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Impact of Curling and Warping on Concrete Pavement

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Impact of Curling and Warping on Concrete Pavement

Abstract

Portland cement concrete (PCC) pavement undergoes repeated environmental load-related deflection resulting from temperature and moisture variations across the pavement depth. This phenomenon, referred to as PCC pavement curling and warping, has been known and studied since the mid-1920s. Slab curvature can be further magnified under repeated traffic loads and may ultimately lead to fatigue failures, including top-down and bottom-up transverse, longitudinal, and corner cracking. It is therefore important to measure the "true" degree of curling and warping in PCC pavements, not only for quality control (QC) and quality assurance (QA) purposes, but also to achieve a better understanding of its relationship to long-term pavement performance. In order to better understand the curling and warping behavior of PCC pavements in Iowa and provide recommendations to mitigate curling and warping deflections, field investigations were performed at six existing sites during the late fall of 2015. These sites included PCC pavements with various ages, slab shapes, mix design aspects, and environmental conditions during construction. A stationary light detection and ranging (LiDAR) device was used to scan the slab surfaces. The degree of curling and warping along the longitudinal, transverse, and diagonal directions was calculated for the selected slabs based on the point clouds acquired using LiDAR. The results and findings are correlated to variations in pavement performance, mix design, pavement design, and construction details at each site. Recommendations regarding how to minimize curling and warping are provided based on a literature review and this field study. Some examples of using point cloud data to build three-dimensional (3D) models of the overall curvature of the slab shape are presented to show the feasibility of using this 3D analysis method for curling and warping analysis.

Keywords

Concrete pavement curling, concrete pavement warping, LiDAR, pavement performance, slab curvature

Disciplines

Civil Engineering

Comments

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National Concrete Pavement Technology Center

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tech transfer summary

The results of this study provide recommendations on how to minimize the degree of curling and warping in concrete pavement design and construction practices to extend the service life of Iowa concrete pavements.

Background

Temperature and moisture variations across the depth of portland cement concrete (PCC) pavements result in unique deflection behavior that has been characterized as pavement curling and warping since the mid-1920s. Repeated slab curvature changes due to curling and warping, combined with traffic loading, can accelerate fatigue failures, including top-down and bottom-up transverse, longitudinal, and corner cracking.

Numerous studies have reported premature transverse cracking resulting from slab curling and warping in concrete pavements, such as the recent series of cracks observed in a section of I-80 near Adair County, Iowa. This is not only a safety issue, but also costs transportation agencies time and money to implement repair solutions.

It is, therefore, of paramount importance to measure the actual magnitude of curling and warping taking place in concrete pavements to develop performance measures and critical threshold magnitudes and gain a better understanding of their relationship to diurnal and seasonal temperature/moisture changes and long-term pavement performance.

Problem Statement

To better understand curling and warping behavior of PCC pavements in Iowa, research efforts are needed to collect data from Iowa pavements and document the true degree of curling and warping.

LiDAR device utilized in this study

Objectives

- Conduct field investigations to survey the degree of curling and warping in Iowa PCC pavements
- Identify the impact of curling and warping on performance of Iowa PCC pavements
- Identify the effects of the concrete mixture, pavement design, construction details, and climate on curling and warping behavior
- Develop recommendations to mitigate the amount of curling and warping in concrete pavements

Research Description

This research was directed toward documenting PCC pavement surface profiles by utilizing the light detection and ranging (LiDAR) system and comparing the degree of curling and warping between the concrete pavement systems used on those pavements. Field investigations were performed at six concrete pavement sites in Iowa at different times of the day during the late fall of 2015.

These sites had PCC pavements with various ages, slab shapes, mix design aspects, and environmental conditions during construction. By using the Leica ScanStation C10 LiDAR device, the researchers obtained point clouds for these sites during field investigations.

The research team obtained three LiDAR scans at each site. They processed the point clouds for registration and segmentation first. Then, the researchers exported and processed each point cloud for the predetermined slabs in the MATLAB environment by fitting a quadratic equation to the scanned slab surface. They then calculated the degrees of curling and warping along the longitudinal, transverse, and diagonal directions of each concrete slab.

