To help prevent cracking due to early loads, construction equipment should not be allowed near the slab edges until the minimum strength is achieved. Curbs and tied concrete shoulders reduce the potential for early-age cracking when the concrete is subject to edge loading.

## Controlling Early-Age Cracks with Joints

Concrete expands and contracts with variations in temperature and moisture content, which can lead to cracking if it is restrained. Cutting the pavement into smaller panels helps relieve the restraint and generally ensures that the cracks form where desired rather than at random.

In jointed pavements (the majority of concrete pavements), the number, location, and size of early-age cracks is controlled by constructing (forming or sawing) joints. Of the three joint types—contraction, construction, and isolation—contraction joints are the most important for crack control. Contraction joints create planes of weakness where cracks form. To control cracking adequately, joints must be constructed correctly. Sawed joints, for example, must be sawed at the correct time, spacing, and depth.

### Timing: The Sawing Window

Joints are usually constructed by saw-cutting the concrete a few hours after placing. The optimum period of time to saw contraction joints is known as the sawing window.

The sawing window for conventional saws generally begins when concrete is strong enough not to ravel excessively along the saw cut. The window ends when significant shrinkage occurs that induces uncontrolled cracking. Good practice generally dictates that, if the slab begins cracking in front of the saw, sawing should be stopped at that joint.

Early-entry saws are now frequently used on paving projects. Smaller and lighter than conventional saws, they have the advantage of allowing sawing to begin within an hour or two of paving. The sawing window for early-entry saws begins earlier and ends sooner than for conventional saws (figure 3).

First-generation early-entry saws cut shallow (25 mm [1 in.]) joints. At final set (near the beginning of the sawing window for early-entry saws), a shallow joint is enough to create a plane of weakness where a crack will form to relieve stresses. Early, shallow cuts work well for transverse joints, regardless of the thickness of the pavement.

Longitudinal joints are typically cut after the transverse joints, often within the first day (concrete moves less in width than in length). Now the concrete has more strength, and a deeper cut is required to create a plane of weakness. Therefore, first-generation early-entry saws are not normally used for longitudinal joints. Newer early-entry saws can cut longitudinal joints to the required depth (one-third of slab).

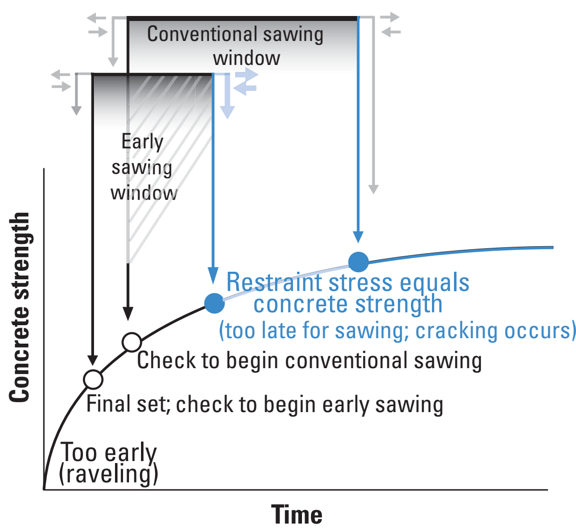


**Figure 3. The exact beginning and end of the sawing window is unique for every concrete pavement system.**

National Concrete Pavement Technology Center


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This technical summary is based on chapter 5 of the IMCP Manual (Taylor, P.C., et al. 2006. *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual*, Ames, Iowa, Iowa State University [FHWA HIF-07-004] [www.cptechcenter.org/publications/imcp/]) and was sponsored by the Federal Highway Administration. (References for any citations in this summary are at the end of the chapter.)




**CP Tech Center Mission**

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.




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A summary of chapter 5 (pages 148–170) of the *IMCP Manual* (reference information on page 4)

# Early-Age Cracking

This document is one of a set of technical summaries of chapters 1 through 10 of the *Integrated Materials and Construction Practices for Concrete Pavements: A State-of-the-Practice Manual* (IMCP manual). The summaries provide an overview of the manual and introduce its important concepts. To be useful for training, the summaries should be used in conjunction with the manual.

This summary covers properties related to potential early-age cracking and briefly describes how concrete mixtures can be optimized to prevent or reduce random early cracks.

## What is Early-Age Cracking?

For purposes of this summary, early-age cracks in concrete pavement are those cracks that, in general, occur during the first few days of pavement life, often before the pavement is open to public traffic.

## Why is it Important?

Most early-age cracks occur when tensile stresses in the concrete exceed its tensile strength. The number and location of these cracks are often controlled by sawing joints in the young concrete at specific locations according to the pavement design. Each joint causes a weakened plane in the concrete slab where cracks form. However, uncontrolled random early-age cracks occasionally occur. It is important to minimize random cracks because they can

- Reduce ride quality.
- Occur at locations without dowel bars or tie bars needed for load transfer and for holding slabs together, respectively.
- Result in surface popouts at the crack face.

