

Use of an Innovative Technology for Measuring Surface Roughness of Pavements

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ABSTRACT

The City of Cranbrook, British Columbia, CA rehabilitated some aged pavement sections. The aging effects on the pavements were reflected by the presence of alligator cracking, transverse cracking and surface rutting. The pavement sections were rehabilitated with a mechanically stabilized aggregate base course layer. Multi-axial geogrids were selected for constructing a mechanically stabilized layer. One of the benefits of mechanical stabilization is to preserve material stiffness for a longer period. The mechanical stabilization also offers an opportunity for pavement designers to optimize pavement layers and attain the same or higher targeted pavement performance. Pavement surface roughness is one of the indicators of pavement performance. The pavement surface roughness influences the ride quality and is affected by the structural stability of the pavement system and the pavement responses due to traffic and climatic fluctuations. Some commonly used indices of surface roughness are Present Serviceability Rating (PSR) and International Roughness Index (IRI). In the last decade, several advanced techniques were introduced to measure IRI cost-effectively and rapidly. This paper describes the use of smartphone-based technology for measuring IRI of rehabilitated pavements. The IRI information for the pavements constructed with different geogrids and different soil conditions were measured, evaluated and discussed.

RÉSUMÉ

La ville de Cranbrook, en Colombie-Britannique au Canada, a remis en état des sections de chaussées âgées. Les effets du vieillissement sur les chaussées se sont traduits par la présence de craquage d'alligator, de fissures transversales et de surfaces sillonnées d'ornières. Les sections de la chaussée ont été réhabilitées avec une couche de base en granulats stabilisée mécaniquement. Les géogrilles multiaxiales ont été sélectionnées pour la construction d'une couche stabilisée mécaniquement. L'un des avantages de la stabilisation mécanique est de préserver la rigidité du matériau pour une période plus longue. La stabilisation mécanique offre également aux concepteurs de chaussées l'occasion d'optimiser les couches de chaussée et d'atteindre des performances de chaussée identiques ou supérieures. La rugosité de la surface de la chaussée influe sur la qualité de la conduite, et est affectée par la stabilité structurelle du système de chaussées, et par les réponses des chaussées au trafic et aux fluctuations climatiques. Parmi les indices de rugosité de surface les plus couramment utilisés, on peut citer l'évaluation de l'aptitude au fonctionnement (PSR) et l'indice de rugosité international (IRI). Au cours de la dernière décennie, plusieurs techniques avancées ont été introduites pour mesurer le IRI de manière rentable et rapide. Ce document décrit l'utilisation de la technologie basée sur le téléphone intelligent pour mesurer l'IRI des chaussées remises en état. Les informations IRI pour les chaussées construites avec des géogrilles différentes et avec des conditions de sol différentes, ont été mesurées, évaluées et discutées.

1 INTRODUCTION

Pavement condition assessment refers to the process of assessing existing functional and structural characteristics of pavement (Bianchini and Bandini 2010). Regular pavement condition assessment helps in tracking pavement performance, identifying deteriorated pavement sections and providing necessary preventive measures. Experiences have shown that regular maintenance and upgrade of a pavement are better and more cost-effective than replacing severely deteriorated pavements (Peshkin et al. 2004; Cuelho et al. 2006).

Transportation-related agencies, such as the Provincial Ministry of Transportations (MOTs), local transit authorities, public works or street maintenance offices of cities, evaluate the condition of existing pavement for identifying and prioritizing maintenance and rehabilitation projects, allocating budgets and planning for new construction (Haas 2001). National Highway Performance Program (NHPP) utilizes pavement condition data such as

International Roughness Index (IRI), percent cracking, rutting, and faulting for developing transportation plans.

