Impact of Joint Sawing Timing and Depth on Random Cracking: A Case Study

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Abstract
The joint sawing "window" has long been recognized as critical to provide a saw cut that is (1) not too early and damages the surrounding concrete, and (2) not too late and results in random slab cracking. The depth of sawcut has also been recognized as critical to providing an adequate weakened plane that sufficiently minimizes the potential of random cracking but provides as much aggregate interlock as possible for load transfer. Both of these aspects of joint formation must be done properly or serious problems such as random cracking can develop. This JPCP project was constructed in a wet-freeze climate in North America that developed significant early longitudinal cracking. Data collected from the project led to an analysis that demonstrates how both time until saw cutting and depth of the saw cut correlated strongly with the amount of random longitudinal cracking that occurred within a few months after placement. Results showed that had the joints been formed within the specification limits for depth and timing there would have almost no chance of random longitudinal cracking.

Pavement Design

A jointed plain concrete pavement (JPCP) was constructed during October and November in a wet-freeze climate in North America. The pavement design was as follows:

- Slab thickness = 200 mm.
- Permeable asphalt treated base course = 100 mm (crushed rock stabilized with 1.8 percent asphalt binder).
- Granular subbase = 100 mm.
- Subgrade (fine grained sandy silt).

The transverse joint spacing was a random skewed sequence of 4.0, 5.8, 5.5, and 3.7 m. Dowels were placed at transverse joints that were 30 mm diameter spaced at 300 mm on center. The cross-section was as follows:

- 1 m tied PCC shoulder (outer lane shoulder)
- 3.75 m traffic lane slab (outer lane)
- 3.75 m traffic lane slab (passing lane)

Note that the full 8.5 m width of the slab was paved at the same time.

Pavement Cracking

By early March of the next year, about 35 percent of the project length contained slabs that had cracked longitudinally. Over 92 percent of these cracks were within the outer lane with the tied PCC 1 m shoulder. It is noted that the outer lane/shoulder longitudinal joint did not crack through, thus effectively making the outside slab width 3.75 + 1.0 = 4.75 m. Slab widths of this magnitude (typical width of ramps) have very often exhibited longitudinal cracking. That is why nearly all longitudinal cracks are in this traffic lane. Figure 1 shows a photo of the cracking.

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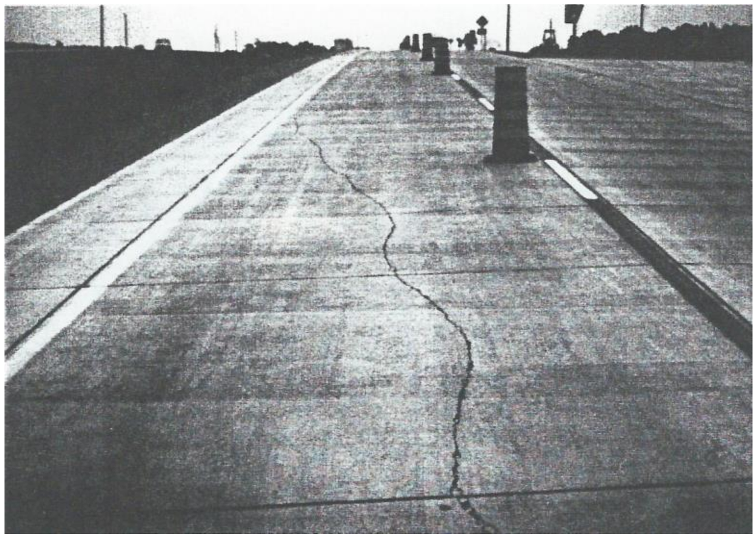

Figure 1. Photo showing longitudinal cracking on outside lane on a section of JPCP.

Figure 2 diagrams the longitudinal cracking on a section of the highway. Several of the longitudinal cracks had spalled and were slightly faulted. Nearly all of the cracking was in the outer traffic lane and not the passing lane due to the 3.75 + 1.0 = 4.75 m wide slab where the lane/shoulder joint did not form and provide a stress relief crack.

An investigation was conducted to determine the cause of the early longitudinal cracking with the following considerations.

