

**BELGIAN ROAD RESEARCH CENTRE**

Institution recognized by application of the Decree-Law of 30.01.1947  
BOULEVARD DE LA WOLUWE 42, B-1200 BRUSSELS

**Final report**

**RESEARCH CONTRACT NO/C3/004**

**PROPOSAL FOR A EUROPEAN STANDARD**  
**IN RELATION WITH THE SKID RESISTANCE**  
**OF ROAD SURFACINGS**

Coordinator and Reporter: Guy DESCORNET, DSc

May 1998

# CENTRE DE RECHERCHES ROUTIERES

ETABLISSEMENT RECONNU PAR APPLICATION DE L'ARRETE LOI DU 30-1-1947  
BOULEVARD DE LA WOLUWE, 42 - 1200 BRUXELLES

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CHARLEROI, le 29 juin 1998

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SERVICES DU PREMIER MINISTRE  
A l'attention de Monsieur J.WAUTREQUIN  
Affaires Scientifiques,  
Techniques et Culturelles  
Rue de la Science 8  
1000 BRUXELLES

Monsieur le Secrétaire général,

## Objet: Contrat de recherche n° NO/C3/004

J'ai le plaisir de vous transmettre ci-joint en quatre exemplaires, dont deux en français et deux en anglais, le rapport final de la recherche intitulée "Proposition de norme européenne relative à la résistance au dérapage des revêtements routiers", objet du contrat en référence. Le rapport consiste en trois parties séparées, à savoir:

- Le corps du rapport;
- L'annexe 1 sous forme de CD-ROM comportant la base de données constituée au cours de cette recherche (notamment les résultats détaillés), les versions française et anglaise du rapport et un programme de "navigation";
- L'annexe 2 consistant en un projet de norme établi sur base des résultats de la recherche et d'ores et déjà en cours d'examen au sein du groupe de travail européen concerné (CEN/TC227/WG5).

J'ajoute deux copies d'une communication au Symposium tchèque sur les caractéristiques de surface des chaussées (2 juin 1998) dans laquelle les résultats de la recherche et leur utilisation en matière de normalisation européenne sont présentés.

En vous remerciant vivement pour votre soutien, je vous prie de croire, Monsieur le Secrétaire général, à l'assurance de ma haute considération.



G.DESCORNET, Dr.Sc.  
Coordinateur

Annexes:     - Rapport en 2 ex. en français + 2 ex. en anglais  
              - Annexe 1 (CD-ROM) en 4 ex.  
              - Annexe 2 (Projet de norme) en 4 ex.  
              - Communication à un symposium en 2 ex.

GHD/ghd

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30. VI. 1998

## **I. Steering Committee membership**

Mr R. JORDENS, Eng., Afdelingshoofd, Rijkswaterstaat, Dienst Weg- en Waterbouwkunde (NL), Chairman of CEN/TC227/WG5/TG1.

Mr F. MONTENY, Prime Minister's Office, Scientific, Technical, and Cultural Affairs.

Mr F. BEUGNIES, C.E., Ingénieur-Directeur a.i., Ministère des Communications et de l'Infrastructure, Administration de la Réglementation de la Circulation et de l'Infrastructure (ARCI), Direction Routes: Normes et Banques de Données.

Mr J. WUSTEMBERGHS, Eng., Conseiller, Institut belge de Normalisation.

Mr L. HELEVEN, C.E., Ministerie van de Vlaamse Gemeenschap, Departement Leefmilieu en Infrastructuur (LIN), Administratie Weg en Verkeer, Afdeling Wegenbouwkunde, Dienst Structuren.

Mr J. CROCHET, C.E., Ingénieur principal des Ponts et Chaussées, Ministère wallon de l'Équipement et des Transports (MET), Direction générale des Routes et Autoroutes, Direction des Structures routières.

Mr D. GORLE, Dr, C.E., Directeur, Opzoekingscentrum voor de Wegenbouw (OCW), Departement Research, Ontwikkeling en Toepassing.

Mr G. DESCORNET, DSc, Chef de Projet, Centre de Recherches routières (CRR), Département Recherche, Développement et Application.

## **II. Acknowledgements**

We should like to thank the Prime Minister's Office for Scientific, Technical and Cultural Affairs for funding the project and, in particular, Mr F. MONTENY for his constant attentive support.

We are grateful to LIN and MET for their excellent cooperation to this project, in particular to Mr L. HELEVEN (LIN), J. CHAVET (MET) and J. CROCHET (MET) for carrying out the skid resistance measurements.

Our best thanks are also tendered to the other members of the Steering Committee and especially to Mr R.A.P. JORDENS, who voluntarily made long early morning journeys to attend various meetings including those of the S.C., and to Mr D. GORLE for his sustained occupation with, and effective and friendly chairing of, the S.C.

We gratefully acknowledge the dedication and competence shown by Messrs. J.M. DESMET and B. BERLEMONT in carrying out their technical tasks and handling the large body of data. We owe a particular debt of gratitude to B. BERLEMONT for the making of the appended CD-ROM.

Finally, we thank PIARC for their permission to reproduce excerpts of the data base of the 1<sup>st</sup> international experiment in Appendix 1 (CD-ROM) for the sake of comprehensiveness.

### **III. Abstract**

There are in Europe over a dozen different models of devices to measure the skid resistance of road surfacings. Up to now each country has been using one or two types of device, with requirements to match in their standard tender specifications and their maintenance policies. The opening up of the single market, however, has created a need for harmonization, to enable any contractor to work to different specifications and road network managers to guarantee homogeneous conditions of safety from one country to the next. This harmonization has been undertaken in CEN - more particularly in group CEN/TC227/WG5. One of the present objectives of this group is to develop a draft standard defining a uniform procedure to determine skid resistance from a dynamic measurement. It will be easily understood that, to be acceptable to a majority of countries, such a procedure can hardly rely on a single device. That is why a philosophy has been adopted to establish equations for converting results produced by different devices, so as to enable anyone to continue to use his or her own method - at least during a period of transition. Anticipating this need, PIARC conducted an international experiment to compare different devices and methods in use to measure friction and surface texture on road and airfield pavements. A final report on this experiment was released by PIARC late in 1995. All devices and methods used in Europe were represented plus one American, two Canadian and two Japanese devices. This experiment produced ample information to set up a large data base, which proves to be a valuable tool in standardization. And the analysis of that information as presented in the final report shows that virtually all devices participating in the experiment can be harmonized using a single equation to relate their outputs to a common scale called (a little prematurely) "International Friction Index" or "IFI", provided allowance is made for a measurement of macrotexture. "Prematurely", because, although this experiment was an indispensable prerequisite, it cannot be used without additional work as a basis to draft a standard that will be acceptable at the European level.

