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Comparison of measurement methods of the friction coefficient of floor coverings

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INRS / CSTB joint publication

Patrice Marchal, Michel Jacques
INRS

Antonino Sigari
CSTB

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A publicly funded institution working for innovation in the building trade, CSTB (*Centre Scientifique et Technique du Bâtiment*), France's Scientific and Technical Centre for the Building Trade has four key activities: conducting research, providing expertise, assessing innovation, and disseminating knowledge, these activities being organised to take up the challenges of sustainable development in the building world. Its range of skills covers construction products, buildings, and how they are integrated into neighbourhoods, towns, and cities.

With its staff of 918, its subsidiaries, and its national, European, and international networks of partners, CSTB works for all of the stakeholders in the building and construction industry, to improve the quality and the safety of buildings.

INRS (French Research and Safety Institute for the Prevention of Occupational Accidents and Diseases) works both for the companies and for their 18 million employees who come under the French Social Security's general scheme.

A general practitioner in occupational safety and health, INRS works with the other institutional stakeholders in occupational risk prevention. From acquiring new knowledge to transferring it out into the field, INRS proposes appropriate responses to occupational risks in all of their diversity. A staff of 632 makes their contributions to a variety of areas such as chemicals, toxicology, mechanics, acoustics, etc. as well as to regulation or standardisation.

Founded in 1947, INRS is a non-profit-making association managed by a Board of Directors made up equally of representatives from employer organisations and of representatives from employee union organisations.

Abstract:

According to the statistics of France's National Health Insurance Fund for Salaried Employees, falls on the same level represent about one quarter of occupational accidents resulting in sick leave. Loss of balance due to slipping is one of the causes of such falls. For some twenty years now, INRS (France's National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases) has been using two testing methods namely the LabINRS and the PFT (Portable Friction Tester), for evaluating the coefficients of friction of floor coverings.
An experimental standard drawn up by the European Committee for Standardization (CEN) proposes two other methods (Ramp test and Pendulum SRT - Skid Resistance Tester).

The aims of this study, conducted in partnership between INRS and CSTB (France's Scientific and Technical Centre for the Building), were thus to compare the four methods, to assess the practical aspects of each of them, and to define the limits of them. To be relevant, the 4 measurement methods need to be sufficiently representative of the slip perceived during walking, and to be sufficiently discriminatory with respect to slips. INRS developed a psychophysical rating method, the aim of which was to make it possible to establish reference rankings based on "perceived slipperiness". Those rankings were to be compared with the rankings obtained using the metrological methods.

This study shows that, from a purely metrological point of view, the *ramp test* and the psychophysical method give the highest correlation coefficients. The second advantage of the ramp test is its renown among trade professionals who have been using it for categorising floor coverings for several decades now, regardless of the types of flooring and of their fields of use. However, implementing it suffers from major drawbacks, such as the need to use test subjects and the impossibility of taking measurements on site.

The *LabINRS* method gives correlation coefficients with the psychophysical method that are very good and that are almost equivalent to those obtained with the ramp test. In addition, it is very simple to implement; however, it suffers from the drawback of not making it possible for measurements to be taken in situ.

Conversely, due to its very simple operating principle and to it being easy implement, the *pendulum SRT* is the best suited to taking measurements in situ. Its renown is high as it has been in use for many years for qualifying road surfaces and pedestrian surfaces. However, the correlation coefficients with the psychophysical method are low, raising questions as to its capacity to rank floor coverings as a function of slipperiness. In addition, it does not make it possible to qualify correctly all types of floor covering, e.g. coverings with macro-relief.

As for *PFT*, the correlation coefficients with the psychophysical method are very satisfactory. Even though it was originally designed to qualify road surfaces, INRS has considerable experience in using it for qualifying pedestrian surfaces, in particular such surfaces that are designed for use in the food industry. It makes it possible to take measurements in the laboratory and in situ, on any type of floor covering.

CONTENTS

1 - OUTLINE OF REASONS AND OBJECTIVES

According to the statistics of France's National Health Insurance Fund for Salaried Employees (*Caisse Nationale de l'Assurance Maladie des Travailleurs Salariés*), falls on the same level represent about one quarter of occupational accidents resulting in sick leave. Loss of balance due to slipping is one of the causes of such falls. For some twenty years now, INRS (France's National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases) has been using two testing methods namely the LabINRS, that it developed, and the PFT (Portable Friction Tester), for evaluating the coefficients of friction of floor coverings. They make it possible, respectively, to conduct measurements in the laboratory and *in situ* [1,2,3].

These two testing methods are essentially known and used for characterising the performance of slip resistance of flooring in workplaces in the food industry.

A European standardisation group recently worked on preparing a Technical Specification [4] representing the current state of the art of the most commonly used test methods for determining slip resistance of pedestrian surfaces. That document has been incorporated into the collections of French experimental standards, with a view to supplementing and to ultimately replacing the experimental standard XP P 05-010 which addresses the same topic. The two most commonly used assessment methods selected by the European Committee for Standardization (CEN) for characterising new products in the laboratory are the Ramp Test [5] taken from German Standard DIN 51130 [6], and whose principle has been taken up in Standard XP P 05-010 [7], and the pendulum Skid Resistance Tester (SRT) developed in Great Britain and described in Standard EN 13036-4 [8].

Assessment by using the ramp test is performed with human testers. This method cannot be used *in situ* and is applicable only for laboratory characterisation of samples of floor coverings. And yet the slip resistance of such coverings need to be tested *in situ*, in particular coverings that are cast on site, in order to check that their coefficients of friction are similar to the coefficients of friction measured on the samples in the laboratory. The coefficients of friction depend on the surface characteristics (roughness, homogeneity, evenness) that in turn depend essentially on the quality of fitting or of casting of the coverings.

The pendulum SRT is transportable and makes it possible to take both laboratory measurements and also *in situ* measurements. However, its measurement distance is only 12 cm. It can be necessary to perform quite large numbers of measurement operations in order to characterise a floor covering *in situ*.

The Ramp Test and SRT methods are in common use in France for assessing the slip resistance of pedestrian surfaces respectively initially in the laboratory, and *in-situ* in a variety of premises and of sectors of activity.

The aims of this study were thus to compare the four methods, to assess the practical aspects of each of them, and to define the limits of them. To be relevant, the 4 measurement methods need to be sufficiently representative of the slip perceived during walking, and to be sufficiently discriminatory with respect to slips. INRS developed a psychophysical rating method, the aim of which was to make it possible to establish reference rankings based on "perceived slipperiness". Those rankings were to be compared with the rankings obtained using the metrological methods.

This study was conducted in partnership between INRS and CSTB (*Centre Scientifique et Technique du Bâtiment*). The aim of this collaboration was to define a common position and to enable that position to be defended more effectively in the working groups and on the standardisation committees.

2 - METHODOLOGY

2.1. Methods studied

In order to meet the objectives of the study, measurements were performed in the laboratory using the 4 methods on a panel of floor coverings so as to rank them from the least slippery to the most slippery.

The tests were distributed in the following manner:
- for the laboratory equipment: the ramp tests were conducted at CSTB, and the LabINRS tests were conducted at INRS;
- for the equipment serving for taking the *in situ* and the laboratory measurements: the PFT tests were conducted at INRS, and the SRT tests were conducted at CSTB.

The principles and operating modes of the 4 methods are described in Appendix 1.

2.2. Floor coverings

Fifteen floor coverings were chosen. That quantity made it possible to obtain a sufficiently broad panel of coefficients of friction and of different materials representatives of the floor coverings used in premises in which there is a risk of slipping over. Each sample of floor covering was identified by a letter given in Appendix 2.

2.3. Materials rubbing on the flooring

For each test method, the types of material that came into contact with the floor coverings and therefore that were subjected to friction were the materials commonly used in the operating mode or in the corresponding test standard (cf. Appendix 1). In the particular case of testing in the barefoot configuration by using the Ramp Test method, the test persons' feet were directly in contact with each test covering.

