Mariusz Wesołowski
Ppłk dr inż.
Instytut Techniczny Wojsk Lotniczych, Warszawa, Zakład Lotniskowy
mariusz.wesolowski@itwl.pl

Paweł Pietruszewski
Mjr mgr inż.
Instytut Techniczny Wojsk Lotniczych, Warszawa, Zakład Lotniskowy
pawel.pietruszewski@itwl.pl

Adam Poświata
Dr inż.
Instytut Techniczny Wojsk Lotniczych, Warszawa, Zakład Lotniskowy
adam.poswiata@itwl.pl

Danuta Kowalska
Mgr inż.
Instytut Techniczny Wojsk Lotniczych, Warszawa, Zakład Lotniskowy
danuta.kowalska@itwl.pl

DOI: 10.35117/A_ENG_18_12_05

The evaluation of airfield pavements in light of applicable normative documents

Abstract: Airfield pavement evenness is, according to applicable normative documents, one of the basic operating parameters, which characterize each airfield functional element. Evenness, in fact the lack of it, determines not only comfort of aircraft movement along an airfield pavement, but also influences the magnitude of the dynamic impacts on the pavement, hence, the safety of air operations. In addition, evenness condition changing as a result of aircraft operation, adverse weather conditions or inappropriate airfield pavement construction technology leads to deviations from the desired condition in the form of longitudinal and transverse unevenness. Pursuant to the applicable normative requirements, measurements on airfield facilities can be executed using a planograph or a staff and a wedge. The used measuring devices differ from each other in terms of dimensions and permissible single unevenness. Regular and correct execution of tests is a very important factor improving air operation safety, but also enabling the designation of zones (areas) with quicker pavement degradation. If the obtained measurement data is not sufficiently reliable, they may consequently lead to making incorrect decisions, which can ultimately impact the safety of air operations.

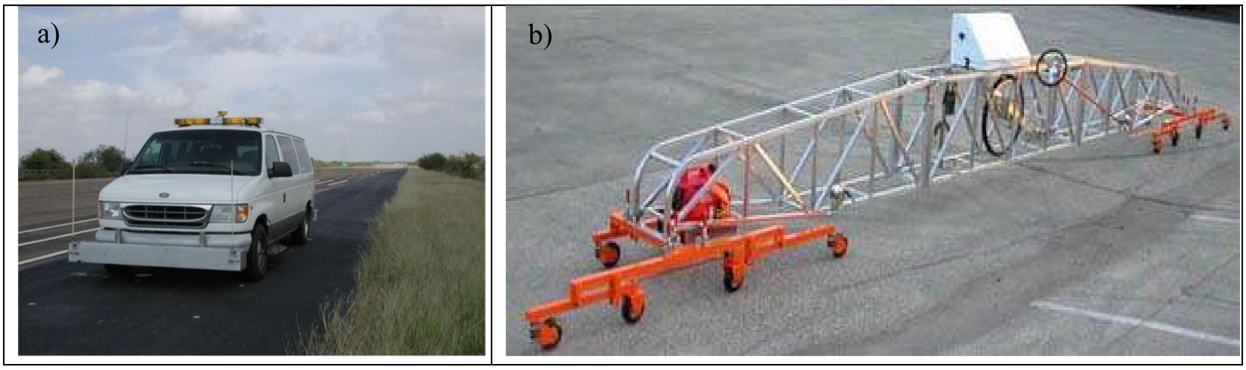
Keywords: airfield pavements; airfield pavement evenness; airfield pavement evenness state evaluation

Introduction

Over the last decade, air transport recorded a significant increase of air operations domestically, as well as worldwide. This was caused also by a significant growth of low-cost commercial carriers, the development of modern technologies and the transport of cargo and materials. However, the dynamic and vibrant development of aviation has also resulted in numerous issues, particularly associated with ensuring air operation safety by deteriorating operational features of a pavement. One of the main operational features, which characterize each airfield or road pavement is, apart from load-bearing capacity and roughness, is unevenness. Pavement evenness due to dynamic loads, adverse weather conditions or incorrect construction technology leads to deviations from the desired condition in the form of longitudinal and transverse unevenness. Pavement evenness, or rather the lack of it, is the only operating parameter, which might be directly felt and noticed by users through inadequate driving comfort, bad rainwater drainage, the formation of isolated water bodies or increased dynamic loads. Formed pavement unevenness also adversely impacts the rolling resistance of vehicle wheels and accelerated surface deterioration, hence, the degradation of safety conditions.