- Materials used in pavement construction.
- The underlying soils.
- Construction procedures, including sawcut depth and time to sawing.
- The pavement and ambient air temperatures during installation, curing, and through the first winter.
- The cracking patterns in the pavement.

The data collected for each of these aspects included visual inspection of the pavement, additional coring of the longitudinal joints and cracks, analysis of the level of frost penetration into the pavement and subgrade, review of construction and inspection records, and discussions with those involved with the construction.

Construction and Joint Sawing

According to the contractor, the saw cutting was done as soon as equipment could get on the pavement. In general, cutting of the transverse joints was completed in 10-12 hours and the longitudinal joints were completed later. Note that no random transverse cracks developed on the entire project.

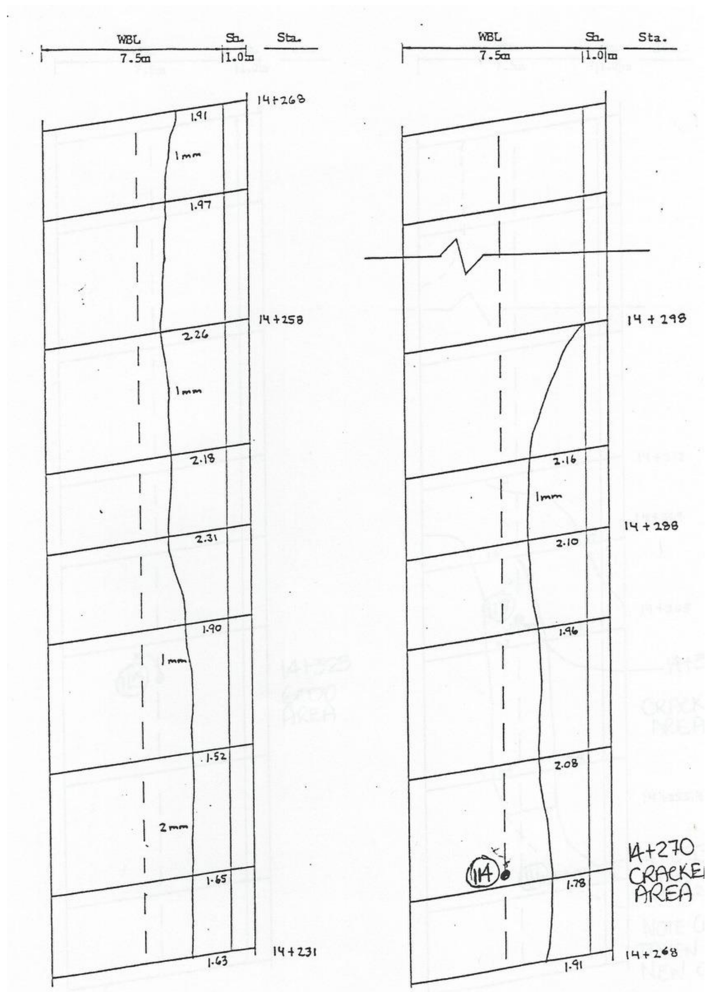

Figure 2. Illustration of longitudinal cracking on a section of the highway.

The specifications allowed no more than 12 hours after passage of the slipform paver for the initial longitudinal and transverse joints to be sawn. According to the inspector's notes, this requirement was not met in part due to the slow curing of the concrete as a result of cool temperatures.

Pavement Cores

Cores were cut for the pavement through the longitudinal centerline joint between the two traffic lanes (termed centerline joint). A plot of sawcut depth along the project is shown in Figure 3. The statistics from the cores are summarized as follows:

- The depth of longitudinal sawcut from the cores ranged from 33 to 67 mm. The specifications called for T/3 minimum depth. Thus, 200/3 = 67 mm was the minimum to meet the specification. All of the measured sawcut depths were less than the T/3.
- Thickness of each core was measured and ranged from 200 to 240 mm, with an average of 216 mm. Percent sawcut depth of actual slab thickness along the pavement ranged from 15 to 32 percent, averaging 25 percent. None of the sawcut depths met the specified minimum 33 percent of the pavement thickness.

