Journal of
Engineering Research

MULTILASER PROFILOMETER CERTIFICATION FOR MEASUREMENT OF RUTFLINING IN PAVEMENTS

Gerber Josafatt Zavala Ascaño
Universidad Nacional Mayor de San Marcos
Lima – Perú
https://orcid.org/0000-0003-1088-4543

Abstract: The purpose of the validations and certification is to guarantee the reliability of the measurements, which will influence the analysis and approach of solution alternatives such as: underdesign or oversizing of the pavement structure, periodic maintenance or rehabilitation needs, and post-construction evaluations. to determine the probable causes of premature pavement deterioration. An initial evaluation of the pavement condition was made to identify potential sections for the execution of the evaluations. Differentiated pavement sections were identified with a range of rutting depths of: 5 mm, 10 mm, 15 mm, 20 mm and greater than or equal to 25 mm; in a test sector length of 350 m, which corresponds to 35 sample units of 10 m length. Three evaluators made manual measurements of the existing rutting, on the left and right tracks, of the 35 pavement sample units. Compilation of the cross section, depth and width of the rutting with the Multilaser profilometer, both in the left and right track of each section at speeds of 40 and 60 km/hour, repeating six (06) times for each speed.

Keywords: Rutting and depths, laser profilometer.

GOAL

Establish the procedure to carry out the certification tests of the pavement rutting measurements, determined using a multilaser device fitted on a vehicle (multilaser profiler), comparing with the measurements carried out with a static or manual reference instrument; including test parameters and pass criteria on what constitutes an acceptable test result.

Establish the procedure to carry out the validation of the Accuracy and Repeatability measurement. The Accuracy validation included in this method is used to determine if there is a systematic deviation in the measurements of a profilometer over time.

VALIDATION

PROCEDURE

The following steps were executed:

1. Reference rutting measurement with the Manual method.

2. Rutting Measurement with the Multilaser Profilometer.

3. Analysis of variance of manual measurements.

4. Comparison of the correlation between the reference method and the multilaser profilometer.

5. Comparison of the Repeatability and Accuracy of the measurements.

PROSECUTION

• Analysis of variance and calculation of the average rutting for the 35 sample units, obtained with the manual method.

Comparative Method

(a) Process each test performed by the Multilaser profilometer in each test section and report the rutting depths per track in ten meter segments. Select rutting depth measurements per track from the one-meter segments that are closest to the corresponding locations where the baseline measurements were made (nominally every 10 meters).

(b) Determine the rutting depths per footprint, every 10 m measured by the reference equipment.

(c) For each of the three speeds, pool the measurement data. Using least squares regression, a best linear fit between the two sets of results must be identified for each velocity fit:

$$ProfAh_{Base} = A \cdot ProfAh_{Perfilómetro} + B$$

Where:

$ProfAh_{Base}$ = Rutting depth calculated from baseline measurement (i.e., cross section recorder – Disktip, staff and level or straight rule)

$ProfAh_{Perfilómetro}$ = Rutting depth calculated from multilaser profilometer operation

TO = Slope of the line equation

B. = Intercept of the equation of the line

The correlation coefficient, for each regression must also be calculated.

(d) Group all the measurements of themultilaser profilometer on a data set. Using least squares regression, a best linear fit between the two sets of results must be identified for each velocity fit:

$$ProfAh_{Base} = A \cdot ProfAh_{Perfilómetro} + B$$

Where:

$ProfAh_{Base}$ = Rutting depth calculated from baseline measurement (i.e., cross section recorder – Disktip, staff and level or straight rule)

$ProfAh_{Perfilómetro}$ = Rutting depth calculated from multilaser profilometer operation

TO = Slope of the line equation

B. = Intercept of the equation of the line

The correlation coefficient, for each regression must also be calculated.

Repeatability
a) **Criterion for Repeatability 1**
Determine the coefficient of variation (ie the standard deviation represented as a percentage of the mean), CV%, of each track per 10 m section from repeated measurements.

$$CV_{nw}(\%) = 100 \frac{\sigma_{nw}}{\bar{X}_{nw}}$$

Where:

$$\sigma_{nw} = \sqrt{\frac{\sum_{i=1}^{N}(X_{nw} - \bar{X}_w)^2}{N - 1}}$$

$$\bar{X}_{nw} = \frac{\sum_{i=1}^{N} \bar{X}_{nw}}{N}$$

w = Fingerprint

no = section number

No. = Total number of measurements in footprint w in section n

X_{nw} = Rutting of track w, section n of measurement i (with i=1 up to N)

b) *Criterion for Repeatability 2*
Determine the average of the coefficients of variation of the sections,, as described: $\overline{CV}\%$

$$\overline{CV}\% = \frac{\sum_{n=1}^{n_s} CV_{wn}\%}{N}$$

Where:

No. = total number of sections

c) *Criterion for Repeatability 3*
Using least squares regression, determine the correlation coefficient, r^2, where the individual rutting values of each track and section (dependent variable, y) correlate with the average value of each track and section (independent variable, x).

