

The common approach to minimizing the effect of induced stresses and subsequent cracking in concrete slabs is to apply proper jointing techniques to create transverse and longitudinal saw cut joints. Sawing too early outside an optimum time window is reported to induce raveling of the concrete from the saw blade, while sawing too late results in pop-off cracks. The desired optimum window is reported to begin when concrete strength is acceptable to saw without excessive raveling along the cut and ends when the concrete volume reduces significantly due to drying shrinkage or contraction (Okamoto et al. 1994; FHWA 2005). Despite the application of proper jointing techniques to limiting induced stress impact, it is highly recognized that substantial changes in weather during and after construction can induce random cracking. Voigt (2002) reported that concrete paved early in the morning under warm, sunny summer conditions exhibit more instances of random cracking than concrete paved during the late morning or afternoon. The FHWA developed the High PERformance Concrete PAVing (HIPERPAVE)® software to address such temperature gradients during construction. HIPERPAVE provides guidance on timelines to saw cut pavement based on factors such as ambient air temperature, wind speed, and strength development rate of concrete (FHWA 2005).

In 2011, the Iowa Concrete Pavement Association reported the sudden appearance of significant amount of longitudinal cracking within 2-3ft of the edge of 10-15 year old 14-ft widened concrete pavements in Iowa (Smith 2011). The subject pavements were reported to be 10 to 12in thick with 20-ft joint spacing and placed over 8 to 9in of granular subbase in the outer wheel area. Voigt (2011) suggested that the degree of support either from settlement or heaving would be a probable cause for the Iowa pavements since the cracking occurred 2 to 3 ft from the edge many years after construction. Voigt called for an investigation of the subbase widening constructed to accommodate the widened lane from the previous lane configuration. An earlier study conducted by Ardani et al. (2003) for IH-70 and USH-287 in Colorado however concluded that 14-ft wide slabs did not contribute to longitudinal cracking on rural highways. Other factors including poor construction and jointing practices, and the presence of untreated native soil with high swelling potential were the main factors that caused cracking on the pavements studied.

Data Collection

Longitudinal cracking measurements were extracted from WisDOT Pavement Inventory File (PIF) database. Longitudinal cracks ≤ 1/2 in wide were classified as low severity; medium severity cracks had width > 1/2 in to ≤ 2 in, while high severity cracks were > 2 in wide. Crack lengths were recorded by severity level for 1,008 pavement segments that averaged 1.14 miles in length. Other characteristics of the segments extracted from the database are shown in Table 1.

Table 1 Basic Data and Levels for Pavement Segments

Pavement Characteristic	Observations, N	Levels/Range	Mean
Segment length, mi	1008	0.28-2.8	1.14
Thickness, in	784	7-12.5	9.83
Age, years	994	2-26	12.74
Trucks,%	986	2.6-22	11.82
Joint Spacing, ft	978	15, 16, 18, 20	-
Panel Width, ft	1008	12,13,14,15	-
Transverse Joint Orientation	1008	0 = Normal, 1 = Skewed	-
Longitudinal jointing technique	757	1 = Sawed, 2 = Parting Strip	-
Surface Tining	1008	0 = None, 1= Transverse, 2 = Longitudinal, 3 = Diamond Grind	-
Rumble Strip placement	1008	0 = None, 1 = AC, 2 = PCC	-
Shoulder Type	1008	1 = Asphalt, 2 = PCC, 3 = Crushed Aggregate Base Course	-
Shoulder/Mainline interface Filler	1008	0 = No, 1 = Yes	-
Base Gradation	715	1 = Dense, 2 = Open	-
Dowel Bar Installation Method	632	1 = Basket, 2 = DBI Inserter	-
Topography	1008	0 = Flat, 1 = Cut, 2 = Fill	-
Curve direction	1008	0 = Tangent, 1 = Left, 2 = Right	-

Data Analysis

A wide range of factors presented in Table 1 have the potential to induce and cause the propagation of longitudinal cracking. This paper presents comparative analyses of longitudinal cracking involving 12-, 14-, and 15-ft concrete pavement panels on the basis of joint spacing, thickness, traffic, and age. The overall purpose is to check whether there is a prevalence of longitudinal cracking due to the use of larger panel widths.

A preliminary analysis of the data indicated that approximately 60% of the total segments exhibited longitudinal cracking while 40% did not. Approximately 56% (502/891) of 14-ft wide panels and 84% (31/37) of 15-ft wide panels experienced longitudinal cracking compared to 81% (58/72) for 12-ft and 100% (8/8) of 13-ft wide panels. The majority of longitudinal cracking across all panel widths was between wheel paths or in the right wheel path.

The longitudinal cracking per mile of segment was calculated for all the segments that exhibited cracking and used for further analyses. As indicated in Table 1, the pavement segments varied considerably in age (2-26 years). To null the effect of age, the calculated values of longitudinal cracking per mile were normalized using the age variable. The resulting value of longitudinal cracking per mile per year was used as the main performance measure in the following analyses.

Panel Width Impact on Longitudinal Cracking

The impact of panel width on longitudinal cracking required assembling from the database pavements with identical joint spacing and thickness, and representing each of the panel width categories to be compared. A one-way Analysis of Variance (ANOVA) was then used to examine the impact of panel width on longitudinal cracking per mile per year, once cracking has initiated. The hypotheses considered are as follows:

H_0: $\mu_{LC12JH} = \mu_{LC14JH} = \mu_{LC15JH}$

H_A: $\mu_{LC12JH} \neq \mu_{LC14JH} \neq \mu_{LC15JH}$

Where,

μ_{LC12JH} =Mean longitudinal cracking for 12-ft panels at joint spacing J and pavement thickness H

μ_{LC14JH} =Mean longitudinal cracking for 14-ft panels at joint spacing J and pavement thickness H

μ_{LC15JH} =Mean longitudinal cracking for 15-ft panels at joint spacing J and pavement thickness H