The serviceability of any road network is directly influenced by the presence of distresses and the surface roughness. The most common types of pavement distress are cracks in different forms as described by Miller and Bellinger (2003). ASTM D6433 (2018) recommends using Pavement Condition Index (PCI) as an indicator of pavement performance based on the level of pavement distress. During traffic loadings, load-transfer mechanisms are disrupted due to the presence of cracks which result in localized concentration of stresses. Additionally, the cracks allow moisture to penetrate the base/subbase layers and subgrade. Moisture has severe detrimental effects on the mechanical characteristic (stiffness) of bases and subgrade (Tamrakar and Nazarian 2017; Tamrakar and Nazarian 2018). The ultimate effect of pavement distresses can be experienced through the vehicle ride quality. The ride quality can be quantified in terms of pavement roughness such as Present Serviceability Rating (PSR) and International Roughness Index (IRI). American

Association of State Highway Officials (AASHO) developed the PSR method in 1960s whereas the World Bank introduced the IRI method in 1980s.

ASTM E1926 (2015) describes the method for obtaining pavement IRI using the longitudinal road profiles. An IRI is a standardized measure of the reaction of a vehicle to roadway profile and roadway roughness that is expressed in “inches per mile” or “meters per kilometer”. The typical IRI threshold limits for different pavement types in the District of Columbia are shown in Table 1. Common devices used for measuring pavement roughness are Profilometer, Profilograph, Roughometer and Ridemeter (Kelly et al. 2002).

Table 1. Typical IRI Threshold Limits for Pavement (from Arhin et al. 2015)

	Pavement IRI Limits (m/km)		
	Freeways	Arterials/ Collectors	Local Roads
Good	≤ 1.26	≤ 2.53	≤ 2.84
Acceptable	1.28 - 2.53	2.54 - 4.73	2.86 - 5.52

In the last decade, several innovative technologies were introduced in the pavement engineering sector for enhancing the efficiency of conventional methods. The use of smartphones for gathering information of pavement condition (Hanson et al. 2014; Islam et al. 2014) by collecting motion data rapidly and cost-effectively is one of the examples. In this paper, the use of smartphone-based technology for measuring IRI of rehabilitated pavements is discussed. Pavements were rehabilitated by constructing a mechanically stabilized layer using multi-axial geogrids.

2 FIELD TESTING METHODOLOGY

Current smartphones consist of several built-in sensitive sensors including an accelerometer. The accelerometer measures phone acceleration in x-, y- and z-directions, and determines motion and orientation of the phone. Such features are essential for map navigation, landscape or portrait display and so on. Several researchers (Hanson et al. 2014; Islam et al. 2014) had utilized smartphone-based acceleration data for capturing vehicle motion, estimating longitudinal road profile, and hence, measuring pavement IRI. As the manual steps involved in operating road profilers are replaced by the automated procedures through built-in functions of smartphones, the researchers had to overcome several challenges such as filtering unwanted signals due to vehicle damping, considering the effects of different models of phone and vehicles, adjusting the signal filtering window based on the sensitivity of the accelerometer and so on (Forsl f and Jones 2015).

The IRI data collection technology for this project was developed by TotalPave Inc. The principles behind the TotalPave system is explained in Cameron (2014). The TotalPave system is calibrated against the standard profiler using different types of smartphone and vehicles (Hanson et al. 2014). The TotalPave data collection process is fully automated. The user needs to mount a smartphone with a TotalPave IRI Calculator app to the vehicle’s windshield.

The mounting device should be sturdy so that the motion detected by the smartphone is totally from the vehicle. The TotalPave app allows users to level a smartphone vertically which helps to accurately detect motions in x-, y- and z-directions. The app collects data when the vehicle speed is more than 20 kmph (12 mph). The app also collects GPS data along with the acceleration data for proper positioning and displaying of IRI data within the map. The TotalPave system analyzes the raw acceleration data and estimates pavement IRI. Using the web portal of TotalPave, users can view the IRI data plotted on the map.

3 PROJECT SITE

The project site is in the City of Cranbrook, British Columbia, CA, which is located 200 km South-west of Calgary, CA (see Figure 1). It consists of 6 rehabilitated pavement sections as mentioned in Table 2. The pavements were less than 3 years old.



