National Concrete Pavement Technology Center

Guide to the Prevention and Restoration of Early Joint Deterioration in Concrete Pavements

tech transfer summary

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Guide to the Prevention and Restoration of Early Joint Deterioration in Concrete Pavements

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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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This guide helps Iowa's road agencies understand the mechanisms behind premature joint deterioration in concrete pavements and the strategies to prevent or reduce such deterioration and thus improve concrete service life.

Background

For more than a century, portland cement concrete pavements have served the traveling public well. During this time, joint design has undergone many changes in regard to spacing, width, depth, and formation, and materials engineers have gained knowledge about the concrete mixture itself related to improving joint performance. In recent years, however, premature concrete pavement joint distresses have occurred, primarily affecting the mortar in the joints, as shown in Figure 1. This premature deterioration has been observed not only in Iowa but in other snowbelt states as well.

Figure 1. Premature joint distress (photo courtesy of Jim Grove, FHWA)

Several states, including Iowa, have been conducting research into this phenomenon and have found two primary mechanisms behind the premature deterioration:

1. Freeze-thaw damage is occurring in joints when a critical degree of saturation is reached or exceeded. Salts can exacerbate the problem by keeping joints in a high state of saturation.

2. Certain deicing/anti-icing salts—calcium chloride and magnesium chloride—react with cement paste to form calcium oxychloride, an expansive compound that is detrimental to concrete pavement performance.

Goals

The primary goal of the guide is to summarize recent research findings in order to help Iowa's concrete pavement engineers understand the causes of premature joint deterioration and the strategies that can help prevent or limit such deterioration. Secondary goals are to summarize best practices for joint maintenance, repair, and restoration. Note that, although the focus of the guide is on joints, the information is relevant for designing, constructing, and maintaining durable concrete pavements in general.

Chapter 1 provides a brief history of concrete pavement joint performance in Iowa. Chapter 2 discusses the mechanisms of premature joint deterioration, citing several salient research efforts. Chapters 3 through 5 focus on designing, constructing, maintaining, and repairing durable joints. Chapter 6 offers guidelines for developing project specifications, with appropriate links to Iowa Department of Transportation Standard Road Plans, Standard Specifications, and Instructional Memoranda. The remaining sections of this tech brief summarize the causes and solutions related to early joint distress.

Culprits in Premature Joint Deterioration

As previously mentioned two primary mechanisms have been identified as contributors to premature joint distress and deterioration: freeze-thaw damage related to saturated concrete, and formation of expansive calcium oxychloride due to cement reactions with certain deicing chemicals.

Saturated freeze-thaw damage

As soon as a concrete pavement exceeds a critical degree of saturation (DOS) (in general, 85 percent, although it can vary from 78 to 91 percent), damage initiates in the concrete. For degrees of saturation below the critical DOS, freeze-thaw damage is generally not observed, even after a large number of freeze-thaw cycles.

Sorption-based models have been proposed (Fagerlund 1977; Bentz et al. 2001; Yang et al. 2006; Todak et al. 2015) to predict the time required for a concrete sample to reach critical DOS after being continuously exposed to water. The sorption model is illustrated in Figure 2.

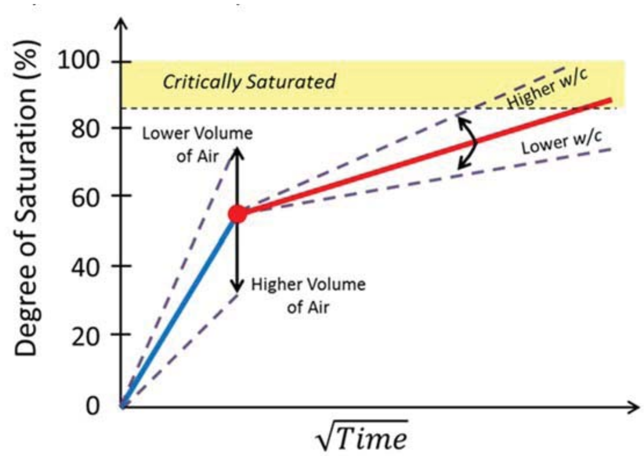

Figure 2. A conceptual illustration of the sorption-based freeze-thaw model

The model reflects the relationship between the DOS in a sample and the critical DOS (shown as the yellow region above the dashed line at about 85 percent DOS) that would result in freeze-thaw damage.