Normative documents

Evaluating the evenness of pavements in highway engineering and aviation, despite the same types of structure, differs in terms of the measurement method, used devices or assessment criteria. In the case of roads, evenness condition measurements are most frequently conducted with the use of multi-sensor laser profilographs (fig. **1**).



1. Devices for measuring pavement unevenness a) RSP-3, b) California Profilograph

The obtained measurement results are converted into the so-called *International Roughness Index IRI*, expressed in mm/m or m/km [9]. Profilometric methods enabling the calculation of IRI are used when evaluating longitudinal evenness of roads. The measuring equipment shall record unevenness with an accuracy of at least 1.0mm, unevenness with characteristic lengths falling within a range from 0.5 to 50m. The IRI values are calculated at least every 50 m, and the length of an evaluated section shall not exceed 1000 m. A reliable IRI value, which is adopted as a sum of the average value and the standard deviation <IRI>+S is used for the evaluation of the longitudinal evenness of highway pavement, as per [8]. Measurements on highways are conducted in the right wheel track on each lane, excluding emergency lanes and RSA roads. Table 1 shows the longitudinal evenness classification criteria [mm/m] regarding highways.

Tab. 1. Longitudinal evenness classification criteria for highways [8]

Pavement element	**Class**		
	A	**B**	**C**
Main and additional traffic lanes	<2	2-3.5	>3.
Tollway roads	<3	3-4.5	>4.5

Whereas pursuant to [7], longitudinal evenness is determined by the permissible average value of the measurement IRI$_{śr}$ and the permissible maximum value of a single measurement IRI$_{max}$, which cannot be exceeded over the length of the evaluated pavement section. Table 2 shows the permissible values for acceptance of the wearing surface using the profilometric method.

Tab. 2. Permissible IRI values [2]

Road class	Pavement element	Permissible acceptance values of indices for a set range of road section length [mm/m]	
		$IRI_{śr}$	IRI_{max}
1	2	3	4
A,S,GP	Main, emergency and additional traffic lanes, additions and exclusions, connecting roads	1.3	2.4
	RSA roads, compacted roadsides	1.5	2.7
G	Main, emergency and additional traffic lanes, additions and exclusions, connecting roads	1.7	3.4
	Compacted sideway	2.0	3.8

The measurements on airfield facilities can be conducted with the use of a planograph or a staff and and wedge. The International Civil Aviation Organization (ICAO), which was founded in 1944 under the Convention of international civil aviation in Chicago, in Annex 14, Volume I – *Aerodromes - Design and Operation*, contains information on the pavement evenness of the most important airfield functional elements, that is the runway. This annex states that the top layer of an airfield pavement, excluding the ridge of the pavement in the case of a chevron-shaped section or in the case of sewers, should be even enough, for the distance between the bottom edge of a 3m long staff, and the pavement surface to be no more than 3 mm along the entire staff length [10]. Moreover, Annex 14 states that isolated unevenness of 2.5 to 3.0 cm, at a distance of 45 m are tolerated. Table 3 shows pavement unevenness, which according to ICAO are divided into three categories: acceptable, permissible and excessive unevenness height.

