STATE OF FLORIDA

Evaluation of Surpro as a Reference Device For High-Speed Inertial Profilers

Research Report
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STATE MATERIALS OFFICE

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INTRODUCTION

The Florida Department of Transportation (FDOT) State Materials and Research Office owns and operates a number of high-speed inertial profilers (HSIP) to measure smoothness for network pavement management, construction acceptance, and research. The Dipstick is another piece of equipment, which has traditionally been used as the reference device to verify the validity of these HSIP. However, the Dipstick is relatively slow and tedious to operate, and requires long duration lane closures. Advances in profiling technology have facilitated the development of other reference profiling devices that can collect data at closer intervals to match the recording interval of HSIP in order to evaluate them. FDOT owns one such device called the Surpro, which has gained wide acceptance in the industry mainly for its relatively faster speed of operation and adjustable sampling interval. There is a need to evaluate the Surpro walking profiler as a reference device for FDOT's HSIP.

PROJECT SCOPE

This study is aimed at evaluating the Surpro as a replacement reference device to the Dipstick. These two reference profile devices were evaluated for their level of agreement with a HSIP in measuring the International Roughness Index (IRI), and to test the devices' cross correlation in terms repeatability and reproducibility for measuring roadway profiles. Two asphalt test sections were used in this study, a 528 ft dense-graded pavement section located at the Gainesville Raceway facility, and a 1,056 ft open-graded pavement section located in the southbound travel lane of SR 24, also known as Waldo Road.

PROFILING EQUIPMENT

Surpro – An International Cybernetics Corporation (ICC) Surpro 2000 with the standard sized tire was used in this study. This inclinometer based roadway profiling instrument was developed for calibration or verification of other devices used for roughness measurement. The unit is operated by pushing on its handle like a lawn mower, at a normal walking speed of up to 2.5 mph. The data sampling distance interval is adjustable and can be preset by the operator. The faster speed of operation provided by the Surpro provides higher production rate and shorter lane closure time frames compared to the Dipstick.

Figure 1. Surpro

Dipstick - the Dipstick is another inclinometer based profile measurement device, which is often used to collect reference profiles in profile verification studies [(1)]. This device was developed, and patented by the Face Company [(2)]. The instrument stands on two support legs and the operator walks it along a survey line alternately pivoting the instrument about each leg. The distance between the footpads is fixed, which only allows a 12 inch sampling interval. This device has served the FDOT well for many years. However, advances in technology and testing procedures make it necessary to upgrade to a faster and higher resolution reference profiling device.

Figure 2. Dipstick

High-Speed Inertial Profiler (HSIP) - the HSIP used in this study is an ICC Multi-Purpose Survey Vehicle (MPSV) equipped with other subsystems in addition to the inertial profiling system. This profiling system has three single point laser sensors and two accelerometers mounted in the front bumper of the vehicle, which allow simultaneous profile measurement in the left and right wheel-paths at the operator’s preset sampling interval.

Figure 3. High-Speed Inertial Profiler (HSIP)

TESTING PROCEDURE

The left wheel-path (LWP) and right wheel-path (RWP) of both test sections were marked with chalk to provide reference lines for the devices to follow, and thus minimize lateral wander during profile measurements. Ten passes were performed with the Surpro in each wheel-path at both test sites, five passes in the forward direction, and five passes in the reverse direction, at 1 inch recording interval. The error of closure at the end of each run was distributed among the data points. Four passes were performed with the Dipstick in each wheel-path of the racetrack test section, two passes in the forward direction, and two passes in the reverse direction, at 12 inch recording interval. On SR 24 only two passes per wheel-path were performed with the Dipstick, one pass in the forward direction and one pass in the reverse direction. Ten repeat passes at 45 mph were conducted at both test sites with the HSIP in both wheel-paths, at 0.68 inch recording interval. The HSIP and the Surpro used a lead-in and a lead-out distance to ensure stability of the sensors.

DATA ANALYSIS

ProVAL Version 2.73, provided by the FHWA, was used to analyze the profile data from the three devices. The IRI roughness values measured by each device at both test section were evaluated. A direct comparison of profiles was also performed using the cross-correlation utility in ProVAL, in terms of repeatability and reproducibility of the IRI filtered profile outputs. A 250 mm moving average was applied in ProVAL for the HSIP profiler data, but was not applied to the Surpro or the Dipstick. This is because the physical footprint of these reference devices is equivalent to using a moving average.