2.4. Contaminants

Some floor coverings are slippery only if a contaminant or pollutant is present between the shod foot or the bare foot and the floor covering. Two contaminants were chosen that represented a majority of situations encountered at workplaces or other premises for pedestrian use:
- mineral oil, of SAE viscosity grade 10W30. That contaminant is representative of the situations in which flooring is soiled with greasy substances;
- water solution containing 1 g/l of neutral wetting agent (sodium dodecyl sulphate – or lauryl sulphate 98%). That contaminant is representative of the situations in which flooring is polluted with dirty or soapy water.

2.5. Psychophysical rating method

INRS has developed a subjective rating method [9] for subjectively rating the slipperiness of floor coverings. It is derived from Thurstone's method of pairwise comparisons. Test persons walk on a particular type of floor covering while generating accelerations, skids, and turns following an established protocol, and then they repeat those operations on another type of

covering. When they have finished, each test person gives a comparative opinion on the perceived performance of the two types of floor covering: the test person designates the slipperier of the two or indicates they consider them to be equivalent. A comparisons record is published per test person and per contaminant. That record makes it possible to give scores to the floor coverings of the panel, and to rank them from the least slippery to the most slippery. The data processing is explained in Appendix 3. A mean ranking is established for each floor covering by adding up the scores given by the various test persons. Twelve test persons took part in the tests. They had to be aged from 18 years to 60 years, without any particular specification as to sex and body measurements.

The consistency of the ratings was validated by establishing the Spearman's correlations of the test persons in pairs, and by establishing the Kendall's coefficient of concordance for all of the test persons. In addition, the number of test persons was validated by comparing the mean rankings obtained with 12 test persons and the mean rankings obtained with 9 test persons.

A test installation (cf. Figure 1) was designed and manufactured by INRS. It enables a test person (wearing a harness and a lifeline for safety) to rate the slipperiness of floor coverings by following a defined protocol.
All of the floor coverings are installed on the floor as shown in Figure 2. The principle is to move a sample e1 past the (n-1) other samples so as to compare it with them. Then, sample e1 is replaced with sample e2 that can be compared with the (n-1) samples, and so on.
The floor coverings were rated in the presence of a contaminant successively in the two following configurations:
-   with mineral oil, of SAE viscosity grade 10W30, and with the test persons wearing specific safety footwear: New 1000 of the "Gaston Mille" brand. The coefficients of friction of all of the items of footwear was measured as soon as they were received using Standard EN 13287 [10] to check their grip characteristics;
-   with water solution containing 1 g/l of neutral wetting agent (lauryl sulphate 98%) in water coming from the water supply network, with the test persons being barefoot.
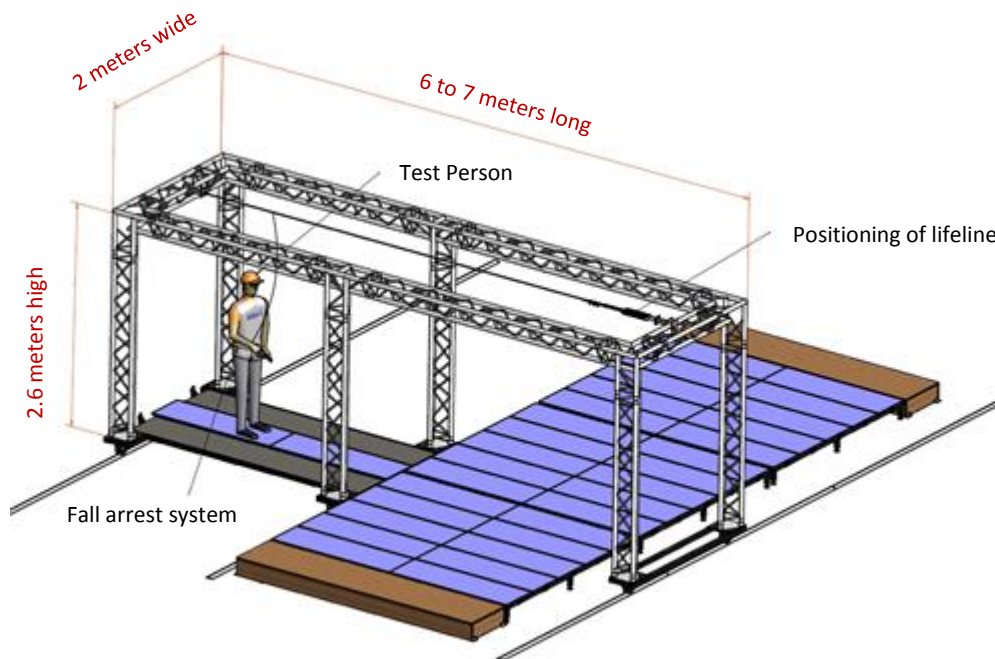

Figure 1. Drawing of the setup for subjectively rating floor coverings.

n-1 stationary floorings

3 m

Movement of the moving sample « e »
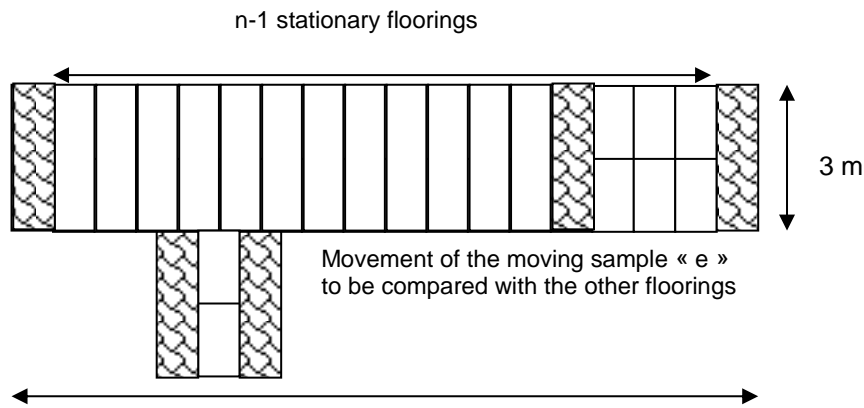to be compared with the other floorings

Figure 2. Layout of the floor coverings during the tests.

This psychophysical rating method made it possible to obtain rankings for the 15 floor coverings based on "perceived slipperiness" as perceived by the test persons.

2.6. Comparison of the methods

2.6.1. Metrological aspects

The methods studied give rankings for the floor coverings on the basis of numerical values obtained using the assessment or rating method of each of them:
- psychophysical rating: score;
- ramp test: angle [°] as from which the test person slips;
- pendulum SRT: Pendulum Test Value [PTV] corresponding to the height to which the pendulum swings after being released;
- PFT: dynamic friction coefficient [µd];
- LabINRS: dynamic friction coefficient [µd].

The rankings were analysed in order to check:
- the Spearman's correlation of each method with the reference rankings;
- the Spearman's correlation of the various methods with one another.

A descriptive analysis was conducted to explain the correlation coefficients, to highlight the specific differences in the rankings of the floor coverings depending on the methods, and to check their slippery/not slippery rankings on the basis of the specifications of each method.

2.6.2. Practical aspects

During the laboratory tests, the practical aspects of use of the 4 methods were assessed to estimate their advantages and their drawbacks.
That assessment was supplemented with *in situ* tests using 2 "transportable" methods. The sites chosen, with the help of the French Occupational Health and Pension Insurance Fund (CARSAT) for the Burgundy and Franche-Comté Regions, were chosen to enable measurements to be taken under a variety of conditions and on a variety of different floor coverings. INRS conducted the PFT tests and CSTB performed the pendulum SRT tests, in the presence of one of the two contaminants (oil or water solution), chosen depending on the activity of the premises.
All of these tests enabled an overall comparison of the 4 method to be made.

3 - MAIN RESULTS

3.1. Psychophysical method

3.1.1. Reference rankings

Reference [9] presents the rankings of the floor coverings, from the least slippery to the most slippery, obtained per test person and per contaminant. They made it possible to establish the reference rankings (cf. Table 1) by adding up, for each floor covering, the scores attributed by the 12 test persons depending on the contaminants.

	Ranking with oil as the contaminant	Ranking with water solution as the contaminant
least slippery	L	X
	X	L
	A	N
	B	A
	N	B
	K	D
	R	C
	S	K
	D	S
	C	H
	E	R
	I	E
	H	I
	U	U
most slippery	M	M

Table 1. Rankings of the floor coverings with 12 test persons.

