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EVALUATION OF THE LONG TERM DURABILITY OF RIGID PAVEMENT JOINTS CUT USING EARLY-ENTRY SAWS

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Research Report ICT-11-076

A report of the findings of
ICT-R27-63
Evaluation of the Long-Term Durability of Joints Cut Using Early-Entry Saws on Rigid Pavement

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The investigation of early-entry sawing was integrated into an active construction project on Illinois Route 59 in Plainfield, IL featuring three 300-ft test sections (a control section cut to a depth of one-third of the slab thickness using a conventional wet saw, a test section cut to a depth of one-third of the slab thickness using an early-entry dry saw, and a test section cut to a nominal depth of 1.25 inches using an early-entry dry saw). During construction, paving and sawing operations were observed and documented; of particular interest were the sawing operations, during which signs of surface scarring, joint raveling, and slab edge breakouts were recorded and the extent of sawing-related damage was subjectively assessed. In addition to general pavement construction observations, climatic conditions were also monitored, along with pavement temperatures. Ambient climate conditions and slab mixture and temperature data were used to perform a HIPERPAV® analysis to assess the potential for early-age cracking. Compressive strength cylinders were also cast and tested at 3, 7, and 28 days.

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The investigation of early-entry sawing was integrated into an active construction project on Illinois Route 59 in Plainfield, IL featuring three 300-ft test sections (a control section cut to a depth of one-third of the slab thickness using a conventional wet saw, a test section cut to a depth of one-third of the slab thickness using an early-entry dry saw, and a test section cut to a nominal depth of 1.25 inches using an early-entry dry saw). During construction, paving and sawing operations were observed and documented; of particular interest were the sawing operations, during which signs of surface scarring, joint raveling, and slab edge breakouts were recorded and the extent of sawing-related damage was subjectively assessed. In addition to general pavement construction observations, climatic conditions were also monitored, along with pavement temperatures. Ambient climate conditions and slab mixture and temperature data were used to perform a HIPERPAV® analysis to assess the potential for early-age cracking. Compressive strength cylinders were also cast and tested at 3, 7, and 28 days.

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Members of the Technical Review Panel (TRP) overseeing the project include:

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Brian Pfeifer, Federal Highway Administration

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- Wight & Company

DISCLAIMER

EXECUTIVE SUMMARY

Early-entry sawing is an attractive operation to expedite the construction of jointed concrete pavements; however, there are some concerns that early-entry sawing may compromise the pavement's long-term performance. The Illinois Department of Transportation sponsored this study as an initial effort to investigate the feasibility of using early-entry sawing on rigid highway pavements without affecting expected long-term joint durability. Although not the focus of this research, the joint performance as a function of cut depth and time was also considered as there has been reported instances in which shallow, early saw cuts (less than one-fourth the pavement's thickness) did not initiate a crack through the pavement as intended when constructing transverse contraction joints in portland cement concrete (PCC) pavement (Wang et al. 2009).

The investigation was integrated into an active construction project along Illinois Route 59 in Plainfield, IL. The test site consisted of a 1000-ft section of new pavement having a relatively flat grade and uniform site conditions. The 1000-ft section was divided into three 300-ft test cells containing 20 joints each (a control cell cut to a depth of one-third of the slab thickness using a conventional wet saw, a test cell cut to a depth of one-third of the slab thickness using an early-entry dry saw, and a test cell cut to a nominal depth of 1.25 inches using an early-entry dray saw), and was paved within an 8-hour period using the same concrete mixture, plant, paver, and crew.

During construction, paving and sawing operations were observed and documented; of particular interest were the sawing operations, during which signs of surface scarring, joint raveling, and slab edge breakouts were recorded and the extent of sawing-related damage was subjectively assessed. A visual rating index was developed based on the extent of damage observed and used in subsequent visits in the months following construction to assess any possible further deterioration.

In addition to general pavement construction observations, climatic conditions were also monitored, along with pavement temperatures. Ambient climate conditions and slab mixture and temperature data were used to perform a HIPERPAV® analysis to assess the potential for early-age cracking. Compressive strength cylinders were also cast and tested at 3, 7, and 28 days.

Additionally, cores were retrieved from joints throughout the test site (6 cores from each test cell), and a battery of durability tests were conducted, including petrographic analysis, freeze-thaw testing, and susceptibility to salt scaling. Observations from the field construction and findings from the laboratory testing program are summarized in this report.

Overall, there were no notable differences in field performance or laboratory test results between the different joint sawing operations studied. The results of this preliminary investigation suggest that early-entry sawing is a viable approach to the creation of joints in PCC pavements. The technique presented no significant issues during the pavement construction, resulted in similar field performance, and laboratory analyses suggest that little to no damage to the concrete in the immediate area adjacent to the joint was caused as a result of early-entry sawing. However, the results of this study are based on very limited data collected from a single site constructed under very favorable conditions, therefore, before general adoption of early-entry sawing is implemented, a broader Phase II study is recommended in order to evaluate early-age PCC material characteristics during early sawing operations, as well as the pavement's long-term performance under different traffic levels, maintenance practices, environmental and climatic conditions, and so on.

CONTENTS

CHAPTER 1 INTRODUCTION

One critical operation in the construction of jointed portland cement concrete (PCC) pavements is the sawing of contraction joints. The joint sawing creates a weakened plane that forces a crack to develop below the saw cut, preventing random, or uncontrolled, cracking and while accommodating slab movement in response to temperature and moisture changes. However, the timing of the joint sawing activity is particularly critical. As conceptually indicated in figure 1, the goal is to saw the joints early enough after the PCC pavement has attained sufficient strength to allow the sawing operation to commence without incurring excessive raveling and/or tearing of the pavement surface, but not too late such that internal stresses develop in the slab that could lead to random cracking (Okamoto et al. 1994).

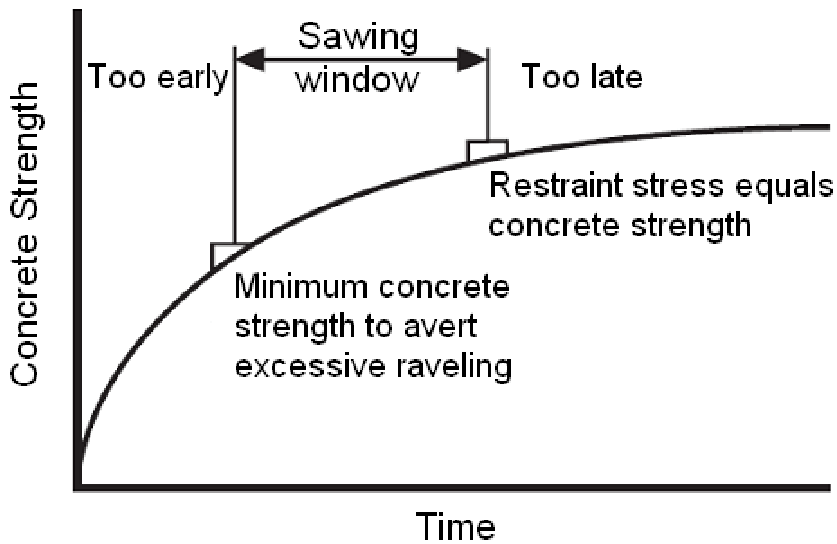

Figure 1. Illustration of concrete sawing “window” in terms of strength vs. time (Okamoto et al. 1994).

Speed of construction can be critical, especially in urban and/or high traffic volume areas, where delays lead to increased congestion and user costs. As will be discussed, early-entry sawing expedites construction, and therefore may be one factor allowing the contractor to accelerate construction without compromising long-term performance, which will benefit the Illinois Department of Transportation (IDOT). This research provides preliminary data evaluating the expected durability of joints cut using early entry techniques compared to conventional means and methods.

1.1 CONVENTIONAL JOINT SAWING

Conventionally, sawing contraction joints is usually initiated as the concrete reaches final set; however, a number of factors can influence when the concrete can satisfactorily undergo the rigors of sawing. For example, concrete mixture properties, such as cement content, type and amount of supplementary cementitious materials (SCMs), admixtures, mixture temperature, climatic conditions (such as ambient temperature, humidity, and wind), curing process, and restraint conditions (such as friction between the slab and underlying base) all factor into how soon sawing may begin. Typically, the conventional sawing window is from 4 to 12 hours after placement (Smith 2007). For most normal climatic paving conditions and pavement designs, it is desired that the sawing window be sufficiently long to complete all joint sawing activities with uniformly good results (Voigt 2000).

Unfortunately, there are occasionally some issues that increase the risk of poor performance arising from conventional joint sawing operations, including (ISU 2004):

- Early cracking due to base or subgrade restraint.
- PCC drying shrinkage.
- Temperature/moisture differential between base material and fresh concrete.
- Daytime/nighttime slab curling and warping.
- Random cracking due to late sawing or inadequate saw cut depth.

1.2 EARLY-ENTRY JOINT SAWING

Lightweight, early-entry saws were commercially introduced in the late 1980s as one way of reducing the potential risk of early-age cracking. Early-entry saws are much lighter than conventional sawing equipment, meaning that they can be used on concrete at an earlier age without marring the surface, typically within 1 to 4 hours of placement (Smith 2007). Moreover, it is postulated that the saw cut can be shallower at an early age, taking advantage of the significant changes in moisture and temperature conditions at the surface of the slab to help initiate cracking below the saw cut (Zollinger, Tang, and Xin 1994).

In addition to its lighter weight (early-entry saws are generally at least half the weight of conventional wet saws), early-entry saws differ from typical concrete pavement saws in operation by being dry (water is not used during the sawing operation) and cutting in an upward motion with respect to the advancement of the saw. Other than requiring a water source, the main difference between wet and dry saws is the type of blade used, specifically in terms of abrasion resistance. Basically, cutting soft, abrasive materials (e.g., green concrete) necessitates a blade with a hard, abrasion resistant matrix that firmly holds the embedded diamond cutting teeth to ensure they are fully utilized before shedding away (see figure 2 for a diagram of the main components of a concrete saw blade); on the other hand, a blade designed for cutting hardened PCC should have a soft bond to allow for ready exposure of new, sharp diamond cutting teeth (Balogh 2010).

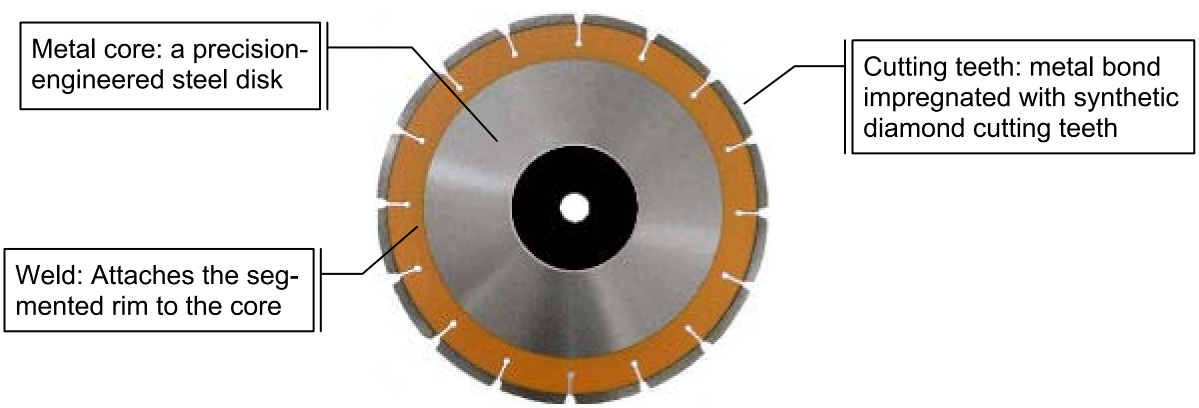

Figure 2. Concrete cutting saw blade diagram (Balogh 2010).

Furthermore, because early-entry saws cut upward as the saw advances, they are equipped with an anti-ravel skid plate. The skid plate slides over the pavement surface and is slotted to allow the saw blade pass through. The skid plate is intended to keep the relatively green concrete in place during sawing, as the upward cutting motion of the saw blade may lift and displace aggregates. The gap between the blade and the skid plate's slot edge is initially very narrow; however, normal wear and tear causes the gap to widen, increasing the risk of joint raveling (McGovern 2002).

When performing conventional joint sawing operations (i.e., sawing 4 to 12 hours after placement), the 1993 *AASHTO Design Guide* recommends that transverse contraction joints be sawed to a depth of one-fourth of the slab thickness (AASHTO 1993). The more recent Mechanistic-Empirical Design Guide (MEPDG) states that a cut depth of one-fourth of the slab thickness has generally worked well, but recommends a saw cut depth of one-third of the slab thickness for PCC slabs placed on permeable or stabilized bases (NCHRP 2004). Neither of these documents addresses the potential use of early-entry saws.

The American Concrete Institute (ACI), in its *Guide for Concrete Floor and Slab Construction*, recommends that saw cuts using conventional equipment be at least one-fourth the slab depth or a minimum of 1 in., whichever is greater (ACI 2004). At the same time, the document recognizes the use of early-entry saws, noting that early-entry saw cuts are typically between 1 and 1.25 inches deep because the early timing allows joints to be made before significant tensile stresses develop, thereby increasing the probability of cracks forming at the joint as intended when such stresses eventually do develop (ACI 2004).

1.3 STATE OF THE PRACTICE

Although the American Concrete Pavement Association (ACPA) online *Database of State DOT Concrete Pavement Practices* reports that at least 50 percent of U.S. state departments of transportation (DOTs) allow the use of early-entry sawing for transverse contraction joints (see table 1 noting that most states still require that conventional sawing depths are required), there is a significant absence of reported long-term performance data on the technique. Although the nature of the crack development in joints cut using early-entry methods is suggested in the literature to be satisfactory (i.e., initiating the crack in a suitable timeframe), it is not known whether the concrete in the vicinity of the saw cut and/or the crack itself has characteristics that might make it more susceptible to deterioration in service; in other words, whether the timing and/or use of the early-entry saw imparts negative effects on the durability of the sawed joint.

A synthesis of current DOT specifications for sawing transverse contraction joints in PCC pavement can be found in appendix A. In general, most DOT transverse contraction joint specifications use wording similar to the following passage from West Virginia's *Standard Specifications for Roads and Bridges*:

> *Transverse contraction joints shall be sawed to the dimensions shown on the Plans. Initial sawing of joints shall commence as soon as the concrete has hardened sufficiently to permit sawing without excess raveling and before uncontrolled shrinkage cracking takes place, but no later than 24 hours after concrete placement. If necessary, sawing operations shall be continuous, through day and night, regardless of weather conditions. In general, all joints should be sawed in sequence. The sawing of any joint shall be omitted if cracking occurs at or near the joint location prior to the time of sawing. Sawing of a joint shall be discontinued when a crack develops ahead of the saw.*

Furthermore, most DOT contraction joint specifications include a provision for widening the joint for sealant after 72 hours following concrete placement. Also, any damage done to membrane curing compound cover is required to be repaired.

Few DOTs make special requirements regarding use of early-entry sawing methods; Kansas, Nebraska, Ohio, Oklahoma, and Wyoming all specify that manufacturer recommendations be followed. Ohio, Oklahoma, and Wyoming also note sawing to approximately 1.5 inches deep when sawing early, unless otherwise recommended by the manufacturer. Furthermore, Oklahoma requires joints to be sawed to one-third of the slab thickness ($T/3$) if the shallow cut did not initiate cracking within 24 hours. Oklahoma also includes a requirement that the "Resident Engineer will inspect the sawed faces to ensure that early cutting does not cause joint undercutting […] deep enough to cause structural weakness or excessive joint roughness." South Carolina requires "some raveling of the green concrete […] to prevent uncontrolled shrinkage cracking" and that if "sharp-edged joints are being obtained" then the sawing operation should be expedited to ensure "some raveling is observed." While Tennessee is reported to allow early-entry sawing methods, the agency's Standard Specifications may be contradictory in that Article 501.15(c), Transverse Contraction Joints, specifies "only lightweight sawing equipment will be permitted on the newly constructed pavement," but Article 501.04(D) notes that concrete saws are to be "equipped with water-cooled diamond edge blades"—water-cooled saws are typically 2 to 3 times heavier than "lightweight" dry cut early-entry saws.

Table 1. State DOT Transverse Contraction Joint Sawing Specifications (ACPA 2010).

State	**Saw Cut Depth** *T = pavement thickness*	**Early-entry Sawing Allowed**	**Joint Sealant Reservoir Width**
Arizona	*T*/3	--	1/8 in.
Arkansas	*T*/3	✓	3/8 – 1/2 in.
California	*T*/3	✓	3/8 in.
Delaware	*T*/3	✓	3/8 in.
Florida	*T*/3, *T*/4	--	1/4 in.
Georgia	*T*/4	✓	1/4 in.
Hawaii	*T*/4	✓	1/4 in.
Idaho	*T*/3	✓	3/8 in.
Indiana	*T*/4	--	1/4 – 3/8 in.
Iowa	*T*/3, *T*/4	✓	1/4 in.
Kansas	*T*/4 + 0.25 in.	✓	3/8 in.
Michigan	*T*>7 in., *T*/3; *T*<7 in., *T*/4	--	1/4 in.; 9/16 in.
Minnesota	*T*/3, *T*/4	✓	--
Missouri	*T*/3	✓	3/8 in.
Montana	*T*/3	✓	--
North Carolina	*T*/3 (3 in. min.)	✓	3/8 in.
Nevada	*T*/3	--	3/8 in.
New York	*T*/3	✓	10 mm
Ohio	*T*>10 in., *T*/3; *T*<10 in., *T*/4	✓ @ 2-1/4 – 2-1/2 in.	1/2 in.
Oklahoma	*T*/3; 1-1/2 in.*	✓	1/4 in.
Pennsylvania	*T*/3	✓	3/8 in.
South Carolina	*T*/4	✓	1/4 in.
South Dakota	*T*/4	✓	3/8 in.
Tennessee	*T*/3	✓	1/4 in.
Texas	*T*/3, *T*/4	--	3/8 in.
Utah	*T*/3	✓	1/8 in.
Virginia	*T*/3	✓	varies
Washington	*T*/3	✓	3/16 – 5/16 in.
West Virginia	*T*/3	✓	--
Wisconsin	*T*/3	✓	--
Wyoming	*T*/3, *T*/4	✓ @0.15T	1/8 – 3/8 in.

It is known that at the time of early-entry sawing, the concrete has just transitioned through initial set and is rapidly gaining strength and stiffness. At a microstructural level, hydration products (predominately calcium-silicate-hydrate and calcium hydroxide) are forming on the surface of the cement grains and in solution, and have just “locked” the concrete together through a very porous solid network. At this juncture, disruption of this microstructure (such as through joint sawing) may lead to permanent damage to the concrete through microcracking, which will decrease the strength in the vicinity of the disruption and allow for the ready ingress of fluids. Over time, and in the presence of a cyclic freezing-thawing environment and deicing chemicals, the early-age damage may begin to break down, leading to joint deterioration.

No studies could be identified that directly examined this potential mechanism for long-term damage, but there are some observations suggesting that early-entry dry sawing may contribute to concrete damage to a greater degree than conventional wet sawing of hardened concrete. For one, it has been noted that a skid plate applying downward pressure along the saw cut is often required to prevent joint raveling. Because early-entry saws are upward cutting, it is the force of this plate that keeps the concrete “in-place” at a macro level by providing downward restraint. However, at the microscopic level, it is not unreasonable to assume that some damage is being incurred through the small concrete displacements initiated as the affected concrete adjacent to the upward cutting blade comes into contact with the plate. This would be especially true if the coarse aggregate was exceptionally hard and required more effort to saw through it. In addition, “break-outs” of the concrete at the end of a transverse joint as the saw approaches the slab edge have been observed, likely the result of the weakness of the concrete and the unrestrained condition at the slab edge (Steffes and Siljenberg 2003). This problem can be addressed by terminating the saw cut at a distance of 0.5 to 0.75 inches from the slab edge (such as specified by the Wyoming DOT), but it also demonstrates that the concrete at this early age is very susceptible to damage. Another factor that might contribute to damage is that dry cutting might also produce more heat and possibly dry out the concrete in the immediate vicinity of the saw blade, denying water to the hydration reactions at a very critical time.

Regarding the effectiveness of early-entry saws to produce a crack beneath the weakened plane sawcut, it is widely recognized that the use of early-entry saws has been effective in creating an acceptable joint in thinner slabs. However, little information is available regarding the effectiveness of early-entry saws in crack development on thicker pavement slabs. Nevertheless, the primary concern remains regarding the durability of the sawed joint and whether it is compromised as the result of the early-entry sawing operation. Thus, the focus of this study is not on the effectiveness of early-entry sawing in initiating a crack, but instead whether the concrete in the vicinity of the early-age saw cut and/or the crack itself has characteristics that might make it more susceptible to durability-related deterioration.

1.4 OBJECTIVES

The objective of this research is to evaluate the expected durability of joints cut using early entry techniques compared to IDOT’s standard practice for saw cuts. The joint performance as a function of cut depth and time shall be considered. Specifically, this research will answer the following questions:

- What is the current national state-of-the-practice regarding the use of early entry sawing for rigid pavements?
- How does early-entry sawing differ from conventional wet sawing technique?
- Using modified standard test methods, are there differences in freeze-thaw durability and resistance to deicers between conventionally sawed joints and early entry sawed joints?

- Are there observable micro-structural differences between conventionally sawed joints and early entry sawed joints and if there are, what is the implication of these differences?
- Based on the collected data, is the early entry saw technique viable for IDOT work?

1.5 WORK APPROACH

In order to investigate the potential for early-entry sawing to affect the concrete durability in the vicinity of the joint saw cut, a field study was established consisting of several different test cells. These test cells allowed comparisons between joints cut conventionally and with early-entry saws, with sawing operations, concrete characteristics, and climatic conditions being carefully monitored. Cores were later retrieved and examined in the laboratory for signs of potential durability issues. Chapter 2 presents a summary of the field study program, with chapter 3 reporting on the findings of the laboratory investigation durability. Chapter 4 provides conclusions and recommendations for future work.

CHAPTER 2 FIELD OBSERVATIONS

2.1 GENERAL INFORMATION

In order to investigate the durability of joints created using early-entry saws, IDOT identified a project to accommodate an approximately 1,000-ft long test section, having a relatively flat grade and uniform site conditions, to be paved within an eight-hour period using the same concrete mixture, plant, paver, and crew. The site chosen is part of the southbound right lane of Phase I of the reconstruction project of Illinois Route 59 (Division St), and is located immediately south of the Renwick Road intersection in Plainfield (located west of Chicago, also see figure 3). The paving contractor was Walsh Construction. The PCC mixture used was mix design number IC881R, summarized in table 2 (the "R" in the mix number indicates use of set retarding admixture). The nominal design for this roadway consists of a 9.75-inch jointed plain concrete pavement (JPCP) resting on a 12-inch base that is composed of 9 inches of crushed concrete and 3 inches of hot-mix asphalt (HMA) millings covering the larger sized crushed concrete. Unsealed transverse contraction joints are spaced at 15-foot intervals, and load transfer is provided by 1.5-inch diameter epoxy-coated dowel bars placed along the transverse joints on 12-inch centers.

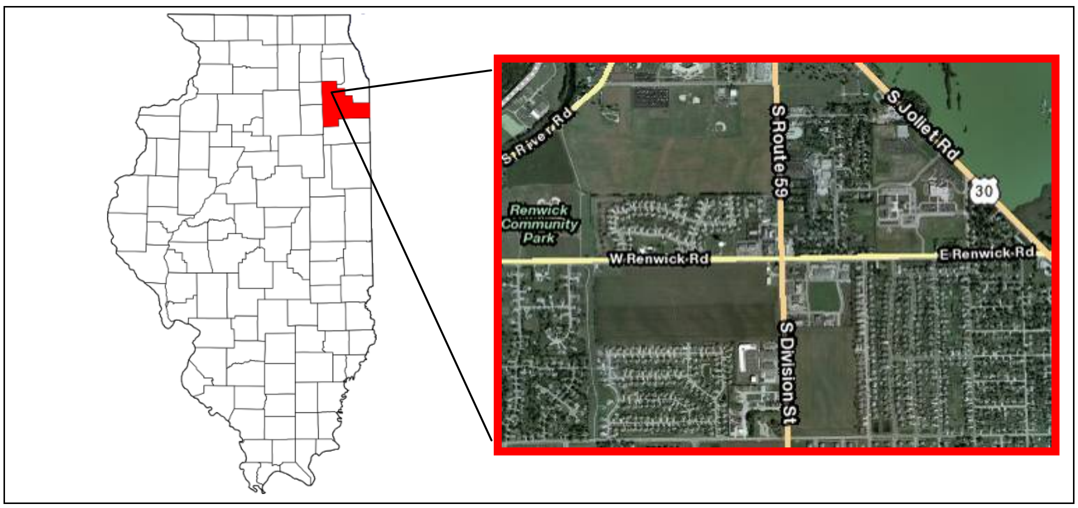

Figure 3. Location of test site.

Table 2. Pavement PCC Mix Design Proportions

Material	Design Quantity
Fine Aggregate	1264 lbs/yd^3
Coarse Aggregate-1	1000 lbs/yd^3
Coarse Aggregate-2	852 lbs/yd^3
Cement	490 lbs/yd^3
Fly Ash, Class C	130 lbs/yd^3
Water (w/c)	220 lbs/yd^3 (0.36)
Air Content	5.0 – 8.0 %

2.2 TEST CELLS

Within the test section, three 300-foot test cells, comprising 20 joints each, were established as illustrated in figure 4. Test cell 1, located at the northern end of the project, is the control section and employed a conventional wet-saw cutting to a depth of one-third of the slab thickness (T/3). Test cell 2 is located south of test cell 1 and used an early-entry dry saw to a conventional depth of T/3. Test cell 3 is located at the southern end of the project and used an early-entry dry saw to a depth of 1.25 ± 0.25 inches.

Figure 4. Test site location and layout.

Prior to paving the test section, the contractor had been paving Illinois Route 59 (Division St) north of Renwick Road, terminating at the Renwick Road intersection, and then resuming paving operations immediately south of the intersection (approximately 50 feet before the start of the first test cell). Work began on the construction of the pavement test cells on August 24, 2009. Key information regarding the test cells and construction timeline is summarized in table 3.

Members of the research team were on site at the time of paving. In addition to observing construction practices, from paving to sawing, team members monitored ambient and concrete surface temperatures using an infrared temperature sensor gun and embedded temperature sensors (i-buttons), which were placed at the base and mid-depth near the middle of the slab as well as attached to an adjacent dowel basket (figure 5) in each test cell to provide continuous temperature measurements. These embedded sensors were set to collect temperature readings every 20 minutes, allowing for up to 28 days of continuous temperature data. The slab temperature data collected by the embedded sensors are summarized in figures 6 and 7; figure 8 illustrates the temperature swings experienced by the slab in relation to the natural variation in ambient temperatures over the same time period. Figure 9 details the temperatures achieved by the slabs in test cells 2 and 3 (as well as the ambient temperatures experienced) during the critical first 72 hours. Additional discussion of the temperature profiles measured by the internal sensors is included in appendix B.

Table 3. General Test Cell Information

	Test Cells		
	1	2	3
Stationing			
Starting	3292+00	3289+00	3286+00
Ending	3289+00	3286+00	3283+00
Temperature Sensors	3290+50[1]	3287+50[2]	3284+75[3]
Paving	08/24/09	08/24/09	08/24/09
Start Time	12:43 pm	1:24 pm	1:55 pm
End Time	1:24 pm	1:55 pm	2:34 pm
Sawing	08/24/09	08/24/09	08/24/09
Start Time	8:15 pm	6:00 pm	7:38 pm
End Time	9:20 pm	7:35 pm[4]	8:40 pm
Time Elapsed			
From Paving to Sawing	7.5 hrs	4.5 hrs	5.75 hrs
PCC Slab Temperature	[5]		
Start of Sawing	~114 – 115 °F	107.6 °F	113.9 °F
End of Sawing	~114 – 115 °F	114.8 °F	114.8 °F

[1] All 3 connections inadvertently severed during paving activity.
[2] Data from bottom midslab sensor could not be downloaded at 28 days.
[3] Data from the joint and bottom midslab sensors could not be downloaded at 28 days.
[4] A 35-minute break was taken at 6:54 pm to allow the pavement more time to harden.
[5] Values estimated based on time of sawing and temperature development in test cells 2 and 3.

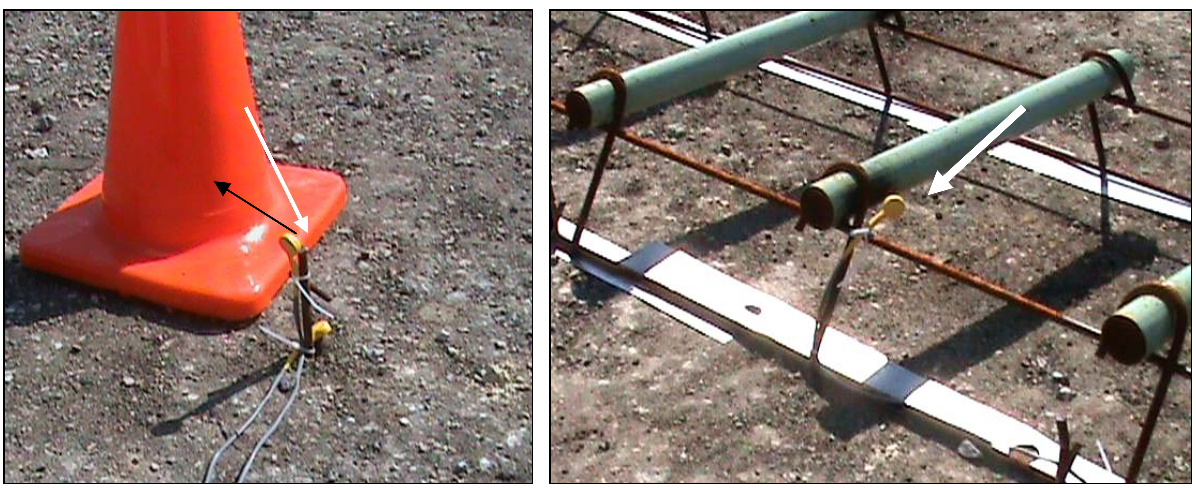

Figure 5. Example of field placement of temperature sensors: two placed middle of slab at mid-depth and base using a dowel basket stake, and one attached to an adjacent dowel basket.

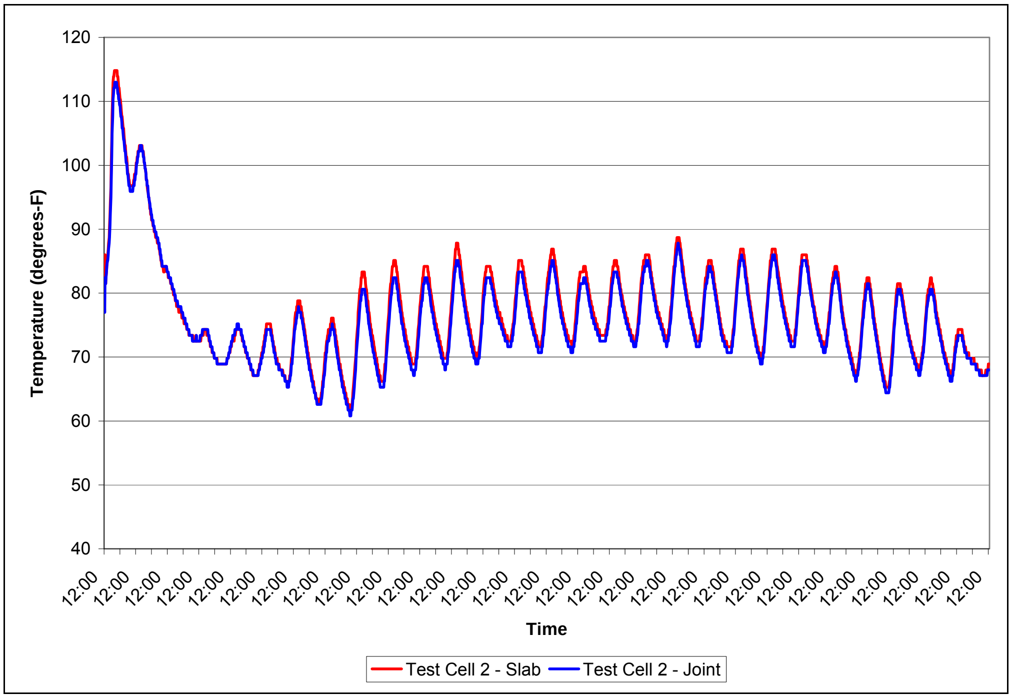

Figure 6. Mid-depth, mid-slab (red) and mid-depth, joint (blue) temperature data for test cell 2.

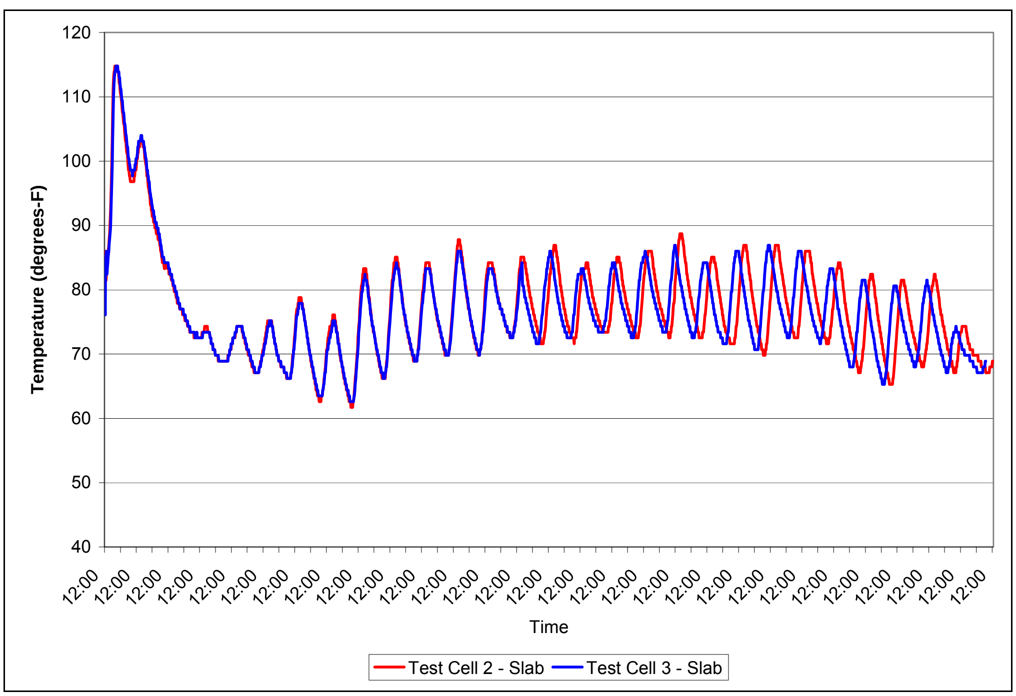

Figure 7. Mid-depth, mid-slab temperature data for test cells 2 (red) and 3 (blue).

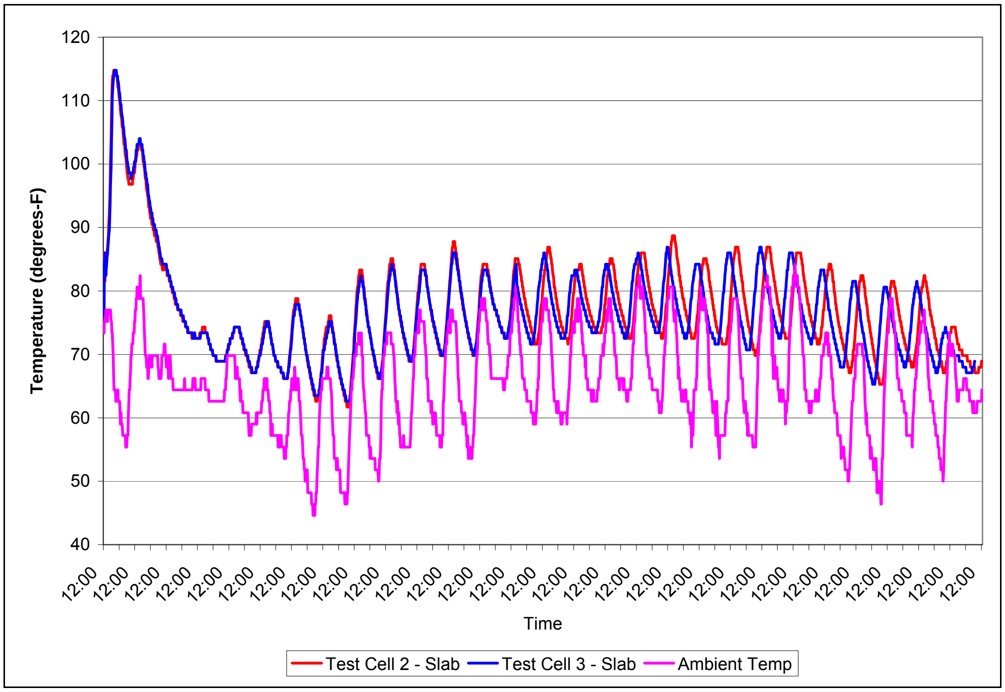

Figure 8. Mid-depth, mid-slab and ambient temperature data for 28 days.

