Resilient and Safe Road Infrastructure

IOP Publishing

IOP Conf. Series: Materials Science and Engineering 356 (2018) 012002
doi:10.1088/1757-899X/356/1/012002

Review of modern methods for continuous friction measurement on airfield pavements

Paweł Iwanowski*, Krzysztof Blacha, Mariusz Wesołowski
Air Force Institute of Technology, Ks. Bolesława 6, 01-494 Warsaw, Poland

*pawel.iwanowski@itwl.pl

Abstract. The safety of traffic, including both road and air traffic on a ground manoeuvre area, depends on many factors. These mainly include the anti-slip properties of a road or airfield pavement on which the traffic takes place. The basic pavement parameter that determines its characteristics in terms of anti-slip properties is the skid resistance, which constitutes the ratio of the wheel downforce and the friction on the contact surface.

There are currently many devices for continuous measurement of the skid resistance (Continuous Friction-Measuring Equipment - CFME) around the world. Most of them, in principle, do not vary much from one another. Most of the devices measure the measuring wheel’s downforce on the pavement and the friction on the wheel-pavement contact surface. The skid resistance is the result of this measurement. The devices vary in many aspects, such as the type and size of the used measuring tyre, pavement-wheel slip or tyre pressure. This does not mean that the results obtained from various devices may be directly compared. On the other hand, each device allows determining the pavement’s anti-slip conditions in terms of the requirements specified for the given type of devices, thereby enabling pavement classification in these terms. The classification allows for comparing the results obtained from various measuring devices.

The paper presents an overview of equipment used in Poland and around the world to measure the skid resistance on airfield pavements. The authors draw attention to the requirements for pavements in terms of their roughness, with division into road and airfield pavements.

1. Introduction

Nowadays, much attention is paid to safety. This is mainly dictated by the high social costs of occurring incidents. In the case of transport, one of the factors that substantially affect safety are the pavement’s anti-slip properties. Any safety systems, from ABS, various traction controls, to advanced anti-slip systems, are sensible only when sufficient tyre-pavement contact is ensured. As for the vehicle, the deciding factors are the selection of proper tyres or suspension configuration. As for the pavement, this includes obtaining the best possible anti-slip properties by ensuring the correct skid resistance measured by standard methods.

There are currently many devices for continuous measurement of the skid resistance (Continuous Friction-Measuring Equipment - CFME) around the world. Only a few of them were admitted measuring the skid resistance on Polish airports and only two on roads. The SRT-3 measuring kit has been used for over 20 years on national roads to assess the anti-slip properties. The TWO device was also admitted measuring campaigns a few years back. Both devices have their supporters and...
opponents, but there are no known procedures that would allow admitting other devices to measuring the skid resistance on national roads. As for now, there is also no institution that would certify such devices.

Some countries provide research programs such as The National Cooperative Highway Research Program (NCHRP) conducts research in problem areas that affect highways. In the result of NCHRP activity there were created “Guide for friction pavement” [1] uses in the USA. There are no known similar guide in the Poland.

The international document titled Doc. 9137 AN/898 Airport Services Manual - Part 2 - Pavement Surface Conditions [2], issued by the International Civil Aviation Organization allows using new measuring devices by providing the criteria and method of procedure in the device’s certification process. The paper is to elaborate on the method of procedure with new CFME devices in the certification process for the road environment.

2. Overview of devices intended for continuous measurement of the skid resistance
There are many CFME-type devices for continuous measurement of the skid resistance around the world. Some of them are used in Poland. Despite the fact that each device measures the same parameter, their configuration affects the obtained result. This section includes presentation of typical devices used for measuring the skid resistance on Polish airfields and roads.

2.1. Airport devices
The Polish defence standard NO-17-A501:2015 Airfield pavements - Friction testing [3] includes a list of CFME-type devices admitted to using in Polish military facilities. The aforementioned standard specifies the requirements for such a device and indicates the possibility of using the devices specified in AC 150/5320-12C FAA [4], Doc. 9137 ICAO [2] and in Annex 14 ICAO [5]. The cited entry demonstrates that also new devices can be used, provided that they meet the specified requirements.