3.1.2. Hierarchical rankings

The dendrograms (cf. Figures 3 and 4) were plotted on the basis of the rankings of the 12 test persons, for each contaminant. They make it possible to show indistinctness, i.e. floor coverings that are substantially similar in terms of slipperiness according to the test persons. This information is useful for putting into perspective any inversions that might be observed when comparing the rankings obtained using the different measurement methods studied.
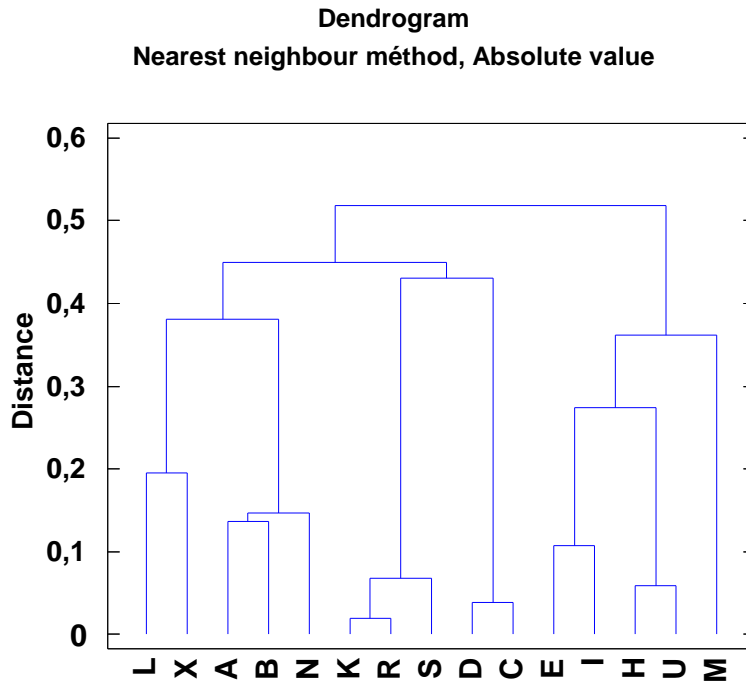
Dendrogram
Nearest neighbour méthod, Absolute value

Figure 3. Dendrogram of the ranking with 12 test persons and oil as the contaminant.

The dendrogram shows that, according to the 12 test persons, it is difficult to distinguish between samples K and R. It is hardly any easier to discriminate between samples D and C.
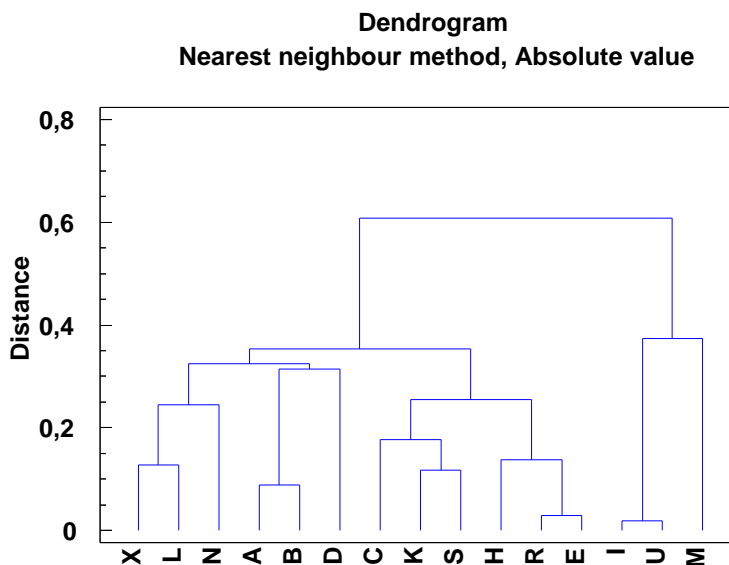
Dendrogram
Nearest neighbour method, Absolute value

Figure 4. Dendrogram of the ranking with 12 test persons and water solution as the contaminant

Some indistinct pairings are highlighted by the dendrograms and these need to be taken into account when comparing the 4 methods studied.

3.1.3. Summary and conclusion of the psychophysical ratings

The consistency of the rankings between the test persons was checked and the number of test persons was validated [9]. The analyses show that the rankings of the 15 floor coverings, obtained from the psychophysical ratings conducted by the 12 test persons with oil and water solution as contaminants are sufficiently robust to be used as references and to be compared with the rankings obtained using the 4 methods studied.

3.2. Comparison of the studied methods – measurements with oil

Table 2 shows the summary of the results of the measurements of all of the floor coverings using the 4 metrological methods and the psychophysical method, in the presence of oil. In addition, for each method, it gives the ranks of the samples.

Sample ref.	Ramp, Oil		SRT, Oil		PFT, Oil		LabINRS, Oil		Psy, Oil	
	[°]	*Rank*	[PTV]	*Rank*	[µd]	*Rank*	[µd]	*Rank*	[score]	*Rank*
M	2	1	13	5	0	3	0	1	2	1
U	3	2	11	1	0	3	0	1	20.5	2
H	6	4	11	1	0	3	0.01	4	23.5	3
I	5	3	13	5	0	3	0.03	5	37.5	4
E	8	5	13	5	0	3	0.008	3	43	5
C	15	8	13	5	0.1	7	0.19	7	69.5	6
D	10	6	13	5	0	3	0.09	6	71.5	7
S	10	6	44	13	0.24	9	0.31	9	93.5	8
R	17	10	41	12	0.29	10	0.34	10	97	9
K	17	10	36	10	0.2	8	0.27	8	98	10
N	24	13	28	8	0.31	11	0.36	11	121	11
B	20	12	45	15	0.45	12	0.38	12	128.5	12
A	19	11	36	10	0.46	13	0.42	13	135.5	13
X	26	14	45	15	0.5	15	0.49	14	155	14
L	30	15	36	10	0.5	15	0.53	15	165	15

Table 2. Results of the slipperiness measurements with the various studied methods in the presence of oil

On the basis of Table 2, Figure 5 gives a matrix of graphs comparing, in pairwise manner, the floor covering rankings obtained using the various methods. In each cell, the axis of abscissas gives the rank obtained by the method of the column in question, and the axis of the ordinates gives the rank obtained by the method of the row in question.
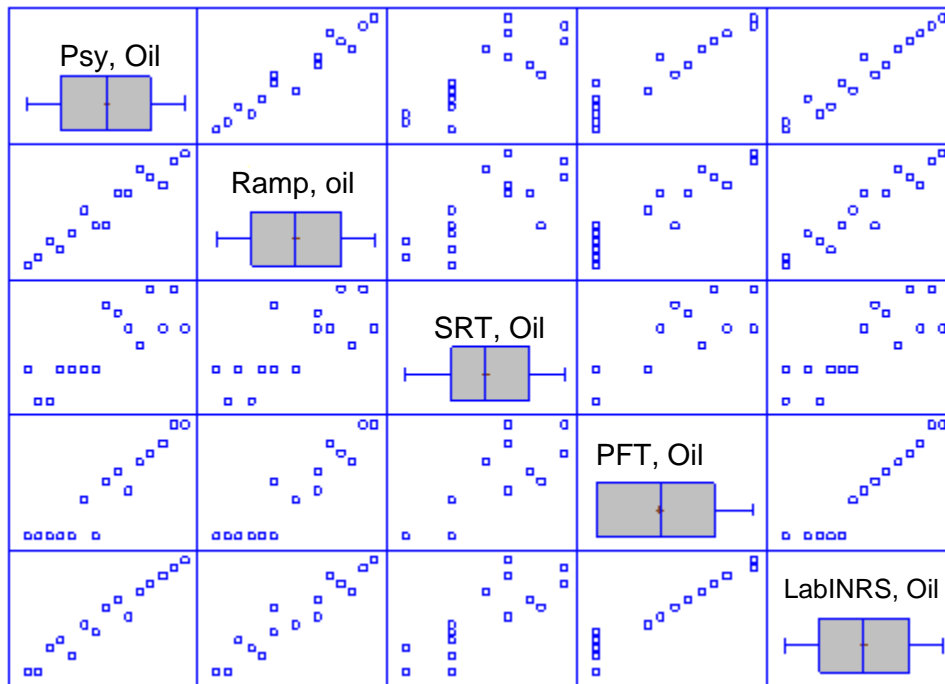
Ramp Oil

Figure 5. Matrix of graphs of the comparisons of the methods, with oil.