These problems may result in long-term durability issues like faulting and crack widening and/or deterioration, as well as increased maintenance requirements (routing and sealing the cracks, etc.) So, it is important to minimize random early-age cracking. This can be accomplished by

- Accounting for potential problems when designing and adjusting the concrete mix and working with mix materials (table 1).
- Using sound pavement design and construction practices like designing effective joint layouts, preparing a uniform subgrade, using good curing methods, protecting concrete from extreme temperature changes during the first days after placement, and limiting loads from construction equipment (table 2).
- Using models, such as FHWA's HIPERPAV (www.hiperpav.com), to analyze risk for early-age cracking in a specific concrete pavement design and mix in a given environment.

## Factors Related to Early-Age Cracking

In general, early-age cracking occurs when stresses develop in the concrete more quickly than strength develops and, as a result, tensile stresses exceed tensile strength. The five primary mechanisms that contribute to early-age cracking are discussed in the following sections.

### Strength and Stiffness

Many factors related to early-age cracking involve concrete's strength and stiffness. The ability of concrete to resist stresses introduced by volume change, loads, etc., depends on the mixture's strength and stiffness:

- Strength—The greater the concrete strength, the greater the stress the concrete will be able to carry.
- Stiffness—The stiffer the concrete (as indicated by the modulus of elasticity), the greater the stresses that result from any volume changes.
- Stiffness increases faster than strength for the first few hours after initial set. The risk of early-age cracking is higher if the concrete experiences rapid and extreme volume changes.

### Restrained Volume Changes

Concrete exhibits volume changes (expansion or contraction)

**Table 1. Mix Design Solutions to Control Early-Age Cracking Caused by Restrained Volume Change or Curling and Warping**

| Method of Control or Prevention | Why This Works |
|---|---|
| Avoid using high early strength cements (Type III cements) unless for special conditions. | High early strength cements increase shrinkage potential by generating heat at a faster rate. |
| Use aggregate with low coefficient of thermal expansion (CTE). | Minimizes aggregate expansion to help control volume change. |
| When possible, avoid high paste content. | High paste and, thus, high water content increases shrinkage potential. |
| Consider using a water-reducing admixture. | Reduces paste content and helps reduce shrinkage. |
| In hot weather, consider using a set-retarding admixture. | Reduces heat generated, thus reducing thermal contraction. |
| Incorporate fly ash or ground, granulated blast furnace (GGBF) slag. | Reduces thermal shrinkage. In comparison to portland, these materials lower the amount of heat generated while extending the hydration process. |
| During hot weather, consider using pre-cooled materials in the batch (e.g., shade and dampen aggregates, use chilled water or ice in the mix). | Lowers the temperature of the mix and, thus, minimizes the amount of cooling and shrinkage after final set. |
| Use saturated, surface dry aggregates. | Dry aggregates absorb moisture meant for cement hydration out of the mix. Wet aggregates add water to the mix, which can increase the water/cement ratio and reduce durability. |
| Use well-graded aggregates. | Requires less paste and thereby less water, which leads to a lesser potential for shrinkage. |

**Table 2. Construction Solutions to Control Early-Age Cracking**

| Mechanism | Method of Control or Prevention | Why This Works |
|---|---|---|
| Restrained volume change | Dampen the pavement subgrade. | Dry subgrade pulls moisture out of the pavement. |
| Restrained volume change | Do not spray water on the slab to facilitate finishing. Do not finish the surface while bleed water is present. | Such actions lead to weakening of the pavement surface and can lead to scaling. |
| Restrained volume change | When weather conditions may cause rapid drying, try to avoid paving during hours when final set would occur at the hottest time of the day. | Such weather conditions can increase potential for plastic or drying shrinkage cracks. |
| Restrained volume change | During extremely hot weather, consider paving in the late afternoon, early evening, or at night. | Minimizes the amount of thermal shrinkage after final set. |
| Restrained volume change; Curling and/or warping | Avoid significant concrete temperature changes as concrete is placed and cured (e.g., protect the surface if exposed to cold fronts within the first two nights). | Such weather conditions can increase differential concrete temperature and volume changes throughout the slab depth, thus resulting in a buildup of stresses from the top to bottom of the slab, causing cracking. |
| Restrained volume change | Cure properly and promptly. (Immediately after finishing, cover surface thoroughly with white-pigmented curing compound.) | Protects surface from high evaporation rates that can lead to shrinkage cracks and loss of water for hydration. |
| Restrained volume change; Loads | Construct joints properly with regard to type, timing, spacing, and depth. | Directs cracks to joint locations and prevents random cracking. |
| Uniformity of subgrade/ base support | Ensure a uniformly stable subgrade and base. | Prevents the stress buildup that results from different support conditions. |
| Loads | Keep construction traffic away from the pavement slab edges when opening strength has not been obtained. | Allows concrete to develop the strength and stiffness necessary to support and distribute loads. |
| Restrained volume change | Do not tie too many lanes together with tiebars. Do not tie lanes together when the weather is excessively hot or cold. | The new (weaker) pavement does not move the same as the existing (stronger) pavement, particularly under high temperature changes. |
| Other | Do not overwork or over-finish. | Leads to bleeding and map cracking. |



in response to temperature and moisture variations as well as other factors. Total shrinkage is the sum of several individual shrinkage mechanisms, including the following:

