Impact of Curling and Warping on Concrete Pavement: Phase II

tech transfer summary

Evaluating the effects of various environmental conditions and design parameters on curling and warping can help improve the performance of Iowa concrete pavements.

Background

Jointed plain concrete pavement (JPCP) can exhibit curling and warping behavior due to temperature and moisture variations, which increases surface roughness and cracking and decreases service life.

Downward curling or warping occurs when the top of the slab has a higher temperature or moisture content than the bottom, while upward curling or warping occurs when the bottom of the slab has a higher temperature or moisture content than the top.

Both environmental factors and the design parameters of concrete slabs play crucial roles in the curling and warping behavior that slabs exhibit over their service lives.

Problem Statement

Iowa has built numerous concrete pavements over the last several decades. However, some of these concrete pavements have experienced curling and warping, which can impact pavement performance and ride quality and lead to increased maintenance costs.

Based on a literature review and the results of a Phase I study, many environmental and structural factors were found to significantly impact the degree of curling and warping in concrete slabs. However, little research and few full-scale field evaluations have been undertaken in Iowa to assess ways to mitigate curling and warping through concrete pavement design.

Objective

This Phase II study aimed to determine the effects of various design considerations and environmental conditions on the degree of curling and warping in Iowa concrete pavements.

Research Description

Thirty-six concrete roadways across Iowa were selected in this study to collect profile data during different seasons and at different times of day. Sites included curled-up and curled-down slabs on Long-Term Pavement Performance (LTPP) Program highway sections, non-LTPP highway sections, and county roads and city streets.

A Class 1 high-speed profilometer developed by Surface Systems & Instruments (SSI) was utilized to gather profile data, and an advanced MATLAB algorithm was developed to compute the degree of curling and warping from the raw profile data. For each site, information was also gathered on variations in temperature and moisture gradients, slab geometry, mix design, shoulder design, and the season in which the pavement was constructed.

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RESEARCH PROJECT TITLE
Impact of Curling and Warping on Concrete Pavement, Phase II

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The Program for Sustainable Pavement Engineering and Research (PROSPER) is part of the Institute for Transportation (InTrans) at Iowa State University. The overall goal of PROSPER is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems.

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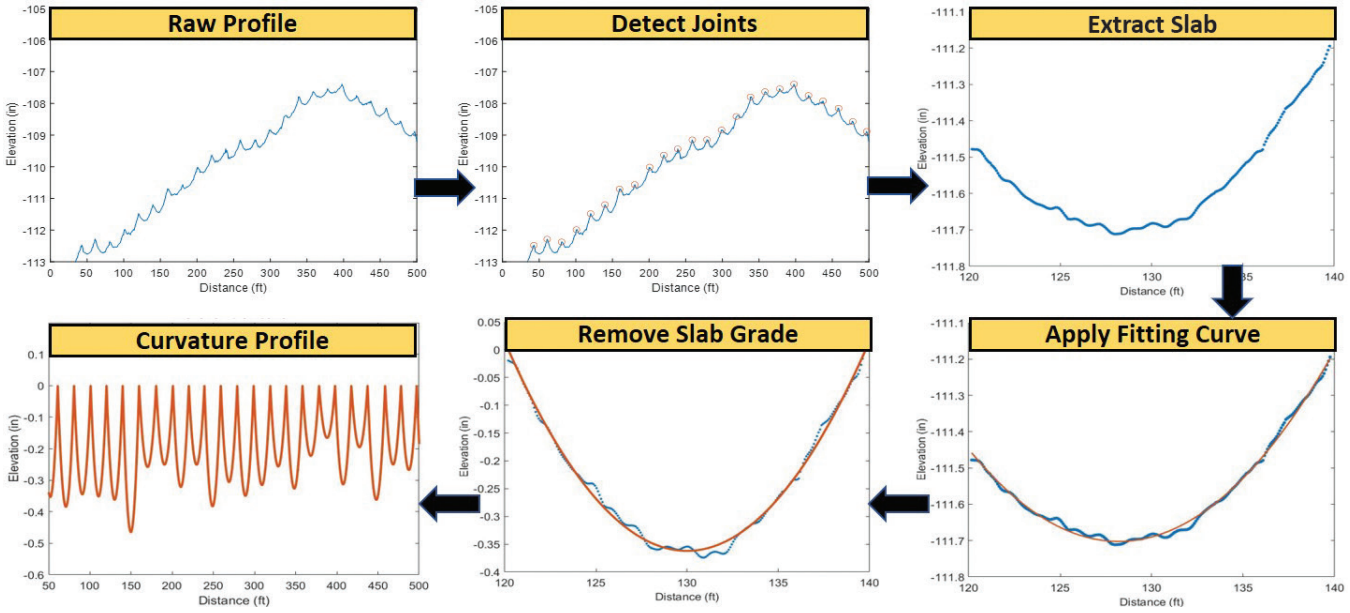