- Inspection of some cores indicated that cracking occurred mainly (about 55 percent for a given core) around the aggregates rather than through them indicating early fracture.

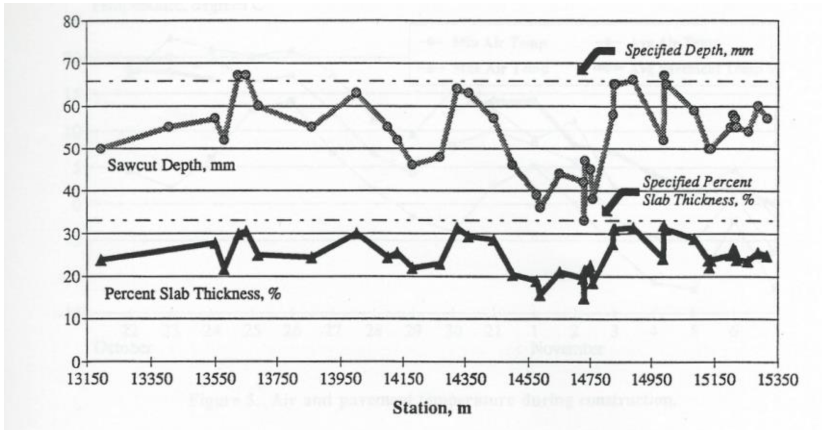

Figure 3. Sawcut depth and percent sawcut depth of slab thickness.

Temperature Conditions during Construction and Curing
Climatic conditions during the construction and curing of the concrete were less than ideal, but steps were taken (protective covers on the new concrete) to protect the maturing concrete from freezing for several days of paving. The cool temperatures contributed greatly to the delay in joint sawing times to achieve sufficient strength to avoid concrete damage when sawing.

Description of Cracking
Longitudinal cracking of slabs in the newly constructed pavement was first reported in December. By March, longitudinal cracking had increased significantly, and a survey indicated that about 35 percent of the concrete slabs contained longitudinal cracks. In August, the pavement was re-surveyed and the locations of new cracks were recorded and used in the analysis. Crack maps were prepared as illustrated in Figure 2. A summary of the longitudinal slab cracking that occurred is shown in Table 1.

Table 1. Summary of Percent Longitudinal Cracks Along the Project.

Evaluation Date	**Percent Cracked Slabs, Percent**	
	Outside (Truck) Lane*	**Passing Lane****
March	37.7	3.0
August	39.6	11.7

*Outside (Truck) Lane is 3.75 m wide adjacent to a 1.0 m wide shoulder.
**Passing Lane is 3.75 m wide with no tied shoulder.

When the sawcut depth was less than T/3, cracking occurred in 59 percent of adjacent slabs for the 44 cores drilled in the centerline joint. Of the 11 cores in which the sawcut depth was less than T/4, 91 percent slabs were cracked.

Causes of Longitudinal Cracking
Longitudinal cracking outside the centerline sawcut of new concrete pavement can result from one or a combination of several factors. Major factors evaluated in this study include:

- Centerline sawcut depth to form an adequate weakened plane.
- Time delay between PCC placement and initial sawing of the longitudinal joints.
- Differential frost heaves resulting from differential soil expansion caused by ice lens formation, and producing heaving such that only longitudinal cracking occurs.

Longitudinal Sawcut Depth Analysis
The mean joint saw depth percentage and mean percentage of adjacent cracked slabs were summarized for each day of paving. The resulting relationship is shown in Figure 4. The correlation is significant with an R-Squared of 79 percent. This indicates that the percent of adjacent cracked slabs increases as the percent of joint saw depth decreases. This finding is of course not new and has been observed for decades and what lead to the T/3 specification for minimum percent depth of saw cut. The results in Figure 4 shows why specifications require a minimum depth of saw cutting: to ensure that an adequate weakened plane will exist so that no random cracking will develop. This graph has limitations, however, because the time delay of joint sawing is confounded within this data.

