STATE OF FLORIDA

EVALUATION OF A LIGHTWEIGHT PROFILER FOR MEASUREMENT OF PCC PAVEMENT ROUGHNESS

Research Report
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EXECUTIVE SUMMARY

Road smoothness/roughness is gaining growing importance as an indicator of a pavement condition, both in terms of performance, and as a major determinant of road user costs. Therefore, attaining acceptable surface smoothness on newly constructed pavements is becoming a major concern to highway agencies. The Florida Department of Transportation (FDOT) currently specifies the use of a California-type profilograph for acceptance purposes of the final surface finish on Portland cement concrete (PCC) pavements. However, testing using such a device is slow, tedious, and labor intensive.

It is Florida's intent to automate the process of ride acceptance. Thus, FDOT initiated a field study to assess the feasibility of implementing the use of laser-based lightweight profilers for such a purpose. If a lightweight profiler is to be considered for ride acceptance in Florida, it is essential to assess its level of correlation with the currently specified profilograph device. Profile Index values were acquired using both a lightweight profiler and a California-type profilograph concurrently on a large number of concrete pavement sections for comparative purposes. In addition, the lightweight profiler testing repeatability and the effects of its testing speed gradients on roughness measurements were also considered.

This report presents a description of the testing program, the data collection effort as well as the subsequent analyses and findings.

BACKGROUND

Road smoothness/roughness is gaining growing importance as an indicator of a pavement condition, both in terms of performance, and as a major determinant of road user costs. Therefore, attaining acceptable surface smoothness on newly constructed pavements is becoming a major concern to highway agencies. This need to quantify pavement surface smoothness has resulted in a number of measurement techniques and devices.

FDOT present procedure requires the use of a California-type profilograph for acceptance purposes of the final surface finish on PCC pavements. The maximum test speed with this hand-pushed profilograph is 5 km/h (3 mph (or walking speed)). Thus, testing using such a device is slow, tedious, and labor intensive.

In recent years considerable attention has been focused on the use of laser technology because of its versatility, ease and speed of use. Of interest to Florida is the lightweight profiler. This golf-cart like vehicle is a single laser sensor system light enough to drive on and profile concrete pavements that have not completely cured so that early corrective actions may be taken. The equipment complies with the requirements of ASTM E950 for Class 1 profiling equipment.

It is Florida's intent to automate the process of ride acceptance on concrete pavements. Thus, FDOT initiated this field study to assess the feasibility of implementing the use of lightweight profilers for such a purpose. If a lightweight profiler is to be considered for ride acceptance in Florida, it is essential to assess its level of correlation with the currently specified profilograph device. Profile Index values were acquired using concurrently both the lightweight profiler and the California profilograph on a large number of concrete pavement sections for comparative purposes. In addition, the lightweight profiler testing repeatability and the effects of its speed gradients on roughness measurements were also evaluated.

This report presents a description of the testing program, the data collection effort as well as the subsequent analyses and findings

OBJECTIVE

The primary objective of this study is to assess the level of correlation of the lightweight profiler with the currently specified profilograph device for ride quality or smoothness of PCC pavements in Florida. The testing precision of the laser-based profiler as well as its ease of use, field-worthiness, and ruggedness were considered. In addition, the effects of testing speed gradients on roughness measurements were also evaluated.

Current Florida State of the Practice

As stated earlier, the current FDOT procedure for acceptance of the final surface finish specifies the use of a California-type profilograph in accordance with the Florida method of testing FM 5-558. Typically, a pavement project is evaluated for surface smoothness in 530 ft (0.1 mile) consecutive sections, beginning and ending 15-ft within the project limits. It should also be noted that a 10-ft rolling straightedge is required on all pavement sections less than 250 ft in length.