Figure 1. Project Site Location

Table 2. Project Section Details

Location	AC (mm)	ABC (mm)	Geogrid	SBC (mm)	Rehab. Year
Cobham Ave West	100	150	TX5	200	2018
2 nd St South	100	100	TX5	300	2017
4 th St South	75	150	TX5	200	2016
9 th St South	75	200	TX7	--	2018
11 th Ave South	100	150	TX5	200	2016
12 th Ave South	75	200	TX7	--	2018

The pavement cross-section typically consisted of 200/300A grade asphalt concrete, 19 mm minus “crushed granular base course” with 0-5% fines (particles passing sieve 200) and 75 mm minus “select granular subbase” with 0-5% fines. Two types of multi-axial geogrid (see Table 3) were placed at the interface between base and subbase.

Table 3. Properties of Geogrids

Index Properties	Geogrid Type	
	TX5	TX7
Longitudinal rib pitch (mm)	40	40
Diagonal rib pitch (mm)	40	40
Mid-rib depth (mm)	1.2~1.3	2.0~1.6
Mid-rib width (mm)	0.9~1.2	1.0~1.3
Aperture shape	Triangular	Triangular

The multi-axial geogrids were selected based on the site conditions and aggregate material types. The triangular apertures of multi-axial geogrids have much more uniform stress and strain distributions than the traditional biaxial geogrid with rectangular apertures (Dong et al. 2011). Under traffic loadings, triaxial geogrid is more effective and efficient in distributing stresses in all directions (Abu-Farsakh et al. 2016; Robinson et al. 2017; Gu et al. 2017; White and Vennapusa 2017; Roodi et al. 2018; Vennapusa et al. 2018; Abu-Farsakh et al. 2019; Wayne et al. 2019). Placing such multi-axial geogrids at the interface between base and subgrade creates a mechanically stabilized layer which improves strength and stability of the pavement system. One of the benefits of such mechanical stabilization is the preservation of material stiffness for a longer period. The mechanical stabilization also offers an opportunity for pavement designers to optimize pavement layers to attain the same or higher targeted pavement performance.

4 RESULT AND DISCUSSION

Figure 2 shows the pavement condition of Cobham Ave W before and after rehabilitation. The ride quality of the pavement was significantly improved after rehabilitation. To quantify such improvements, pavement condition evaluation surveys were conducted over six different streets in the city of Cranbrook (as mentioned in Table 2). Surveys were conducted in both directions for measuring pavement IRI. Figure 3 provides the average IRI of pavement sections through the color-coded map as displayed in the web portal of TotalPave. The legend in the figure represents the IRI ranges. Most of the pavement sections have low IRI (<1.5 m/km) as represented by dark green color. Only a few pavements have sections where IRI is in the range 3.5-4 m/km.

Figure 4 provides pavement IRI based on the normalized distance. As the total survey distance of different pavement sections is different, the IRI values are presented based on the normalized distance. The normalized distance was computed using the actual distance of IRI measurement divided by the total survey

distance. Figure 4 illustrates the distribution of pavement IRI along the longitudinal distance of the roadway. As indicated in the figure, almost all IRI measurements are in the good range as specified by Arhin et al. (2015).



Figure 2. Before and After Rehabilitation of Cobham Ave West

To understand the overall condition of pavement, the IRI values shown in Figure 4 are averaged and presented in Figure 5. All pavements had IRI values in the good range. The pavement of Cobham Ave W had the lowest IRI