Panel Width Impact on Longitudinal Cracking at 15-ft Joint Spacing

The results of the ANOVA tests are plotted in Figure 1 to compare the panel width performance at a joint spacing of 15ft for thicknesses of 9in and 10 in. In Figure 1, the means of longitudinal cracking per mile per year between panel widths show significant statistical differences if the Least Significant Difference (LSD) intervals generated for the panels do not overlap. In LSD, the intervals are scaled to control the error rate at 5% (i.e. at 95% confidence level). Figure 1 part (a) shows that at a joint spacing of 15ft, there is a significant difference in the mean level of longitudinal cracking in feet per year per mile between the panel widths for the 9-in pavement thickness. In addition, higher mean cracking levels are associated with the small and intermediate panel widths compared to the larger 15-ft panel. The reverse is generally expected. The anomaly was investigated by examining the level of traffic associated with the individual panels. Figure 1 part (b) shows higher mean truck percentages for the 9-in pavement in the same order as shown for the panels in Figure 1 part (a). Similar results are obtained for a 10-in thickness shown in Figure 2 part (b) where higher Annual Average Daily Truck Traffic (AADTT) occur on the 10-in pavement in the same order as occurred in Figure 2 part (a). In Figure 2 part b), there were missing AADTT data for the 12-ft panel so it was not included in the analysis. Therefore, the higher level of truck traffic on the panels may partly explain the anomaly displayed in part (a) of Figures 1 and 2.

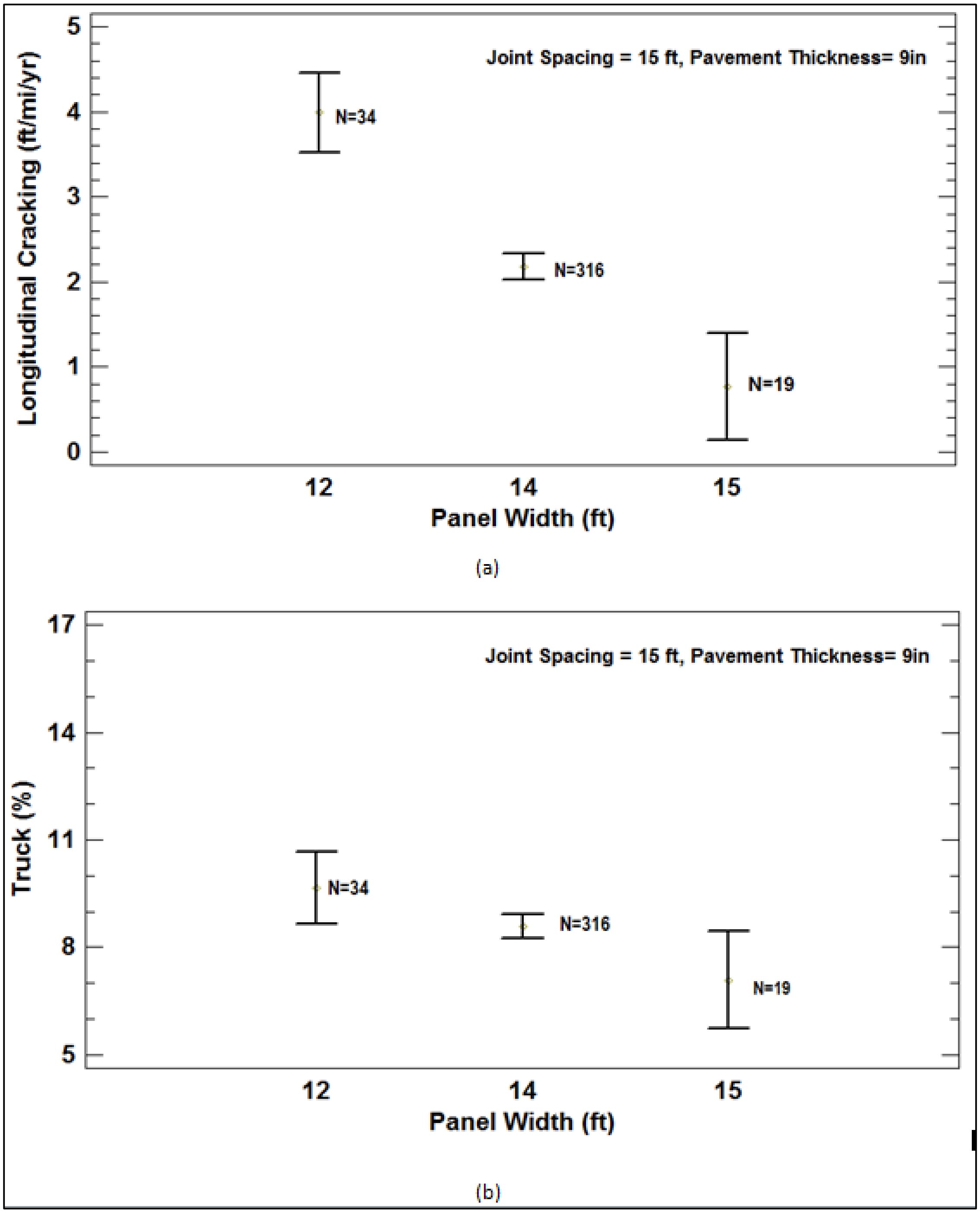

Figure 1: Comparison of Longitudinal Cracking and Truck Traffic for Panel Widths at 15-ft Joint Spacing (Thickness = 9in)