Steps involved in profile data processing

SSI high-speed profilometer

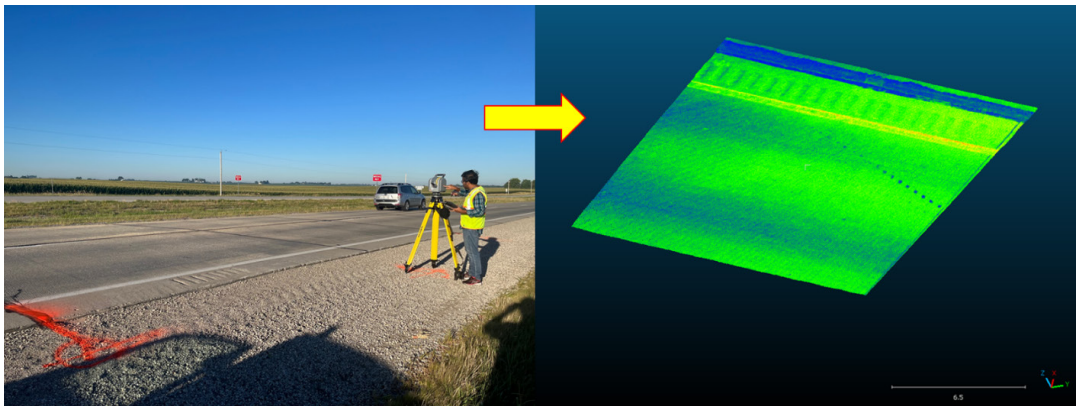
The degree of curling and warping in the profiled pavements was evaluated in terms of four indicators: curvature International Roughness Index (IRI), deflection, deflection ratio, and degree of curvature.

The temperature and moisture gradients of the pavement sections were extracted in AASHTOWare Pavement ME Design and then converted into equivalent temperature differences.

Seasonal and diurnal effects on curling and warping behavior were assessed for all curled-up sites. The effects of slab geometry, mix design, and construction season on curling and warping behavior were evaluated separately for LTPP highways, non-LTPP highways, and county roads and city streets.

A one-way analysis of variance (ANOVA) and multiple linear regression analyses were also performed to identify the significant factors that affect the curling and warping behavior of concrete slabs.

To compare the results from this Phase II study with those from the Phase I study, a stationary light detection and ranging (LiDAR) system was used to collect three-dimensional (3D) concrete slab profiles at three sites from the Phase I study and an additional site from the Phase II study.



Field LiDAR scanning (left) and resulting 3D slab profile (right)

Key Findings

- For curled-up sites near reliable climate stations, the degree of curling and warping decreased as the overall equivalent temperature difference increased from -10°F to 0°F.
- The concrete pavements in this study typically exhibited the highest curling and warping in the fall and the lowest curling and warping in the spring and summer.
- Compared to profile measurements taken at noon and in the late afternoon, measurements taken in the morning reflected higher average values for all four curing and warping indicators across all sites.
- LTPP highways constructed with larger diameter dowel bars exhibited less curling and warping behavior. However, these sections are typically associated with thicker slabs, which could also affect curling and warping behavior. Slabs with a 10 in. thickness had a higher degree of curvature than those with an 11 in. thickness.
- For non-LTTP highways, rectangular joints exhibited much lower average values for all four curling and warping indicators than skewed joints.
- For non-LTPP highways, projects constructed with tied PCC shoulders exhibited significantly less curling and warping across all four indicators than projects with untied (HMA and gravel) shoulders.
- For LTPP highways, projects constructed using a high-strength mix exhibited higher curling and warping behavior than projects constructed using a low-strength mix. For non-LTPP highways, projects constructed using the quality management concrete (QMC) mix exhibited lower curling and warping behavior across all four indicators than projects built using a pre-QMC mix.
- For non-LTPP highways, sites paved in the spring exhibited the lowest average values for all curling and warping indicators except degree of curvature. For county roads and city streets, projects constructed in the summer demonstrated a slightly higher average degree of curling and warping than those constructed in the fall.
- The statistical analyses indicated that slab thickness and mix type are significant parameters for LTPP highways and that slab thickness, joint type, and mix type are significant parameters for non-LTPP highways in terms of curling and warping behavior.
- The LiDAR data indicated that measurements taken in the morning typically exhibited a higher relative deflection than measurements taken in the afternoon. These results are consistent with the results obtained using a high-speed profiler.
- The design and construction parameters evaluated in this study showed more significant impacts on concrete curling and warping behavior than seasonal and diurnal environmental effects.

Key Recommendations

- Paving in the spring or fall can reduce permanent curling and warping in concrete due to the lower temperature gradients during these seasons.
- Increasing slab thickness, using rectangular joints, using tied shoulders, and using the QMC mix can mitigate curling and warping behavior.
- Research involving additional concrete pavements with comparable and well-documented design variables and construction information should be conducted to more comprehensively assess curling and warping conditions.

Implementation Readiness and Benefits

Understanding and addressing the design, construction, and environmental factors affecting curling and warping in Iowa concrete pavements can help decrease surface roughness and cracking, reduce maintenance costs, and lengthen service lives.

The advanced MATLAB-based algorithm developed in this study to calculate the degree of curling and warping using pavement profile data can help the Iowa Department of Transportation (DOT) and Iowa's cities and counties better understand the curling and warping conditions of Iowa concrete pavements.

The recommendations resulting from this research can help mitigate curling and warping. Additionally, the results regarding the seasons and times of day that exhibit the highest curling and warping can help the Iowa DOT and Iowa's cities and counties optimize diamond grinding plans for local concrete pavements.