That is why the general objective of this project was to draft a European standard after carrying out the necessary additional work.

As a reminder, the PIARC definition of IFI is as follows:

$$IFI = A + B * F * \exp[(\tau * V - S_R) / (a + b * T)] + C * T$$

where:

- F: the measured friction coefficient
- V: measuring speed
- S<sub>R</sub>: reference tyre-road slip speed (60 kmph)
- T: texture depth
- τ: rate of slip
- a, b: empirically determined coefficients to compensate for the influence of speed on the coefficient of friction on the basis of a texture measurement (T)
- A, B, C: empirically determined coefficients specific to each device.

The first task was to resume the analysis of the data base from the PIARC experiment in order to determine the optimum values to be attributed to the parameters used in the definition of IFI. The term "optimum values" was understood to mean those allowing the subset of European devices to reproduce IFI with the greatest possible accuracy. In order that the redefinition of IFI may privilege the measuring equipment and methods actually used in Europe, and with a view to drafting a CEN standard relating to dynamic measurements, twenty-one devices in total were selected according to these two criteria. After the PIARC experiment had been completed, and using data collected in it, an ISO standard 13473-1 was developed defining the way to calculate mean profile depth from profilometer measurements. This work should be taken into account here, all the more as CEN/TC227/WG5 is considering whether to adopt this standard. Now CRR is the only one among the participating teams to have recorded and archived all measured profiles in digital form, which makes it possible to reprocess them by the new technique. Furthermore, it has been necessary to complement the analysis by an evaluation of the repeatability and reproducibility of IFI.

This additional analysis has led us to define a "European Friction Index" or "EFI", which has the following advantages over the IFI proposed by PIARC:

- the role of the texture measurement and, consequently, of the additional errors it may introduce is minimized in two ways. Firstly, a rational choice of the reference speed minimizes the magnitude of the correction to be made for the influence of speed; the optimum reference speed is 30 kmph. Secondly, it has been demonstrated that there is no need to include a texture-dependent term (coefficient C in the equation above) in the definition of EFI for devices fitted with patterned tyres;
- the latter aspect introduces a simplification and, therefore, a fuller harmonization, since, unlike for IFI, the definition of EFI is the same whatever the type of tyre used on a given device;
- EFI takes account of the ISO standard definition of texture depth estimated from a profilometer measurement;
- its definition is based on data relating to (dynamic) European equipment. This data base being more restricted than that of the PIARC experiment, it is possible to obtain values for repeatability and reproducibility which are more representative of the performance levels to be expected from the measuring systems employed in Europe (a knowledge of these values is necessary for the standardization work). The repeatability of EFI has been evaluated at 0.08 on an average for all devices and test sites and its reproducibility between devices at 0.14;

- its main advantage, however, lies in considerably reducing or even eliminating, on the average, the systematic differences in the friction coefficients delivered by the various types of device. This is exactly where the object of harmonization is attained, even at the expense of a lower reproducibility than between devices of the same type.

The second objective of the project was to validate the extension of EFI to other types of surfacing not adequately or not at all considered in the PIARC experiment, by including the various road paving materials and technologies representative of European practice and developments in this field. For that purpose, and with the cooperation of the regional road authorities, skid resistance measurements with the SCRIM of LIN and the odoliograph of MET and texture measurements with the laser profilometer of CRR were performed on twenty-three road sections, 1/3 of which had a conventional surfacing (included as a reference) and 2/3 a surfacing type either recently introduced or more limited in application (such as porous asphalt, porous cement concrete, stone mastic asphalt, chipped resinous slurry, and various other types of thin surfacing). The criterion to be met in validating EFI for a given surfacing was that the latter should obey an empirically established equation which enables the susceptibility of the friction coefficient to the slip speed to be predicted as a function of texture depth. Given the precision of this equation, it can be stated that according to both the PIARC data (except for special cases such as the pavements of two American airfields in Spain) and the data from the additional tests in Belgium, no surfacing type significantly and systematically deviates in one way or another from that relation.

Finally, in pursuance of the third and last objective a draft standard was prepared which:

- 1) defines EFI, i.e. the equation to change over from one measuring method to another while stating the margin of error associated with this conversion. The equation is essentially the same as above, but the corresponding coefficients have been recalculated and coefficient C has been omitted;
- 2) proposes a procedure for calibrating friction devices based on EFI. To maintain EFI, it is enough to periodically convene small subsets of (two or three) devices for mutual comparison and adjustment of their coefficients A and B. But these meetings of devices should be organized in such a way as to prevent any subsets from gradually drifting from one another, by observing certain criteria for the pairing of devices.

A first draft of this standard was presented to CEN/TC227/WG5 during the November 21-22, 1997 meeting of this group in Brussels. An amended version including the comments of the group was presented at the meeting of May 25-26, 1998 and it is the third draft prepared after this meeting which is appended to this report as a separate document.

To fully benefit from the work achieved, the following may be recommended.

1. The demonstration of the feasibility of converting the various skid resistance measurements practiced in Europe to a common scale should be disseminated and used as a decisive argument for standardization bodies, road managers, road contractors, suppliers of road construction materials and suppliers of measuring equipment to adopt a policy of "harmonization" rather than "standardization". Harmonization by applying the EFI concept will enable users to continue to use their own tests and to feed their road data bases without breaking with the past and giving up large investments and long-standing experience in the process, as would be the case with the standardization of a single method. This need not keep anyone from preparing the development of a single test method at the European level or in a more general international context over the next fifteen or twenty years. The use of EFI will then have permitted a transition process which may be qualified as "democratic".
2. This requires that the scientific, administrative and political authorities concerned should support the urgent setting up of a European organization for the regular calibration of skid resistance devices as suggested in the draft standard. This organization would not need to have reference test tracks at its disposal; the draft standard makes no requirement to that effect, as comparisons between devices can, in principle and in general, take place in any country or region of Europe as long as the criteria set in the standard are satisfied. The main thing is to have a full-time team dedicated to the organization of tests, the interpretation of results, the issuing of certificates, etc., and capable of moving to the site which is considered to be most appropriate from a practical and economic point of view for convening a given subset of (probably most often two or three) devices.