The researchers correlated the degree of curling and warping at each site to pavement performance, mix design, pavement design, and construction-related variations.

The researchers developed recommendations on how to minimize curling and warping based on literature review findings and field investigations. They also developed some examples of how to use LiDAR point cloud data to build three-dimensional (3D) models for the overall curvature of the slab shape to show the feasibility of using this 3D analysis method for studying the curling and warping behavior of concrete pavements.

Field investigation of concrete pavement systems on US 30 near Ames in Story County, Iowa

Key Findings

- Curling and warping can influence PCC pavement performance. The factors that can impact curling and warping behavior include slab temperature and moisture gradients, shrinkage, built-in curling, creep, slab geometry, concrete materials and mix characteristics, the type of underlying layers, and on-site weather conditions.

- Cracks were observed at the sites having both a high degree of curling and warping and high traffic volumes. This could be attributed to the combined effect of environmental and traffic loads, because the tensile stresses induced by a high degree of curling and warping can be magnified when combined with high traffic loads.

- A high degree of built-in curling may result in a higher degree of curling and warping over the service life of jointed plain concrete pavement (JPCP) and consequently may lead to poor pavement performance.

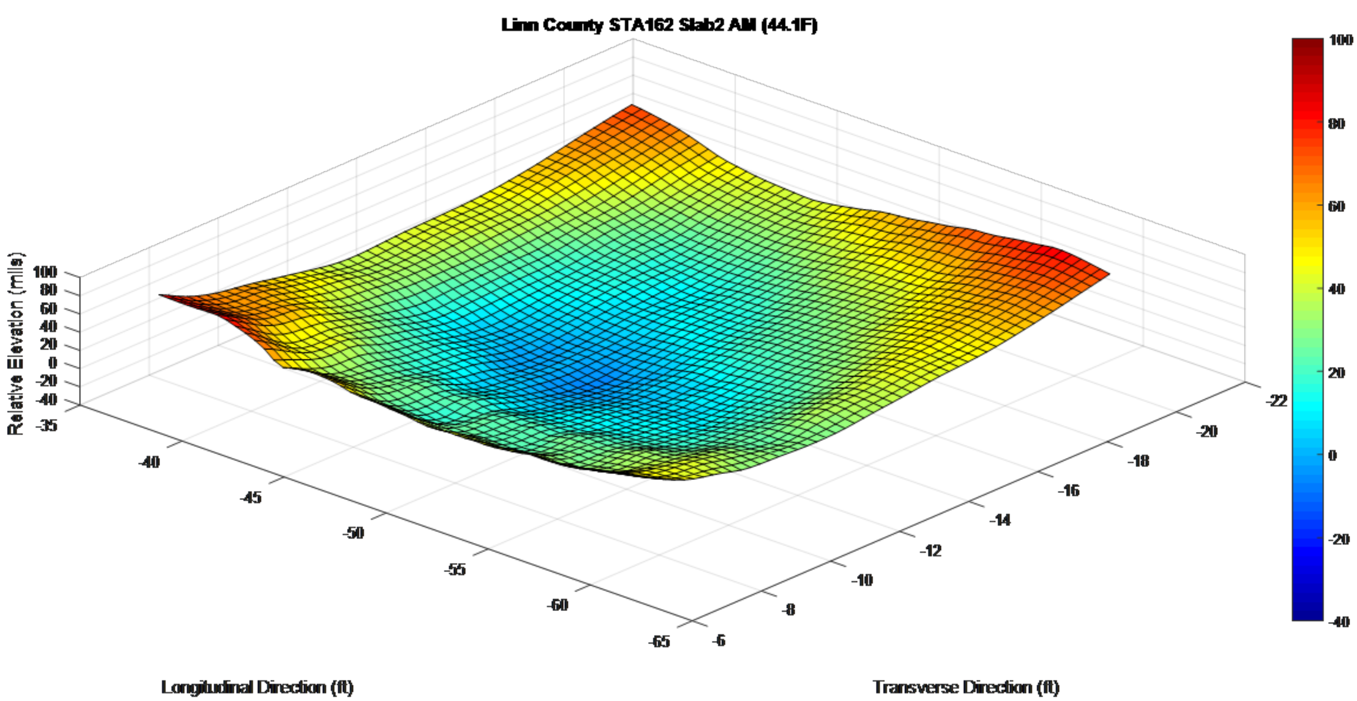
- Pavement design can have an influence on the degree of curling and warping. Thicker and shorter slabs result in a lesser degree of curling and warping. Concrete slabs with a typical joint spacing of 20 ft in Iowa suffer from relatively higher levels of curling and warping stresses compared to slabs with a 15 ft or shorter joint spacing in other parts of the country.