IRI RESULTS

The average IRI and the IRI range, which is the difference between the minimum and the maximum IRI value, for all three devices are reported in Tables 1 and 2, for the Racetrack and SR 24, respectively.

Table 1. Racetrack IRI

Device	Average IRI (in/mile)		IRI Range (in/mile)	
	LWP	RWP	LWP	RWP
Dipstick	**43.8**	**56.8**	0.7	0.2
Surpro	**42.7**	**55.4**	1.1	1.0
HSIP	**43.4**	**54.4**	1.2	2.4

Table 2. SR 24 IRI

Device	Average IRI (in/mile)		IRI Range (in/mile)	
	LWP	RWP	LWP	RWP
Dipstick	**33.1**	**33.0**	0.3	0.1
Surpro	**34.4**	**33.8**	1.1	1.7
HSIP	**40.2**	**41.3**	2.3	1.6

The following observations were noted from the IRI results in Tables 1 and 2:

- At the Racetrack, the Surpro and Dipstick IRI match equally well with the HSIP's IRI.
- For SR 24, the Surpro and Dipstick IRI match well in both wheel-paths.
- For SR 24, the HSIP's average IRI values are different from the IRI values from the Dipstick and the Surpro. This is mainly due to the limitation of single point laser sensors which are sensitive to the short wavelength features in textured surfaces (Figure 4). This

problem does not affect the Surpro or Dipstick profiles because each device's footprint bridges over these features when in contact with the pavement (Figure 5).