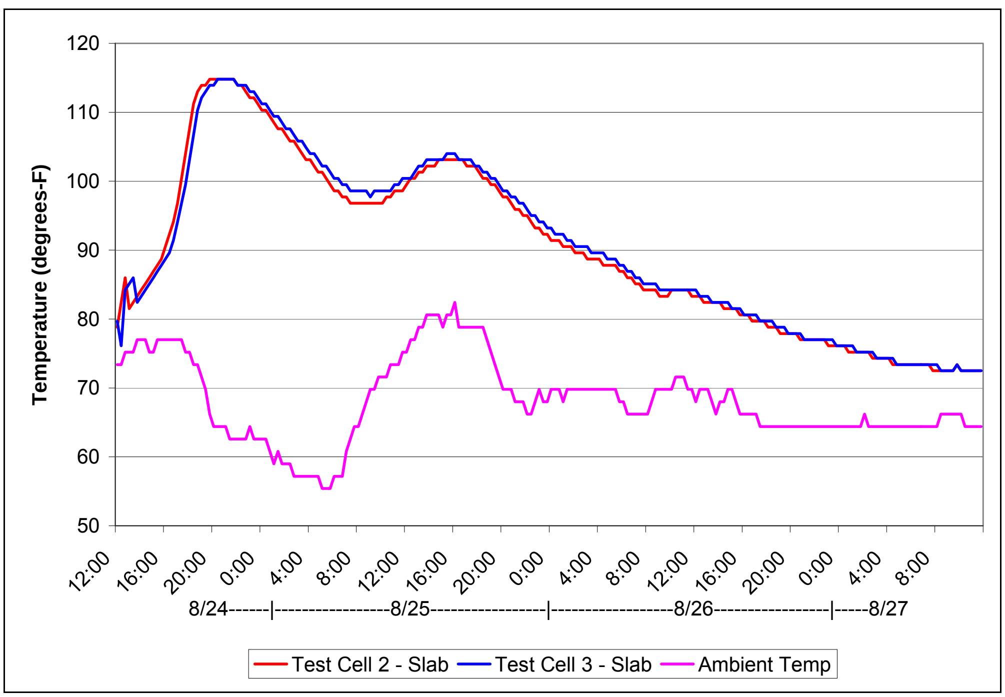

Figure 9. Mid-depth, mid-slab and ambient temperature data for first 72 hours.

Figure 6 shows that the temperature profile of the concrete material near the mid-slab of the pavement is essentially the same as that experienced near the joint, although there appears to be at most +2 °F difference, which may be an artifact of the sensors' accuracy, noted in the manufacturer's specifications to be ± 2 °F. Furthermore, the temperature profile measured in test cell 3 is essentially the same as that of test cell 2; thus, the temperature profile would likely be similar for test cell 1 had the sensor connections not been inadvertently severed during construction. Concerning the data offset between test cells 2 and 3 observed in figures 7 and 8, there appears to have been a data collection glitch on September 6 for the temperature sensor located in test cell 3; between 4:00 pm and 4:20 pm, there is an anomalous 3.6 °F drop. The lost sensors and observed data collection glitch emphasize the value in having multiple sensors present to provide redundancy.

Ambient climate conditions (e.g., temperature, humidity, wind speed, cloud cover, and so on) and slab mixture and temperature data were used in the FHWA's HIPERPAV® program to assess the potential for early-age cracking on these test sections (Xu et al. 2009). HIPERPAV® allows users to evaluate the effects materials, construction, environment, and design practices have on the short-term and long-term performance of concrete pavements, thereby providing the ability to minimize the potential for random cracking. Detailed information must be entered into the program, such as pavement width, depth, joint spacing, batch proportioning, cement type, and concrete strength, as well as environmental factors, including hourly air temperature, relative humidity, wind speed, and cloud coverage for the first 72 hours after the concrete placement. Although environmental data can be based on a 30-year historical weather database built into the software, the analysis performed for this project used recorded data supplemented by weather data available online at Weather Underground (www.wunderground.com).

The results of the analysis showed that early-age cracking was not expected to be an issue, as the PCC strength gain was greater than the critical tensile stresses developing at the top and bottom of the pavement slab, and thus the stress-to-strength ratio remained below 100 percent throughout the critical early ages (see figure 10). The complete HIPERPAV® report is included in appendix C.

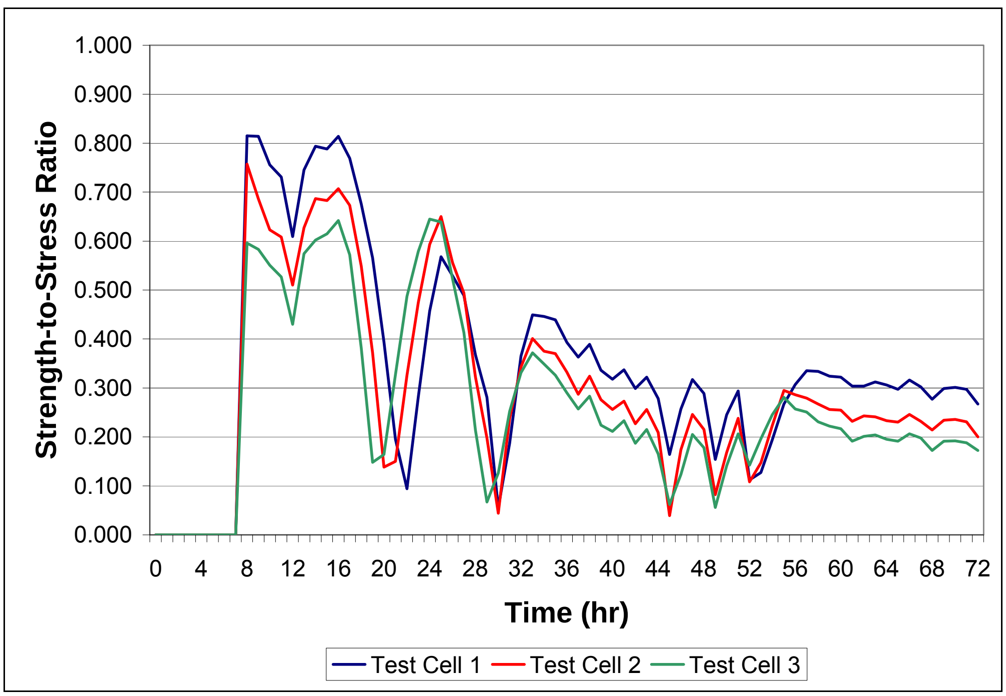

Figure 10. Plot of HIPERPAV® analysis showing concrete stress-to-strength ratio over the first 72 hours for the three test cells.

During the construction of each test cell, nine 6- × 12-inch cylinder specimens were cast and cured adjacent to the pavement (IL Modified AASHTO T 23) for determining compressive strength at 3, 7, and 28 days (IL Modified AASHTO T 22). Specimen molding and strength testing was performed by ECM Testing Services, Inc.; test results are summarized in table 4. Additionally, as part of normal quality control testing by the Contractor, total air content was measured twice using a pressure meter (Illinois Modified AASHTO T 152) within the test area; once at the start of placement for test section 1 (7.1 percent air content), and again at a location that was 75 feet into paving test cell 3 (6.6 percent air content).

Table 4. Average compressive strength test results.

Age	Test Cell 1 Conventional (*T*/3)	Test Cell 2 Early-Entry (*T*/3)	Test Cell 3 Early-Entry (1.25 inch)	Average	Standard Deviation (% of avg)
3-day	3,340 psi	3,290 psi	3,700 psi	3,443 psi	224 psi (6.5)
7-day	5,050 psi	5,320 psi	5,620 psi	5,330 psi	285 psi (5.3)
28-day	5,140 psi	5,420 psi	5,670 psi	5,410 psi	265 psi (4.9)

The temperature data and strength data provide some assurance that the PCC throughout the test section is generally uniform and would likely exhibit similar durability characteristics except as affected by the joint sawing operation.

2.3 JOINT SAWING OPERATION

The joint sawing contractor for the project was Quality Saw and Seal. Test cell 1, the control section, was cut using the conventional timing (as the concrete approaches final set) and depth (*T*/3) using a Sanders Saws & Blades model SS7060 wet saw. Test cells 2 and 3 were cut using a Husqvarna Soff-Cut 5000 early-entry dry cutting saw at depths of 3.25 inches (*T*/3) and 1.25 inches, respectively. (A vacuum system for the dry cutting saw was brought to the site for dust control, but could not be used because a necessary connector piece was not included with the equipment as supplied by the distributor.)

As noted before, early-entry saw cutting can begin as soon as the slab can support the weight of the saw and operator without disturbing the finish (ISU 2004). Based on the time test cell 2 was paved (between 1:30 and 2:00 pm) and the prevailing weather conditions (sunny, high ambient air temperature of 77 °F, very little wind), the saw operator anticipated sawing to begin at 6:00 pm; the operator performed a scratch test using a set of ordinary keys to see how deeply the surface scratched or gouged to determine when the pavement was suitable for sawing.

At first, although no raveling of the joint was observed, edge "break-outs" occurred on both the east and west edges of the slabs during the sawing operations on test cell 2. In an effort to minimize those "break-outs," the saw operator suggested sawing down at the slab edge—as opposed to through it—by lifting up the blade, moving the saw forward, and sawing down where the pavement surface and slab edge meet. The "break-outs" on the west slab edge were reduced to zero occurrences when the saw operator began using this "sawing down" procedure. The east slab edge still experienced small, shallow "break-outs" at every other joint, on average—likely due to the lack of direct sunlight warming the slab edge during and after paving, unlike the west slab edge that received direct sunlight in the afternoon. The "saw down" approach was used for test cell 2 only; it was unnecessary for test cell 3 due to the relative shallowness of the cut and thus the joints were sawed through normally. Because of three consecutive deep "break-outs" leading up to joint 18 of test cell 2, the saw operator waited 35 minutes to allow the pavement more time to harden.

Regarding test cell 3, typical early-entry saw cut depths reported in the literature range from 1 to 1.5 inches (Zollinger, Tang, and Xin 1994; Steffes and Siljenberg 2003; Wang et al. 2009). Initially, the saw operator expressed concern that sawing with a 14-inch diameter blade to such a shallow depth might cause excessive raveling due to lateral vibration of the large blade. Because the mechanical depth gauge of the Soff-Cut 5000 is metered from 3 to 4 inches for a 14-inch blade, to saw at a depth less than 3 inches requires "eyeballing" handmade markings (figure 11). Thus, cutting the first three joints of test cell 3 involved some trial and error until a satisfactory depth could be consistently achieved. At first, worse raveling was observed (figure 12) where the saw cut depth was less than 1.25 inches; while a more consistently clean joint was obtained at depths between 1.25 and 1.5 inches. However, as the concrete hardened, cuts as shallow as 1 inch were made without raveling (figure 13). A summary of the actual saw cut depth per joint in each test cell is shown in figure 14; the plot shows the average depth based on three measurements taken at each joint.

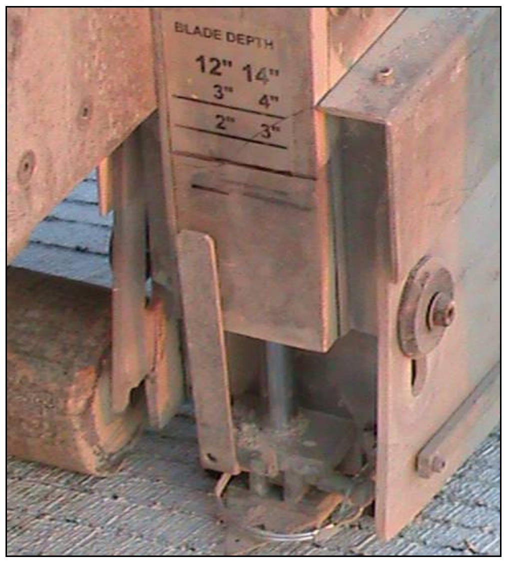

Figure 11. Husqvarna Soff-Cut 5000 mechanical depth gauge.

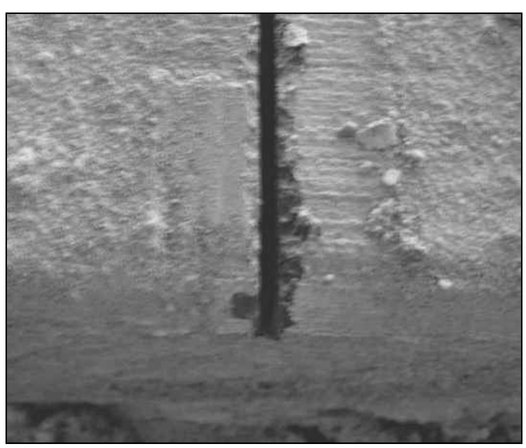

Figure 12. Raveling of shallow (≤1.25-inch) saw cut.

Figure 13. Clean shallow saw cut (Test Cell 3, joint 15 @ 1.00 inch).

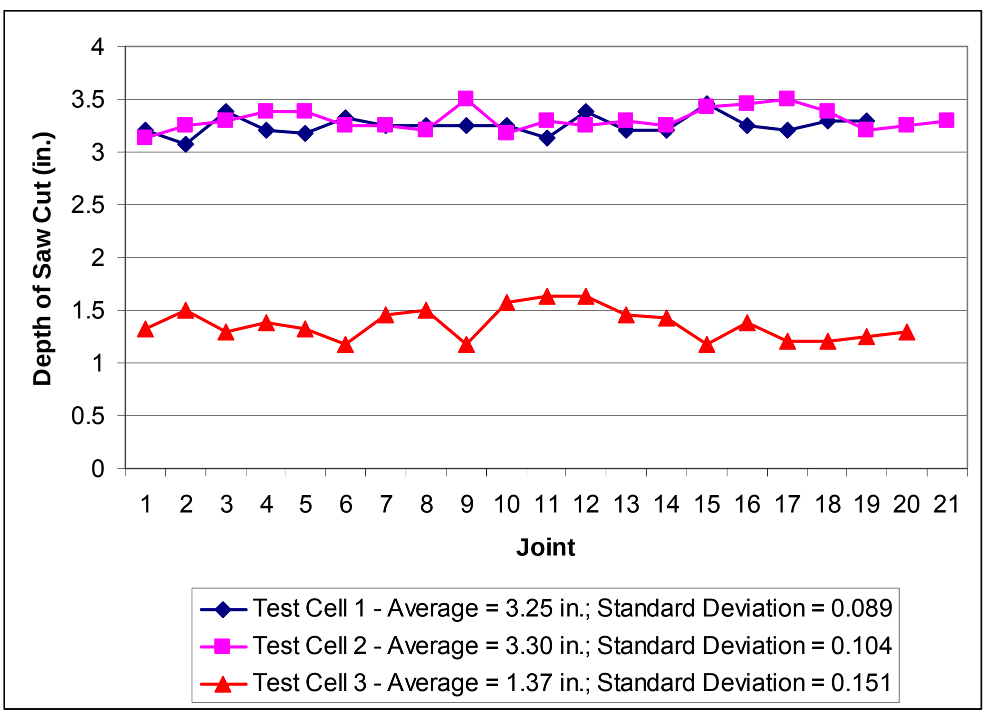

Figure 14. Plot of average saw cut depth for each test cell's joints.

Although not the primary focus of this study, test cell 3 also afforded the opportunity to assess the ability of a shallow early-entry cut to initiate a crack at the joint as desired. According to a published report written to document other aspects of this project, approximately 99 percent of the joints throughout the three test cells exhibited cracks beneath the initial saw cut at a time period of 10 days after placement (Scofield 2009). It was also observed that every fourth or fifth joint opened "wider than the rest" regardless of the depth of saw cut or whether it was cut early (Scofield 2009). This by itself is not an unusual occurrence, as those joints that crack first often experience greater openings to accommodate the movement of the slab.

2.4 JOINT RAVELLING ASSESSMENT

To assess the occurrence of joint raveling and whether it was progressing, the research team made three follow-up visits to the project site to examine the condition of the pavement. The first follow-up visit was made in November 2009 before the first winter, a second visit was made in March 2010, and a final visit was made August 2010. No random cracking was observed in any of the test sections during these visits, indicating effective establishment of the transverse contraction joints, regardless of the technique used.

To conduct the examination of each joint during the field inspections, the research team developed a joint raveling index (JRI) as a means of assessing the relative condition of the joint after the joint sawing operation. Table 5 presents the criteria used for rating joint damage due to sawing operations, with JRI values ranging from "0" (representing a joint without any raveling or joint sawing damage) to "3" (representing a joint with extensive raveling or edge damage at more than 50 percent of the joint length). The criteria and example images provided in table 5 are based on perceived differences noted in the field and captured in photos.

While visually assessing extent of joint damage, it was important to determine whether the perceived damage was due to the sawing operation or possibly associated with the transverse surface tining. In many instances, what was initially perceived as joint damage was actually attributable to surface texture roughness caused by the transverse tining operations. Some details suggesting that the damage was from tining include:

- Presence of curing compound film—not green concrete—along suspected raveled area.
- Raveled area corresponding to locations where tining skew intersects saw cut (figure 15).
- Edge of one joint face appears raveled while the opposite is cleanly cut (figure 16).

The results of the raveling surveys conducted in fall 2009, spring 2010, and summer 2010 are presented in figure 17. As can be seen, there was slightly more raveling observed in the early-entry saw cutting test cells; however, in no cases was the raveling considered to be extensive, and the overall differences between the three treatments were relatively minor. Further, there was no significant change observed in the joint performance over one winter of service.

Table 5. Joint Raveling Index (JRI) evaluation criteria.

JRI	Description	Example
0	No raveling or edge damage observed. No "break-out" at slab edge.	 
1	Rougher edges observed. "Break-out" at slab edge primarily characterized by loss of curing compound film, not concrete.	 
2	Moderate raveling or edge damage (e.g., displaced aggregate, spalling) observed along less than 50% of joint.	 
3	Extensive raveling and/or edge damage observed along greater than 50% of joint.[1]	 

[1] Although no occurrence of "extensive" joint raveling was observed, large "break-outs" did occur and were cause for the saw operator to stop sawing until the concrete could harden further.

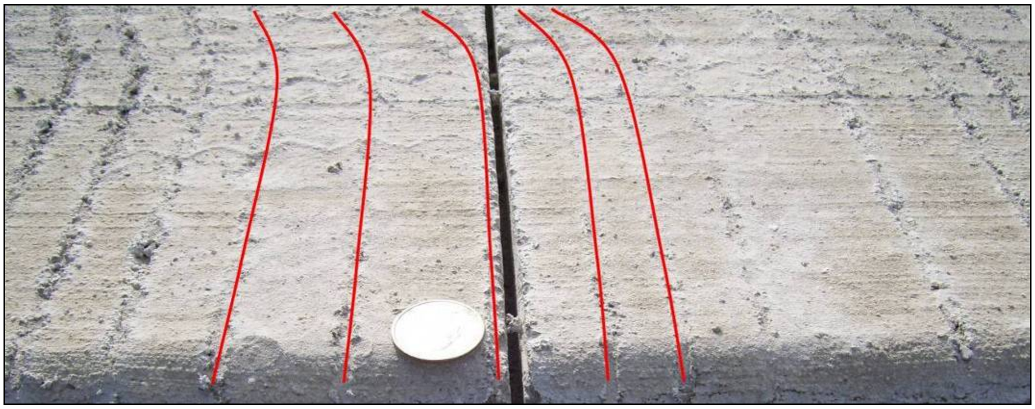

Figure 15. Example of saw cut along transverse tining (indicated by the red lines).

Figure 16. Example of saw cut along transverse tining where the left edge of the joint face appears to be lightly raveled while the right edge is more cleanly cut.

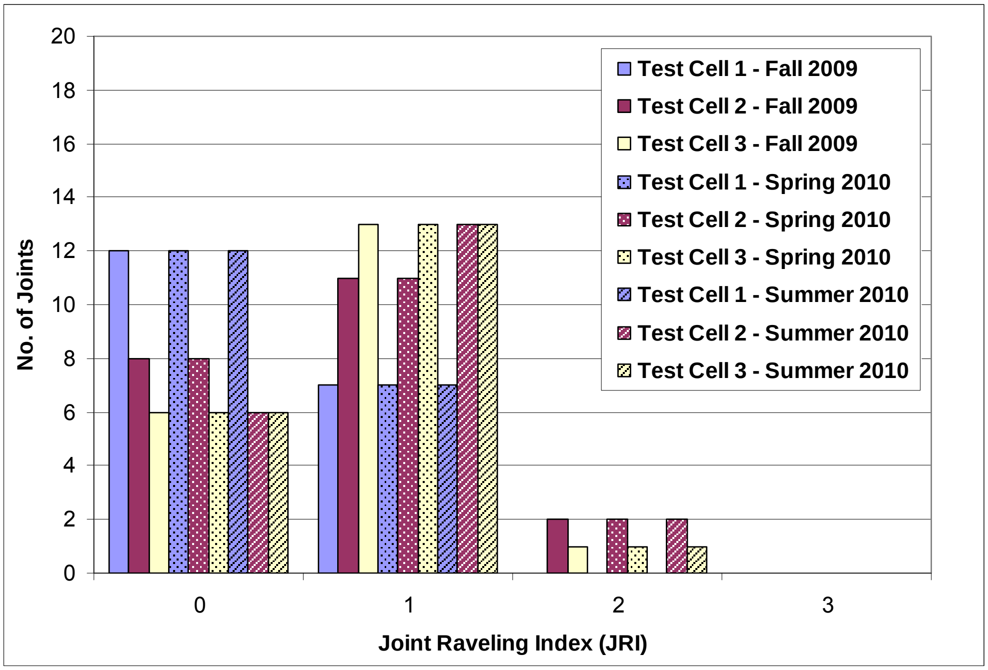

Figure 17. Histogram plot summarizing joint raveling ratings for the three test cells based on three visits before and after winter season 2009-2010 and during summer 2010.

2.5 SUMMARY

A test site constructed on Illinois Route 59 (Division St) immediately south of the Renwick Road intersection in Plainfield, IL demonstrated the feasibility of using early-entry sawing techniques to adequately create transverse construction joints, avoiding any uncontrolled cracking. Temperature monitoring revealed that embedded temperature sensors could accurately record internal concrete pavement temperature for at least 28-days, providing valuable information for the assessment of early-age cracking. Failures in a few sensors also demonstrated the need to embed redundant sensors.

A joint raveling index (JRI) was developed to assess the degree of raveling induced through the sawing operation. Although slightly more raveling was noted when early-entry sawing was used, it was neither severe nor significantly higher than that incurred under conventional sawing. After one winter, field evaluations indicated that all joints were performing adequately.

CHAPTER 3 LABORATORY TESTING

To study the potential long-term durability of the saw cut joints, a total of eighteen cores were pulled from the three test cells (six cores from each individual test cell) 28 days after paving; table 6 summarizes the location from which each core was extracted and the tests conducted. These cores—shown in figures 18 through 20—were subjected to petrographic examination and laboratory durability testing for freeze-thaw resistance and susceptibility to salt scaling; the joints cored and corresponding testing conducted on the specimens extracted are summarized in table 6. All tests were conducted at Michigan Technological University.

Table 6. Summary of Joints Cored and Corresponding Testing Regimen

Test Cell	Joints Cored		
	Petrography (one specimen per joint)	**Freeze-thaw** (two specimens)	**Salt-scaling** (two specimens)
1	7, 16	10	13
2	4, 13	7	10
3	2, 12	5	9

3.1 PETROGRAPHIC EXAMINATION

For petrographic evaluation, two cores from each test cell were cut into slabs perpendicular to the joint and polished to show the entire pavement joint in cross-section. In all cases, a crack had initiated from the saw cut and propagated the full depth of the core. In general, the concrete from all three test cells appeared to be of similar quality and consistency. Figures 21 and 22 show overviews of the slabs prepared from test cell 1. Some branching of the primary crack is observed toward the bottom of the core shown in figure 22. Figure 23 shows more detailed views of the saw-cut portions of the joints from the same test cell 1 slabs.

Figures 24 and 25 show the slabs prepared from test cell 2 with figure 26 showing more detailed views of the saw cut portions of the joints from the same test cell 2 slabs. As shown in figure 26, one of the saw cut portions of the joint intersected a very large (1-inch diameter) entrapped air void.

Figures 27 and 28 show the slabs prepared from test cell 3 with figure 29 showing more detailed views of the saw cut portions of the joints from the same test cell 3 slabs. In figures 28 and 29, it is observed that the primary crack in one of the cores is branched in the vicinity of the saw cut. It is believed that the branching of the primary crack, whether observed in the concrete extracted from test cell 1 or test cell 3, is not out of the ordinary and is not associated with any observed pavement distress.

As shown in figures 21, 22, 24, 25, 27, and 28 carbonation (as approximated by mortar unaffected by phenolphthalein stain) was limited to the pavement surface, and to a depth on the order of 0.02 in (0.5 mm) for all of the slabs prepared from all of the test sites.

As shown in figures 23, 26, and 29, there are no detectable differences in the degree of microcracking in the immediate vicinity of the saw cut portion of the concrete extracted from the joints for the three test cells   Yet the limited number of specimens tested affects the ability to predict future performance due to the different saw cutting operations.

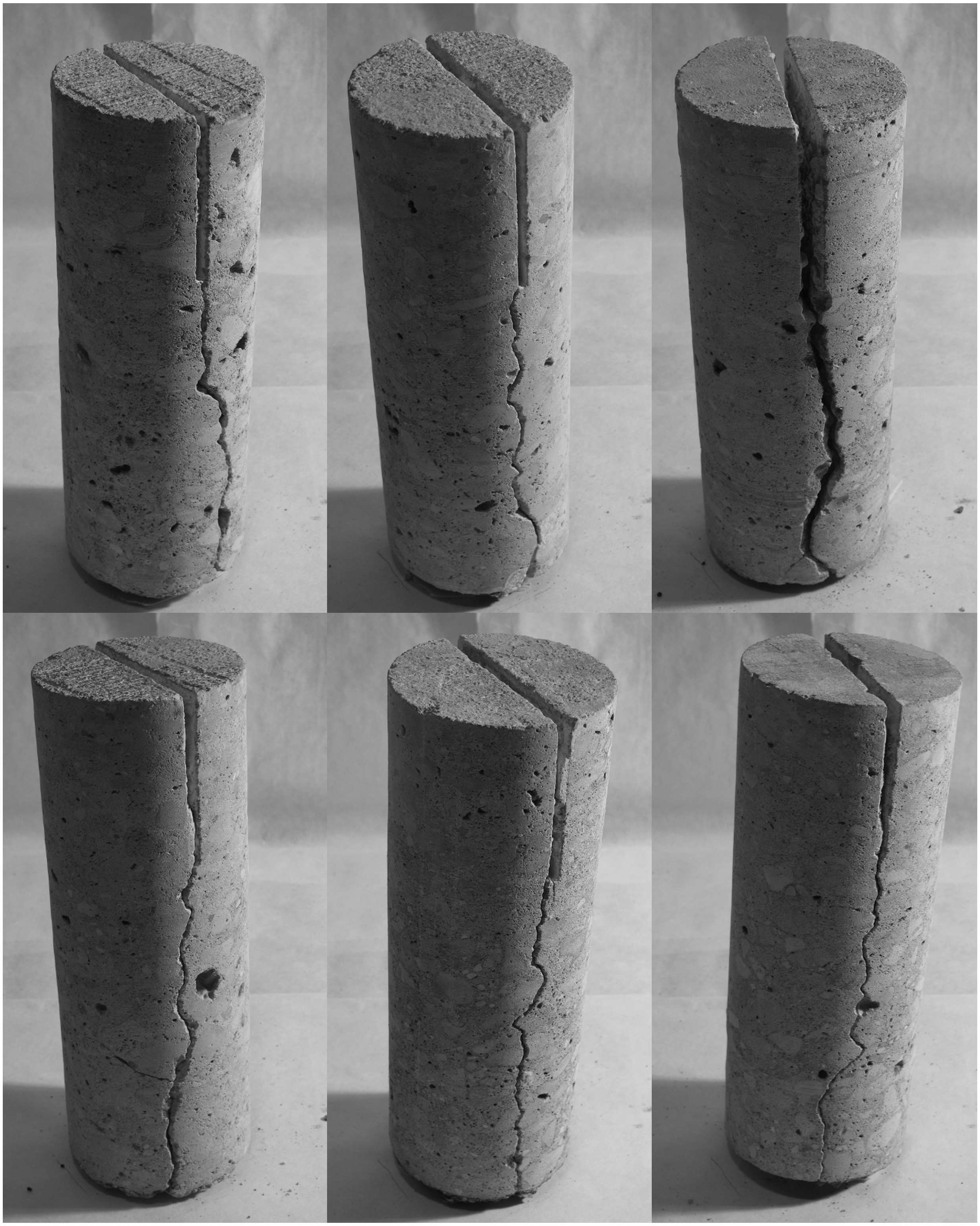

Figure 18. Six cores as-received from test cell 1.

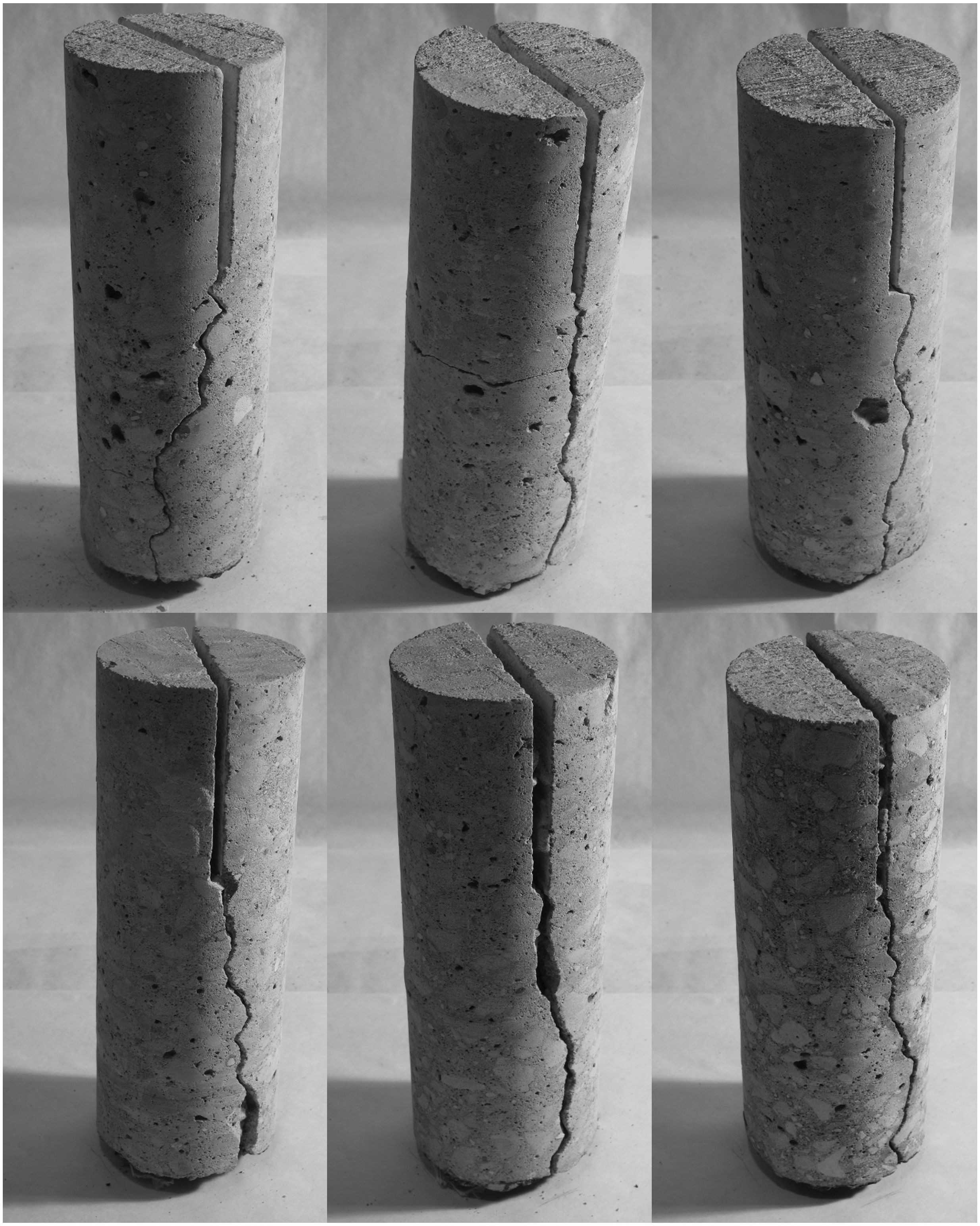

Figure 19. Six cores as-received from test cell 2.

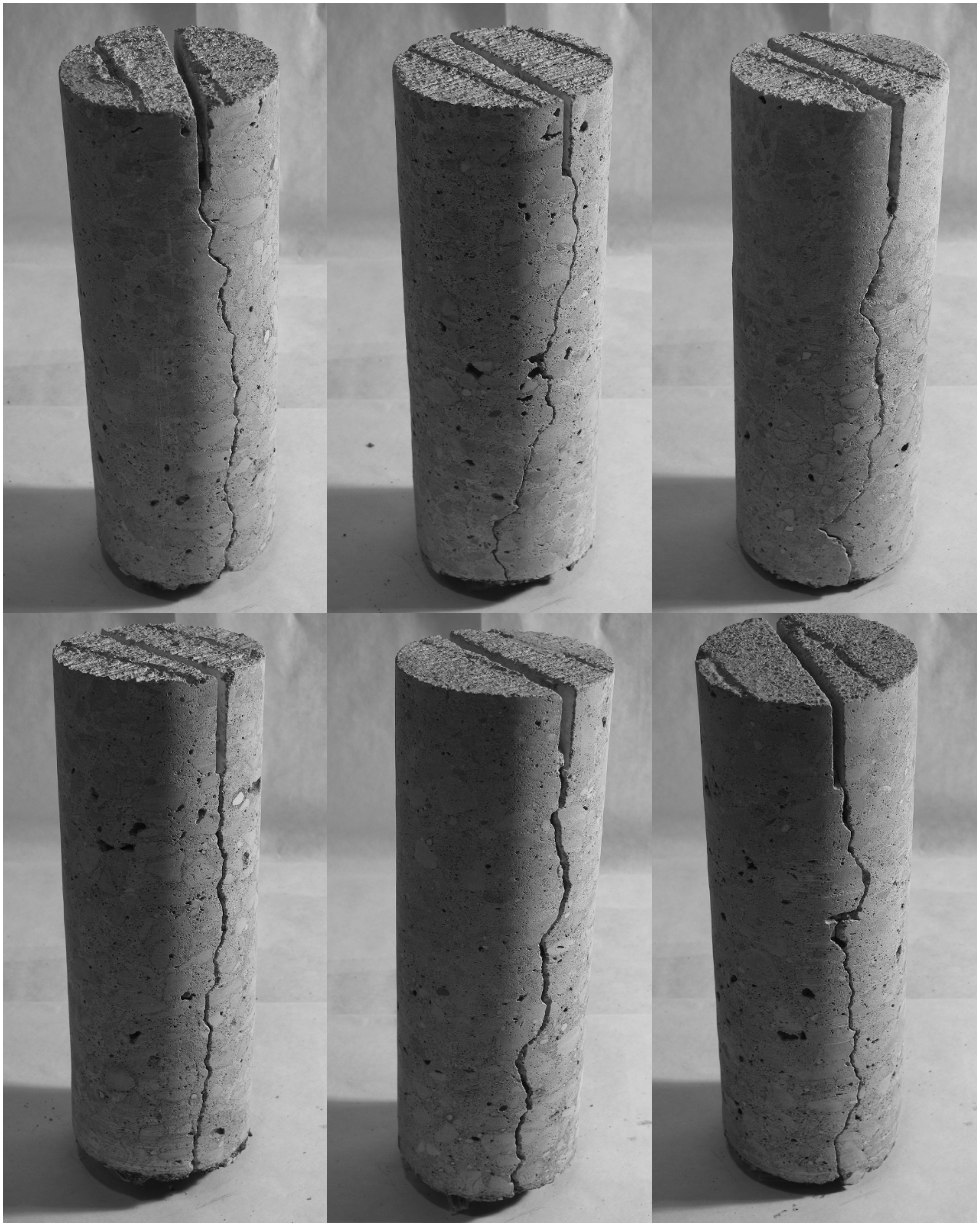

Figure 20. Six cores as-received from test site 3.

