PROPOSAL OF A COMPARISON METHOD TO ASSES SKID RESISTANCE AND MACROTEXTURE MEASURED WITH DIFFERENT DEVICES.

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ABSTRACT

When defining a comparison method between skid resistance or macrotexture measuring devices, the joint effect of skid resistance and macrotexture over pavement friction should be considered. This is particularly important when pavement friction thresholds are controlled in a road network in terms of specific equipments.

The study presents a comparison method to asses skid resistance and macrotexture measures performed with different devices. The proposed method considers the combined effect of skid resistance and macrotexture over pavement friction. A harmonization procedure between Grip tester and SCRIM (Sideway Coefficient Routine Inspection Machine) measures, and between different laser profilers is presented. The method considers a combination of the findings obtained from the PIARC (World Road Association) model and HERMES experiment. The effects of measuring speed and pavement temperature over skid resistance are also considered by the methodology.

A general framework is presented for the application of the proposed method, which considers three consecutive steps: Application of temperature and speed correction factors to Grip tester measures, harmonization of Grip tester measures to SCRIM measures and harmonization of laser profilers.

With the application of the proposed method, correlation factors were obtained for the comparison of Grip tester and SCRIM measures. To consider the effect of macrotexture over skid resistance when comparing Grip tester and SCRIM, calibration factors for each profiler were also estimated. Given the effects of temperature and measuring speed observed over skid resistance measures, correction factors were designed to adjust skid resistance data measured with Grip tester.

1. INTRODUCTION

Several skid resistance and macrotexture measuring devices are available nowadays for the assessment and management of pavement friction in road networks. In the case of skid resistance, measuring technologies and principles differ between devices. While SCRIM (Sideway Coefficient Routine Inspection Machine) measures transverse skid resistance with a blocked test tyre mounted at an angle of 20° to the direction of travel, Grip Tester measures longitudinal skid resistance with a partially blocked tyre. For the assessment of pavement macrotexture with laser profilers, although technologies are similar, measuring principles differ between devices. Therefore, a common comparison basis is required to compare measures between devices. In the case of skid resistance, this is especially important when comparing devices at different speed levels.

When defining a comparison method between skid resistance or macrotexture measuring devices, the joint effect of skid resistance and macrotexture over pavement friction should be considered. This is particularly important when pavement friction thresholds are controlled in a road network in terms of specific equipments.

A three year study was carried out in Chile by the Pontificia Universidad Catolica de Chile for the development of a national standard for the assessment of skid resistance and macrotexture of the road network *(1)*. As part of this study skid resistance and macrotexture thresholds were defined for the network *(2)*. Currently one SCRIM is owned by the Ministry of Public Works of Chile, while several Grip testers and laser profilers are available in Chile. Given that skid resistance thresholds were defined in terms of SCRIM measures (Sideway Force Coefficient or SFC) and using a specific laser profiler, a comparison method was developed to asses skid resistance and macrotexture measures performed with different devices. With this, any available device can be compared to threshold values defined in the standard.

1.1 OBJECTIVES AND SCOPES

The objective of the study is to define a comparison method to asses skid resistance and macrotexture measures performed with different devices. The proposed method considers the harmonization between Grip tester measures with SCRIM and between different laser profilers based on the PIARC (World Road Association) model. Prior harmonizing measures the method proposes the application of speed and temperature correction factors to Grip tester measures.

The development and application of the proposed method considers the following scopes and findings:

- Skid resistance measuring devices use different technologies and procedures to estimate the skid resistance of a pavement, therefore, their measures need to be harmonized. In this study one SCRIM and three Grip Testers were harmonized.
- For the evaluation of macrotexture, one of the most commonly used technologies are laser profilers. Even though a similar technology is used between devices, dissimilar procedures to estimate macrotexture values are considered. Given this,

a harmonization method is required to compare measures from different devices. In this study three laser profilers were harmonized.

- For the development of the harmonization procedure the correlation between macrotexture and skid resistance was considered. Both characteristics define in conjunction the surface friction of a pavement.
- Pavement skid resistance is affected by measuring speed and pavement temperature. Because of this, skid resistance data should be carefully processed prior harmonization, considering correction factors for speed and temperature when required.

1.2 RESEARCH METHODOLOGY

The research methodology considered four experiments: temperature tests, speed tests, harmonization of skid resistance measuring devices and harmonization of macrotexture measures from laser profilers. Prior to these experiments, repeatability and reproducibility tests were held with each device considered in the study. The measuring methodology, repeatability tests and reproducibility tests followed a standard procedure described in detail in de Solminihac et al. (*3; 4*).

