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TechBrief

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U.S. Department of Transportation
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Early-Entry Sawing of Portland Cement Concrete Pavements

This TechBrief discusses the creation of contraction joints in portland cement concrete pavements using early-entry saws. It explains the need for joints, provides an overview of traditional joint sawing practices, and describes the early-entry joint sawing approach and associated equipment. A brief summary of studies on the use of early-entry sawing is provided, along with general guidelines for employing early-entry sawcutting technology.

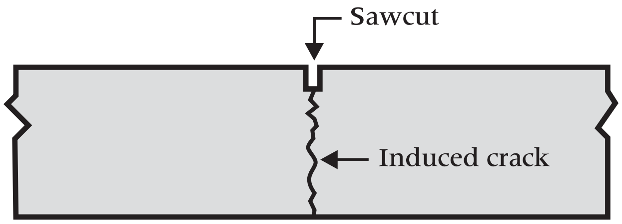
BACKGROUND

Joints are placed in portland cement concrete (PCC) pavements principally to prevent the development of uncontrolled, random cracking brought about by environmental forces (temperature and moisture) and concrete shrinkage. These forces are most acute during the first 72 hours after placement as the young concrete is still gaining strength.

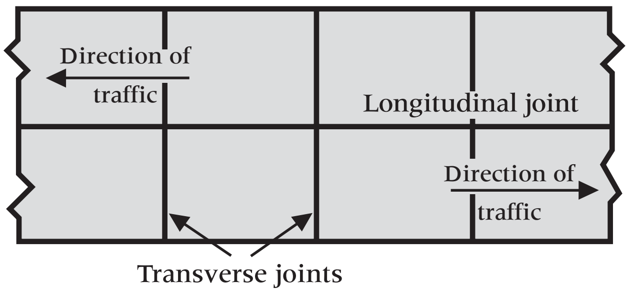
Although there are a number of ways to create joints in PCC pavements, the most common method is by sawing the hardened PCC to an established depth, typically one-quarter to one-third of the slab thickness; this creates a weakened plane, thus encouraging cracking to occur at that location in a controlled manner (see Figure 1a). This sawing must be done before significant restraint stress has developed in the concrete. When sawed to an appropriate depth and at the right time, and when constructed at appropriate intervals within the pavement (typically transverse joints at 4.6-m [15-ft] intervals along the length of the paving project and longitudinal joints at 3.7-m [12-ft] intervals across the width of the paving project), as shown in Figure 1b, these joints provide effective stress relief to prevent the development of random cracking.

Determining the appropriate sawcut depth and timing needed to ensure the formation of the cracks below the weakened plane has proven to be a complicated task (Okamoto et al. 1994). For conventional joint sawing, the depth of sawing is often taken to be one-quarter of the slab thickness for transverse contraction joints and one-third of the slab thickness for longitudinal contraction joints (AASHTO 1993). However, others suggest that the depth should always be at least one-third of the slab thickness (ACPA 1991). Still others advocate that a shallower cut—usually at least 25 mm (1 in.)—may be adequate if the sawing is done early enough (Zollinger, Tang, and Xin 1994; Zollinger 2001).

There is an ideal joint-sawing "window," at which time the joints should be cut, as shown in Figure 2. The goal in timing the sawcutting operation is to saw neither too soon (which will cause raveling of the concrete) nor



a) Cross section of contraction joint



b) Transverse and longitudinal joint orientation

Figure 1. Joint formation and layout (ISU 2004).

too late (which may result in random cracking due to the buildup of residual stresses). The later time limit is of particular concern because the longer that sawing is delayed, the greater the chance that random cracking may develop (ACPA 2002).

In general, the sawing should occur between about 4 and 12 hours after paving, but this timeframe will vary considerably depending upon the constituent materials, mix properties, external restraint forces, and environmental factors. The timing of the joint sawing is often based on the experience of the operator, and often includes a "scratch test" as an indicator of the hardness of the concrete surface.