The profile testing is conducted along the travel wheel path at approximately 3 ft from the longitudinal outward edge of a pavement. Two profile runs are performed for each pavement lane. The level of the test section smoothness is defined in terms of an average Profile index value, in excess of a 0.2 in. blanking band. The longitudinal centerline of this band is optimally positioned between the high and low of a profile record considering at least 100 feet of pavement. For acceptance purposes, the PI requirement for each profile trace run is as follows:

- For pavement sections on tangent alignment and horizontal curves with centerline radius of 2,000 ft or more, the maximum allowable PI is 7 in./mile.

- For pavement sections on horizontal curves with a centerline radius between 1,000 to 2,000 ft and for pavement sections within a superelevation transition of such curves, the maximum allowable PI is 9 in./mile.
- In addition to the above PI requirements, the pavement surface areas with individual profile deviations in excess of 0.3 in from a chord representing 25 ft or less on the longitudinal scale must be corrected.

EXPERIMENTAL PROGRAM AND DATA COLLECTION

Smoothness-Measuring Devices

In the following sections, the pavement profile-measuring devices used in this study are described. The description includes an overview of the development of each device and its physical and testing characteristics.

California Profilograph

The profilograph used for this study was a computerized California-type model, as seen in Figure 1. The mechanical models of these profilographs have been produced since 1960, while the automated version was introduced in the mid-1980s. The automated profilograph consists of a 25-ft aluminum frame supported on both ends by a non-uniformly spaced series of ten wheels. It is equipped with a specifically designed computer for data acquisition and a gas generator to provide operating power. The surface-sensing wheel and recorder are located at the center of the reference platform.

Lightweight Profiler

As illustrated in Figure 2, the lightweight profiler is a golf-cart like vehicle light enough to drive on “green” concrete pavements. It uses an infrared laser sensor and a precision accelerometer to measure a pavement’s longitudinal profile. The laser and accelerometer are mounted on the front bumper of the vehicle. A computer with an active matrix flat panel display is used as a data acquisition and display system. A fifth wheel with a pulse generator is used to monitor the testing distances. It is also equipped with a photo-triggering device to accurately start and stop the data collection process. The data collected can be used to produce a variety of ride parameters such as International Roughness Index, Ride Number, or simulate the output from a California profilograph. The equipment operates at speeds of up to approximately 20 mph and complies with the requirements of ASTM E950 for Class 1 profiling equipment.

Data Collection

Profile measurements were acquired using both the lightweight profiler and the California profilograph concurrently (thus minimizing the temperature effects on test results) on a large number of concrete pavement sites. These profile data were then analyzed to determine the Profile Indexes (PI) at each test site. The results were used for the purpose of this study. All the sites were randomly selected from three different projects in an effort to achieve unbiased test site distributions. Each test site was 0.1 mile long. Within each test site, roughness data were continuously collected on predefined paths of the travel lane.

Lightweight Profiler vs. California Profilograph Measurements

To assess the level of correlation of the lightweight profiler with the California profilograph, 16 test sites were considered. Within each site, 3 profile measurements (or passes) were taken along each wheel path using both devices. The lightweight profiler was operated at a speed of 18 mph. The same operator was used throughout this testing for each of the equipment to minimize the operator effect.

Lightweight Profiler Precision

Two of the most important criteria of the usefulness of any testing device are accuracy and precision. Although, the profiler accuracy may not be easy to assess in this case, the precision was addressed in term of the level of testing repeatability. Therefore, measurements from three additional test sites were used to assess the testing repeatability of the lightweight profiler. Within each site, 10 measurements were taken using the lightweight profiler along predetermined paths. The path was predefined on the concrete surface to control the longitudinal alignment of the testing operation. Two operators repeated the above sequence of operation so that the effect of operator could also be evaluated. The profiler was operated at speeds of 15 to 18 mph.

Speed Gradient Effect on Profiler Measurements

When measuring a pavement surface profile, a lightweight profiler may be operated at speeds ranging from approximately 5 to 20 mph. An evaluation was then performed to ensure that any test speed within this range would result in comparable PI values. For this purpose, 2 test sections and 3 operating speeds were considered.