Table 1. presents the list of devices specified by the standard [3] including the measurement conditions and requirements applicable to airfield pavements.

| Measurement device | Test tyre Type | Test tyre Pressure (kPa) | Measurement speed (km/h) | Water film thickness (mm) | Friction coefficient values |
|--------------------|----------------|--------------------------|--------------------------|--------------------------|---------------------------|
|                     |                |                          |                          |                          | Friction coefficient values |
|                     |                |                          | Design values for new pavements | Values for planning repair activities | Minimum (threshold) values |

| Measurement device | Test tyre Type | Test tyre Pressure (kPa) | Measurement speed (km/h) | Water film thickness (mm) | Friction coefficient values |
|--------------------|----------------|--------------------------|--------------------------|--------------------------|---------------------------|
|                     |                |                          |                          |                          | Friction coefficient values |
|                     |                |                          | Design values for new pavements | Values for planning repair activities | Minimum (threshold) values |

| Measurement device | Test tyre Type | Test tyre Pressure (kPa) | Measurement speed (km/h) | Water film thickness (mm) | Friction coefficient values |
|--------------------|----------------|--------------------------|--------------------------|--------------------------|---------------------------|
|                     |                |                          | Design values for new pavements | Values for planning repair activities | Minimum (threshold) values |

| Measurement device | Test tyre Type | Test tyre Pressure (kPa) | Measurement speed (km/h) | Water film thickness (mm) | Friction coefficient values |
|--------------------|----------------|--------------------------|--------------------------|--------------------------|---------------------------|
|                     |                |                          | Design values for new pavements | Values for planning repair activities | Minimum (threshold) values |

| Measurement device | Test tyre Type | Test tyre Pressure (kPa) | Measurement speed (km/h) | Water film thickness (mm) | Friction coefficient values |
|--------------------|----------------|--------------------------|--------------------------|--------------------------|---------------------------|
|                     |                |                          | Design values for new pavements | Values for planning repair activities | Minimum (threshold) values |
On Polish airfields, the most popular skid resistance measuring devices are the ASFT (Airport Surface Friction Tester) devices mounted on a vehicle (Figure 1) or on the ASFT T-10 trailer hauled by a vehicle (Figure 1). Both devices allow for continuous, linear measuring of the friction between the airfield pavement and a model airplane wheel at the speed of 65 or 95 km/h. They are equipped with a water tank and a pavement humidifying mechanism that allows obtaining the water film of no less than 1 mm in thickness required by the standards.

| Vehicle Runway Friction Tester | B | 210 | 65 | 1.0 | 0.82 | 0.60 | 0.50 |
|-------------------------------|---|-----|----|-----|------|------|------|
| Vehicle TATRA Friction Tester | B | 210 | 95 | 1.0 | 0.74 | 0.54 | 0.41 |

| Vehicle Runway Friction Tester | B | 210 | 65 | 1.0 | 0.76 | 0.57 | 0.48 |
|-------------------------------|---|-----|----|-----|------|------|------|
| Vehicle TATRA Friction Tester | B | 210 | 95 | 1.0 | 0.67 | 0.52 | 0.42 |

Figure 1. The ASFT T-10 trailer, ASFT vehicle in the background, ASFT measuring system on left [10].

Smaller functional airfield elements, the geometry of which disallow measurement at the speed of 65 or 95 km/h, can be tested by using the BVS-1 device or the T2Go manual portable roughness tester (Figure 2). Currently, the relevance of the BVS-1 testing apparatus decreased in favour of the T2Go. The T2Go allows for continuous measuring of the skid resistance at low speeds and proper correlation between the results obtained by using the ASFT T-10 trailer allows for referring to the requirements specified in the aforementioned documents.
Figure 2. The measurement of the skid resistance on the airfield apron’s pavement using the T2Go device.