Tab. 3. Acceptable, permissible and excessive surface unevenness limits [10],[6]

Surface unevenness	Unevenness length (m)								
	3	6	9	12	15	20	30	45	60
Acceptable surface unevenness height (cm)	2.9	3.8	4.5	5.0	5.4	5.9	6.5	8.5	10.0
Permissible surface unevenness height (cm)	3.9	5.5	6.8	7.8	8.6	9.6	11.0	13.6	16.0
Excessive surface unevenness height (cm)	5.8	7.6	9.1	10.0	10.8	11.9	13.9	17.0	20.0

Whereas according to the requirements of the Federal Aviation Administration (FAA), which was brought to life by way of a Federal Act on Aviation of 1958 as the Federal Aviation Agency (adopting the current name in 1966, when it became a part of the US Ministry of Transport), permissible single unevenness of an airfield pavement may be 6.4mm over a section of 5m [2],[1]. Figure **1** shows a sample device for measuring road pavement unevenness used domestically and a device for measuring airfield pavement unevenness used in the USA as per FAA requirements.

In a situation of deviation from a desired pavement condition on roads, there is a possibility of placing (installing) signs warning about road unevenness and a speed limit on a given road section. Moreover, removing the formed damage and restoring an appropriate surface evenness condition is possible without entirely putting a given road section out of operation, and only limiting it, through temporary traffic and using, e.g. alternating traffic. Unfortunately, such actions are impossible in the case of air traffic, and therefore, the requirements for airfield pavements must be much higher than the criteria used for road pavements. In the light of the above, it is not recommended to apply the requirements and road criteria to evaluate the technical condition of airfield pavements.

Trying to meet the presented issue half-way, the authors, along with a broader research team, drawing from more than 60 years of experience gained during the execution of investments and repairs at airfield facilities, developed a Defence Standard NO-17-A502:20175 *Airfield pavements. Evenness testing*, which is applied by military, as well as civil airport services. The standard in question determines the procedure for evaluating airfield pavement evenness condition on individual airfield functional elements (AFE), the evaluation criteria and the manner of presenting the obtained field test results. In addition, the a/m standard draws attention to the need to determine the evenness condition of newly constructed and renovated pavements prior to handing them over to operation, and to systematic periodic inspections, over the course of their operation process. It will enable tracking the changes undergoing during operation, determining the areas in which degradation is faster, and also forecast their rate.

Evaluating evenness pursuant to NO-17-A502:2015

The measurement of airfield pavement evenness as per NO-17-A502:2015 *Airfield pavements. Evenness testing* shall be conducted with the use of a 4m or 3m long planograph, which enables unevenness recording. When the geometrical dimensions of an evaluated AFE make it impossible to use a planograph for the measurements, measuring with a 4m or 3m long staff is permitted [2].

A planograph used for measuring airfield pavement unevenness is a modernized device made in Poland. The executed modernization involved adding: an assembly recording pavement unevenness, unevenness sensor, transformer converter for linear displacements, road increment sensor, serial interface, computer for analysing and software developed at the Air Force Institute of Technology (AFIT). Figure **4** shows a planograph after modernization.

