Development and Evaluation of a Portable Device for Measuring Curling and Warping in Concrete Pavements

tech transfer summary

The device developed through this research could be adopted for standard curling and warping measurements in the field and help improve concrete pavement construction practices.

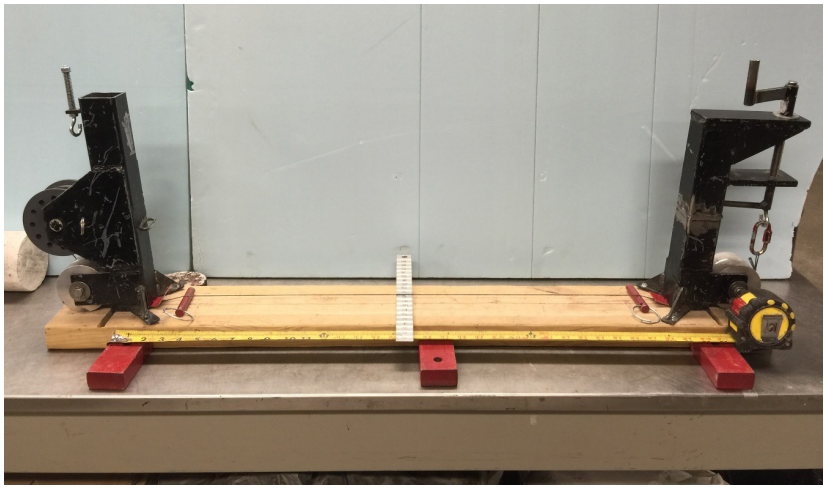
Background

Portland cement concrete (PCC) pavement undergoes repeated environmental load-related deflection resulting from temperature and moisture variations across the pavement depth. This has been recognized as resulting in PCC pavement curling and warping 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. Measuring the true degree of curling and warping in PCC pavements is therefore significant, not only for quality control (QC) and quality assurance (QA), but also for obtaining a better understanding of its relationship to long-term pavement performance.

Problem Statement

Several approaches and devices, including linear variable differential transducers (LVDT), digital indicators, and some profilers, have been proposed for measuring curling and warping. However, their application in the field has been limited by cost, inconvenience, and complexity of operation.



Final version (fourth generation) of the ISU curling and warping measurement device with all accessories

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MTC RESEARCH PROJECT TITLE
Development and Evaluation of a Portable Device for Measuring Curling and Warping in Concrete Pavements

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The Midwest Transportation Center (MTC) is a regional University Transportation Center (UTC). Iowa State University, through its Institute for Transportation (InTrans), is the MTC lead institution.

MTC's research focus area is State of Good Repair, a key program under the 2012 federal transportation bill, the Moving Ahead for Progress in the 21st Century Act (MAP-21). MTC research focuses on data-driven performance measures of transportation infrastructure, traffic safety, and project construction.

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Objective

The objective of this research was to develop a simple, portable, reliable, and economical device to be used primarily for measuring curling and warping in concrete pavements with an accuracy comparable to or better than that of existing methodologies.

Research and Device Description

Currently available technologies/devices with the potential to measure concrete slab curling were reviewed and evaluated and their limitations identified. From this review, design criteria were established for the development of a proposed device. The first-generation prototype of the newly designed Iowa State University (ISU) curling and warping measurement device was developed and fabricated based on the following design criteria:

- The device should be able to measure the true deflection profile of a pavement.
- The device should be small enough to be easily transported to the field.
- The device should weigh less than 25 lbs so an adult can easily carry and set it up.
- The device should be easy to operate without special training.
- The device should be quick to set up and perform measurements (10 minutes or less).
- The resolution should be greater than 1/4 in.
- The available measuring range should be at least 1/4 in. to 1 in.
- Results should be repeatable.
- No complex calibration and calculation should be required.
- The device should be economical.

The resulting device is a static pavement deflection profiling instrument that sets up a tightened string over a concrete slab surface and measures the mid-chord deflection of the pavement. Readings can be easily taken at random intervals along the string to develop an overall pavement deflection profile.

The total weight of the first-generation prototype was about 24 lbs. The two main columns were 21 in. high and can be placed in a small bucket to transport in the field.

Setup, including placing the tape to record the locations of the measured points, takes about 3 minutes. Measurement of one point requires about 2 seconds.

