Comparison of experimental procedures of a method for continuous friction measurement in airport pavements

L Martins¹, A Ribeiro¹, J Alves e Sousa² and H Dimas¹

¹LNEC – National Laboratory for Civil Engineering, Lisbon, Portugal
²IPQ – Portuguese Institute for Quality, Caparica, Portugal

E-mail: lfmartins@lnec.pt

Abstract. This paper describes a comparison performed between two experimental procedures (with the Grip Tester and the Continuous Friction Measurement Equipment) of the fixed-slip method for longitudinal continuous friction measurement in airport pavements. The measurement framework is described, namely, the experimental testing and the related conformity assessment procedure supported by different friction thresholds. The experimental results of the comparison are presented (raw data, differences between friction estimates and corresponding experimental probability distributions) and its impact on the conformity assessment result is discussed. Conclusions are drawn based on the obtained difference dispersion, instrumental measurement uncertainties and expected difference between the two experimental procedures.

1. Introduction

In the framework of laboratories accreditation based on ISO/IEC 17025:2017 [1] method validation is considered a major requirement for the quality of experimental results and, in cases where conformity assessment is performed, it provides confidence to apply decision rules.

This is the case studied in this paper, regarding the continuous friction measurement in airport pavements, because measurement results are related to the pavement condition by scales establishing classes, being subsequently these used to take management decisions on the technical improvement of the tested pavement conditions.

The common cases for the use of proficiency tests [2, 3] as “quality assurance procedures” consider that the measurand is obtained from a reference method having experimental procedures that can be compared and evaluated using quality parameters (e.g., z-score). In this particular case, however, conventional proficiency testing comparison cannot be applied, as the experimental procedures are based on the same method but use two different numerical scales not directly comparable by the measurement results but only by the classes they establish (in both scales the output classes are the same).

In view of the above, the approach here considered was to develop a testing setup to evaluate the performance obtained by the two procedures, both having measurement traceability under comparable reference conditions (using same alignments on an airport runway). Validation of the relation of procedures with the method was achieved by the comparison and the analysis of the classification categories obtained.
2. Continuous friction measurement framework

The experimental testing activities performed in the context of airport pavements construction, maintenance and rehabilitation, have a significant impact on safety, characterization of surfaces and improved knowledge on operational performance. One major test regularly performed in airport pavements is the determination of the skid resistance in a wet condition, which can be achieved by the use of different continuous friction measurement equipment developed independently by different entities, in some cases, for over 50 years. Since different equipment can be used to determine friction in the same airport runway, a measurement uncertainty component related to the method reproducibility should be accounted for. In addition, friction traceability to the SI is indirectly obtained by the calibration of force (horizontal and vertical) measuring chains in a static mode, and the use of reference materials suitable for long distance measurement is unknown.

In this context, conformity assessment of the friction surface condition of airport pavements [4] is supported by three reference thresholds and the corresponding performance levels – design level (new pavement), operational level (used pavement), maintenance level (pavement requiring rehabilitation) and minimum level (non-admissible pavement). The magnitude of the friction thresholds depends on the adopted test speed and water depth (influence quantities) but also on the used equipment, as shown in figures 1 and 2.

![Figure 1. Friction thresholds for 65 km/h test.](image1)

![Figure 2. Friction thresholds for 95 km/h test.](image2)

Considering a certain test speed, the friction threshold differences can be interpreted as different measurement scales related to the applied equipment. This paper is focused on two particular measuring equipment – the Grip Tester (GT) [5] and the Continuous Friction Measurement Equipment (CFME) [6] – which were used for testing the same airport runway, aiming at the validation of the measurement method (fixed-slip method).

Both equipment allows the longitudinal friction measurement through the use of a standard tire [7, 8], mounted on a test wheel connected to a partial blocking system, which results in a lower tire circulation speed with respect to the test speed, thus creating a horizontal slip force on the tire. The action of this horizontal force and the vertical (load) force on the test wheel results in the elastic deformation of the axis where the wheel is installed. This axis is instrumented in order to measure the instantaneous longitudinal friction value, defined by ratio between the horizontal and vertical forces. Complementary measurement chains allow measuring both the travelled distance, the test speed and, in some cases, the water flow.

Different friction estimates given by these two equipment, in the same runway alignment, can be related to: (i) the standard tires used; (ii) the water projection systems of each equipment; (iii) the suspension system which mechanically connect the test tire to the surrounding structure; (iv) the dynamic stability of the test wheel attached to a trailer (in the case of the GT) or integrated in a vehicle (in the case of the CFME).
3. Experimental results

The continuous friction measurement tests were performed during the night period in an airport runway, between its initial and final markings, with a total dimension of 3100 m. The results shown are related to an alignment located 7.5 m away from the runway centerline. A nominal test speed of 65 km·h⁻¹ and a 1 mm nominal water depth were defined and both equipment were subjected to prior calibration immediately before the test took place.

The following figures show the results obtained, namely: (i) the collected raw data of friction estimates measured in a 10 m spatial interval (Figure 3); (ii) the corresponding differences between friction estimates of the GT and CFME devices (Figure 4); (iii) the corresponding experimental probability distribution of differences (Figure 5); (iv) the order of changes in class (zero, one, two or three levels) in the surface condition due to friction estimate differences (Figure 6), considering compared results obtained by the two experimental procedures.