4. A post-modernization P-3Z planograph

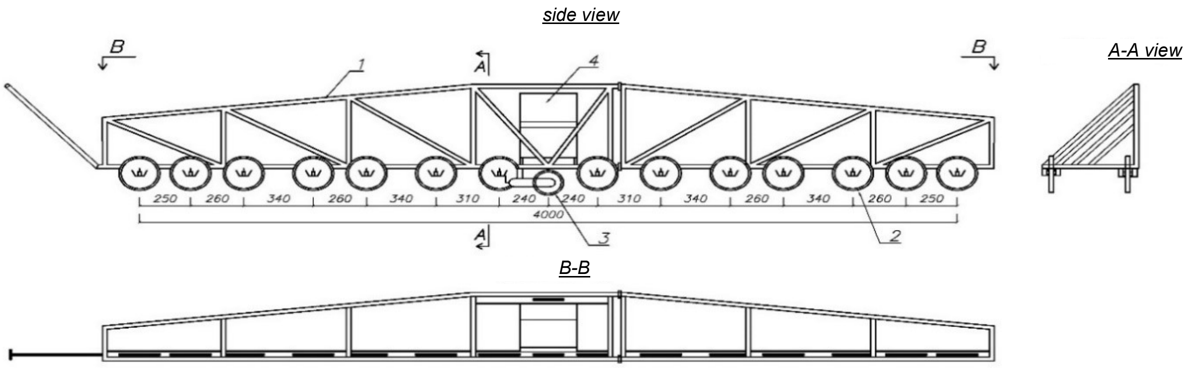
Measurement with a staff

A staff should be made from metal or wood. However, it is recommended to use staff made from aluminium alloy sections. The bottom plane (measuring) aimed towards the pavement should be smooth and even. A 3m long staff shall be made with a tolerance of ± 3 mm, and a 4m with a tolerance of ± 4 mm. The rigidity of the staff should be such that the deflection in the centre, when supporting on the ends, does not exceed 0.5 mm [3],[5]. A 3m long measurement staff is shown in figure **2**. A 4m long measurement staff is identical to a 3m one.

2. A 3m long measurement staff

Measurement with a planograph

A planograph used to measure airfield pavement evenness condition records the displacement of a mobile measuring wheel relative to a four-meter or a three-meter baseline, moving along the pavement on 14 or 10 rolling wheels. The planograph design should ensure adequate rigidity, which is defined by its deflection in the central part when supported only on the extreme wheels. The deflection of a planograph structure should not exceed 0.3 mm. The axes of extreme wheels in a 4m long planograph should be placed at a distance (4000± 70) mm, and in a 3m long planograph – (3 000 ± 50) mm, with the spacing of the other wheel with a tolerance of ± 5 mm. The diameter of rolling wheels should be (200 ± 10) mm, with the diameter of a measuring wheel being (159 ± 5) mm [3]. A general diagram of a 4 m long planograph is shown in figure **3**. A diagram of a 3m long planograph is identical as of a 4m long one, with the remarks as discussed above. This sets allows to measure the unevenness present on a pavement, in the form of road length increment, with an accuracy of 0.3mm and a frequency every 10 cm.



Explanations
1 – trolley frame, 2 – rolling wheel, 3 – measuring wheel, 4 – measuring table (a recording set, transmitting the results to a computer)
3. A diagram of a 4m long planograph [3]

Test methodology and evaluation

Airfield pavement evenness, pursuant to the standard NO-17-A502:2015, should be expressed by the defectiveness degree W. This term is understood as a percentage share of the number of 5m long route sections, with at least one event of exceeding the permissible value between the theoretical connecting line, formed by contact points of planograph rolling wheels and the upper pavement surface. Based on the conducted analyses, a measurement route division into 5m modules was adopted. The adopted length of 5m corresponds to a pavement slab most frequently used at airports. As a result, a set of a defined number of readings is taken for the evaluation, which makes the measurement itself and the later analysis more accurate. A studied AFE is divided into 100m long (1 hectometre) test areas. Pavement areas, which can be assigned a certain rating, are obtained as a consequence of that division. A facility is evaluated in terms of evenness, by analysing the mean defectiveness value W, which is determined from a relationship:

$$W = \frac{\sum_{i=1}^{n} w_i \cdot F_i}{\sum_{i=1}^{n} F_i} \tag{1}$$

where:
W – defectiveness of the evaluated area or zone [%],
w_i – defectiveness of the “ith” evaluated test area [%],
F_i – length of the evaluated route section (test area) adopted for assessment [m].