Spot measuring of the skid resistance is possible by using a British skid resistance tester. The results provide an idea of the skid resistance of the tested pavement. However, it refers to a specific spot in contrast to the earlier presented devices which allow continuous measuring. The skid resistance tester is currently used mainly in laboratory testing. In the field, it is to compare to the results obtained by other methods. The criteria for the SRT indicator obtained from testing with the British skid resistance tester are known only for road pavements.

Less frequently, but our airfields use devices as the Griptester MK2 (Figure 3) and Skiddometer BV11 (Figure 3) as well. Both devices operate similarly to the ASFT T-10 by allowing for continuous measuring of the skid resistance, whereas the Griptester MK2 is characterised by its small weight and sizes. Each of the aforementioned devices is hauled during measuring by a wheel vehicle and requires constant feeding of water from the vehicle’s tank.

Figure 3. Griptester MK2 (left) [11], Skiddometer BV11 (right) [12].

For measuring the skid resistance, the Griptester MK2 uses a 10-inch slick tyre which is in compliance with the ASTM 1844 specification. The device’s running wheels also have a 10-inch diameter, however, they are treded tyres. The measuring tyre’s pressure during testing amounts to 140 kPa.

Two types of tyres can be used to test the skid resistance using the Skiddometer BV11. The first tyre type is the ASTM low-pressure tyre and the second one is the T520 high-pressure slick tyre. Both comply with the FAA and ICAO recommendation. The measuring wheel’s working pressure amounts to 210 kPa and the wheel’s slip in relation to the running wheels amounts to 17%.
2.2. Road devices
In the road environment, there are also many devices that are used to assess the pavement’s anti-slip properties. They allow measuring the skid resistance at speeds from 30 to 120 km/h. Depending on the method of measurement; it is possible to distinguish the following device groups:

- “side force” - the measuring wheel is rotated with the device’s motion direction by an angle of 7.5° - 20° and the side friction is measured. This group includes, among others, the SCRiM, SKM, Mu-Meter, Stradograf;
- “fixed slip” - the measuring wheel is set parallel to the device’s motion direction and the friction is measured at a fixed slip. This group includes, among others, the DWW Trailer, Skidometer BV-8, GripTester, TWO;
- “variable slip” - the measuring wheel is set parallel to the device’s motion direction and the friction is measured at a variable slip. This group is represented by the ViaFriction;
- “locked slip” - the measuring wheel is set parallel to the device’s motion direction and the friction is measured with the wheel completely locked (100% slip). These devices include, among others, Adhera, Stuttgarter, Reibugsnesser, Pavement Friction Tester, SRT-3.

The SRT-3 and TWO devices were admitted to using on Polish national roads in accordance with Ordinance no. 34 of the General Director for National Roads and Motorways of 30 April 2015 [6]. The SRT-3 device (Figure 4) was constructed by the Road and Bridge Research Institute, whereas the TWO devices (Figure 5) is a foreign design.

Figure 4. SRT-3 measuring kit [13].
Figure 5. TWO measuring kit [14].

The SRT-3 measuring kit, classified as the “locked wheel”, allows measuring the skid resistance with a fully locked measuring wheel. SRT-3 can’t be included to CFME devices but it is worth to be mentioned due to widespread use on Polish roads. The skid resistance can be determined in two ways, i.e. either by measuring the wheel’s measuring point or by direct measurement of the friction on the tyre-pavement contact point. Thanks to the reviewed device, it is also possible to measure the maximum skid resistance at the set measurement speed as well as turning resistances. The testing can be conducted both on straight road sections and on curves.

The TWO kit, classified as the “fixed slip”, is intended to measure the skid resistance both on roads and on airfield facilities. The measuring device is mounted directly on a car. It is equipped with two wheels combined with each other by a chain so that they move relatively to one another with a slip of 17.8%. One of the wheels constitutes the reference point and the other is the measuring wheel. The measurement can be conducted both on a wet or dry pavement at the speed of 2 to 100 km/h. The quantity of water fed is adjustable and allows for creating a water film with a thickness of 0.1 to 1 mm. Both slick and treaded tyres can be used for measuring.