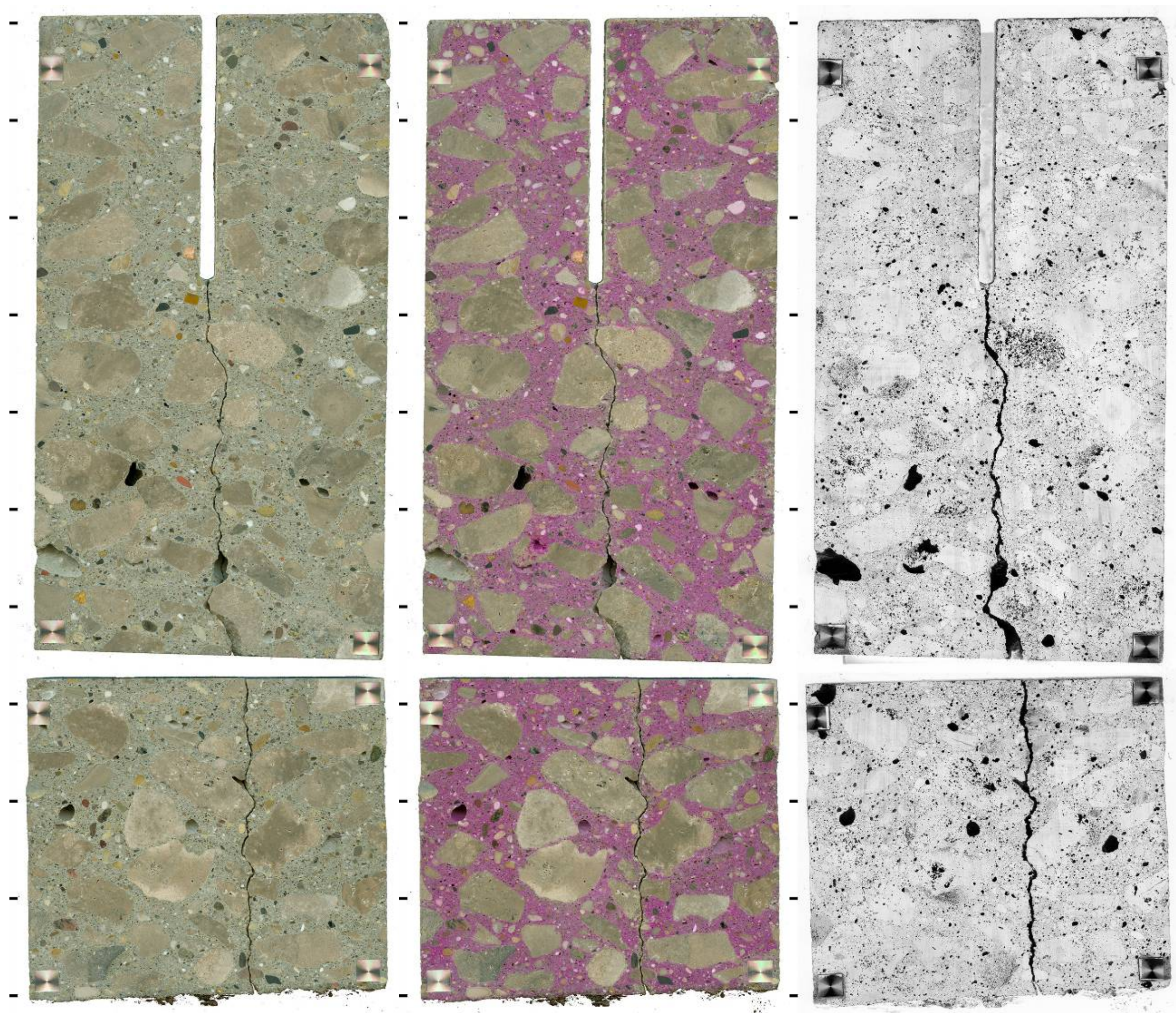

Figure 21. Scanned images of polished slab showing cross-section of core from test cell 1, from left to right: as-polished, after application of phenolphthalein stain, and after treatment to enhance visibility of pores and cracks (tic marks every inch).

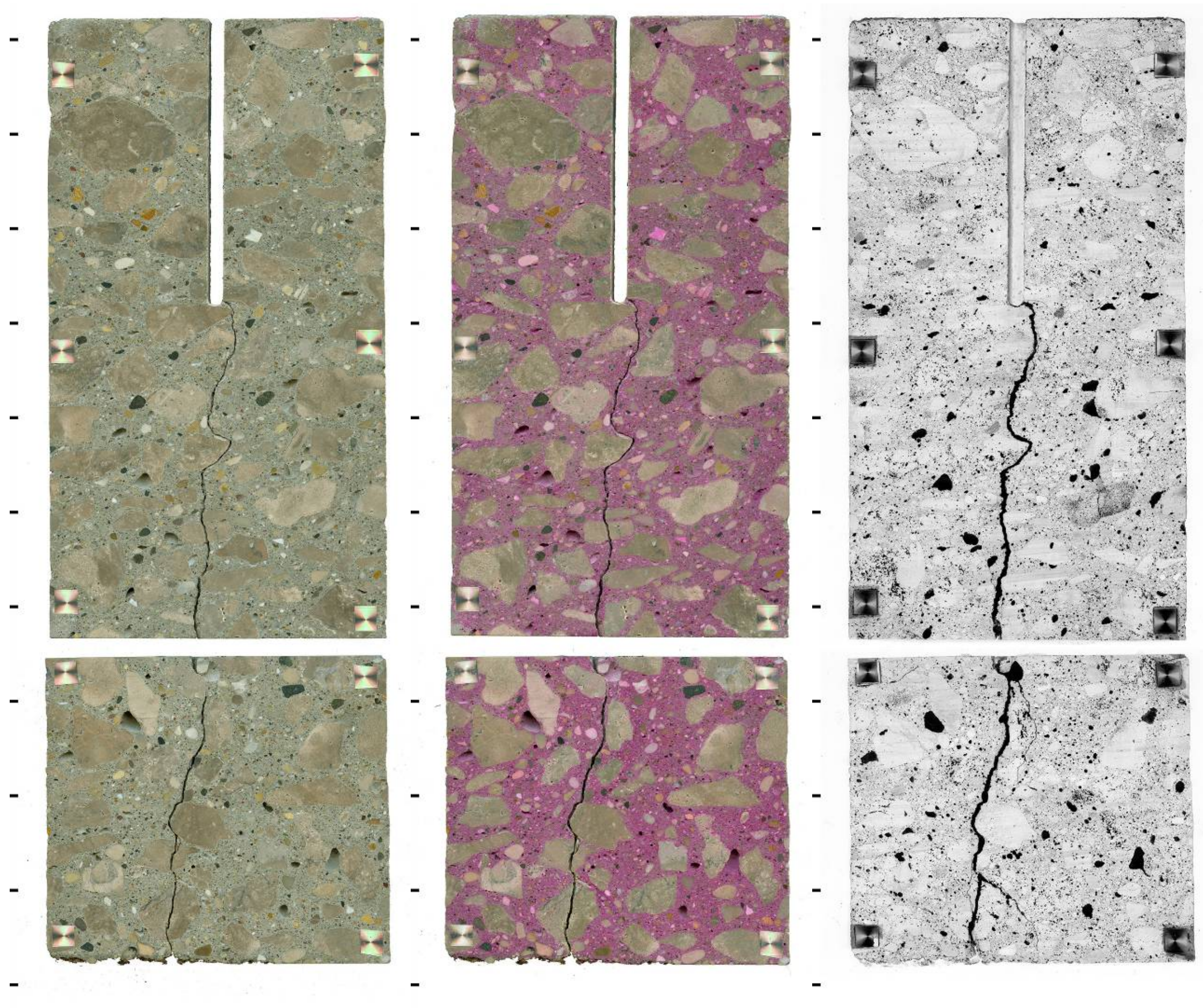

Figure 22. Scanned images of polished slab showing cross-section of core from test cell 1, from left to right: as-polished, after application of phenolphthalein stain, and after treatment to enhance visibility of pores and cracks (tic marks every inch).

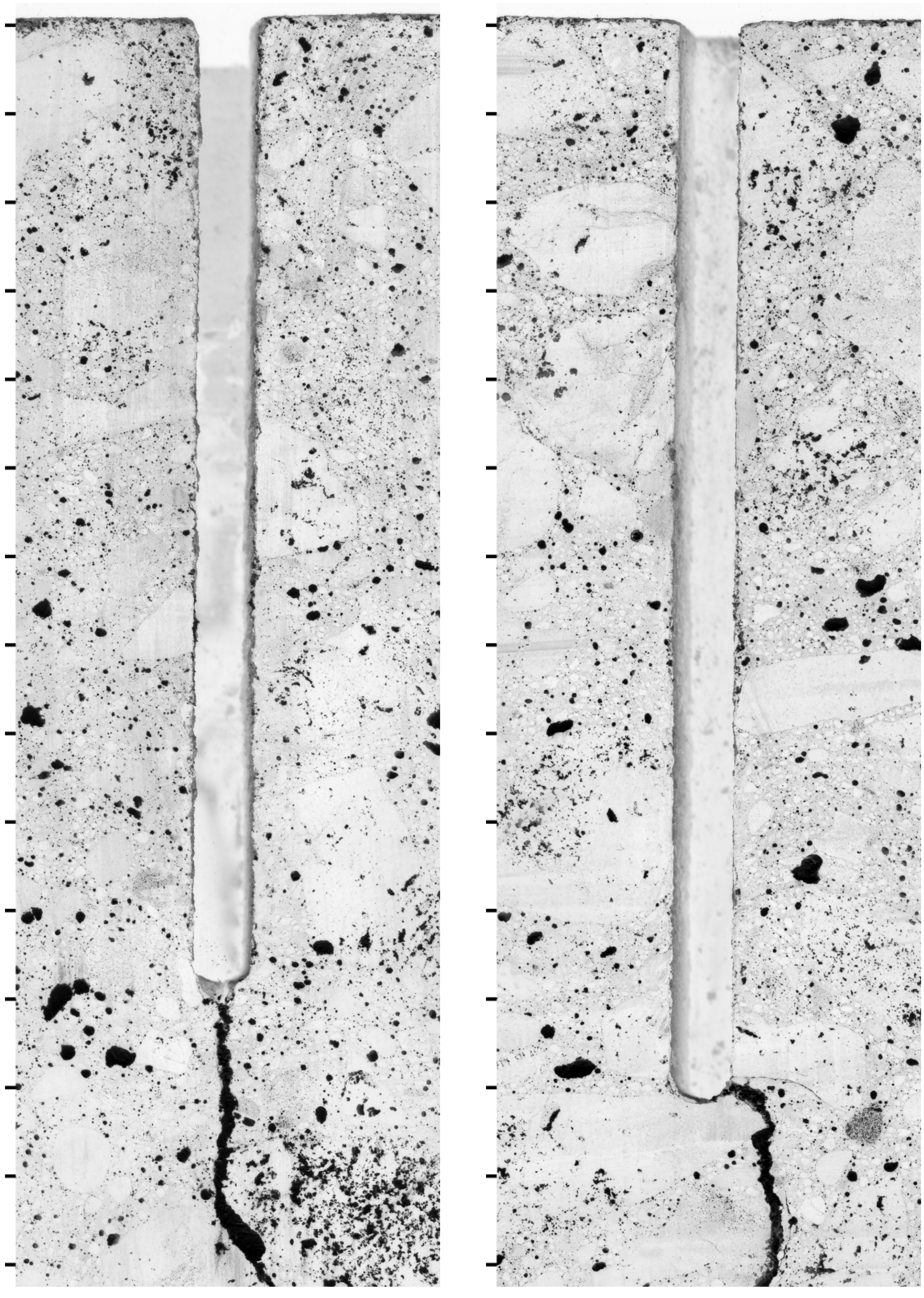

Figure 23. Detail of scanned images from figure 21 (left) and figure 22 (right) depicting saw cut joints from test cell 1 (tic marks every 0.25 inch).

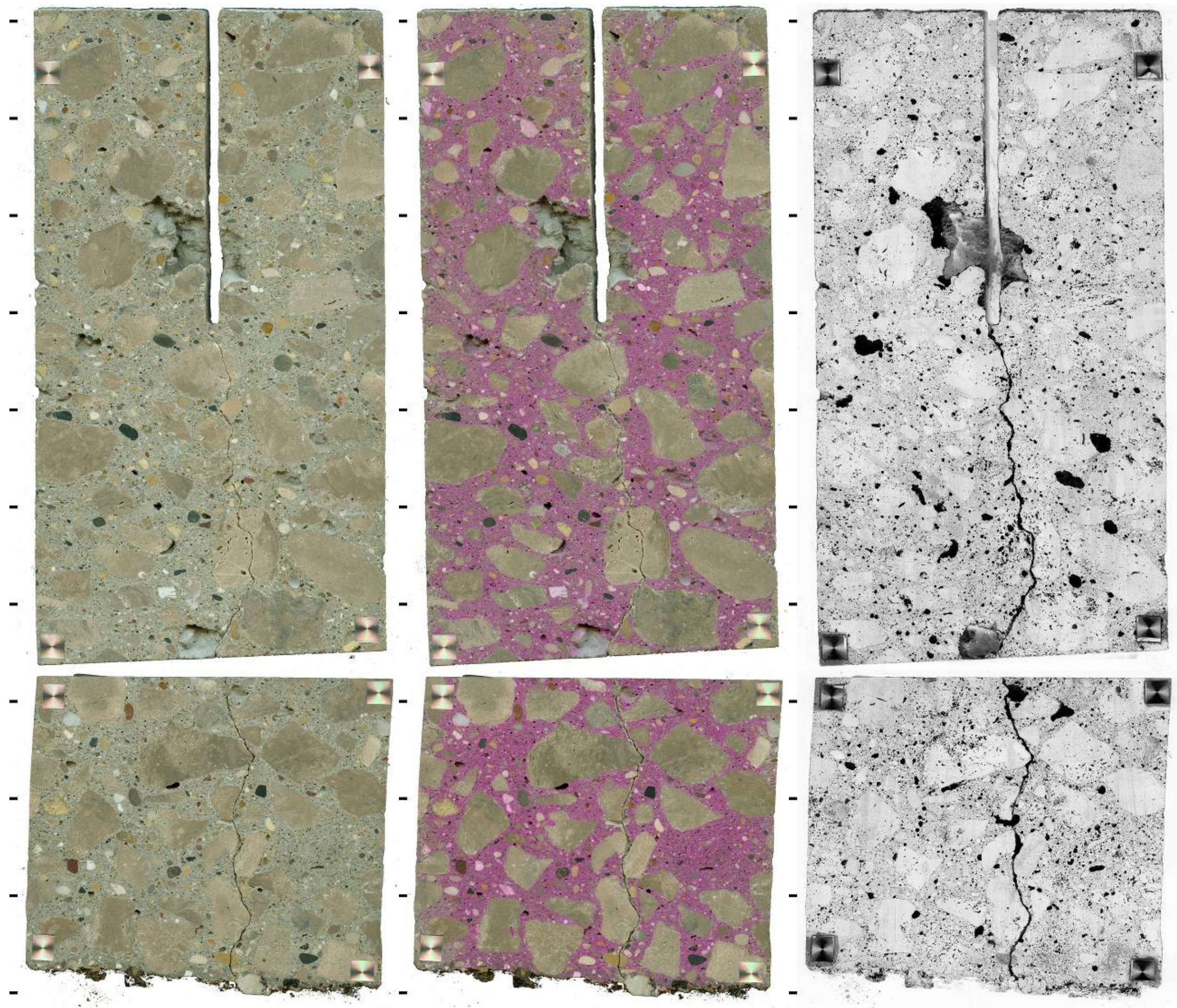

Figure 24. Scanned images of polished slab showing cross-section of core from test cell 2, from left to right: as-polished, after application of phenolphthalein stain, and after treatment to enhance visibility of pores and cracks (tic marks every inch).

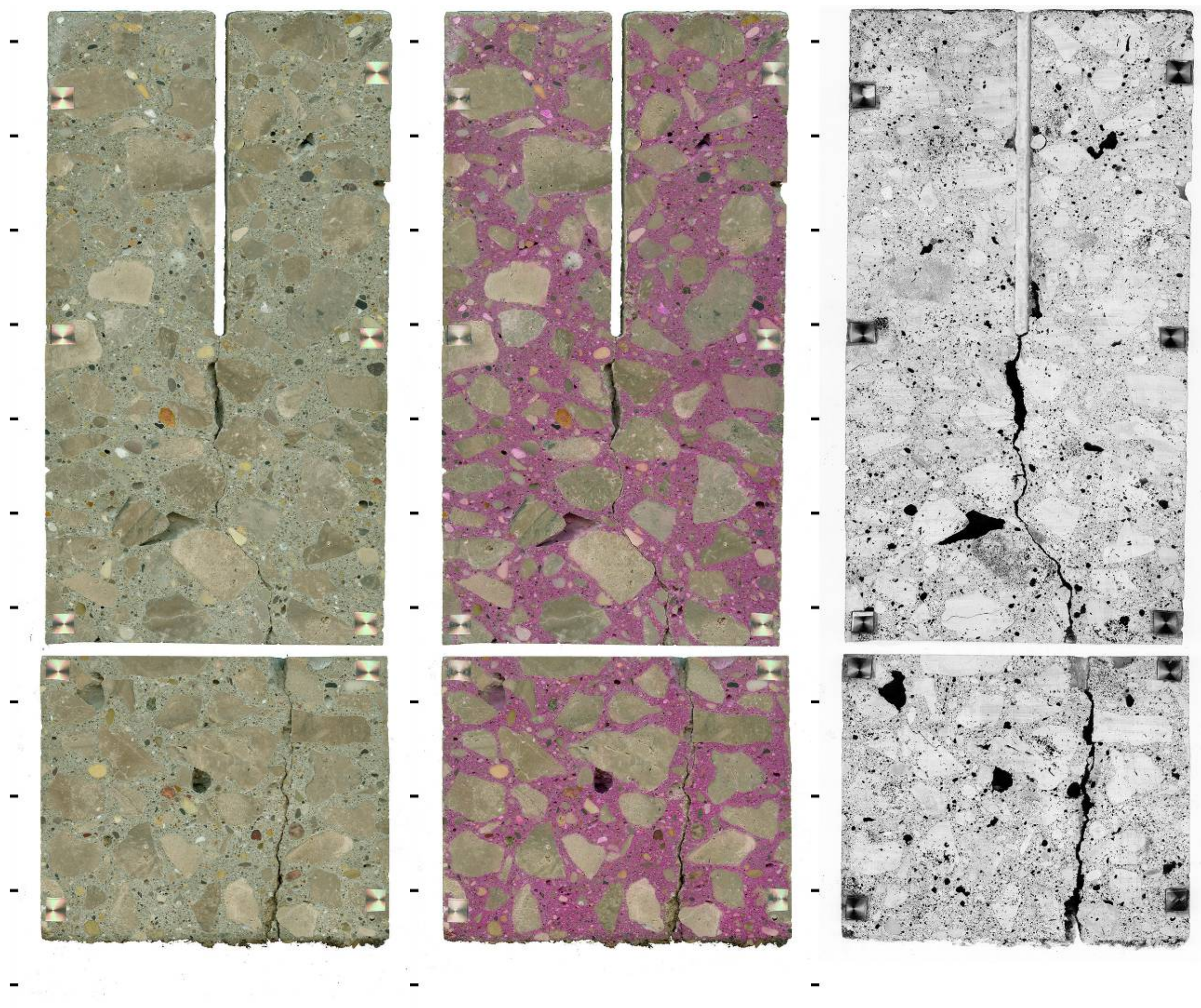

Figure 25. Scanned images of polished slab showing cross-section of core from test cell 2, from left to right: as-polished, after application of phenolphthalein stain, and after treatment to enhance visibility of pores and cracks (tic marks every inch).

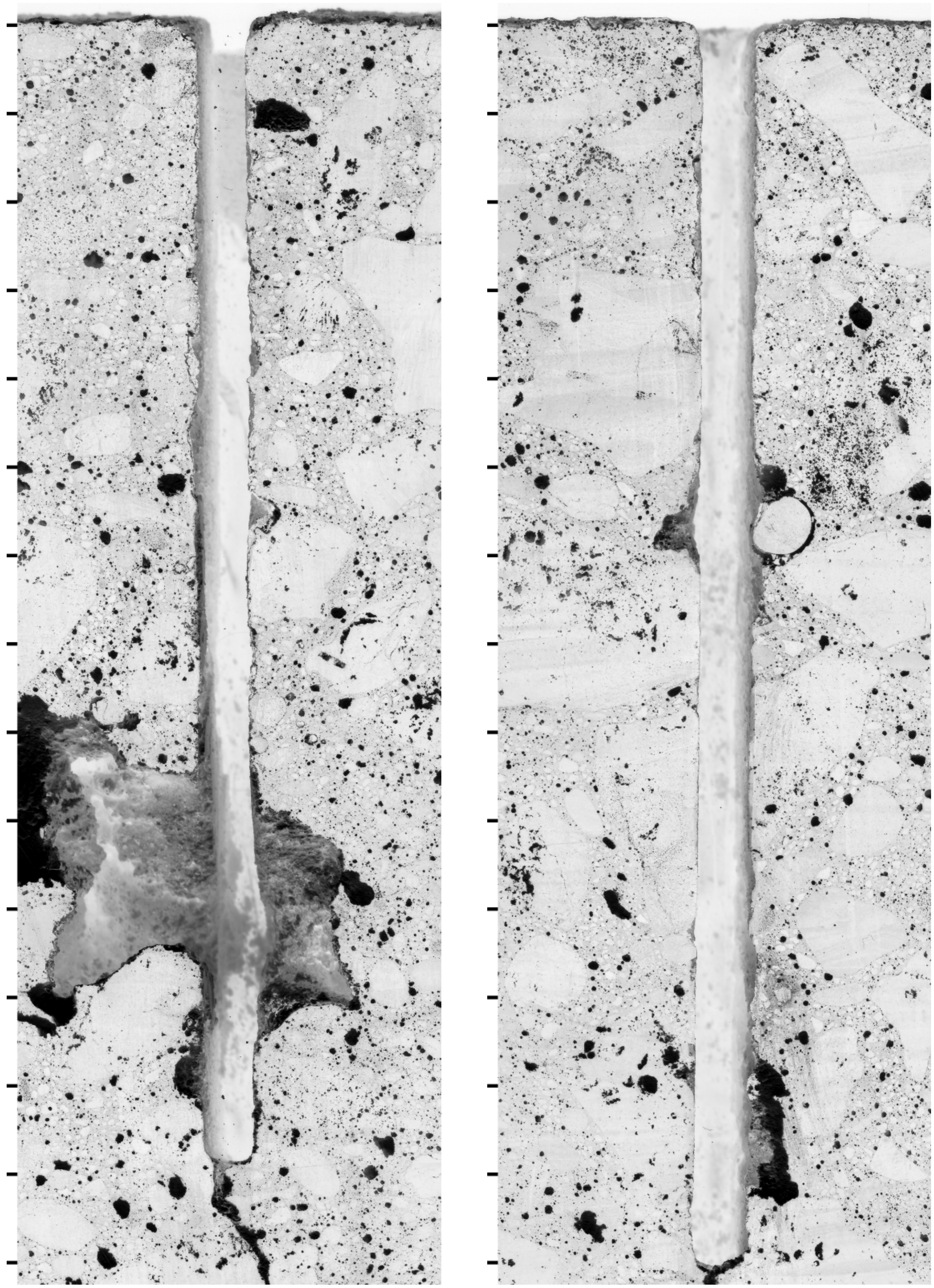

Figure 26. Detail of scanned images from figure 24 (left) and figure 25 (right) depicting saw cut joints from test cell 2 (tic marks every 0.25 inch).

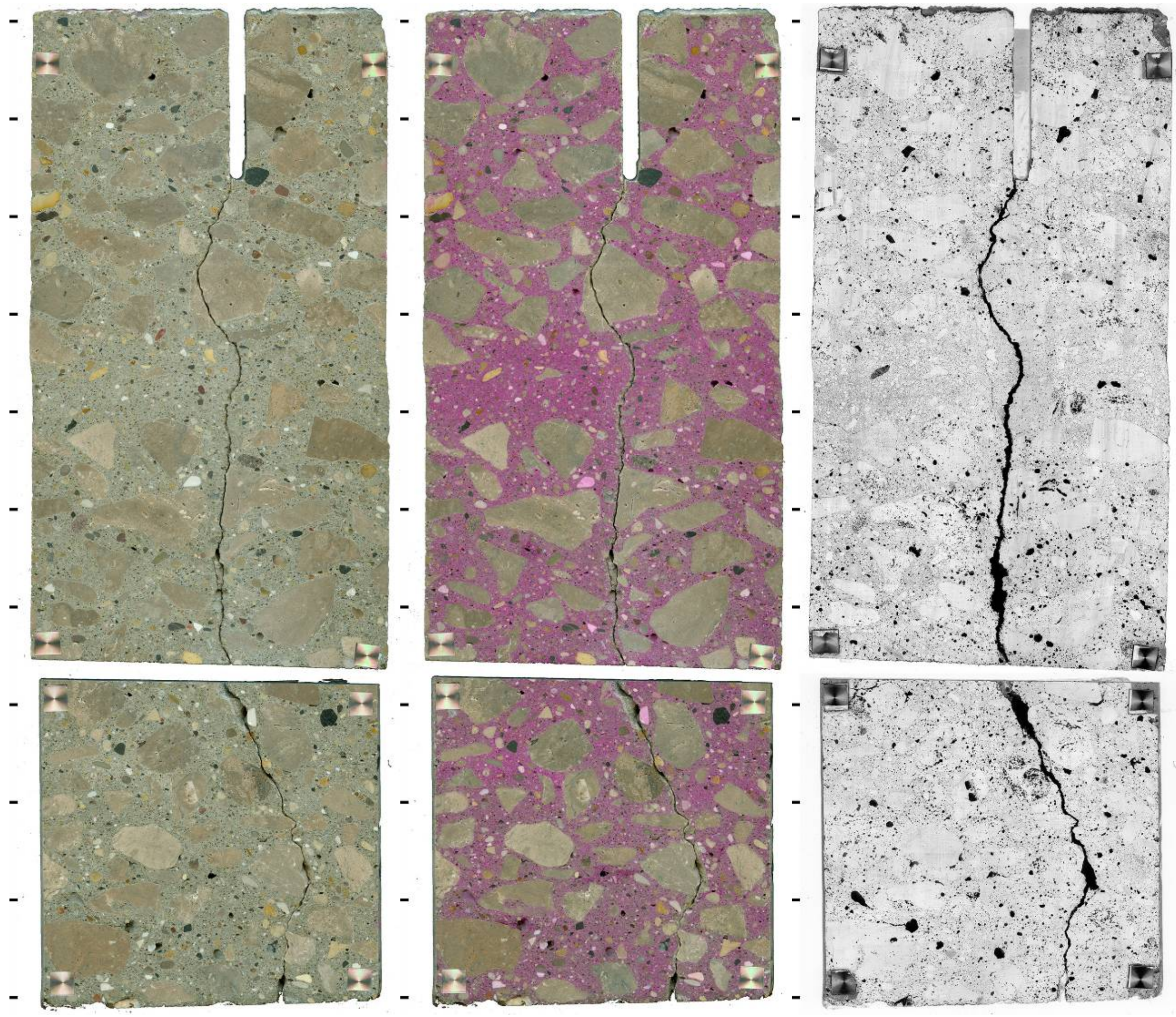

Figure 27. Scanned images of polished slab showing cross-section of core from test cell 3, from left to right: as-polished, after application of phenolphthalein stain, and after treatment to enhance visibility of pores and cracks (tic marks every inch).

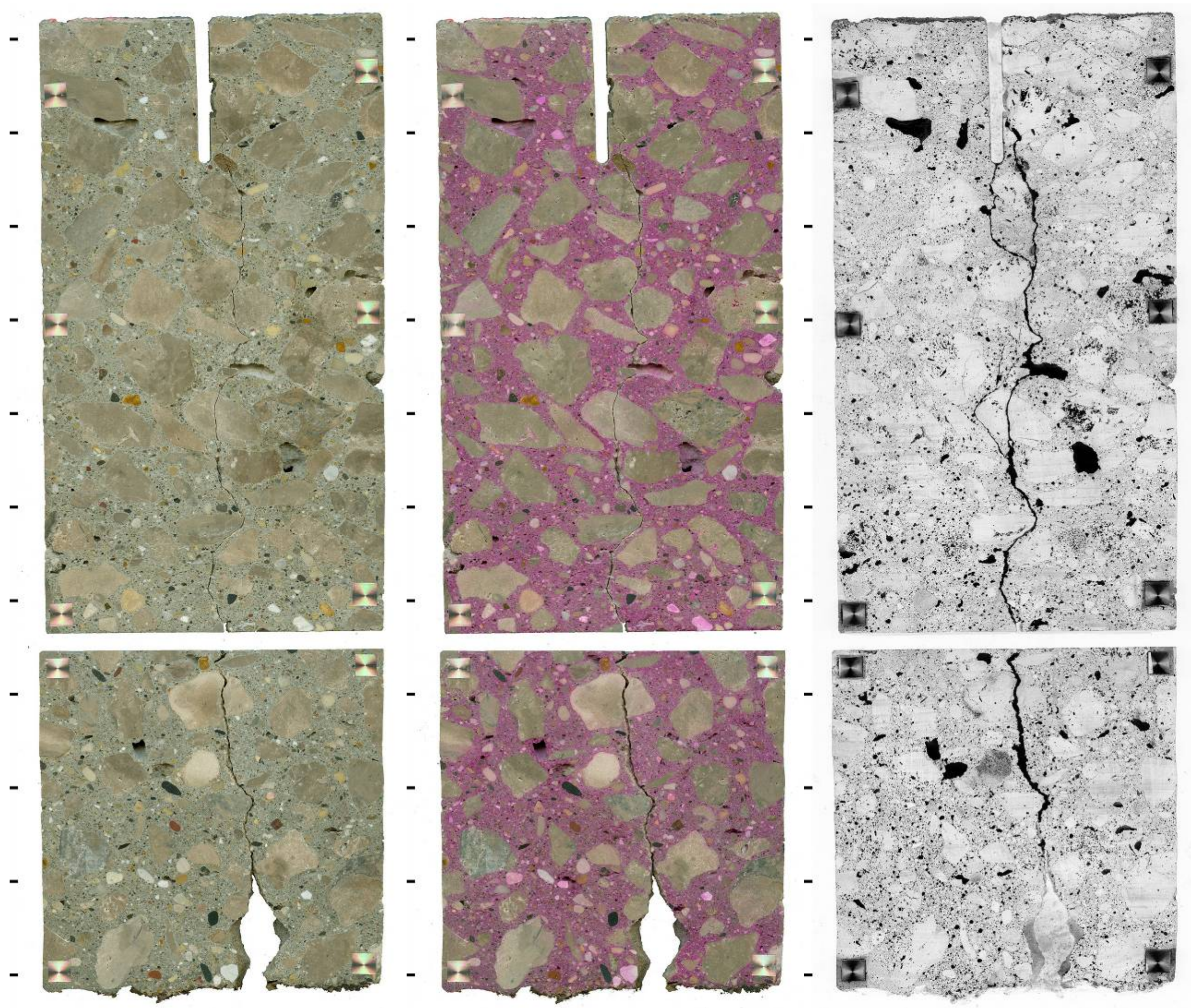

Figure 28. Scanned images of polished slab showing cross-section of core from test cell 3, from left to right: as-polished, after application of phenolphthalein stain, and after treatment to enhance visibility of pores and cracks (tic marks every inch).

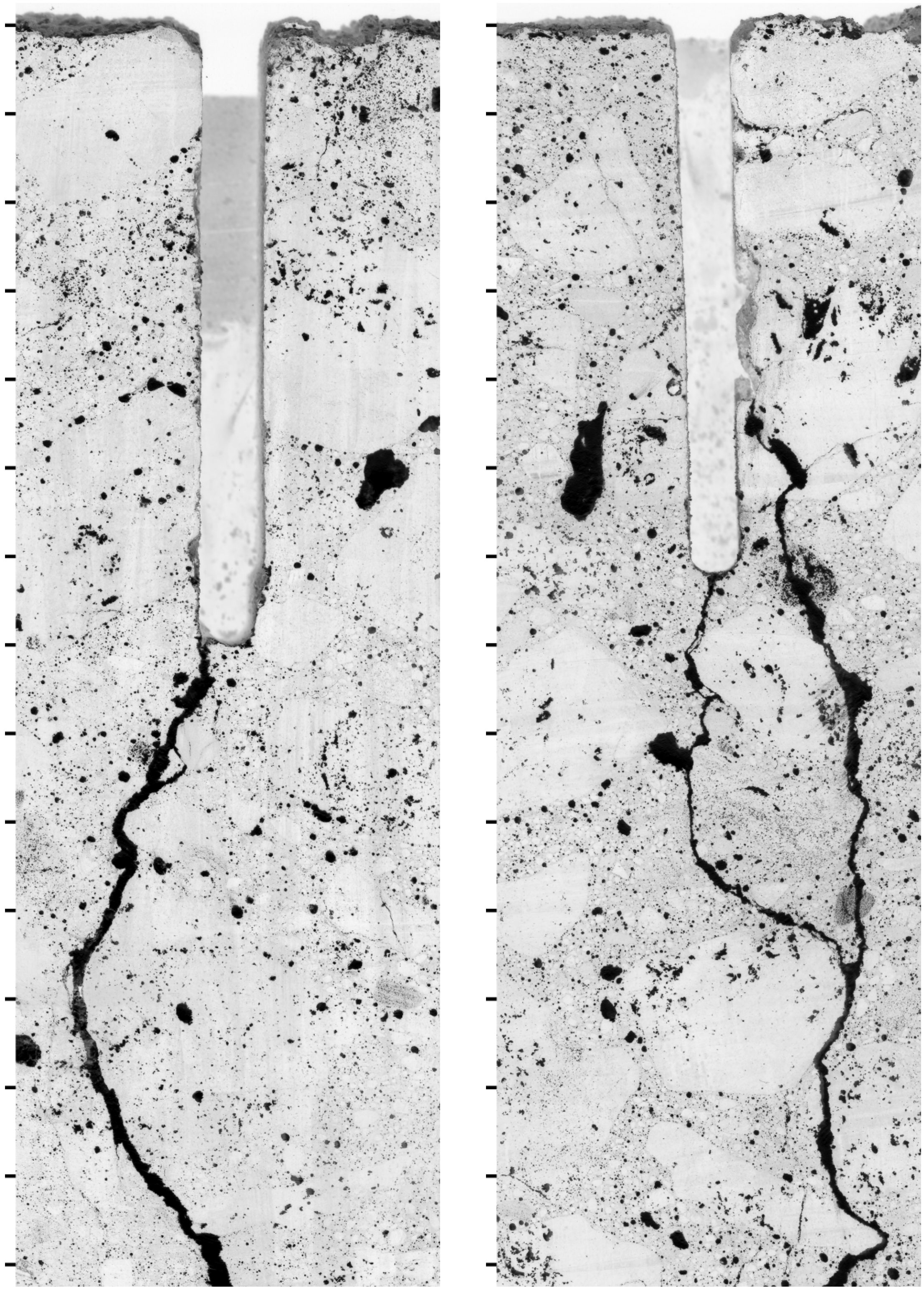

Figure 29. Detail of scanned images from figure 27 (left) and figure 28 (right) depicting saw cut joints from test cell 3 (tic marks every 0.25 inch).

3.2 FREEZE-THAW DURABILITY

Two cores from each test cell were subjected to 361 freezing and thawing (F-T) cycles in conditions described in ASTM C666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing Method B*, with the exception that cores were used in lieu of prisms and no measurement was made of the specimens' dynamic modulus of elasticity. In the course of the testing, the cores were wrapped with bands of vinyl tape to keep the halves together. The cores were examined visually for signs of deterioration at regular intervals and weighed for mass loss. Figures 30 through 35 show photographs taken during each of the visual inspection and weighing intervals. After 361 cycles none of the cores showed any visual indication of deterioration. Figure 36 plots weight change versus F-T cycles. Weight change was limited to the loss of saw cut residue that had been retained in the cut portion of the joint prior to testing.

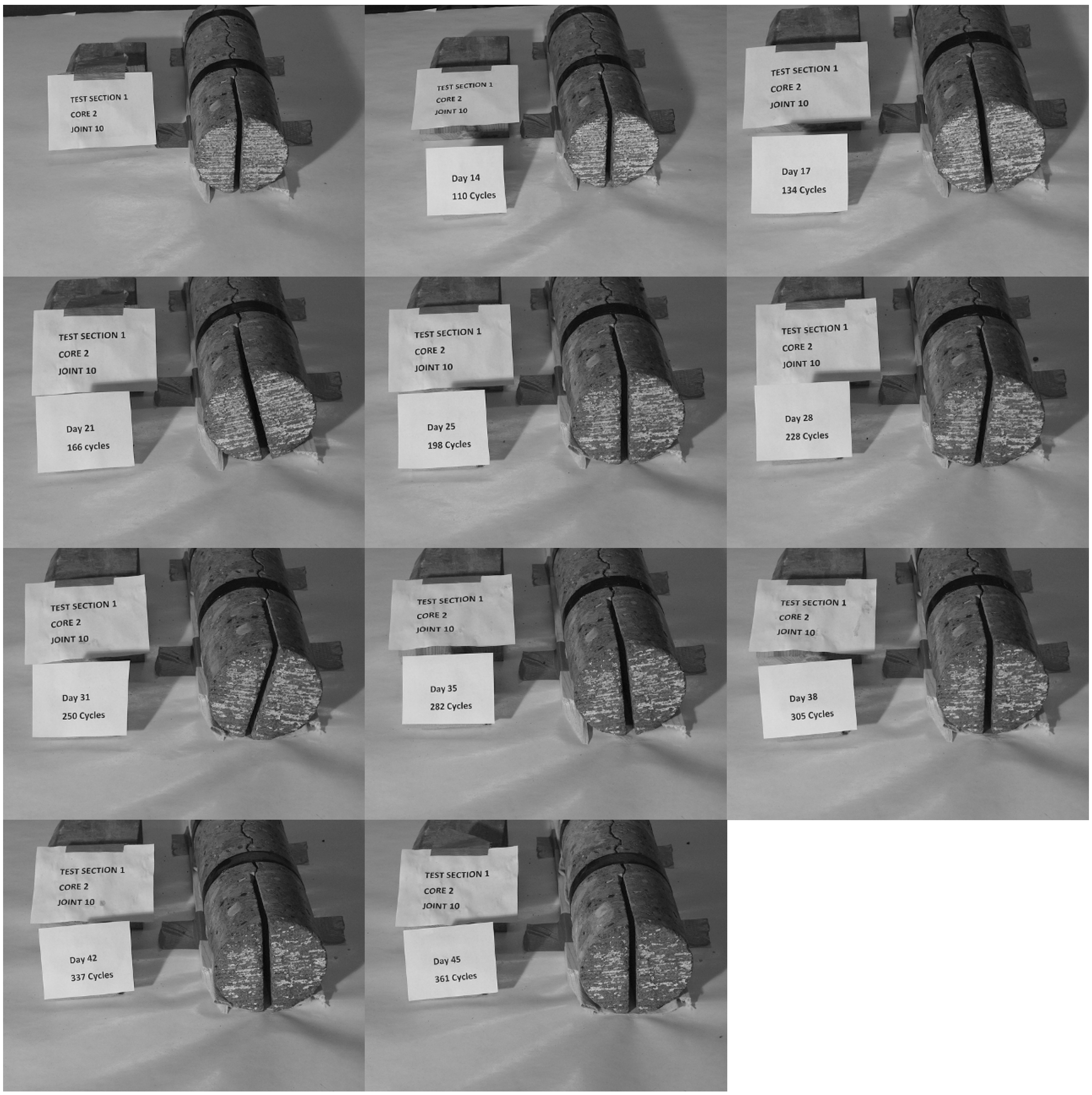

Figure 30. Photo of core from test cell 1 prior to testing (upper left corner) and at 30-cycle intervals, starting at 110 cycles (increasing cycle numbers from left to right, top to bottom).