DATA ANALYSIS

If a lightweight profiler is to be considered for ride acceptance in Florida, it is essential to assess its level of correlation with the currently specified profilograph device. Thus, the primary objective of this study was to compare lightweight profiler measurements with those of the profilograph. The profile data as collected during the course of this investigation were first analyzed to determine the Profile Indexes at each test site. The results were then used as a basis for an evaluation of the level of correlation between the two profiling devices.

Lightweight Profiler vs. California Profilograph Measurements

The illustrative comparison, in terms of PI values, of all the data collected on 16 test sites using both profiling devices is shown in Figure 3. Within each site, 3 profile measurements (or passes) were taken along each wheel path using both devices. Therefore, the comparison considered a total of 96 paired-data points. Figure 3 also shows the level of agreement between the profilograph and profiler PI values. This plot indicates that there is a good correlation between the two devices as reflected by the R-square value of 0.98. In addition, all the measurements lower than about 20 in./mile fall near a straight line with relatively little dispersion about the regression curve. Within this range, the regression curve is below but still closer to the equality line. This implies then that, within the same test site, the current profilograph-based procedure would generally result in a relatively, but not necessarily significantly, lower PI than the profiler. Above the 20 in/mile mark, the regression curve starts diverging away from the equality line.

The number of rough areas as determined using each of these devices was also analyzed. These rough areas are defined herein as the scallops or excursions of a pavement surface trace at least 0.03 in. vertically above and below the blanking band. As stated previously, Florida uses a blanking band of 0.2 in. in height. An illustrative comparison of all the respective number of rough areas as obtained on each of the test sites using the two profile devices is given in Figure 4. The plots shows that the profiler indicated a lower number of rough spots than the profilograph on a large number of test segments. One could assume that, based on the PI values comparison described above, the magnitude of some of these scallops may not be comparatively significant or excessive. Furthermore, the number of individual areas requiring corrective grinding is shown in Figure 5. The current Florida procedure specifies that the pavement surface areas with individual profile deviations in excess of 0.3 in. from a chord representing 25 ft or less on the longitudinal scale must be corrected. Figure 5 indicates that, within each test site requiring spot grinding, the profilograph determined a higher number of areas requiring grinding that the profiler. As also shown in Table 1, out of the 10 test segments requiring localized corrective actions, the two profiling devices strongly agree on the number of "must grinds" on 3 sites and strongly disagree on at least 4 sites. On the latter cases, the profilograph indicated approximately twice as many "must grinds" as the profiler. The results were somewhat comparable on the remaining 3 sites. In addition, both devices agree that the other 22 segments that were also tested did not require any localized corrective actions. All these findings are based on the average of three passes per site.

Lightweight Profiler Precision

A statistical analysis was also performed to assess the test data variability and the testing repeatability of the lightweight profiler. This assessment was in statistical terms of range values (differences between the highest and lowest PI values), standard deviations (square root of the variance), and coefficients of variation (standard deviation divided by the mean, expressed as a percentage). The range serves herein as a convenient measure of the dispersion of the test data, while the standard deviation and coefficient of variation provide, respectively, a convenient measure of deviation around the mean and a normalized way of expressing data variability. For the purpose of such an analysis, 3 sections were randomly selected and 2 operators were used on each of these sections. On each section, both operators conducted 10 profiler runs along predefined longitudinal paths. The results, summarized in Table 2, indicate that, in general, the PI data were more repeatable and less variable on section 1. Also, there seems to be more dispersion in the data collected by Operator 1 than in those of Operator 2 on Sections 2 and 3.