Repeatability tests were held to ensure the precision and reliability of each device under constant testing conditions. All devices tested presented good repeatability, considering thresholds defined by standards and international experience.

From reproducibility tests it was confirmed that Grip tester measures are similar between devices, and therefore, the fleet is reproducible. In the case of laser profilers important differences were observed between measures from different devices. Although equipments consider the same technology, the procedure to estimate macrotexture values varies from one device to another. Given the low reproducibility of the fleet it is therefore necessary to harmonize laser profilers.

To estimate the temperature factor, measures with Grip Tester were performed in roads presenting different climates and important daily temperature oscillations. Measures showed a considerable difference when temperatures ranged between 15°C and 40°C.

To obtain the speed factor, measures with three different Grip Testers were performed at 30 km/h, 50 km/h and 70 km/h. Tests were performed in roads presenting different geometrical and surface characteristics.

To harmonize Grip Tester measures to SCRIM measures, expressed in Grip Number (GN) and Sideway Force Coefficient (SFC) respectively, tests were performed with both devices at 30km/h, 50 km/h and 70 km/h. Selected road sections presented different skid resistance and macro texture levels. The harmonization experiment of laser profilers was held at one speed level in sections presenting a wide range of macrotexture values.

Data obtained from the four main experiments was analyzed in detail. Correction factors for temperature and speed were defined. From the harmonization experiments correlation equations were obtained between Grip tester and SCRIM and between laser profilers.

2. PROPOSED COMPARISON METHOD TO ASSES SKID RESISTANCE AND MACROTEXTURE MEASURES

The proposed method considers the application of three consecutive steps: Application of temperature and speed correction factors to Grip tester measures, harmonization of Grip tester measures to SCRIM measures and harmonization of laser profilers. Figure 1 presents a general framework for the application of this method. For each step input and output data are presented.