Figure 4. SR 24 Profile from the HSIP

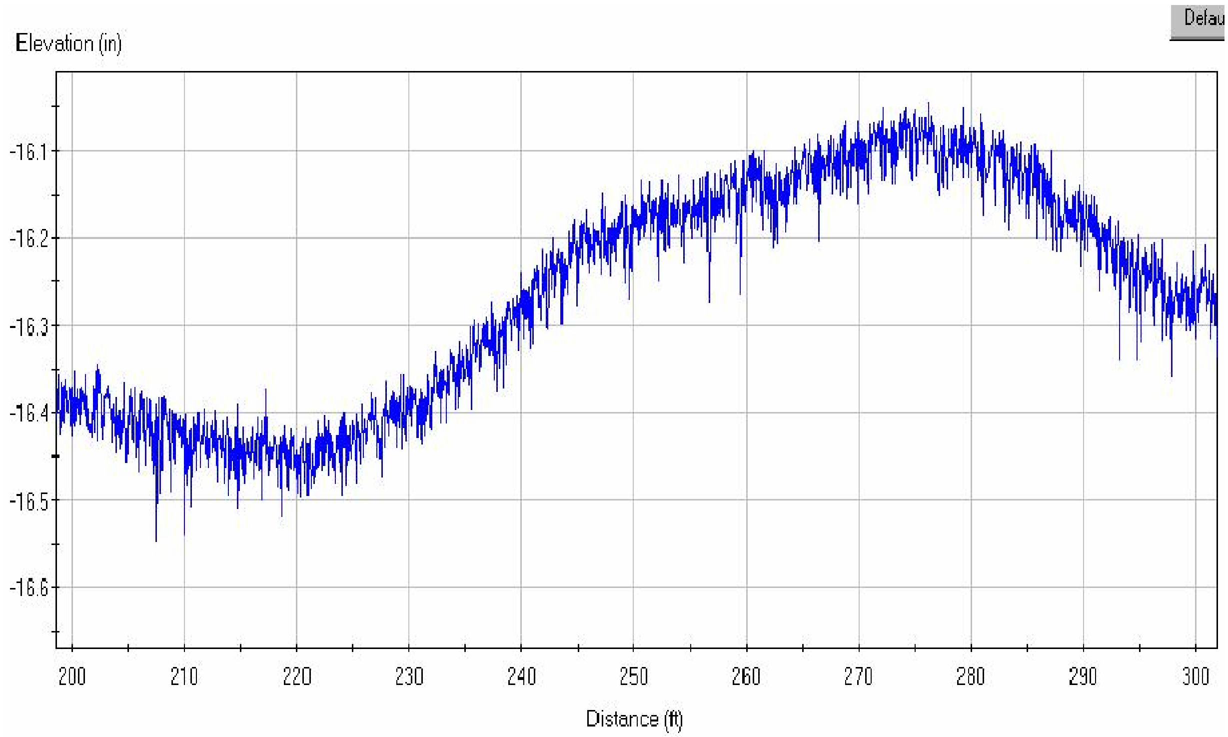
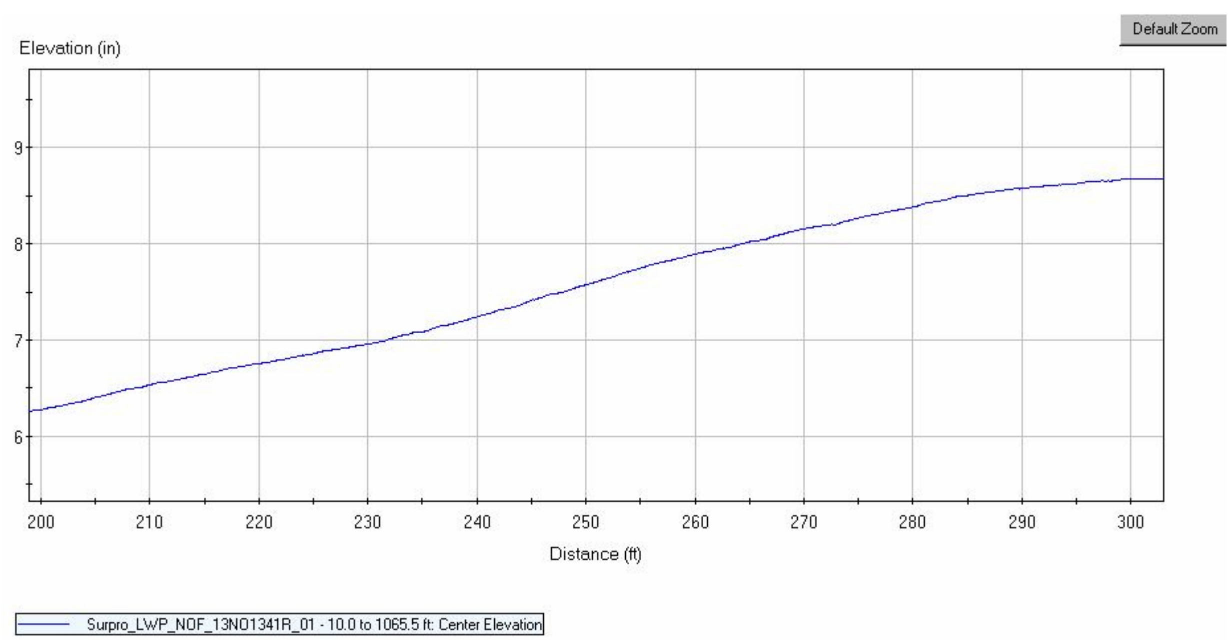


Figure 5. SR 24 Profile from the Surpro



CROSS-CORRELATION

The cross-correlation is a statistical method used for rating the agreement between profiles. Direct profile comparison is necessary to study the performance of profilers, because index values may compare favorably for a device due to compensating error, even when the profiles do not [(3)]. In this study, cross correlation was performed on the output of the IRI filter which is applied to profile data for evaluating profiler repeatability and reproducibility [(4)]. This rating of agreement represents repeatability when it is applied to two or more measurements of the same profile by the same device. It represents reproducibility when it is applied to two measurements of the same profile by different devices, and it represents accuracy when a measurement from one of those devices is deemed to be correct [(1)]. Since the "golden" profiler that measures the "Truth" is not yet available, one cannot tell whether the Surpro or the Dipstick is closer to the "Truth". Therefore for this study, the comparison between any two devices will be addressed in terms of reproducibility.

The ProVAL Version 2.73 software was used to analyze the cross-correlation repeatability and reproducibility. When the starting points for the devices do not match, the cross-correlation technique is used to correct for this by determining the proper offset to get the starting point of the two profiles to match. This analysis method is compliant with the AASHTO provision standard, PP49, "Standard Practice for Certification of Inertial Profiling System", which requires a minimum of 90% for repeatability of a particular device, and a 92% for reproducibility when comparing a reference device to a candidate device.