#### **IV. Abbreviations**

B	Blank (or "smooth") tyres
BB	Asphalt (asphalt concrete)
BC	Concrete (cement concrete)
BD	Porous concrete
BFC	Braking force coefficient
CEN	European Committee for Standardization
CRR	Centre de recherches routières (= OCW)
E	Surface dressing
ED	Porous asphalt
EFI	European Friction Index
ESHDP	High-performance surface dressing
ETD	Estimated texture depth determined from MPD
IFI	International Friction Index
ISO	International Standardization Organization
LIN	Dienst Leefmilieu en Infrastructuur
MET	Ministère wallon de l'Équipement et des Transports
MPD	Mean profile depth
MTD	Mean texture depth by volumetric method
G	Designates the full set of devices without distinction by tyre type OCW          Opzoekingscentrum voor de Wegenbouw (= CRR)
PIARC	World Road Association
RMD	Gap-graded thin surfacing
RMS	Root-mean-square of texture profile
RMTO	Open-textured thin surfacing
RP	Ribbed or otherwise patterned tyres
RUMG	Coarse-graded ultrathin surfacing
SCRIM	Sideways Force Coefficient Routine Investigation Machine
SCRIMTEX	SCRIM with added texture-measuring laser profilometer
SFC	Sideways force coefficient
SMA	Stone mastic asphalt
SSTC	Office for Scientific, Technical and Cultural Affairs

## **V. Symbols**

$\mu$	Mean
$\rho$	Correlation coefficient
$\sigma$	Standard deviation
$\tau$	Rate of slip
A, a	Intercept of a regression line
B, b	Slope of a regression line
E	Estimated EFI value
F	Friction coefficient
$F_{10, \dots, F_{90}}$	Value of friction coefficient reduced to a slip speed of 10, ..., 90 kmph
$F_S$	Value of friction coefficient reduced to slip speed S
$F_0$	Friction coefficient extrapolated to zero speed
i	Index varying with the device considered
j	Index varying with the half section considered
J	Total number of half sections
m	Index representing the sequence number in a series of measurements performed with a given device on a given half section
n	Number of measurements considered in calculating a regression
N	Total number of devices
R	Index characterizing a value which depends on the choice of S
r	Repeatability
R	Reproducibility
S	Slip speed
$S_0$	Parameter describing the influence of slip speed on the friction coefficient; more simply referred to as "speed parameter"
$S_0^*$	Optimum speed parameter for a given half section
$S_0^{**}$	Optimum speed parameter predicted from texture
$S_R$	Reference slip speed
T	Texture depth
x	Index varying with the type of texture measurement considered

## **VI. Introduction**

There are in Europe over a dozen different models of devices to measure the skid resistance of road surfacings. Up to now each country has been using one or two types of device, with requirements to match in their standard tender specifications and their maintenance policies. The opening up of the single market, however, has created a need for harmonization, to enable any contractor to work to different specifications and road network managers to guarantee homogeneous conditions of safety from one country to the next. This harmonization has been undertaken in CEN - more particularly in group CEN/TC227/WG5, of which R. JORDENS, J. CHAVET, L. HELEVEN and G. DESCORNET are members. One of the present objectives of this group is to develop a draft standard defining a uniform procedure to determine skid resistance from a dynamic measurement. It will be easily understood that, to be acceptable to a majority of countries, such a procedure can hardly rely on a single device. That is why a philosophy has been adopted to establish equations for converting results produced by different devices, so as to enable anyone to continue to use his or her own method - at least during a period of transition. Anticipating this need, PIARC conducted an international experiment to compare different devices and methods in use to measure friction and surface texture on road and airfield pavements. A final report on this experiment was released by PIARC late in 1995. All devices and methods used in Europe were represented plus one American, two Canadian and two Japanese devices. This experiment produced ample information to set up a large data base, which proves to be a valuable tool in standardization. And the analysis of those data as presented in the final report shows that virtually all devices participating in the experiment can be harmonized using a single equation to relate their outputs to a common scale called (a little prematurely) "International Friction Index" or "IFI", provided allowance is made for a measurement of macrotexture. "Prematurely", because, although this experiment was an indispensable prerequisite, it cannot be used without additional work as a basis to draft a standard that will be acceptable at the European level.

The general objective of this project was to draft a European standard after carrying out the necessary additional work, which consisted in:

- 1) resuming the analysis of the data base while restricting it to the dynamic devices used in Europe and reconsidering the reference speed empirically adopted in the definition of IFI with a view to redefining an IFI optimized for European standardization, i.e. an EFI;
- 2) complementing the analysis by an evaluation of the repeatability and reproducibility of EFI;
- 3) extending the validity of EFI to new types of surfacing and material not adequately or not at all considered in the PIARC experiment. This required a programme of friction and texture measurements with the various devices available in Belgium on a selected representative sample of different types of

surfacing.

The draft standard was to:

- 1) define EFI, i.e. the equation to change over from one measuring method to another while stating the margin of error associated with this conversion;
- 2) propose a procedure for calibrating friction devices.

## **VII. Analysis of the data base from the international experiment (PIARC, 1992)**

As explained above, the purpose of this analysis was to determine, from data collected in the PIARC experiment, the optimum values to be attributed to the parameters used in the definition of the "International Friction Index" or "IFI" proposed in the report on that experiment. The term "optimum values" was understood to mean those allowing the subset of European devices to reproduce IFI with the greatest possible accuracy.

### ***VII.1 Selection of the series of measurements to be considered***

In order that the definition of EFI may privilege the measuring equipment and methods actually used in Europe, the following files<sup>1</sup> were selected - in agreement with the Steering Committee<sup>2</sup> - from the PIARC experiment data base. Furthermore, with a view to drafting a CEN standard relating to dynamic measurements, static test methods were excluded from the analysis.

#### **VII.1.1 Friction**

##### Selected files:

B1LKD.FR	B2SLP.FR	B5SLP.FR	C5.FR	C9.FR	D2.FR	D5.FR
B1SLP.FR	B3.FR	C1.FR	C6E.FR	C10.FR	D3.FR	D6.FR
B2LKD.FR	B5LKD.FR	C3B.FR	C8.FR	D1E.FR	D4.FR	D8.FR

##### Discarded files:

A12.FR	Not European. Moreover did not operate correctly.
A13.FR	Not European.
A14.FR	Pendulum. Not dynamic nor full-scale.
B1ABS.FR	ABS system. Actual slip speed unknown.
B4ESLP.FR	Though European, not selected because the conditions of measurement are not "pure" (mixture of fixed slip speed and variable rate of slip).
B4ESWP.FR	Though European, not selected because the conditions of measurement are not pure (mixture of fixed slip speed and variable rate of slip, making the PIARC model inapplicable).
B5ABS.FR	ABS system. Actual slip speed unknown.
B6501.FR	Not European.
B6524.FR	Not European.