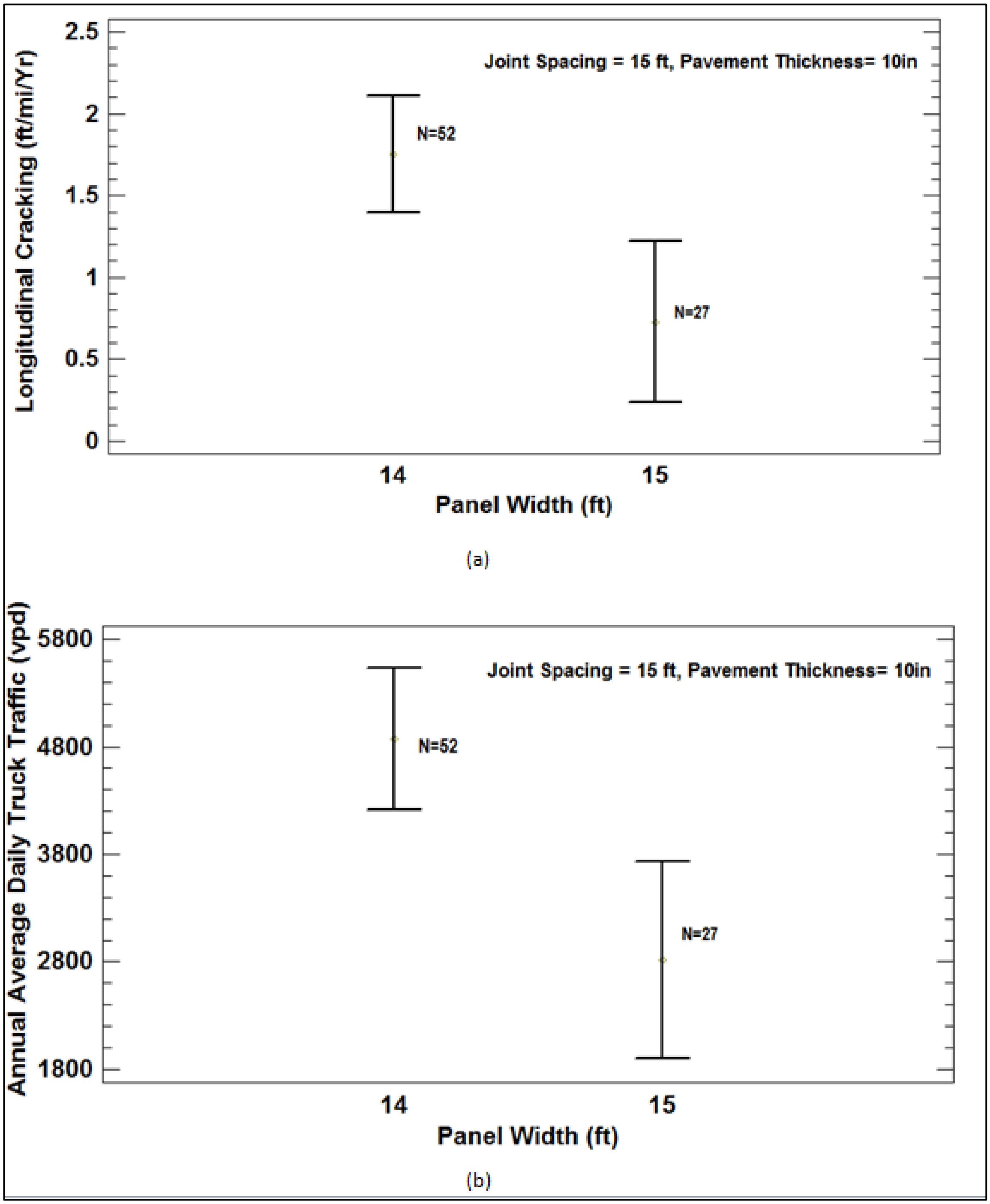

Figure 2: Comparison of Longitudinal Cracking and Truck Traffic for Panels at 15-ft Joint Spacing (Thickness =10in)

Panel Width Impact on Longitudinal Cracking at 16-ft Joint Spacing

At a joint spacing of 16ft, the longitudinal cracking exhibited by a 9 in. pavement shows a progression and significant differences between the 12-ft panel and each of the other two panel widths as shown in Figure 3. The difference in mean cracking between the 14- and 15-ft panels is not significant. Hence, the best performance at a joint spacing of 16ft may be attained by using 12-ft panels.

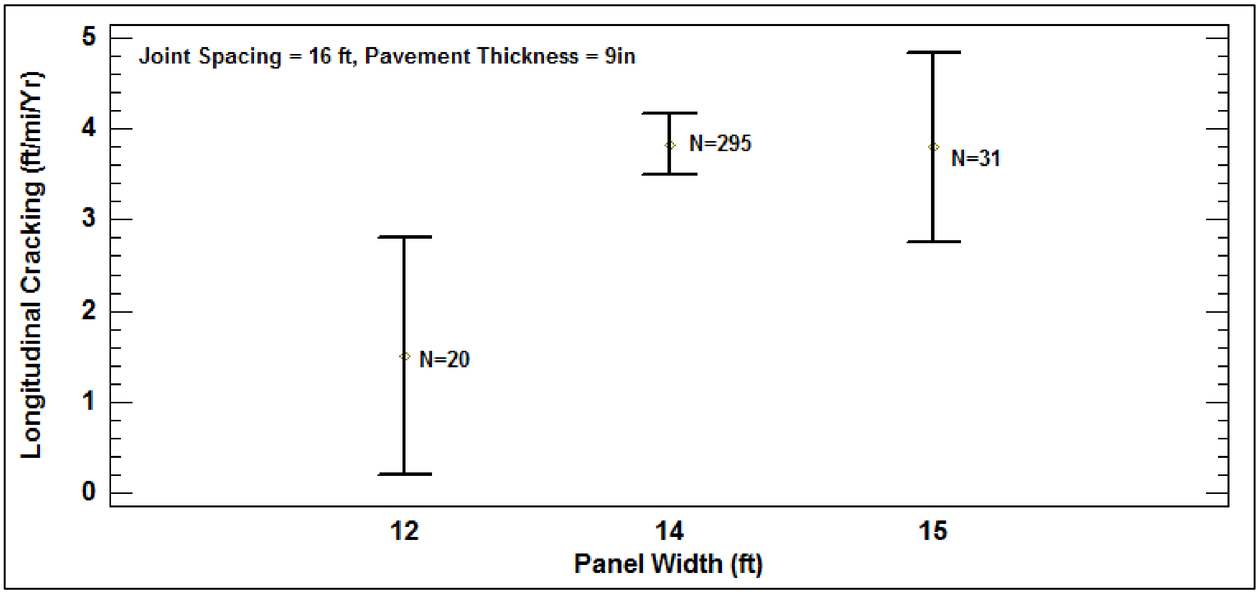

Figure 3: Comparison of Longitudinal Cracking for Panels at 16ft Joint Spacing (Thickness = 9in)

4.1.3 Panel Width Impact on Longitudinal Cracking at 18-ft Joint Spacing

Although Figure 4 part (a) shows a slightly higher level of cracking in the 14-ft panel than the 15-ft panel at a joint spacing of 18ft for a 9-in pavement thickness, the difference is not statistically significant. The higher level of cracking in the 14-ft panel may be attributed to the higher level of AADTT that occurred on the 14-ft panels as shown in Figure 4 part (b).