To further analyze the effect of both Operators on the PI data, paired-difference experiments were conducted. The intent was to determine the significance level of the observed differences between and within the operators' data on each test section. The hypothesis concerning the equality between the corresponding PI results was tested using the Student t-test. The computed t values within each of the 3 test sections were 0.074, 0.566, and 1.5436, respectively. The critical value of t based upon $n - 1 = 9$ (n is the number of paired differences, which is 10 (10 runs per operator)) degrees of freedom and a level of significance $\alpha = 0.05$ is $t_\alpha = 2.262$. The comparison of this latter value to the computed ones indicates that, within the test range, the PI measurements as collected by both operators were not statistically different within each of the test section. Both operators were collecting profile measurements at the same mean level. Moreover, to ensure that this analysis is not skewed by the presence of potential outliers, a Wilcoxon signed-rank test was also applied. This test indicated that both operators recorded comparable measurements on the first 2 sections. However, on section 3, Operator 1 yields were statistically significantly lower than those of operator 2 at a level of significance $\alpha = 0.05$. It is possible, when further reviewing the Operator 1 individual test data on section 3, to consider the PI values corresponding to test runs (passes) 1 and/or 3 as outliers. Ignoring these test runs 1 and 3 in the analysis, the Wilcoxon signed-rank test subsequently indicated that the measurements were statistically comparable.

Speed Gradient effect on Profiler Measurements

The effects of profiler test speed gradients on the PI values were also evaluated. For this purpose, one operator, 2 sections, and 3 test speeds 6, 12, and 18 mph were considered. The overall results, as shown in Table 3, indicated that operating the profiler at a test speed of 12 mph generated more consistent and less dispersed PI data among the 5 passes within each test section.

Moreover, a two-way analysis of variance (ANOVA) was also conducted. The ANOVA procedure was used to further analyze the data as a factorial experiment with three levels of testing speed and two levels of testing path. The purpose of such an analysis was to evaluate, within each test section, if there was any evidence of real differences between and within the respective PI values as determined using the three test speeds on the two testing paths. An important result of ANOVA is the *P*-value corresponding to the factor(s) considered (testing speeds and testing paths in this case). Basically, the *P*-value for a particular factor indicates the probability of error of the hypothesis that the factor has a significant effect on the measured parameters.

The results of the ANOVA are presented in Table 4. The calculated F values are compared with the critical F value for the corresponding degrees of freedom to determine whether to accept the null hypothesis of no difference between the PI data. It can be inferred from these ANOVA results that, at 95 percent confidence level, the profile measurements are separately affected by the testing speed of the profiler and the testing path. The interaction effect, however, between the two factors is not significant. In addition, the measurements within each test path at each test speed are not statically different, again at 95 percent confidence level.

CONCLUSIONS

The present study was conducted to assess the level of agreement of the lightweight profiler with the currently specified profilograph device for ride quality determination of PCC pavements in Florida. The profile data as collected during the course of this investigation were first analyzed to determine the Profile Indexes at each test site. The results were then used as a basis for an evaluation of the level of correlation between the two profiling devices. Also, the profiler testing repeatability as well as its testing speed gradient effects on roughness measurements were considered. Within the test range, the findings indicated the following:

- A comparison considering a total of 96 paired-data points showed a good correlation between the two devices as reflected by the R-square value of 0.98. In addition, the current profilograph-based procedure generally generated relatively, but not necessarily significantly, lower PI values than the profiler.
- The profiler found a lower number of rough areas than the profilograph on a large number of test segments. These rough areas are defined herein as the excursions of a pavement surface trace at least 0.03 in. vertically above and below the blanking band. However,

based on the PI values comparison, the magnitude of some of these scallops may not be comparatively significant or excessively above or below the band.

- The two profiling devices showed disagreement on at most 7 sites out of 32 on the number of individual areas requiring corrective grinding.
- Within the test range, the overall results of statistical analyses indicated that the profiler PI values were relatively repeatable showing statistically insignificant variability. Both operators, when more than one operator was used, collected profile data at the same mean level.
- A two-way ANOVA indicated that, at 95 percent confidence level, the profile measurements are affected by the testing speed of the profiler and the testing path. Also, the effect of interaction between the profiler speed and the testing path is not significant. However, the measurements within each test path at each test speed are not statically significantly different, again at 95 percent confidence level.
- Operating the profiler at a test speed of 12 mph generated more consistent and less dispersed PI data within each test section.