Initial absorption occurs very quickly, during the first 12 to 24 hours for 50 millimeter samples, and is represented by the blue line. This initial absorption includes the filling of the gel and smaller capillary pores. The secondary absorption occurs over a longer time and is represented by the red line. During secondary absorption, the entrained and entrapped pores fill. If the entrained and entrapped voids fill to a point where the concrete exceeds the critical DOS, the concrete will begin to show damage after freeze-thaw cycles.

Although more research is needed, the model indicates that, as the water-to-cementitious-materials (c/m) ratio increases and the air content decreases in the concrete mixture, the concrete is closer to critical saturation after only a short time of exposure to water.

Calcium oxychloride formation-related damage

Deicing and anti-icing salts and salt brines applied to concrete pavements can react with the concrete's cement matrices, resulting in secondary deposits in the concrete that can diminish durability.

A reaction between the deicing salt calcium chloride and a preliminary product of cement hydration, calcium hydroxide, produces calcium oxychloride. Calcium oxychloride is expansive and can damage the cement matrix. Greater amounts of calcium oxychloride form at higher concentrations (Farnam et al. 2014; Farnam et al. 2015a) and at temperatures greater than freezing.

Magnesium chloride deicing salt can also produce oxychlorides. Cement matrices exposed to magnesium chloride show the formation of both magnesium oxychloride and calcium oxychloride, although the temperature for magnesium oxychloride formation is approximately 15° C greater than for calcium oxychloride formation (Farnam et al. 2015b).

Damage associated with salt-matrix reactions generally consists of the loss of concrete "flakes" at the joint, where the salts tend to concentrate. This damage tends to dislodge aggregate, because calcium oxychloride preferentially occurs around the aggregate.

Note that the deicing salt sodium chloride is not as reactive with the cement matrix in concrete (Suraneni et al. 2016), although it is corrosive to steel. Calcium magnesium acetate solutions may be the most deleterious deicing brine with respect to chemical attack of concrete (Darwin et al. 2007).

Solutions to Prevent or Mitigate Premature Joint Damage

Best practices for preventing premature joint damage include designing a durable concrete mixture, using deicing/anti-icing chemicals judiciously, and following general good practice for concrete pavement design, construction, and maintenance.

Design a durable concrete mixture

Emphasize the following mix parameters:

- **Low w/c ratio**. A low w/c ratio will help ensure a durable, low permeability cement paste, which will reduce the rate of water absorption and the concrete's susceptibility to freeze-thaw damage. (Consider a w/c ratio of 0.40.)
- **An adequate entrained air system**. A good air system can reduce concrete's initial DOS and thus enhance freeze-thaw durability. (Consider an air content between 5 and 8 percent, with 5 percent minimum in place.)
- **Supplementary cementitious materials (SCMs), especially Class F fly ash**. Class F fly ash and other SCMs tend to consume calcium hydroxide, potentially reducing the opportunity for formation of calcium oxychloride. The use of SCMs also helps ensure durable, freeze-thaw resistant concrete. (Consider a cement replacement rate of 20–25 percent Class F fly ash or 30–35 percent Class C fly ash or a combination of 20 percent slag and 20 percent Class C fly ash.)
- **Well-graded aggregates**. When aggregate gradation is optimized, the intermediate aggregates fill voids between the large aggregate particles, reducing the required cement paste content. Lower cement paste content helps control shrinkage and reduces the amount of paste available to undergo chemical and physical distress mechanisms.