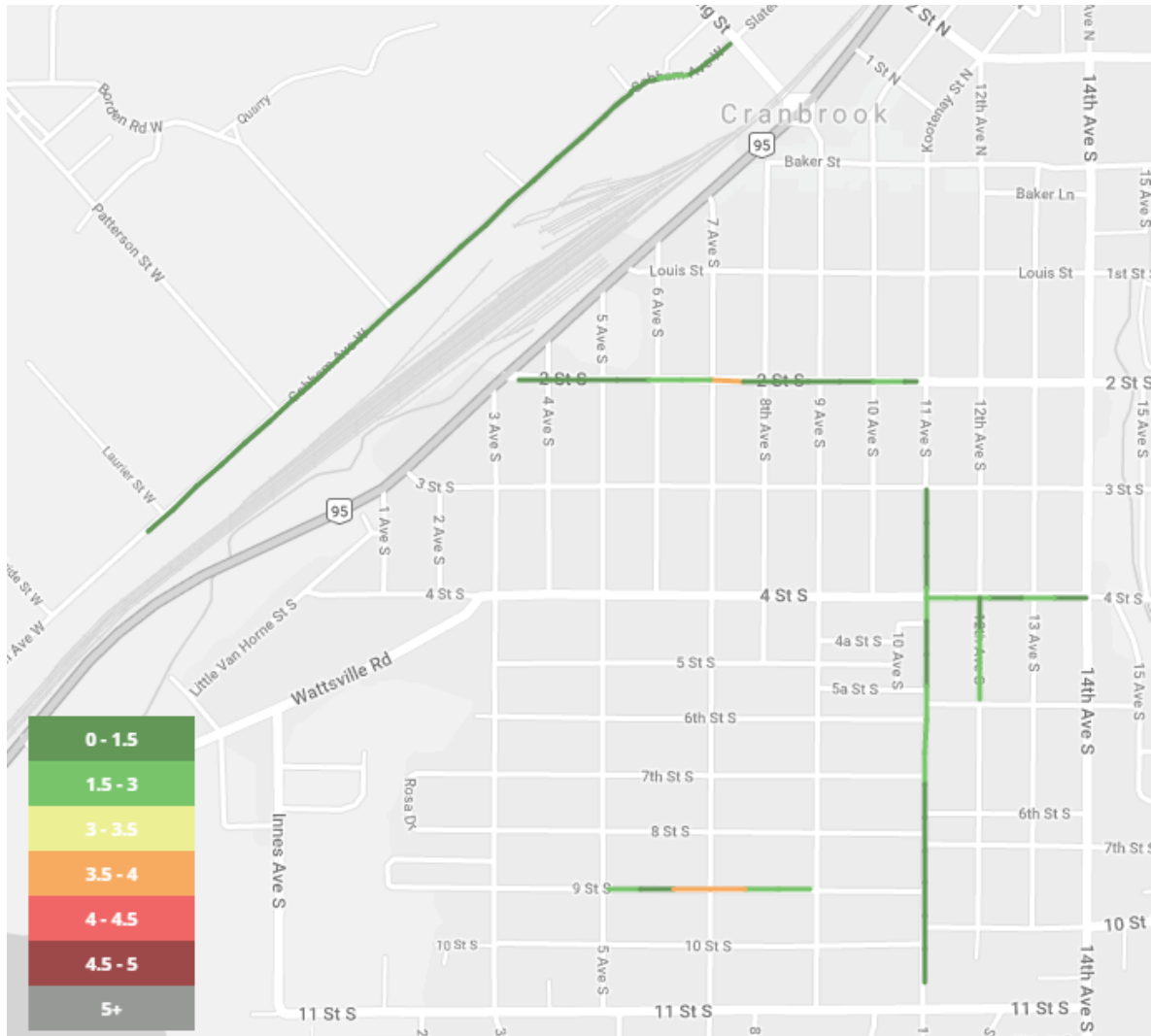


Figure 3. Results of IRI Surveys

and 9th St had the highest. Since the high IRI was reported for the pavement section (9th St) near the roadway intersection, the turning traffic might have contributed to increasing pavement roughness. Additionally, the roadway intersection was not rehabilitated. The other potential factors affecting IRI measurements are subgrade condition, braking of the vehicle, longitudinal pavement slope, underground utilities, freezing/thawing of unbound pavement layers and so on.