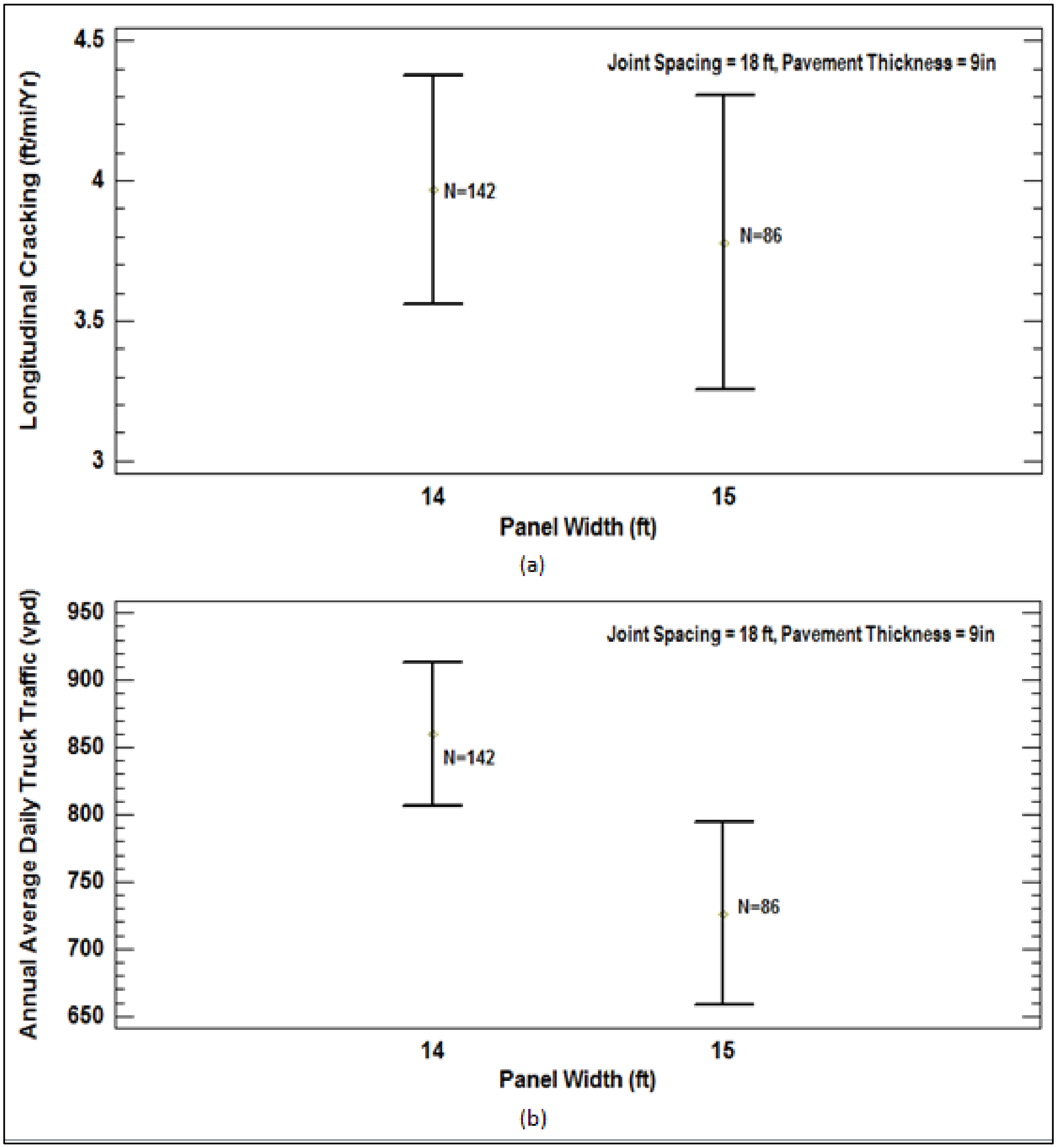

Figure 4: Comparison of Longitudinal Cracking and AADTT for Panels at 18ft Joint Spacing (Thickness = 9in)

Panel Width Impact on Longitudinal Cracking at 20-ft Joint Spacing

At a joint spacing of 20ft and for a 9-in pavement thickness, there are no statistically significant differences between the panel widths in terms of longitudinal cracking as shown in Figure 5. However, the larger panels (14ft and 15ft wide) exhibit higher mean cracking levels compared to the 12-ft panels.