Figure 5 shows that the graphs of the PFT and of the pendulum SRT present alignments of points in their bottom portions. The floor coverings in question have levels of slipperiness less than the sensitivity of the 2 methods and the ranks that are attributed to them are equal.

Comparison of the rankings of the 3 methods comprising the ramp test, the PFT method, and the LabINRS method gives linear links with the psychophysical ratings; the rankings are quite similar. Comparison between the ranks of the psychophysical ratings and the ranks obtained with the pendulum SRT gives a cluster of points in the top portion; the rankings are different.

Mutual comparison of the 3 methods comprising the ramp test, the PFT method and the LabINRS method gives linear links. These methods rank the floor coverings in quite similar manner. Regardless of the method with which it is compared, the pendulum SRT method does not have any very visible link. The graphs show 2 clusters of points: one for the slippery floor coverings and one for those considered as having grip.

	Psy, Oil	**Ramp, Oil**	**SRT, Oil**	**PFT, Oil**	**LabINRS, Oil**
Psy, Oil		0.92	0.58	0.82	0.88
Ramp, Oil			0.74	0.93	0.95
SRT, Oil				0.83	0.82
PFT, Oil					0.97
LabINRS, Oil					

Table 3. Spearman's correlation between the methods.

Table 3 gives the Spearman's rank correlation coefficients between each pair of methods. These correlation coefficients vary over the range 0.58 to 0.97 and they measure the

strength of the association between the methods. At the level of confidence 99%, all of the methods are correlated, except for the pendulum SRT with the psychophysical rating method. The numerical values confirm the graphical analyses.

Figure 6 shows a graphical comparison of the rankings and of the levels of slipperiness of the floor coverings that were obtained by the various methods and by the psychophysical ratings.

The values used in the graph show the slip indices of 15 floor coverings with oil. The grey zone represents the limit or boundary between slippery and not slippery, namely:

-   PFT → 0.30 ± 10% (INRS limit)
-   LabINRS → 0.30 ± 10% (INRS limit)
-   Ramp → 20° ± 10% PC20 (XP P05-011 limit)
-   Pendulum SRT → 35 ± 10% (NF EN 1339 limit).
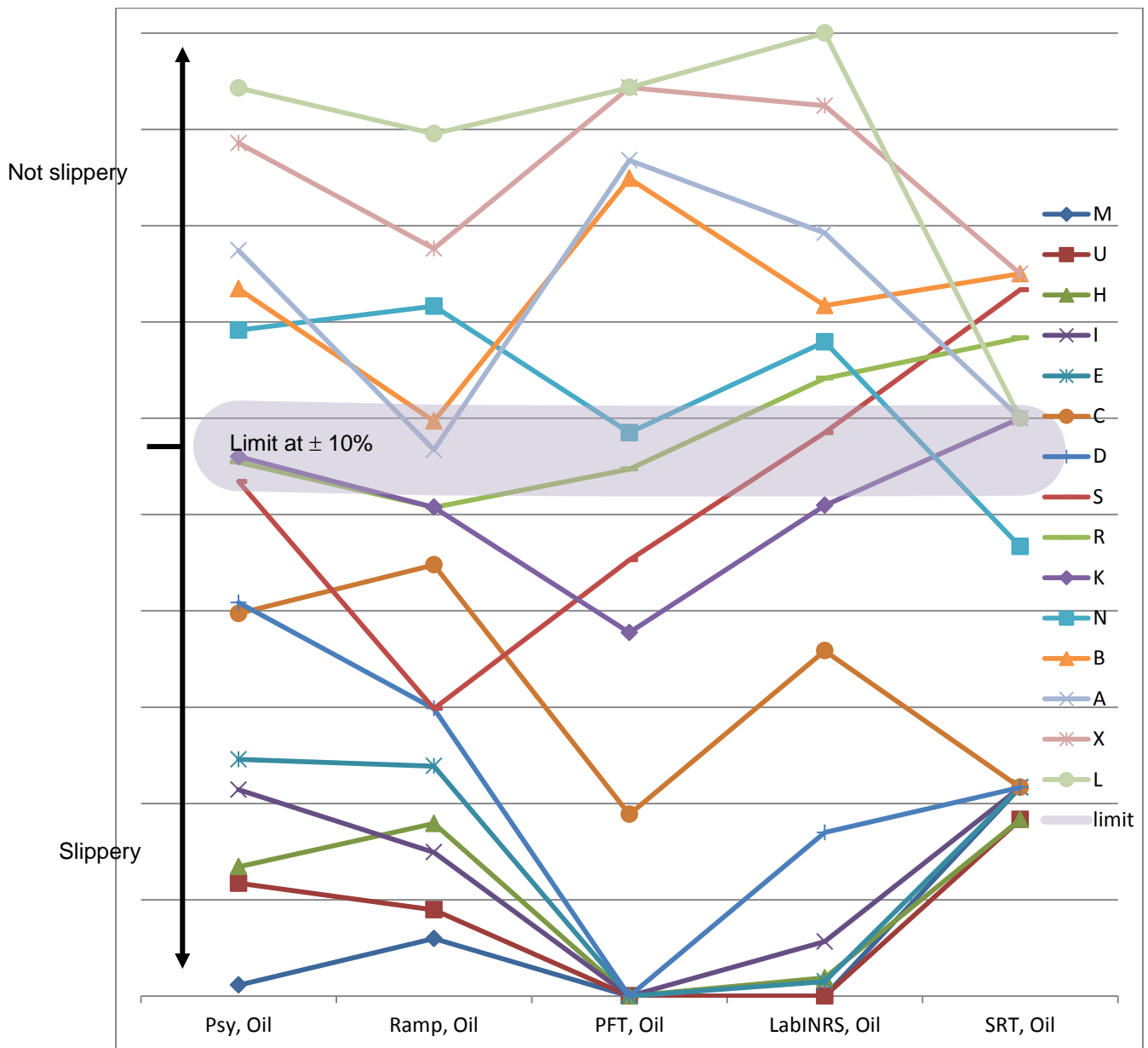

Figure 6. Comparison of slipperiness measurements depending on the methods.

Figure 6 shows overall consistency for all of the methods in ranking the floorings in terms of slipperiness or non-slipperiness, except for the samples S and N and for the pendulum SRT.

On the basis of the dendrogram, it is possible to consider 5 clusters (L, X), (A, B, N), (K, R, S), (D, C), and (E, H, I, M & U).

The cluster of floor coverings E, H, I, M and U, which was deemed to be the most slippery by the psychophysical rating method, remained regardless of the method. This graph confirms that the pendulum SRT, the PFT, and, to a lesser extent, the LabINRS could not distinguish between these 5 floor coverings; their levels of slipperiness are less than the sensitivity of these three methods. Conversely, the ramp test does discriminate between them.

For the other samples, the ramp test, the PFT, and the LabINRS kept the clusters, except for the sample S. The pendulum SRT inverts the ranks of certain non-slippery coverings from one cluster to another.

3.3. Comparison of the studied methods – measurements with the water solution

Table 4 shows the summary of the results of the measurements of all of the floor coverings using the 4 metrological methods and the psychophysical method, in the presence of water solution. In addition, for each method, it gives the ranks of the samples.

Sample ref.	Ramp, Water		SRT, Water		PFT, Water		LabINRS, Water		Psy, Water	
	[°]	Rank	[PTV]	Rank	[µd]	Rank	[µd]	Rank	[Score]	Rank
M	14	2	10	1	0.11	1	0.11	1	0.5	1
U	12	1	15	2	0.19	3	0.21	3	19.5	2
I	16	3	19	3	0.35	5	0.32	4	20.5	3
E	17	4	28	5	0.34	4	0.33	5	51.5	4
R	27	10	61	10	0.59	11	0.56	9	53	5
H	17	4	25	4	0.17	2	0.12	2	60	6
S	23	8	62	11	0.42	6	0.52	8	73	7
K	21	7	48	8	0.55	9	0.45	6	79	8
C	19	6	42	7	0.56	10	0.59	10	88	9
D	23	8	37	6	0.53	7	0.50	7	106	10
B	31	11	68	15	0.54	8	0.67	11	122	11
A	35	14	65	14	0.62	12	0.77	13	126.5	12
N	35	14	54	9	0.69	13	0.73	12	143	13
L	35	14	64	12	0.93	15	1.03	15	155.5	14
X	35	14	65	14	0.83	14	0.97	14	162	15

Table 4. Results of the slipperiness measurements with the various studied methods in the presence of water solution.