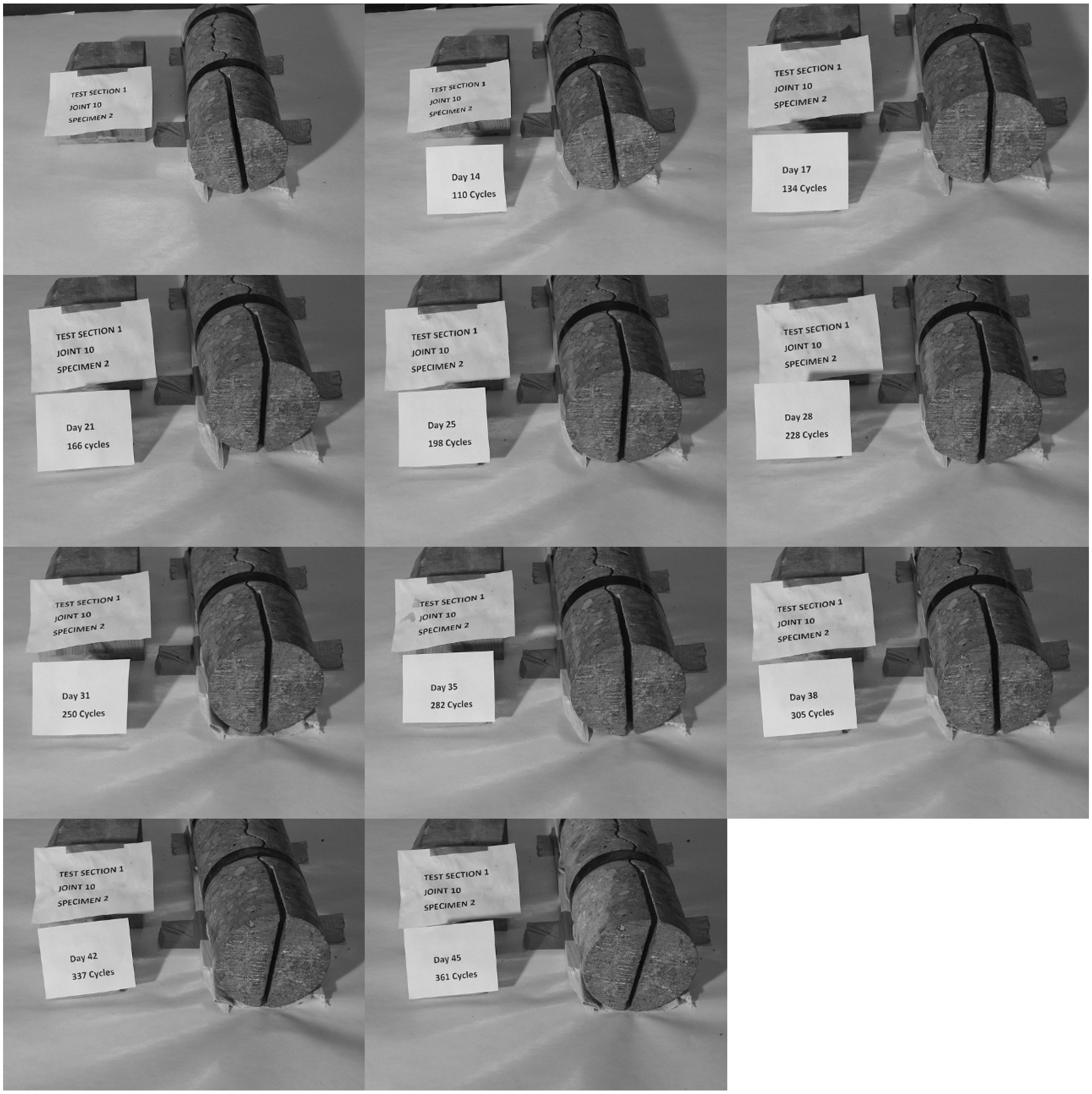

Figure 31. Photo of core from test cell 1 prior to testing (upper left corner) and at 30-cycle intervals, starting at 110 cycles (increasing cycle numbers from left to right, top to bottom).

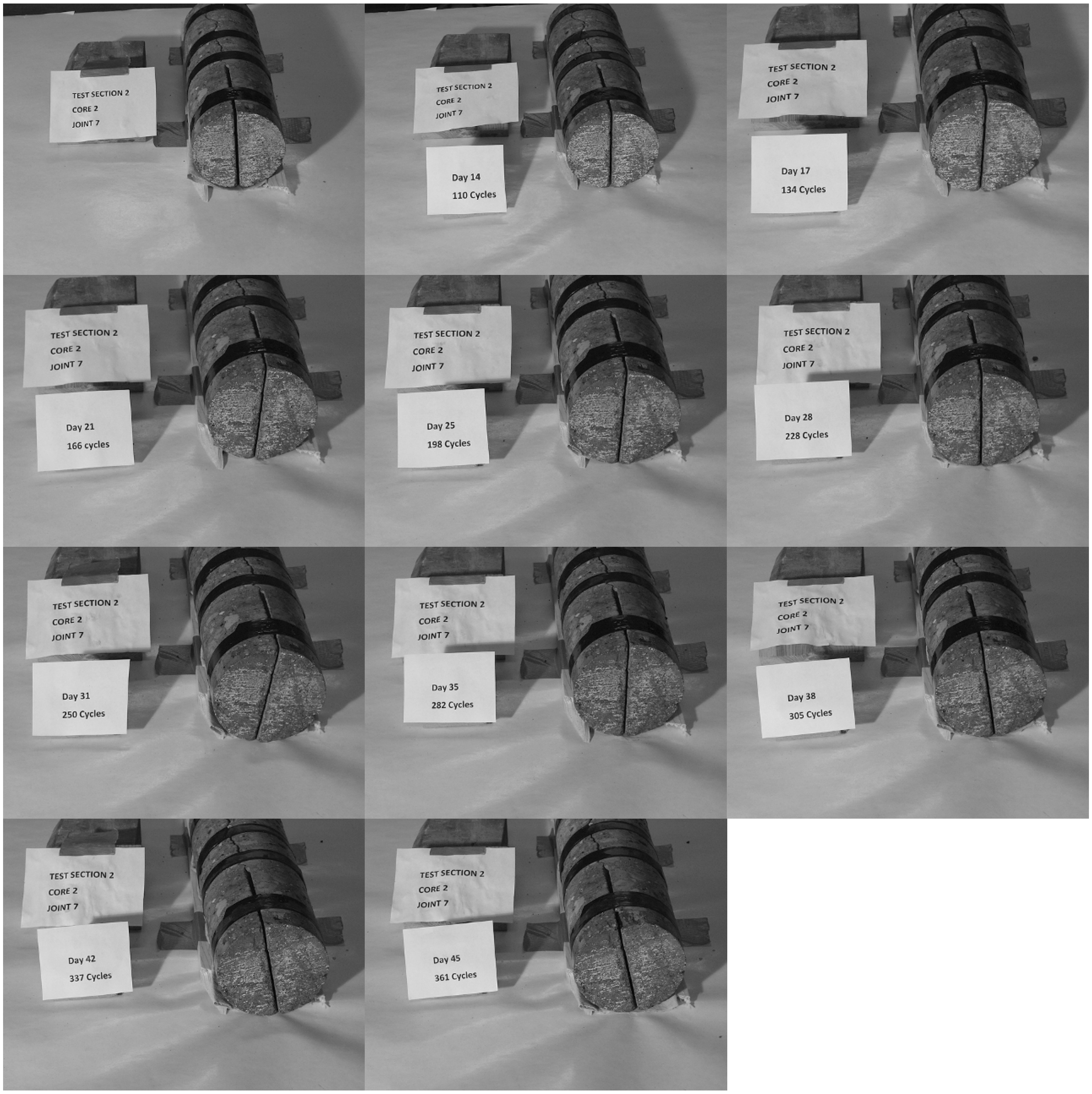

Figure 32. Photo of core from test cell 2 prior to testing (upper left corner) and at 30-cycle intervals, starting at 110 cycles (increasing cycle numbers from left to right, top to bottom).

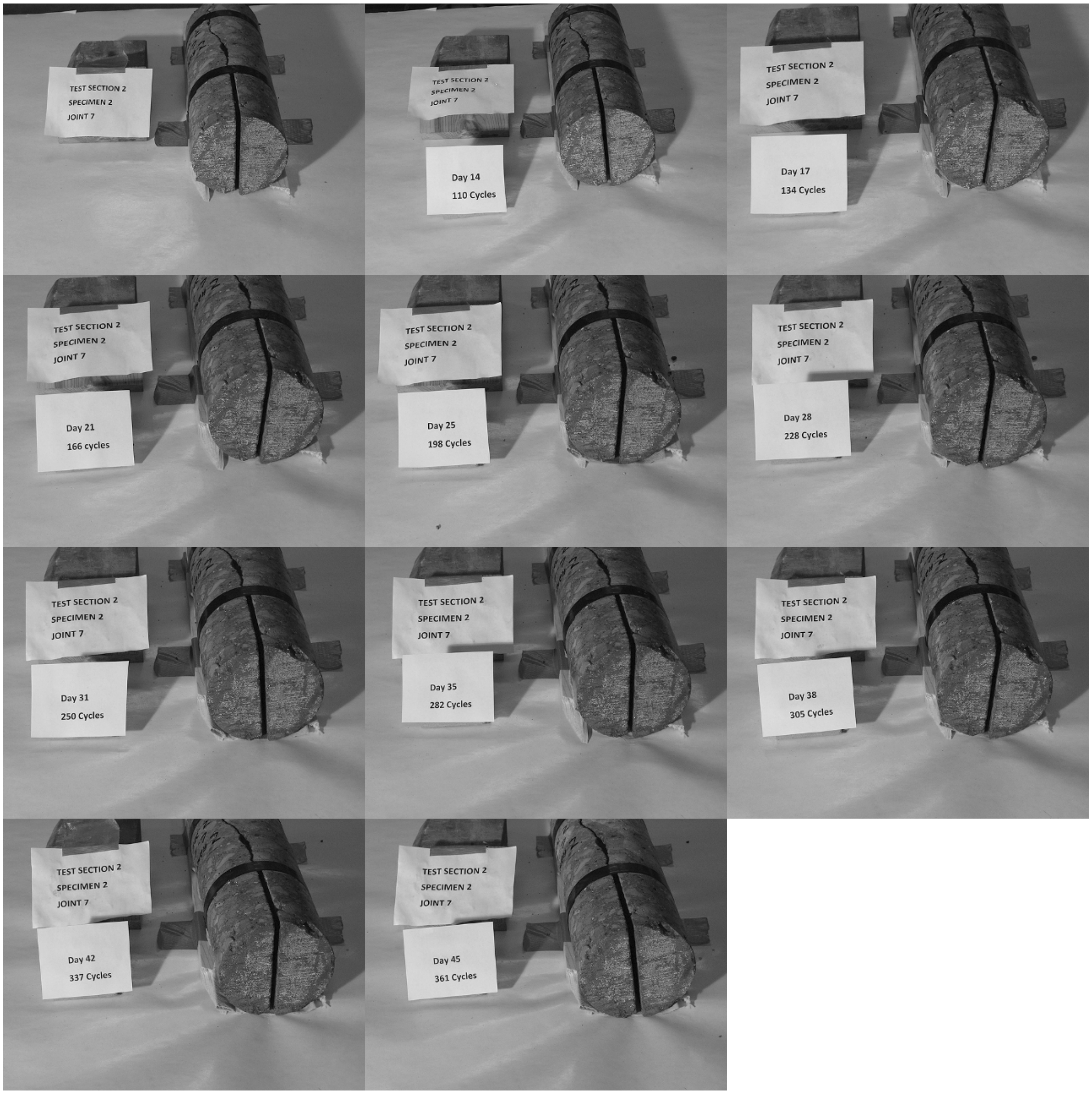

Figure 33. Photo of core from test cell 2 prior to testing (upper left corner) and at 30-cycle intervals, starting at 110 cycles (increasing cycle numbers from left to right, top to bottom).

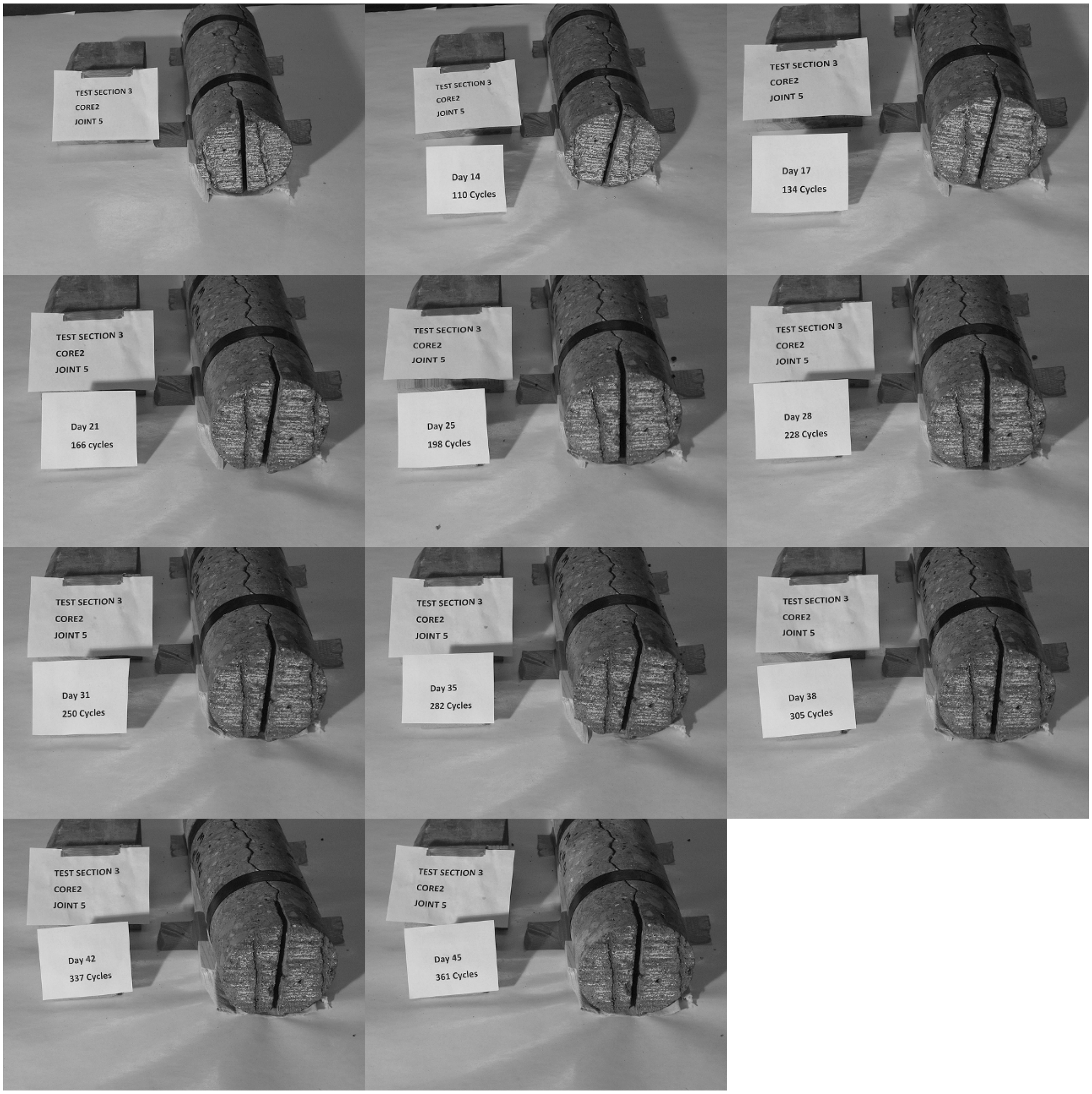

Figure 34. Photo of core from test cell 3 prior to testing (upper left corner) and at 30-cycle intervals, starting at 110 cycles (increasing cycle numbers from left to right, top to bottom).

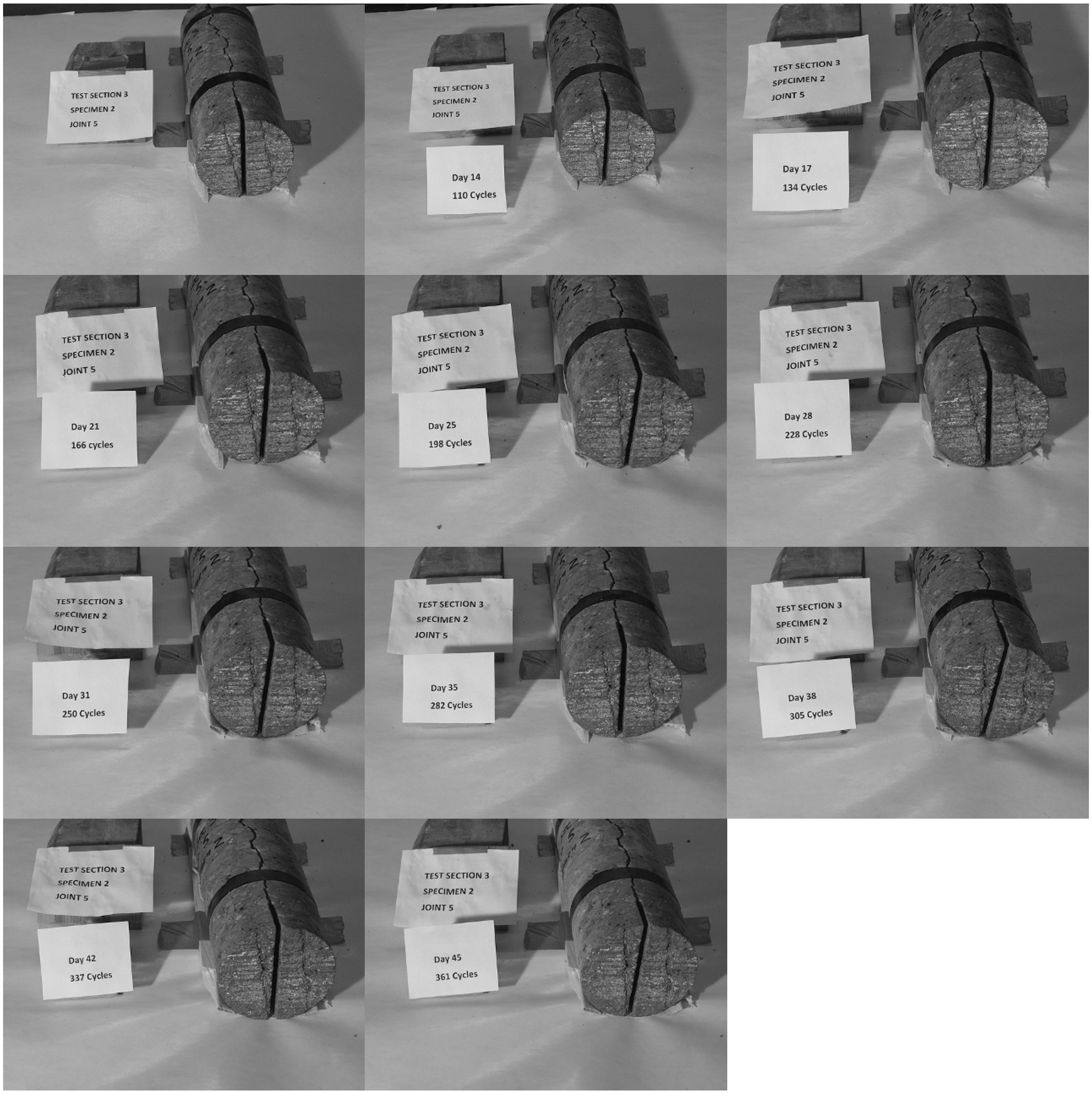

Figure 35. Photo of core from test cell 3 prior to testing (upper left corner) and at 30-cycle intervals, starting at 110 cycles (increasing cycle numbers from left to right, top to bottom).

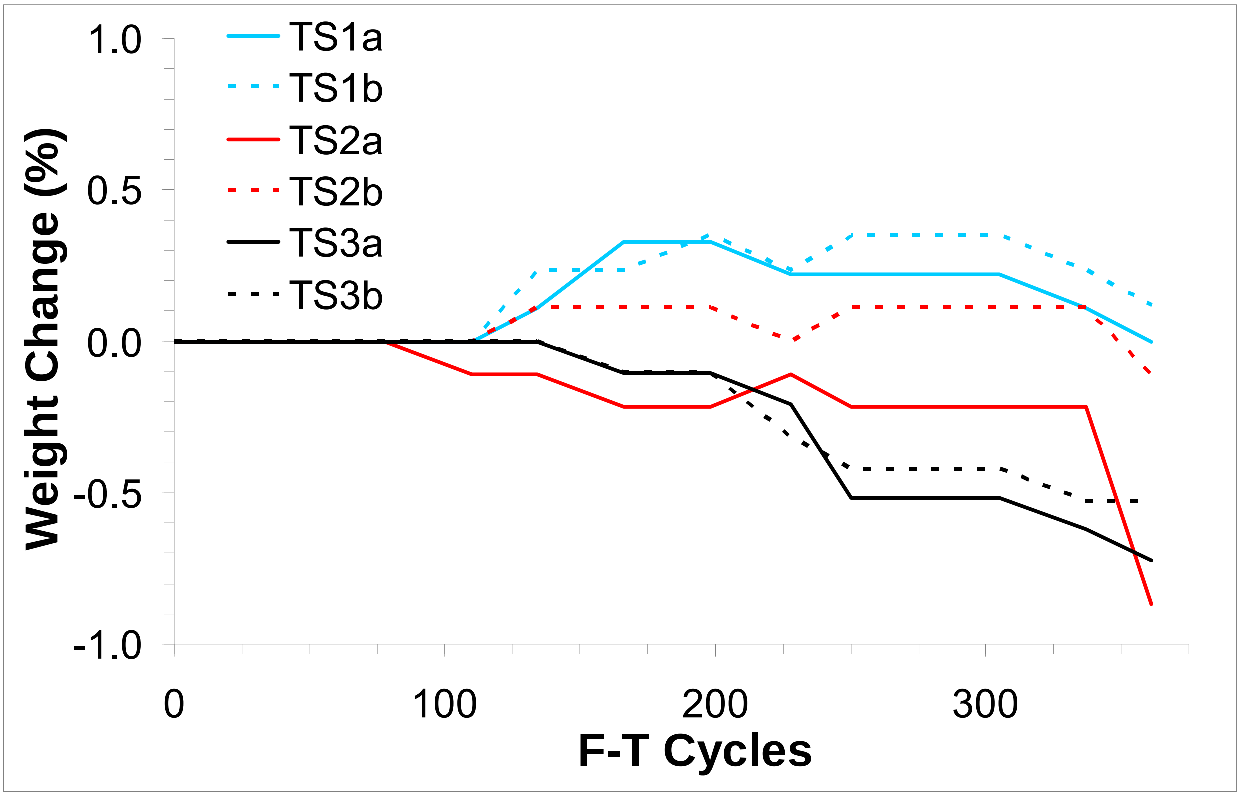

Figure 36. Weight change versus number of F-T cycles for the two cores from each test cell. Reported mass decreases are due to incremental loss of saw cut residue material that was retained in the cut portion of the joint prior to testing.

3.3 SALT SCALING RESISTANCE

Two cores from each test cell were ponded with calcium chloride deicing solution and subjected to 50 F-T cycles under conditions described ASTM C672, *Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals*, except that the cores were used in lieu of prisms. To make the ponding specimens, the bottom thirds of the cores were removed with a wet-cutting diamond saw, and the sides of the remaining top portions of the cores coated with silicone sealant and slid into 4-inch diameter plastic cylinder molds. The tops of the cylinder molds extended above the pavement surfaces of the cores to create dams sufficient to retain the ponding solution. For ponding, a concentration of 4 grams of anhydrous calcium chloride per 100 milliliters of solution was used. At the onset of 25 cycles, all of the specimens exhibited very slight scaling (0.12 inch maximum depth, with no coarse aggregate visible) and maintained the same rating up to 50 cycles. Figures 37 through 42 show photographs taken of the specimen surfaces at 5-cycle intervals. The weight of material flushed from the surfaces was measured at 30 cycles, and monitored every five cycles thereafter, as shown in figure 43. Flushed material consisted of a combination of surface scaling and saw cut residue materials that were retained in the saw cut portions of the joints. In no case was joint deterioration observed; however, one of the conventionally saw cut specimens from test cell 1 had significantly higher measured mass loss, but at 6.5 grams this loss was still minor.

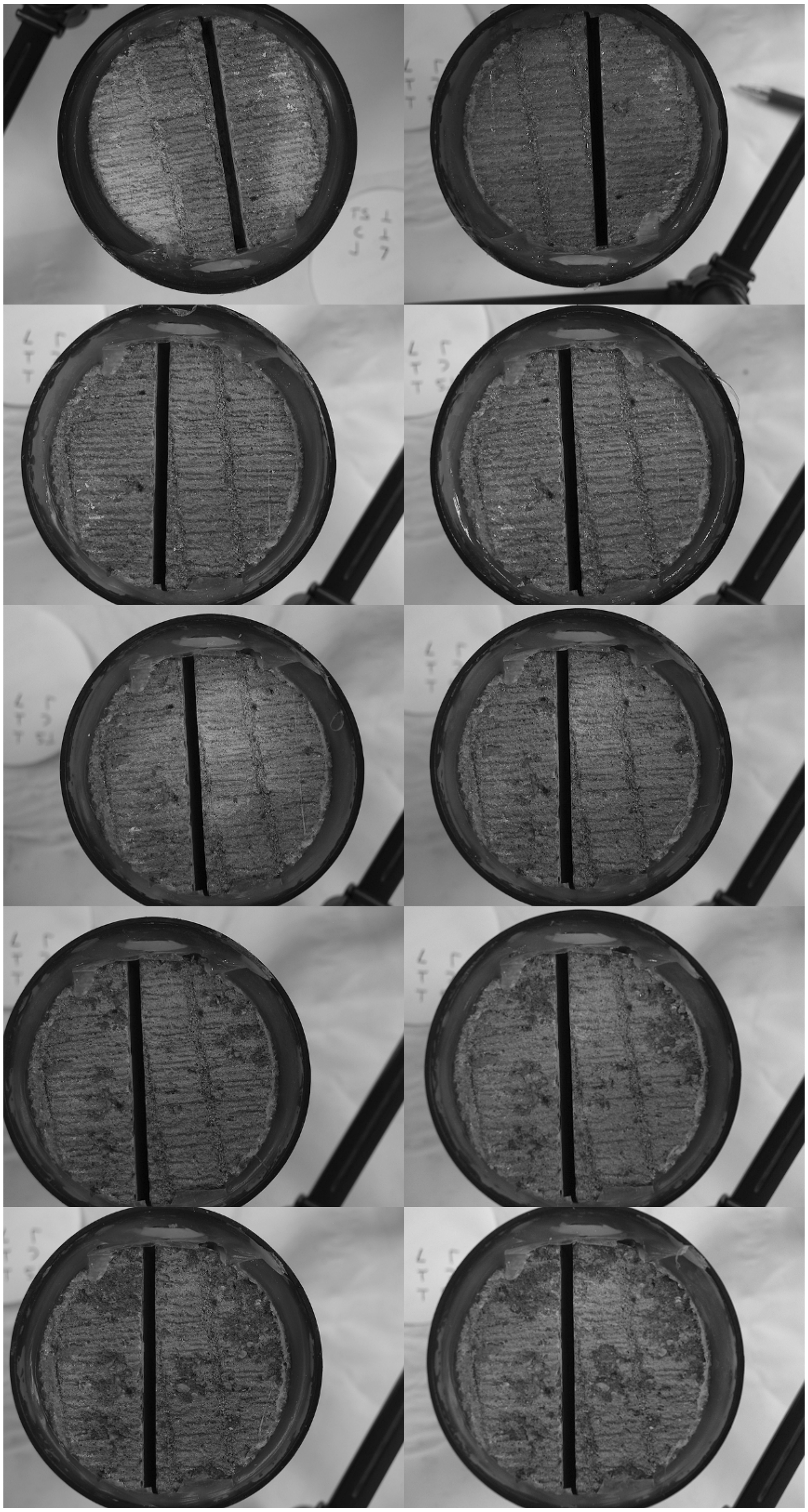

Figure 37. Photos of cores from test cell 1 throughout deicer-ponded F-T cycling, starting at 5 cycles (upper left corner) and after each additional 5-cycle interval (increasing cycle numbers from left to right, top to bottom).

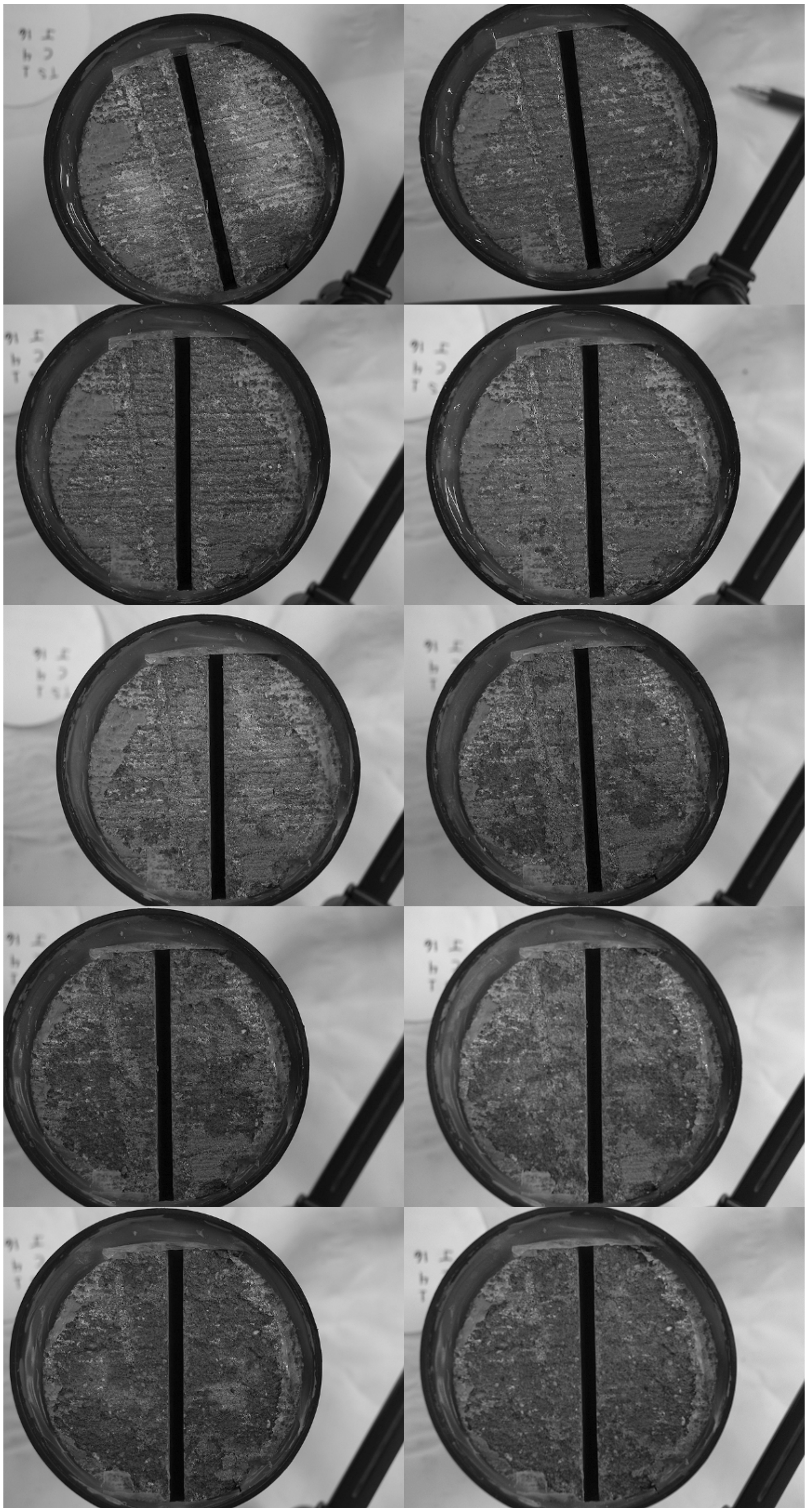

Figure 38. Photos of cores from test cell 1 throughout deicer-ponded F-T cycling, starting at 5 cycles (upper left corner) and after each additional 5-cycle interval (increasing cycle numbers from left to right, top to bottom).

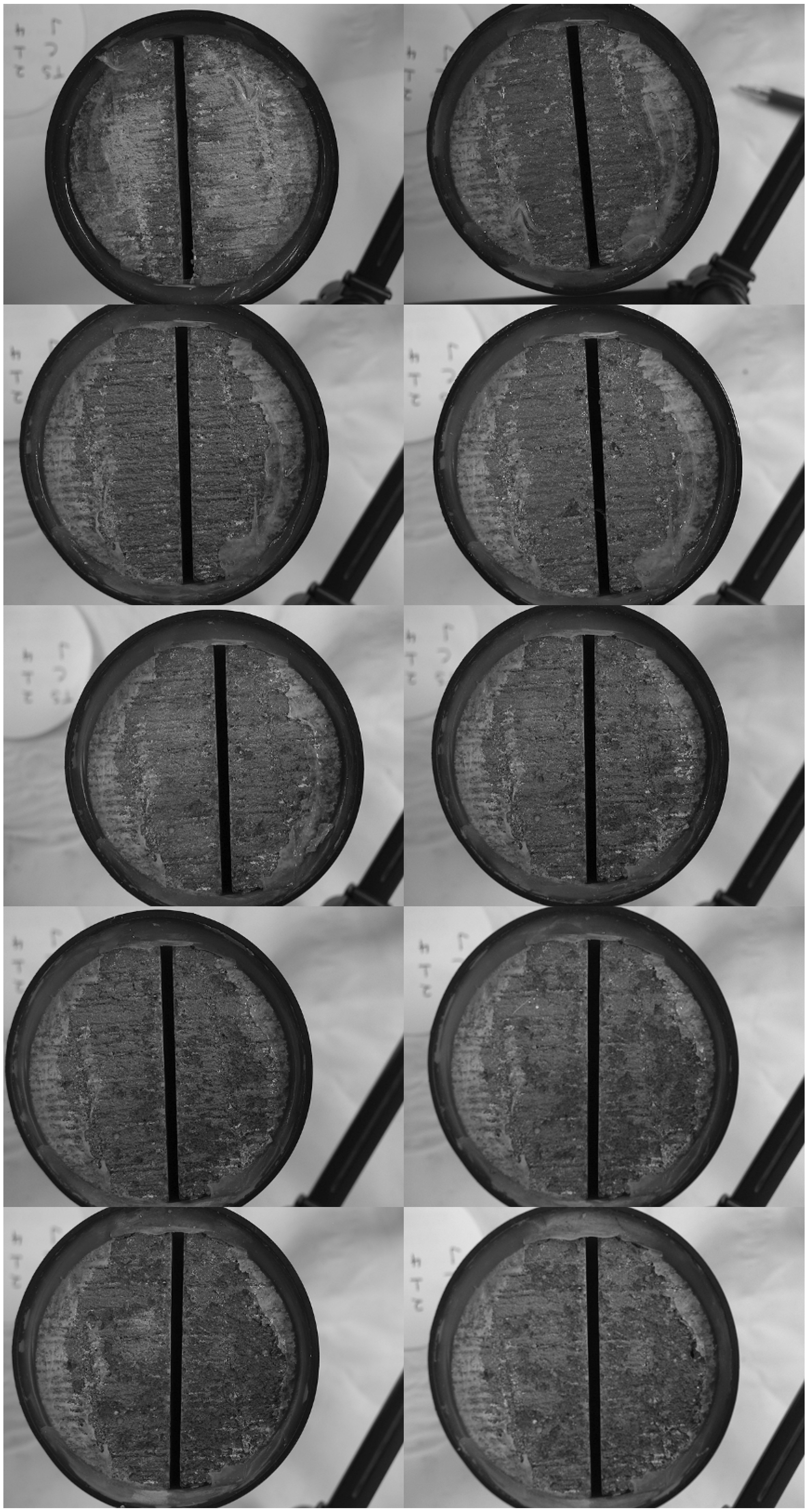

Figure 39. Photos of cores from test cell 2 throughout deicer-ponded F-T cycling, starting at 5 cycles (upper left corner) and after each additional 5-cycle interval (increasing cycle numbers from left to right, top to bottom).