![Figure 3. Raw data of the friction estimates.](image1.png)

![Figure 4. Differences between friction estimates.](image2.png)

![Figure 5. Histogram related to the differences between friction estimates.](image3.png)

![Figure 6. Changes in the classification due to friction differences between the two procedures.](image4.png)

The magnitude of the observed estimate differences is characterized by a dispersion of values mainly comprised between 0.00 and 0.20, which includes the expected difference related to the friction threshold values. In fact, for a test speed of 65 km·h⁻¹ and a water depth equal to 1 mm, differences between GT and CFME threshold values correspond to 0.07 and 0.08 [4]. The obtained experimental probability distribution is centered around the 0.15 value and as a symmetrical shape, close to a Gaussian distribution. The instrumental measurement uncertainties of the equipment – between 0.01 and 0.08 [9] – also contributed for the obtained dispersion of values and took into account the following uncertainty components: calibration, resolution and systematic deviations of the
measurement standard and the calibrated equipment; the interference between horizontal and vertical force measurement chains.

A residual number of cases were obtained where differences between estimates result in changes of two or three classification levels and only when the friction averaged values are related to a 10 m spatial interval (raw data). In general, from 70 % up to 80 % of the assigned classifications by both equipment match and between 20 % and 30 % differ only in one level, noticing that sometimes the measured values are quite close to the threshold value. The use of the moving average in a 100 m spatial interval originates a slightly lesser impact of the assigned levels (filtering effect).

The different spatial intervals (10 m or 100 m) and the type of average (fixed or moving) used for the estimate calculation does not have a significant impact on the evolution and on the obtained differences.

Additional alignments were performed in the same runway showing similar results. An exception was recorded concerning an alignment located 3.0 m away from the runway centerline, where the results shown in figures 7 to 10 were obtained.

Figure 7. Raw data of the friction estimates.

Figure 8. Differences between friction estimates.

Figure 9. Histogram related to the differences between friction estimates.

Figure 10. Changes in the classification due to friction differences between the two procedures.

Major differences were observed (Figures 7 and 8) in the initial and final segments of this alignment which can be justified by: (i) circulation of the equipment with a spatial gap between both passages; (ii) transient effects in the beginning and in the ending of the test due to the variation of influence quantities such as circulation speed (deviation from the 65 km·h⁻¹ circulation speed nominal value) and water film thickness (deviation from the 1 mm nominal value).
As a result of these differences, the obtained experimental probability distribution (Figure 9) shows a higher asymmetrical and non-Gaussian shape when compared with the previous one (Figure 5). This fact can be used as a quality assessment tool in the comparison of results produced by different testing equipment.

The dimension of these segments is reduced when compared with the total dimension of the alignment, noticing that in the central region of the runway, the results obtained are within the dispersion obtained in the previous studied alignment (located 7.5 m away from the runway centerline). However, the founded differences result in significant changes of the classification levels (Figure 10) noticing a high number of cases where a difference of one or two levels occurs and, in some residual cases, even three levels.

The impact of the different friction estimates obtained in the performed alignments can also be seen in a global perspective, considering the minimum values (conservative safety approach) of the moving averages related to each testing equipment in partial (the middle region B and the two ends A and C of the runway) and total dimension of the runway, as shown in tables 1 and 2.

| Table 1. Minimum friction values of the moving averages in the first studied alignment. |
|-------------------|----------------|-------------------|
| Testing equipment | GT             | CFME             |
| Runway Region A   | 0.65           | 0.85             |
| Runway Region B   | 0.55           | 0.61             |
| Runway Region C   | 0.68           | 0.67             |

| Table 2. Minimum friction values of the moving averages in the second studied alignment. |
|-------------------|----------------|-------------------|
| Testing equipment | GT             | CFME             |
| Runway Region A   | 0.47           | 0.52             |
| Runway Region B   | 0.48           | 0.48             |
| Runway Region C   | 0.68           | 0.50             |

In the first alignment, the global and partial classifications assigned by both equipment agree (green operational level) with only one exception, in region C, where the GT assigns a blue design level (high friction in the runway) while the CFME classifies this region with a green operational level (normal friction in the runway), although the proximity of the friction estimates.

An interesting case is noticed in the second alignment, namely, in the global classification. A minimum friction value of 0.47 (yellow maintenance level) is assigned by the GT, while the CFME assigns a higher friction estimate, however, corresponding to unacceptable friction (red level).

4. Conclusions
The experimental tests performed with different equipment, aiming at the comparison analysis of the airport pavements continuous friction measurement, shows results within a difference dispersion between 0.00 and 0.20, being of the same magnitude of the instrumental measurement uncertainty and of the expected difference between GT and CFME results.

The best obtained dispersion has a direct impact between 20 % and 30 % of the assigned classifications for the surface condition of the tested runway. The risk of changes in the classification can be mitigated with the improvement of the spatial sampling procedure (higher number and proximity between alignments) and the knowledge of the test repeatability (successive repetitions of the performed alignment in a given direction).

Future work to be developed intends to evaluate the influence of repeatability and to perform a sensitivity study of other influence quantities [10] in order to obtain a more robust analysis of the comparison evaluation.

References
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