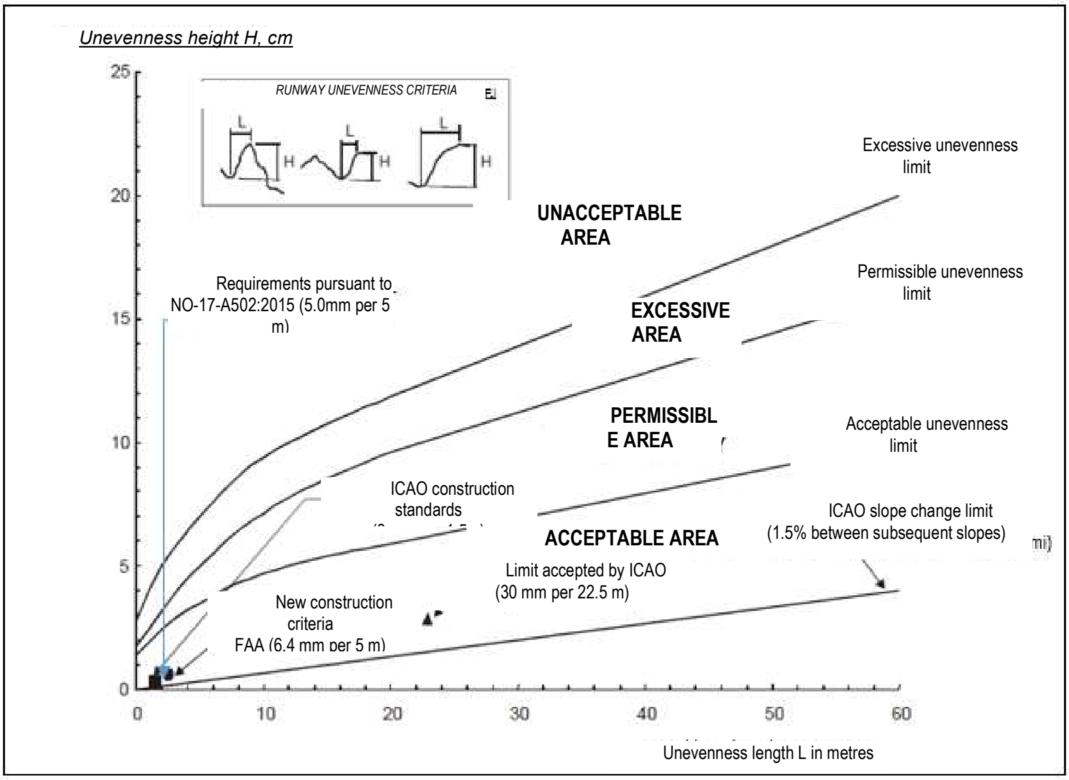
The airfield pavement evenness condition is evaluated through a defectiveness criterion, which is determined using a five-grade scale presented in table **4**.

Tab. 4. Airfield pavement evenness condition evaluation criteria

Evenness condition according to defectiveness evaluation	Planograph length		Colours of an evaluated area
	4 m	3 m	
Very good	W≤5%		
Good	5%<W≤10%		
Adequate	10%<W≤20%		
Unsatisfactory	20%<W≤50%		
Insufficient	W>50%		

A test result is deemed positive when the number of measurement route 5m sections exceeding permissible unevenness is lower than 20% for newly constructed or renovated pavements, and lower than 50% for operated pavements.

As per [3],[5],[4], the permissible unevenness for newly constructed pavements and the maximum unevenness values for operated pavements are shown in table 5. Fig. 5 shows the pavement evaluation criteria according to ICAO, FAA and NO-17-A502:2015.



5. Unevenness criteria comparison

Tab. 5. Airfield pavement maximum and permissible unevenness

Device type	Maximum unevenness [mm]	Permissible unevenness [mm]
Planograph or a 4m staff	12	5
Planograph or a 3 m staff	9	3

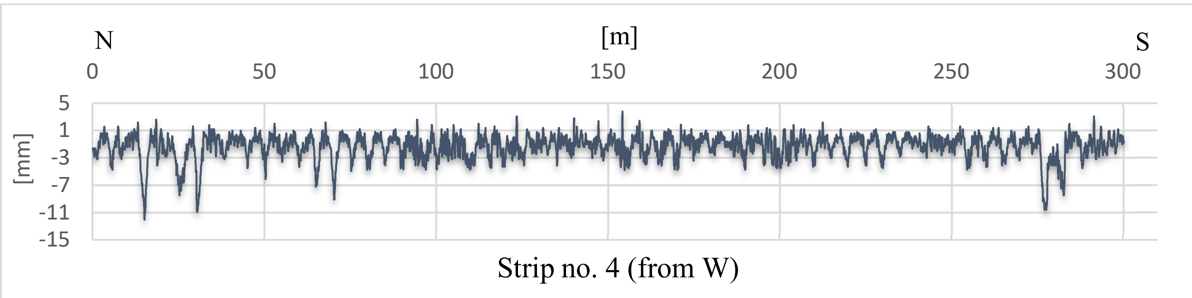
Test result presentation

According to the defence standard NO-17-A502:2015, an airfield pavement evenness analysis is performed on all operated AFEs, however the scope and presentation manner of the results depends on their function during air operations. As a consequence, evaluating evenness condition and the test scope depends on the fact, whether the measurements are performed on runways, taxiways or aprons. However, regardless of the AFE being measured, a result of an airfield pavement evenness condition test is a mean value of calculated defectiveness and mean unevenness values, standard deviations and numerical values of unevenness for the adopted sections.