- Skewed joints effectively increase slab dimensions and consequently result in higher curling and warping stresses and deflections compared to rectangular joints.

- Material selection can have a significant influence on curling and warping. The use of coarse aggregates with a larger maximum aggregate size, higher specific gravity, lower coefficient of thermal expansion (CTE), and lower water absorption are desired. Fine aggregates with coarser particles and lower water absorption are also desired. Moreover, cement with lower C3A (a tricalcium aluminate) and alkali content can help reduce warping. Use of supplementary cementitious materials (SCMs) such as fly ash can help reduce curling and warping as well.

- Concrete mix design containing more coarse aggregates and less paste can result in less warping of PCC slabs. Additionally, a moderate water-to-cementitious materials (w/cm) ratio is desired, because a higher w/cm ratio can lead to higher drying shrinkage, while a lower w/cm ratio can lead to higher autogenous shrinkage.

- Construction of PCC pavements under high ambient temperatures, low ambient relative humidity (RH) levels, or high wind can result in greater curling and warping. Construction during the latter half of the day or during nighttime helps reduce the time that fresh concrete is exposed to strong solar radiation, which thereby reduces a degree of built-in curling and warping.



Computer-generated three-dimensional (3D) shape of an upwardly curled and warped PCC slab in the field under temperature and moisture gradients produced from processing LiDAR point cloud data

Implementation Readiness and Benefits

The results of this research are readily implementable by transportation agencies and contractors to minimize the degree of PCC curling and warping in design and construction to achieve well performing PCC pavements.

The research outcomes provide recommendations on how to minimize curling and warping in concrete pavement systems. However, the PCC pavements investigated in this study were mainly selected from Iowa highways, which have different pavement design features than the state's county and city roads (which, for example, have thinner PCC slabs).

Note that thicker and shorter PCC slabs can result in a relatively lower degree of curling and warping. In addition, the number of PCC pavements selected and the relevant data collected were not sufficient for validating the recommendations derived from the literature review findings.

For example, the curling and warping literature suggests that water absorption of coarse aggregate is one of the significant mix design variables affecting the degree/magnitude of warping, but little reported information exists on the water absorption properties of the coarse aggregate used in Iowa PCC pavements to validate this literature review finding.

Therefore, a more comprehensive follow-up study on the impact of curling and warping on Iowa concrete pavement is recommended.

Future Research Recommendations

- Further research is needed to validate the preliminary findings of this study by utilizing a larger number of concrete pavement systems from Iowa highways and county and city roads to determine which factors (through a sensitivity study) have the most influence on the curling and warping behavior of PCC pavements and how pavement design engineers and contractors can minimize the degree of curling and warping to extend the service life of Iowa PCC pavement systems.

- The current algorithm for 3D modeling described in this study is a semi-automated process. Further research and improvements are needed to make it fully automated to process the data more quickly.

- The researchers also recommend that other beneficial uses of LiDAR devices for pavement inspection, such as pavement roughness, cross slope, and crack detection, be investigated.

- Further research is needed to validate the preliminary findings of using LiDAR devices to document the built-in curling and warping measurements in concrete pavements.

- The researchers recommend that other platforms for LiDAR devices, such as airborne laser scanner (ALS) and mobile laser scanner (MLS), be investigated for pavement inspection purposes in the future.