TECH**BRIEF**

Curl and Warp Analysis of the LTPP SPS-2 Site in Arizona

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This document is a technical summary of the Federal Highway Administration (FHWA) report *Curl and Warp Analysis of the LTPP SPS-2 Site in Arizona* (FHWA-HRT-12-068).

Introduction

Variability in the roughness levels of jointed portland cement concrete (PCC) pavements can often be observed over short periods of time. This study demonstrated specialized analyses for quantifying the effect of curl and warp on the roughness of jointed PCC pavements using profile data from the Long-Term Pavement Performance (LTPP) Specific Pavement Studies (SPS)-2 site in Arizona.

The study sought to quantify and explain changes in the International Roughness Index (IRI) observed over time on the LTPP SPS-2 site in Arizona using methods that were applied to other sites.[1] The study analyzed the profiles in detail by calculating their IRI values, examining the spatial distribution of roughness within them, viewing them with post-processing filters, and examining their spectral properties. The study also attempted to relate changes in IRI over time to design variables, maintenance history, and observations of distress.

Traditional profile analyses revealed roughness caused by transverse and longitudinal cracking as well as some localized roughness caused by built-in defects on some test sections. However, the analyses showed that curl and warp contributed to, and in some cases dominated, the roughness on many test sections. In addition, roughness did not increase steadily with time

The Long-Term Pavement Performance (LTPP) program is a large research project for the study of in-service pavements across North America. Its goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. LTPP was established under the Strategic Highway Research Program and is now managed by the Federal Highway Administration.

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because of diurnal and seasonal changes in slab curl and warp.

Objective

Using the LTPP SPS-2 site in Arizona for a pilot demonstration, this study applied objective profile analyses to quantify the level of curl and warp on each section and distinguish the portion of IRI caused by curl and warp from the portion caused by other sources of roughness.

The project team used objective algorithms to estimate the gross strain gradient needed to deform each slab into the shape present in the measured profile and produced a pseudo strain gradient (PSG) value. The levels of curl and warp within each test section were summarized by the average absolute PSG value for the slabs within it.

By relating changes in PSG to changes in IRI, the portion of roughness change associated with PSG could be identified. Using these methods, the study examined the IRI progression of 21 test sections on the LTPP SPS-2 site in Arizona over the first 16 years of the experiment. The site included 12 test sections from the standard experiment and 9 supplemental test sections designed by the Arizona Department of Transportation. The project also sought to diagnose the sources of roughness and link the observations to records of distress and its development.

Slab Curvature Index

Analyses performed to distinguish the portion of roughness caused by curl and warp from the rest of the irregularities within each profile used a summary index for estimating slab curvature. As in previous studies, this quantified the portion of IRI linked to slab curl and warp and the portion associated with other sources of roughness, such as built-in defects and surface distress.[2]

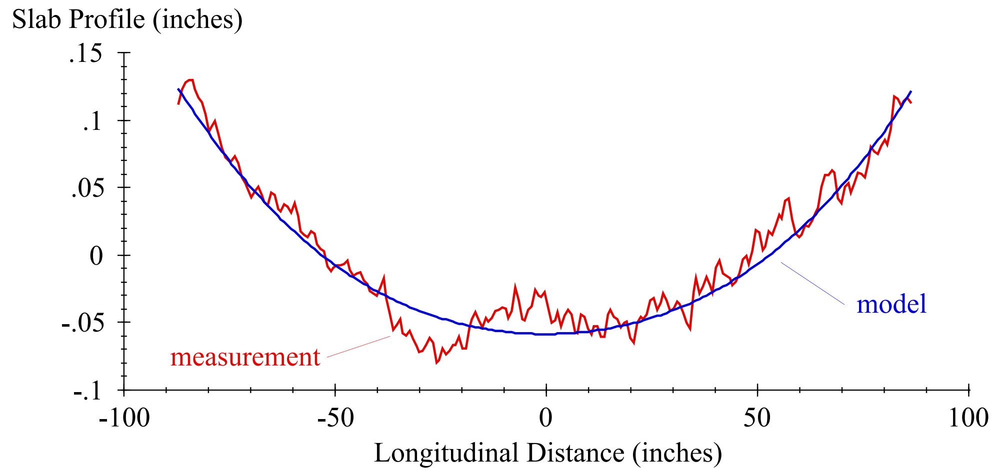
The level of curl and warp present within each profile was estimated using slab-by-slab analysis of local profile segments. An automated procedure isolated the profile of each slab by seeking the locations where negative spikes appeared in the same locations within a set of five repeated profile measurements.

The analysis quantified the level of curl and warp on each slab using PSG. The procedure estimated the PSG value for a given slab using an approach proposed by Chang et al.[3] In this procedure, an idealized profile for a slab with curling and warping proposed by Westergaard in the classical literature is fit to the measured profile of each slab. The shape of the idealized profile is fixed by estimating the radius of relative stiffness, slab thickness, Poisson's ratio, and slab length. The curve fit yields a value of strain gradient required to deform a slab into the shape that appears within its measured profile from a flat baseline.