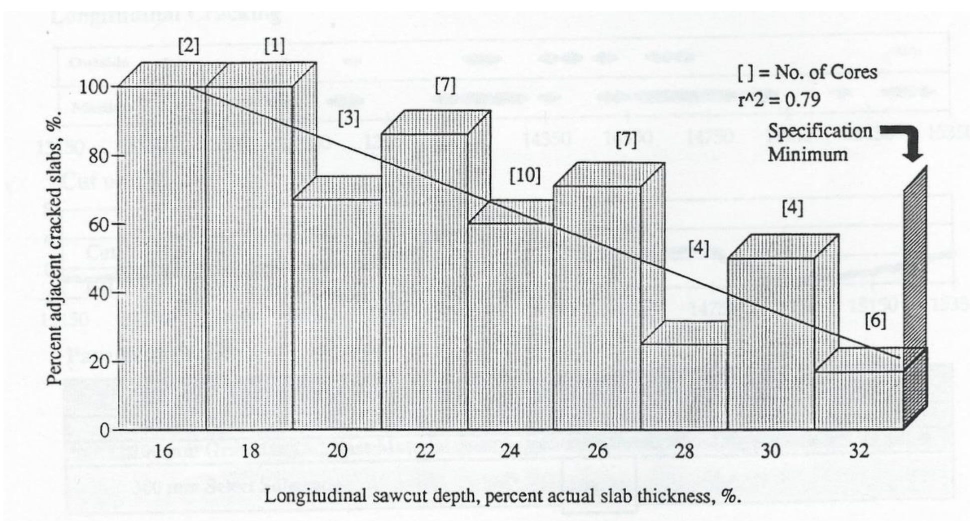

Figure 4. Relation of longitudinal sawcut depth (percent of thickness) to percent of adjacent longitudinal cracked slabs over the project.

Delay Between PCC Placement and Longitudinal Sawcutting
Comparisons were then made between sawing delay and the presence of longitudinal cracks in adjacent slabs. Figure 5 shows a plot of mean Percent Adjacent Cracked Slabs versus Time Between Placement and longitudinal joint sawing in hours. The R-Squared for this plot is 58 percent and represents a reasonable correlation. As the time between placement and longitudinal joint sawing increases, the percent adjacent cracked slabs increase also. This result is again expected and shows the risks of delays in sawing. However, includes the confounding effects of joint saw depth on longitudinal cracking.

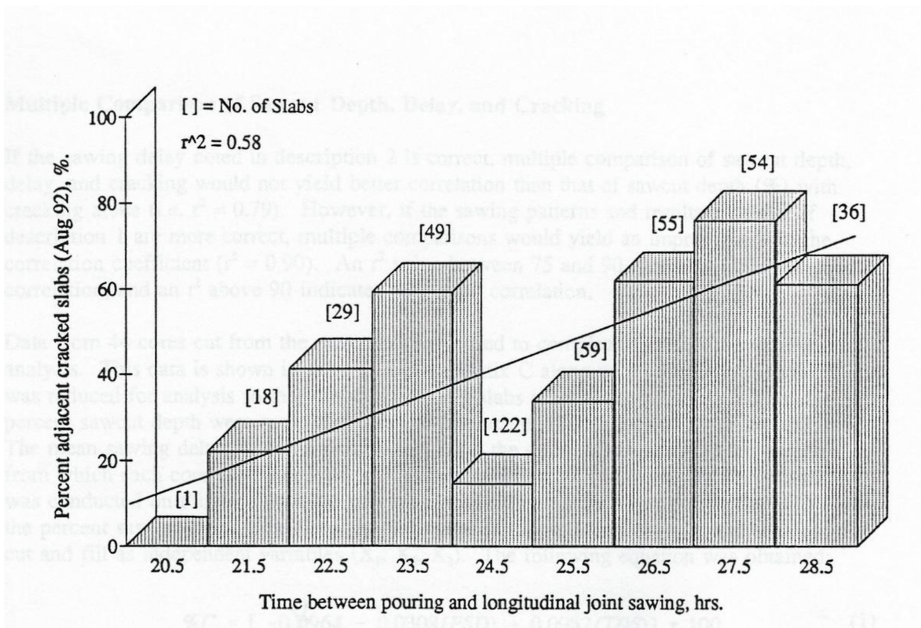

Figure 5. Relation of sawing delay to cracked adjacent slabs.

