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PROJECT SUMMARY REPORT

Develop a Methodology for Establishing Bump Detection Using Inertial Profile Measurements for Implementation with the Ride Specification: Summary Report

The Texas Department of Transportation (TxDOT) started implementing its new ride quality specification in 2002. This specification requires the use of inertial profilers in lieu of profilographs for quality assurance testing of surface smoothness on new construction and rehabilitation projects. The profilograph-based ride specification that it replaced includes criteria for both section-wide and localized roughness. Although a method is currently used to evaluate localized roughness, its assessment, as well as that of section-wide roughness, is based on different criteria. The new ride specification identifies defects based on an allowable difference between the average measured profile and its moving average, and assesses section-wide roughness using the International Roughness Index (IRI).

While both criteria are correlated to user perception of ride quality as measured by the Present Serviceability Index (PSI), PSI is not presently used to establish the need for corrections, nor are the improvements in PSI resulting from corrections evaluated or predicted in the new ride specification. A new equation was developed in Project 7-4901 using data collected from two ride surveys conducted during the project. From analysis of profile data collected to verify the model, researchers on Project 7-4901 found the new equation to be more sensitive to the occurrence of localized roughness than IRI or the current ride equation. Thus, TxDOT initiated Project 0-4479 to investigate the application of the new equation for detecting defects in a smoothness specification. Its objectives are to:

- determine methods for defining localized roughness characteristics that are objectionable to ride, and
- establish how these characteristics can be measured in an effective way for construction quality control and assurance using inertial reference profile data.

What We Did...

The method developed from this project uses bump templates to scan measured profiles for the occurrence of localized defects. It is referred to as the Template Analysis Procedure (TAP). TAP finds bumps and dips by cross-correlating bump templates with the measured profile of a section under evaluation. This process yields a set of correlation statistics that indicates how closely a particular area in the section follows the different templates. TAP then compares the absolute value of each statistic to a threshold. Where the specified threshold is exceeded, a bump or dip is recorded at that location depending on whether the correlation is positive or negative, respectively. The magnitude of the bump or dip is then determined from the profile of the section at the located point.

To develop the procedure, researchers initially identified a bump signature that could be used to establish templates for cross correlation by varying the wavelength and/or amplitude of the signature profile. For this purpose, researchers evaluated a number of artificial bumps, fabricated in a previous TxDOT project, to determine if one of the bumps could be used for the cross correlation. Each bump was profiled and inserted into various measured profiles representative of smooth pavements. Although any of the bumps would have worked, researchers selected

bump 5 of the set as the "golden" bump as it consistently showed one of the smoother transitions when inserted into the various profiles for study. Figure 1 shows a photograph of bump 5 on one of the test sections located at the Texas A&M University Riverside Campus. Having established the "golden" bump, research and development efforts proceeded according to the following work plan.
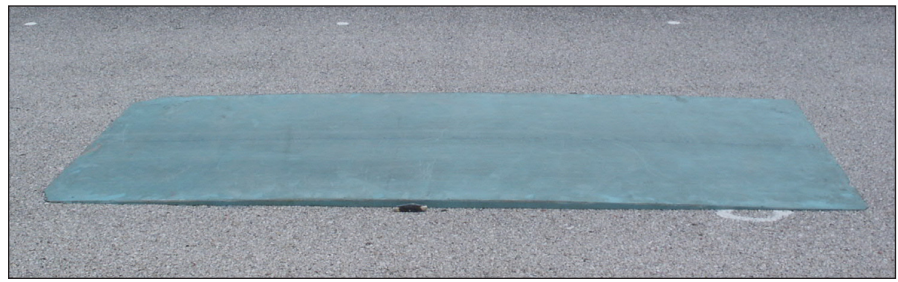

Figure 1. Photo of Bump 5 on Pavement Test Section.

Proof-of-Concept

To provide an initial assessment of whether template analysis would work as a method for detecting localized defects, researchers used the method on two test sections with known defects. One of the sections is located along Pearce Lane in Austin, where a pothole was observed. The other section is at the Texas A&M Riverside Campus, where researchers placed the artificial bump 5 on one of the wheel paths. Various bump templates were then generated from the profile of this "golden" bump by varying its wavelength. Researchers then cross-correlated the templates with the measured profiles on the test sections to establish the viability of the template analysis procedure.