RECOMMENDATIONS

All the findings of the present study suggest that the lightweight profiler can be a practical, fast, and reliable alternative to a California-type profilograph for acceptance purposes of the final surface finish on Portland cement concrete (PCC) pavements. It is, however, suggested that its accuracy be further investigated. The intent is to develop potential precision and bias estimates. It is also suggested that experienced operators be used, the testing speed be set at approximately 20 km/h (12 mph), and that the testing be conducted on both wheel paths.

ACKNOWLEDGMENTS

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Table 1 Summary of Number of Individual Areas Requiring Grinding

Site No.	Profiler	Profilograph
1	1	1
2	1	1
3	1	1
4	0	1
5	2	3
6	2	4
7	3	7
8	3	5
9	4	5
10	3	5

Table 2 Results of Profiler Testing Repeatability and Operator Effects on PI Values, in./mile

Pass No.	Section 1			Section 2			Section 3		
	Operator 1	Operator 2	Diff.	Operator 1	Operator 2	Diff.	Operator 1	Operator 2	Diff.
1	3.0	3.5	0.5	4.6	5.8	1.2	3.1	4.7	1.6
2	3.3	3.5	0.2	5.8	6.4	0.6	4.8	5.0	0.2
3	3.1	2.9	0.2	6.4	7.1	0.7	3.0	5.9	2.9
4	3.7	2.8	0.9	6.5	5.9	0.6	4.8	4.8	0.0
5	3.2	3.3	0.1	4.9	5.6	0.7	4.3	5.6	1.3
6	3.5	2.9	0.6	6.4	7.4	1.0	3.8	5.0	1.2
7	3.1	2.6	0.5	7.3	6.3	1.0	5.0	5.3	0.3
8	3.1	3.9	0.8	7.4	7.0	0.4	5.1	5.2	0.1
9	3.1	3.2	0.1	6.2	6.2	0.0	4.9	5.3	0.4
10	2.9	3.2	0.3	6.7	6.6	0.1	3.8	5.1	1.3
Average	3.2	3.2	0.0	6.2	6.4	0.2	4.3	5.2	0.9
Range	0.8	1.3	0.5	2.8	1.8	1.0	2.1	1.2	0.9
Std. Dev.	0.2	0.4		0.9	0.6		0.8	0.4	
Coef. Var.,%	7.5	12.2		14.7	9.3		18.4	6.9	

Table 3 Summary of Results on Speed Gradient Effects on PI Values, in./mile

Pass No.	Section 1					
	Path 1			Path 2		
	6 mph	12 mph	18 mph	6 mph	12 mph	18 mph
1	6.7	3.9	4.3	7.2	2.9	3.2
2	9.3	4.9	3.6	5.6	2.7	2.8
3	8.2	5.0	4.4	3.7	2.7	3.3
4	7.3	4.6	2.5	5.8	2.3	2.9
5	8.2	4.4	3.5	7.4	2.7	2.9
Average	7.9	4.6	3.7	5.9	2.7	3.0
Range	2.6	1.1	1.9	3.7	0.6	0.5
Std. Dev.	0.99	0.44	0.76	1.49	0.22	0.22
Coef. Var., %	12.55	9.55	20.64	25.24	8.11	7.23
	Section 2					
	Path 1			Path 2		
1	3.7	2.8	3.2	3.3	0.7	0.9
2	4.4	1.7	1.5	2.8	0.6	0.4
3	5.9	2.2	1.6	2.8	0.7	0.8
4	5.6	2.6	0.9	3.0	1.1	1.0
5	3.7	2.6	1.7	4.5	0.5	0.9
Average	4.7	2.4	1.8	3.3	0.7	0.8
Range	2.2	1.1	2.3	1.7	0.6	0.6
Std. Dev.	1.04	0.44	0.85	0.71	0.23	0.23
Coef. Var., %	22.14	18.26	47.37	21.58	32.58	29.32