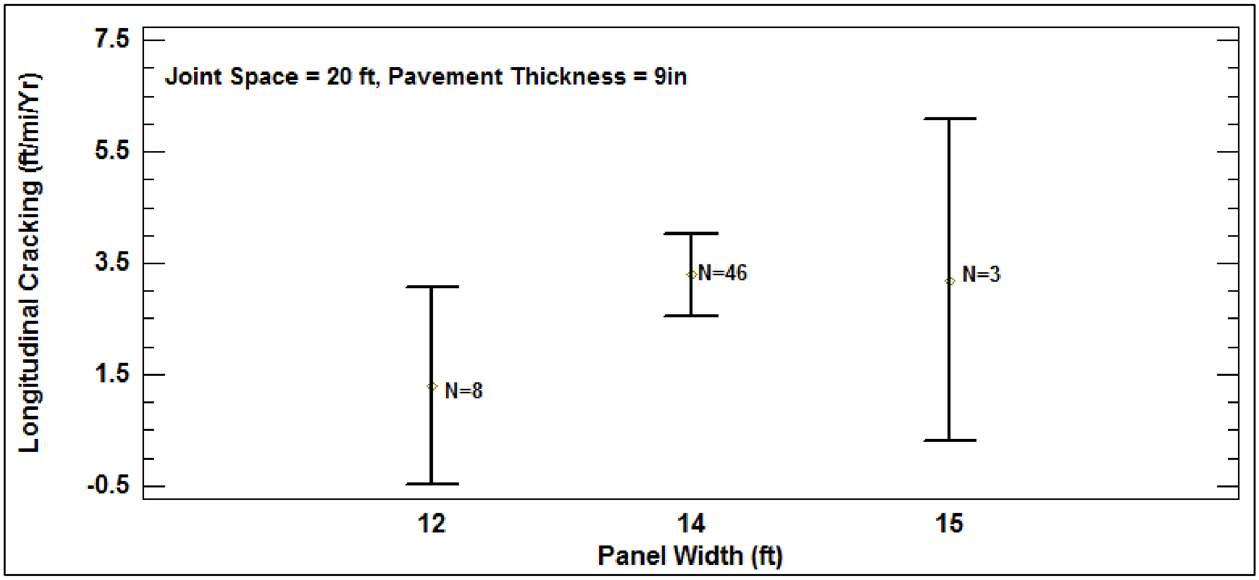

Figure 5: Comparison of Longitudinal Cracking for Panels at 20ft Joint Spacing (Thickness = 9in)

Joint Spacing Impact on Longitudinal Cracking

The next phase of the analysis was to examine the impact of joint spacing on the mean longitudinal cracking in feet per mile per year for each panel width class (12ft, 14ft, 15ft) when the panel width class has the same pavement thickness at the different joint spacings. A one-way ANOVA was again used based on the following hypothesis of equal population means:

$$H_0: \mu_{LC15pwiH} = \mu_{LC16pwiH} = \mu_{LC18pwiH} = \mu_{LC20pwiH}$$

$$H_A: \mu_{LC15pwiH} \neq \mu_{LC16pwiH} \neq \mu_{LC18pwiH} \neq \mu_{LC20pwiH}$$

Where,

$\mu_{LC15pwiH}$ = Mean value of longitudinal cracking in feet per mile per year associated with 15-ft joint spacing for panel width i for pavement thickness H

$\mu_{LC16pwiH}$ = Mean value of longitudinal cracking in feet per mile per year associated with 16-ft joint spacing for panel width i for pavement thickness H

$\mu_{LC18pwiH}$ = Mean value of the average longitudinal cracking in feet per mile associated with 18-ft joint spacing for panel width i for pavement thickness H

$\mu_{LC20pwiH}$ = Mean value of the average longitudinal cracking in feet per mile associated with 20-ft joint spacing for panel width i for pavement thickness H

P_{wi} = Panel width class (12ft, 14ft, and 15ft)

Joint Spacing Impact on Longitudinal Cracking for 12-ft Panels

For a panel width of 12ft and 9in pavement thickness, there is a significant statistical difference between the 15-ft joint spacing and each of the two longer spacings as shown in Figure 6 part (a). The shorter joint spacing is characterized by a higher mean cracking level than the longer spacings. A further review of pertinent truck traffic data presented in Figure 6 part (b) shows the anomaly may be due to the higher percentage of truck traffic associated with the pavements segments with shorter joint spacing.

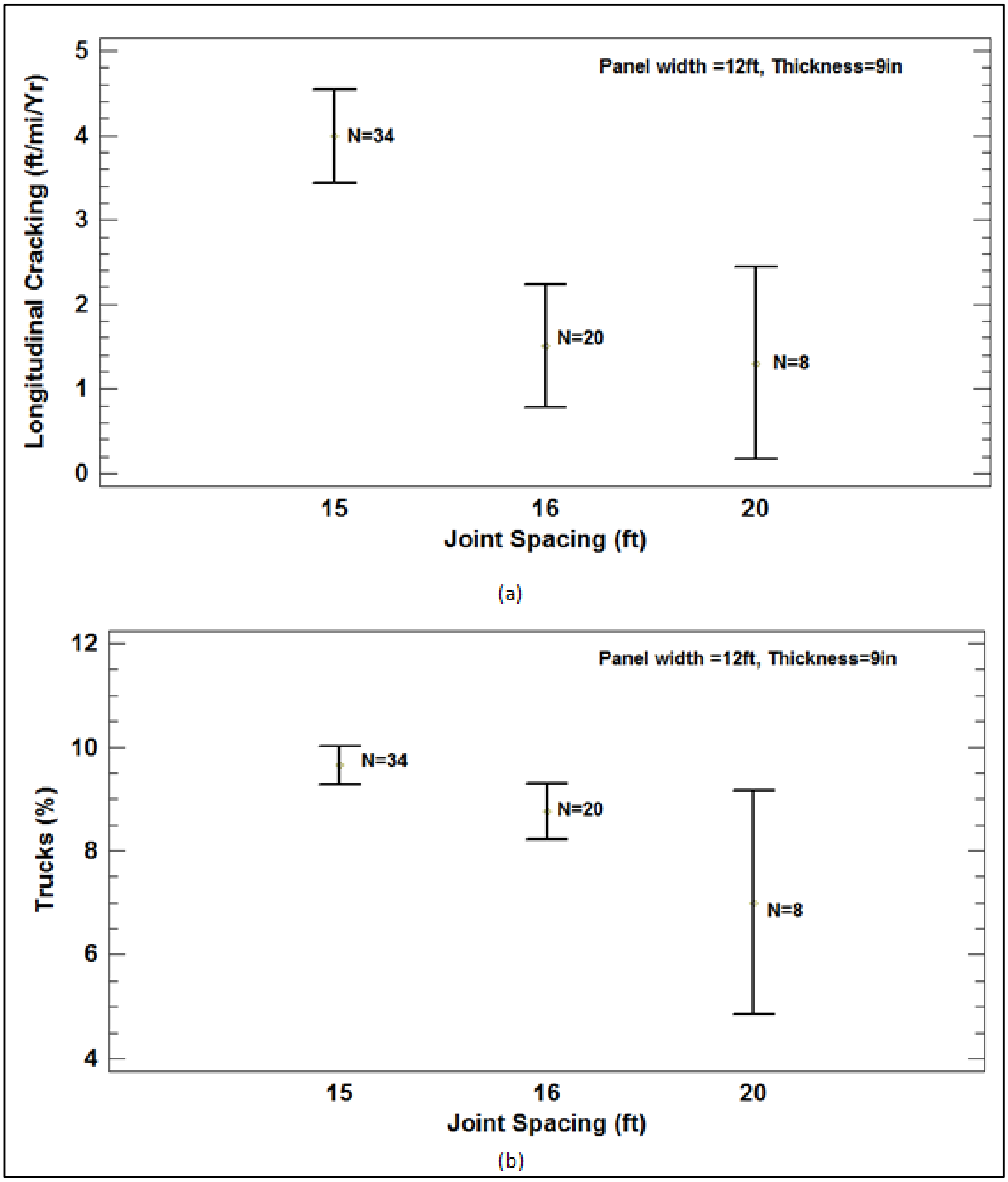

Figure 6: Comparison of Longitudinal Cracking and Truck Traffic for 12-ft Panels at Various Joint Spacings (Thickness =9 in)