Figure 1 shows an example curve fit for a slab in section 0215. Before the curve fit, the segment of profile shown was detrended and shifted to a mean elevation value of zero. In this case, the radius of relative stiffness was estimated at 40.7 inches with a slab thickness of 11 inches and a Poisson's ratio of 0.15. For the slab shown in figure 1, the PSG value was 70.57 με/inch.

The analysis produced a summary PSG value for a test section by averaging the

Figure 1. Example curve fit for estimation of PSG.



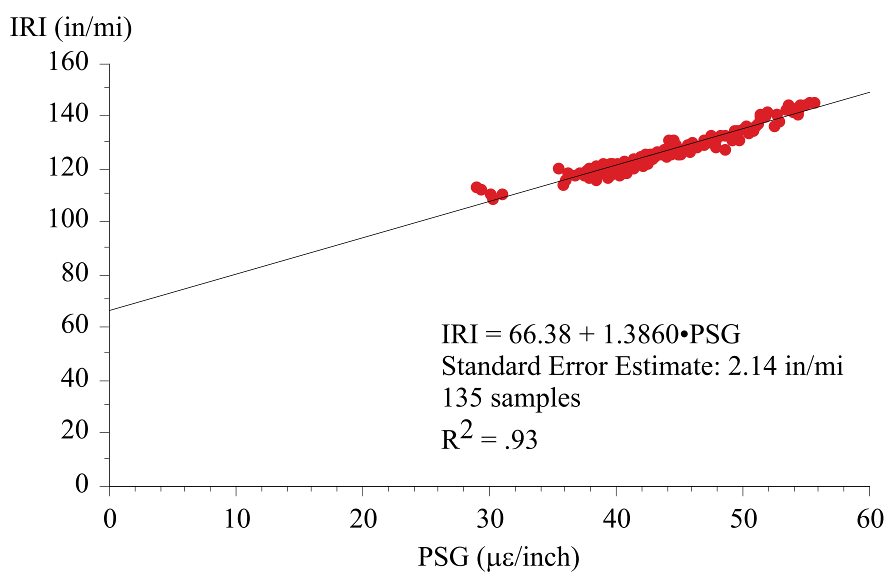
absolute PSG values over all the slabs within the section.

Relationship to IRI

The study empirically related changes in summary PSG over time to changes in IRI. Figure 2 shows an example for section 0215 (a seasonal monitoring section) over several seasonal and diurnal visits throughout 3 years.

Figure 2 shows a useful statistical relationship. Changes in curl and warp exhibit a linear relationship to changes in IRI with a low standard error of estimate. Using extrapolation to a PSG value of zero, an empirical estimate of IRI caused by roughness not associated with curl and warp is possible. For the example in figure 2, the relationship projects to an IRI value of 66 inches/mi for a PSG of 0 με/inch.

Figure 2. IRI versus PSG for right side of section 0215.



Data with this level of historical detail were only available for section 0215 on the Arizona site. However, data from a recent FHWA experiment included seasonal and diurnal variations over a 1-year cycle for the 12 sections in the core experiment.[3] The slope of the IRI-PSG relationship was used to estimate the portion of IRI associated with curl and warp within each profile. The balance of the roughness was considered to be linked to other sources, such as built-in defects and surface distress. The FHWA data included a broad enough variety of temperature conditions to capture a close relationship between IRI and PSG on low-strength sections, but the change in PSG was too small on the high-strength sections to provide useful observations.

IRI Trends

Figure 3 shows the results of the analysis for the right-side profile of section 0215. The circular marks show the IRI values for each set of five passes over the section, and the cross marks show the portion of IRI associated with sources other than curl and warp. IRI increases overall over the first 8 years of the experiment, but several seasonal and diurnal changes in IRI are evident. When the contribution of slab curl and warp is removed, the balance of the roughness is between 60 and 80 inches/mi throughout the monitoring period. Figure 3 shows that curl and warp impose a penalty to the roughness of up to 80 inches/mi. The figure also shows that other sources of roughness, such as distress, did not increase over the 16-year monitoring period.

Figure 4 shows the results of the analysis for the right-side profile of section 0213. On this section, the overall IRI on the right side shows a net growth over the monitoring period, but diurnal and seasonal variations caused IRI to increase inconsistently. When the influence of curl and warp is removed, the balance of the roughness contributes

Figure 3. Right IRI progression for section 0215.