Evaluation of Effects of Localized Roughness on Smoothness Indices

Researchers investigated the effects of bumps on TxDOT's current Serviceability Index (SI), the IRI, and the New SI (NSI) from Project 7-4901. For this evaluation, simulated bumps were generated by varying the amplitude and wavelength of the "golden" bump. These simulated bumps were then inserted into the measured profile of a 0.1-mile smooth section. Researchers then computed the SI, IRI, and NSI for the range of simulated bumps considered.

Development of Cross-Correlation Method

Researchers established a procedure for determining the threshold correlation coefficient for identifying localized defects using TAP. In addition, a MATLAB program was written to process profile data for evaluating the locations, widths, and amplitudes of bumps and dips in a given section.

Application of TAP

Researchers collected profile data on a rehabilitation project along US 290 near Brenham. The data were processed using TAP and the results compared with those determined using SS 5880 and Item 585.

What We Found…

Proof-of-Concept

Using TAP, researchers were able to locate the defects in the test sections and establish their amplitudes and lengths. From the analysis, researchers found that the new SI is significantly affected by the pothole in the Pearce Lane section. For the same profile data, the new ride equation gave an SI value of 2.9 versus 4.3 from the current equation, which is based on a correlation between SI and IRI. For the same section, the computed IRI is about 48 in/mile. In the opinion of the researchers, an SI of 4.3 is rather high as the pothole provided significant roughness. Since the current SI is determined from IRI, these results reflect the averaging effect of the IRI statistic. Whereas the effect of the pothole on IRI (and the current SI) over a short section would be more dramatic, its effect over 0.1 miles was not as great. In view of these findings, an evaluation of the effects of bumps on the current SI, IRI, and the new SI was conducted.

Evaluation of Effects of Localized Roughness on Smoothness Indices

Application of the new ride equation to compute the SI on the Pearce Lane section demonstrated the sensitivity of the new SI to the presence of localized roughness. Further investigations of the effects of simulated bumps on various ride statistics revealed that the new SI is affected by both the amplitude and wavelength of a bump. In contrast, the current SI and IRI were found to be sensitive only to the bump amplitude for the range of simulated bumps considered in the analysis. These findings are illustrated in Figures 2 and 3.

Development of Cross-Correlation Method

The threshold correlation coefficient is critical to the success of detecting defects using TAP. Researchers established a method for determining the threshold based on the acceptable NSI specified by the engineer. In this method, TAP is used to evaluate the correlation coefficients for an unbiased sample of 0.1-mile pavements having new SIs greater than or equal to the acceptable value. The resulting set of correlation coefficients is then used to estimate the expected value of the distribution of the maximum correlation coefficients and its variance. These estimates are then used in the following equation to determine the correlation threshold corresponding to the acceptable level of the new SI specified by the engineer:
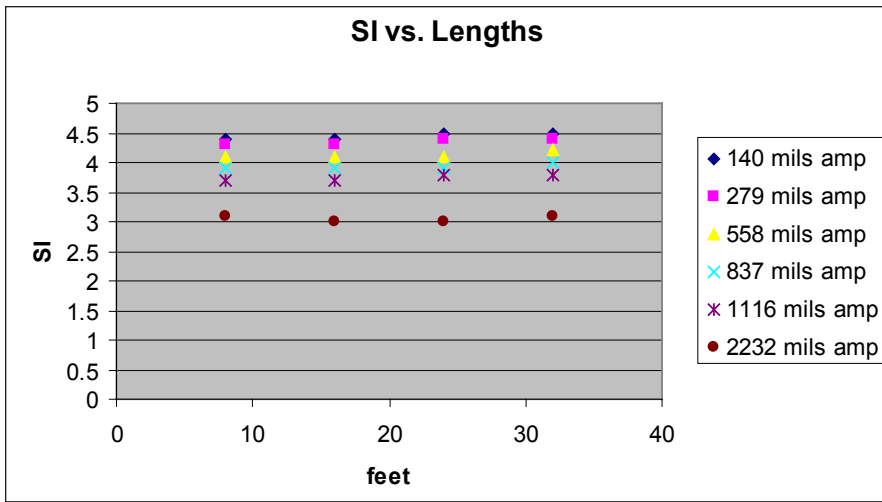
SI vs. Lengths