Joint Spacing Impact on Longitudinal Cracking for 14-ft Panels

For the 14-ft panels, the amount of mean longitudinal cracking exhibits a random pattern among the joint spacings for the 9-in thickness and the differences are significantly different at least between the 15-ft and each of the other longer joint spacing as shown in Figure 7 part (a). Figure 7 part (b) shows that the random pattern is almost identical to the percent of trucks experienced by the pavement segments at the various joint spacings. Therefore, a 15-ft joint spacing will produce the better performance for a 14-ft panel. For the 10-in thickness, Figure 8 shows a general expected progression of cracking from shorter to longer joint spacings.

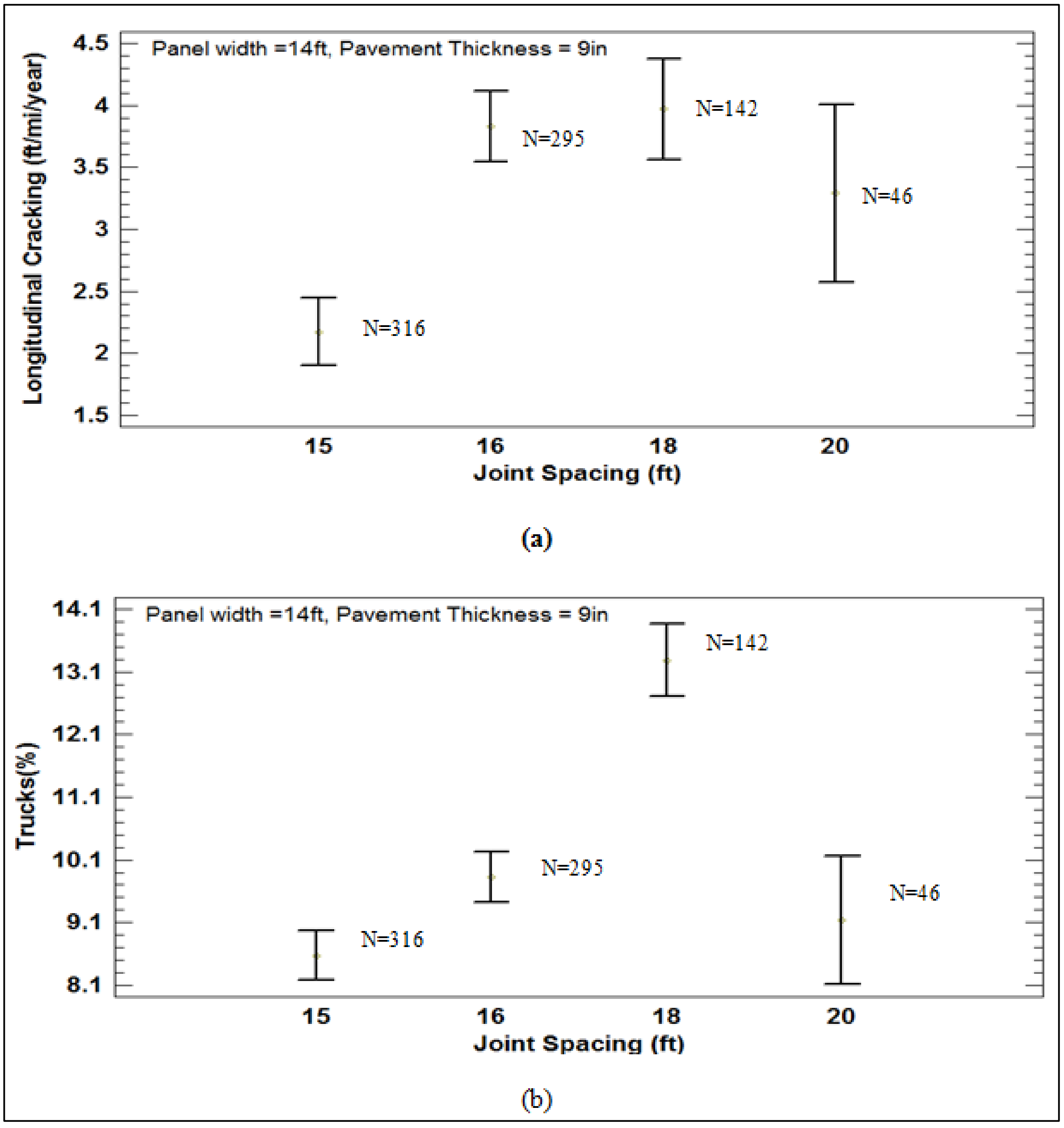

Figure 7: Comparison of Longitudinal Cracking and Truck Traffic for 14-ft Panels at Various Joint Spacings (Thickness = 9in)