Repeatability Cross Correlation

To determine repeatability of a device when using ProVAL cross-correlation, at least three replicate profiles from the same device must be selected. For repeatability assessment, "passing" was considered a mean of 92% or greater. The average repeatability of the HSIP and Surpro was determined by performing a cross-correlation for all 45 profile pair combinations from the ten repeat runs in each wheel-path. The repeatability of the Dipstick at the Racetrack was determined in the same manner using six combination profile pairs from the four runs in each wheel-path. The Dipstick repeatability on SR 24 was not evaluated since only two passes in each wheel-path were conducted at this test site. The results of the cross correlation repeatability test for the HSIP, Surpro and Dipstick at the Racetrack and on SR 24 are reported in Tables 3 and 4, respectively.

Table 3. Repeatability on Racetrack

	HSIP		**Surpro**		**Dipstick**	
	LWP	**RWP**	**LWP**	**RWP**	**LWP**	**RWP**
Comparison Count	45	45	45	45	6	6
% Passing	80	84	100	100	100	100
Mean	**93**	**95**	**98**	**98**	**99**	**99**
Minimum	83	88	96	96	98	99
Maximum	97	98	98	99	99	100
Std. Deviation	4.0	2.7	0.6	0.8	0.4	0.4

Table 4. Repeatability on SR 24

	HSIP		Surpro		Dipstick	
	LWP	**RWP**	**LWP**	**RWP**	**LWP**	**RWP**
Comparison Count	45	45	45	45	-	-
% Passing	0	0	71	49	-	-
Mean	**72**	**70**	**93**	**92**	-	-
Minimum	68	63	90	88	-	-
Maximum	77	76	95	96	-	-
Std. Deviation	2.1	2.8	1.1	1.8	-	-

The following observations were noted from the repeatability cross correlation results in Tables 3 and 4:

- For the Racetrack, all three devices achieved good to excellent repeatability. The Dipstick achieved the highest repeatability (99%), followed by the Surpro (98%), and the HSIP (95%).
- For SR 24, the Surpro achieved a repeatability of 93% and 92% in the LWP and RWP, respectively.
- For SR 24, the HSIP achieved a repeatability of 72% and 70% in the LWP and RWP, respectively. The lower repeatability is due to the high frequency of short wavelength features in the texture, which is reflected as "noise" in the profile.

Reproducibility Cross Correlation

When evaluating the cross correlation reproducibility between two devices using ProVAL, one profile is selected as the "Reference Profile", and another profile is selected to represent the "Candidate Profile". For these reproducibility comparisons, "passing" was considered a mean of 90% or greater. The Surpro was considered the "Reference" and the HSIP was the "Candidate" when evaluating these two devices. The average Surpro profile measurements was first determined, and then compared to each profile trace from the HSIP. The reproducibility results are shown in Tables 5 and 6 for the Racetrack and SR 24, respectively.

Table 5. Average Surpro Vs HSIP Reproducibility on Racetrack

	LWP	**RWP**
Comparison Count	10	10
% Passing	80	90
Mean	**91**	**93**
Minimum	77	89
Maximum	95	96
Std. Deviation	1.2	1.0

Table 6. Average Surpro Vs HSIP Reproducibility on SR 24

	LWP	**RWP**
Comparison Count	10	10
% Passing	0	0
Mean	**70**	**61**
Minimum	67	60
Maximum	72	63
Std. Deviation	1.6	1.0

The Dipstick was considered the "Reference" and the Surpro the "Candidate" when comparing these two devices. The reproducibility results from the Racetrack LWP and RWP are shown in Tables 7 and 8, respectively. The reproducibility results from SR 24 for these two devices are reported in Table 9.

Table 7. Dipstick Vs Surpro Reproducibility on Racetrack LWP

	Run 1		**Run 2**	
	Forward	**Return**	**Forward**	**Return**
Comparison Count	10	10	10	10
% Passing	0	0	0	0
Mean	**85**	**86**	**86**	**86**
Minimum	83	85	83	83
Maximum	89	89	90	90
Std. Deviation	2	1.7	2.2	2.2

Table 8. Dipstick Vs Surpro Reproducibility on Racetrack RWP

	Run 1		**Run 2**	
	Forward	**Return**	**Forward**	**Return**
Comparison Count	10	10	10	10
% Passing	100	100	100	100
Mean	**93**	**93**	**93**	**94**
Minimum	91	90	91	92
Maximum	95	94	95	95
Std. Deviation	1.4	1.4	1.3	1.2

Table 9. Dipstick Vs Surpro Reproducibility on SR 24

	LWP		RWP	
	Forward	Return	Forward	Return
Comparison Count	10	10	10	10
% Passing	0	0	0	0
Mean	**82**	**86**	**80**	**80**
Minimum	80	84	77	77
Maximum	84	89	84	84
Std. Deviation	1.5	1.6	2.0	2.1

The average Dipstick profile measurements was determined, and then compared to each profile trace from the HSIP. The Dipstick was considered the "Reference" and the HSIP was the "Candidate" when evaluating reproducibility between these two devices. The reproducibility results are shown in Tables 10 and 11 for the Racetrack and SR 24, respectively.