On the basis of Table 4, Figure 7 gives a matrix of graphs comparing, in pairwise manner, the floor covering rankings obtained using the various methods.
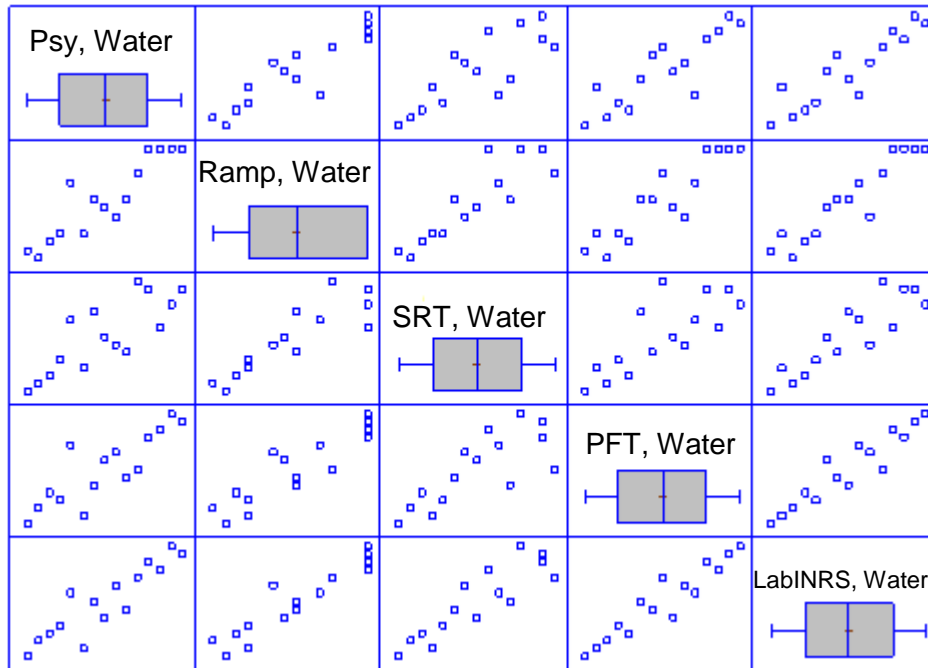

Figure 7. Matrix of graphs of the comparisons of the methods, with water solution.

The graphs plotted on the basis of the values from the ramp test show alignments of points in the top portions corresponding to the maximum limit of that method. The samples assessed at 35° all have the same rank.

Figure 7 shows that the 4 metrological methods substantially give linear links with the psychophysical ratings: the rankings are quite similar. Only the pendulum SRT compared with the psychophysical ratings shows an elongate cluster of points in the portion of the floor coverings with grip; this highlights some rank inversions.

Mutual comparison of the 4 metrological methods substantially gives linear links: the rankings are quite similar. Only the pendulum SRT shows an elongate cluster of points in the portion of the floor coverings with grip compared to the other three metrological methods; this highlights some rank inversions.

	Psy, Water	Ramp, Water	SRT, Water	PFT, Water	LabINRS, Water
Psy, Water		0.91	0.81	0.86	0.90
Ramp, Water			0.90	0.90	0.93
SRT, Water				0.78	0.88
PFT, Water					0.95
LabINRS, Water					

Table 5. Spearman's correlation between the methods.

Table 5 gives the Spearman's rank correlation coefficients between each pair of methods. These correlation coefficients vary over the range 0.78 to 0.95 and they measure the

strength of the association between the methods. At the level of confidence 99%, all of the methods are correlated.

Figure 8 shows a graphical comparison of the rankings and of the levels of slipperiness that were obtained by the various methods relative to the reference rankings obtained on the basis of the psychophysical ratings. The graph is plotted in the same manner as the graph of Figure 6.
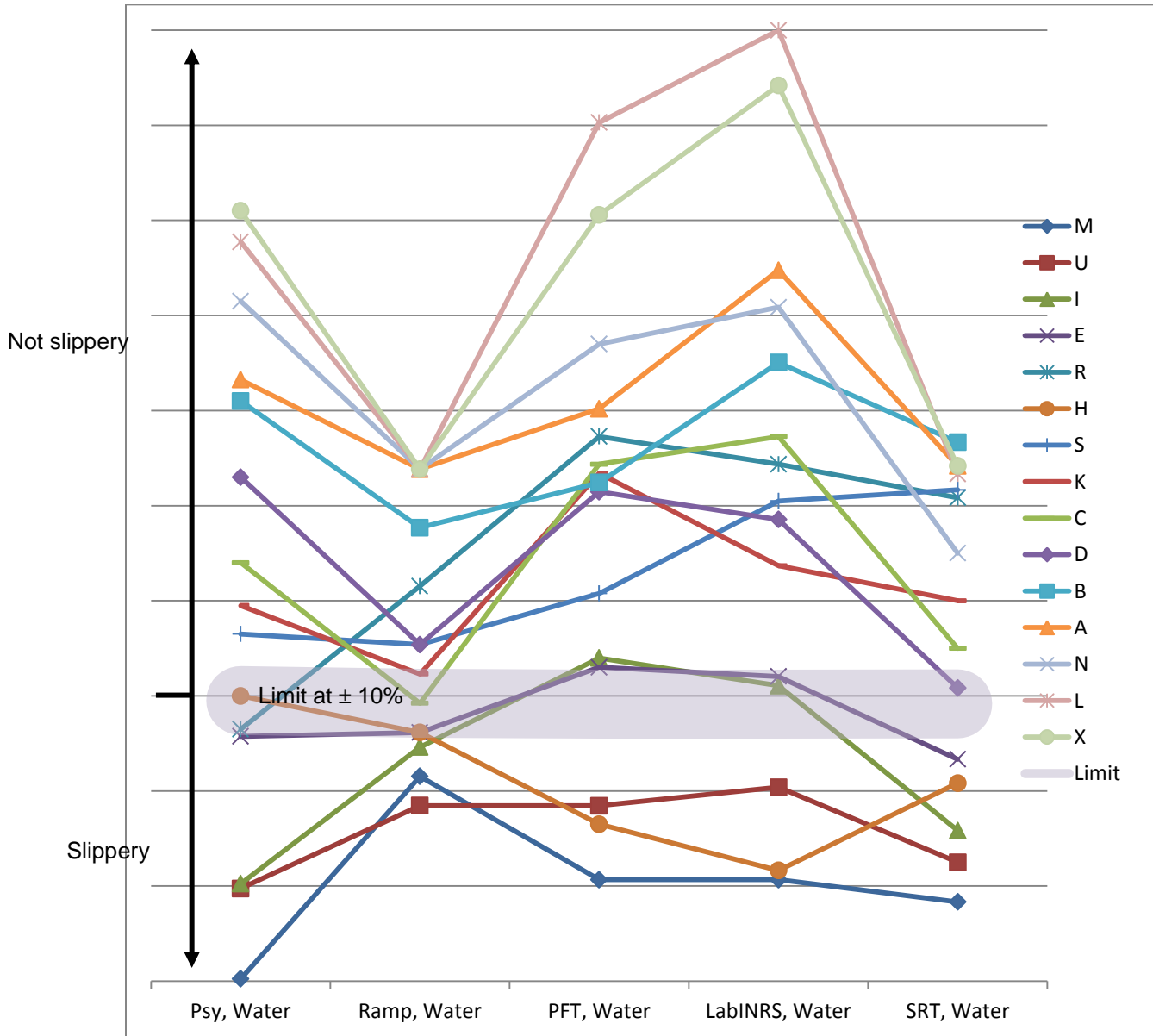

Figure 8. Comparison of the slipperiness measurements depending on the methods.