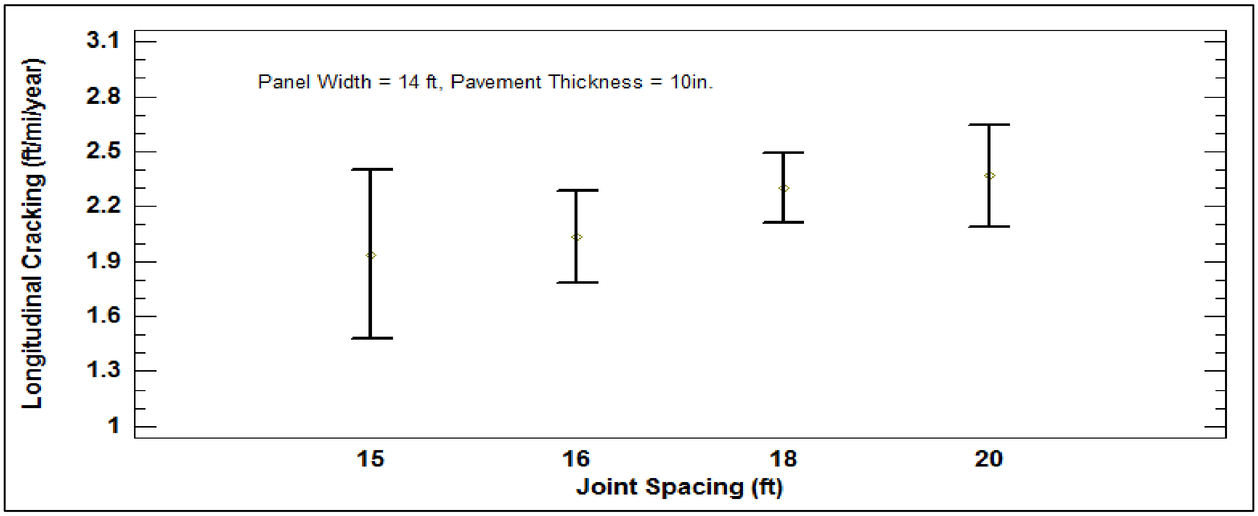

Figure 8: Comparison of Longitudinal Cracking in 14-ft Panels at Various Joint Spacings (Thickness =10in)

Joint Spacing Impact on Longitudinal Cracking for 15-ft Panels

From Figure 9, significant statistical differences exist in the mean longitudinal cracking between the shorter 15-ft joint spacing and each of the longer joint spacings for the same pavement thickness of 9 in. However, there is no significant statistical difference in the mean longitudinal cracking between the 16-ft and 18-ft pavement. In general, a lower mean cracking value is experienced at the lower joint spacing compared to the longer spacings.

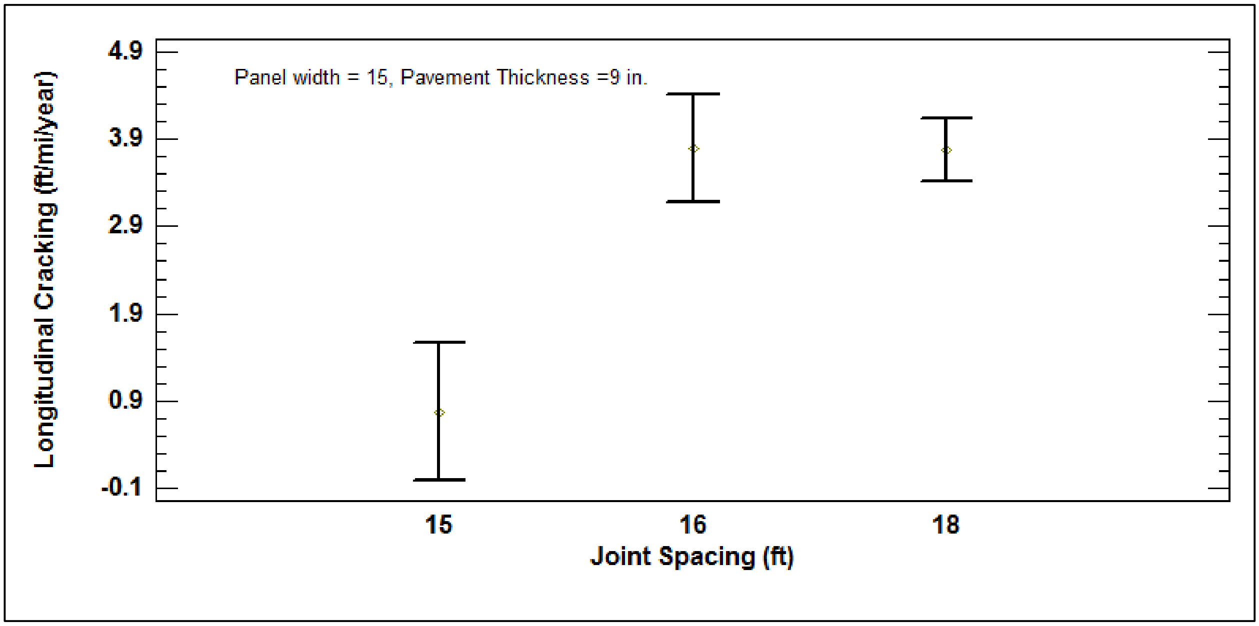

Figure 9: Comparison of Longitudinal Cracking in 15-ft Panels at Various Joint Spacings

Longitudinal Cracking Models

Traffic in the form of percent trucks, AADT, or AADTT appeared to have influenced the mean longitudinal cracking for some cases in the previous analyses. Hence, models were developed to help explain the variation in longitudinal cracking per mile per year associated with specific panel widths at known joint spacings and known thicknesses. Table 2 is a summary of models that showed significant statistical relationships between longitudinal cracking and traffic. The longitudinal cracking per mile per year shown in the models ignores cracking severity with the exception of models 6 and 7 for the 14-ft panel, which establish significant statistical relationships between longitudinal cracking at severity level 2 (> 1/2in crack width ≤ 2in) and AADT for the 14-ft panel at 16ft and 20ft joint spacings with pavement thickness equal to 10 in.

For the traffic variable represented in the models, AADT is the controlling factor for explaining longitudinal cracking variations in 10-in 14-ft wide panels at 16-ft and 20-ft joint spacings. For 12-ft wide panels, the percent trucks appeared to be the dominant factor in explaining longitudinal cracking variations at a joint spacing of 15ft for a 9-in pavement thickness and at joint spacings of 16ft, 18ft, and 20ft for pavement thickness of at least 12 in. For 15-ft wide panels with a 9-in thickness, the percent truck is the prevailing factor for variations in longitudinal cracking for joint spacings of 16ft and 18ft.