Table 4 ANOVA Results on Effects of Testing Speed and Testing Path on PI Values

Source of Variation	Deg. of Freedom	Sum of Squares	Mean Squares	F-value	*P*-value	F crit
			Section 1			
Testing Speed	2	80.41	40.20	59.24	5.21938E-10	3.40
Testing Path	1	17.18	17.18	25.31	3.84483E-05	4.26
Interaction	2	2.87	1.44	2.12	0.142392049	3.40
Within	24	16.29	0.68			
Total	29	116.74				
			Section 2			
Testing Speed	2	43.69	21.84	50.10	2.71018E-09	3.40
Testing Path	1	13.47	13.47	30.89	1.0205E-05	4.26
Interaction	2	0.58	0.29	0.67	0.521157251	3.40
Within	24	10.46	0.44			
Total	29	68.20				

Figure 1 Illustration of a California-Type Profilograph.

Figure 2 Illustration of a Lightweight Profiler.

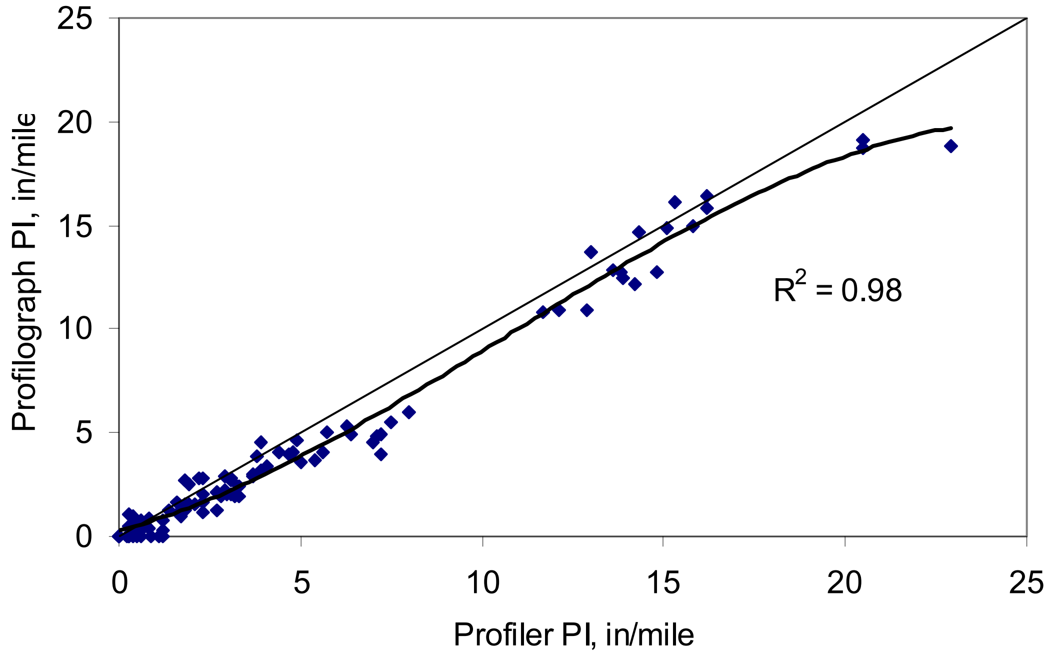

Figure 3 Illustrative comparison of Profile Indexes as determined using both profiling devices.