In most conventional joint-sawing operations, the joints are cut with single-blade, water-cooled, walk-behind saws. A continuous water supply (usually a water truck with a driver) and a crew of at last two people are needed for these operations. Clearly, both the depth and the timing of the sawcut are critical aspects of any sawcutting operation.

EARLY-ENTRY SAWS

In 1988, early-entry saws were commercially introduced to the paving industry (Concrete Construction 1988). Early-entry saws are much lighter than conventional sawing equipment, which allows them to be used on concrete at a much earlier age, often as soon as workers can walk on the concrete. Moreover, it is postulated that the shallower sawcuts take advantage of the significant changes in moisture and temperature conditions at the surface of the slab to help initiate cracking below the sawcut (Zollinger, Tang, and Xin 1994).

Early-entry saws have other characteristics that are believed to contribute to their effectiveness. For example, many early-entry saws employ a patented "skid plate" straddling the blade that exerts downward pressure on the surface of the concrete to prevent chipping or raveling of the sawcut (McGovern 2002). In addition, most early-entry saws use a dry-cutting operation with specially designed blades that do not require water for cooling (Chojnacki 2001). Finally, early-entry saws use an "up-cutting" rotation of the blade to help keep debris out of the joint. Figure 3 shows an early-entry saw, and Figure 4 contrasts the differences in sawcut depths from conventional and early-entry sawcutting operations.

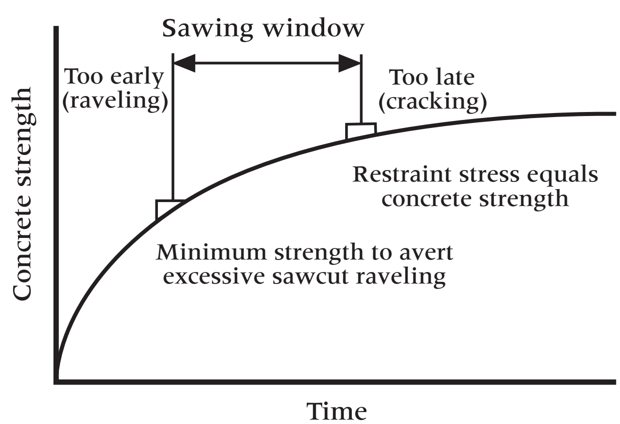


Figure 2. Concept of a joint-sawing "window" (Okamoto et al. 1994).

Figure 3. Early-entry saw (Rasoulian, Titi, and Martinez 2006).

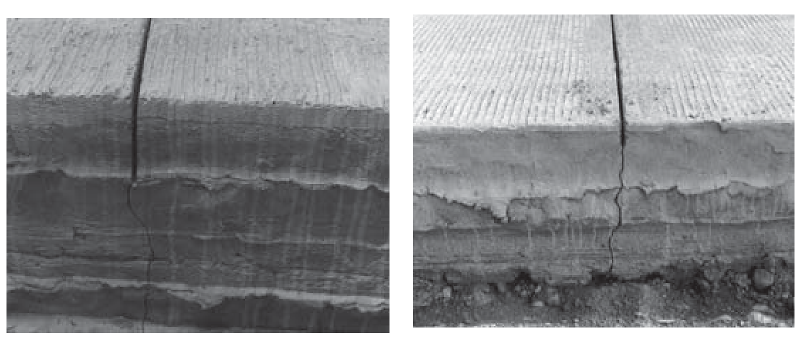
A variety of early-entry sawing models are available, each targeted to a specific type of application. Models used for most street and highway paving projects are self-propelled, equipped with 16.4- to 20.1-kW (22- to 27-hp) gasoline engines, and may employ 200- to 350-mm (10- to 14-in.) diameter blades in widths ranging from 3 to 6 mm (0.10 to 0.25 in.) (Soff-Cut 2007). The weight of the equipment depends on the model, and can range from as little as about 11 kg (25 lb) for lightweight, electric models up to about 227 kg (500 lb) for heavy-duty, high-production models. The heavier models are capable of sawcut depths up to 100 mm (4 in.).

