TECH**BRIEF**

Achieving a High Level of Smoothness in Concrete Pavements without Sacrificing Long-Term Performance

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Introduction

For a portland cement concrete (PCC) pavement, it is important to achieve both a high level of smoothness during construction as well as a satisfactory long-term performance. It is not acceptable to construct a pavement with a high initial smoothness that will give poor long-term performance. Smoothness measurements for construction acceptance are usually performed shortly after paving is completed, using either a profilograph or a lightweight inertial profiler. However, it is unclear whether the smoothness of a pavement measured immediately after it is paved truly reflects the initial smoothness of the pavement because the smoothness can undergo changes over the short term (e.g., within 3 months) due to curling or warping effects. In other words, a pavement can have a very high smoothness immediately after construction, followed by a decrease in smoothness over a short time period because of changes in slab shape that occur with curling and warping. This research project was performed to:

- Assess whether high initial smoothness translates into better long-term performance.
- Identify design features and material properties in PCC pavements that can cause an initially smooth pavement to exhibit detrimental long-term performance.
- Provide guidance on adjustments that can be made to materials properties, design features, and construction procedures in order to avoid these detrimental effects.
- Investigate early age changes in smoothness of PCC pavements.
- Provide recommendations and guidelines regarding smoothness testing.

The Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the CPTP's primary goals are to reduce congestion, reduce costs, improve performance, and foster innovation. The program is designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materials selection, mix design, pavement design, construction, and rehabilitation of concrete pavements.

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The roughness data collected from the Long-Term Pavement Performance (LTPP) GPS-3 experimental jointed plain concrete (JPC) test sections were used to study the roughness progression of JPC sections. The changes in smoothness of the test sections were evaluated to determine what effect the mix design properties, material properties, and design features have on pavement performance. The change in smoothness that occurs over the short term on JPC pavements was investigated by collecting profile data on test sections established on new PCC pavements in five projects. The test sections were profiled 1 day, 3 days, 7 days, and 3 months after paving. The main findings from this study are described in the following sections.

Value of Building Smoother Pavements

The roughness progression plots for JPC pavements in the LTPP GPS-3 experiment showed a parallel pattern in roughness progression. The experiment showed that pavements that are built smoother retain their smoothness over a longer period than those that are built less smooth. Hence, pavements that are built smoother provide a longer service life and provide road users a better ride quality.

Effect of Design Features on Smoothness of JPC Pavements

- Construction of nondoweled pavements in freezing regions is not recommended because in this type of climate, they have shown poor performance from a roughness point of view.

- Some nondoweled pavements have shown a high increase in upward slab curvature over time. These pavements have a high amount of faulting. Many of these pavements are showing other distress. Factors associated with higher amounts of slab curling over time are high values of freezing index, coefficient of thermal expansion, and PCC elastic modulus. Higher values of the following factors were associated with lower curvature: mean annual temperature, annual precipitation, number of wet days per year, and slab thickness. To prevent upward slab curvature, it is recommended that dowels are used for all pavements constructed in freezing areas.

- The provision of dowels in pavements has served its intended function by preventing faulting. If there is any reason to believe there is even the slightest possibility for faulting to occur, dowels are recommended.

- Doweled pavements with a joint spacing of 4.8 meters (m) (16 feet (ft)) or less seem to perform better than those having a higher joint spacing. It is recommended that States utilizing a joint spacing of greater than 4.8 m (16 ft) investigate whether using a joint spacing of 4.8 m (16 ft) or less will give better performance.

Effect of PCC Material Properties on Smoothness of JPC Pavements

- For both doweled and nondoweled pavements, using PCC with higher split tensile strength (which results in a higher flexural strength) appears to be beneficial for long-term performance from a roughness point of view.

- In nondoweled pavements, generally pavements having high elastic modulus values (greater than 35,000 megapascals (MPa) (5 million pounds per square inch (psi)) or pavements having a high ratio (greater than 8000) between elastic modulus of concrete and split tensile strength appear to be showing high rates of increase of roughness. These trends were not seen for doweled pavements.

- Evidence suggests that higher values of coarse to fine aggregate ratio in concrete results in pavements that maintain their smoothness over longer periods.

- A survey of State departments of transportation (DOT) personnel and concrete industry personnel showed no evidence suggesting that contractors have been adjusting their mix designs to achieve higher smoothness. The general consensus was that no modifications have been required in the concrete mix design to achieve higher smoothness.

Construction Considerations

- The construction procedures needed to construct a smooth PCC pavement are documented in publications prepared by Federal Highway Administration (FHWA) (*Portland Cement Concrete Pavement Smoothness: Characteristics and Best Practices for Construction*, Publication No. FHWA-IF-02-025) and the American Concrete Pavement Association (*Constructing Smooth Concrete Pavements*, Technical Bulletin TB-006.0-C). Adherence to these procedures is recommended for constructing smooth pavements.