<sup>1</sup> To save space, the various test methods are referred to by the identification codes used in the report on the international experiment. The names of the corresponding devices, with the nationalities of the measuring teams and the types and characteristics of measurement, are presented in **Table 1** and **Table 2** for skid resistance and texture, respectively.

<sup>2</sup> Minutes of the meeting of the Steering Committee held on November 14, 1996.

B6CHP.FR	Not European.
B6ULT.FR	Not European.
B7.FR	Pendulum. Not dynamic nor full-scale.
B10E.FR	Performed measurements on only four sites.
C3E.FR	Many erroneous measurements due to a mechanical problem (see the poor correlation coefficients with other SCRIM devices in the PIARC report [ref. 1, p. 105]).
C4.FR	Not European.
D7B.FR	Performed measurements on only thirteen sites and the results were generally poorly correlated with the outputs of the other devices.

A total of twenty-one devices was thus selected.

### VII.1.2 Texture

#### Selected files<sup>3</sup>:

A1.TX	A3E.TX	D2.TX	D5.TX
A2.TX	A4.TX	D3.TX	
A3B.TX	A5.TX	D4.TX	

#### Discarded files:

A8.TX	Static test. Non-European standard.
A12.TX	Not European. Moreover did not operate correctly.
B8.TX	Static test.
B11E.TX	Static test. Non-European standard.

After the PIARC experiment had been completed, and using data collected in it, an ISO standard 13473-1 [ref. 2] was developed defining the way to calculate mean profile depth from profilometer measurements. This work should be taken into account here, all the more as CEN/TC227/WG5 is considering whether to adopt this standard. Now CRR is the only one among the participating teams to have recorded and archived all measured profiles in digital form, which makes it possible to reprocess them by the new technique. Though not really dynamic, the stationary version of CRR's laser profilometer (A5) was selected as it is actually mobile (towed at low speed by a vehicle) and mainly because it is more precise than the truly dynamic version (A4).

### VII.1.3 Sites

As explained in the PIARC report, each test site was composed of two adjacent half sections each 75 m long, with half section B following half section A. Site 3 being discarded as it was tested by only one device, we had a total of 106 half sections.

<sup>3</sup> A3B.TX was selected in spite of its non-European (Canadian) origin, as several units of this device are in use in Europe.

## VII.2 Data processing

The PIARC experiment data base comprises a series of (ASCII) files having the extension .FR or .TX for the results of friction or texture measurements, respectively<sup>4</sup>. The data selected was processed in the following stages.

1. Each \*.FR file was complemented by a column entitled "RELSP" (for "relative speed"), giving for each individual measurement the actual slip speed, S, as determined by the appropriate equation:

$$\begin{aligned} S &= V \sin(\alpha) && \text{for SFC-type devices, where } \alpha = \text{yaw angle;} \\ S &= \tau V && \text{for BFC-type devices, where } \tau = \text{rate of slip (for locked wheel} \\ &&& \text{measurements, } \tau = 1). \end{aligned}$$

2. For each half section (A and B) and for each device, the linear regression

$$\ln(F_{mij}) = A_{ij} + B_{ij} * S_{mij}$$

where F is the measured friction coefficient and S the relative slip speed, was calculated by means of the least squares method. The following results were archived:

$A_{ij}$ : intercept,

$B_{ij}$ : slope,

$\rho_{ij}$ : correlation coefficient,

$\sigma_{ij}$ : residual standard deviation,

$n_{ij}$ : number of points,

m: sequence number of the measurement in the series,

i: apparatus considered,

j: half section considered.

These regressions were not used in the subsequent calculations to determine EFI. They were used to verify for each case the validity of the exponential "PIARC" model. After a visual examination of the graph of each exponential equation

$$F = F_0 * \exp(- S/S_0)$$

where  $F_0 = \exp(A_{ij})$  and  $S_0 = - 1/B_{ij}$ , the series of measurements exhibiting an anomaly such as an erratic point, a zero or positive slope, a number of data smaller than three or concentrated in too narrow a range of speeds, etc. were discarded. Only nineteen such outlying series were found (in a total of over two thousand series) :

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<sup>4</sup> *These initial data being the property of PIARC, it has not been reproduced in Appendix 1 (on the CD-ROM), which essentially contains the results from our new analyses.*

<u>Device</u>	<u>Half section</u>
B1SSLP:	26.2A
B3:	24.A, 24B
C10:	63B
D2:	62A
D4:	26.A, 26.2B, 68A, 81.2B, 81.31, 81.4B
D5:	26.2A, 26.2B, 33.3A, 33.3B, 81.1A, 81.2A
D6:	17B
D8:	19B

A normal series and an outlying series are shown in **Figure 1** and **Figure 2**, respectively. All graphs are visible in **Appendix 1** (on the CD-ROM).

3. A result file \*.FR' listing the half sections with the corresponding parameters A, B, F, F<sub>0</sub>, S<sub>0</sub>, ρ, σ and n was associated with each \*.FR file. All these results, including those which were discarded, have been tabulated in **Appendix 1**.
4. The \*.FR' files were complemented with columns F<sub>10</sub>, F<sub>20</sub>, F<sub>30</sub>, F<sub>40</sub>, F<sub>50</sub>, F<sub>60</sub>, F<sub>70</sub>, F<sub>80</sub> and F<sub>90</sub>, i.e. the F values recalculated for the S values from 10 to 90 kmph, to put the results in order and to archive them with a view to subsequent visualization and printing - if necessary - of the graphs corresponding with the series of measurements and representing their parameters and regression curves. These results have been tabulated in **Appendix 1**.
5. All the texture data measured with the CRR laser profilometer (device A5) were reprocessed into new values for MPD (mean profile depth) according to ISO standard 13473-1. The symbol used for this new variable is T<sub>A5ISO</sub>. The old T<sub>A5MPD</sub> and new T<sub>A5ISO</sub> values averaged per half section are presented in **Table 3** and have been plotted against each other in **Figure 3**. The regression between the two can be written as :

$$T_{A5ISO} = 0.04 + 0.78 * T_{A5MPD}$$

with a correlation coefficient of 0.988 and a virtually negligible residual standard deviation and ordinate at the origin. A proportionality relation

$$T_{A5ISO} / T_{A5MPD} = 0.78$$

can, therefore, be adopted.