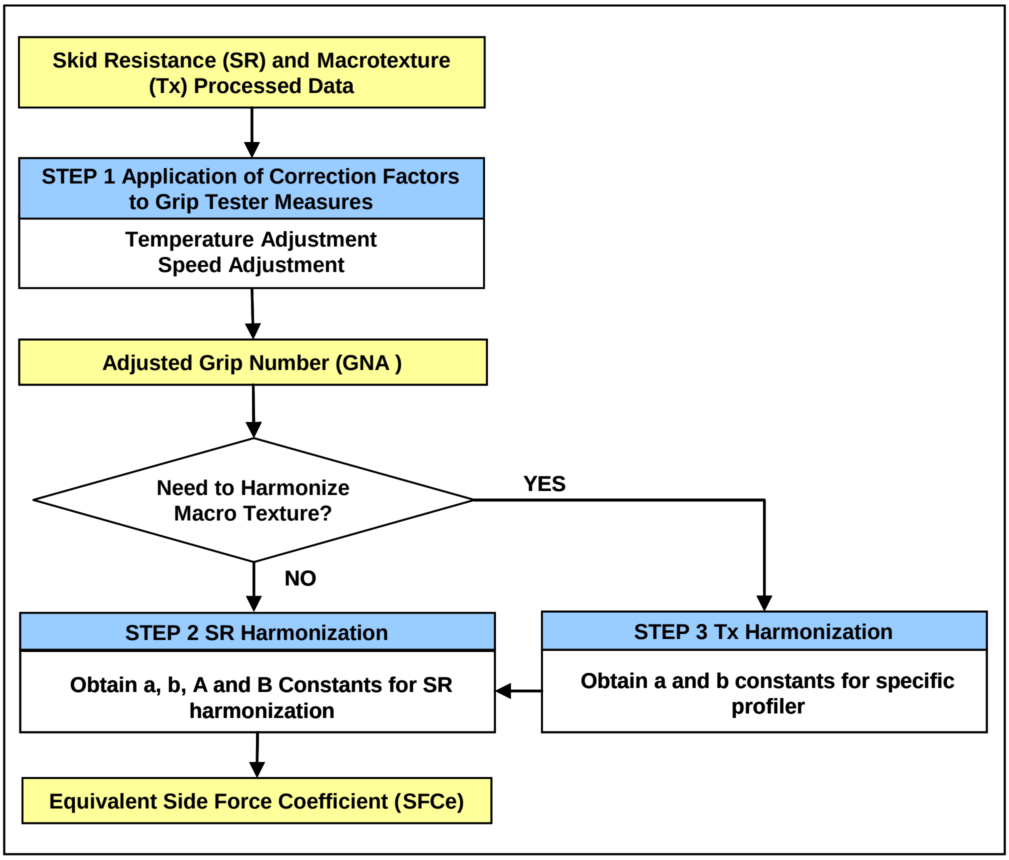

FIGURE 1 Comparison Method to Asses Skid Resistance and Macrotexture Measures

The proposed comparison method is part of a general framework defined in the Chilean national standard for the assessment of skid resistance and macrotexture of the road network *(1)*. The comparison method is of general application and can be adapted to any type of equipment used to measure skid resistance and macrotexture. The method is also independent of the number of vehicles considered in the fleets. The possible adaptations of the method will depend on local requirements and available equipments. For example, in cases where only one profiler is available to measure macrotexture, no harmonization of this device will be required. Speed correction factors developed in the study are applicable to Grip tester measures, if other devices are considered, correction factors should be estimated following the methodology presented in this study. Temperature correction factors are typical to Chilean climates; therefore, their application should be verified and adapted for other conditions.

The application of the proposed method is particularly relevant and useful when skid resistance and macrotexture thresholds of a road network are defined in terms of one equipment, and more than one type of device is available to assess both pavement characteristics. In the case of this study, skid resistance thresholds for the Chilean road network are defined in terms of SCRIM measures (Sideway Force Coefficient or SFC) and using a specific laser profiler. Currently one SCRIM, three Grip testers and several laser profilers are available in Chile. Given this, the proposed method is demanding for the satisfactory application of the Chilean standard. The Chilean standard recommends a yearly update of skid resistance and macrotexture harmonization factors, due to possible variations in the equipments and fleets. It is recommended to consider the latter when adapting the proposed methodology to other networks.

3. DEVELOPMENT OF THE COMPARISON METHOD

2.1 STEP 1: APPLICATION OF CORRECTION FACTORS

2.1.1 Temperature Correction Factor

The objective of temperature adjustments is to correct Grip Tester measurements performed in periods during a day where the temperature gradient is high. GN values obtained in several test sections presenting different climatic and temperature regimens showed to be sensible under extreme conditions. Pavement temperature has logistic behavior during the day ranging between two high and low asymptotic temperature values, named thermal stability. Only when the pavement reaches its thermal stability, GN values are no longer affected by temperature oscillations. Outside the thermal stability range, GN values may be highly affected by temperature changes.

The temperature correction factor should be applied when measures are made during moments of the day where the pavement temperature differs significantly to a reference condition. The principle of this factor is to take the GN values to an equivalent value. By convention, the reference values were defined as GN values measured at 20 °C. Equation 1 presents the recommended temperature adjustment factors for Grip Tester, where T_a stands for environmental temperature.

$$F_T(20) = \begin{cases} 0.10 - 0.005(T_a) & ; \quad 10°C < T_a < 20°C \\ 0.06 - 0.003(T_a) & ; \quad 20 \leq T_a \leq 30°C \\ 0.04 - 0.002(T_a) & ; \quad T_a > 30°C \end{cases} \qquad (1)$$

This temperature correction factor is applied only during summer months, as during the rest of the year temperature oscillations do not affect measures significantly. It has to be noticed that the temperature factors were developed for Chilean temperature regimes and seasonal conditions. It is recommended that similar factors should be developed for local conditions, when not available.

3.1.2 Speed Correction Factor

The purpose of the speed factor is to take measures performed at different speeds to a reference speed of 50 Km/h. According to measuring recommendations for the Chilean road network (2; *3*), measures should be made at 50 ± 4 Km./h in secondary roads and at 70 Km./h ± 4 Km./h in primary roads and freeways. When traffic conditions cannot ensure this speed ranges, the driver may adjust the measuring speed to the traffic conditions to guarantee safety during surveys. For all cases when the reference speed of 50 ± 4 Km./h is not fulfilled, the correction factors presented in Equations 2 and 3 should be applied. The relationship between speed and Grip Number considered in these equations was estimated from the speed tests.