Table 2 Longitudinal Cracking Models for Concrete Pavement Panels

Model #	Panel Width (ft)	Joint Spacing (ft)	Pavement Thickness (in)	Model Form	Model R^2 (%)	Model F-ratio	Degrees of Freedom, n	Model Parameter, P-value
1	12	15	9	$L_{cpmpy} = \frac{1}{\left(-0.144036 + \frac{6.5648}{T}\right)}$	17.7	7.76	37	0.0085
2		16	12	$L_{cpmpy} = \sqrt{\left(0.416358 + 0.00073436T^2\right)}$	68.1	23.44	12	0.0005
3		18	≥12	$L_{cpmpy} = \frac{1}{\left(0.00756561 + \frac{11.367}{T}\right)}$	59.4	24.89	18	0.0001
4		20	12	$L_{cpmpy} = 0.584125 + 0.0121531\,T$	60.1	16.54	12	0.0019
5	14	16	10	$L_{cpmpy} = \sqrt{\left(-7.90575 + 3.98494x10^{-8} AADT^2\right)}$	41.6	110.24	157	0.0000
6*		16	10	$L_{cpmpy} = \sqrt{\left(-16.5679 + 5.15232x10^{-8} AADT^2\right)}$	56.9	104.25	80	0.0000
7*		20	10	$L_{cpmpy} = -2.91719 + 0.0368389\sqrt{AADT}$	19.3	12.71	54	0.0008
8	15	16	9	$L_{cpmpy} = \sqrt{\left(-56.9081 + 2.20392T^2\right)}$	75.7	90.21	30	0.0000
9		18	9	$L_{cpmpy} = Exp\left(2.06118 - \frac{10.0222}{T}\right)$	37.2	49.7	85	0.0000

L_{cpmpy} =Longitudinal cracking in feet per mile per year; T =% trucks, AADT = Annual Average Daily Traffic in vehicles per day.

*Model represents Longitudinal cracking at severity level 2

Summary and Conclusions

The Wisconsin Department of Transportation (WisDOT) began the construction of widened concrete pavements (>12ft panels) in the early 1990's with the objective of reducing stress and deflection at the pavement edge of smaller panels (≤ 12ft) due to tire loads near the slab edge. Subsequent field evaluation revealed that the additional 2-3ft paved beyond the normal traffic path was successful in eliminating the hazard of edge drop off at the edge of the 12-ft driving lane, and also reducing shoulder maintenance cost. However, the use of larger panels may have made the pavement more susceptible to other forms of distress, specifically, longitudinal cracking. This prompted a study by WisDOT to examine the prevalence of longitudinal cracking in wider JPCP panels and to understand the factors attributable to the cracking phenomenon.

This paper presented the results of comparative analyses of longitudinal cracking occurring in 12-, 14-, and 15-ft wide concrete panels focusing on four main factors including joint spacing, thickness, traffic, and pavement age. On the basis of the analyses, it is concluded that:

- For the same pavement thickness and joint spacing, panel widths of 12ft and 14ft that exhibited higher amount of longitudinal cracking than the 15-ft panel, received corresponding higher levels of truck traffic than the larger 15-ft panel.
- A 9-in pavement thickness at a joint spacing of 20ft experienced a higher amount of cracking in 14- and 15-ft wide panels than in a 12-ft wide panel.
- For a 9-in pavement thickness at a joint spacing of 16ft, the best performance may be attained by using 12-ft wide panels.
- For a 14-ft wide panel with 9in or 10in thickness, the best performance may be attained using a 15-ft joint spacing.
- AADT is the controlling factor in explaining longitudinal cracking variations in 14-ft wide panels with 16ft and 20ft joint spacings and having a thickness 10-in.
- For 12-ft wide panels, percent trucks is the dominant factor in explaining longitudinal cracking variations at a joint spacing of 15ft for a 9-in pavement thickness. For a pavement thickness of at least 12 in., longitudinal cracking variation is explained by the same factor except at joint spacings of 16ft, 18ft, and 20ft.
- For 15-ft wide panels with a 9-in thickness, the percent truck is the prevailing factor for variations in longitudinal cracking for joint spacings of 16ft and 18ft.

References

Ardani, A., Hussain, S., and LaForce R. (2003). "Evaluation of Premature PCCP Longitudinal Cracking in Colorado", Colorado Dept. of Transportation Research Branch, Report No. CDOT-DTD-R-2003-1, Denver, CO.

Corley-Lay and Morrison (2002). "Thirty-three –year Performance of Jointed Concrete Test Sections in North Carolina."*Journal of The Transportation Research Board*, No. 1806, 88-94.

Federal Highway Administration (2005). "Computer-Based Guidelines For Concrete Pavements Volume II-Design and Construction Guidelines and HIPERPAV II User's Manual", FHWA-HRT-04-122 Report, Washington, D.C. 2005.

Halm, H.J., W.A. Yrjanson and E.C. Lokken (1985). “Investigation of Pavement Cracking Utah I-70, Phase I Final Report”, ID-70-1 (31) 7, American Concrete Pavement Association, Arlington Heights, IL.

Okamoto, P. A., Nussbaum, P.J., Smith, K.D., Darter, M.I., Wilson, T.P., Wu, C.L., Tayabji, S.D. (1994). “Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements, Volume 1: Final Report”, FHWA-RD-91-079, FHWA, U.S. Department of Transportation.

Richardson, J.M., and Armaghani, J.M. (1987). "Stress Caused by Temperature Gradient in Portland Cement Concrete Pavement. *Transportation Research Record 1121*, TRB, National Research Council, Washington, D.C., pp.7-13.

Smith, G. (2011). Personal Communication, Iowa Concrete Pavement Association, 2011.

Voigt, G.F. (2011). Personal Communication, ACPA, June 2011.

Voigt, G.F. (1992). “Cracking on Highway 115 Petersborough, Ontario”, American Concrete Pavement Association, Arlington Heights, IL.

Voigt, G.F. (1994). “Investigation of Pavement Cracking on General Aviation Airport, Fremont Nebraska”, American Concrete Pavement Association, Arlington Heights, IL.

Weiss, W.J. (1999). "Prediction of Early Age Cracking in Concrete," PhD thesis, Northwestern University, Evanston, IL.