Use deicing/anti-icing chemicals appropriately

- **Select deicing/anti-icing salts carefully**, based on the environmental conditions at the time. Avoid or reduce the use of the more reactive calcium chloride and magnesium chloride, limiting their use to much lower temperatures when they are more effective. Whenever possible, use sodium chloride, which is less reactive with the cement paste in concrete. See Table 1 and Figure 3 in the sidebar on page 4. (Note: The use of calcium magnesium acetate is not recommended in Iowa for deicing/anti-icing purposes.)
- **Consider waiting 30 days** before exposing newly placed concrete to deicing/anti-icing chemicals.

Follow other best practices

Finally, follow general best practices in concrete pavement design, construction, and maintenance practices, such as the following:

- **Drainage**. To help keep joints dry, design and maintain a drainable pavement system that allows water to leave the joints, with stable support layers and either drains or an extended drainable layer.
- **Curing**. Good curing practices promote cement hydration by maintaining the necessary moisture and temperature of the concrete immediately after placement and finishing.
- **Joint sawing**. The question remains whether or not joint sawing, even when done properly, causes weakening of the concrete that may lead to joint deterioration. Clearly, however, improper sawing or sawing at the wrong time can result in bruised or raveled concrete or micro-cracks emanating from the joint.
- **Joint maintenance**. Inspect joints every three years to ensure that joint sealant (if used) is performing properly and joints are free of incompressible materials.

Choosing salt based on environmental conditions

Table 1 shows the freezing point for common deicing salts. The least damaging salt, sodium chloride, has a freezing point of -6 degrees F. Figure 3 shows that the concentrations for the three salts used in Iowa—sodium chloride, magnesium chloride, and calcium chloride—are basically the same for temperatures in the 20-degree F range.

Table 1. Salt Brine Freezing Points

Salt	Concentration (wt%)	Freezing Point (F)
Sodium Chloride	23.30	-6.16°
Magnesium Chloride	21.00	-24.50°
Calcium Chloride	30.22	-57.60°
Calcium Magnesium Acetate	32.50	-17.50°

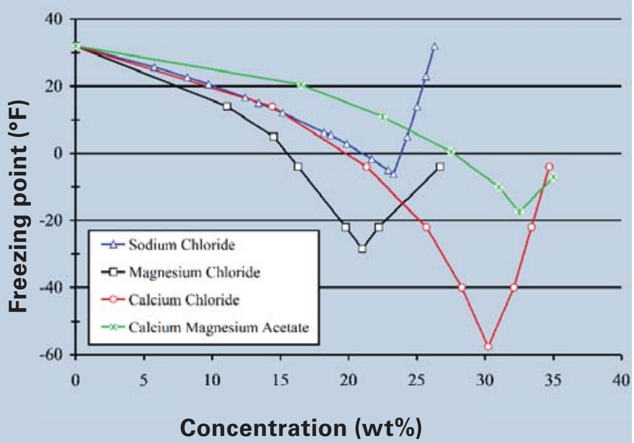

Figure 3. Partial phase diagrams for brines with common deicing/anti-icing salts. The freezing points of the solutions are plotted as a function of the salt concentraion in weight percent. For all salts a minimum freezing point is shown (Sutter 2008)

Implementation Benefits and Readiness

The guide is implementation ready. Iowa's state and local highway agencies can use the information in the guide to develop an understanding of the causes of premature joint deterioration in concrete pavements and implement preventive solutions in their next concrete paving projects.

As a result, agencies should experience reduced need for concrete pavement joint repair and related costs, and the traveling public should experience fewer joint repair related disruptions.

Using surface sealers

One of the first lines of defense against premature joint deterioration is to design concrete pavement mixtures with the desired performance in mind. However, many factors (e.g., material availability, cost) affect pavement design and, therefore, a second line of defense may be the application of surface sealers on the joints of new pavements to prevent or reduce the ingress of moisture and salts into the concrete. In addition, if joints in existing concrete pavements are displaying early signs of distress, such as shadowing or light spalling, consider applying surface sealers to the joint faces.

It is important to thoroughly coat the vertical surfaces or faces of the joint with the sealer. Surface sealers must be re-applied periodically.

Note that surface sealers will not remediate concrete that has already failed and can provide only marginal protection for concrete that is not properly designed and constructed with quality materials or that is not properly placed and cured.

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