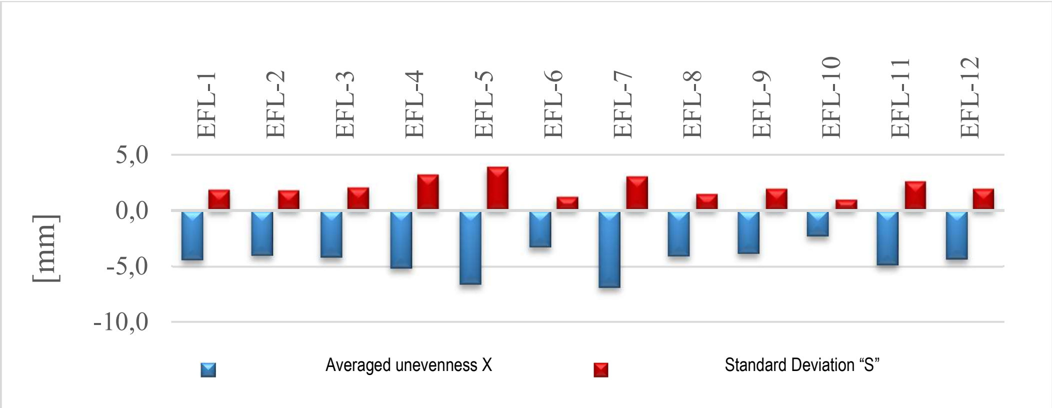
Measurements on a runway are performed on all strips in the longitudinal direction and every 50m in the transverse direction. A 100m long module with calculated defectiveness *W* is adopted to evaluate the evenness condition of runways. The obtained values of defectiveness in the longitudinal and transverse directions are plotted on accurately determined test areas, which are marked with colours adopted for individual evenness conditions as per table 1, with the resulting *Evenness condition evaluation metrics*. Test areas comprise separated long runway pavement surface areas, 100m (1 hectometre) long and usually 5m wide (strip or slab width).

Measurements on taxiways and aprons are performed in all strips in the longitudinal directions and every 50m in the transverse direction (transverse measurements on taxiways up to 25m wide are not required, unless the presence of water pools is identified, or it is required by the Ordering Party). Taxiways and aprons are evaluated separately in the longitudinal direction, whereas in the transverse direction, a collective assessment is presented. The final rating of a facility, apart from the mean defectiveness value, contains average unevenness, standard deviation, percentage share of individual exceedings and unevenness profiles in the road increment function [5],[4].

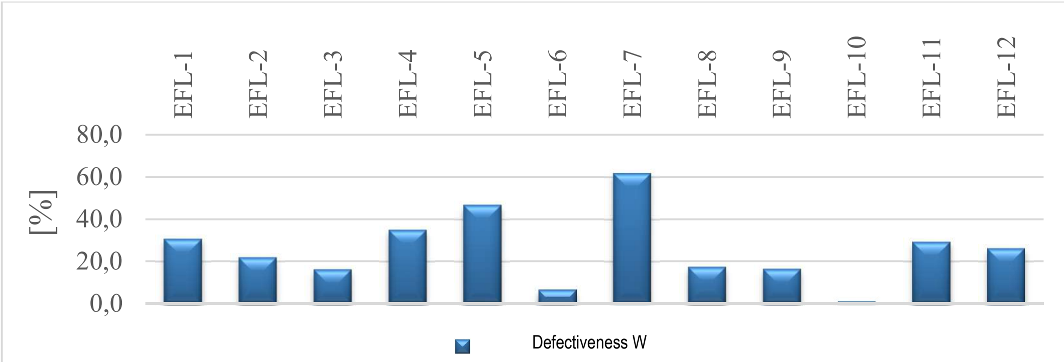
An example analysis of the test results, together with the manner of their presentation are shown in figures **6-9** and table **6**.