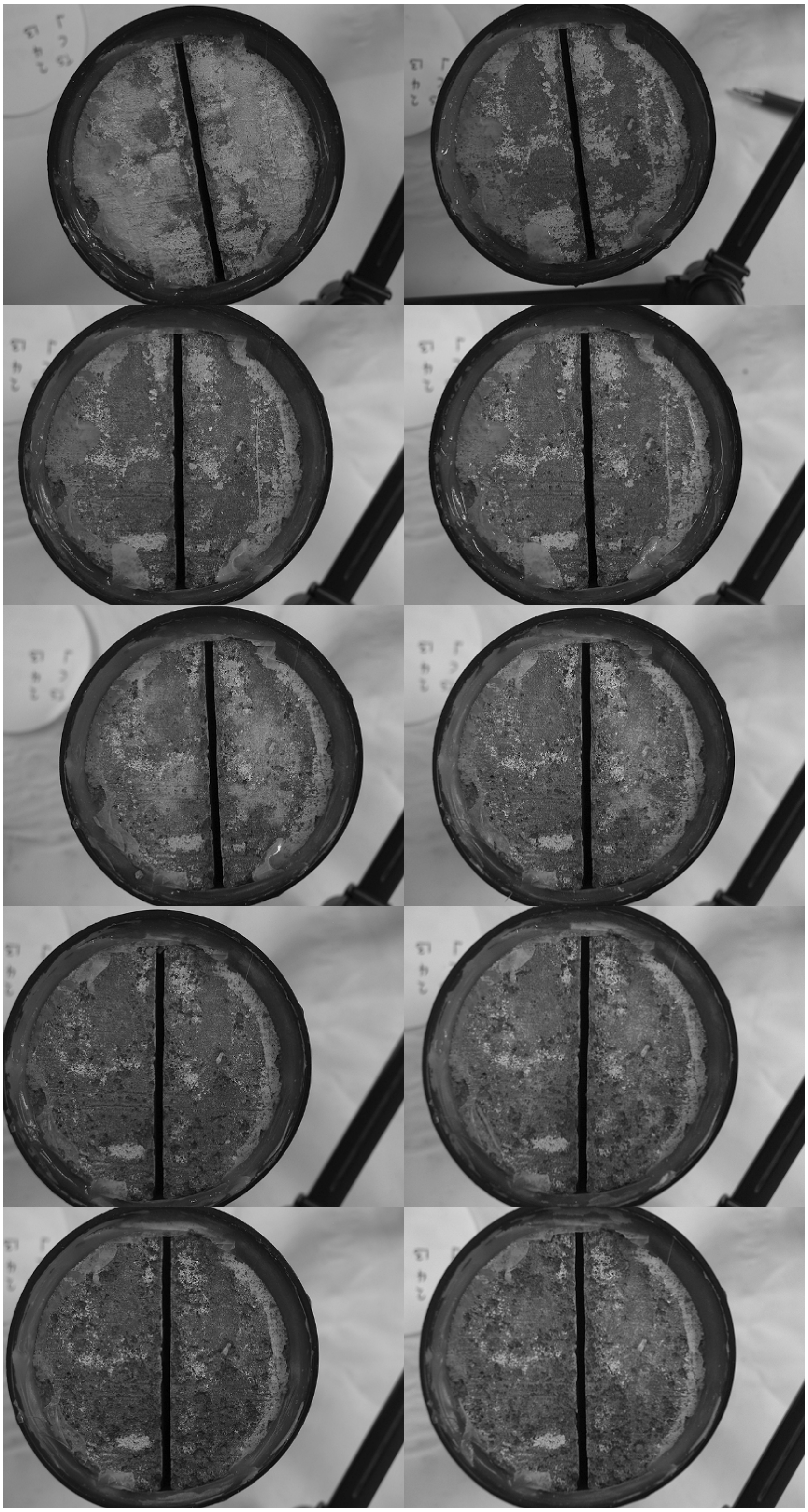

Figure 40. Photos of cores from test cell 2 throughout deicer-ponded F-T cycling, starting at 5 cycles (upper left corner) and after each additional 5-cycle interval (increasing cycle numbers from left to right, top to bottom).

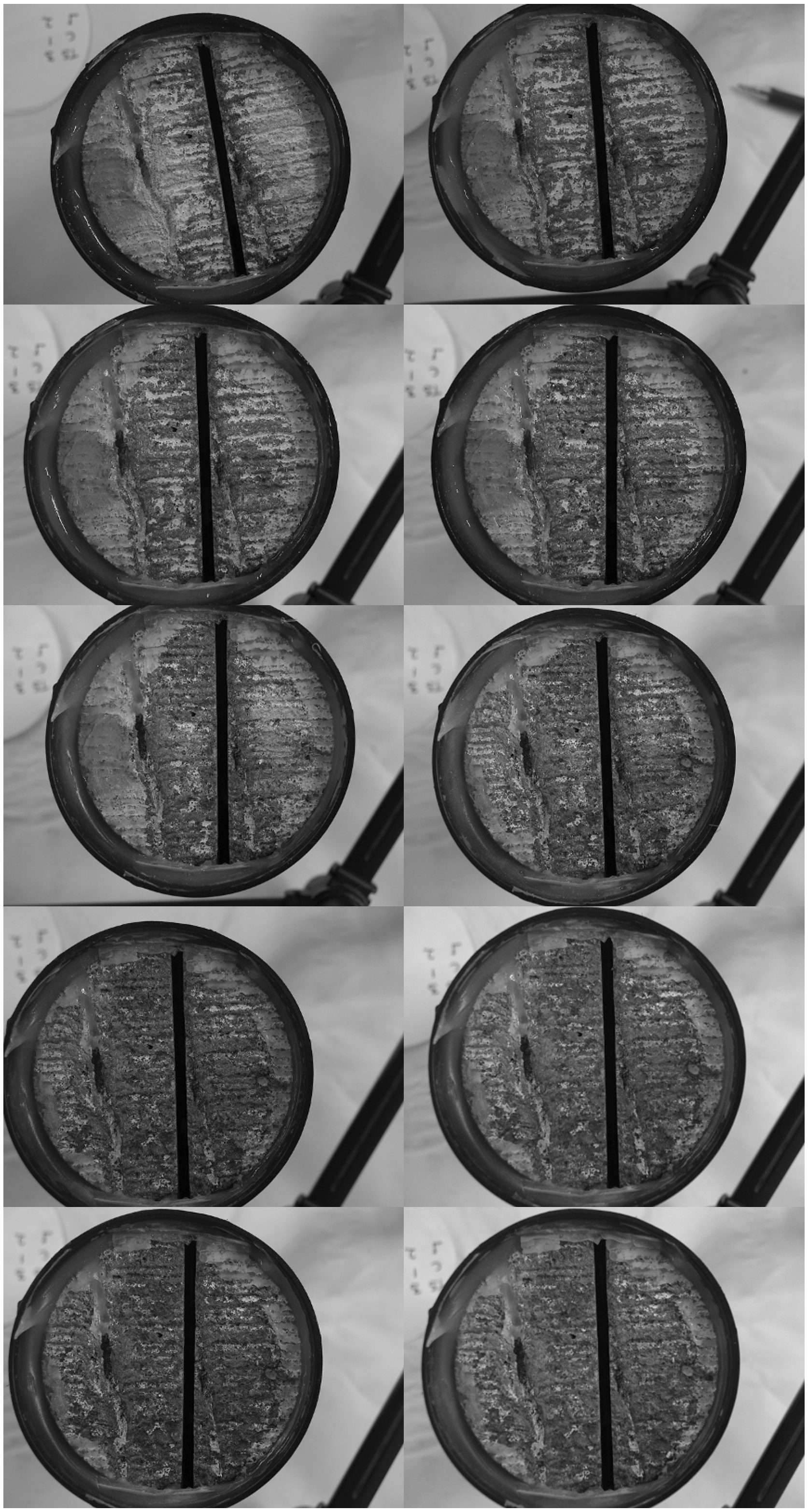

Figure 41. Photos of cores from test cell 3 throughout deicer-ponded F-T cycling, starting at 5 cycles (upper left corner) and after each additional 5-cycle interval (increasing cycle numbers from left to right, top to bottom).

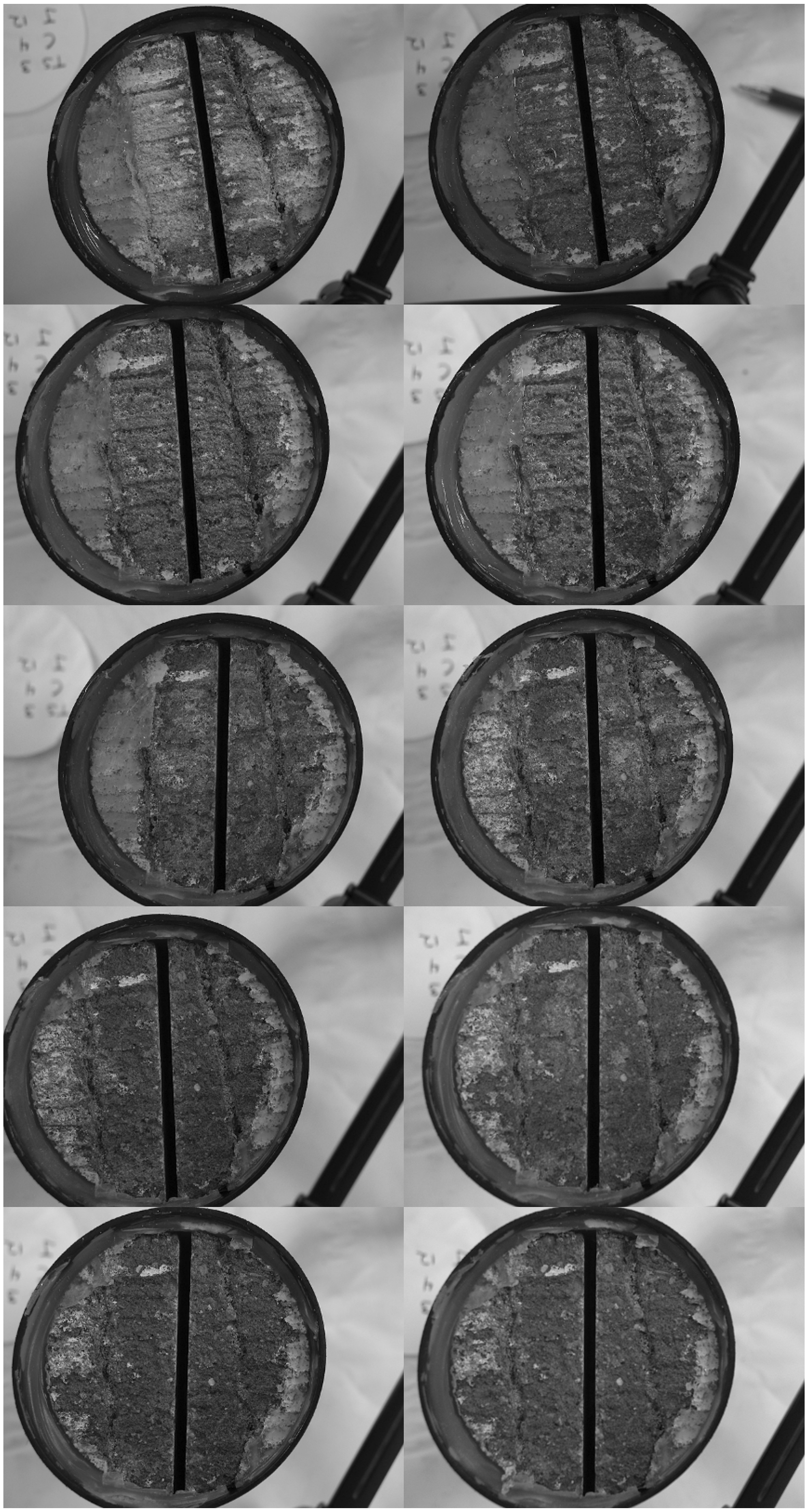

Figure 42. Photos of cores from test cell 3 throughout deicer-ponded F-T cycling, starting at 5 cycles (upper left corner) and after each additional 5-cycle interval (increasing cycle numbers from left to right, top to bottom).

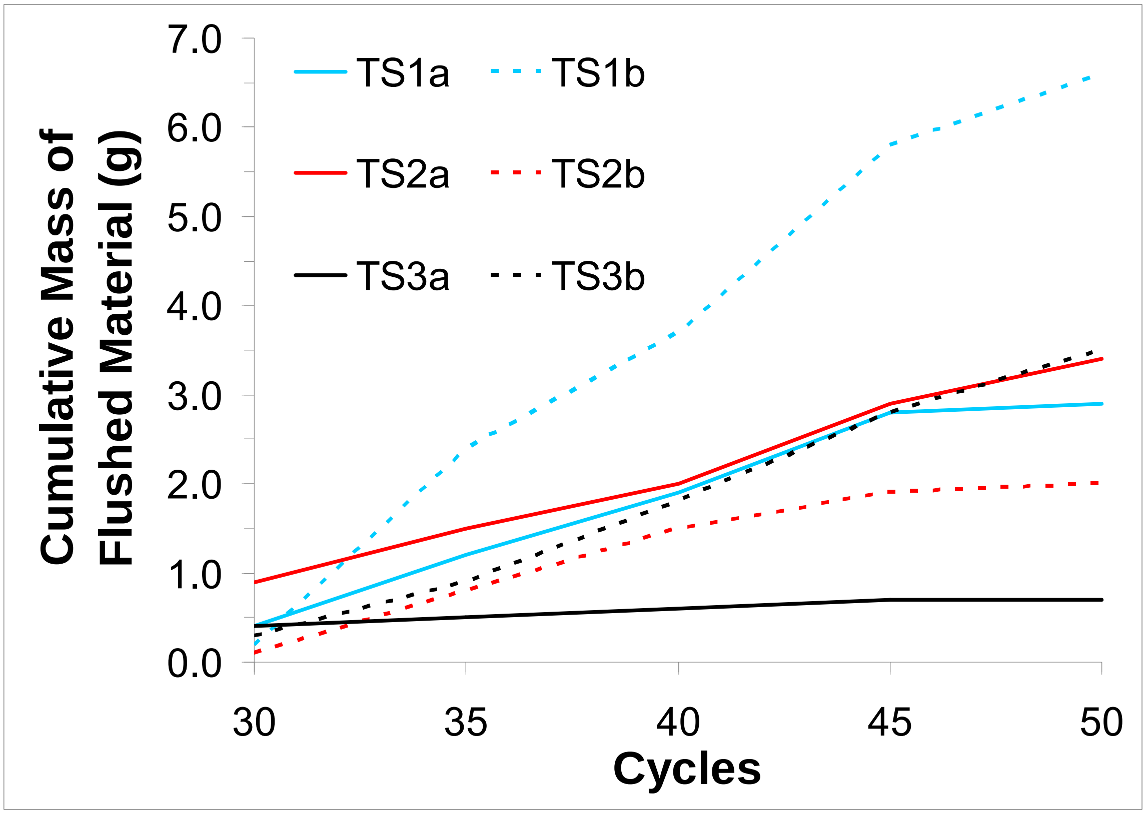

Figure 43. Cumulative mass of flushed material (starting at 30 deicer-ponded F-T cycles) versus number of cycles for the two cores from each test cell. Flushed material consisted of a combination of scaling from the surface and saw cut residue material that was retained in the cut portion of the joint prior to testing.

3.4 SUMMARY OF LABORATORY TESTING RESULTS

The significant findings from the laboratory testing can be summarized as follows:

- Petrographic examination: There are no detectable differences in the degree of microcracking in the immediate vicinity of the saw cut portion of the joints for any of the three test cells, regardless of the saw cut equipment or depth used. Branching of the primary crack was observed in two instances (test cell 1 and test cell 3). Long-term performance ramifications of observed branching, if any, are unknown.
- Freeze-thaw durability: After 361 cycles, none of the cores showed any visual indication of deterioration.
- Salt scaling resistance: At the onset of 25 cycles, all of the specimens exhibited very slight scaling (0.12 inch max depth) which did not progress through the end of testing at 50 cycles No indication of joint deterioration was observed regardless of saw cut equipment or depth of sawing.

CHAPTER 4 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Early-entry sawing is an attractive operation to expedite the construction of jointed concrete pavements although some concerns have been expressed that long-term performance might be adversely affected. As an initial effort to investigate the feasibility of using early-entry sawing, IDOT sponsored this study to evaluate the expected joint durability of joints when cut using early-entry techniques compared to the IDOT's standard practice for saw cuts. Joint performance as a function of cut depth and time was also considered.

The field investigation was integrated into an active construction project. On August 24, 2009, a test section comprised of three test cells was paved along approximately 1000 feet of IL 59/Division St in Plainfield, IL. During construction, paving and sawing operations were observed and documented by photos, video, and note taking. Of particular interest were the sawing operations, during which signs of surface scarring, joint raveling, and slab edge breakouts were recorded and the extent of sawing-related damage was subjectively assessed, in addition to measuring the depth of saw cut. In addition to general observations, climatic conditions were monitored, as were pavement temperatures from time of paving onward. Ambient climate conditions and slab mixture and temperature data were used to perform a HIPERPAV® analysis to gauge potential for early-age cracking, which was shown to not be an issue. Compressive strength cylinders were also cast and tested at 3, 7, and 28 days.

By 10 days after construction, it was noted that approximately 99 percent of the joints exhibited cracks beneath the initial saw cut (Scofield 2009). Furthermore, it was observed that every fourth or fifth joint opened "wider than the rest" regardless of depth of saw cut or whether it was cut early (Scofield 2009).

Initially, for test cell 1—the conventionally sawed test cell—12 joints were rated at 0 (no visible sign of joint damage) and 7 joints were rated at 1 (slight roughness at joint edge). Test cell 2—the early-entry test cell sawed to a depth of *T*/3—rated 8 joints at JRI 0, 11 joints at JRI 1, and 2 joints at JRI 2 (increased roughness and/or displaced aggregate). Test cell 3—the early-entry test cell sawed at nominal depth of 1.25 inch—rated 6 joints at JRI 0, 13 joints at JRI 1, and one joint at JRI 2. No change in joint condition has been observed in subsequent inspections conducted in the fall 2009 and spring 2010. In addition, no random cracking has been observed within the test section.

A total of 18 cores were retrieved from joints throughout the test site (6 cores from each test cell). A battery of durability tests were conducted on the cores taken with the following results:

- Petrographic analysis: No detectable differences were noted in the degree of microcracking in the immediate vicinity of the saw cut portion for the three test cells.
- Freeze-thaw testing: After 361 cycles, none of the cores showed any visual indication of deterioration, and weight change was limited to the loss of saw cut residue retained in the joint prior to testing.
- Salt scaling testing: At the onset of 25 cycles, all of the specimens exhibited very slight scaling (0.12 inch max depth) which did not progress through the end of testing at 50 cycles. No indication of joint deterioration was observed regardless of saw cut equipment or depth of sawing.

Overall, the results of this preliminary investigation suggest that early-entry sawing is a viable approach to the creation of joints in PCC pavements. The technique presented no significant issues during the pavement construction, resulted in similar field performance, and laboratory analyses suggest that little to no damage to the concrete in the immediate area adjacent to the joint was caused as a result of early-entry sawing.

4.2 RECOMMENDATIONS

Although the results of this study are promising, they are based on very limited data collected from a single construction site. Before general adoption of early-entry sawing is implemented, a broader Phase II study should be conducted to evaluate a greater number of variables while developing an improved understanding of long-term performance. The following elements should be considered:

- Various pavement projects have been constructed in Illinois in which early-entry sawing equipment/techniques have been used. As many of these projects as possible should be identified and visually assessed to determine the joint performance. Coring and petrographic analysis could be used to supplement visual assessment.
- New projects should be constructed to evaluate the impact of concrete mixture designs, coarse aggregate hardness, climatic conditions, construction practices, and so on, on joint performance. In total, perhaps nine to twelve different projects should be included. This work can also advance the use of embedded sensors to better understand early-age concrete pavement behavior.
- Several variables may need to be considered in determining when early-entry sawing is suited to a particular paving project, and although much of the sawing operation is dependent on the experience of the individual saw operators, guidelines should be developed to provide sound engineering data and understanding for not only deciding when to saw early but possibly also how deep to saw. For example, figure 44 illustrates slab temperature development within the two early-entry test cells and suggests the temperature for commencing joint sawing in each test cell; similar data from additional projects may produce trends that could be incorporated along with HIPERPAV® analyses into such guidelines, which would encourage contractors to instrument their paving projects so as to accurately determine optimum sawing times. For instance, the Ohio DOT currently requires HIPERPAV analyses to determine contraction and longitudinal joint sawing time limits.

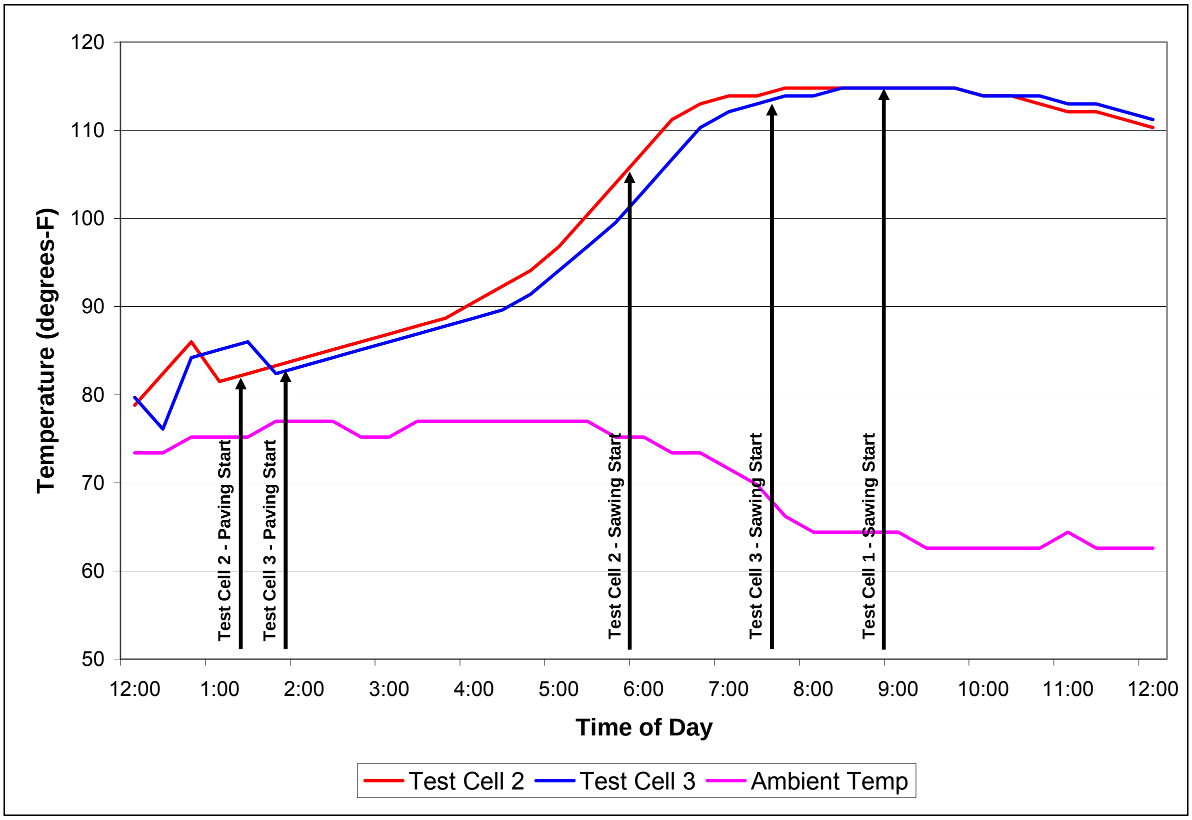

Figure 44. 12-hour temperature profile with notes indicating start of paving and sawing operations.

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APPENDIX A
Synthesis of State DOT PCC Pavement Sawing Specifications

Alabama 2008 Standard Specifications for Highway Construction

Section 450 – Portland Cement Concrete Pavement

450.03(b)6. CONCRETE SAWS. Equipment shall be provided for the sawing of joints. An adequate number of saws shall be utilized to complete the sawing within time to prevent cracking of the concrete.

450.03(j)2. SAWING CONCRETE FOR JOINT CONSTRUCTION. All joints except expansion joints shall be prepared by sawing. Sawing shall be done with a concrete saw equipped with a guide frame or other approved device that will assure cutting of the joint within 1/4 of an inch of the designated alignment and to the required joint size shown on the plans. All vertical joints shall be constructed perpendicular to the pavement surface.

Because of the importance of sawing the joints at the proper location and at the proper time, early sawing is imperative.

Arizona 2008 Standard Specifications for Road and Bridge Construction

Section 401 – Portland Cement Concrete Pavement

401-3.06 Joint Construction:
(A) Sawed Joints: Longitudinal or transverse weakened plane joints shall be sawed to the dimensions shown on the plans. Excess water from the sawing operation will not be permitted to stand on any subgrade to be paved. The contractor shall provide and maintain acceptable methods to control the water used in the sawing so the subgrade is not damaged. Sawed joints shall be constructed before uncontrolled pavement cracking occurs; however, joints shall not be sawed until the concrete has hardened enough to prevent excessive tearing or raveling during sawing operations. The exact time when sawing will be done shall be determined by the contractor.

The contractor shall maintain an additional concrete span saw on the project site at all times during which sawed joints are being constructed. The additional saw shall be maintained in good operating condition and shall be readily available as a substitute for the primary concrete saw.

Any procedure used to saw joints which results in premature uncontrolled cracking shall be revised immediately. The contractor shall repair damaged areas or random cracks as specified and as directed by the Engineer.

If joints are sawed in stages, the initial saw cut shall be of the minimum specified width and shall be sawed to the depth shown on the plans. Suitable guidelines or other devices shall be used to assure that joints are constructed at the locations shown on the plans.

Arkansas 2003 Standard Specifications for Highway Construction

Section 501 – Portland Cement Concrete Pavement

501.05(j) Joints. (1) General. The Contractor shall establish the location of all joints in concrete pavement. Longitudinal and transverse joints shall be located as shown on the plans in relation to the dowel or tie bars. Longitudinal and transverse joints shall be constructed to conform to the types, dimensions, and other details shown on the plans.

Longitudinal joints include the longitudinal joint between lanes, lanes and shoulders, and longitudinal construction joints between placements in sequence or placements against existing pavement. Transverse joints include expansion joints, contraction joints, warping joints, and construction joints.

All longitudinal and transverse joints shall be constructed, finished, filled, and sealed with joint material as shown on the plans. The joint grooves shall be thoroughly clean and dry when joint material is placed.

Sawed joints shall be formed by cutting the groove in the hardened concrete with an approved concrete saw capable of cutting the joint to the specified dimensions and true to line within the allowable variation.

Joints shall be sawed as soon as the concrete has hardened to the extent that tearing and raveling will not occur, but before development of any random cracking. Sufficient saws and saw blades to accomplish the work shall be available at all times. Should any procedure result in premature and uncontrolled cracking, the Contractor shall immediately revise the method and/or sequence of cutting the joints. Any curing media removed during sawing shall be immediately replaced.

California 2006 Standard Specifications

Section 40 – Portland Cement Concrete Pavement

40-1.08B Weakened Plane Joints. Longitudinal weakened plane joints shall be constructed at traffic lane lines in multilane monolithic concrete pavement by the sawing method. Transverse weakened plane joints shall be constructed either by the sawing method or by the insert method at the option of the Contractor. [The insert method consists of placing an insert of bond breaking material in freshly placed concrete—40-1.08B(2)]

40-1.08B(1) Sawing Method. The sawing method shall consist of cutting a groove in the pavement with a power driven concrete saw. Sawed grooves for longitudinal and transverse weakened plane joints shall be cut to the minimum width possible with the type of saw being used, but in no case shall the width exceed 0.02-foot [0.25-in.]. The minimum depth of cut for each individual lane shall be calculated as follows:

$d = t / 3$

where:

d = calculated minimum depth of cut rounded up to the nearest 0.01-foot.
t = greatest thickness of pavement in each lane.

The exact time of sawing longitudinal and transverse weakened plane joints shall be the Contractor's responsibility. Sawing transverse weakened plane joints shall be completed within 24 hours following paving. Sawing longitudinal weakened plane joints shall be completed within 12 hours following paving, unless a later time is ordered or permitted by the Engineer, but in any event before opening the pavement to any traffic. The Contractor shall exert every possible effort to prevent volunteer cracking. To achieve this, the sequence of sawing may be varied, or other measures not detrimental to the pavement surface may be utilized.

Excessive ravelling or tearing of concrete adjacent to saw cuts, shall be repaired as provided in Section 40-1.08B(3), "Repair of Spalls, Ravelling and Tearing." Excessive ravelling or tearing shall be defined as an accumulation of more than one foot of ravelling or tearing which exceeds 0.04-foot in width, exclusive of the saw cut, in a 12-foot lane, or an accumulation of more than 3 feet of ravelling or tearing which exceeds 0.02-foot in width, exclusive of the saw cut, in a 12-foot lane.

Colorado 2005 Standard Specifications for Road and Bridge Construction

Section 412 – Portland Cement Concrete Pavement

412.07(d) Concrete Saw. When sawed joints are required, the Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing to the required dimensions and at a rate that will control cracking. The Contractor shall provide at least one standby concrete saw in good working order at all times. An ample supply of saw blades shall be maintained at the site of the work at all times during sawing operations. The Contractor shall provide adequate artificial lighting facilities for night sawing. All of this equipment shall be on the job during concrete placement.

412.13(b) Weakened Plane Joints. Weakened plane joints shall be spaced and skewed as specified in the Contract and formed by sawing. The time of sawing shall be determined by the Contractor to prevent random cracking, and raveling from the sawing. The time will depend upon weather conditions, temperature, and other factors affecting the setting of concrete. If uncontrolled cracking occurs during or prior to joint sawing, the Contractor shall move the sawing operation ahead and, if necessary, add additional sawing units to eliminate uncontrolled cracking.

Connecticut 2004 Standard Specifications for Roads, Bridges, and Incidental Construction

Section 4.01 – Concrete Pavement

4.01.03F6(c) Transverse Contraction Joints: Transverse contraction joints shall consist of planes and of weakness created by forming or cutting grooves in the surface of the pavement and, when shown on the plans, shall include transfer assemblies.

i. Formed grooves shall be made by depressing an approved tool or device into the plastic concrete. The tool or device shall remain in place until the concrete has attained its initial set and shall then be removed without disturbing the adjacent concrete, unless the device is designed to remain in the joint.
ii. Sawed contraction joints shall be created by sawing grooves in the surface of the pavements of the dimensions and at the spacing and lines shown on the plans with an approved concrete saw. After each joint is sawed, the saw cut and adjacent concrete surface shall be thoroughly cleaned. Sawing of the joints shall commence as soon as the concrete has hardened sufficiently to permit sawing without excessive raveling, usually 4 to 24 hours. All joints shall be sawed before uncontrolled shrinkage cracking takes place. If necessary, the sawing operations shall be carried on both during the day and night, regardless of weather conditions. The sawing of any joint shall be omitted if a crack occurs at or near the joint location prior to the time of sawing. Sawing shall be discontinued when a crack develops ahead of the saw. In general, all joints should be sawed in sequence. If extreme conditions exist, which make it impractical to prevent erratic cracking by early sawing, the contraction joint groove shall be formed prior to initial set of concrete as provided above. The Engineer will review and approve procedures and methods to correct random cracking.

Delaware 2001 Specifications for Road and Bridge Construction

Section 501 – Portland Cement Concrete Pavement

501.16 Joints. Joints of the type and dimensions indicated shall be constructed at locations required by the Plans or Special Provisions.

1. Transverse Contraction Joints. Transverse contraction joints shall be spaced at intervals no less than 6.5' (2 m) and no greater than 45' (13.5 m), or as directed. A load transfer device as shown on the Plans or an approved alternate design shall be placed across each contraction joint. Unless otherwise specified or directed, all transverse contraction joints shall be sawed. Sawing shall be done with approved sawing equipment. The saw shall be equipped with adequate guides, blades, guards, water cooling system, and a method of controlling the depth of cut. An adequate supply of water, and a standby saw in good working condition with an ample supply of blades shall be available at the site of the work during the sawing of contraction joints. Joints shall be sawed in succession as soon as the saw can be operated on the pavement without damaging the surface or washing the mortar away from the coarse aggregate adjacent to the joint. The sawing shall be regulated so that each joint is sawed at the proper time. Sawing shall continue until all joints in the newly placed concrete are completed. The joints shall be sawed completely from edge to edge of the pavement. When a membrane curing agent is used, the edge of exposed pavement shall be sprayed with the curing agent upon the completion of the sawing of joints. All transverse joints shall be sawed without delay to prevent uncontrolled random cracking, usually four to 24 hours after the concrete placement, depending on the weather. Adequate lighting shall be provided to facilitate sawing operations performed during the night. If the wet sawing method is used, the joint shall be flushed clean with water after the concrete has gained sufficient strength to preclude washing of mortar from the joint faces.

Florida 2010 Standard Specifications for Road and Bridge Construction

Section 350 – Cement Concrete Pavement

350-12.3.2 Transverse Contraction Joints: Construct transverse contraction joints at the interval indicated in the plans consisting of planes of weakness created by sawing a groove in the surface of the hardened concrete. Place the groove perpendicular to the surface of the pavement. Install load transfer devices in transverse contraction joints.

Ensure that the sawing equipment does not damage the pavement, and saw the transverse contraction joints as soon as the pavement has hardened to the degree that tearing and raveling are not excessive and before uncontrolled shrinkage cracking begins.

Accomplish the joint sawing in two steps. Make the initial cut 1/8 inch wide by a depth at least 1/3 of the pavement thickness and as soon as possible but in no case longer than 12 hours after placing the concrete. Make a second saw cut, to provide the joint dimensions indicated in the plans, just prior to sealing the load transfer device.

In cases where a strip of pavement is being placed immediately adjacent to a previously constructed strip of pavement, construct transverse contraction joints using extreme care to time sawing so as to prevent uncontrolled cracks.

Georgia Standard Specifications

Section 430 – Portland Cement Concrete Pavement

430.3.05.J. Provide Joints. Ensure that joints are designed, configured, and located as shown on the Plans or required by the Specifications.

1. Provide dowel bars at transverse joints unless otherwise noted.
2. Remove and replace plain concrete pavement that cracks during construction with no additional cost to the Department, at the Engineer's discretion.
3. When chipping out random cracks for sealing, use nonrigid epoxy on cracks that are not under expansion-contraction influence and that meet Subsection 886.2.01.
4. Seal continuous cracks that are under movement with sealant that meets Subsection 833.2.06.
5. When removing and replacing a pavement section, remove an area at least 6 ft (1.8 m) long and the full width of the lane.
    a. Saw to vertical face the sections to be removed and replace the concrete as a construction joint with dowels.
    b. Use deformed bars as dowels in the saw-cut construction joint. Use the size specified for contraction joints in the Plans.
6. Thoroughly clean the drilled holes of contaminants and set the dowels into the hardened concrete face of the existing pavement with a Type VIII epoxy bonding compound. See Section 886 for epoxy bonding requirements.
7. For contraction joints, use undamaged and properly positioned dowels in existing construction or slab replacement areas. Coat the protruding dowel portions with a thin film of heavy grease.
8. When both sides of an existing construction or contraction joint require slab replacements, replace slabs continuously from saw-cut construction joint to saw-cut construction joint. Use dowels specified for contraction joints.
9. Before placing concrete, uniformly apply a thin coat of heavy grease to epoxy-coated dowels.
10. When placing slabs continuously across transverse contraction joint locations, use saw-cuts to provide planes of weakness according to the requirements of this Specification and the standard drawing for contraction joints.

430.3.05.K. Types of Joints

[…]

4. Transverse Joints. Transverse joints consist of construction joints, contraction joints, or expansion joints constructed at required locations.

[…]

6. Contraction Joints. Create planes of weakness in plain Portland cement concrete pavement by cutting joints in the pavement surface. Create the planes according to the Plans as follows:

a. Saw transverse contraction joints before the pavement cracks. Begin sawing when the concrete has hardened enough to prevent surface raveling, usually 4 hours after placement, but no more than 24 hours.
b. Continue sawing day and night regardless of weather conditions.

Idaho 2004 Standard Specifications for Highway Construction

Section 409 – Portland Cement Concrete Pavement

409.03B 3. Concrete Sawing Equipment. The Contractor shall provide a minimum of three production saws, including one standby unit, of adequate power to perform the work. Unless otherwise provided or allowed, all saws shall be multiple arbor, multiple blade gang saws. All saws operated on 3 to 4 hour old pavement (nonrigid) shall be work bridge mounted so the machine weight is not placed on the new concrete. The Contractor shall provide adequate artificial lighting facilities for night sawing. All of this equipment shall be maintained in good working order and shall be on the job before and continuously during concrete paving operations. An ample supply of saw blades shall be maintained at the site of the work at all times during the sawing operations. Paving will not be allowed until concrete sawing equipment is on site and ready for use.

409.03 H. Joints. Joints shall be constructed in conformance with the details shown on the plans. Suitable guidelines or devices shall be used to assure sawing the joints at the proper location as determined in the field.

1. Stress Relief Joint Sawing. The initial stress relief saw cuts shall be made, to control shrinkage cracking, as soon as the concrete has hardened sufficiently to permit sawing without raveling, and shall be sawed to the depth, width, line, and spacing shown on the plans. If necessary, stress relief sawing operations shall continue at night or under inclement weather conditions. If the sawing operation fails to keep pace with the paving operation, paving work shall be stopped until the sawing operation can keep pace with the paving operation.