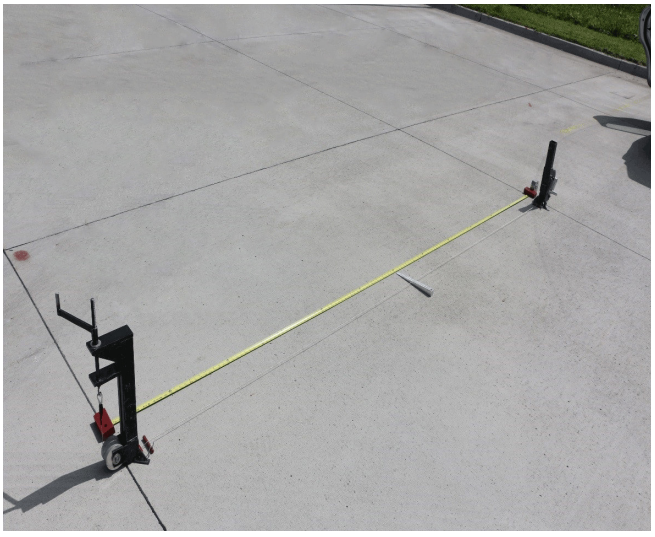
Because measuring the entire pavement deflection profile for curling and warping is unnecessary, 5 to 9 data points at critical locations should be sufficient; completely measuring a concrete slab takes less than 1 minute.

After laboratory testing and assessment, the researchers found that the first-generation prototype could be made lighter, smaller, and easier to use. The 30 in. long legs supporting the main columns were replaced with two 2 in. long feet, which were added laterally at the bottom of the column to maintain balance on uneven pavement surfaces.

A field test was conducted on October 24, 2014, to assess the performance of the second-generation device in situ and seek further improvements. After the initial test, two clips and two small pins were added to push the measuring string more firmly to the pavement surface. Additional field tests were conducted in the morning and afternoon of November 10, 2014.

After these tests, several higher resolution alternative rulers were compared with respect to measuring range, price, resolution, ease-of-use, and total time needed to take five basic point measurements. Additional field tests were then performed to validate the feasibility of using the digital height gauge and digital tread depth gauge for deflection measurement.

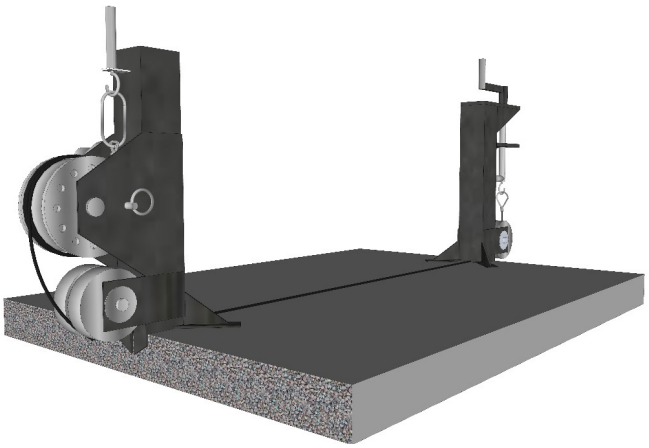
Additional modifications were made to further reduce the device size and weight, resulting in the fourth-generation prototype. Tests were conducted on June 20, 2015, to assess and validate the latest version of the device on the same concrete slab used for the earlier field tests.



ISU curling and warping measurement device during field evaluation

Key Findings

- Based on the field tests, the accuracy and repeatability of the implementation of the finalized ISU curling and warping measurement device satisfy the requirements of curling and warping measurements in the field.
- The final version (fourth generation) of this instrument has two main columns 12 in. high and weighs 18 lbs. The unit can be easily carried and used in the field by one adult.
- Two levels of resolution (0.05 in. and 0.001 in.) can be achieved using either a measuring gauge and/or digital height gauge, depending on project requirements and the total degree of curling and warping. If the degree of curling and warping is small, the higher resolution ruler should be used.
- The horizontal measuring range is 30 ft, depending on the length of string used; longer strings can be used if the slab is longer than 30 ft.
- The total cost of this instrument is about $320.



Three-dimensional rendering of the ISU curling and warping measurement device

Implementation Readiness and Benefits

The developed ISU curling and warping measurement device is ready for use in the field. The device has several advantages and benefits over existing devices and methods:

- This device is small and relatively light for convenient transportation to the field.
- This device has a flexible resolution (0.001 in. or higher, depending on the rulers used), which is comparable to that of existing devices.
- Compared to other available devices such as rod and level and straight edge, this device has a faster operational speed without requiring intensive labor. Only one adult is required for operation.
- Compared to both low- and high-speed profilers and LiDAR systems, the device is much more portable and easier to operate. No complex training or software is required for operation, data processing, and calibration.
- Compared to LVDTs and digital indicator–based curling and warping measuring systems, the device can be used without pre-installed time consuming and labor-intensive sensing systems and can provide flexible measurement across the entire pavement.
- The $320 device costs much less than LVDT systems (at least $3,000 for a single PCC slab, including installation and datalogger costs), digital indicator systems ($2,000, including datalogger costs), profilers (at least $5,000), and LiDAR systems ($100,000, including software and data processing costs). The price of this device could be further reduced to just $100 if produced on an industrial scale.