- Autogeneous shrinkage—Chemical shrinkage due to the fact that the hydration products of cement occupy less space than the original materials.
- Settlement—Shrinkage due to settlement of the solid particles and the upward movement of water.
- Plastic shrinkage—Moisture loss before setting (loss of moisture from the surface of fresh concrete).
- Drying shrinkage—Moisture loss after setting (loss of mixing water through hydration/evaporation).
- Thermal contraction—Temperature drop after the concrete has set (significant ambient temperature change can cause differential volume changes throughout the depth of the concrete slab as the hydration is slowing down).

In concrete pavement, volume changes can be restrained internally or externally:

- Internal restraint arises when, for example, the outer concrete shrinks and the core does not.
- External restraint is due to friction between the subgrade or base and the bottom of the slab, the pavement adjacent to a structure, or abrupt changes in the slab's cross section.

Restraint results in the development of tensile stresses in the concrete (figure 1). When the stress from restrained shrinkage exceeds the concrete's tensile strength at any point in the slab, a crack will form. This is commonly refered to as shrinkage cracking.

Restrained thermal contraction and drying shrinkage are the most frequent causes of early-age cracks. Thermal-related cracks are normally observed in the first day, while drying-related cracks may appear over a longer period.

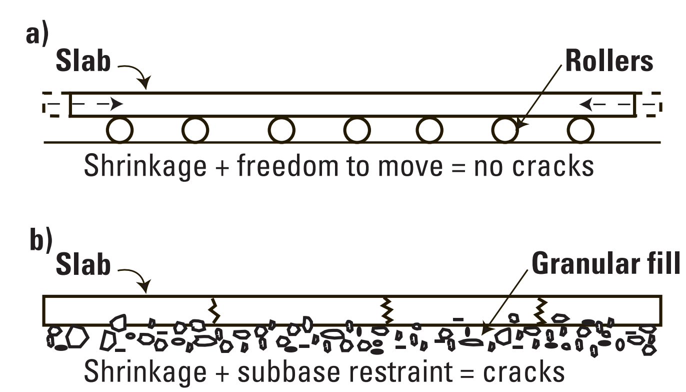


**Figure 1. (a) Cracks generally do not develop in concrete that is free to shrink. (b) In reality, slabs are restrained by the subbase, creating tensile stresses and cracks.**

## Curling and Warping

Expansion and contraction of concrete can also lead to curling or warping of the slab. Curling is caused by differences in temperature between the top and bottom of the slab. Warping is caused by differences in moisture between the top and bottom of the slab.

Both curling and warping mechanisms cause a slab's edges to turn up or down, depending on the relative temperature and moisture content of the top and bottom of the slab. Curling and warping actions may compound or counteract each other. Both curling and warping actions can affect structural and functional performance of the pavement. When slab edges curl up, the pavement corners can become cantilevered and unsupported. Repeated traffic loadings at the corners (compounded by the slab weight) create vertical deflection and the potential for fatigue cracking (figure 2).

## Non-Uniform Subgrade Support

If the concrete slab is not supported on a uniform and stable subgrade or base, the consequent bending (tensile) stresses can lead to cracking. The loss of support may be due to a lack of stability and uniformity or subsequent erosion of the support materials.

## Early Loads

Concrete pavements can distribute traffic wheel loads over a large area. Proper load transfer at the joints helps distribute loads between slabs, reducing the potential for faulting under repeated heavy axle loads. At the edges and corners of a slab, there is less area to distribute the load, so stresses are higher. The edges and corners of a slab are particularly sensitive to loading and, thus, susceptible to cracking—especially before the concrete has gained sufficient strength.

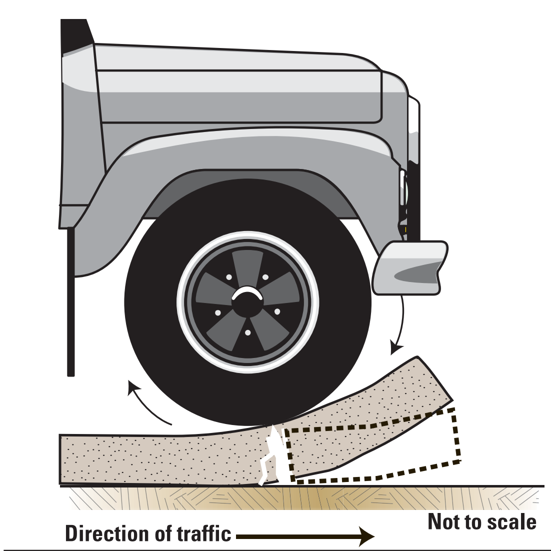


**Figure 2. Curling causes the edge of the slab at a joint or free end to lift off the base, creating a cantilevered section of concrete that can break off under heavy wheel loading.**