Indiana 2010 Standard Specifications

Section 503 –Portland Cement Concrete Pavement (PCCP) Joints

503.03 Joints. Joints shall be constructed in accordance with the type and dimensions and at the locations shown on the plans or as directed. All joints shall be perpendicular to the subgrade.

Transverse joints shall be at right angles to the centerline and be continuous for the full width of the pavement.

All joints shall be cut to the required dimensions and sealed. All sawed joints shall be made by sawing equipment in accordance with 508.07 and shall be in accordance with the following.

(a) Type D-1 Contraction Joint. Type D-1 contraction joints shall be created by sawing slots in the pavement unless alternative methods are approved. The sawed contraction joint spacing shall be as shown on the plans or as directed, but shall not exceed 18 ft (5.5 m).

   Sawed contraction joints shall be cut in two operations. The initial saw cut shall commence as soon as the concrete has hardened sufficiently to permit sawing without raveling, usually 2 to 12 h after placement. All joints shall be saw cut through the edges of the pavement to the required depth before uncontrolled shrinkage cracking takes place. The sawing operations shall be carried on during day and night, regardless of weather conditions. The sawing of a joint shall be omitted if a crack occurs at or near the joint location prior to the time of sawing. Sawing shall be discontinued if a crack develops ahead of the saw. Formed contraction joints may be used where conditions make sawing impractical.

   The second saw cut shall be made after the concrete has sufficiently cured, but before opening the pavement to non-construction traffic. Slurry or saw residue remaining in the slot shall be immediately flushed with water. Construction traffic shall not be allowed on the PCCP after the second saw cut until the joint is sealed.

Section 508 – Equipment

508.07 Sawing Equipment. Sawing equipment shall be self-propelled single or gang-mounted units. The saw shall be capable of maintaining the specified alignment and depth of cut without damaging the PCCP.

Iowa 2009 Standard Specifications for Highway and Bridge Construction

Section 2301 – Portland Cement Concrete Pavement

2301.04N. Sawing Joints.

1. Saw joints in a single cutting operation for a specific joint. Make saw cuts true to line and to the dimensions shown in the contract documents.
2. Begin joint sawing as soon as the concrete has hardened sufficiently to permit sawing without raveling or moving of aggregate. Saw joints before uncontrolled cracking takes place.
3. Control joints may be sawed by any saw designed for concrete sawing.
4. If necessary, use continuous sawing operations regardless of weather or daylight conditions.
5. Discontinue sawing a joint if a crack develops ahead of the saw.
6. A heavy span saw which is supported on the new pavement will not be allowed for sawing pavements and concrete overlays less than 7 inches (180 mm) deep.
7. If the pavement has been covered or protected due to cold weather, rain, or snow, saw joints by conventional saw equipment only.

Kansas 2007 Standard Specifications for State Road and Bridge Construction

Section 501 – Portland Cement Concrete Pavement (QC/QA)

501.4g. Joints. (1) General. Construct joints according to the Contract Documents. Failure to construct the joints in the best possible manner will be cause for suspension of work until the cause of the defective work is remedied.

The objective is to create or form a plane of weakness in the fresh concrete before uncontrolled or erratic cracking occurs. The following methods are acceptable:

- Use concrete saws to saw all contraction joints no wider than the initial saw cut and to a depth of D/3 ± ¼ inch. Extreme conditions could exist which make it impracticable to prevent erratic cracking by sawing the joints early. At the onset of the project, devise methods, with the approval of the Engineer, to control this cracking.
- Make a "plastic concrete cut" straight and well defined so it can be sawed out by the saw crew. The "plastic concrete cut" would replace the specified initial saw cut. Suggested procedures could be the use of a stiff metal parting strip, with or without handles that would be gently inserted in the fresh concrete and removed, thereby parting the interlocking coarse aggregate and providing a plane of weakness.
- Cut the fresh concrete with a mason's trowel and straightedge from a worker's bridge. It is imperative that the "plastic concrete cut" joint and the second stage saw cut are in the same exact location.
- At the Contractor's option, "early entry" saws may be used based on satisfactory performance and depth of cut recommended by the equipment manufacturer.
- Procedures to control erratic cracking are not limited to these examples.

501.4g(3) Contraction Joints. Install contraction joints of the type, dimensions and spacing shown in the Contract Documents.

Stretch a stringline along the centerline of the joint, or otherwise adequately mark it to assure dowel bar joint assembly alignment.

501.4g(7) Joint Construction. Construct all joints as shown in the Contract Documents. Repair or replace any curing medium damaged during joint construction. Construct joints as follows:

(a) Induced Plane of Weakness. The first saw cut is a relief cut at the proper joint location, approximately ⅛ inch wide and to the full joint depth as shown in the Contract Documents (D/3 ± ¼ inch). Make the relief cut as soon as the concrete has hardened enough so that no excess raveling or spalling occurs, but before any random cracks develop. The sequence of the relief sawing is at the Contractor's option, provided all relief sawing is completed before random cracking develops. Use suitable guide lines or devices to cut the joint straight and in the correct location. Repair curing membrane damaged during sawing as directed by the Engineer. See subsection 502.3g.(1) for alternate methods to the first stage sawing.

Kentucky 2008 Standard Specifications for Road and Bridge Construction

Section 501 – JPC Pavement, PCC Base, and JPC Shoulders

501.02.20 Concrete Saws. Provide concrete saws for sawing joints that are powerdriven, having diamond-edge or abrasive saw blades, capable of cutting to the alignment, depth, and width specified for the joints, and in sufficient numbers to ensure all joints are sawed within the specified time limits.

501.03.17 Joints. Construct all joints, longitudinal and transverse, according to the Plans and Standard Drawings. Use epoxy coated or other approved corrosion resistant tie bars and hook bolts. Construct all joints perpendicular to the surface of the pavement and to true alignment.

Ensure that sawed joints are of uniform width throughout. Use sawing equipment to cut the joint in strict conformity with the required alignment and depth. The Engineer will allow spraying of water on the saw blades during the cutting. Do not saw the joints until the concrete has hardened to the extent that tearing and raveling will not occur, but as soon as necessary to preclude random cracking. Do not allow any traffic on the pavement until the joints are sawed. The Engineer may require the construction of sawed joints at the time, day or night, and in the order or sequence that will most effectively hold random cracking to a minimum. Provide a standby machine and a sufficient supply of saw blades available at all times.

Cut transverse saw cuts for joints that are to be sealed with preformed compression joint seals in one continuous cut across the pavement.

D) Transverse Contraction Joints. Construct transverse contraction joints in ramp tapers, intersections, and similar areas at locations specified in the Plans and Standard Drawings. On uniform width roadway construction, install transverse contraction joints at the spacing specified in the Plans and Standard Drawings.

Form transverse contraction joints by sawing, perpendicular to the surface of the pavement[.]

Louisiana 2006 Standard Specifications for Roads and Bridges

Section 601 – Portland Cement Concrete Pavement

601.03(b) Sawing Equipment: When joints are sawed in accordance with Subsection 601.09, the contractor shall provide adequate equipment to complete the sawing to required dimensions, and in a timely manner to prevent cracking. The contractor shall have back-up equipment at the jobsite to continue sawing operations if the primary sawing equipment malfunctions.

601.09(c) Transverse Contraction Joints (Type TCJ): Transverse contraction joints shall consist of planes of weakness created in the cross section of the pavement. The joints shall include load transfer devices. Joints for pavement with a design speed greater than 45 mph (70 km/h) shall be constructed by sawing as specified in Heading (1) below.

1. Joints shall be constructed by sawing after the concrete has reached sufficient strength to support sawing equipment. During paving operations, joint locations shall be clearly marked by approved methods. Joints may be either sawed to required joint width and depth at one time, or may be initially sawed to a width of approximately 1/8 inch (3 mm) and to the required joint depth and subsequently widened by sawing to required joint width. Sawing shall be to the specified depth for the full width of roadway or lane. When the transverse contraction joint cannot be sawed to the edge of the pavement due to forms, an insert shall be placed in the 6 inches (150 mm) adjacent to the forms. Initial sawing shall be done as soon as the concrete has hardened sufficiently that tearing of the concrete will not occur, and shall be completed in a timely manner such that cracking does not occur.

   No equipment other than the sawing machine and testing equipment will be permitted on the pavement during sawing operations. Sufficient back-up equipment shall be provided at the jobsite to continue sawing operations in case of a break-down of the primary sawing equipment.

   If sawing operations are not providing proper crack control the contractor shall modify sawing operations, equipment, timing and/or concrete mix as required to provide proper crack control.

Section 520 – Plain and Reinforced Portland Cement Concrete Pavements

520.03.14 Joints. Construct joints in conformance with the details specified, perpendicular to the finished grade of the pavement, and sealed as specified in Section 523. Transverse expansion and contraction joints shall be straight and continuous from edge to edge of the pavement.

520.03.14(c) Contraction Joints. Construct longitudinal and transverse contraction joints by sawing. If gravel aggregate is used, tool the joint, or form it by using an approved insert.

1. Sawed Joints. Sawcut to the specified depth using a 1/8 in. blade. Base the time of sawing on current and anticipated weather conditions and to prevent uncontrolled cracking of the pavement. Start the sawing operation as soon as the concrete has hardened sufficiently to permit cutting the concrete without chipping, spalling, or tearing. Respray damaged membrane cured surfaces as soon as the surface is dry. After completion of the curing period, widen the upper portion of the groove by sawing to the specified width and depth. The saw blades may be single or gang type, with one or more blades mounted in tandem. Do not sawcut into load transfer devices. Immediately after sawing the joint, thoroughly flush the saw cut and adjacent concrete surface with water to remove all waste.

Massachusetts 1995 Standard Specifications for Highways and Bridges

Section 476 – Cement Concrete Pavement

476.68 Joints. Joints shall be constructed of the types and dimensions and at the locations required by the plans, or specifications, or as directed by the Engineer. They shall be placed to a true alignment as shown on the plans or as directed. The sides of joints shall be protected during the curing period. Joint spaces shall be protected against infiltration of foreign materials before the time of sealing. All joints shall be sealed before the pavement is opened to any kind of traffic.

The Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing with a water-cooled diamond edge saw blade or an abrasive wheel to the required dimensions and at the required rate, he/she shall provide at least one standby saw in good working order. An ample supply of saw blades shall be maintained at the site of the work at all times during sawing operations. The Contractor shall provide adequate artificial lighting facilities for night sawing. All of this equipment shall be on the job both before and continuously during concrete placement.

The Contractor shall submit for approval by the Engineer his/her proposed equipment for lighting and sawing prior to commencing work on the project.

476.68(C) Transverse Contraction Joints. These joints shall consist of planes of weakness created by sawing grooves in the surface of the pavement at the locations indicated on the plans.

When approved by the Engineer, a vibrating bar may be used to move coarse aggregate off the line of the saw cut. The vibrating bar shall be used only in plastic concrete and so as not to produce areas of segregated mortar.

The Contractor’s sawing equipment and method of sawing shall be subject to the approval of the Engineer. The timing and sawing and the order in which joints are sawed shall be subject to such control by the Engineer as in his/her judgment is necessary to protect the pavement from raveling, spalling, cracking, or other damage. Normally, contraction joints will be sawed progressively with an approved circular saw at not less than 6 nor more than 24 hours after finishing. All joints shall be sawed before uncontrolled shrinkage cracking takes place. If necessary, the sawing operations shall be carried on both during the day and the night regardless of weather conditions.

The pavement shall be cut for not less than 3 millimeters in width to a depth at least one-fourth of the pavement thickness.

Secondary saw cuts shall be made as necessary so that the final joint width is at least 10 millimeters or as shown on the plans. In the event of excessive relief of the joint, care should be taken to secure this minimum opening.

To control random cracking the Engineer may require that initial curing (for the first 24 hours) be done with wet burlap. The sawing of any joint shall be omitted if a crack occurs at or near the joint location prior to the time of sawing. Sawing shall be discontinued when a crack develops ahead of the saw. In general, all joints should be sawed in sequence. All contraction joints in lanes adjacent to previously constructed lanes shall be sawed before uncontrolled cracking occurs.

Michigan 2003 Standard Specifications for Construction

Section 602 – Concrete Pavement Construction

602.03.F.3. Transverse Joints. Saw all transverse contraction and expansion joints according to subsection 602.03.N. Construct transverse plane-of-weakness joints in pavements without load transfer bars according to the details shown on the plans.

602.03.N. Sawing Joints. Saw joints according to the standard plans. The concrete saw is permitted on the pavement to saw the joints. The water supply truck is not permitted on the pavement until the pavement has attained the strength specified in subsection 104.11.

602.03.N.2. Transverse Contraction and Expansion Joints. Construct the joint groove in expansion joints as shown in the standard plan. Flush loose concrete and slurry from the groove and the immediate area.

If the specified seal is not installed within 7 days of final sawing, temporarily seal the joint groove with a suitable material or device to prevent the infiltration of foreign material.

Install either the permanent seal or a temporary seal before allowing vehicles over the full width joint grooves. Saw joints in two stages.

For joints constructed in one operation, saw the joint groove before transverse cracks develop. Repair raveling or spalling along the joint by either sawing a wider groove and installing a neoprene joint seal of proportionate size or repairing the raveled and spalled areas according to subsection 602.03.P.

Saw joints in two stages as follows.

First Stage. Place a relief cut directly over the center of the load transfer assembly or over the preformed joint filler. Make the relief cut when the concrete has hardened enough that no excess raveling or spalling occurs but before random cracks develop. For closely spaced joints in non-reinforced pavements, relief cut alternately spaced joints provided all sawing is completed before random cracking develops. Do not permit traffic over the expansion joint relief cuts.

Second Stage. Begin second stage sawing after the concrete has attained at least 1000 psi compressive strength. Center the joint groove over the relief cut. Adjust the groove width to compensate for change in the relief cut due to pavement contraction. If necessary, maintain the curing of the concrete near the joint by installing the permanent joint sealant or by placing temporary cover material. Give second stage sawing of expansion joints priority over contraction joints when higher pavement temperatures are pending.

Minnesota 2005 Standard Specifications for Construction

Section 2301 – Concrete Pavement

2301.3.K Joint Construction. Unless otherwise indicated in the Plans, all joints shall be perpendicular to the subgrade.

Contraction joints shall be spaced at the intervals shown in the Plans except that, adjacent to header joints, reinforced panels, railroad grade crossings, and the free ends of pavement, the spacing shall be shortened as necessary to provide panel lengths not less than 3 m (10 feet) long.

Initial joint sawing shall be approximately 3 mm (1/8 inch) wide and to the full joint depth. The initial sawing shall be accomplished as soon as the condition of the concrete will permit without raveling and before random cracking occurs. The sequence of initial sawing shall be at the Contractor's option. Widening of the joints to full width shall not be performed until the concrete is at least 24 hours old and shall be delayed longer when the sawing causes raveling of the concrete.

Mississippi 2004 Standard Specifications for Road and Bridge Construction

Section 501 – Portland Cement Concrete Pavement

501.03.6.1 Concrete Saw. When sawing joints is elected or specified, the Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing to the required dimensions using a water-cooled diamond edge saw blade, abrasive wheel, "early entry dry cut" type blade, or other device approved by the Engineer.

501.03.16 Joints. Joints shall be constructed of the type and dimensions and at the locations required by the plans, or as directed.

Sawing of joints shall commence as possible after the concrete has hardened and before uncontrolled shrinkage cracking occurs. The saw blades, and skid plates if early entry method is used, shall be changed as often as necessary to control and minimize spalling/raveling. A sufficient number of saws, replacement blades and skid plates shall be available at the project site to insure that the sawing operations will proceed until completion without interruption.

501.03.16.3 Transverse Contraction Joints. Transverse contraction joints shall consist of planes of weakness created by forming or sawing grooves in the surface of the pavement as shown on the plans and shall include load transfer assemblies when specified.

Missouri 2010 Standard Specifications for Highway Construction

Section 502 – Portland Cement Concrete Base and Pavement

502.3.4 Concrete Saw. If sawed joints are required, equipment shall be capable of providing a groove of the specified dimensions in the concrete. Equipment shall be a wet-cut saw, referred to as a “conventional concrete saw” or a lighter weight dry-cut saw, referred to as an “early-entry concrete saw,” used to establish joints sooner than the conventional saw.

502.5 Joints. Joints shall be of the specified type and dimensions, and constructed at the locations shown on the plans or as approved by the engineer.

502.5.3 Sawing Joints. Unless otherwise provided, all transverse contraction joints and all Type L longitudinal joints shall be sawed in a single cutting operation with the joint groove cut to the dimensions shown on the plans except as herein specified. If the groove for poured type transverse joints is cut prior to removal of the forms, the groove shall be cut as close as is practical to the concrete base or pavement edge, and the resulting crescent shaped plug in the groove, immediately adjacent to the form, will be acceptable. For intersections and irregular pavement, joints shall be sawed at locations as approved by the engineer. Sawing of the joints shall begin as soon as the concrete has hardened sufficiently to permit sawing without excessive raveling. All joint grooves shall be established before uncontrolled shrinkage cracking takes place. The sawing of any joint shall be omitted if a crack occurs at or near the joint location prior to the time of sawing. Sawing shall be discontinued when a crack develops ahead of the saw. The engineer reserves the right to have the contractor install preformed type joints on multiple width construction when the use of sawed joints fails to prevent random cracking. Any joint that opens more than ¼ inch (6 mm) shall be sealed. Any pavement with random cracking not controlled by dowels or tie bars shall be either removed and replaced using dowels or tie bars as appropriate to the nearest controlled joint or repaired with some other method approved by the engineer at the contractor's expense.

Montana 2006 Standard Specifications for Road and Bridge Construction

Section 501 – Portland Cement Concrete Pavement

501.03.13D. Transverse Contraction Joints. Saw transverse contraction joints to the specified width, depth, and spacing using a power-driven gang saw with at least four separate blades.

Saw initial or "control" transverse contraction joints at 54 foot (16.5 m) intervals or another multiple of the specified joint spacing that reduces uncontrolled cracking with the least number of initial contraction joints. Saw initial contraction joints as soon as possible after the concrete is placed. Do not permit the saw to tear or ravel the adjacent concrete. Saw the remaining contraction joints typically within 24 to 48 hours after concrete is placed.

Be responsible for determining joint-sawing methods, sequences, and timing to prevent random cracking. Immediately revise methods that cause random cracking.

Protect saw cuts in concrete 60 hours old or less from rapid drying using twisted paper, fiber or rope cords, waterproof covering, or other approved methods.

Have at least one stand-by saw in good condition and additional saw blades at the job site during sawing operations.

Section 601 – Portland Cement Concrete Pavements General Requirements

601.02.12d.

(1) The mechanical joint saw blade shall be water-cooled with an adjustable guide to insure that a true line is cut.
(2) The initial cut can be made with either a carbide or diamond-toothed blade.
(3) The final cut shall be made with a diamond-toothed blade.
(4) Two joint saws shall always be maintained on the project.
(5) In an emergency, dry sawing is allowed with the Engineer's approval.

Section 603 – Concrete Pavement

603.03.8. Joint Construction Procedures:

603.03.8.a. (1) Contraction joints in concrete pavement, with the exception of curbed sections, may be formed by any method shown in Section 601 with the approval of the Engineer. The joints shall be constructed to the dimensions shown in the plans or when “early-cut” type sawing of the joint, the cut shall be the depth recommended by the manufacturer. Curbed sections must be cut with a saw equipped with a diamond tipped blade.

(2) Initial sawing shall begin when the concrete can support the weight of the saw and sawing does not create raveling. Sawing must be completed before random cracking occurs.

[…]

(5) Each transverse joint shall be cut to the prescribed depth in one continuous pass.

(6) The Contractor shall be responsible for repairing all random cracks. The cracks shall be repaired as shown in the plans or as directed by the Engineer.

(7) Joints at gutters or integral curbs must be cut to the proper depths to prevent erratic cracking.

603.03.8.c. (1) Any spalls over 0.25 inch (6 mm) wide and over 0.50 inch (13 mm) below the surface of the pavement or over 0.25 inch (6 mm) wide and over 2.00 inches (50 mm) in length regardless of the depth below the surface shall be patched with epoxy mortar as prescribed in Section 1018 or the manufacturer's recommendations.

Nevada 2001 Standard Specifications for Road and Bridge Construction

Section 409 – Portland Cement Concrete Pavement

409.03.02(e) Concrete Saw. Provide sawing equipment adequate in number of units and power to complete the sawing with a water-cooled diamond edge saw blade or an abrasive wheel to the required dimensions and at the required rate. Provide at least one standby saw in good working order. Maintain an ample supply of saw blades at the site of the work at all times during sawing operations.

409.03.09 Joints. (a) General. Joints in pavement will be designated as longitudinal and transverse contact joints, transverse expansion joints, and longitudinal and transverse weakened plane joints.

Construct transverse joints at the angle to the centerline of the pavement shown on the plans. Construct faces of both transverse and longitudinal joints normal to the surface of the pavement.

Keep sawed joints clean and free of all foreign material after completion of shoulder work and before acceptance of the contract.

Provide a positive method of marking the locations of the transverse joints.

409.03.09(c) Weakened Plane Joints. Space transverse weakened plane joints 4.5 m (15 ft) on center and perpendicular to centerline. Saw transverse weakened plane joints by cutting the pavement with a power driven saw. Saw cut the grooves for transverse weakened plane joints to the dimensions shown on the plans for “Transverse Weakened Plane Joint, Double Saw Cut.” Initially saw cut the 3 mm (1/8 in.) wide joint within 16 hours after the concrete has been placed. Perform the 10 mm (3/8 in.) wide transverse reservoir saw cutting no sooner than 24 hours after the concrete has been placed. Do not perform the initial weakened plane saw cutting and reservoir saw cutting at the same time or in one operation.

Construct sawed joints before uncontrolled pavement cracking occurs; however, do not saw joints until the concrete has hardened enough to prevent tearing or raveling during the sawing operations. Determine the exact time to saw joints.

Immediately revise any procedure used to saw joints which results in premature uncontrolled cracking. Repair damaged areas or random cracks as specified herein and as directed. Repair any spalled or chipped concrete along the joints as approved.

For plain jointed (non-doweled) concrete pavements, do not saw where volunteer transverse cracks exist. If a volunteer transverse crack falls within 1.5 m (5 ft) of the location of a proposed sawed joint, omit the sawed joint. Joints sawed in violation of the provisions in this paragraph will not be paid for.

Repair portions of curing seal which are disturbed by sawing operations by spraying the areas with additional curing seal.

Keep a standby power saw on the project at all times when concrete paving operations are under way.

New Jersey 2007 Standard Specifications for Road and Bridge Construction

Section 405 – Concrete Surface Course

405.03.02G Sawcutting Relief Joints. Relief joints are a preliminary step in the construction of transverse and longitudinal joints. The Contractor may begin sawcutting relief joints as soon as hardened concrete can support operations without spalling and must finish within 18 hours of placing concrete. Sawcut transverse relief joints above the joint assembly and sawcut longitudinal relief joints if more than 1 lane was paved in 1 paving operation. Sawcut 1/8-inch wide relief joints to a depth of 1/3 of the thickness of the concrete pavement. Do not sawcut expansion joints or butt joints created by 2 separate paving operations.

405.03.02H. Sawcutting and Sealing Joints. After completion of diamond grinding operations as specified in 405.03.04 and before opening to traffic as specified in 405.03.02.K, sawcut 3/8-inch-wide transverse and longitudinal joints to a depth of 1/2 inch at relief joints and butt joints. After sawcutting, immediately remove sawing slurry from the sawcut cavity and surrounding pavement surface.

Section 1008 – Miscellaneous Equipment

1008.04 PAVEMENT SAW. Provide a power-driven pavement saw capable of sawing to the required dimensions in 1 pass without causing uncontrolled cracking. Equip the pavement saw with water-cooled, circular, diamond-edge blades or abrasive wheels, and alignment guides. Ensure that the pavement saw is capable of immediately collecting the slurry produced from the operations. The Contractor may use a pavement saw that does not collect slurry if the RE approves an alternate slurry collection method.

Provide within the Project Limits spare saw blades and at least 1 standby saw that meets the above requirements.

Section 450 – Portland Cement Concrete Pavement (QLA)

450.3.2.5 Concrete Jointing Equipment. Provide enough sawing Equipment or joint insertion Equipment to complete the Work within the allotted time. The Contractor may use a water-cooled diamond edge saw blade, an abrasive wheel, an “early entry dry cut” type with a skid plate, as defined by ACI 302 or a control joint insertion system approved by the State Materials Bureau.

450.3.4 Joints. Submit a joint layout plan to the Project Manager for review and approval at least 28 Days before starting concrete slab construction. The Department’s Pavement Design Section will either approve or reject the submittal within 14 Days from the date of submittal. Construct joints at the locations, intervals, and dimensions specified in the Contract, and seal them in accordance with Section 452, “Sealing and Resealing Concrete Pavement Joints.” It is recommended that the spacing between joints not exceed 24 times the thickness of the concrete. However, the spacing between joints can not be greater than 15 ft, and the maximum length to width ratio for the resulting slab is 1.5:1. Ensure there are no re-entrant corners. Avoid tapered corners; if a tapered corner is formed, place a control joint at:

1. One-half the distance between the end of the taper and the opposite side, if the base leg is less than or equal to 10 ft and longer than 5 ft; or
2. Third points along the base leg, if the base leg is longer than 10 ft.

Construct joint faces perpendicular to the PCCP surface.

Construct transverse and longitudinal contraction joints by inserting control joints while the concrete is still plastic, or by sawing the freshly hardened concrete as soon as possible after placing it. Make transverse contraction and longitudinal joints in two-phases. Make the initial saw cut or inserted joint wide enough and deep enough to ensure that a sufficiently weakened cross-section exists. Make the second sealant reservoir-shaping saw cut in accordance with the details shown in the Plans. Do not damage the steel reinforcement with any saw cut.

The Contractor will take whatever actions are necessary to prevent all uncontrolled cracks in the concrete.

Change saw blades (and the skid plates, when using the early entry dry cut method) as often as required to control and minimize spalling.

Saw joints sequentially. However, the Contractor may saw control transverse joints at intervals shown in the Contract, or at an interval that will most effectively minimize the possibility of uncontrolled cracking.

If necessary, perform the sawing operations day and night, regardless of weather conditions. Do not saw a joint if a crack occurs at or near the joint location before sawing. Immediately discontinue sawing of a joint when a crack develops ahead of the saw. Immediately repair damage to the concrete resulting from the sawing operations after the sawing is completed at no additional cost to the Department.

450.3.4.2 Transverse Joints. Create transverse contraction joints in the surface of the pavement with an approved saw or joint insertion system.

New York 2008 Standard Specifications

Section 502 – Portland Cement Concrete Pavement

502-2.04E. Saw Cutting Equipment. Use diamond blade saws capable of making straight cuts to the dimensions depicted in the Standard Sheets that are equipped with cutting guides, blade guards, water cooling systems, dust controls, and cut depth control. Where beveled saw cuts are required, use a cutting or grinding device attached to the saw blade, or a separate device following the saw.

Maintain equipment and supplies to ensure uninterrupted saw cutting. Early entry saws require approval from the Director, Materials Bureau. Submit requests to use early entry saws at least 7 calendar days before paving.

502-3.06 A. Transverse Joints. Transverse joints include contraction, expansion, hinge, and construction joints. Secure joint supports to the permeable base or subbase as depicted in the Materials Details.

Maintain joint supports in their proper position and alignment during paving.

Construct transverse joints perpendicular to both the pavement surface and longitudinal joints in the area being paved. Use a 16 foot typical transverse joint spacing for pavements having standard slab widths of 12 and 14 feet. For pavements having other slab widths, determine typical maximum and minimum transverse joint spacings in accordance with the following:

L_{max} = maximum transverse joint spacing (slab length), feet = $W_{min} \times 1.33$
L_{min} = minimum transverse joint spacing (slab length), feet = $W_{max} \div 1.33$
W_{max} = maximum slab width across the pavement (load carrying slabs only), feet $\leq$ 16 feet
W_{min} = minimum slab width across the pavement (load carrying slabs only), feet

The range of slab lengths may be extended to 10 to 16.5 feet (from Lmin - Lmax above) in accordance with the contract documents to accommodate utilities, drainage structures, and irregular areas.

1. Transverse Contraction Joints. All transverse joints are contraction joints unless otherwise shown in the contract documents. Typically, contraction joints are constructed in a straight line across the full width of the PCC pavement and shoulders. Contraction joints may be slightly angled (rather than straight across a pavement) at tied longitudinal joints between lanes placed separately if the placements do not have the same centerline, e.g., where a ramp centerline diverges from parallel to the pavement centerline. Contraction joints may terminate at, or be misaligned at, untied longitudinal joints as discussed in §502-3.06B3, Untied Longitudinal Joints with Keyway.

Make first-stage saw cuts as soon as the concrete has hardened sufficiently to permit sawing without causing raveling wider than 1/8 inch. Replace blades if raveling persists. Center firststage saw cuts within 1 inch of the longitudinal midpoints of the dowels.

Complete first-stage saw cuts before any uncontrolled cracking occurs. Be prepared to make first-stage saw cuts 24 hours a day to prevent uncontrolled cracking. Provide lighting required to make first-stage saw cuts at night at no additional cost to the State.

North Carolina 2006 Standard Specifications for Roads and Structures

Section 700 – General Requirements for Portland Cement Concrete Paving

700-11 JOINT CONSTRUCTION
(A) General. Construct all joints in accordance with the requirements of these Specifications and the details shown on the plans. Saw all transverse joints and seal them with joint sealer in accordance with the dimensions and details shown in the contract. Seal joints in accordance with the requirements of Article 700-12.

Utilize an early entry dry-cutting sawing system. Have an adequate amount of sawing equipment available to match the production and concrete paving operations.

A minimum of one standby sawing unit is recommended. Construct the joint groove using a 1/8" saw blade to a minimum depth of 3". Perform sawing as soon as the concrete has hardened sufficiently without undercutting, spalling and raveling to control random cracking. Complete all saw cutting before seven hours has elapsed from the time of concrete placement.

Saw the concrete pavement as soon as it can support the weight of the equipment and operator without disturbing the final finish. Saw joints in a neat, vertical straight line without chipping, spalling, tearing or disturbing the final finish.

Immediately reapply curing membrane following the sawing operation. Deviations from the method of joint construction specified in the plans or Specifications requires prior approval in writing. Such approval is conditional and is subject to obtaining satisfactory results.

(B) Transverse Contraction Joints. Construct transverse contraction joints in accordance with the details, dimensions and intervals as shown on the plans.

North Dakota 2008 Standard Specifications for Road and Bridge Construction

Section 153 – Portland Cement Concrete Equipment

153.12 CONCRETE SAWS. Saws shall be adequately powered and furnished with suitable blades to effectively cut pavement joints to required dimensions. Each blade of multiple-blade saws shall be maintained in accurate alignment to the other blades. A device shall be provided to guide the saw along the required joint alignment. Manual guidance of the saw will be permitted if specified results are obtained. A sufficient number of sawing units shall be available to maintain required progress and provide prompt replacement in case of breakdown. Adequate artificial lighting shall be provided for night sawing.

Section 550 – Portland Cement Concrete Pavement

5540.04.I. Joints.
1. General. Joints in concrete pavement shall be of the design specified and shall be constructed at the spacings and locations shown. The ramp joints be yond the ramp taper shall have the same spacing sequence as the mainline. The Contractor shall establish joint locations.

2. Transverse Contraction Joints. The contraction joints shall consist of weakened planes created by sawing on main line and shoulders, and by either sawing, inserting preformed inserts, or forming grooves in the pavement surface on small areas or tapers.

Sawed contraction joints shall be cut to the required dimensions with equipment meeting Section 153.12. The time and sequence of sawing shall be adjusted so all joints are cut before uncontrolled cracking occurs, and to permit sawing without excessive raveling. Joints shall be sawed within 24 hours to prevent uncontrolled cracking. If an uncontrolled crack occurs within 5 feet of any proposed joint location before or during sawing, the joint shall be omitted and sawing of the joint discontinued. Any joint sawed within 5 feet of an uncontrolled crack shall be repaired at the Contractor's expense. When sawing is performed before removing side forms, the initial saw cut will extend to within 1/2 inch or less of the side forms. If the forms have been removed, the saw cut will be extended to the edges of the slab. Any curing media removed during sawing shall be immediately replaced.

Ohio 2010 Construction and Materials Specifications

Section 451 – Reinforced Portland Cement Concrete Pavement

451.08 Joints. Unless otherwise directed, construct all transverse joints normal to the centerline of the pavement lane and of the type, dimensions, and at locations specified.

Determine contraction and longitudinal joint sawing time limits to protect the concrete from early cracking by using HIPERPAV software.

Twenty four (24) hours before placing concrete pavement create a HIPERPAV project date file according to Supplement 1033, HIPERPAV Requirements for Concrete Pavement.

Provide the completed file and the printout to the Engineer. When HIPERPAV predicts early age slab cracking will occur, whether due to standard construction practices, joint sawing methods, mix design or curing, either do not start construction until modifications have been made to eliminate HIPERPAV's predicted slab cracking or do not pave.

Perform a HIPERPAV analysis for each pour.

If software analysis determines joint sawing could exceed twenty four (24) hours, assure all joints are sawed by the 24th hour.

451.08.D. Contraction Joint. For pavement less than or equal to 10 inches (225 mm) thick, saw contraction joints with a standard (water cooled diamond bladed) concrete saw to a minimum depth of one-fourth of the specified pavement thickness. For pavement greater than 10 inches (255 mm) thick, saw contraction joints to a minimum depth of one-third the specified pavement thickness. When cutting joints using a standard (water cooled diamond blade) saw assure the joint is 1/4 ± 1/16 inch (6 ± 1.6 mm) wide when measured at the time of sawing.

When using the option of early-entry (dry cut, light weight) saws, only use saw blades and skid plates as recommended by the saw manufacturer for the coarse aggregate type being used in the concrete. Perform the early entry contraction joint sawing after initial set and before final set. Saw the contraction joint 2-1/4 to 2-1/2 inches (56 to 63 mm) deep. Ensure any early entry saw joints are approximately 1/8 inch (3 mm) wide at the time of sawing.

If the pavement is constructed in two or more separately placed lanes, install the joints continuous for the full width of the pavement. Saw the pavement with sawing equipment approved by the Engineer as soon as the saw can be operated without damaging the concrete. Provide saws with adequate guides, blade guards, and a method of controlling the depth of cut. During sawing of contraction joints, maintain a standby saw in working condition with an adequate supply of blades.

Oklahoma 2009 Standard Specifications

Section 414 – Portland Cement Concrete Pavement

414.03.C. Concrete Saw. Provide a concrete saw that is conventional wet cut type or early entry dry cut type. Provide at least one standby saw. Maintain an ample supply of saw blades at the work site during sawing operations. Provide artificial lighting for night sawing.

414.04.H. Joints. Construct joints perpendicular to the surface of the slab of the type, dimensions, and locations shown on the Plans. Align the joints using guidelines or devices approved by the Resident Engineer.

Ensure the sawed joints are straight and true to line; repair joints that are not. Seal the sawed joints in accordance with Subsection 415.04, "Construction Methods."

414.04.H(2)(b) Contraction Joints. Form transverse contraction joints by sawing to the depth shown on the Plans without damaging the pavement or joint. Saw succeeding joints consecutively from the beginning to the end of the day's run, and saw all transverse joints soon enough to prevent uncontrolled transverse cracking.

Clean and dry the sawed area. Keep it free from dust, chalk, contaminants, and spalling. Fill the sawed area with joint sealing material. Ensure the curing period for joints is complete before allowing construction equipment and vehicles on the pavement.

414.04.H(3) Lightweight Early-Entry Saw Joints. The Department will allow the construction of transverse joints using a lightweight, early-entry saw. Ensure the blade is 1/8 in (3mm) thick and the sawed joint is at least 1 ½ in (38 mm) deep. Saw joints in accordance with the manufacturer's recommendation. Begin sawing the joint when the concrete is hard enough to cut without raveling, chipping, spalling, or tearing. The Resident Engineer will inspect the sawed faces to ensure that early cutting does not cause joint undercutting. Delay sawing if undercutting is deep enough to cause structural weakness or excessive joint roughness. Saw the joints consecutively at the spacing required by the Contract. Immediately after sawing, clean the cut and adjacent concrete surface. Respray damaged membrane-cured surfaces. Inspect the lightweight early-entry saw joints the next day. If a crack is not evident within 24 hr, re-saw the joint to a depth of T/3. Clean and seal joints in accordance with the manufacturer's recommendations, unless otherwise required by the Contract.

Oregon 2008 Standard Specifications

Section 00756 – Plain Concrete Pavement

00756.24 Concrete Saws – Provide power driven concrete saws for sawing joints, adequate in number of units and power to complete the sawing at the required rate. Also provide a standby saw on the jobsite.

00756.48 Joints:
(a) General – Construct joints of the kinds shown and where shown or directed. Joint types in the concrete pavement will be contraction, construction or expansion. They shall be transverse or longitudinal, as shown or directed. Extend all joints and joint filler to pavement edges or to each other.

00756.48(d) Contraction Joints – Construct all contraction joints by sawing. Create contraction joints at intervals shown on drawings.

Section 501 – Reinforced or Plain Cement Concrete Pavements

501.3(i) Transverse Joints. In new multilane pavements, place transverse joints perpendicular to centerline to form a continuous joint across the entire pavement width and locate dowels as shown on Standard Drawing RC 20M, except where paving operations must cease temporarily due to unavoidable conditions. Where existing concrete pavements are widened, align transverse construction or contraction joints, if possible, with existing construction or contraction joints or cracks; otherwise, do not place within 3 m (10 feet) of a joint.