3. Procedure with new CFME devices

The international document titled Doc. 9137 AN/898 ICAO [2] specifies the criteria for new CFME-type devices, whereas appendix no. 3 [7] to the document includes the testing procedures for those devices. It is thus possible to introduce other devices for use than the ones currently specified in the standard documents, provided that specific requirements are met.

3.1. Requirements for new devices according to Doc. 9137 AN/898

In 1974, the basic technical and operating criteria for the CFME-type (designed by ICAO) devices were presented and recommended for runway skid resistance measurements. In 1991, the requirements were amended and included in the Airport Service Manual Doc. 9137 AN/898 ICAO [2]. The criteria are intended to standardise the design parameters for new friction measuring devices. They are also intended to ensure flexibility and allow for adding new devices in the future without excluding technical progress in this area.

The basic requirements for new CFME-type devices specified in the document are as follows:

- a measurement mode that should allow for continuous measuring in motion along the tested element;
• the ability to calibrate the device to ensure control over the correctness of the results. Even slight deviations during calibration have substantial impact on the test result;
• the measuring wheel’s breaking point - the measuring wheel should be in a continuous slip in relation to the pavement (in the range of 10% to 20%), whereas in devices simulating the side force, the set angle should be between 5° and 10°. Currently, the most popular configuration used on Polish airfields is a 15% wheel slip without a set side force;
• limitation of excessive vibration - the device should be designed in a way that minimises or even eliminates the vibration of the absorbed or non-absorbed mass in the full range of the measuring speed, especially in relation to the measuring wheel. Vibrations affect the quality of the measuring apparatus’ readings and the control of the wheel’s downforce;
• device stability when driving, providing the ability to quickly leave the runway. The device cannot cause an air traffic hazard on the ground manoeuvre area and must be able to quickly move to the safe zone on the traffic controller’s request;
• the recorded friction coefficient must be in the range between 0 and 1.0;
• the device should ensure continuous recording of the runway’s friction coefficient chart and allow the operator to enter any observations as well as the recording’s date and time. Continuous recording is a simplification, because the CFME-type devices record their results at specific intervals; the distance travelled by the device is so small in relation to the measuring section’s length that it can be deemed as a continuous measurement;
• the device should be able to repeat the average friction coefficient results within ± 0.06 µ, at a confidence level of 95.5% (or two standard deviations);
• the friction coefficient should constitute the ratio of the longitudinal friction and the vertical measuring wheel load, in the case of a measurement simulating the side force, the skid resistance should correspond to the ratio of the side force and measuring wheel load. This requirement results from friction coefficient definition;
• the range of the device’s possible measuring speeds should amount from 40 to 130 km/h. Despite the fact that the measuring range is broad, the standards speeds at which the skid resistance is measured are 65 and 95 km/h, while the other measuring speeds are intended for determining the correlations between devices as precisely as possible;
• the device should at least specify the average friction coefficient for: the first 100m of the runway, each 150m of the measuring section and for each one-third of the runway’s length. The division of the runway to three parts is especially important for the pilot. When approaching to land, the pilot is provided with information about the skid resistance on particular runway fragments. Thanks to this, the pilot knows what to expect after touch down and how to manoeuvre the aircraft on subsequent runway parts;
• the measuring tyre should correspond to the types specified in the document; the tyre can be replaced with a different one, provided that reliable and certain results are ensured. The standardisation of measuring tyres is intended to eliminate the impact of the type of tyre used on the measurement conditions;
• the devices must be able to conduct the measurements regardless of the atmospheric conditions. The skid resistance measurements on airfields are most often conducted if there is suspicion that the pavement’s anti-slip properties have deteriorated. Usually, such situation occurs as results of the impact of disadvantageous atmospheric conditions. For this reason, the device must be ready for operation in any atmospheric conditions;
• the device must be sufficiently easy in maintenance to ensure safety during measurement and transport;
• the device must be equipped with a pavement rinsing system to ensure a water film with a thickness of at least 1 mm.
3.2. New device testing procedure

