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Conclusions from the Investigation of Deterioration of Joints in Concrete Pavements

Peter Taylor
Iowa State University, ptaylor@iastate.edu

Jiake Zhang

Xin Wang

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Abstract

Premature deterioration of concrete at the joints in concrete pavements and parking lots has been reported across the northern states. The distress may first appear as shadowing when microcracking near the joints traps water, or as cracks parallel to and about 1 inch from the saw cut. The distress later exhibits as a significant loss of material. Not all roadways are distressed, but the problem is common enough to warrant attention. The aim of the work being conducted under this and parallel contracts was to improve understanding of the mechanisms behind premature joint deterioration and, based on this understanding, develop training materials and guidance documents to help practitioners reduce the risk of further distress and provide guidelines for repair techniques. While work is still needed to understand all of the details of the mechanisms behind premature deterioration and the prevention of further distress, the work in this report has contributed to advancing the state of the knowledge.

Keywords

Pavement joints, Concrete pavement, Deicing salts, Portland cement concrete

Disciplines

Civil Engineering

Comments

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tech transfer summary

Understanding the mechanisms of premature joint deterioration in concrete pavements and parking lots can help mitigate this distress and improve concrete service life.

Problem Statement

Premature deterioration of the joints in concrete pavements and parking lots has been reported in a number of locations in cold-weather regions. The distress first appears as cracking and spalling at the joints and later exhibits as a significant loss of material, eventually reducing the concrete's service life. While not all roads are affected, the problem is common enough to cause some local agencies to reconsider using concrete in their pavements.

Background

No single mechanism can account for all occurrences of joint deterioration. Factors that contribute to distress include chemical reactions, inadequate air voids, poor mix design, inadequate drainage, or poor construction practices.

This research is part of a larger program encompassing parallel work funded by the Federal Highway Administration (FHWA) and other research conducted at Purdue University and Michigan Technological University.

Objective

The objective of this research was to investigate the mechanisms related to concrete joint deterioration in the laboratory.

Research Description

Five laboratory tests were conducted to further investigate the mechanisms of joint deterioration.

Monitoring temperature and humidity change within a concrete slab

This test examined the influence of the environment on concrete internal temperature and relative humidity. An instrumented concrete slab, 20 × 20 × 8 inches, was built using a typical concrete pavement mixture containing 20 percent fly ash.

The slab was cast in early October, moist-cured for two weeks, placed in a freezer for one month, and then placed into the ground. Sodium chloride was applied to the top of the slab during snow events. Temperature data were recorded.

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PRINCIPAL INVESTIGATOR
Peter Taylor, Director
National Concrete Pavement Technology Center
Iowa State University
515-294-9333
ptaylor@iastate.edu

MORE INFORMATION
www.cptechcenter.org

National CP Tech Center
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-3230

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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Instrumented slab buried in the ground during a snow event, showing sodium chloride applied

Mechanisms of damage in the interfacial transition zone

This test investigated the damage mechanisms occurring within the joint's interfacial transition zone. A single concrete batch was mixed in accordance with ASTM C192 and cast into 4 × 3 × 16 inch beams.

The beams were cured in a fog room for 28 days and then cut into 1/2 inch thick slices. The slices were partially immersed in either water, 3 percent sodium chloride (NaCl), or 3 percent magnesium chloride ($MgCl_2$) at a constant 40°F for 56 days. After 56 days, the slices were cut into two halves to examine the effects of the solutions through the thickness of the samples.

Selected samples were examined using a scanning electron microscope.

Influence of pore sizes on paste freezing and thawing durability

This test examined the parallels between paste porosity and nondurable coarse aggregates using cement pastes with different water-cement (w/cm) ratios, supplementary cementitious materials (SCMs), and drying treatments.

Samples partially immersed in testing solution

Oven-dried paste samples with different w/cm ratios after one freeze-thaw cycle

Paste samples were cured in sealed containers for 24 hours after mixing while being continually rotated. Samples were kept in sealed bottles for 7 days at 75°F before a cyclic freeze-thaw test. The lids were then removed, and the oven-dried samples were kept in an oven at 122°F until constant mass was achieved.

Samples were then sent for mercury intrusion porosimetry testing. Paste samples prepared from the same mixtures were also subjected to freeze-thaw cycles following the same preparation and curing procedures. The dried samples were placed in a freezer at 0°F (18°C) for 12 hours and thawed to 70°F (21°C).

Effect of subsurface permeability

This test examined the relationship between pavement performance and the permeability of subsurface layers. Field tests were conducted on a city street in Ames, Iowa, which had been paved in 1997 in one day using a full-width slipform paver. Joint sealing details and the extent of the pavement's distress were mapped.

Joint distress on a city street in Ames, Iowa

Five cores were extracted over two years, with cores from a sound joint and a distressed joint sent for petrographic examination. Field borehole permeameter tests were also conducted. The influence of freezing on the moist base material's permeability was then evaluated in the laboratory.