Figure 8 shows overall consistency for all of the methods for ranking the floorings in terms of slipperiness or non-slipperiness. Only sample R was rated as slippery by the test persons while being defined as having grip by the 4 studied methods. The explanation is to be found in the fact that its surface was not entirely even. A layer of contaminant laid stagnant on it and gave rise to a phenomenon of aquaplaning during the psychophysical rating movements.

Apart from sample R, the order obtained with the psychophysical ratings is substantially the same with the 4 studied methods, and confirms the high correlation coefficients.

3.4. Assessment of the practical aspects

Apparatus for assessing the level of slipperiness of a floor covering needs to satisfy not only metrological requirements, but also practical requirements.
The following rating system was used for assessing the practical capacity of the apparatus to measure coefficient of friction:

- ++ very good
- + good
- 0 sufficient
- - insufficient
- -- very insufficient
- / Not applicable

	Ramp Test	PFT	LabINRS	pendulum SRT
Size	--	++	--	++
Weight	--	+	--	+
Possibility of being transported (measurement *in situ*)	--	++	--	++
Independence of the power supply	--	+	--	++
User-friendliness / Intuitiveness	--	++	+	+
Mode of use	--	++	++	0
Ease of cleaning/maintenance	0	0	0	++
Mechanical reliability	0	0	-	0
Electronic reliability	0	-	-	++
Measurement of floor coverings having macro relief	++	++	-	--
Measurement area	-	++	-	--
Ease of implementation	-	++	+	0
Measuring time	--	++	0	++
Influence of the test technician	++	++	++	0
Influence of the human test person	-	/	/	/
Ease of calibration	0	0	-	+
Ease of adjustment	--	++	++	0
Renown / Standardisation	++	-	--	++
Purchase price	-	+	--	++
Cost price of the measurement	-	+	+	+

Table 6. Comparison of the practical aspects.

Table 6 shows that none of the devices assessed satisfies all of the requirements. Conversely, it shows that the pendulum SRT and the PFT have indisputable advantages as regards practical aspects.

4 - DISCUSSION AND CONCLUSIONS

4.1. Test methods

To assess the metrological methods, INRS developed a method for psychophysically rating the "perceived" slipperiness of floor coverings. This method made it possible to establish reference rankings per contaminant for the 15 floor coverings, from the least slippery to the most slippery. Twelve test persons, spread over 4 campaigns of tests, took part in these ratings. Analysis showed that they were in close agreement as regards the comparison of the 15 floor coverings. Hierarchical rankings obtained from the dendrogram made it possible to establish clusters of floor coverings and to highlight a few indistinct pairings in terms of slipperiness that were useful for comparing the studied methods.

This study shows that, from a purely metrological point of view, the ramp test and the psychophysical method give the highest correlation coefficients. The second advantage of the ramp test is its renown among trade professionals who have been using it for categorising floor coverings for several decades now, regardless of the types of flooring and of their fields of use. However, implementing it suffers from major drawbacks, such as the need to use test subjects and the impossibility of taking measurements on site.

The LabINRS method gives correlation coefficients with the psychophysical method that are very good and that are almost equivalent to those obtained with the ramp test. In addition, it is very simple to implement; however, it suffers from the drawback of not making it possible for measurements to be taken *in situ*.

Conversely, due to its very simple operating principle and to it being easy implement, the pendulum SRT is the best suited to taking measurements *in situ*. Its renown is high as it has been in use for many years for qualifying road surfaces and pedestrian surfaces. However, the correlation coefficients with the psychophysical method are low, raising questions as to its capacity to rank floor coverings as a function of slipperiness. In addition, it does not make it possible to qualify correctly all types of floor covering, e.g. coverings with macro-relief.

As for PFT, the correlation coefficients with the psychophysical method are very satisfactory. Even though it was originally designed to qualify road surfaces, INRS has considerable experience in using it for qualifying pedestrian surfaces, in particular such surfaces that are designed for use in the food industry. It makes it possible to take measurements in the laboratory and *in situ*, on any type of floor covering.

4.2. Risk prevention / Standardisation

Currently, with the two methods proposed in French Standard XP P05-010 and in European Technical Specification XP CEN/TS 16165, it is impossible to define a model for predicting the values obtained using the pendulum SRT on the basis of the values measured using the ramp test or *vice versa*. With oil as the contaminant, it was observed that a floor covering from the panel that was assessed as having grip when the pendulum SRT was used could be considered to be slippery when the ramp test is used, and *vice versa* with some other floor covering. Such a situation is difficult to accept for standardisation.

Floor covering manufacturers and fitters, clients and operators, and occupational risk preventers wish to have the means to enable them to measure the coefficients of friction of floor surfaces in the laboratory and *in situ* with the possibility of comparing the values easily:
  - It has been observed that, due to wear and/or to the cleaning and maintenance protocol used, the surfaces of certain floor coverings can change significantly. Since

wear is a function of use and of cleaning & maintenance, it therefore appears necessary to enable them to take measurements for monitoring the slip resistance performance periodically and on a case-by-case basis (and therefore *in situ*).

- The grip qualities of floor coverings that are cast are directly related to the quality of the casting and can vary from one site to another and from one zone to another on the same site. This is therefore another reason for the need to take measurements *in situ*.

The PFT satisfies these various constraints. It would appear judicious to propose PFT for standardisation, as the means for measuring the dynamic coefficient of friction. It offers the advantage of being as metrologically satisfactory as the Ramp Test and of being as practical the pendulum SRT.

The pendulum SRT could also satisfy the constraints subject to properly targeting the field of use (type of flooring, type of surface, etc.) for which the link with the Ramp Test or with the LabINRS could be established satisfactorily.

Although the LabINRS and the Ramp Test are less practical to use, they remain metrologically satisfactory as laboratory reference methods with a view to determining the initial standard slip resistance performances of floor coverings.

4.3. Prospects

The experience acquired by INRS using the PFT and the LabINRS in the food industry sector could be extended to other sectors of activity such as the metallurgical industry, automobile garages, etc. In addition, this study has made it possible to show that it is possible to use the PFT with the two contaminants proposed by the experimental standard. It therefore appears apposite to further extend its scope of action to other sectors of activity for evaluation *in situ*.

Furthermore, CSTB has significant past experience with the Ramp Test. Advantageous use could be made of that experience so as ultimately to develop the initial slip resistance assessments in sectors other than industry or than the food industry, or for barefoot use.

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APPENDIX 1: TEST EQUIPMENT

Measurements using the Ramp Test method

The inclined-plane (or inclinable-plane) or ramp test method makes it possible to assess the slip resistance of a floor covering. The test bench used is the inclined plane or ramp (Figure 13) initially designed and developed in Germany.

The principle of the ramp test method is based on having a human tester walk forwards and backwards over the sample of floor covering which is inclined at an increasing angle α relative to the horizontal, until a slip starts to occur.

The test bench is equipped with a system making it possible to incline the sample of floor covering relative to the horizontal at a maximum speed of 1° per second. An angle sensor makes it possible to measure the angle of inclination with accuracy of 0.5°, but the angle it indicates is not visible to the test person.

The test person is equipped with a harness and with a fall arrester in order to be protected in the event of sudden slippage. With the flooring sample initially in the horizontal position, the test person walks forwards and backwards several times while taking half steps (each half step being equivalent to half the size of the test person's shoe), and while, as far as possible, walking at a gait of 2.4 half-steps per second, and then the test person increments the angle of inclination. This procedure is repeated until the instability limit angle is reached, or until a forward slip is obtained. The corresponding angle α is then noted to within 0.1°. The test result can also be expressed as a coefficient of friction µ by the relationship $\mu = tg\ \alpha$.

The basic operating modes of operation for the measurements and for the test configurations are those given in French Standard XP P 05-010.