6. A "TEXTURE" file was created giving for each half section the various measurements of texture<sup>5 6</sup> produced by the selected devices (see above) plus A5/ISO :

<sup>5</sup> For A3B, we have the average values for the three operating speeds: 30, 60 and 80 kmph.

<sup>6</sup> For A42, each half section was attributed the average value over the pair of two half sections, as this was the only value provided by the device.



A1/RMS	A2/RMS	<b>A2/MPD</b>	A2/TDMA	A3B/TX1	A3B/TX2
A3E/RGH1	A42/RMS	A42/MPD	<b>A5/MPD</b>	D2/MTD	D3/RA
D3/RQD4/CSMTD	D5/SMTD	<b>A5/ISO</b>			

The three files in bold italic have been reproduced in **Appendix 1**.

7. Eleven files called "TabX" were created giving for each site/section the "X" value produced by each device (one column per device), with  $X = S_0, F_0, F_{10}, \dots, F_{90}$ .  $F_S$  values for which the slip speed, S, was outside the actual measuring range of the apparatus were discarded, except those corresponding with the decade just below and the decade just above that range. These files have been reproduced in **Appendix 1**.

8. From the initial data files (one file per device, comprising 52 pages each reporting the data measured on two half sections):

- the average of the  $\ln(F)$  values,  $\langle \ln F \rangle_{ij}$ , and the average of the S values,  $\langle S \rangle_{ij}$ , were calculated and the number  $n_{ij}$  of measurements was selected for each series of measurements (m) per device (i) and per half section (j);
- from this point onwards, the calculations were made separately for the subset of devices using smooth tyres, the subset of those with patterned tyres and the two combined, leading to a systematically triple presentation of results with the notations G for overall, B for blank (or smooth), and RP for ribbed or otherwise patterned;
- for some fifty  $S_0$  values ranging from 10 to 500 by geometric progression, the residual standard deviations,  $\sigma_{ij}$ , of the series of measurements  $\{ F_{mij} \}$  from the equation curve

$$F = \text{EXP}\{\langle \ln F \rangle_{ij} - (S - \langle S \rangle_{ij})/S_0\}$$

were calculated. In a graph showing  $\ln F$  versus S, this curve becomes a line with a variable slope passing through the centre of gravity of the points representing the data measured by the device considered on the half section considered. These graphs are visible in **Appendix 1**;

- for each half section (j), the overall average residual standard deviation

$$\langle \sigma \rangle_j = \text{SQRT}\{ \sum_i n_{ij} \sigma_{ij}^2 / \sum_i n_{ij} \}$$

was calculated for each  $S_0$  value;

- for each half section (j),  $\langle \sigma \rangle_j$  was plotted against  $S_0$  and the  $S_0$  value minimizing  $\langle \sigma \rangle_j$ ,  $S_{0j}^*$ , was determined (by parabolic interpolation between the lowest three points) - see the example of **Figure 4**. These graphs are visible in **Appendix 1**.

In this way of determining an "average"  $S_o$  value characteristic of a half section but common to all devices, each individual measurement is accounted for with the same weight. More particularly, the influence of the deviation of a given measurement from the model is the same for all measurements whichever device is considered, whatever the measuring speed and whatever the number of measurements performed by the device on the site. This method differs from that described in the report on the PIARC experiment [ref. 1, p. 128], which simply averages the  $S_o$  values found by regressive fitting of the exponential model to each series of measurements made by a given device on the site considered; in our processing scheme, this would amount to taking the average of the  $S_{oj}$  values of each device as the optimum value  $S_{oj}^*$ , using the equation:

$$S_{oj}^* = \Sigma_i (-1/B_{ij}) / \Sigma_i n_{ij}$$

Now this method introduces two sorts of biases.

Firstly, high  $S_o$  values are given more weight than low values. At worst, it would take only one friction coefficient virtually not decreasing with speed to have a corresponding  $S_o$  value tending to infinity, thereby determining the average value all by itself.

Secondly, the  $S_o$  values found for devices operated at low slip speed are more sensitive to errors in measurements of  $F$  than those calculated over a wider range of speeds, whereas they are given the same weight.

The method adopted here gives exactly the same weight to each individual measurement and the optimum  $S_o$  value for a given half section is that minimizing the sum of the squares of all deviations from the  $F(S)$  curves.

**Figure 5** presents an example of the fitting of exponential curves of equal slope to a set of series of data measured with different devices on a given half section.

9. For all reference speeds  $S_R$  ranging from 10 to 90 kmph with intervals of 10 kmph, the following operations were performed :

- for each measurement (measurement  $m$ , device  $i$ , half section  $j$ ): separate calculation and tabulation, with the corresponding slip speed  $S_{mij}$  given in the first column, of the value of friction coefficient  $F_{Rmij}$  reduced to the reference speed, using the equation:

$$F_{Rmij} = \exp\{\ln F_{mij} - (S_R - S_{mij})/S_{oj}^*\}$$

- averaging the  $F_{Rmij}$  values over all devices for each half section:

$$\langle F_R \rangle_j = \Sigma_m \Sigma_i F_{Rmij} / \Sigma_i n_{ij}$$

This value corresponds with the "golden" (ideal) value defined in the report on the PIARC experiment [ref. 1, p. 127]. For each device and each  $S_R$  value,  $F_{Rmij}$  was plotted against  $\langle F_R \rangle_j$  while representing all half sections on the same graph (**Figure 6**), and parameters  $A_{Ri}$ ,  $B_{Ri}$ ,  $\rho_{Ri}$  and  $\sigma_{Ri}$  of the linear regression :

$$\langle F_R \rangle_j = A_{Ri} + B_{Ri} * F_{Rmij}$$

were calculated.