Appendix 3 [7] specifies four basic assumptions that should be met during the testing of a new CFME-type device:

- it is necessary to determine whether the equipment and the device’s water distribution systems calibration procedures applied by the manufacturer are satisfactory. The document does not specify concrete requirements, which is why an appropriate assessment of the experts participating in the testing is extremely important;
- the measurements must be conducted on at least four different types of pavements ensuring a broad range of skid resistance results. The document does not specify concrete parameters to be met by a pavement, such as, for example, its micro- and macro-structure, however it is worth selecting at least four types of pavements varying from one another with the obtained skid resistances;
- the measurements should be conducted at least two measuring speeds, i.e. 65 and 95 km/h. These are the standards speeds of the skid resistance measurement reproduced in many documents, whereas to ensure a broader range of results, it is also necessary to conduct the measurements at other speeds. This will increase the quantity of data and broaden the range of results;
- for each combination of measurement conditions, it is necessary to conduct the measurements in repeatable conditions and, if possible, conduct a measurement in the same conditions with another, certified CFME-type device to check the compliance of the results.

Meeting the aforementioned conditions will ensure significant degree of repeatability of the results and allow for controlling the obtained results.

Despite the fact that the document does not include such an entry, it is worth ensuring cleanliness of the pavement on which the measurement is conducted. The authors’ experiences demonstrate that the spread of the results obtained on a contaminated pavement is broad. Even certified devices can be unable to ensure repeatability of ± 0.06 μ, at a confidence degree of 95.5%. To maintain proper pavement cleanliness during the measurements, it is advantageous to clean the pavement prior to each passage of the measuring device. At airfields, the quickest solution is to use an airfield cleaner.

The next steps of the CFME devices testing procedure, according to Appendix 3 [7] are as follows:

- checking the device’s components, tyre and data recording system in terms of correct configuration and operating conditions.
- conducting the device’s calibration according to the manufacturer’s instructions and recording the results.
- checking the water distribution system in terms of compliance of the distributed water quantity with the assumptions and whether the water is properly fed under the measuring wheel at various speeds. The document does not specify the method of performing such a check. In practice, the length and width of the water footprint created during the measurement are measured and the water film thickness created in front of the wheel is determined based on the device’s water consumption.
- repeating the first three steps for a second certified CFME-type device used to determine the correlation of results, if such device is used.
- if the testing features more than a single device, it is necessary to determine the order of the devices during passages and maintain the order throughout the testing. This is important, because the determination of the correlation features a comparison of the results obtained from particular passages of the measuring devices. Despite the fact that the document does not specify so, it is necessary to take care that the time between the passages of comparable devices is as short as possible.
• performance of two or three test passages with each of the CFME-type devices on the assumed pavement to stabilise the friction coefficient for a wet pavement and achieve an acceptable repeatability of ±0.03. If an acceptable repeatability is not achieved after two passages at similar speeds, it is necessary to check the measuring and data recording systems to identify the incorrectnesses. If necessary, correct any incorrectnesses and repeat the device’s calibration before continuing testing.

• at each analysed speed, it is necessary to perform at least 6 measurement passages for each device and for each of at least 4 pavement types. Naturally, the probability of the device’s correct assessment increases along with the increase of the number of measurements.

• each of the selected pavements must be subjected to measurements at a minimum of two measuring speeds - 65 and 95 km/h. Other measuring speeds allow for more precise determination of the dependency of the friction coefficient on speed.

• analysing the recorded data to determine the accuracy, repeatability and compliance of the results for each pavement and measuring speed.

• for the purpose of comparison with the friction coefficient obtained on a wet pavement, it is necessary to conduct two dry tests for each pavement and at similar measuring speeds as used in the case of wet pavement measurements.

• performance of repeated calibration of the devices according to the manufacturer’s guidelines at the end of testing and results recording. The values obtained during the calibration should be similar to those from before the testing. If this isn’t the case, it is necessary to identify the cause and repeat the testing, if necessary.