Prior to any measurement campaign, the two test persons check whether they are capable of performing the tests by each taking 5 measurements on a flooring sample whose statistic limit angle α_R is known. The mean limit angle obtained (α_M) and the standard deviation of the measurements are computed. A test person is validated for the test campaign if the following condition is satisfied:

$\alpha_R - 1.5\ \sigma \le \alpha_M \le \alpha_R + 1.5\ \sigma$

For each flooring sample and for each contaminant, 2 test persons, ideally of different heights and weights, each perform 5 successive measurements. If the values obtained differ by more than 2°, the measurements continue until 5 consistent values are obtained. The result taken into account for a flooring sample is the arithmetic mean computed on the basis of the measurements taken by the two test persons, on the condition that the individual means of each test person do not differ by more than 2°. Otherwise, the entire test is performed again.

For the tests performed in the context of this study, the samples were measured successively with the lauryl sulphate solution as the contaminant (in the barefoot configuration), and then with 10W30 mineral oil as the contaminant (in the shod configuration).

1: Walkway receiving the floor covering sample
2: Mechanical tilt system
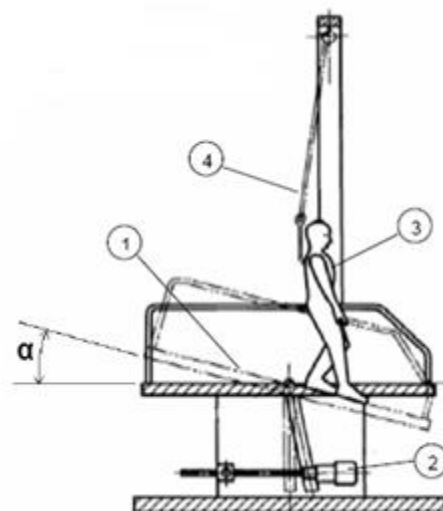3: Test Person
4: Safety harness

Figure 9. Diagram showing the principle of the inclinable plane (ramp).

Measurements using the pendulum SRT

The pendulum SRT (Skid Resistance Tester) was developed by the "Transport and Road Research Laboratory" in Great Britain. The aim of the method is to measure the grip of a floor covering by means of a slider coated with an elastomer material. This instrument is portable.

The elastomer slider, which has a surface of area 76 mm x 25 mm is mounted at the end of a metal arm that can swing pendulum-like about a horizontal axis.

Released with the arm horizontal, the slider comes to rub against the floor covering over a distance of 127 mm (Figure 14). A spring system incorporated into the arm makes it possible, during the rubbing, to apply a constant force F_N of 22 N, normal to the test surface. The height to which the pendulum swings depends on the energy absorbed by the friction during the rubbing, and is indicated by a needled placed in front of a dial with graduations in the form of Pendulum Test Value (PTV) units.

The basic operating modes for taking the measurements, preparing the slider, and checking the pendulum SRT are described in the tests standard EN 13036-4.

The slider used for taking the measurements is made of elastomer of the four S (Standard, Simulated Shoe Sole) type, also known as Slider 96 rubber, having Shore A hardness of 96 ± 5.

For each sample of flooring and for each contaminant, at least 3 series of 5 measurements are taken at various different locations. The result taken into account for any flooring sample is the arithmetic mean computed on the basis of the measurements taken at the 3 locations.

For the tests performed in the context of this study, the samples were measured successively with 10W30 mineral oil as the contaminant and then with lauryl sulphate solution as the contaminant. The contaminant was placed in a sufficient quantity on the flooring sample to completely cover the friction zone over which the slider rubs.
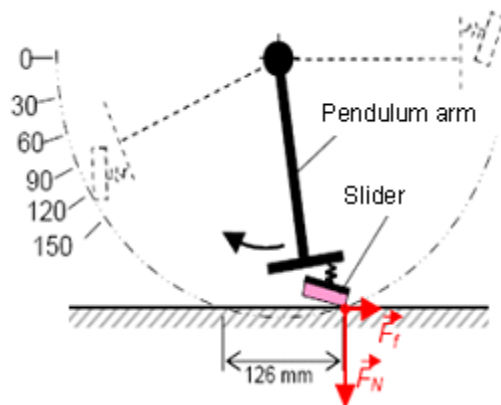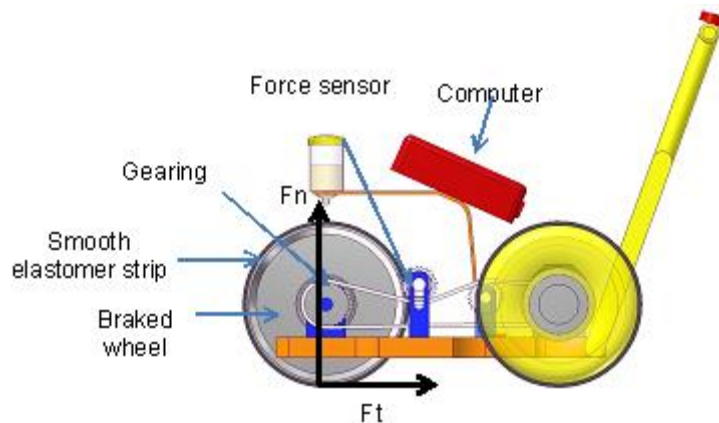

Figure 10. Diagram showing the principle of the pendulum SRT.

Measurements using the "PFT"

The Portable Friction Tester (PFT) is a tribometer developed by VTI (the Swedish Road and Traffic Research Institute) for measuring the dynamic friction coefficient (µd) of road or other surfaces (Figure 11). It is transportable and enables measurements to be taken *in situ* and over long distances.

The measurement is based on the principle of a braked wheel. When the instrument is in motion, the two rear wheels of the PFT drive gearing via a chain. The gearing implies a smaller speed of rotation to the front test wheel, thereby generating a slip resistance force between the surface or the flooring and the test wheel. That force activates a sensor that generates an electrical signal that is proportional to the slip resistance. The test wheel is covered with a smooth elastomer strip of formulation identical to the formulation of a safety footwear sole, whose Shore hardness is 80 ± 5. A tank of contaminant (oil or lauryl sulphate solution) situated above the test wheel provides lubrication between that wheel and the surface or floor covering.

The dynamic friction coefficient µd is measured at stabilised speed. It is equal to the ratio of the modulus of the horizontal slip resistance force Ft to the modulus of the flooring vertical reaction force Fn at the point of contact of the test wheel: µd = Ft/Fn

For laboratory measurements, the tests are performed at a temperature of 23 ± 5°C. As for measurements *in situ*, they are taken at ambient temperature. The floor covering is cleaned before the testing. At least three passes are performed without measurements being taken, in order to lubricate the measurement zone uniformly.

During the measurement, the instrument is pushed at constant speed (about 0.4 metres per second, as checked on the speed indicator). Five measurements are taken on each sample. The result taken into account is the arithmetic mean computed over the 5 measurements.

For the tests performed in the context of this study, the samples were measured successively with 10W30 mineral oil as the contaminant and then with lauryl sulphate solution as the contaminant.
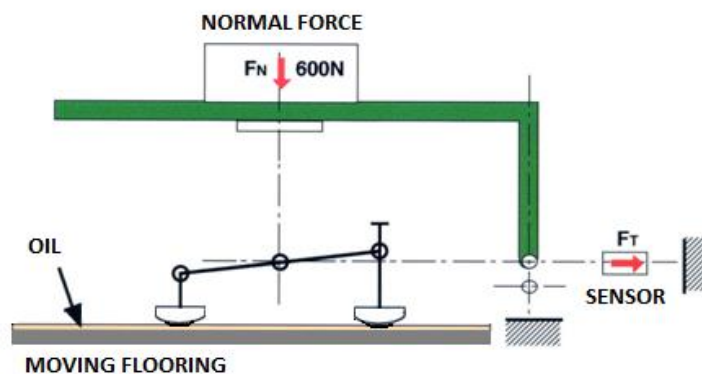

Figure 11. Diagram showing the principle of the PFT (Portable Friction Tester).