– High Macro texture (> 1 mm) $$F_S(50) = 0.08 - 0.0015(S_e) \quad (2)$$

– Low Macro texture (< 1 mm) $$F_S(50) = 0.30 - 0.006(S_e) \quad (3)$$

3.1.3 Calculation of the Adjusted Grip Number

The Adjusted Grip Number (GNA) is estimated using Equation 4. The GNA is the corrected GN value obtained after eliminating invalid data and after applying the speed and temperature adjustment factors to the data set. This is the output value of the data processing step from the general procedure.

$$GNA = GN + F_S(50) + F_T(20) \quad (4)$$

3.2 STEP 2: HARMONIZATION OF GRIP TESTER MEASURES TO SCRIM MEASURES

Harmonization can be defined as the action of making identical or minimizing the differences between related measures of similar scope but performed with different devices or procedures. Therefore, measurements of two or more equipments that evaluate the same phenomena but with different procedures can be compared between each other when harmonized. In the case of this study, the scope is to compare measurements of Grip Tester to SCRIM, by obtaining a GN value equivalent to a SCRIM value, so called equivalent SFC (SFC_e).

Several skid resistance and friction harmonization methods have been developed, such as the International Friction Index (IFI) by PIARC (World Road Association), European Friction Index (EFI) obtained from the HERMES experiment , the International Runway Friction Index IRFI, ESDU method and direct correlations (5; *6; 7; 8; 9*).

The proposed harmonization method considers concepts from the first three methodologies. Equations 5 and 6 were deducted from the theoretical approach of the IFI calculation procedure.

$$SFCe = C(Se_2, Sp_2, V)\left\{A_1 + B_1\left[(GNp)D(Se_1, Sp_1, V)\right]\right\} \quad (5)$$

$$C(Se_2, Sp_2, V) = e^{\frac{V - Se_2}{Sp_2}} \; ; \; D(Se_1, Sp_1, V) = e^{\frac{Se_1 - V}{Sp_1}} \quad (6)$$

Where, Sp_1 and Sp_2 are speed constants; V is the reference speed; Se_1 and Se_2 are the measuring speeds of Grip Tester and SCRIM respectively; and, A_1 and B_1 are calibration constants.

With these two equations an equivalent SFC value can be estimated from a GN value obtained from a Grip Tester (GNp) that is representative of a Grip Tester fleet. The equations consider the correlation existing between macrotexture and skid resistance through the speed constants Sp_1 and Sp_2. The V constant is used to optimize the calibration between both equipments. In the PIARC experiment, from where IFI was derived, this speed was 60 Km/h, whereas in the EFI experiment this value was from 30 Km/h.

An important issue is that the GNp value considered in the equations represents the GN value of a particular device harmonized to a virtual Grip Tester representative of a Grip Tester fleet. This GN value must be corrected previously considering the temperature and speed factors. When calibrating Equations 4 and 5 to local conditions, it is recommended that the virtual Grip Tester should be estimated in terms of the mean GN values of a fleet.

3.3 STEP 3: HARMONIZATION OF MACROTEXTURE MEASURES FROM LASER PROFILERS

The procedure to estimate Sensor Measured Texture Depth (SMTD) differs between devices in three aspects: base length, frequency between readings, SMTD aggregation method in each base length. This is the reason why measures performed with the same principle differ between equipments. Because of this, macrotexture measures between different laser profilers need to be harmonized. For this, a reference profiler is selected, which typically will be that used on the estimation of constants A, B and a_R, b_R during the harmonization of skid resistance. All other profilers are harmonized to this device. The speed constants for these devices are presented in Equations 7 and 8.

Reference Device: $Sp_R = a_R + b_R(Tx_R)$ (7)

Device 1: $Sp_1 = a_1 + b_1(Tx_1)$ (8)

The macrotexture harmonization principle proposes that the speed constants between both devices are similar. With this, macrotexture measures of device 1 can be expressed in terms of the reference device, as presented in Equation 9.

$$Sp_1 = Sp_R + \varepsilon_{1R} \Rightarrow Tx_1 = \hat{\alpha}_1 + \hat{\beta}_1(Tx_R) \quad (9)$$

Constants α and β can be obtained from measures performed in similar conditions with both devices in the same sections. For this, sections presenting a wide range of macrotexture levels should be considered.

From skid resistance harmonization procedure, constants a_R and b_R are obtained. Finally, calibration parameters of device 1, a_1 and b_1, are estimated with equations 10 and 11.

$$b_1 = \frac{b_R}{\hat{\beta}_1} \tag{10}$$

$$a_1 = a_R - \left(\frac{\hat{\alpha}_1}{\hat{\beta}_1} \right) b_R \tag{11}$$

Values a_1 and b_1 are the calibration values used in the estimation of the speed constant Sp when measuring SMTD values with device 1. Therefore, the speed constant for the harmonized device 1 is:

$$Sp_1 = a_1 + b_1 (SMTD_1) \tag{12}$$

Sp values must be estimated for each laser profiler correlated to SCRIM and Grip tester measures.