Early-entry sawing can begin as soon as 1 to 4 hours after concrete placement, depending on weather conditions and concrete mix characteristics (ACI 2001). This early access to the pavement is believed to increase the probability that the concrete will crack below the sawcut location (Zollinger 2001). And, because the pavement is being sawed earlier, the depth of sawing needed to initiate cracking beneath the sawcut can be reduced, with a minimum depth of 25 mm (1 in.) suggested (Zollinger, Tang, and Xin 1994; ACI 2001). Furthermore, because the sawing is done while the concrete is young and relatively weak, the sawing operation is expected to proceed rapidly while also reducing blade wear.

Early-entry sawing technology has been used in a range of applications, from warehouse floors to parking lots, and from residential and city streets to major highways. In addition, the ability to get on the pavement soon after concrete placement makes early-entry sawing particularly applicable for fast-track paving operations.

EXPERIENCE WITH EARLY-ENTRY SAWING

Early-entry saws are now frequently used on paving projects. According to the database of State highway practices compiled by the American Concrete Pavement Association, currently 25 of 33 responding highway agencies allow the use of early-entry joint sawing (ACPA 2007). However, only a few of these agencies have separate standards for early-entry sawing techniques and equipment, meaning that the other agencies may allow the use of early-entry saws, but by default they require that the joints be cut to the conventional depth of either one-third or one-quarter of the slab thickness. Among the agencies with separate specifications are Iowa, Tennessee, and North Carolina. Iowa specifies a sawing depth of 32 ± 6 mm (1.25 ± 0.25 in.) for joints created with early-entry saws, whereas North Carolina and



a) Conventional *b) Early-entry*

Figure 4. Contrast in sawcut depths (Rasoulian, Titi, and Martinez 2006).

Tennessee prescribe the use of "lightweight" sawing equipment on all new PCC pavement construction and sawing to the depth shown in the plans.

A study in Texas that evaluated joint sawcut depth requirements from a fracture mechanics standpoint included an investigation of early-entry sawing (Zollinger 1994). A field experiment was constructed that featured 330-mm (13-in.) PCC pavements placed directly on the subgrade, along with several variables including coarse aggregate type, curing method, concrete mixture, and sawcutting methodology (Zollinger, Tang, and Xin 1994). The sawcutting methodologies included conventional water-cooled sawing to a depth of 75 mm (3 in.) (approximately one-quarter of the slab thickness) and early-entry dry cutting to a depth of 25 mm (1 in.) and typically at about 2 to 3 hours after the concrete had been placed. Overall field performance of the early-entry sawcuts was satisfactory, and preliminary recommendations for using a narrow sawcut depth, on the order of 25 mm (1 in.), and early-age sawcutting practices were advocated (Zollinger, Tang, and Xin 1994).

In 2000, Missouri conducted a study on the use of early-entry joint sawing technology on three new PCC paving projects (Chojnacki 2001). On the first project, a 300-mm (12-in.) PCC pavement located on US 60, transverse joints were sawed 38 mm (1.5 in.) deep (one-eighth of the slab thickness) between 3 and 6 hours after PCC placement. A post-construction evaluation revealed that the joints cracked beneath the sawcuts and there was no random cracking within the project. Based on the initial success of this project, two other projects were constructed using early-entry sawing technology, one on US 50 and one on US 65. In both instances, the sawing quality and performance of the joints were equal to or better than the conventional sawing methods (Chojnacki 2001). It was noted that the use of one early-entry saw resulted in equivalent or greater sawing production (in terms of the number of joints per hour) than the use of two conventional saws.