A search was then made for all deviations greater than  $3\sigma_{Ri}$  from the regression line; such a deviation being indicative of a systematic wide shift of the series of measurements to which it belonged. The following outlying series were found (see the example in **Figure 7**):

- Graphs without distinction by type of tyre:

C1: 61A, 61B, 82.3A, 82.3B  
 C5: 66A, 66B  
 C8: 26.1A, 26.1B, 82.3A  
 C9: 26.1A, 26.1B  
 C10: 26.1A, 26.1B, 50A, 50B  
 D6: 26.1A, 26.1B, 33.1A, 33.1B, 34A, 34B  
 D8: 81.3A, 81.3B

- Specific graphs for smooth tyres:

C8: 26.1B  
 D2: 12A, 12B  
 D6: 26.1A, 34A, 34B, 50B, 53A  
 D8: 81.3A, 81.3B

- Specific graphs for patterned tyres:

B5LKD: 82.2A, 82.2B, 82.3A, 82.3B  
 C1: 82.1A, 82.3B.

At this stage of the analysis, these series of data were maintained; we shall see later on whether their removal significantly improved the precision of EFI. All these graphs, including those discarded after the calculations, are visible in **Appendix 1**.

11. The relative and absolute values of the overall residual standard deviation,  $\sigma_R$ , of all measurements were plotted against  $S_R$  (**Figure 8**). The relative values prove to slightly increase with  $S_R$ , this can be explained by considering that in the diagram of  $\ln F$  versus  $S$ , the prediction of  $\langle F_R \rangle_j$  from an  $F_{Rmij}$  measurement is made by means of parallel lines having a slope  $-1/S_{qj}^*$  and that, consequently, the deviations do not vary with the choice of  $S_R$ . Now the relative deviations are nothing else but the deviations on  $\ln F$ , and that is why the relative  $\sigma_R$  is approximately constant. As for the absolute  $\sigma_R$ , it decreases when  $S_R$  increases; likewise, at equal  $S_0$  value, the variation between two decreasing exponential curves in the diagram of  $F$  versus  $S$  decreases when  $S$  increases.
12. The graphs representing  $S_{qj}^*$  versus texture measurement  $T_{ISO}$  were drawn either separately for the devices with smooth tyres (**Figure 9**) and those with patterned tyres (**Figure 10**) or for all devices regardless of tyre type (**Figure 11**). It can be seen that considerably outlying results were found for three sites:
- the two half sections of site 34,
  - the eight half sections of site 81,
  - the two half sections of site 82.2.

Site 81 is, in fact, the main runway of the NASA air base at Moron (Spain). One explanation could be the observation made by participants that this pavement, which has a relatively fine macrotexture ( $0.44 \text{ mm} < T_{ISO} < 0.57 \text{ mm}$ ), seems to include aggregate obtained from volcanic rock extremely rough to the touch. There are obviously no errors in measurement or abnormal measuring conditions involved, as the  $S_{qj}^*$  values were determined from the outputs of all the devices. Special cases like this should be remembered as calling for further investigation. Nevertheless, we have to exclude them from the analysis for the time being. This being done, parameters  $a_{ISO}$ ,  $b_{ISO}$  and  $\sigma_{ISO}$  of the regression<sup>7</sup>

$$S_{qj}^* = a_{ISO} + b_{ISO} * T_{ISO}$$

were calculated, taking the data of device A5 as a basis.

Site 82 is on another NASA base at Rota in Spain. Here the explanation could be local traces of rubber left by the tyres of aeroplanes landing on the test sections. Perhaps those traces were larger or more marked on section 82.2 than on the other two adjacent sections.

Site 34 is the only surfacing of the ESHP type and is made of highly abrasive fine chippings spread on a tack coat in epoxy resin. The case is similar to that of the runway of Moron, though much milder. Moreover, the outliers are limited to smooth-tyred devices.

<sup>7</sup> Index ISO refers to the fact that the data base contains other texture measurements.

These twelve special half sections were excluded from the analysis. **Figure 12**, **Figure 13** and **Figure 14** show the new graphs "trimmed" of outliers and the results of the updated regressions are presented in **Table 4**. It should be noted that from this point onwards texture depth by the ISO standard will have to be considered.

A remarkable finding here is that none of the three sites in porous asphalt stands out from the rest, as could be expected on account of their peculiar macrotexture. In the PIARC report they were discarded a priori without further justification.

13. Finally, stages 9 and 10 were repeated using  $S_{q''}$  values, i.e.  $S_{q^*}$  values predicted from texture depth values determined by the ISO method. This resulted in end values for  $A_{RI}$ ,  $B_{RI}$ ,  $\rho_{RI}$  and  $\sigma_{RI}$ .

### **VII.3 Separation by tyre type**

Devices measuring skid resistance by means of a smooth tyre should, in principle, be more sensitive to the macrotexture of the road surfacing under test than those using a patterned tyre, as the former call upon the macrotexture to do all the drainage whereas the latter perform this drainage partly by themselves, through the grooves in their treads. As a result, the parameters of the PIARC model, especially parameter  $S_0$ , may be expected to differ significantly on a given site according to the tyre type used. That is why stages 8 to 13 were repeated while distinguishing between devices using a smooth tyre (C3B, C5, C64, C8, C9, C10, D1E, D2, D3, D4, D5, D6, D8) or a patterned tyre (B1LKD, B1SLP, B2LKD, B2SLP, B3, B5LKD, B5SLP, C1). The relations between  $S_0$  and  $T_{ISO}$  (**Figure 12** and **Figure 13**) actually appear to differ significantly (from a statistical point of view<sup>8</sup>) according to tyre type. However, the correlation is markedly better when considering all the devices together, regardless of tyre type. The residual standard deviations on  $S_0$  are 20 kmph overall and 21 and 29 kmph for the series corresponding with patterned and smooth tyres, respectively. It should be noted that this finding need not be paradoxical: the  $S_0$  values differ between the three series because they each result from a new least squares fit to the set of series of measurements per half section and per device.

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<sup>8</sup> Using the SNEDECOR-FISHER test for comparing slopes.