Accuracy
Calculate the Accuracy between the comparison and reference data set as described:

$$BE = \left| \frac{100}{n} \sum_{w=1}^{2} \left[\sum_{i=1}^{n} \frac{\bar{X}_{Ri} - \bar{X}_{Ci}}{\bar{X}_{Ri}} \right] \right|$$

Where:

BE = Accuracy between comparison and reference data set

$\overline{X}_{Rwi}$ = Average rutting depth of track reference data w, section i

$\overline{X}_{Cwi}$ = Average rutting depth of track comparison data w, section i

no = total number of sections

ACCEPTANCE RANGES

The acceptance of the results of the measurements carried out was determined through statistical analysis that covered three phases:

COMPARATIVE METHOD

(a) A statement as to whether the profilometer PASSES or DOES NOT PASS profile measurement validation - the profilometer is considered to have passed profile measurement validation if all values are within the following ranges:

- Automated device (for example:cross section recorder – Disktip):

Individual speeds 6.2(c)	$0.90 \leq A \leq 1.10$	$-2.5 \leq B \leq 2.5mm$	$r^2 \geq 0.900$
Combined Results 6.2(d)	$0.925 \leq A \leq 1.075$	$-2.5 \leq B \leq 2.0mm$	$r^2 \geq 0.925$

- Manual reference device (for example: straight rule of two meters):

Individual speeds 6.2(c)	$0.90 \leq A \leq 1.10$	$-2.5 \leq B \leq 2.5mm$	$r^2 \geq 0.900$
Combined Results 6.2(d)	$0.925 \leq A \leq 1.075$	$-2.5 \leq B \leq 2.0mm$	$r^2 \geq 0.925$

REPEATABILITY

(a) A statement of whether the criteria forREPEATABILITY1 has been passed - when 90% of all values are less than or equal to 1 mm as reported in (b) or less than or equal to 10% as reported in (d).

(b) A statement of whether the criteria forREPEATABILITY2 has been approved - when the value reported in (c) is less than or equal to 1 mm or the value reported in (e) is less than 7%.

(c) A statement of whether the criteria forREPEATABILITY3 has been approved - when all values reported in (f) are greater than or equal to 0.90.

ACCURACY

(a) A statement of whether the Accuracy criterion has been approved - when the Accuracy is less than or equal to 5%.

LONGITUDINAL DISTANCE ACCURACY

(a) The Accuracy of the distance must be within 0.2% of the actual length of the test length.

RESULTS

MANUAL RUTTING MEASUREMENT

PROGRESSIVE (Km)	RUDTING MANUAL MEASUREMENT (AM)			
	LEFT		RIGHT	
	DEPTH(mm)	WIDTH(mm)	DEPTH(mm)	WIDTH(mm)
00+000	5.0	47.3	2.0	43.0
00+010	0.0	0.0	2.7	47.7
00+020	2.7	55.7	3.7	57.7
00+030	8.3	74.0	0.7	13.3
00+040	3.0	65.0	4.0	65.0
00+050	4.0	74.0	2.0	70.0
00+060	2.0	57.0	4.0	78.0
00+070	23	69.0	2.0	90.0
00+080	3.0	89.0	2.0	83.3
00+090	3.0	64.3	2.7	66.7
00+100	23	65.3	2.0	72.7
00+110	2.0	49.0	1.7	69.7

TABLE 1 - AVERAGE MEASUREMENTS CARRIED OUT BY THREE EVALUATORS

r	:	3
Correction term	:	12696.51
total sum of squares	:	8513.49
Intergroup sum of squares	:	37.73
Intragroup sum of squares	:	8475.76
Intergroup root mean square	:	18.86
Intragroup root mean square	:	85.61
F	:	0.22
Degrees of freedom		
Numerator	:	2
Denominator	:	99
F (Fisher)	:	4.88
Interpretation	:	**There is no significant difference**