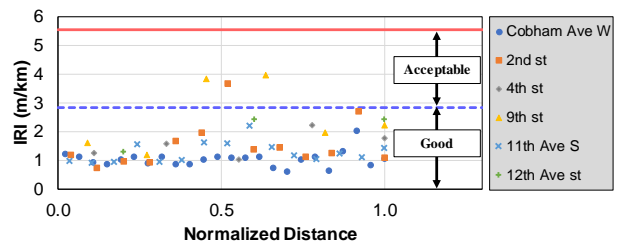


Figure 4. Pavement IRI based on the Normalized Distance

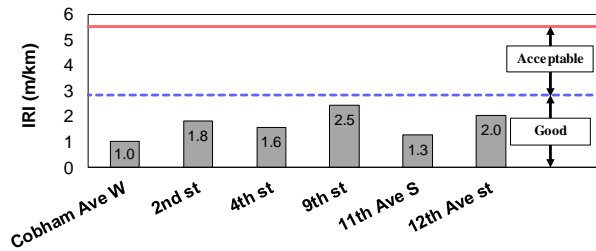


Figure 5. Representative Pavement IRI

Using the box-and-whisker plots, the statistical summary (a.k.a. a five-number summary) results for all test section are presented in Figure 6. The figure shows the minimum value, lower quartile (25%, Q1), median (50%, Q2), upper quartile (75%, Q3), and maximum value. The dots above each whisker are the potential outliers. Due to few datasets, the plot for 12th Ave st is not presented. As seen from the figure, the IRI measurements for Cobham Ave W, 4th st and 11th Ave S are consistent. And, the pavement sections of 2nd st and 9th st have a relatively high variation in IRI measurement which is also seen from Figure 4.

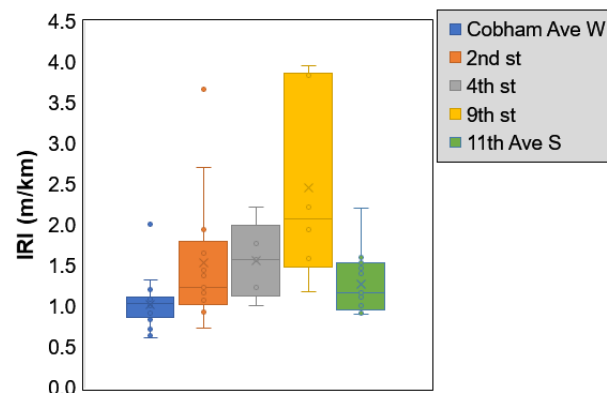


Figure 6. Box-and-Whisker Plots for IRI Data

5 SUMMARY AND CONCLUSION

Municipalities have a growing need for infrastructure improvements while at the same time revenues are not keeping up with rising replacement costs. The City of Cranbrook sought an innovative approach to address this infrastructure gap. Some pavement sections in the City of Cranbrook, British Columbia, CA were rehabilitated using a mechanically stabilized aggregate base course layer with Multi-axial geogrids. The use of mechanically stabilized aggregate base course layers to optimize pavement thickness resulted in reduced upfront costs of pavement rehabilitation in comparison to a conventional construction approach.

The performance of the rehabilitated pavements was assessed by measuring pavement surface roughness in

terms of International Roughness Index (IRI). A smartphone-based technology was implemented for measuring rehabilitated pavement IRI. All geogrid-stabilized pavements had good IRIs (<2.5 m/km).

Based on this research, the smartphone-based technology was found to be very convenient and efficient for collecting IRI data. Although the quality and accuracy of IRI data may not be as high as that measured from a standard profiler, given the lower comparative cost and ease of use the smartphone-based IRI data is sufficient for measuring pavement performance. Transportation agencies could utilize the smartphone-based technology for measuring pavement IRI and making preliminary decisions.

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