#### VII.4 Choice of the reference speed

At this stage, the harmonized coefficient of friction - which may be called EFI by now - can be predicted from an individual measurement  $F_{mij}$  performed at a speed  $S_{mij}$  by means of the equation<sup>9</sup>

$$EFI_j = A_{Ri} + B_{Ri} * F_{mij} * \exp\{(S_{mij} - S_R)/(a_{ISO} + b_{ISO} * T_{ISO})\}$$

The various devices have different ranges of operating speeds. With a device capable of measuring at the reference speed  $S_R$  it will be possible to do without knowledge of macrotexture, the fractional exponent in the above equation being reduced to zero. In general, more allowance for the texture measurement will have to be made as the measuring speed,  $S_{mij}$ , is different from the reference speed. This means that the greater the difference between the measuring range of a device and  $S_R$ , the more any imprecision of a device  $x$  used to measure texture will affect (through errors in measuring  $T_x$  as well as through the imprecision of the equation to predict  $S_{qj}^*$ ) the accuracy of EFI prediction with this device. To minimize this source of error, an  $S_R$  value must, therefore, be chosen which in a way corresponds to the average of the operating speeds of the various devices. More precisely, this optimum reference speed will be that which minimizes the standard deviation, calculated over all half sections  $j$ , of the differences between, on the one hand,  $EFI_j$  found with the prediction of  $S_{qj}^*$  based on some other texture measurement,  $T_x$ , than the standardized ISO measurement - parameters  $A_{Ri}$  and  $B_{Ri}$  remaining unchanged as they are part of the definition of EFI - and, on the other, its "true" value,  $\langle F_R \rangle_j$ . The definition of EFI being based on the newly standardized measurement  $T_{ISO}$ , the differences in  $S_{qj}^*$  predictions between the various selected texture measuring methods and the ISO method can, indeed, be considered as representative of the source of errors due to the texture measurement. The texture measurement files only contain the average values per half section. Neither the differences between measurements replicated at the same location nor the differences between the measurements at locations spread over the section were archived. As a result, the method proposed to determine an optimum value for the reference speed does not take account of the intrinsic errors in measurements (repeatability), but only of the imprecision or uncertainty in the equation to predict  $S_{qj}^*$ .

An estimate,  $E_{Rmixj}$ , of  $\langle F_R \rangle_j$  was thus calculated from all  $F_{mij}$  values and for all reference speeds, using the equation

$$E_{Rmixj} = A_{Ri} + B_{Ri} * F_{mij} * \exp\{-(S_R - S_{mij})/S_{oxj}^{**}\}$$

where

$$S_{oxj}^{**} = a_x + b_x * T_{xj}$$

<sup>9</sup> The subscript  $j$  affixed to EFI characterizes a half section, whatever the measuring method used.

giving

$$E_{Rmixj} = A_{Ri} + B_{Ri} * F_{mij} * \exp\{-(S_R - S_{mij}) / (a_x + b_x * T_{xj})\}$$

Then the absolute and relative quadratic means of the differences between  $E_{Rmixj}$  and  $\langle F_R \rangle_j$  were calculated by summation over all the friction measurements performed by all the devices on all the sites and further summation over all the texture measurements other than ISO:

$$\sigma_{R,x,abs} = \text{SQRT}\{\sum_x \sum_j \sum_i \sum_m (E_{Rmixj} - E_{Rmi,ISOj})^2 / \sum_x \sum_j \sum_i \sum_m 1\}$$

$$\sigma_{R,x,rel} = \text{SQRT}\{\sum_x \sum_j \sum_i \sum_m [(E_{Rmixj} - E_{Rmi,ISOj}) / E_{Rmi,ISOj}]^2 / \sum_x \sum_j \sum_i \sum_m 1\}$$

The standard deviations found (**Figure 15** and **Figure 16**) as a function of the reference speed exhibit a maximum at roughly  $S_R = 30$  kmph; this value will henceforth be proposed for the definition of EFI. Consequently, it is possible to give the regression parameters enabling each device to predict this EFI, either regardless of tyre type (first part of **Table 5**) or according to it (second part of **Table 5**).

### VII.5 Repeatability of EFI

The repeatability of each method to measure F was investigated and reported in the PIARC report [ref. 1, p. 45]. The investigation related to variations between measurements replicated under the same conditions, especially of specified speed<sup>10</sup>. What we are interested in here is the repeatability of the EFI value whatever the operating speed, since the allowance made for texture is nothing else but a correction for the influence of speed which reduces EFI to a fixed reference speed. As stated above, we only have replicated measurements for skid resistance and not for texture, for which only average values per half section were archived. This means that the repeatability of EFI considered here is assessed from replicated measurements of F converted in terms of EFI using a single value of T measured on the site considered.

The repeatability of EFI per half section was calculated by means of standardized equations [ref. 4]:

$$\begin{aligned} N &= \sum_i 1 \\ n_{ij} &= \sum_m 1 \\ \mu_{ij} &= \sum_m \text{EFI}_{est,mij} / n_{ij} \\ \sigma_{ij} &= \text{SQRT}\{\sum_m (\text{EFI}_{est,mij} - \mu_{ij})^2 / (n_{ij} - 1)\} \\ \sigma_{rj} &= \text{SQRT}\{\sum_i (n_{ij} - 1) \sigma_{ij}^2 / (\sum_i n_{ij} - N)\} \\ r_j &= 2\sqrt{2} \sigma_{rj} \end{aligned}$$

<sup>10</sup> Although the operating speeds were very often rather different from the specified speed, which may have affected the repeatability values found.

Calculations were made on the one hand on the "trimmed" data (outliers removed) used to define EFI and, on the other, on the "untrimmed" full initial data. The results are presented in **Table 6**. Averaged over all sites, using the standardized equations

$$J = \sum_j 1$$

$$r = \sum_j r_j / J$$

a repeatability of 0.08 to 0.10 is found, according to whether the trimmed or untrimmed data is considered. It should be noted that analysing the devices in one or two separate classes according to tyre type has virtually no influence on the repeatability of EFI.

### **VII.6 Reproducibility of EFI**

Since EFI must be determined from a skid resistance and a texture measurement, its reproducibility depends, strictly speaking, on both types of measurement. In our analysis, it is characterized by the standard deviations of the differences in EFI values - all other relevant things remaining unaltered - between pairs of different measuring systems. "Measuring system" here is understood to mean the association of a method to measure F with a device producing a measurement of T in accordance with the ISO standard. Although both friction and texture measurements may be combined in a single device as in the case of the SCRIMTEX, the devices to measure F and T should not, in principle, be considered as paired but rather as independent, i.e. any method to measure F can be associated, for a given series of measurements, with any method to measure  $T_{ISO}$ . This, in any case, is an assumption which puts us on the safe side, by maximizing the possible deviations. Under such conditions, the overall reproducibility of EFI at the optimum reference speed  $S_R = 30$  kmph should be characterized by the variations between pairs of measuring systems (F,  $T_{ISO}$ ), all possible combinations being included. Unfortunately, our device is the only one capable of producing ISO standard values for the textures considered in the PIARC experiment. Estimating the reproducibility of EFI from varied pairs of measurements (F,  $T_{ISO}$ ) is, therefore, impossible. As a result, the calculation presented below only takes account of the variations in EFI predictions due to the use of different friction devices, the texture measurement being assumedly performed with a single device. The reproducibility of EFI is then calculated by the following standardized equations [ref. 4]:

$$n_j = \{(\sum_i n_{ij})^2 - \sum_i n_{ij}^2\} / \{(N-1) \sum_i n_{ij}\}$$

$$\mu_j = \sum_i n_{ij} \mu_{ij} / \sum_i n_{ij}$$

$$\sigma_{R_j}^2 = \{(\sum_i n_{ij} (\mu_{ij} - \mu_j)^2) / (N-1) - \sigma_{\eta}^2\} / n_j$$

$$R_j = 2\sqrt{2} \text{ SQRT}(\sigma_{R_j}^2 + \sigma_{\eta}^2)$$

$$R = \sum_j R_j / J$$



The results are presented in **Table 6**. Depending on whether the results were trimmed of outliers or not, values between 0.14 and 0.17 are found for the overall reproducibility of EFI. Like for repeatability, separate consideration by tyre type does not result in a significant improvement.

The reproducibility of EFI can be assessed from another angle : that of the harmonization between the various measuring methods. Let us take the example of the two Belgian devices which participated in the PIARC experiment - the SCRIM of LIN and the odoliograph of MET - and let us compare the results they produced at the same speed on a given site. **Figure 26** and **Figure 27** show the distributions of differences found between the two measurements, for the friction coefficient (SFC) determined by each device using its own method and for the harmonized friction coefficient (EFI), respectively. It can be seen that the conversion to EFI values not only significantly reduces the average absolute difference (from 0.08 to 0.01) but also leads to a decrease in standard deviation (from 0.08 to 0.05). This virtual elimination of average difference is nothing else but the objective of harmonization, i.e. to enable different devices to express their results on a single common scale of friction coefficient.

### **VII.7 Accuracy of EFI**

There is no such thing as a single absolutely accurate tyre-road friction coefficient, because of the numerous factors involved and the difficulty or even impracticability of defining, maintaining and reproducing reference surfaces and/or tyres which can be used as stable standards. EFI is, in fact, a "floating" standard, which may drift with the set of devices upon which its definition is based. The concept of accuracy of an EFI value is, therefore, meaningless. However, the accuracy of a given device can be considered as the degree of agreement of its output with the EFI value. In this respect, the accuracy of a device *i* would be nothing else but the residual standard deviation,  $\sigma_i$ , of the regression which determines parameters  $A_i$  and  $B_i$  as presented in **Table 5**. Averaged over all the devices, the residual standard deviation in predicting EFI is found to be 0.050 (in relative terms : 9.4 %) overall for all tyres and 0.047 (in relative terms : 9.0 %) if the type B and type RP tyres are taken separately.

### **VII.8 Sensitivity of EFI to imprecisions in estimating $S_{oj}^*$**

The prediction,  $S_{oj}^{**}$ , of  $S_{oj}^*$  from texture depth (**Figure 14**) is affected by an imprecision which can be described by the residual standard deviation from the regression

$$S_{oj}^{**} = a + b * ETD_{ISO}$$

This deviation,  $\sigma_{Sp}$ , has a value of 20 kmph after the outliers have been discarded. The resulting imprecision in predicting EFI will depend on the difference between the operating speed (actual slip speed) and the reference (slip) speed of 30 kmph, as well as on the friction level measured. The standard deviation,  $\sigma_{EFI}$ , of this source of potential errors can be derived from the equation relating EFI to  $S_p$  :

$$\sigma_{EFI} = \sigma_{Sp} * B * F * ((30-S)/(S_{oj}^{**})^2) * \exp((S-30)/S_{oj}^{**})$$

or, in general terms, since A and B are close to zero and unity, respectively, and after replacing  $\sigma_{Sp}$  with its value and eliminating F in order to include EFI:

$$\sigma_{EFI} = 20 * EFI * \text{ABS}((30-S)/(S_{oj}^{**})^2)$$

The values of  $\sigma_{EFI}$  are presented in **Table 10** through **Table 15**.

## **VIII. Additional measurements (SSTC, 1997)**

As stated before, the objective of these measurements was to try and extend the validity of IFI to road surfacings having an anisotropic texture (grooved cement concrete), to open-textured surfacings (porous asphalt, open-textured thin surfacing, gap-graded thin surfacing, coarse-graded ultrathin surfacing) and to special materials (high-performance surface dressing), which had not been adequately considered in the PIARC experiment. This required a programme of additional road tests.

### ***VIII.1 Selection of sites***

The twenty-five sites selected for the measurements are presented in **Table 7**. The sample was composed of eight conventional surfacings (one surface dressing, three type I (dense) asphalts, and four exposed aggregate concretes) and seventeen special surfacings (four porous asphalts, one high-performance surface dressing, one porous (cement) concrete, one type II (dense) asphalt 0/10, one fine-graded exposed aggregate (cement) concrete 0/7, five open-textured thin surfacings, two coarse-graded ultrathin surfacings, one gap-graded thin surfacing, and one grooved (cement) concrete).

### ***VIII.2 Equipment used***

The devices used were the odoliograph of MET and the SCRIMTEX of LIN. The former already participated in the PIARC experiment, while the latter was a new device having, in principle, the same characteristics and performance as the SCRIM of LIN which participated in the PIARC experiment.

### ***VIII.3 Implementation***

All the planned measurements were actually performed except on sites 15 and 25, which had become impracticable at the time of testing. The skid resistance measurements took place from 1st till 7th April 1997, and the texture measurements from 8th April till 21st May 1997. The conditions of measurement were strictly the same as in the PIARC experiment. More particularly, the sections of 150 m were divided in two and results were reported for each half section of 75 m. The skid resistance measurements were repeated by making two runs at each of the specified three speeds (30, 60 and 90 kmph). The texture measurements were made on four locations in each half section and the average values were reported.

### ***VIII.4 Results***

The results are given in **Appendix 1**. The reduced data, i.e. the parameters of the exponential regression between the friction measurements and slip speed, are reviewed in **Table 8** and **Table 9**.

In **Figure 24** and **Figure 25**, comparisons based on the SCRIM and the