4. APPLICATION OF THE PROPOSED COMPARISON METHOD

The proposed method was applied in the Chilean road network, considering roads of three central regions of the country. 51 sample sections of 200m long were selected from thirteen different roads, totaling in 10.2 km. From these, 21 sections were of asphalt concrete, 14 of Portland cement concrete (PCC) and 16 of double treated surfaces. Sections presented macrotextures ranging from 0.33 to 1.15 mm, measured in SMTD, and skid resistances ranging from 0.3 to 0.63.

The experiment considered one SCRIM, three Grip testers and three laser profilers. Measures with SCRIM and Grip tester were performed at 30, 50 and 70 km/h. Measures with laser profilers were performed at 50 km/h. Repeatability and reproducibility tests were held to check the precision of equipments and reproducibility of the grip tester fleet.

The three steps of the proposed method were applied as presented in Figure 1. First, Grip tester measures were corrected with temperature and speed factors. From this, an Adjusted Grip Number (GNA) was estimated per sample section. Skid resistance harmonization was developed considering one reference laser profiler. This profiler was then correlated to the other two laser profilers using the macrotexture harmonization procedure.

From the application of the proposed comparison methodology it was observed that skid resistance harmonization varies depending on macrotexture levels. Therefore, calibration constants A and B were estimated for two macrotexture levels, higher than 1 mm and lower or equal to 1 mm. Speed constant (Sp) and calibration factors for macrotexture, a and b, were obtained for the three profilers correlated to Grip tester and SCRIM. Calibration constants obtained are only valid for skid resistance and macrotexture ranges considered in the experiment. A mean prediction error of 9% and 6% was obtained from the harmonization of Grip tester and laser profilers respectively. A summary of the calibration factors obtained from the application of the proposed methodology are presented in Tables 1 and 2.

Table 1. Harmonization factors for Grip tester

$SMTD_{REF}$	Calibration Factors		Reference Speed (Km./h)
	A	B	
> 1 mm	0.384	0.136	25
≤ 1 mm	0.21 – 0.25	0.79	25

Table 2. Harmonization factors for Laser Profilers

Device	Sp_{GT}		Sp_{SCRIM}	
	a_{GT}	b_{GT}	a_{SCRIM}	b_{SCRIM}
Reference Profiler	-183.0	614.0	7.4	108
Profiler 1	-406.4	755.2	-31.8	132.8
Profiler 2	-300.4	539.3	-13.2	94.9

4. CONCLUSIONS AND RECOMMENDATIONS

This study presented a comparison method to asses skid resistance and macrotexture measures performed with different devices. The proposed method considered the combined effect of skid resistance and macrotexture over pavement friction. With this, skid resistance data can be analyzed systematically and be consistently compared to threshold values defined in terms of SCRIM measures (SFC), or else in terms of other measures.

From the study it was observed that skid resistance values measured in warm seasons are affected by daily temperature oscillations. An adjustment factor was therefore proposed to standardize Grip Tester values measured under different temperature conditions during warm seasons.

Skid resistance values are also affected by measuring speed. Skid resistance measurements performed under heterogeneous traffic conditions may present considerable alterations. The speed adjustment factor proposed in the present study standardizes measures performed at any speed to a reference speed of 50 Km/h.

When skid resistance thresholds are referred to a specific device, measurements from other devices need to be harmonized to this equipment. This is the case of the Chilean standard, which is defined in terms of SCRIM values (SFC). The harmonization method presented in this study is applied to the case when Grip Tester measurements (GN) need to be harmonized to SFC. However, the proposed method can be generalized and applied with other devices.

When more than one laser profiler is used to asses macrotexture of a road network, devices must be harmonized in order to define a common comparison basis. This is a critical step when harmonizing skid resistance measures as they are affected by macrotexture levels and, therefore, are dependant of the laser profiler being used.

Finally, from the application of the proposed methodology it was observed that skid resistance harmonization varies depending on macrotexture levels. Therefore, skid resistance calibration constants, A and B, had to be estimated for two macrotexture levels. When applying the proposed methodology is highly recommended to analyze these types of behaviors and, when necessary, the harmonization should be breakdown considering different skid resistance and/or macrotexture ranges.

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