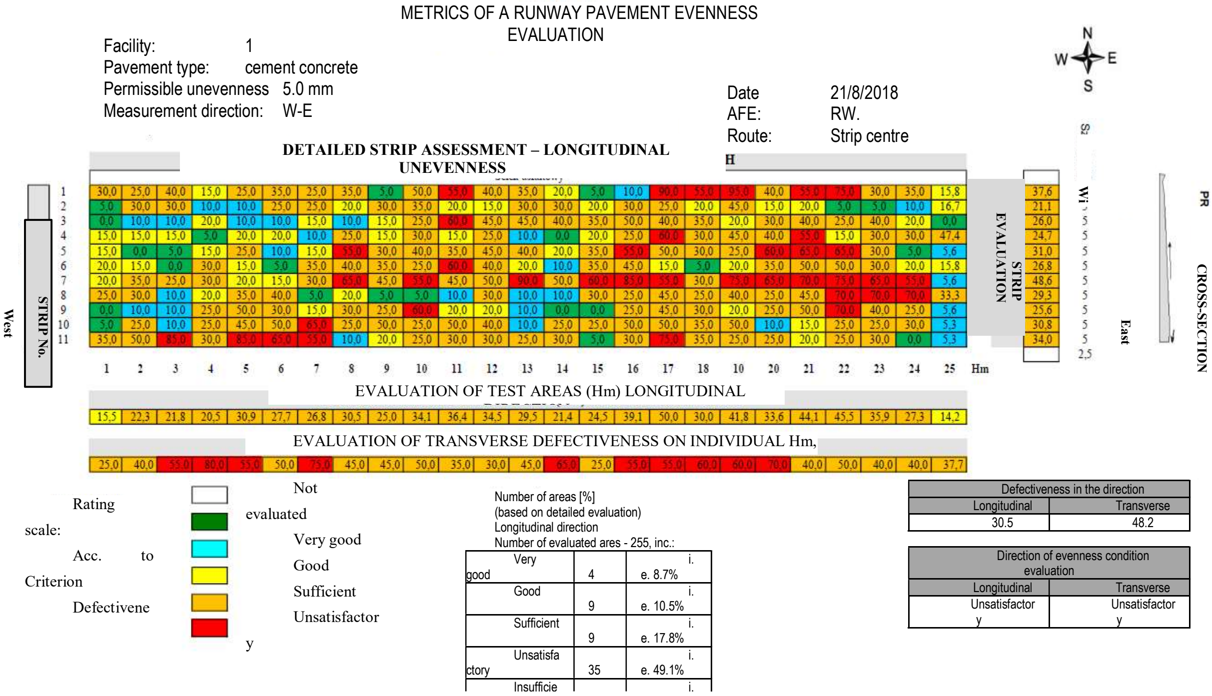
6. Longitudinal unevenness profile on a strip example



7. Average quantities of longitudinal unevenness and standard deviations on individual AFEs



8. Percentage number of slabs exceeding normative requirements (defectiveness) on individual AFEs



9. Runway airfield pavement evenness condition evaluation

Tab. 6. Mean values of longitudinal unevenness, standard deviation, defectiveness and the number of unevenness within individual unevenness ranges and individual strips