A base material with a gradation similar to that of the base material from below the mid-panel was tested. Samples were prepared with different moisture contents and were then compacted, frozen, and subjected to a falling head permeability test.

Effect of sawing

This test assessed whether sawing practice influences joint damage. A 12 × 18 × 4 inch slab was cast outdoors using a standard paving mixture. A handheld saw fitted with a diamond blade was use to dry-cut joints in the slab starting too early, causing extreme raveling. The operator was asked to push hard on the blade and to induce a curve to mimic poor practice.

After the slab hardened and gained strength, a full-depth section was cut perpendicular to the hand-sawn joints to observe the concrete condition at the bottom of the cuts.

Saw cutting a test slab using poor practices

Key Findings

Monitoring temperature and humidity change within a concrete slab

- The temperature at the bottom of the slab did not fluctuate as markedly as the top surface. During one of the greatest temperature swings, the difference between the top and bottom of the slab never exceeded about 8°F.
- The edge of the slab showed higher temperature differentials, likely because the soil at the edge of the slab was not thoroughly compacted and thus acted as a better conductor of heat than the concrete. This is also likely true of the interior of a sawn joint.

Mechanisms of damage in the interfacial transition zone

- Exposure to water and NaCl above freezing temperatures results in negligible distress.
- The failure mechanism in $MgCl_2$ does not appear to be related to freezing/thawing of water, salt crystallization, or dissolution of the interfacial transition zone.
- The paste appears to expand in the presence of $MgCl_2$ and thus becomes debonded from the coarse aggregate particles that are not expanding. The mechanism of expansion is likely the formation of calcium oxychloride ($Ca(ClO)_2$) in the paste.

Influence of pore sizes on paste freezing and thawing durability

- Increasing the w/cm ratio increases the total porosity and pore sizes of the hardened cement paste. Notably, the peak pore sizes in the lower w/cm ratio mixtures were within the range considered to be problematic based on the mixtures' abilities to allow water to evaporate.
- The high w/cm mixture had similar peaks in the fine zone but had a far larger peak on the coarse side, likely meaning that water is able to enter and leave the system readily, which allows the system to dry out enough to avoid freezing-related distress. This does not justify choosing mixtures with high w/cm ratios but does mean that systems with a w/cm ratio of about 0.4 have to be protected by other means.

Effect of subsurface permeability

- The results of the field borehole permeameter tests indicate that a low-permeability subsurface layer may correlate with joint deterioration under freezing conditions.
- The laboratory falling head permeability tests show that permeability decreases as moisture content increases and that freezing of the moist base material significantly reduces permeability.

Effect of sawing

- Under an optical microscope, the only evidence of joint-related damage due to sawing was a small piece of aggregate cracked at the tip of one of the cuts.

Conclusions and Recommendations

The following conclusions and recommendations are based on of the work performed for this project as well as the related projects conducted under this research program.

Two primary mechanisms appear to be driving distress:

1. Freeze-thaw damage incurred in saturated concrete, typically appearing as thin flakes. Saturation may be due to the following:
   - Presence of deliquescent deicing salts
   - Uncracked slabs or tight cracks under saw cuts, preventing drying of the saw-cuts
   - Poor drainage structures under the slab
   - Water ponding in low-lying elements
   - High water tables
   - A paste microstructure with insufficient air voids to slow saturation
   - A pore system that slows or prevents drying

2. Paste deterioration due to chemical attack. Distress may appear as cracking at regular intervals parallel to the saw cut and/or as a loss of paste, leaving clean aggregates in the voids. Paste deterioration may be due to the following:
   - Formation of expansive calcium oxychloride in the presence of calcium and magnesium chloride at certain temperatures
   - Ettringite deposition that accelerates saturation of air voids
   - Formation of expansive Friedel's salt

The following can reduce the risk of joint distress in concrete:

- Using a low w/cm ratio, ~ 0.40 to 0.42
- Using supplementary cementitious materials appropriately
- Ensuring an adequate air-void system behind the paver
- Selecting cementitious systems with high silicon/calcium (Si/Ca) ratios that are more resistant to oxychloride formation
- Paying attention to drainage at all locations
- Applying penetrating sealants that will slow water and salt penetration into the microstructure
- Using aggressive salts only in times and at temperatures necessary for safety

Implementation Readiness and Benefits

Understanding the mechanisms of premature joint deterioration in concrete can help mitigate this distress and improve service life.

A number of training sessions partially or fully funded by this project were conducted in several states across the US in 2013 and 2014. Workshops were targeted at municipal jurisdictions and included topics such as the mechanisms of joint deterioration, quality assurance and testing, and partial-depth repairs. Several guidance and research documents were distributed to participants.

Several academic and research publications were also produced as a result of the work conducted under this project.