TABLE 2 - ANALYSIS OF VARIANCE: LEFT RUTTING

REPEATABILITY

PROGRESSIVE (Km)	MAXIMUM DEPTH OF THE TRACK IN SECTIONS OF 10 m (mm)						AVERAGE(mm)	REPEATABILITY CRITERIA 01		
	1	2	3	4	5	6		STANDARD DEVIATION	CV(%)	CONDITION
00+010	4.2	2.9	2.9	3.1	3.4	3.9	3.4	0.5	14.7	MEETS
00+020	3.5	3.7	3.7	3.9	3.6	3.5	3.6	0.2	5.6	MEETS
00+030	2.4	1.6	1.5	1.6	2.5	2.4	2.0	0.5	25.0	MEETS
00+040	3.1	2.8	2.5	2.7	3.0	3.0	2.9	0.2	6.9	MEETS
00+050	2.1	1.8	1.4	1.7	1.5	2.4	1.8	0.4	22.2	MEETS
00+060	2.2	2.0	2.1	1.9	2.4	2.2	2.1	0.2	9.5	MEETS
00+070	0.8	0.8	0.8	0.9	0.7	0.6	0.8	0.1	12.5	MEETS
00+080	1.5	1.4	1.2	1.7	1.4	1.4	1.4	0.2	14.3	MEETS
00+090	3.0	3.0	2.9	2.9	2.7	2.9	2.9	0.1	3.4	MEETS
00+100	2.0	2.1	23	2.0	23	2.6	2.2	0.2	9.1	MEETS
00+110	2.7	23	2.1	2.5	3.0	3.0	2.6	0.4	15.4	MEETS
00+120	11.6	11.4	10.9	11.7	11.6	12.0	11.5	0.4	3.5	MEETS
00+130	3.8	3.9	3.8	3.6	4.7	3.9	4.0	0.4	10.0	MEETS
00+140	3.5	3.2	3.5	3.4	3.4	3.1	3.4	0.2	5.9	MEETS
00+150	13.2	13.2	13.6	13.4	14.1	11.1	13.1	1.0	7.6	MEETS
00+160	18.1	19.7	20.2	20.3	20.6	18.6	19.6	1.0	5.1	MEETS
00+170	14.8	14.4	16.1	16.9	15.7	15.3	15.5	0.9	5.8	MEETS
00+180	17.0	14.3	16.8	15.6	19.2	16.8	16.6	1.6	9.6	MEETS
00+190	12.6	11.9	11.5	14.2	14.2	14.2	13.1	1.2	9.2	MEETS
00+200	8.4	8.4	8.0	8.6	8.9	9.0	8.6	0.4	4.7	MEETS
00+210	12.2	12.1	9.9	12.0	10.0	12.2	11.4	1.1	9.6	MEETS
00+220	9.2	10.7	9.9	13.5	8.7	10.9	10.5	1.7	16.2	FAILS
00+250	13.1	10.1	13.8	9.5	13.8	13.5	12.3	2.0	16.3	FAILS
00+260	3.1	2.2	3.1	2.2	3.3	3.3	2.9	0.5	17.2	MEETS
00+270	16.1	15.5	15.9	13.5	14.9	15.2	15.2	0.9	5.9	MEETS
00+280	9.0	8.9	9.2	9.4	9.6	9.2	9.2	0.3	3.3	MEETS
00+290	7.3	6.0	6.4	6.8	6.9	6.2	6.6	0.5	7.6	MEETS
00+300	10.4	10.0	10.4	9.4	9.3	9.3	9.8	0.5	5.1	MEETS
00+310	8.9	8.5	8.0	8.6	7.2	7.2	8.1	0.7	8.6	MEETS
00+320	7.9	9.2	8.3	6.1	6.9	8.0	7.7	1.1	14.3	FAILS
00+330	0.7	0.7	1.3	1.3	0.8	0.5	0.9	0.3	33.3	MEETS
00+340	3.3	2.6	3.6	2.2	3.5	3.5	3.1	0.6	19.4	MEETS
00+350	2.6	3.0	2.8	3.0	2.5	2.7	2.8	0.2	7.1	MEETS
Average	**7.1**	**6.8**	**7.0**	**7.0**	**7.2**	**7.1**	**7.0**	**0.6**	**11.0**	**MEETS**
r	0.992	0.988	0.991	0.982	0.988	0.988	**REPEATABILITY CRITERIA 02**			
r2	0.983	0.976	0.981	0.965	0.975	0.976	**MEETS**			
Slope (A)	1,005	0.949	1,023	1,004	1,069	0.952				
Interception (B)	0.122	0.034	-0.140	-0.140	-0.235	0.302				
CONDITION	MEETS	MEETS	MEETS	MEETS	MEETS	MEETS	**REPEATABILITY CRITERIA 03**			