Table 10. Average Dipstick Vs HSIP Reproducibility on Racetrack

	LWP	RWP
Comparison Count	10	10
% Passing	10	100
Mean	**88**	**92**
Minimum	83	90
Maximum	90	94
Std. Deviation	2.1	1.2

Table 11. Average Dipstick Vs HSIP Reproducibility on SR 24

	LWP		RWP	
	Forward	**Return**	**Forward**	**Return**
Comparison Count	10	10	10	10
% Passing	0	0	0	0
Mean	**65**	**68**	**60**	**60**
Minimum	63	65	57	57
Maximum	67	70	63	62
Std. Deviation	1.7	1.7	1.6	1.5

The following observations were noted from the average reproducibility cross correlation results:

- On the Racetrack, the reproducibility between Surpro and HSIP was 91% and 93% in the LWP and RWP, respectively.
- On the Racetrack, the reproducibility between Dipstick and the Surpro was 86% in the LWP, and 93% in the RWP.
- On the racetrack, the reproducibility between Dipstick and HSIP was 88% in the LWP and 92% in the RWP
- On SR 24, the reproducibility between the Surpro and HSIP was 70% and 61% in the LWP and RWP, respectively.
- On SR 24, the reproducibility between the Dipstick and Surpro was 84% in the LWP and 80% in the RWP.
- On SR 24, the reproducibility between the Dipstick and HSIP averaged 67% in LWP and 60% in RWP.

CONCLUSIONS

The results of the analysis show that the Surpro can and should be used as a profile reference device to replace the Dipstick. This is supported by the following facts and findings:

1. All three devices had a good to excellent cross correlation repeatability on both test sections, except for the HSIP on SR 24 due to limitation of single spot lasers on the coarse textured surface.
2. The Surpro showed a better reproducibility cross correlation with the HSIP than did the Dipstick on the Racetrack and on SR 24.
3. The IRI from the Surpro and Dipstick showed good agreement with each other on both the Racetrack and SR 24.
4. AASHTO PP-49 indicates the maximum measurement interval for a reference profile device should be 2.75 inches. The Surpro meets this requirement, but the Dipstick does not meet the requirement.
5. AASHTO PP-49 states the reporting interval for a HSIP must be 2 inches or less, and shall be no greater than 2.75 inches for a reference device. The dipstick's fixed 12 inch recording interval is too long, and can miss features between the footpads. This is not the case with the Surpro, as it can record profile measurements at 1 inch intervals. Hence, the Surpro can more easily match the HSIP's recording interval, making the Surpro superior to the Dipstick.
6. The Surpro is faster to operate than the Dipstick, which reduces the time needed for lane closures, and lessens the inconvenience to the traveling public. A reduced number of repeat runs will be required, as more familiarity is gained with the Surpro.

The surface texture on SR 24 presented a challenge for the HSIP due to the limitation of single point laser which senses the short wavelength features in the surface texture, and is miss-interpreted as roughness. The same phenomenon is expected on diamond ground and longitudinally tinned concrete pavements. This problem was not observed when using the Surpro or the Dipstick, because the Surpro's tire and Dipstick footpads act as a mechanical filter by bridging over the surface texture features. There is therefore a need to establish an appropriate method to eliminate these unwanted features from the profile output by using an appropriate digital filtering method and wide footprint laser(s), with a reduced lateral wander of the host vehicle. The profiling community is continuously working on addressing and resolving this problem.

RECOMMENDATIONS

The findings of this study show the Surpro is a superior reference device for validating a HSIP compared to the Dipstick. However, further study is needed to validate HSIP using the Surpro on textured pavement surfaces like open-graded friction course and longitudinally ground concrete surfaces, which still present a challenge to single spot lasers**.**

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