- Analysis of data from five projects indicated that the smoothest pavement was constructed in the project where the tie bars were attached to chairs fixed to the base. The dowel bars were also fixed to the base in this project. The International Roughness Index (IRI) of the test section established in this project was 0.80 meters per kilometer (m/km) (51 inches/mi). The IRI of the test sections established on the other four projects, where the tie bars were inserted by the paver, were 1.11, 1.44, 0.95, and 1.07 m/km (70, 91, 60, and 67 inches/mi). In three of the projects, the dowels were fixed to the base, but for the project that had an IRI of 1.07 m/km (67 inches/mi), dowels were inserted during the paving process. Although fixing the tie bars to the base prior to paving may be more costly, these results indicate that doing so may achieve a smoother pavement.

Measurement of Smoothness

- The surface of the pavement must be clean when performing profile measurements. Residue from the saw-cutting operation that is present adjacent to the transverse joints can appear as small humps on the measured profile, and these can affect the smoothness indices computed from the profile data.

- The data collected by lightweight profilers do not measure the shape of the joint accurately. Profilers from different manufacturers are using different methods to filter data. As a result, joints are being measured differently. Some profilers eliminate most of the effect of a joint by filtering, which flattens out the profile at the joint. Nonetheless, differences in smoothness indices between devices may still occur between equipment manufactured by different manufacturers.

- In many States, an initial sawcut is made on the pavement, a joint reservoir is formed, and then the joint is sealed. Profile measurements should not be obtained when the joint reservoir is formed and the joint has not yet been sealed. At that point, data can yield high roughness values because the joint reservoir appears in the profile data.

- On transverse tined surfaces, when three repeat runs were obtained with lightweight profilers, the difference between the maximum and minimum IRI of the three runs over an approximate distance of 161 m (528 ft) typically ranged from 0.03 to 0.06 m/km (1.9 to 3.8 inches/mi). However, in longitudinally tined surfaces, this value was much higher and ranged from 0.06 to 0.09 m/km (3.8 to 5.7 inches/mi). Because of the interaction between the laser sensor and the longitudinal tines, the IRI obtained on longitudinally tined surfaces is less repeatable than that obtained on transverse tined surfaces.

- If a profiler is used to measure smoothness of concrete pavements, this profiler should be certified on PCC sections. Differences in the way profilers treat joints and tining can affect smoothness indices obtained from profile data. Hence, certifying profilers on asphalt surfaces and using the profilers to measure smoothness on concrete surfaces may not necessarily mean that comparable data are obtained by different profilers.

Early Age Changes in Roughness and Profile

- Testing at the five projects indicated negligible built-in slab curling was present on the pavement. Curvature of slabs changed little over a 31/2-month period, and no noticeable effect of changes in slab curvature affecting the IRI was noted.

- A study performed on five projects indicated somewhat variable results in changes that occur in the IRI over the first 3 months after paving. In some projects, very little change in IRI was noted (within ±5 percent). In some projects, changes up to ±10 percent were noted. It is unclear whether these changes occurred because of changes in pavement profile or whether they were related to either equipment effects or lateral wander during profiling.

- For a specific profiler, no significant changes in IRI were observed from measurements obtained when the 3-milimeter-(mm) (0.12-inch-) wide initial sawcut was present on the pavement and after the joint reservoir was sawed and sealed. Although a significant difference was not seen for the profilers used in this study, differences may nonetheless occur between these measurements in some profilers because of the different data filtering methods they use.

- Based on the five projects used in this study, it appears that smoothness measurements can be performed at any time within the first few months of a pavement's life as long as the pavement is clean.

Use of Profile Data for Achieving Smoother Pavements

- Usually smoothness indices like IRI are computed for each lane over a 161 m (528 ft) length. The IRI for the overall section does not provide any information on how IRI varies within the section or where rough spots within the section are located. A roughness profile of the section that shows how the roughness is distributed within the section can be used to investigate the spatial distribution of roughness and to see where rough spots within the section are located. The location of the rough spots can then be correlated to the construction process to obtain information on a specific construction event that occurred at that location and resulted in a high roughness value.

- Advanced profile analysis techniques, such as power spectral density (PSD) plots, can be used to identify whether a roughness associated with a specific repetitive wavelength or a waveband significantly contributes to the roughness. Using such procedures on projects having problems in achieving the desired smoothness can help troubleshoot the cause for such problems.

- Using roughness profiles as well as PSD plots on profile data collected at the start of a paving project will indicate whether any features in the profile are contributing to a high roughness. If such features are identified, they can be corrected at the start of the project.

Researchers—This study was performed by R.W. Perera and S.D. Kohn of Soil and Materials Engineers, Inc., Plymouth, MI and S. Tayabji of Construction Technology Laboratories, Inc., Columbia, MD.

Distribution—This Tech Brief is being distributed according to a standard distribution. Direct distribution is being made to the Divisions and Resource Centers.

Availability—The report will be available in summer 2005 and may be obtained from the FHWA Product Distribution Center by e-mail to report.center@fhwa.dot.gov, by fax to 301–577–1421, or by phone to 301–577–0818.

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