TABLE 3 - RIGHT RUTCHING: OPERATION SPEED 40 Km/h

ACCURACY

Progressive (Km)	rutting depth (mm) Basis X_{Ri}	profilometer X_{Ci}	Calculations $\bar{X}_{Ri} - \bar{X}_{Ci}$	$\dfrac{\bar{X}_{Ri} - \bar{X}_{Ci}}{\bar{X}_{Ri}}$
00+010	2.7	3.4	-0.700	-0.259
00+020	3.7	3.6	0.100	0.027
00+030	0.7	2.0	-1.300	-1.857
00+040	4	2.9	1.100	0.275
00+050	2	1.8	0.200	0.100
00+060	4	2.1	1.900	0.475
00+070	2	0.8	1.200	0.600
00+080	2	1.4	0.600	0.300
00+090	2.7	2.9	-0.200	-0.074
00+100	2	2.2	-0.200	-0.100
00+110	1.7	2.6	-0.900	-0.529
00+120	11.7	11.5	0.200	0.017
00+130	4.7	4.0	0.700	0.149
00+140	2.7	3.4	-0.700	-0.259
00+150	12.3	13.1	-0.800	-0.065
00+160	20.7	19.6	1.100	0.053
00+170	19.7	15.5	4.200	0.213
00+180	15.7	16.6	-0.900	-0.057
00+190	15	13.1	1.900	0.127
00+200	10.3	8.6	1.700	0.165
00+210	13.7	11.4	2.300	0.168
00+220	15.7	10.5	5.200	0.331
00+250	13	12.3	0.700	0.054
00+260	3	2.9	0.100	0.033
00+270	15.3	15.2	0.100	0.007
00+280	8.7	9.2	-0.500	-0.057
00+290	8.7	6.6	2.100	0.241
00+300	10	9.8	0.200	0.020
00+310	10	8.1	1.900	0.190
00+320	11.3	7.7	3.600	0.319
00+330	0.7	0.9	-0.200	-0.286
00+340	3.7	3.1	0.600	0.162
00+350	3.3	2.8	0.500	0.152
TOTAL				0.635
Accuracy				1.9

TABLE 4- RIGHT RUTCHING: OPERATION SPEED 40 Km/h

PROGRESSIVE (Km)	BASE TRIM DEPTH (mm)	PROFILOMETER TRIM DEPTH (mm)
00+010	2.7	3.4
00+020	3.7	3.6
00+030	0.7	2.0
00+040	4.0	2.9
00+050	2.0	1.8
00+060	4.0	2.1
00+070	2.0	0.8
00+080	2.0	1.4
00+090	2.7	2.9
00+100	2.0	2.2
00+110	1.7	2.6
00+120	11.7	11.5
00+130	4.7	4.0
00+140	2.7	3.4
00+150	12.3	13.1
00+160	20.7	19.6
00+170	19.7	15.5
00+180	15.7	16.6

00+190	15.0	13.1
00+200	10.3	8.6
00+210	13.7	11.4
00+220	15.7	10.5
00+250	13.0	12.3
00+260	3.0	2.9
00+270	15.3	15.2
00+280	8.7	9.2
00+290	8.7	6.6
00+300	10.0	9.8
00+310	10.0	8.1
00+320	11.3	7.7
00+330	0.7	0.9
00+340	3.7	3.1
00+350	3.3	2.8
Average	**7.8**	**7.0**
r	0.970	
r2	0.941	
Slope (A)	1,079	
Interception (B)	0.228	
CONDITION	**MEETS**	

TABLE 5 - RIGHT RUTCHING: OPERATION SPEED 40 Km/h

LONGITUDINAL DISTANCE ACCURACY

ACCEPTANCE REQUIREMENTS : $\leq 0.2\% * L = 0.12m$

MEASUREMENT LENGTH (m)	MEASUREMENTS(m)					AVERAGE MEASUREMENTS	≤0.2%*L	CRITERION
	1	2	3	4	5			
60	60,034	60,034	60,051	60,042	60,038	60,040	0.066	MEETS

CUADRO Nº 01

LONGITUDINAL DISTANCE ACCURACY (DMI)

SECTION LENGTH: 60 m

REFERENCES

Standards of reference

Método de Ensayo AUSTROADS AG: AM/T009. Medición de Ahuellamiento en Pavimentos con Perfilómetro Multiláser. Marzo 2007.

Método de Ensayo AUSTROADS AG: AM/T010. Validación de Perfilómetro Láser para Medición de Ahuellamiento en Pavimentos (Método alternativo). Marzo 2007.

Método de Ensayo AUSTROADS AG: AM/T012. Verificación de la Precisión y Repetibilidad para Perfilómetro Multiláser. Marzo 2007.

Organización Internacional para la Estandarización (ISO) 1994. Gestión y Aseguramiento de la Calidad: Vocabulario, ISO 8402, ISO, Ginebra.