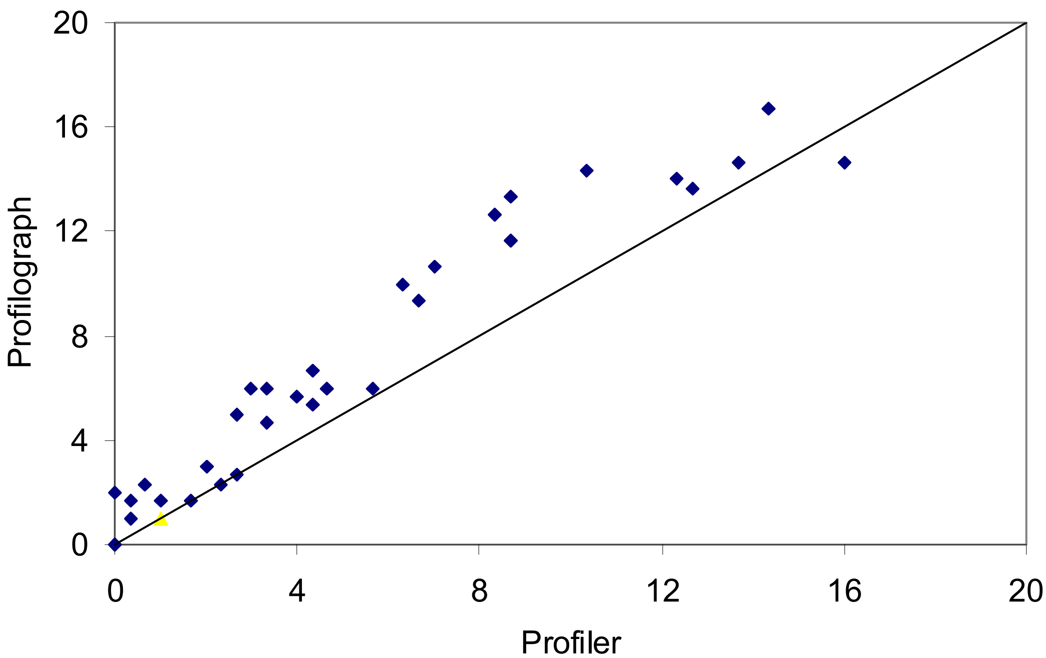

Figure 4 Illustrative comparison of number of rough areas as determined using both profiling devices.

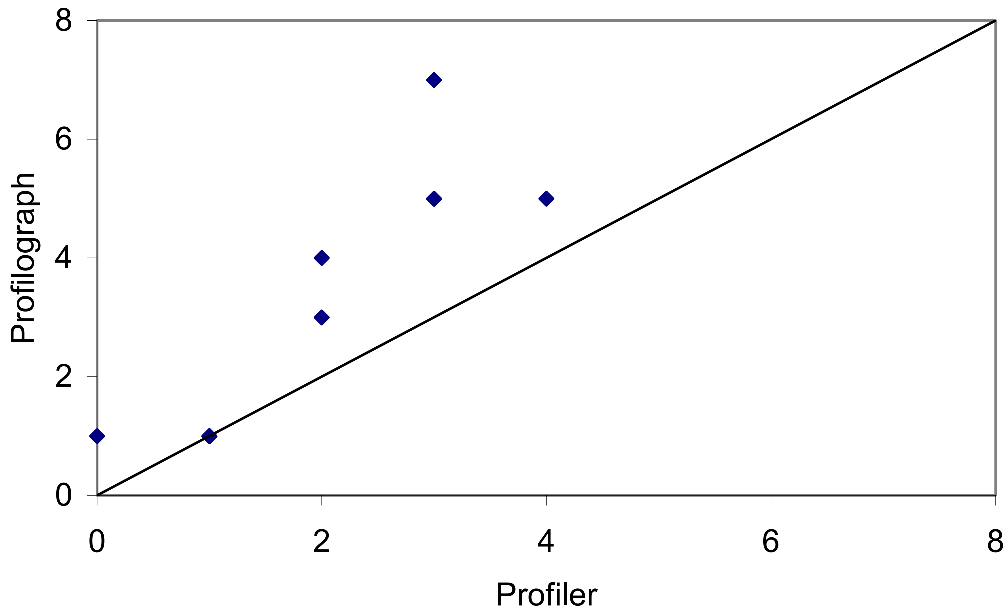

Figure 5 Illustrative comparison of number of “must grind” areas as determined using both profiling devices.