2. Contraction Joints. Accurately mark using tacks or other approved methods the location for the center of the sawed transverse contraction joints. The sawed transverse joint must be located directly ±13 mm (±1/2 inch) over the centerline of the dowel basket assemblies or the centerline of the mechanically implanted dowels. Saw joints with equipment having guides, a blade guard, watercooling system, and cut-depth control. Provide adequate and extra equipment and parts at the site, before placing concrete and during sawing operations.

The Representative will not allow displacing coarse aggregate from the joint location by use of a vibrating T-bar, or by use of a filler strip at the joint. In single-lane construction, mark the joints that have cracked and opened on the first lane placed. Align the location of the first joints sawed in the second lane with the marked joints on the first lane. In lanes adjacent to previously constructed lanes, saw joints before uncontrolled cracking occurs. Make the full required depth cut from edge to edge of the pavement. In formed paving, do this by loosening or removing the side forms or by other acceptable methods. Saw all initial saw cuts to prevent random cracking, without damaging the pavement surface. If necessary, conduct sawing operations continuously, both day and night, regardless of weather conditions.

Rhode Island 2004 Standard Specifications for Road and Bridge Construction

Section 501 – Portland Cement Concrete Pavement and Base

501.03.2c. Concrete Saw. When sawing joints is elected or specified, the Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing with a water-cooled diamond edge saw blade or an abrasive wheel to the required dimensions and at the required rate. The Contractor shall provide at least one standby saw in good working order.

An ample supply of saw blades shall be maintained at the site of the work at all times during sawing operations. The Contractor shall provide adequate artificial lighting facilities for night sawing.

501.03.9 Joints. Joints shall be constructed of the type and dimensions, and at the locations required by the Plans or Special Provisions.

501.03.9c. Transverse Contraction Joints. Transverse contraction joints shall consist of planes of weakness created by cutting grooves in the surface of the pavement and, when shown on the Plans, shall include load transfer assemblies.

1. Sawed Contraction Joints shall be created by sawing grooves in the surfaces of the pavement or base to the dimensions and at the spacing and lines shown on the Plans with an approved concrete saw.

If curing blankets are used they shall be removed from the pavement only at the location(s) where a joint is to be sawed and only a sufficient width to allow the cut to be made.

As soon as the cut has been made curing material shall be replaced. In no case shall either the top or edges of concrete be left unprotected for more than one-half hour.

Sawing of the joints shall commence as soon as the concrete has hardened sufficiently to permit sawing without excessive raveling, usually 4 to 24 hours. All joints shall be sawed before uncontrolled shrinkage cracking takes place. If necessary, the sawing operations shall be carried on during the day and night, regardless of weather conditions. The sawing of any joint shall be omitted if a crack occurs at or near the joint location prior to the time of sawing. Sawing shall be discontinued when a crack develops ahead of the saw. The pavement within the lane where cracks occur shall be removed to the full width of the lane and replaced. The minimum lane length of pavement replacement shall be 6 feet. If cracking occurs on both sides of the same joint, the dowel assembly and a minimum of 3 feet on each side of the joint shall be removed and replaced, all at the Contractor's expense.

In general, all joints should be sawed in sequence. All contraction joints in lanes adjacent to previously constructed lanes shall be sawed before uncontrolled cracking occurs. If extreme conditions exist which make it impractical to prevent erratic cracking by early sawing, the contraction joint groove shall be formed prior to initial set of concrete.

Section 501 – Portland Cement Concrete Pavement

501.3.13 Concrete Saws. Provide sawing equipment in adequate numbers and power to complete the sawing to the required dimensions and at the required rate. Ensure that the saws are equipped with water-cooled diamond edge saw blades or abrasive wheels. If desired, early entry saws may also be used with the prior approval of the RCE. Provide at least one standby saw that is in good working order. Maintain an ample supply of saw blades at the site of the work at all times during sawing operations. Provide adequate artificial lighting facilities for night sawing. Maintain all of this equipment on site in working order before beginning each workday and continuously during concrete placement.

501.4.13 Joints

501.4.13.1 General Requirements. Construct longitudinal and transverse joints at the locations and in accordance with the dimensions and other requirements shown on the Plans or in the Special Provisions. Cut all joints using a diamond-bladed saw; parting strips and tooling are not acceptable.

Construct transverse joints at right angles to the pavement centerline and extending the full width of the pavement. Construct all joints true to line with their faces perpendicular to the pavement surface.

When the pavement is placed in lanes or partial width slabs, or when existing pavement is widened, place transverse joints in line with like joints in the adjacent pavement unless otherwise shown on the Plans.

501.4.13.4 Transverse Contraction Joints. Construct transverse contraction joints to the dimensions, lines, and spacing shown on the Plans. Only sawed transverse contraction joints are permitted. The forming of joints by using preformed parting strips of any kind is prohibited. Construct sawed joints as follows:

- Establish sawed contraction joints by sawing grooves in the surface of the pavement with an approved concrete saw. After each joint is sawed, thoroughly clean the saw cut and adjacent concrete.
- Commence sawing of the joints as soon as the concrete has hardened sufficiently to permit sawing without excessive raveling, usually 4 to 6 hours. Some raveling of the green concrete is desired in order for the sawing process to prevent uncontrolled shrinkage cracking.
- If sharp-edged joints are being obtained, expedite the sawing process to the point where some raveling is observed.
- Continue this process during the day and night regardless of the weather conditions until all joints in the day’s paving have been sawed.
- In case the sawing procedure is delayed due to emergency or equipment failure, saw every third transverse joint as a control system to prevent cracking until raveling is again observed. Complete the intermediate saw cuts immediately.

South Dakota 2004 Standard Specifications for Roads and Bridges

Section 380 – Portland Cement Concrete Pavement

380.3.B.5. Concrete Saw: Sawing equipment, adequate to complete the sawing to the required dimensions and at the required rate, shall be provided. At least one standby saw in good working order shall be provided.

380.3.M. Joints: Immediately after sawing the joints to their final configuration, the resulting slurry shall be completely removed from the joint and the immediate area by flushing with a jet of water and other tools as necessary. Curing membrane damaged or protective cover removed during the sawing operation shall be repaired or replaced by the Contractor as directed by the Engineer at no cost to the Department.

380.3.M.3. Transverse Contraction Joints: Transverse contraction joints shall be created by sawing. The initial saw cut shall commence when the concrete has hardened sufficiently to permit sawing without raveling. The widening cut shall not commence until completion of the concrete cure period. Joints shall be sawed before uncontrolled shrinkage cracking takes place. If necessary, the initial sawing operations shall be performed on both day and night, regardless of weather conditions. The initial sawed joint will not require reapplication of curing compound.

Section 501 – Portland Cement Concrete Pavement

501.04(D)10. Concrete Saw. When sawed joints are elected or specified, the Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing to the required dimensions and at the required rate. The saws shall be equipped with water-cooled diamond edge blades.

The Contractor shall provide at least one standby saw in good working order. An ample supply of saw blades shall be maintained at the site of the Work at all times during sawing operations. The Contractor shall provide adequate artificial lighting facilities for night sawing. All of this equipment shall be on the job both before and continuously during concrete placement.

501.15 Joints. Joints shall be constructed of the type and dimensions and at the locations required by the Plans and in accordance with the provisions of these Specifications.

Transverse joints shall be straight, vertical to the pavement surface and shall be at the angle to the center-line of the pavement shown on the Plans.

Unless otherwise specified or directed, all contraction and construction joints shall be of the plain sawed groove type.

501.15(c) Transverse Contraction Joints. Transverse contraction joints shall be placed at the intervals specified and resulting in the desired shape. Formed contraction joints shall not be used unless specified or required by the Engineer to control random cracking.

1. Sawing of the joints shall commence as soon as concrete has hardened sufficiently to permit sawing without excessive raveling. Once started, the sawing operation shall be continuous until all transverse contraction joints are sawed. When necessary, the contractor shall provide for bad weather or nighttime operations. The sawing of any joint shall be omitted if a crack occurs at or near the joint location prior to the time of sawing. The sawing of a joint shall be discontinued when a crack develops ahead of the saw. In general, all joints shall be sawed in sequence.

   All contraction joints in lanes adjacent to previously constructed lanes shall be sawed before uncontrolled cracking occurs. If extreme conditions exist which make it impractical to prevent erratic cracking by early sawing, a contraction joint groove shall be formed at intervals of every 3rd or 4th joint or as often as required prior to initial set of concrete as provided for under (c) 3, below. Immediately after sawing, the joints shall be thoroughly cleaned of all residue by flushing with water under pressure.

   Sawing equipment shall be approved by the Engineer. Only lightweight sawing equipment will be permitted on the newly constructed pavement. See Subsection 501.10(d)10. Gang saw units or similar heavy equipment may be used provided the equipment is operated from a bridge or platform supported independently of the pavement.

Texas 2004 Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges

Section 360 – Concrete Pavement

360.3.F. Sawing Equipment. Provide power-driven concrete saws to saw the joints shown on the plans. Provide standby power-driven concrete saws during concrete sawing operations. Provide adequate illumination for nighttime sawing.

360.4.J. Sawing Joints. Saw joints to the depth shown on the plans as soon as sawing can be accomplished without damage to the pavement regardless of time of day or weather conditions. Some minor raveling of the saw cut is acceptable. Use a chalk line, string line, sawing template, or other approved method to provide a true joint alignment. Provide enough saws to match the paving production rate to ensure sawing completion at the earliest possible time to avoid uncontrolled cracking. Reduce paving production if necessary to ensure timely sawing of joints. Promptly restore membrane cure damaged within the first 72 hr. of curing.

Utah 2008 Standard Specifications for Road and Bridge Construction

Section 02752 – Portland Cement Concrete Pavement

3.9 JOINTS
A. Construct contact joints, sawed joints, or transverse expansion joints as shown on the plans.

B. Keep the faces of all joints at right angles to the top surface of the pavement with all longitudinal joints parallel to the centerline and coinciding with the traffic lane lines.

E. Longitudinal and Transverse Sawed Joints

1. Single cut all transverse and longitudinal joints. Refer to PV Series Standard Drawings.
2. Saw joints before uncontrolled cracking occurs.
3. Conduct continuous sawing operations during both day and night regardless of weather conditions.
4. Provide lighting during nighttime sawing.
5. Thoroughly clean joints of all loose debris, cement powder, etc.
6. Clean and dry joints before placing sealant.
7. Use hot-pour joint sealant unless specified otherwise. Refer to AASHTO M 324.
8. Fill the longitudinal joints flush. Refer to PV Series Standard Drawings.
9. Do not permit hauling equipment or traffic on the pavement before all sawed joints are sealed.
10. Match joints in adjacent lanes to form a continuous line across the pavement width including the concrete shoulders.

Virginia 2007 Road and Bridge Specifications

Section 316 – Hydraulic Cement Concrete Pavement

316.03(i) Concrete Saw: When sawing joints is elected or specified, the Contractor shall provide sawing equipment adequate in number of units and power to complete the sawing to the required dimensions and at the required rate with a water-cooled, diamond-edged saw blade or an abrasive wheel.

316.04(g) Jointed Pavement: Joints shall be installed in a manner and at such time to prevent random or uncontrolled cracking. If random or uncontrolled cracking occurs, sufficient concrete shall be removed and replaced on each side of the cracking to form a slab at least 10 feet long.

316.04(g)3. Transverse contraction joints: Transverse contraction joints shall consist of planes of weakness created by cutting grooves in the surface of the pavement and, when shown on the plans, shall include load transfer assemblies. Edges of concrete adjacent to the joint may be rounded or beveled to a radius or length approved by the Engineer. Any joint having an insufficient opening shall be resawed or ground to the proper size. Where a joint opening is larger than that specified, the Contractor may be required to build up the joint with epoxy mortar or to furnish a larger size seal as determined by the Engineer.

Washington State 2010 Standard Specifications for Road, Bridge, and Municipal Construction

Section 5-05 – Cement Concrete Pavement

5-05.3(3)D Joint Sawing Equipment. The Contractor shall provide approved power driven concrete saws for sawing joints, adequate in number of units and power to complete the sawing at the required rate. The Contractor shall provide at least one standby saw in good working order. An ample supply of saw blades shall be maintained at the site of the Work at all times during sawing operations. The Contractor shall provide adequate artificial lighting facilities for night sawing. All of this equipment shall be on the job both before and continuously during concrete placement. Sawing equipment shall be available immediately and continuously upon call by the Engineer on a 24-hour basis, including Saturdays, Sundays and holidays.

5-05.3(8) Joints. Joints in cement concrete pavement will be designated as longitudinal and transverse contraction joints, longitudinal and transverse construction joints, or isolation joints, and shall be constructed as shown in the Plans and in accordance with the following provisions:

All contraction joints shall be constructed at the locations, intervals, and depths shown in the Standard Plan. The faces of all joints shall be constructed perpendicular to the surface of the cement concrete pavement.

5-05.3(8)A Contraction Joints. All transverse and longitudinal contraction joints shall be formed with suitable power-driven concrete saws. The Contractor shall provide sufficient sawing equipment capable of completing the sawing to the required dimensions and at the required rate to control cracking. The Contractor shall provide adequate artificial lighting facilities for night sawing. Joints shall not vary from the specified or indicated line by more than ¾-inch.

Commencement of sawing transverse contraction joints will be dependent upon the setting time of the concrete and shall be done at the earliest possible time following placement of the concrete without tearing or raveling the adjacent concrete excessively.

Any damage to the curing material during the sawing operations shall be repaired immediately after the sawing is completed.

When cement concrete pavement is placed adjacent to existing cement concrete pavement, the vertical face of all existing working joints shall be covered with a bond-breaking material such as polyethylene film, roofing paper, or other material as approved by the Engineer.

Section 501 – Portland Cement Concrete Pavement

501.5.6-Concrete Saw: When sawing joints is elected or specified, the Contractor shall provide sawing equipment, adequate in number of units and power to complete the sawing to the required dimensions and at the required rate for preventing uncontrolled cracking. A standby saw and ample supply of saw blades shall be maintained at the site of the work at all times during sawing operations. The Contractor shall provide adequate artificial lighting facilities for night sawing. All of this equipment shall be on the job both before and continuously during concrete pavement.

501.11-JOINTS:
Joints shall be constructed of the type and dimensions and at the locations required by the Plans.

501.11.3-Transverse Contraction Joints: Transverse contraction joints shall consist of planes of weakness created by sawing or forming grooves, normal to the grade, in the surface of the pavement as shown on the Plans. These contraction joint grooves shall be centered, within 1 in. (25 mm) of the mid-length of the dowels, over the coated dowel bars specified.

Unless otherwise specified or authorized, all transverse contraction joint grooves shall be constructed in two steps as described, resulting in the dimensions detailed on the Plans and at the spacing and locations shown on the Plans. Grooves shall be cured in accordance with 501.11.8 and sealed in accordance with 501.16.

As soon as feasible after placing the concrete, the contraction joints shall be sawed or formed to the dimensions shown on the Plans. Initial sawing of joints shall commence as soon as the concrete has hardened sufficiently to permit sawing without excess raveling, usually 4 to 24 hours. All joints shall be initially sawed before uncontrolled shrinkage cracking takes place, but no later than 24 hours after placement of concrete. If necessary, initial sawing operations shall be continuous, through day and night, regardless of weather conditions. In general, all joints should be sawed in sequence. The initial sawing of any joint shall be omitted if cracking occurs at or near the joint location prior to the time of sawing. Initial sawing of a joint shall be discontinued when a crack develops ahead of the saw. If extreme conditions exist which make it impractical to prevent erratic cracking by early sawing, the contraction joints shall be formed in the plastic concrete.

When the concrete has hardened sufficiently, but no earlier than 72 hours after placement of the concrete, final or second-step sawing shall be performed.

Wisconsin 2010 Standard Specifications

Section 415 – Concrete Pavement

415.3.9.2 Transverse Joints. Construct as specified in the plan details. Construct contraction, construction, or expansion joints at the locations the contract specifies, or as the engineer directs.

Unless the plans show otherwise or the engineer directs, install all transverse joints perpendicular to the pavement surface and continuous through adjacent lanes and contiguous curb & gutter.

Complete the sawing of contraction joints for each day's pour by approximately midnight of the same day if normal or rapid concrete setting conditions prevail. If cool weather or other conditions cause retarded setting of the concrete, delay sawing for as long as necessary to preclude tearing of the concrete adjacent to the joint, or cracking of the concrete during the sawing. Provide artificial light if joint sawing after daylight hours.

Saw the joints, in a single cut, to the width and depth the plans show, as soon as the saw can be operated without damaging the concrete and before random cracking occurs. The contractor may temporarily hand tool joints to prevent premature cracking. Permanently saw all hand tooled joints to the plan depth as soon as possible. The engineer may direct the contractor to saw joints by the skip method, wherein every third joint is sawed as soon as possible. Following this skip sawing, make the cuts of the remaining intermediate joints as soon as possible.

Wyoming 2003 Standard Specifications for Road and Bridge Construction

Section 414 – Portland Cement Concrete Pavement

414.4.10.10 Joints. Concrete pavement joints are designated as transverse expansion and weakened plane joints, longitudinal weakened plane joints, and construction joints. Ensure joints are placed in accordance with the plans and are of the type shown in the contract.

Provide sawed joints of 3/16 inch [5 mm] width for all liquid applied sealants. Do not chamfer edges unless elastomeric compression joint seals are used. Ensure joints are sawed in a timely manner. Remove and replace areas with uncontrolled cracking. Provide standby saws on the project site when work is in progress.

If using a conventional wet sawing method, saw to a depth of T/3 (where T = slab thickness) where T is greater than 10 inch [250 mm], or to a depth of T/4 where T is less than or equal to 10 inch [250 mm].

If an early-entry, dry-cutting system is used, perform the work in accordance with the manufacturer’s recommendations as approved by the engineer. Saw joints to a depth of 0.15T unless otherwise recommended by the manufacturer. Replace saw blades in accordance with the manufacturer’s recommended frequency. Replace the anti-raveling skid plate each time the saw blade is replaced. End early-entry saw cuts before free edges to avoid spalling.

APPENDIX B
Test Cell Temperature Profile Plots

In addition to observing construction practices, pavement temperatures were monitored using embedded temperature sensors to provide continuous temperature measurements. The embedded sensors were placed at the slab-base interface and at mid-depth near the middle of the each test cell's tenth slab, as well as attached to an adjacent dowel basket; the sensors were set to collect temperature readings every 20 minutes, allowing for up to 28 days of continuous temperature data. Details from the slab temperature data collected are summarized in the following figures, which illustrate the temperature gains experienced by each test cell relative to each other, as well as the temperature swings experienced by the slab in relation to the natural variation in ambient temperatures over the same time period.

Figure B1 below shows the first day of the test section from the time of setup starting at 7 am until the end of the day. The brief temperature drops shown are when the Contractor sprayed the base layer with water in anticipation of PCC placement. The final temperature drop noted in the figure indicates where paving reached the sensors' location. As can be seen figures B1, B2, and B3, the plots for the sensors located in test cell 2 maintain an approximately 30-minute lead ahead of the sensor in test cell 3 consistent with the delay in paving between the two sections.

After the third day, the temperature profiles of the two test sections sync with each other, as shown in figures B4 and B5, and are governed by the fluctuations of ambient temperature.

Figure B6 shows that the temperature profiles of test cells 2 and 3 are essentially the same although there appears to be an offset between the two about halfway through the 28 days of data collection. Concerning that data offset, there appears to have been a data collection glitch on September 6 for the temperature sensor located in test cell 3; between 4:00 pm and 4:20 pm, there is an anomalous 3.6 °F drop as shown in figure B7.

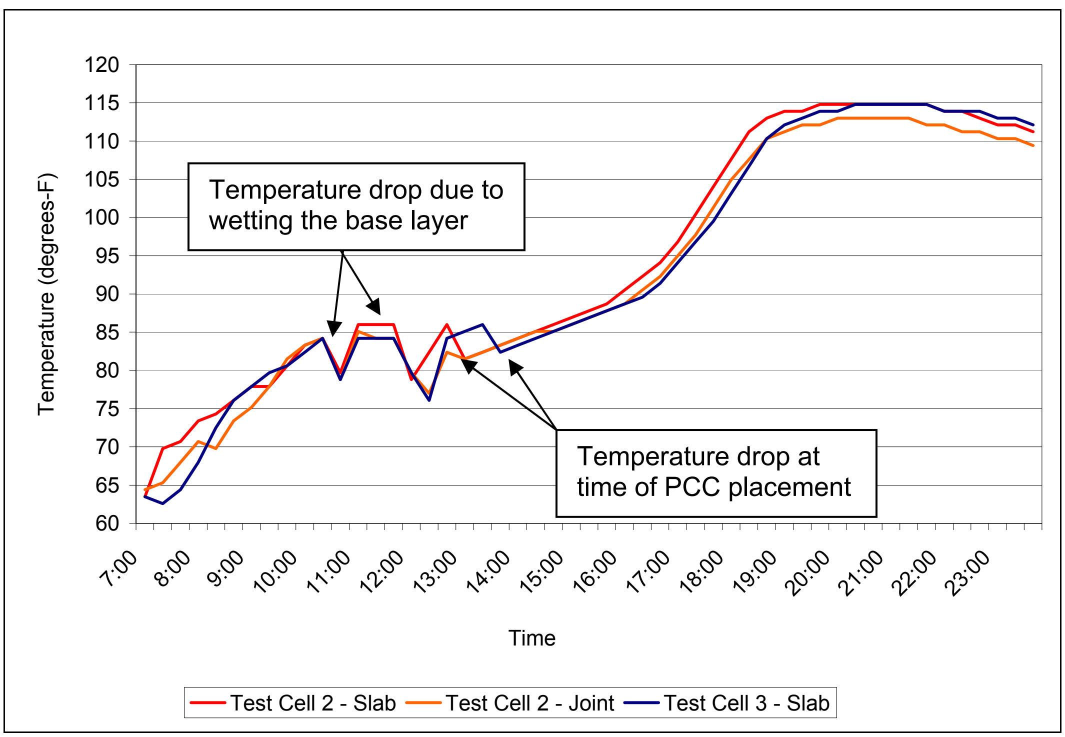


Figure B1. Plot depicting temperature profile of test cells 2 and 3 during the first day (08/24/09) from setup (7 am) through paving and sawing operations and until 12 am.

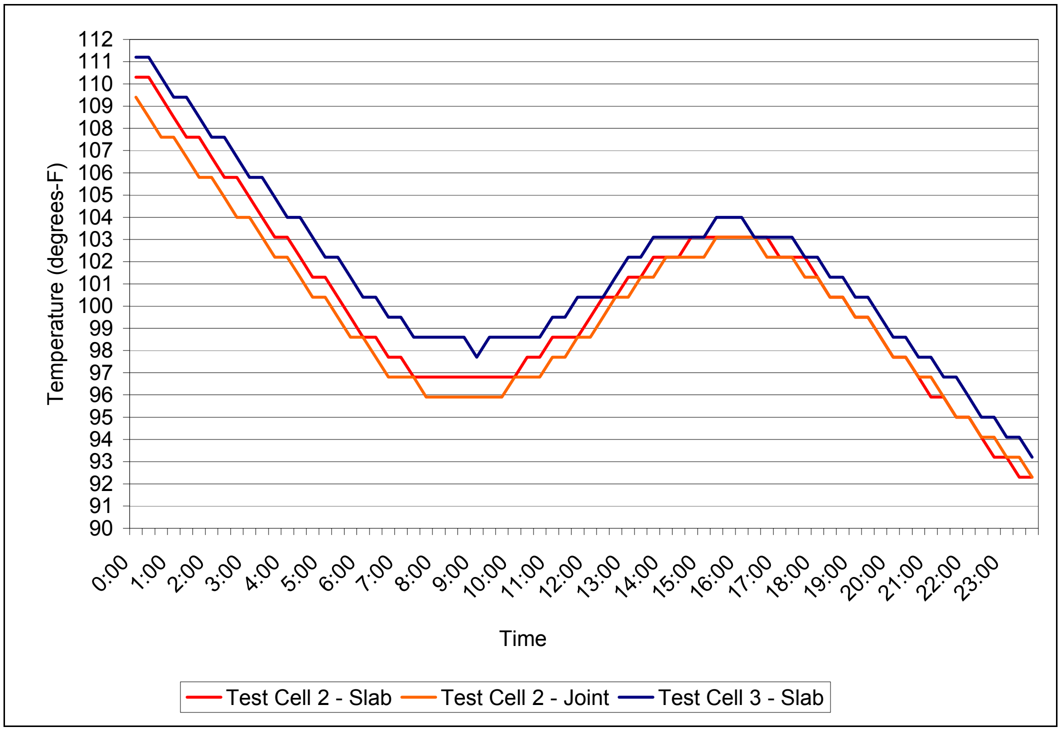


Figure B2. Plot depicting temperature profile of test cells 2 and 3 during the second day (08/25/09) from 12 am until midnight.

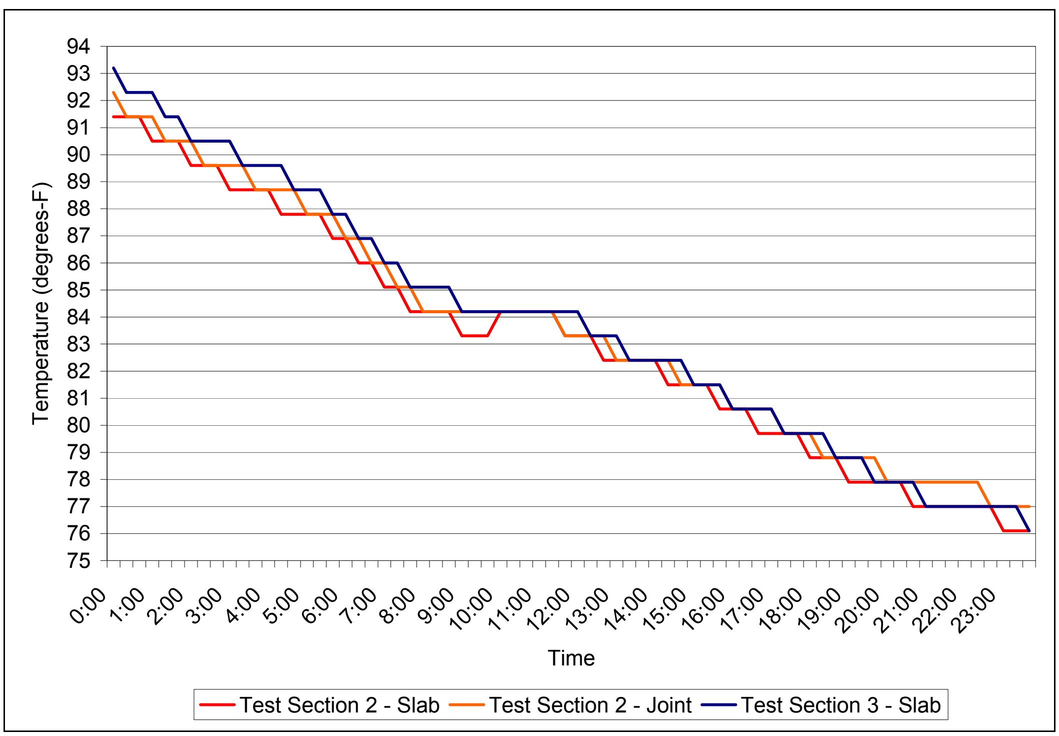


Figure B3. Plot depicting temperature profile of test cells 2 and 3 during the third day (08/26/09) from 12 am until midnight.

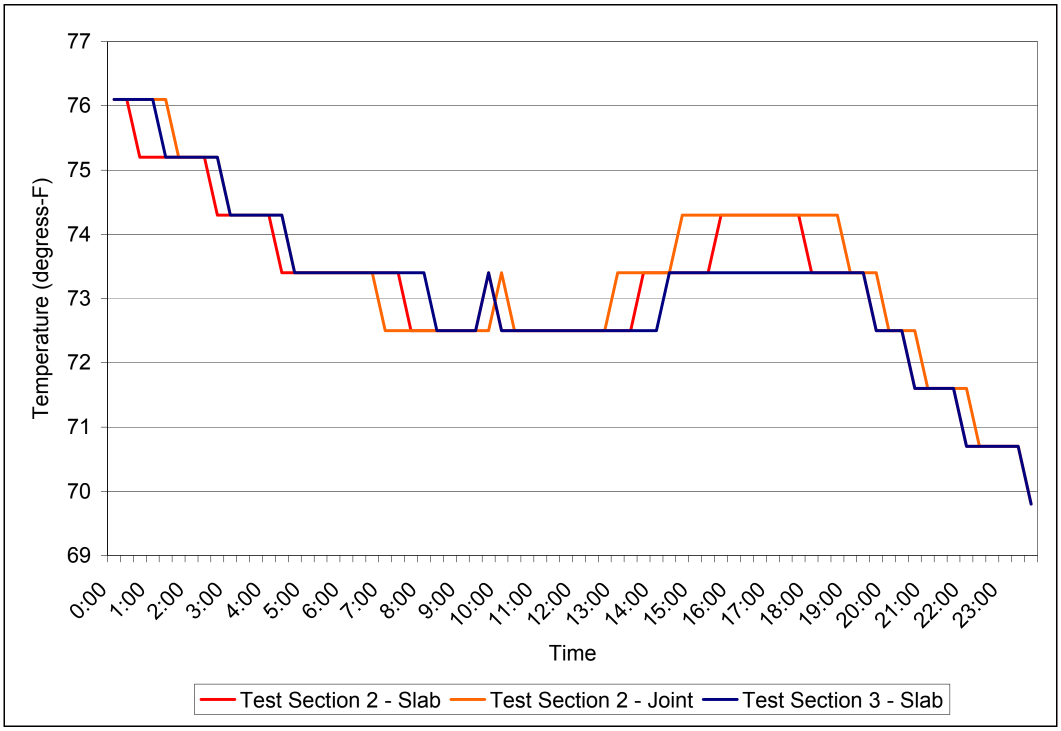


Figure B4. Plot depicting temperature profile of test cells 2 and 3 during the fourth day (08/27/09) from 12 am until midnight.

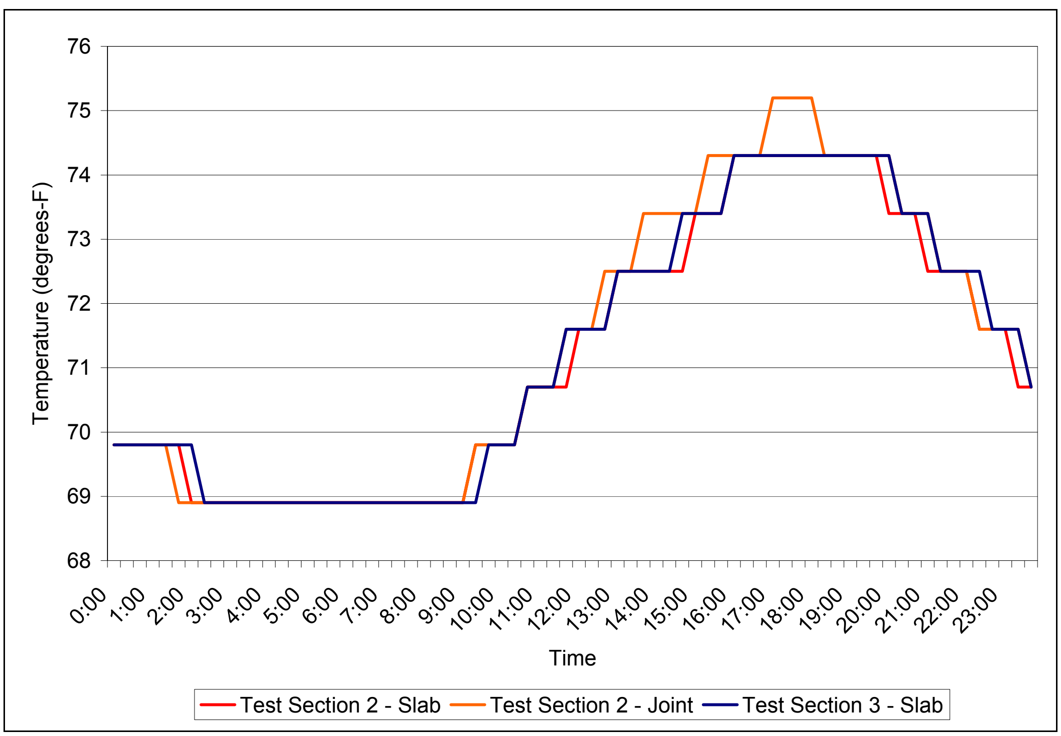


Figure B5. Plot depicting temperature profile of test cells 2 and 3 during the fifth day (08/28/09) from 12 am until midnight.

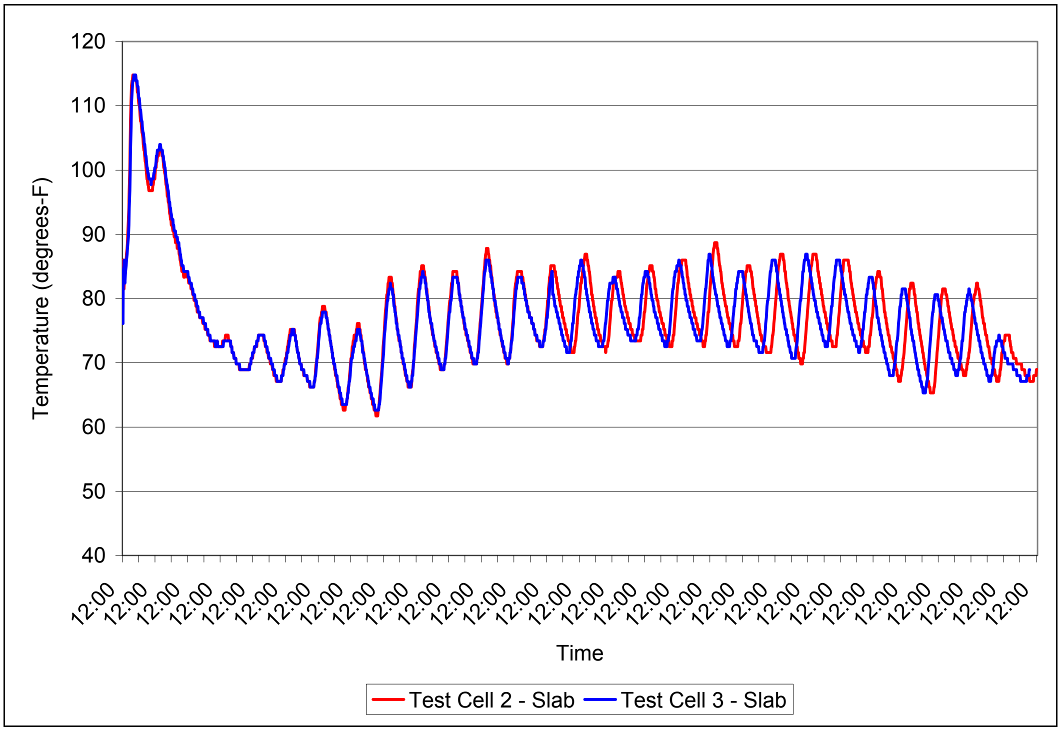


Figure B6. Plot of temperature profile for test cells 2 and 3 from paving and over the following 28 days.

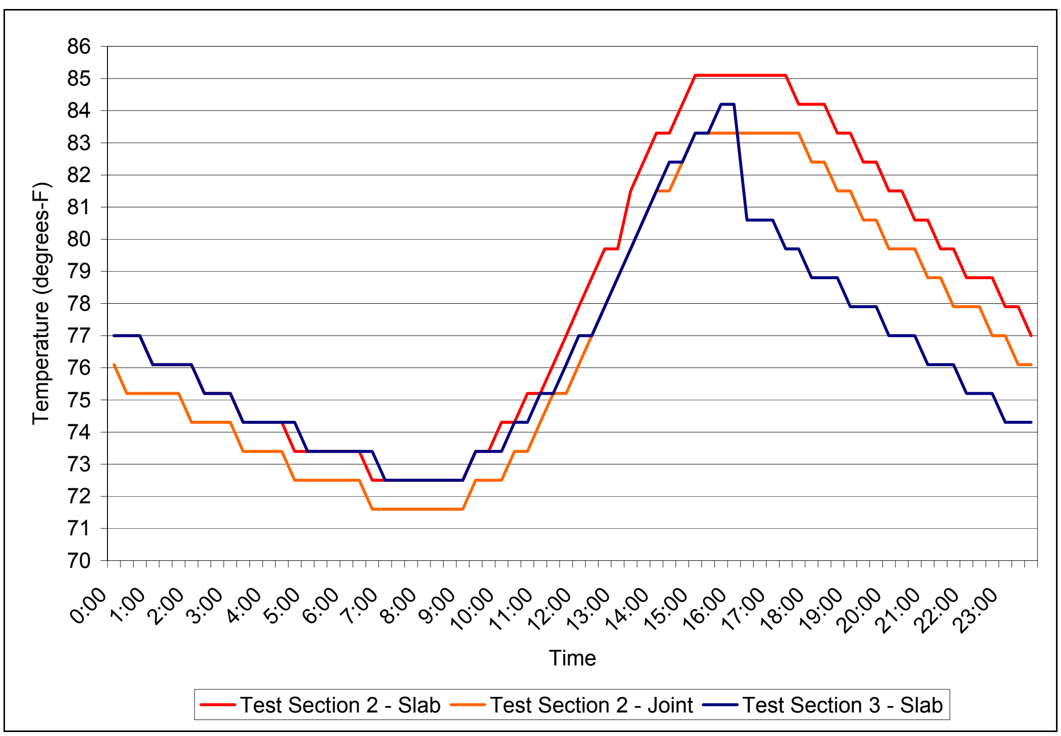


Figure B7. Plot depicting temperature profile of test cells 2 and 3 when the anomalous temperature drop was recorded resulting in the apparent offset in profile experienced in test cell 3 compared to that of test cell 2 and shown in figure B7.