Visualization of Sawcut Depth, Delay, and Cracking

To more effectively determine the effects of both saw depth and delay in sawing, multiple regression was performed to effectively show the simultaneous impact of both factors on longitudinal cracking. The following equation was derived from the data that includes the impact of both sawcut depth and time delay.

$$\%\ \text{Longitudinal Cracked Slabs} = [\ -0.964 - 0.0308\ PSD + 0.0957\ TDS\ ]*100 \qquad [1]$$

Where:

% Longitudinal Cracked Slabs = Percent adjacent longitudinally cracked slabs, %
PSD = Percent Sawcut depth of slab thickness, %
TDS = Time Delay between placement and longitudinal joint sawing, hours

Statistics:

$R^2 = 0.90$
Standard Error = 10.9 %
N = 9 (number of increments in percent sawcut depth based on daily placement)

This equation has a high R-Squared as well as reasonable standard error of the estimate. Figure 6 compares the actual percent of cracked slabs with the percent predicted by Equation 1 for each paving increment day. The correlation is very good, and the residuals are small, random, and centered around zero, indicating that the linear equation is adequate and the model predicts the data well.

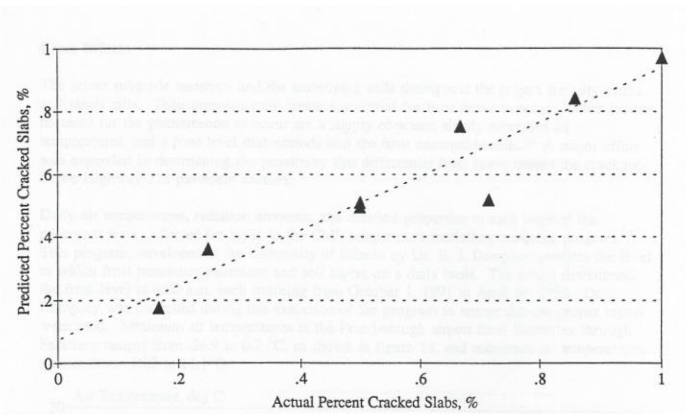

Figure 6. Predicted versus actual percent longitudinal cracked slabs based on Equation 1.

Figure 7 illustrates the overall results graphed from equation 1 in three dimensions with percent longitudinal cracked slabs as a function of sawing delay (hours) and sawcut depth (percentage of slab thickness). When both joint forming variables are considered simultaneously, the prediction ability is much better (e.g., 90 percent) than separately.

The project specification limits are indicated on Figure 7 (33 percent sawcut depth and 12 hours maximum sawing delay) that clearly indicates that had the joints been formed within the specification limits there would have almost no chance of random longitudinal cracking. These results demonstrate simply but effectively how both of these aspects of joint formation must be fully considered to avoid random cracking on a given project. Of course, these results for sawcut depth and timing cannot be extrapolated directly to other projects with differing materials and pavement designs, and climates, but the concepts are applicable to all projects.