Figure 2. Sensitivity of Current SI to Simulated Bumps of Various Amplitudes and Wavelengths.
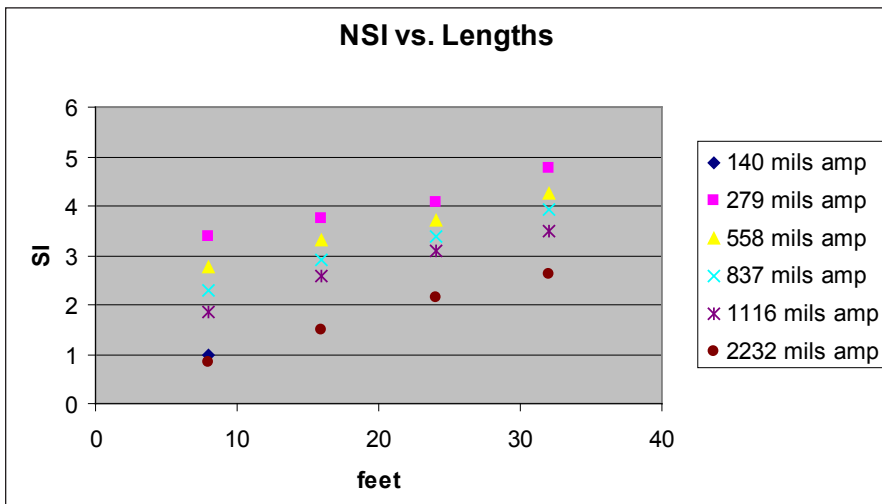
NSI vs. Lengths

Figure 3. Sensitivity of New SI to Simulated Bumps of Various Amplitudes and Wavelengths.

$$T_{NSI} = r_{max} + Z \frac{\sigma}{\sqrt{n}}$$

where:

T_{NSI}	=	threshold correlation coefficient
r_{max}	=	mean of the sample of maximum correlation values for a given acceptable NSI
Z	=	the desired normal or t distribution confidence area
σ	=	the unbiased estimate of the population standard error
n	=	sample size

Application of TAP

Researchers evaluated the template analysis procedure using profile data collected on a rehabilitation project along US 290 near Brenham. From this evaluation, the following findings are noted:

• The number of defects detected using TAP increases with the acceptable level of NSI for the range of threshold values considered in the analysis (3.6 to 3.9). This result is to be expected since more 0.1-mile sections are evaluated as the threshold NSI increases.

• If all defects detected are counted, TAP yielded more defects than SS 5880 for the same profile data. However, the new method yielded fewer defects than SS 5880 if each set of overlapping bumps or dips is counted as one occurrence.

The Researchers Recommend…

Because of the one-year duration of this project, it was not possible to compare TAP with the current ride specifications on additional projects. To determine the potential impact of the proposed method to current practice, additional shadow testing on other rehabilitation projects is needed. In addition, the following recommendations are offered:

• For implementation purposes, a table of recommended threshold correlation coefficients for different acceptable levels of NSI should be established.

• The practical utility of the TAP program would be enhanced if a function is included that would estimate how the NSI would change as specific bumps or dips are taken out. In this way, the engineer can identify the corrections that are predicted to provide the most improvement in the ride quality of a given project.

• TxDOT should consider using TAP to evaluate localized roughness during quality assurance testing of initial pavement smoothness. In the proposed approach, researchers recommend that the new SI be used to establish the need for evaluating localized roughness on a given section. The engineer specifies an acceptable NSI for a given project. For sections where the new SIs are equal to or greater than this threshold, no evaluation of localized roughness is performed since the ride quality is deemed acceptable from a road-user perspective. However, for sections where the new SIs are lower than the threshold, TAP is used to locate defects within those sections. This approach is recommended based on the greater sensitivity of the new SI to localized defects over a 0.1-mile section compared to the current SI or IRI.

For More Details...

The research is documented in Report 0-4479-1, *A Methodology for Bump Detection Using Inertial Profile Measurements*.

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Disclaimer

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the U.S. Department of Transportation, Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. Trade names were used solely for information and not for product endorsement. The engineer in charge of the project was Dr. Roger S. Walker, P.E. (Texas, Serial No. 3154).

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