APPENDIX C
HIPERPAV III Analysis Report

HIPERPAV Version: 3.20.0006

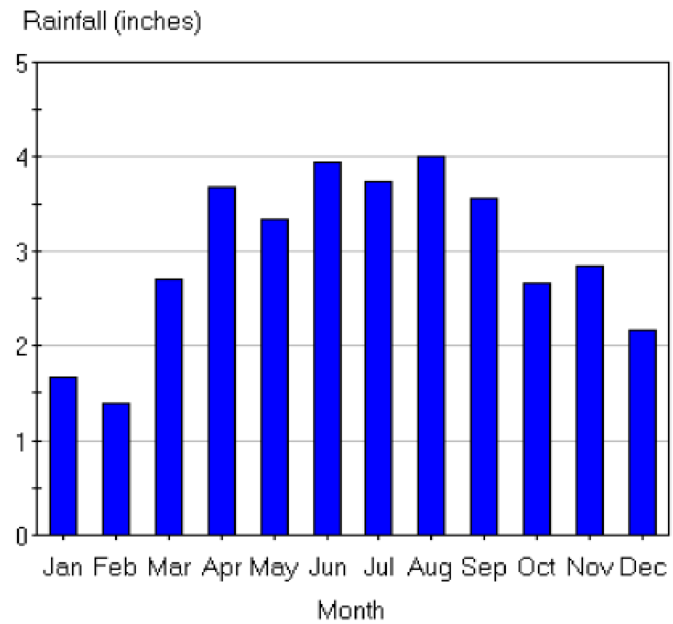
Project Information

Input	Value Unit
Project Name	08-058-ME01
Project ID	ICT Early-entry PCC Joint Sawing Research Project
Section Name	IL-59/Division St Southbound (S of Renwick Rd)
Begin Station	3290+00
End Station	3281+00
Comments	

Project Environment Data

Input	Value Unit
Latitude	41.5 °
Longitude	-88.2 °
Elevation	641.65 ft
Thornwaite Index	27

Month	Rainfall (inches)
January	1.7
February	1.4
March	2.7
April	3.7
May	3.3
June	3.9
July	3.7
August	4.0
September	3.6
October	2.7
November	2.8
December	2.2
Total	**35.6**



Strategy Information

Input	Value Unit
Title	New Strategy 1
User Name	J. Krstulovich
Analysis Date	11/18/2009 3:16:23 PM
Reliability Level	90 %
Comments	

Design - Geometry

Input	Value Unit
Slab Width	12 ft
New Slab Thickness	9.75 inches
Transverse Joint Spacing	15 ft

Design - Dowels

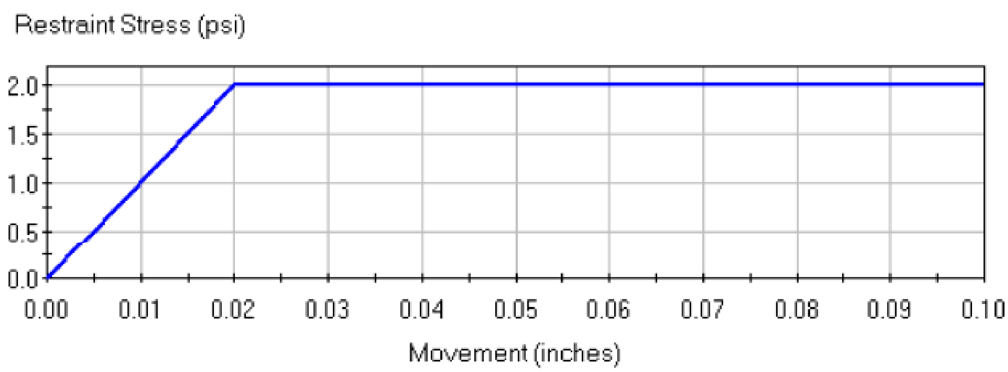
Input	Value Unit
Dowel Size	1.500 in.
Dowel Poisson's Ratio	0.3
Dowel Elastic Modulus	29000 ksi
28-Day Effective Modulus of Dowel Support	1500000 psi/inch

Design - Slab Support

Input	Value Unit
Material Type	Unbound Aggregate Subbase
k-Value	200 psi/inch
Subbase Thickness	12 inches
Subbase Modulus	30000 psi

Default Axial Restraint

Input	Value Unit
Critical Restraint Stress	2 psi
Movement at Sliding	0.02 inches



Materials and Mix Design - Cement

Input	Value Unit
Estimate Blaine Fineness Index	True
Cement Type	Type I

Materials and Mix Design - PCC Mix

Input	Value Unit
Aggregate Type	Limestone
Admixtures (ASTM C 494 Type)	Type B - Retarding
Fly Ash Class	Class C
Water/Cement Ratio	0.449
Water/Cementitous Ratio	0.355

Batch Proportions

Constituent	Mass (lb/yd³)
Coarse Aggregate	1852
Fine Aggregate	1264
Water	220
Cement (Type I)	490
Fly Ash	130
GGBF Slag	0
Silica Fume	0
Total	3956.0

Materials and Mix Design - PCC Properties

Input	Value Unit
PCC Strength Type	Compressive
28-Day Strength	5000 psi
Estimate PCC 28-Day Modulus	True
CTE (User-Defined PCC CTE)	5.5 microstrains/°F
Estimate PCC Ultimate Shrinkage	True
Tensile Strength Coefficient A	1.65
Tensile Strength Coefficient B	0.667
Splitting Tensile Strength	484 psi
Compressive Strength Coefficient A	1
Compressive Strength Coefficient B	1
Compressive Strength	5000 psi

Materials and Mix Design - Maturity Data

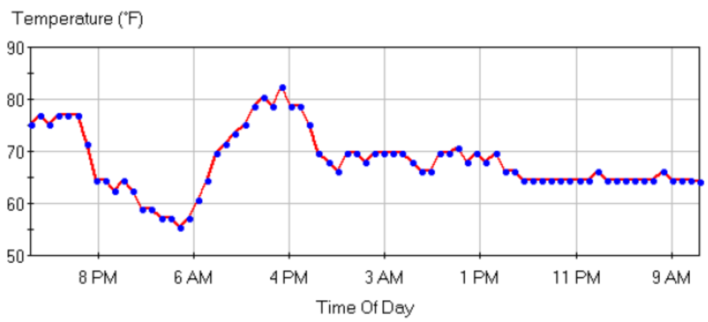
Input	Value Unit
Default Strength Gain	True

Early-Age Environment

Input	Value Unit
Construction Date	8/24/2009
Time of Day of Construction	1 PM

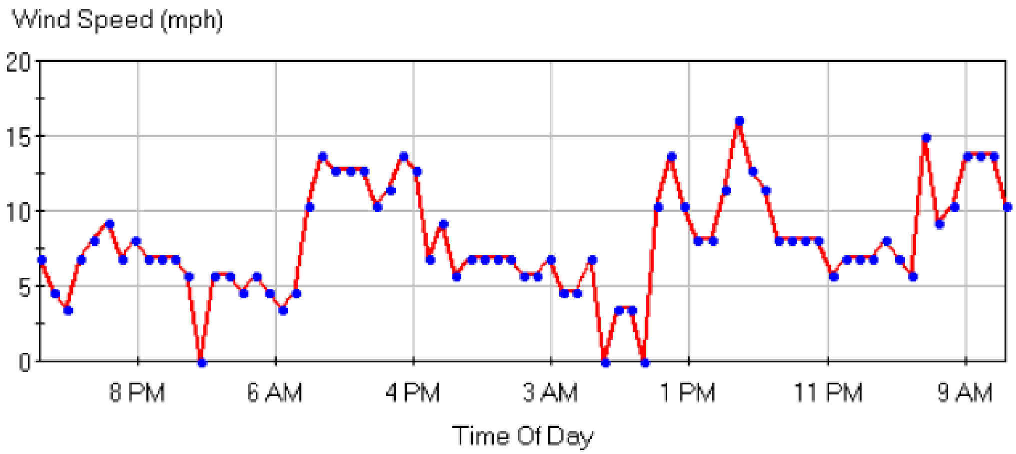
Early-Age Environmental Data - Average Temperatures (°F)

Time (Hour)	Value	Time (Hour)	Value	Time (Hour)	Value
1 PM (0)	75.2	2 PM (25)	80.6	3 PM (50)	69.8
2 PM (1)	77.0	3 PM (26)	78.8	4 PM (51)	66.2
3 PM (2)	75.2	4 PM (27)	82.4	5 PM (52)	66.2
4 PM (3)	77.0	5 PM (28)	78.8	6 PM (53)	64.4
5 PM (4)	77.0	6 PM (29)	78.8	7 PM (54)	64.4
6 PM (5)	77.0	7 PM (30)	75.2	8 PM (55)	64.4
7 PM (6)	71.6	8 PM (31)	69.8	9 PM (56)	64.4
8 PM (7)	64.4	9 PM (32)	68.0	10 PM (57)	64.4
9 PM (8)	64.4	10 PM (33)	66.2	11 PM (58)	64.4
10 PM (9)	62.6	11 PM (34)	69.8	12 AM - Midnight (59)	64.4
11 PM (10)	64.4	12 AM - Midnight (35)	69.8	1 AM (60)	64.4
12 AM - Midnight (11)	62.6	1 AM (36)	68.0	2 AM (61)	66.2
1 AM (12)	59.0	2 AM (37)	69.8	3 AM (62)	64.4
2 AM (13)	59.0	3 AM (38)	69.8	4 AM (63)	64.4
3 AM (14)	57.2	4 AM (39)	69.8	5 AM (64)	64.4
4 AM (15)	57.2	5 AM (40)	69.8	6 AM (65)	64.4
5 AM (16)	55.4	6 AM (41)	68.0	7 AM (66)	64.4
6 AM (17)	57.2	7 AM (42)	66.2	8 AM (67)	64.4
7 AM (18)	60.8	8 AM (43)	66.2	9 AM (68)	66.2
8 AM (19)	64.4	9 AM (44)	69.8	10 AM (69)	64.4
9 AM (20)	69.8	10 AM (45)	69.8	11 AM (70)	64.4
10 AM (21)	71.6	11 AM (46)	70.7	12 PM - Noon (71)	64.4
11 AM (22)	73.4	12 PM - Noon (47)	68.0	1 PM (72)	64.3
12 PM - Noon (23)	75.2	1 PM (48)	69.8		
1 PM (24)	78.8	2 PM (49)	68.0		



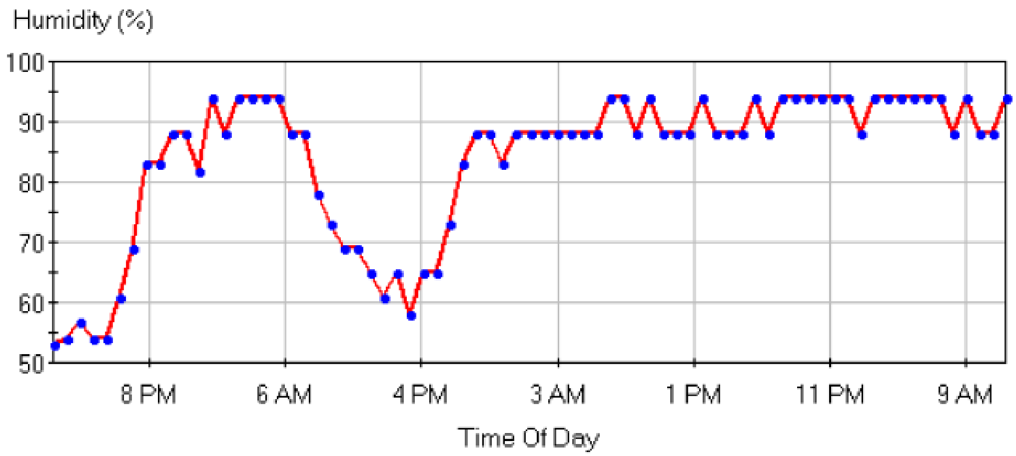
Early-Age Environmental Data - Average Wind Speed (mph)

Time (Hour)	Value	Time (Hour)	Value	Time (Hour)	Value
1 PM (0)	6.9	2 PM (25)	10.4	3 PM (50)	8.1
2 PM (1)	4.6	3 PM (26)	11.5	4 PM (51)	11.5
3 PM (2)	3.5	4 PM (27)	13.8	5 PM (52)	16.1
4 PM (3)	6.9	5 PM (28)	12.7	6 PM (53)	12.7
5 PM (4)	8.1	6 PM (29)	6.9	7 PM (54)	11.5
6 PM (5)	9.2	7 PM (30)	9.2	8 PM (55)	8.1
7 PM (6)	6.9	8 PM (31)	5.8	9 PM (56)	8.1
8 PM (7)	8.1	9 PM (32)	6.9	10 PM (57)	8.1
9 PM (8)	6.9	10 PM (33)	6.9	11 PM (58)	8.1
10 PM (9)	6.9	11 PM (34)	6.9	12 AM - Midnight (59)	5.8
11 PM (10)	6.9	12 AM - Midnight (35)	6.9	1 AM (60)	6.9
12 AM - Midnight (11)	5.8	1 AM (36)	5.8	2 AM (61)	6.9
1 AM (12)	0.0	2 AM (37)	5.8	3 AM (62)	6.9
2 AM (13)	5.8	3 AM (38)	6.9	4 AM (63)	8.1
3 AM (14)	5.8	4 AM (39)	4.6	5 AM (64)	6.9
4 AM (15)	4.6	5 AM (40)	4.6	6 AM (65)	5.8
5 AM (16)	5.8	6 AM (41)	6.9	7 AM (66)	15.0
6 AM (17)	4.6	7 AM (42)	0.0	8 AM (67)	9.2
7 AM (18)	3.5	8 AM (43)	3.5	9 AM (68)	10.4
8 AM (19)	4.6	9 AM (44)	3.5	10 AM (69)	13.8
9 AM (20)	10.4	10 AM (45)	0.0	11 AM (70)	13.8
10 AM (21)	13.8	11 AM (46)	10.4	12 PM - Noon (71)	13.8
11 AM (22)	12.7	12 PM - Noon (47)	13.8	1 PM (72)	10.4
12 PM - Noon (23)	12.7	1 PM (48)	10.4		
1 PM (24)	12.7	2 PM (49)	8.1		



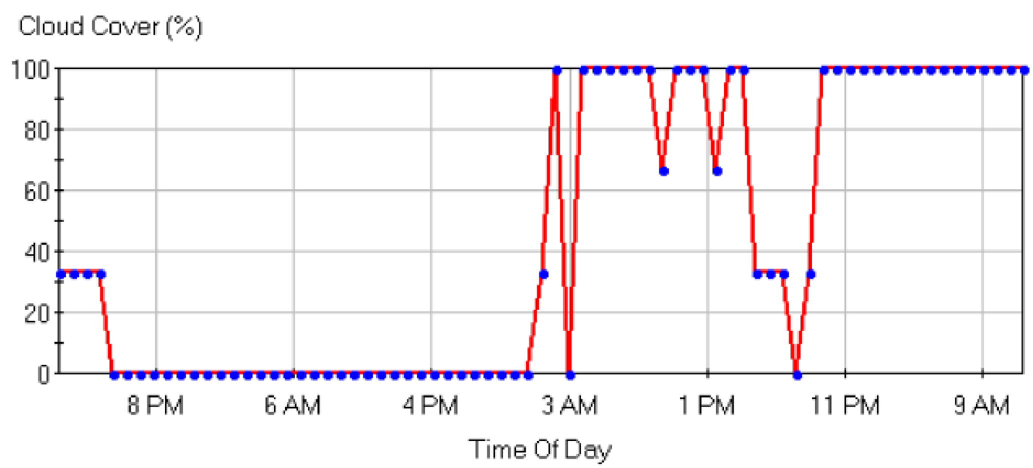
Early-Age Environmental Data - Average Humidity (%)

Time (Hour)	Value	Time (Hour)	Value	Time (Hour)	Value
1 PM (0)	53.0	2 PM (25)	61.0	3 PM (50)	88.0
2 PM (1)	54.0	3 PM (26)	65.0	4 PM (51)	88.0
3 PM (2)	57.0	4 PM (27)	58.0	5 PM (52)	88.0
4 PM (3)	54.0	5 PM (28)	65.0	6 PM (53)	94.0
5 PM (4)	54.0	6 PM (29)	65.0	7 PM (54)	88.0
6 PM (5)	61.0	7 PM (30)	73.0	8 PM (55)	94.0
7 PM (6)	69.0	8 PM (31)	83.0	9 PM (56)	94.0
8 PM (7)	83.0	9 PM (32)	88.0	10 PM (57)	94.0
9 PM (8)	83.0	10 PM (33)	88.0	11 PM (58)	94.0
10 PM (9)	88.0	11 PM (34)	83.0	12 AM - Midnight (59)	94.0
11 PM (10)	88.0	12 AM - Midnight (35)	88.0	1 AM (60)	94.0
12 AM - Midnight (11)	82.0	1 AM (36)	88.0	2 AM (61)	88.0
1 AM (12)	94.0	2 AM (37)	88.0	3 AM (62)	94.0
2 AM (13)	88.0	3 AM (38)	88.0	4 AM (63)	94.0
3 AM (14)	94.0	4 AM (39)	88.0	5 AM (64)	94.0
4 AM (15)	94.0	5 AM (40)	88.0	6 AM (65)	94.0
5 AM (16)	94.0	6 AM (41)	88.0	7 AM (66)	94.0
6 AM (17)	94.0	7 AM (42)	94.0	8 AM (67)	94.0
7 AM (18)	88.0	8 AM (43)	94.0	9 AM (68)	88.0
8 AM (19)	88.0	9 AM (44)	88.0	10 AM (69)	94.0
9 AM (20)	78.0	10 AM (45)	94.0	11 AM (70)	88.0
10 AM (21)	73.0	11 AM (46)	88.0	12 PM - Noon (71)	88.0
11 AM (22)	69.0	12 PM - Noon (47)	88.0	1 PM (72)	94.0
12 PM - Noon (23)	69.0	1 PM (48)	88.0		
1 PM (24)	65.0	2 PM (49)	94.0		



Early-Age Environmental Data - Average Cloudiness (%)

Time (Hour)	Value	Time (Hour)	Value	Time (Hour)	Value
1 PM (0)	33.0	2 PM (25)	0.0	3 PM (50)	100.0
2 PM (1)	33.0	3 PM (26)	0.0	4 PM (51)	100.0
3 PM (2)	33.0	4 PM (27)	0.0	5 PM (52)	33.0
4 PM (3)	33.0	5 PM (28)	0.0	6 PM (53)	33.0
5 PM (4)	0.0	6 PM (29)	0.0	7 PM (54)	33.0
6 PM (5)	0.0	7 PM (30)	0.0	8 PM (55)	0.0
7 PM (6)	0.0	8 PM (31)	0.0	9 PM (56)	33.0
8 PM (7)	0.0	9 PM (32)	0.0	10 PM (57)	100.0
9 PM (8)	0.0	10 PM (33)	0.0	11 PM (58)	100.0
10 PM (9)	0.0	11 PM (34)	0.0	12 AM - Midnight (59)	100.0
11 PM (10)	0.0	12 AM - Midnight (35)	0.0	1 AM (60)	100.0
12 AM - Midnight (11)	0.0	1 AM (36)	33.0	2 AM (61)	100.0
1 AM (12)	0.0	2 AM (37)	100.0	3 AM (62)	100.0
2 AM (13)	0.0	3 AM (38)	0.0	4 AM (63)	100.0
3 AM (14)	0.0	4 AM (39)	100.0	5 AM (64)	100.0
4 AM (15)	0.0	5 AM (40)	100.0	6 AM (65)	100.0
5 AM (16)	0.0	6 AM (41)	100.0	7 AM (66)	100.0
6 AM (17)	0.0	7 AM (42)	100.0	8 AM (67)	100.0
7 AM (18)	0.0	8 AM (43)	100.0	9 AM (68)	100.0
8 AM (19)	0.0	9 AM (44)	100.0	10 AM (69)	100.0
9 AM (20)	0.0	10 AM (45)	67.0	11 AM (70)	100.0
10 AM (21)	0.0	11 AM (46)	100.0	12 PM - Noon (71)	100.0
11 AM (22)	0.0	12 PM - Noon (47)	100.0	1 PM (72)	100.0
12 PM - Noon (23)	0.0	1 PM (48)	100.0		
1 PM (24)	0.0	2 PM (49)	67.0		



Early-Age Construction

Input	Value	Unit
Initial PCC Mix Temperature	60	°F
Initial Support Layer Temperature	70	°F
Base is moist		
Strength for Opening to Traffic	350	psi
PCC Strength Type	Splitting Tensile	
Curing Method	Single Coat Liquid Curing Compound	
Age Curing Applied	1	hours
Age Curing Removed	72	hours
User-Defined Sawing Age	6	hours

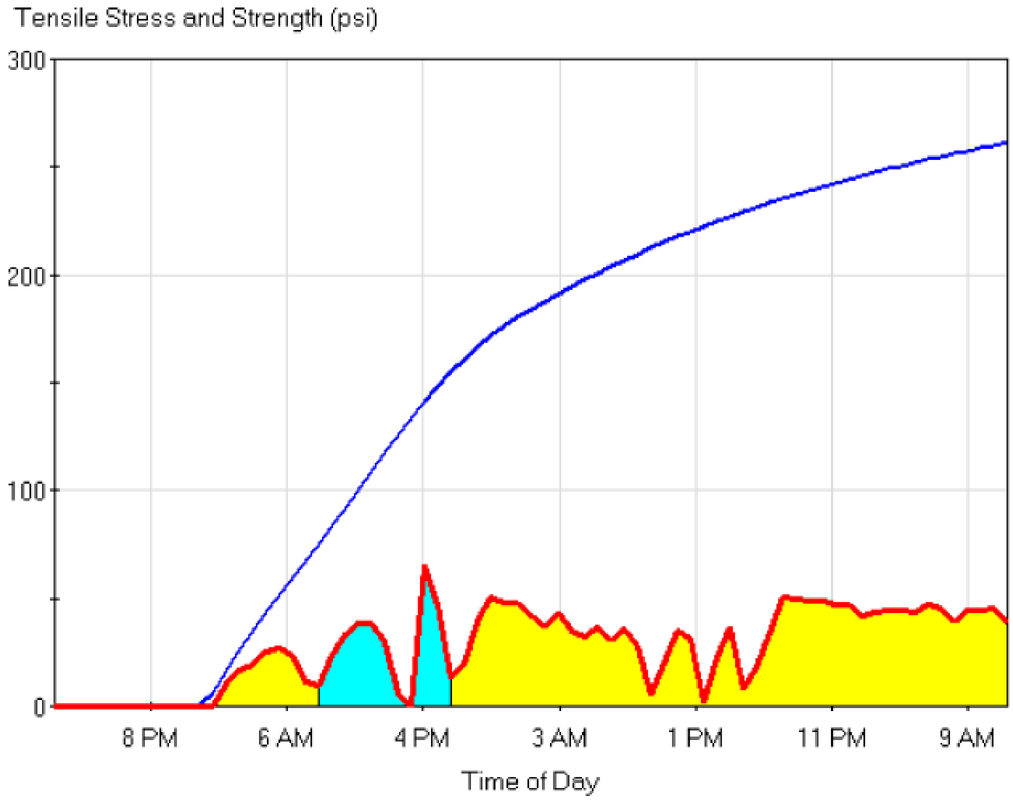
Analysis (psi)

Time	Hour	PCC Strength	Critical Stress	Critical Stress at Slab Top	Critical Stress at Slab Bottom
1 PM	0	0.0	0.0	0.0	0.0
2 PM	1	0.0	0.0	0.0	0.0
3 PM	2	0.0	0.0	0.0	0.0
4 PM	3	0.0	0.0	0.0	0.0
5 PM	4	0.0	0.0	0.0	0.0
6 PM	5	0.0	0.0	0.0	0.0
7 PM	6	0.0	0.0	0.0	0.0
8 PM	7	0.0	0.0	0.0	0.0
9 PM	8	0.0	0.0	0.0	0.0
10 PM	9	0.0	0.0	0.0	0.0
11 PM	10	0.0	0.0	0.0	0.0
12 AM - Midnight	11	0.8	0.0	0.0	0.0
1 AM	12	6.3	0.0	0.0	0.0
2 AM	13	16.4	10.3	10.3	0.0
3 AM	14	26.1	16.2	16.2	0.0
4 AM	15	35.3	19.4	19.4	0.0
5 AM	16	43.7	25.0	25.0	0.0
6 AM	17	51.7	26.6	26.6	0.0
7 AM	18	59.3	23.3	23.3	0.0
8 AM	19	66.7	11.1	11.1	0.0
9 AM	20	74.9	9.3	0.0	9.3
10 AM	21	83.3	23.8	0.0	23.8
11 AM	22	91.6	33.5	0.0	33.5
12 PM - Noon	23	100.0	38.7	0.0	38.7
1 PM	24	108.6	38.4	0.0	38.4
2 PM	25	117.3	29.9	0.0	29.9
3 PM	26	125.8	6.2	0.0	6.2
4 PM	27	133.9	0.0	0.0	0.0
5 PM	28	141.6	65.2	0.0	65.2
6 PM	29	148.7	47.1	0.0	47.1
7 PM	30	155.1	13.4	0.0	13.4
8 PM	31	160.8	18.8	18.8	0.0
9 PM	32	166.5	38.8	38.8	0.0
10 PM	33	171.6	50.6	50.6	0.0
11 PM	34	176.0	48.0	48.0	0.0
12 AM - Midnight	35	180.1	47.5	47.5	0.0
1 AM	36	184.0	41.8	41.8	0.0
2 AM	37	187.7	36.8	36.8	0.0
3 AM	38	191.3	43.7	43.7	0.0
4 AM	39	194.6	35.1	35.1	0.0
5 AM	40	197.9	32.5	32.5	0.0
6 AM	41	201.0	36.6	36.6	0.0
7 AM	42	204.0	30.4	30.4	0.0
8 AM	43	206.9	35.5	35.5	0.0
9 AM	44	209.6	28.3	28.3	0.0
10 AM	45	212.4	4.9	0.0	4.9
11 AM	46	215.1	20.4	20.4	0.0
12 PM - Noon	47	217.7	35.1	35.1	0.0
1 PM	48	220.1	31.3	31.3	0.0
2 PM	49	222.5	1.8	1.8	0.0
3 PM	50	224.9	22.4	22.4	0.0
4 PM	51	227.1	36.7	36.7	0.0
5 PM	52	229.4	8.0	8.0	0.0
6 PM	53	231.5	18.4	18.4	0.0
7 PM	54	233.6	33.7	33.7	0.0
8 PM	55	235.5	50.9	50.9	0.0

(Continued)

Analysis (psi)

Time	Hour	PCC Strength	Critical Stress	Critical Stress at Slab Top	Critical Stress at Slab Bottom
9 PM	56	237.4	49.4	49.4	0.0
10 PM	57	239.2	49.1	49.1	0.0
11 PM	58	241.0	49.0	49.0	0.0
12 AM - Midnight	59	242.7	46.9	46.9	0.0
1 AM	60	244.3	46.8	46.8	0.0
2 AM	61	246.0	41.8	41.8	0.0
3 AM	62	247.5	43.2	43.2	0.0
4 AM	63	249.1	44.1	44.1	0.0
5 AM	64	250.5	44.1	44.1	0.0
6 AM	65	252.0	43.6	43.6	0.0
7 AM	66	253.4	46.9	46.9	0.0
8 AM	67	254.8	45.6	45.6	0.0
9 AM	68	256.1	39.6	39.6	0.0
10 AM	69	257.5	44.2	44.2	0.0
11 AM	70	258.7	44.5	44.5	0.0
12 PM - Noon	71	260.0	45.4	45.4	0.0
1 PM	72	261.2	38.1	38.1	0.0



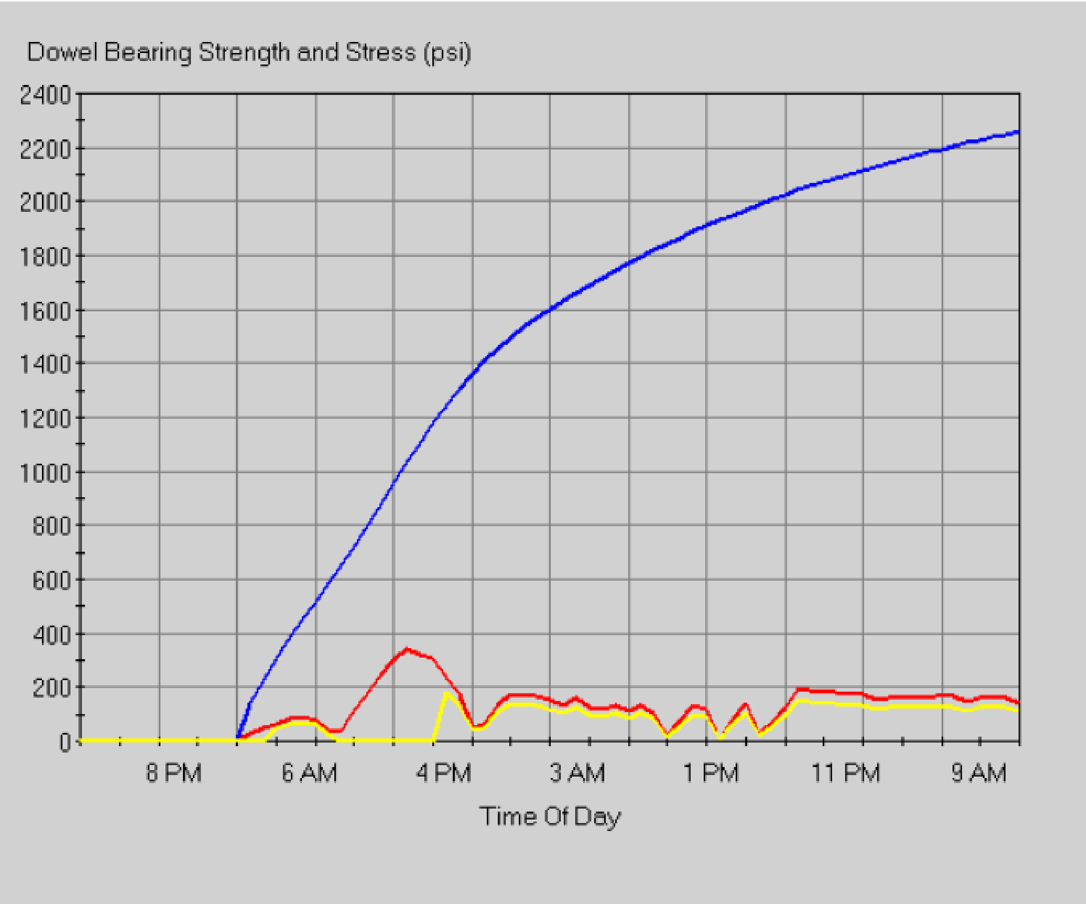
Dowel Analysis (psi)

Time	Hour	Bearing Strength	Curl-Curl Stress	Flat-Curl Stress
1 PM	0	0.00	0.00	0.00
2 PM	1	0.00	0.00	0.00
3 PM	2	0.00	0.00	0.00
4 PM	3	0.00	0.00	0.00
5 PM	4	0.00	0.00	0.00
6 PM	5	0.00	0.00	0.00
7 PM	6	0.00	0.00	0.00
8 PM	7	0.00	0.00	0.00
9 PM	8	0.00	0.00	0.00
10 PM	9	0.00	0.00	0.00
11 PM	10	0.00	0.00	0.00
12 AM - Midnight	11	0.00	0.00	0.00
1 AM	12	0.00	0.00	0.00
2 AM	13	138.91	27.20	1.00
3 AM	14	225.36	46.32	1.00
4 AM	15	305.84	61.04	47.73
5 AM	16	381.69	80.66	63.14
6 AM	17	451.41	87.49	68.56
7 AM	18	516.95	76.97	60.33
8 AM	19	580.87	38.40	29.99
9 AM	20	645.42	36.39	1.00
10 AM	21	715.86	109.88	1.00
11 AM	22	795.05	177.31	1.00
12 PM - Noon	23	873.59	242.55	1.00
1 PM	24	952.42	301.78	1.00
2 PM	25	1030.65	340.49	1.00
3 PM	26	1104.79	319.59	1.00
4 PM	27	1175.94	306.94	1.00
5 PM	28	1242.26	234.48	183.97
6 PM	29	1303.53	173.27	135.78
7 PM	30	1358.93	49.58	38.56
8 PM	31	1408.48	64.93	50.55
9 PM	32	1453.14	135.80	106.11
10 PM	33	1493.78	177.74	139.03
11 PM	34	1531.40	170.26	133.08
12 AM - Midnight	35	1566.63	169.65	132.54
1 AM	36	1599.97	150.35	117.32
2 AM	37	1631.78	132.80	103.51
3 AM	38	1661.96	158.09	123.30
4 AM	39	1690.80	127.86	99.55
5 AM	40	1718.60	118.62	92.28
6 AM	41	1745.21	133.89	104.20
7 AM	42	1770.84	111.27	86.46
8 AM	43	1795.51	130.39	101.38
9 AM	44	1819.30	104.49	81.11
10 AM	45	1843.03	18.09	13.96
11 AM	46	1866.13	74.76	57.89
12 PM - Noon	47	1887.93	129.71	100.71
1 PM	48	1908.83	116.28	90.20
2 PM	49	1929.62	6.62	5.10
3 PM	50	1949.88	82.72	64.01
4 PM	51	1969.03	136.87	106.18
5 PM	52	1987.90	29.63	22.84
6 PM	53	2006.40	68.30	52.77
7 PM	54	2024.09	125.39	97.13
8 PM	55	2040.84	189.72	147.30

(Continued)

Dowel Analysis (psi)

Time	Hour	Bearing Strength	Curl-Curl Stress	Flat-Curl Stress
9 PM	56	2056.87	184.91	143.51
10 PM	57	2072.34	184.07	142.82
11 PM	58	2087.30	182.36	141.46
12 AM - Midnight	59	2101.82	173.89	134.83
1 AM	60	2115.91	171.96	133.30
2 AM	61	2129.67	154.42	119.60
3 AM	62	2143.04	163.13	126.38
4 AM	63	2156.05	166.69	129.13
5 AM	64	2168.71	163.04	126.26
6 AM	65	2181.08	158.51	122.71
7 AM	66	2193.10	172.88	133.89
8 AM	67	2204.81	164.57	127.40
9 AM	68	2216.31	146.50	113.31
10 AM	69	2227.51	162.18	125.50
11 AM	70	2238.44	164.48	127.28
12 PM - Noon	71	2249.10	163.25	126.29
1 PM	72	2259.54	142.36	110.03



Free Evaporation Rate Analysis (lb/ft²/hr)

Time	Hour	Free Evaporation Rate
	0.0	0.02
	0.1	0.04
	0.2	0.05
	0.3	0.05
	0.4	0.06
	0.5	0.04
	0.6	0.05
	0.7	0.05
	0.8	0.05
	0.9	0.06
	1.0	0.06
	1.1	0.06
	1.2	0.06
	1.3	0.07
	1.4	0.07
	1.5	0.06
	1.6	0.06
	1.7	0.06
	1.8	0.07
	1.9	0.07
	2.0	0.07
	2.1	0.07
	2.2	0.07
	2.3	0.07
	2.4	0.07
	2.5	0.11
	2.6	0.11
	2.7	0.12
	2.8	0.12
	2.9	0.12
	3.0	0.12
	3.1	0.12
	3.2	0.13
	3.3	0.13
	3.4	0.13
	3.5	0.15
	3.6	0.15
	3.7	0.15
	3.8	0.15
	3.9	0.16
	4.0	0.15
	4.1	0.15
	4.2	0.15
	4.3	0.15
	4.4	0.15
	4.5	0.15
	4.6	0.15
	4.7	0.15
	4.8	0.15
	4.9	0.15
	5.0	0.14
	5.1	0.13
	5.2	0.13
	5.3	0.12
	5.4	0.12
	5.5	0.10

(Continued)

Free Evaporation Rate Analysis (lb/ft²/hr)

Time	Hour	Free Evaporation Rate
	5.6	0.10
	5.7	0.10
	5.8	0.10
	5.9	0.10
	6.0	0.09
	6.1	0.08
	6.2	0.08
	6.3	0.08
	6.4	0.08
	6.5	0.09
	6.6	0.09
	6.7	0.09
	6.8	0.09
	6.9	0.08
	7.0	0.08
	7.1	0.08
	7.2	0.08
	7.3	0.08
	7.4	0.08
	7.5	0.07
	7.6	0.07
	7.7	0.07
	7.8	0.07
	7.9	0.07
	8.0	0.07
	8.1	0.06
	8.2	0.06
	8.3	0.06
	8.4	0.06
	8.5	0.06
	8.6	0.06
	8.7	0.06
	8.8	0.06
	8.9	0.06
	9.0	0.06
	9.1	0.06
	9.2	0.06
	9.3	0.06
	9.4	0.06
	9.5	0.06
	9.6	0.06
	9.7	0.06
	9.8	0.06
	9.9	0.06
	10.0	0.05
	10.1	0.05
	10.2	0.05
	10.3	0.05
	10.4	0.05
	10.5	0.06
	10.6	0.06