Measurements using the "LabINRS" bench

The LabINRS method draws its inspiration from measuring the dynamic coefficient of friction of safety footwear. It makes it possible to assess the slip resistance of a floor covering (Figure 16).
The test consists in measuring the dynamic coefficient of friction between a model of sole and the sample of floor covering. This coefficient is the ratio of the modulus of the friction force Ft that opposes the movement to the modulus of the force Fn normal to the friction plane: $\mu d = F_t/F_n$
The testing was performed in the presence of a contaminant.
The model of sole, laid flat, is made up of two smooth elastomer sliders (the elastomer being polychloroprene of formulation identical to that of a safety footwear sole) whose Shore hardness is 80 ± 5. It bears a load of 600 N. The semi-cylindrical shape of the elastomer sliders facilitates penetration of the contaminant and prevents the elastomer from catching on and being braced against pieces in relief on the floor coverings.
The sample of flooring is moved in reciprocating rectilinear motion. The dynamic friction force is measured at the instant when the speed reaches its maximum, i.e. 0.2 metres per second. It suffices to divide this value by the vertical load of 600 N in order to obtain the dynamic coefficient of friction μd.

The tests are performed at a temperature of 23 ± 5°C. The sample is cleaned before the testing. The contaminant is placed in a sufficient quantity on the flooring sample to completely cover the friction zone over which the sliders rub. Ten cycles are performed before the recording sequence is triggered. The variation in the friction force is then recorded over 2 cycles.

At least five tests are conducted on each sample, with each contaminant, in order to assess the coefficient of friction of the floor covering. The result taken into account is the arithmetic mean computed over the 5 measurements.
For the tests performed in the context of this study, the samples were measured successively with 10W30 mineral oil as the contaminant and then with lauryl sulphate solution as the contaminant.

Figure 12. Diagram showing the principle of the LabINRS method.

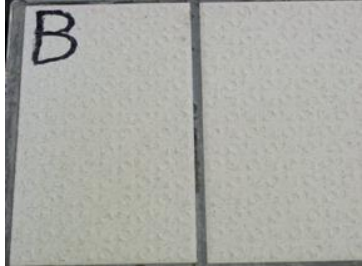## APPENDIX 2: IDENTIFICATION AND DESCRIPTION OF THE TEST FLOOR COVERINGS

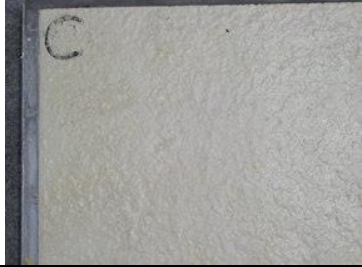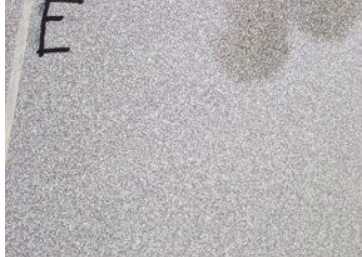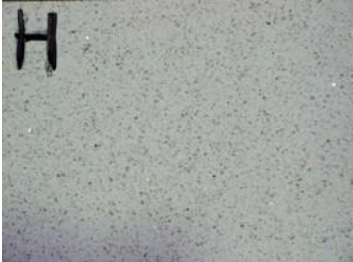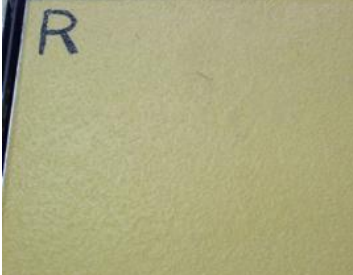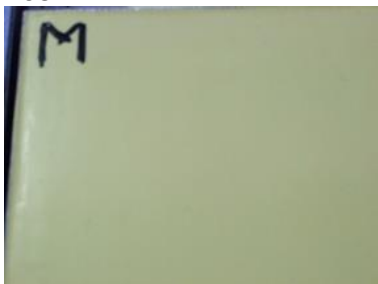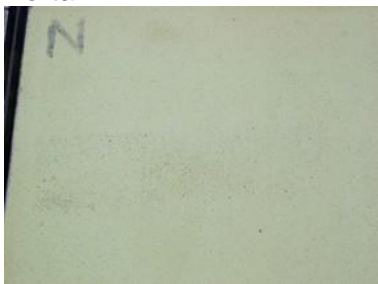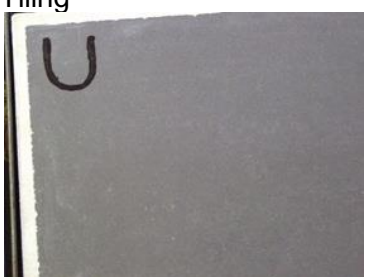| Type	Description	Identification
Tiling 	Unglazed ceramic tiles, Grains-of-rice structured surface, Size: 20 cm x 20 cm.	A
Tiling 	Unglazed ceramic tiles, Diamond tips structured surface, Size: 20 cm x 20 cm.	B
Tiling 	Unglazed ceramic tiles, Structured surface Size: 50 cm x 50 cm.	C
Tiling 	Unglazed ceramic tiles, Smooth surface, Size: 20 cm x 10 cm.	D
Tiling 	Unglazed ceramic tiles, Smooth surface, Size: 40 cm x 40 cm.	E

Table 7. Description of the floor coverings.

Type	Description	Identification
Stone 	Agglomerated stone based on resin and minerals, Smooth surface with a softened finish, Size: 60 cm x 60 cm.	H
PVC 	Resilient floor covering made of compact PVC, Slightly grainy surface.	I
PVC 	Resilient floor covering made of compact PVC, Smooth surface with mineral particles included.	K
Tiling 	Unglazed ceramic tiles, Rough surface, Size: 20 cm x 20 cm.	L
Resin 	Floor covering system based on resins with mineral fillings in the range 0.3 mm to 0.7 mm, Rough surface,	R

Type	Description	Identification
Resin 	Self-levelling floor covering system based on resins, Smooth surface.	M
Mortar 	Floor covering system made of resin mortar, Rough surface	N
Mortar 	Floor covering system made of resin mortar, Rough surface.	X
Tiling 	Unglazed ceramic tiles, Rough surface, Size: 20 cm x 20 cm.	S
Tiling 	Unglazed ceramic tiles, Smooth surface, Size: 60 cm x 60 cm.	U

APPENDIX 3: ENTERING AND PROCESSING DATA OBTAINED USING THE PSYCHOPHYSICAL ASSESSMENT

Table 8 shows an example of a matrix plotted on the basis of the psychophysical assessment results. This matrix makes it possible to obtain, for a test person and for a contaminant, the score of each covering and the rankings of the 15 test floor coverings.

Each cell of the matrix gives the result of the comparison of the floor covering of row i with the floor covering of column j. A value is then assigned to the corresponding cell:

1 :   if i is estimated to be more slippery than j
0.5 :   if i is estimated to be equivalent to j
0 :   if i is estimated to be less slippery than j

The "total" column gives the sum of the values of any one row. It makes it possible to assign a score to the various floor coverings. These scores are used to define the rankings, from the highest to the lowest, i.e. from the most slippery floor covering to the least slippery floor covering.

↱	A	B	C	D	E	H	I	K	L	M	N	R	S	U	X	Total		Rankings
A		0	0	0	0	0	0	0	1	0	1	0	0	0	1	3	X	1
B	1		0	0	0	0	0	0	1	0	1	0	0	0	1	4	L	1.5
C	1	1		0	1	0	0	0	1	0	1	0	1	0	1	7	N	1.5
D	1	1	1		0	1	0	0	1	0	1	0	0	0	1	7	A	3
E	1	1	0	1		0	0	0	1	0	1	0	0	0	1	6	B	4
H	1	1	1	0	1		0	0	1	0	1	0	1	0	1	8	E	6
I	1	1	1	1	1	1		1	1	0	1	1	1	0	1	12	C	7
K	1	1	1	1	1	1	0		1	0	1	0	1	0	1	10	D	7
L	0	0	0	0	0	0	0	0		0	0.5	0	0	0	1	1.5	S	7
M	1	1	1	1	1	1	1	1	1		1	1	1	1	1	14	H	8
N	0	0	0	0	0	0	0	0	0.5	0		0	0	0	1	1.5	K	10
R	1	1	1	1	1	1	0	1	1	0	1		1	0	0	10	R	10
S	1	1	0	1	1	0	0	0	1	0	1	0		0	1	7	I	12
U	1	1	1	1	1	1	1	1	1	0	1	1	1		1	13	U	13
X	0	0	0	0	0	0	0	0	0	0	0	1	0	0		1	M	14

Table 8. Example of an assessment matrix for a test person and for a contaminant.