The Iowa Department of Transportation has allowed contractors the option of using early-entry saws since 1992. One problem that was occasionally observed with early-entry sawing was the break-out of some of the concrete around the end of the joint as the saw blade approached the edge of the slab, presumably because of the weak PCC and the unsupported slab edge (Steffes and Siljenberg 2003). An experiment was conducted to evaluate the efficacy of creating a "short joint" in which the sawing terminates approximately 13 to 19 mm (0.50 to 0.75 in.) before the blade reaches the edge of the slab. The research found no negative aspects associated with sawing the "short joint," and, consequently, that sawing technique is now a specified practice (Steffes and Siljenberg 2003). The joints were sawed to a depth of 29 mm (1.125 in.).

A Swedish study on early-entry sawing was conducted in 2004, with the objective of comparing the performance and effectiveness of early-entry dry sawcutting operations with conventional wet sawcutting operations (Löfsögård 2004). The depth of cut for the early-entry sawing was one-fifth of the slab thickness. Although the work was carried out on a small project, the field investigation indicated that the cracking beneath the early-entry sawcut was as good as that under the conventional sawcut.

A recent laboratory study examined the timing and depth of sawcutting for PCC pavements, and included an evaluation of early-entry saws (Thier 2005). The results of that study suggested that early-entry saws can be used to create sawcuts without significant raveling at approximately the halfway point between the initial and final set of the concrete, as determined by ASTM C403 (Thier 2005). However, there were some concerns about the ability of shallow, 25-mm (1-in.) sawcuts to effectively reduce the probability of random cracking.

A study conducted by the Louisiana Transportation Research Center evaluated the use of shallow transverse contraction joints in PCC pavements in five test sections located throughout the State. The study included an evaluation of early-entry saws for creating weakened plane contraction joints. The results of the study indicated that the early-entry sawcut joints were very slow in cracking beneath the sawcuts, and this was attributed to the use of ground granulated blast furnace slag in the concrete mix and the related delay in setting times (Rasoulian, Titi, and Martinez 2006). Consequently, in order to ensure that the cracks would form, the early-entry joints were sawed deeper, from an original prescribed depth of 38 mm (1.5 in.) to a new prescribed depth of 65 mm (2.5 in.). At the new depth, all early-entry joints were cracked after about 1 month (Rasoulian, Titi, and Martinez 2006).

SUMMARY

Early-entry saws are lightweight devices capable of getting on a concrete pavement as soon as it can support the weight of the equipment, typically between 1 and 4 hours after paving. They saw a very shallow notch in the surface of the pavement that, coupled with the early timing of the sawcut and the localized stress distributions at the surface of the pavement, has been shown to be successful in establishing effective weakened-plane contraction joints. Specific features of early-entry sawing equipment include a dry-cutting operation (the blades are designed to cut without water for cooling), upcutting blade rotations (to keep debris out of the freshly cut joint), and, on selected devices, a skid plate straddling the blades to help minimize raveling and tearing of the young concrete.

Although a relatively new development, early-entry sawing technology holds the potential for increased productivity, reduced costs, and reduced manpower requirements, making it a viable alternative to conventional joint-sawing operations. A number of States currently allow the use of early-entry sawing equipment, and several more have developed separate specifications governing their use. Following are some general recommendations on early-entry sawcutting operations:

- Start sawing as soon as the concrete can support the weight of the equipment and the operator without disturbing the final finish. It is imperative to finish the sawing before the final set of the concrete, when the concrete starts cooling and the built-in restraint stress may exceed the concrete strength.
- Unless specified otherwise, cut the joints to an initial depth of between 25 and 38 mm (1 and 1.5 in.), generally regardless of the thickness of the pavement (Taylor et al. 2006). If required, a second widening cut can be made later to establish the joint reservoir.
- If corner spalling in the freshly placed concrete is a concern, stop sawing the joint approximately 13 to 19 mm (0.50 to 0.75 in.) from the edge of the slab to prevent corner spalling and edge breakout (Steffes and Siljenberg 2003).
- Use skid plates to help control raveling along the length of the joint. These skid plates should be changed regularly and in accordance with manufacturer recommendations for maximum effectiveness (ACI 2004).

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