• development of charts for the dependency of friction coefficient on speed for each pavement. In the case of using more than one device, it is necessary to apply the charts for each device to a single chart.

• designation of the linear dependency and correlation coefficient for each case. The values should be presented on each of the charts.

• development of the list of main test parameters, including: test date, number of test passages, measurement times, type of pavement, measurement speed, measurement direction, water film depth, average friction coefficient,

• creation of a copy of historical test data, general notes, weather conditions and other observations to present them to the proper certifying institution. In general, the documents are sent to the ICAO, which checks the correctness of the conducted procedure and approves the device. In Poland, the unit that can admit a device for use on domestic airfields is the Civil Aviation Authority.

The document recommends taking photographs or making films during the testing, although it is not mandatory. Experiences show that it is an important procedure which facilitates reproducing the device’s testing process.

4. Summary
The spectrum of continuous friction-measuring equipment available around the world is very broad. There are many such devices and new ones are created from time to time. One of the factors that favour this process is ensuring proper anti-slip conditions on road and airfield pavements by controlling them and quickly reacting to observed incorrectnesses. This is to ensure the safety of road and airport users.

Based on international documents, the Polish defence standard [3] specifies a list of devices that allow for designating the skid resistance on functional elements of airfields. The list includes eight of the most popular devices, some of which are used by operating services of the Polish aviation facilities. The standard also allows using two alternative devices (BVS-1 and ASFT T2Go) when the element’s geometrical dimensions prevent from using the standard testing apparatuses.
On national roads, it is standard to use SRT-3 device, which is used by the General Directorate for National Roads and Motorways on a daily basis. Moreover, it is possible to use the TWO device in measuring campaigns in accordance with the ordinance [6].

The aviation environment is not closed to devices specified currently in the standard documents and enables introducing new CFME-type devices for testing. The document titled Doc. 9137 AN/898 [2] specifies the procedure for such cases in fair detail. It includes requirements for new devices and their testing procedure cited in this article. Appendix 3 [7] to the aforementioned document specifies further steps of procedure along with the testing conditions, basic assumptions, requirements for results interpretation and correct test documentation.

The paper is intended to present the road environment with the testing procedure for a new CFME-type device in the process of its certification at airfield facilities and the possibilities of introducing new measuring apparatuses into the list of devices admitted by national and international aviation institutions.

The authors point out the possibilities of adapting the presented method for use by the road environment to admit alternative devices intended for testing the anti-slip properties of road pavements.

Bibliography (numbered in the order of appearance in the text)

[1] J.W. Hall, K.L. Smith, L. Titus-Glover, J.C. Wambold, T.J. Yager, Z. Rado, Guide for pavement friction, Contractor’s final report for NCHRP Project, 2009

[2] Doc. 9137 AN/898 Airport Services Manual - Part 2 - Pavement Surface Conditions,

[3] NO-17-A501:2015 Airport pavements - Friction testing,

[4] AC 150/5320-12C FAA Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces

[5] Annex 14 to the Convention on International Civil Aviation, Airfields - Volume I - Engineering and operation of airfields

[6] Ordinance no. 34 of the General Director of National Roads and Motorways of 30 April 2015

[7] Appendix 3 NASA Certification Test Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities

[8] W. Gardziejczyk, M. Wasilewska, P. Gierasimiuk, M. Motylewicz, Przegląd urządzeń do oceny właściwości przeciwpoślizgowych nawierzchni drogowych [Overview of devices intended for assessing the anti-slip properties of road pavements], VIII Techniczne dni drogowe, Białystok 2015

[9] W. Gardziejczyk, M. Wasilewska, P. Gierasimiuk, M. Motylewicz, Ocena właściwości przeciwpoślizgowych nawierzchni drogowych przy wykorzystaniu urządzeń two, ctm i dft, journal of civil engineering, environment and architecture, 2016

[10] http://www.asft.se

[11] http://www.griptester.us

[12] http://www.moventor.com

[13] http://www.docplayer.pl

[14] http://www.two-friction.com