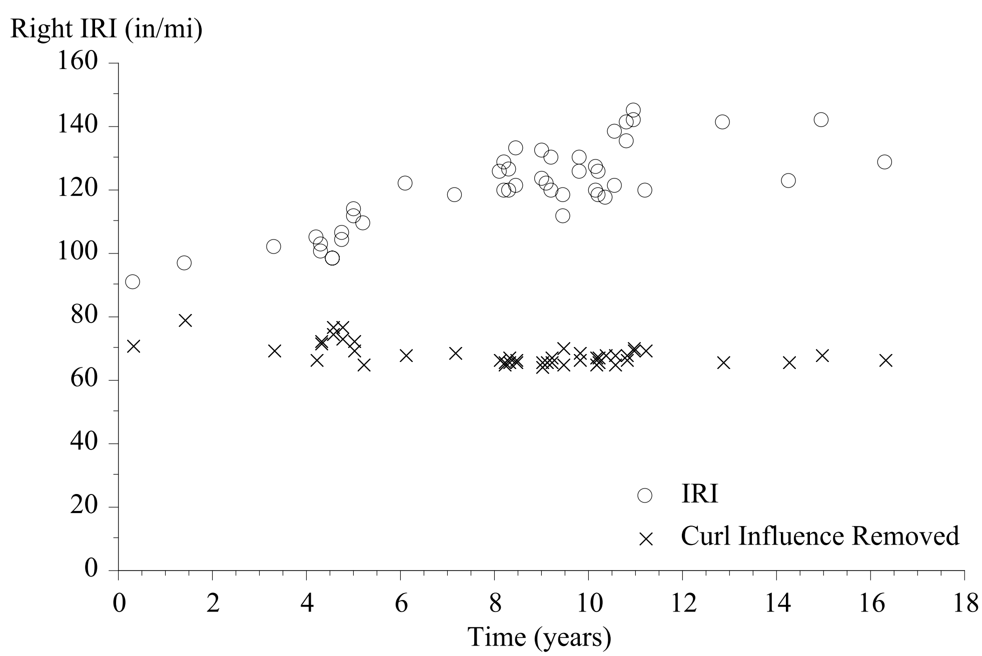
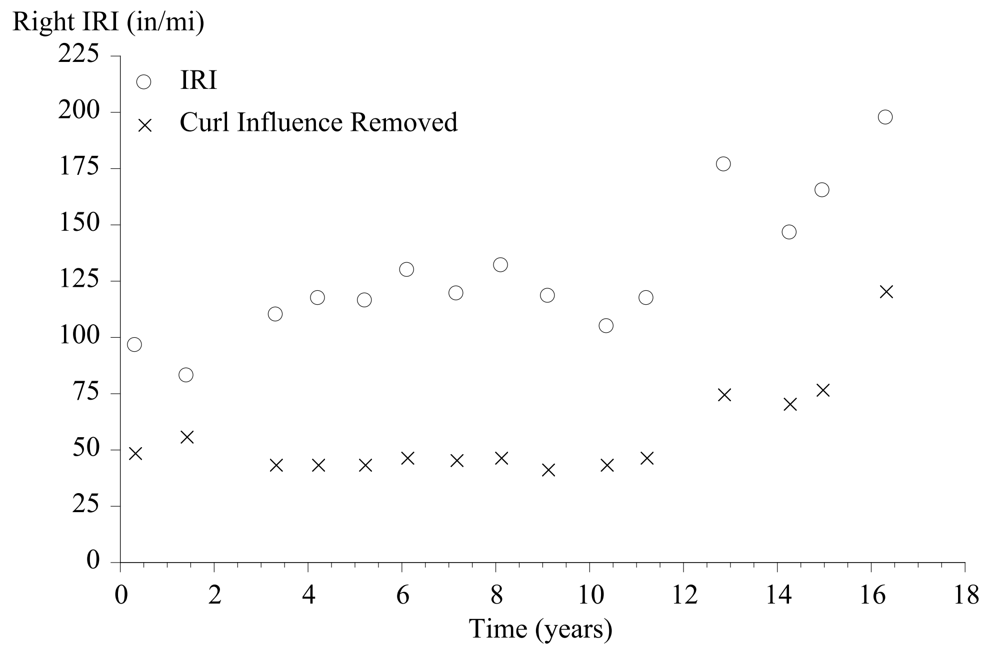


Figure 4. Right IRI progression for section 0213.



50 inches/mi to IRI over the first 11 years of the experiment. After 11 years, longitudinal cracking caused an increase in roughness.

On both test sections, curl and warp contributed up to 80 inches/mi to IRI at various times throughout the monitoring history. This has important implications to the functional performance of each section. However, the influence of structural failures such as longitudinal cracking was obscured by the inconsistent contributions of curl and warp to roughness.

Results

The study demonstrated the potential for isolating the effect of curl and warp from other sources of roughness due to the strong statistical relationship between changes in IRI and changes in PSG on low-strength test sections. The study also demonstrated that long-term increases in IRI may be caused solely by changes in curl and warp and do not necessarily indicate structural failure or increased surface distress.

The analysis methods applied several assumptions that require verification over a broader dataset. Further, a method is needed to derive the IRI-PSG relationship that does not involve as much measurement effort and that can be validated for high-strength pavements. However, this study clearly demonstrated the potential for applying this process and the value in further analysis, as being able to quantify the curl and warp impacts of jointed PCC pavements can greatly inform the most appropriate measures to address increases in roughness.

References

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Availability—The publication associated with this TechBrief is *Curl and Warp Analysis of the LTPP SPS-2 Site in Arizona* (FHWA-HRT-12-068). It is available in print and online at http://www.fhwa.dot.gov/research.

Key Words—LTPP data, International Roughness Index, Jointed PCC, Curl and warp.

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