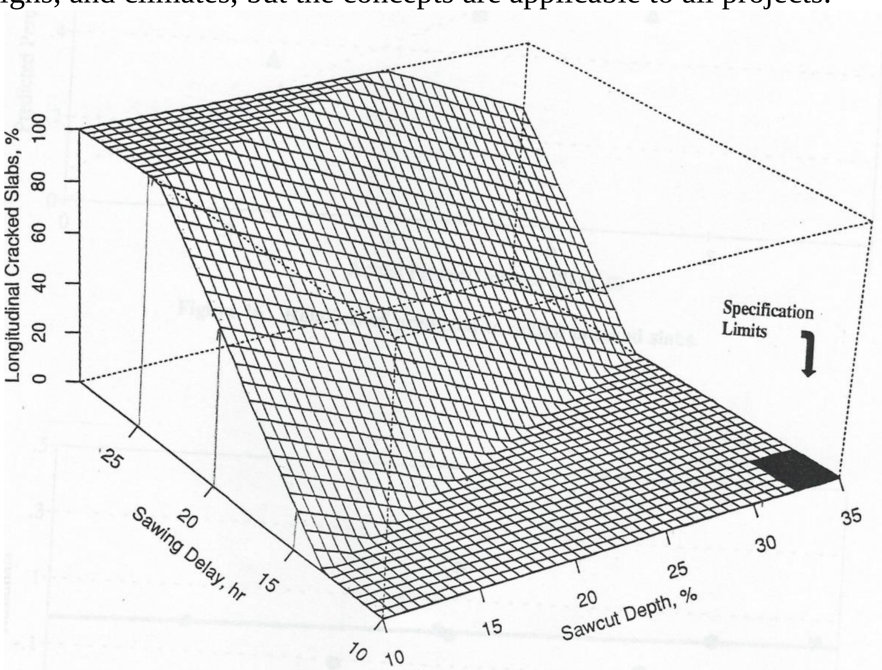

Figure 7. Relation of sawing delay and sawcut depth to random slab adjacent longitudinal slab cracking derived from Equation 1 for the project under consideration.

Frost Effects

A major effort was expended in determining the possibility that differential frost heave caused the longitudinal cracking. The Integrated Climatic Model (ICM) developed at the University of Illinois was used to compute frost depths on an hourly basis throughout the winter months. There was no frost penetration into the subgrade until mid-January. The maximum level of penetration only reached the top 42 mm of the select subgrade material and never reached the underlying soils. The frost line remained in the select subgrade material for only 1 to 2 weeks. As a result it is highly unlikely that any ice lenses could have developed and that differential frost heave damage occurred.

Research Significance

Based on the review of project records, visual surveys, coring results, soils evaluation, frost depth analysis, and statistical comparisons, two factors are believed to be responsible for a large portion of the longitudinal cracking in this project.

- The ratio of depth of the initial sawcut to the concrete slab thickness. As the ratio decreased the amount of longitudinal cracking increased. The saw depth did not meet the T/3 specification requirement throughout the project. Over 35 percent of the adjacent slabs developed longitudinal cracking some of which spalled and became working within a year of opening to traffic. The T/3 minimum saw depth is critical to prevent longitudinal cracking.
- The time delay between concrete placement and longitudinal joint sawing. The longer this delay, the more longitudinal cracking occurred throughout the project. Part of the problem was the cooler weather resulted in insufficient curing of the PCC to prevent raveling during the sawing operation which delayed the sawing, increasing the risk of random cracking.

Other factors that did not show any relationship to cracking included cut and fill depths beneath the pavement, differential frost heave, cold weather curing, unstable support materials, and early loading by sawing equipment. A few other practical comments are provided:

- When a saw depth specification, such as T/3 minimum is set on a project, continuous checking of saw depth is required. If there is reason to believe that the concrete slab will actually be thicker than T, the design thickness, an adjustment of the depth of sawcut should be considered. On this project the porous asphalt treated base resulted in some concrete mix infiltrating into the top of the open graded asphalt treated base resulting in a thicker slab than anticipated. A thicker slab can also occur in transition slabs that require an increased thickness so saw depth must be adjusted to provide T/3 minimum.
- If a project cannot be sawed within the specification limits due to cold temperatures or some other reason due to raveling during the trial sawcut, then special attention must be paid to the section in question to make sure that sawing is expedited as soon as possible for longitudinal joints to minimize the risk of random cracking.
- Designing a project with a narrow PCC shoulder (e.g., 1 m) is risky because the tied longitudinal joint often may not crack even if the saw cut is sufficiently deep and sawed on time, resulting in increased potential for longitudinal cracking in the traffic lane. One prime example of this is on ramps, where narrow tied longitudinal joints are specified on each side of the ramp at the lane paint stripes. If the traffic lane is 3.7 m wide, then only

0.6 m of shoulders would exist on each side. Thus, a 0.6 m wide shoulder would exist with a sawed longitudinal joint. This joint often does not crack through, resulting in a crack down the traffic lane. This has occurred on many ramps with such a design. A far better solution is to simply place a tied joint at the center of the 4.9 m ramp and not two longitudinal joints on each side. The slab width of 2.5 m would not cause any problems.