STRIP No.	Averaged values "X"	Standard Deviation "S"	Defectiveness "W"	Number of slabs with max. unevenness			
				to -5.0 mm	from -5.1 to -9.0 mm	from -9.1 to -12.0 mm	above -12.0 mm
	[mm]	[mm]	[%]	[%]	[%]	[%]	[%]
Longitudinal unevenness							
1	-4.8	2.0	37.7	62.3	34.1	2.8	0.8
2	-4.0	1.6	21.1	78.9	20.1	0.6	0.4
3	-4.3	1.9	26.6	73.4	24.5	1.2	0.8
4	-4.2	1.9	24.6	75.4	22.6	1.2	0.8
5	-4.6	2.1	31.1	68.9	26.1	4.2	0.8
6	-4.1	1.7	26.9	73.1	25.5	1.4	0.0
7	-5.2	2.1	48.8	51.2	43.6	4.8	0.4
8	-4.4	1.7	29.3	70.7	28.1	1.0	0.2
9	-4.2	1.6	25.7	74.3	24.7	1.0	0.0
10	-4.3	1.7	30.9	69.1	28.9	2.0	0.0
Mean	-4.4	1.8	30.5	69.4	28.2	2.0	0.4
Transverse unevenness							
Mean	-5.3	2.2	48.2	51.8	41.8	5.2	1.3

Conclusions

The main operational features characterizing each road and airfield pavements are its evenness, load-bearing capacity and roughness. The assessed pavement evenness parameter determines not only the comfort of traffic over the pavement, but also influences the magnitude of dynamic loads on the pavement. Achieving required evenness is also a prerequisite for a quick and efficient drainage of rainwater or defrosting agents from the pavement. Even small unevenness of a pavement may be a base for the formation of water pools, which deteriorate safety conditions through the possibility of *aquaplaning*, which is a loss of adhesion between a wheel and a surface.

However, despite so many features mutual for road and airfield pavements, taking into account, among others, AFE geometric dimensions, and grounded on many years of experience, the pavement evenness assessment is conducted based on developed independent requirements and criteria, which was discussed in NO-17-A502:2015 *Airfield pavements. Evenness testing.*

The modern, extremely dynamic development of aviation and the constantly growing intensity of air operations, which has increased several times over the last 12 years, forces the conducted tests to be as accurate as possible, and the obtained results to be reliable and reflect the existing pavement status as closely as possible. The applied measuring devices must guarantee the correctness of obtained results, since the safety of air operations depends on them. In the light of the above, there is a constant need to monitor the condition of airfield pavement evenness, which will enable the designation of zones (areas), with the fastest degradation and to forecast its progress over time.

Moreover, information about the condition of airfield pavements obtained from the measurements conducted as per the defence standard NO-17-A502:2015 *Airfield pavements.*

Evenness testing are very crucial for an Administrator of the facility and enable taking actions allowing the determination of their causes through detailed diagnostics, hence, reduce the deterioration rate through selecting an appropriate remedial technology.

Source materials

[1] Annex to ED Decision 2017/021/R (CS-ADR-DSN Issue 4).
[2] FAA AC 150/5300-13A - Airport Design.
[3] NO-17-A502:2015 *Nawierzchnie lotniskowe - Badanie równości [Airfield pavements - Evenness testing]*
[4] Pietruszewski P. Poświata A. Wesołowski M. *Evaluation of airfield pavement evenness.*IOP Conf. Series: Materials Science and Engineering, 2018
[5] Poświata A. Pietruszewski P. *Wpływ stanu równości nawierzchni lotniskowych na bezpieczeństwo wykonywania operacji lotniczych [The impact of airfield pavement evenness condition on the safety of air operations].* Autobusy, no. 12, 2016.
[6] Regulation of the Committee (UE) NO. 139/2014 of 12 February 2014 laying down requirements and administrative procedures related to aerodromes pursuant to Regulation of the European Parliament and of the Council (EC) No. 216/2008
[7] Regulation of the Minister of Infrastructure of 17 February 2015 (Dz. U. 2015, item 329).
[8] ROZPORZĄDZENIE MINISTRA INFRASTRUKTURY z dnia 16 stycznia 2002 r. w sprawie przepisow techniczno-budowlanych dotyczacych autostrad płatnych *[Regulation of the Minister of Infrastructure of 16 January 2002 on the technical-construction legislation regarding tollways]*, (2002)
[9] System Oceny Stanu Nawierzchni „SOSN”, Wytyczne stosowania [*Pavement Condition Assessment System “SOSN”, Application guidelines*], GDDP BSSD, Warsaw, February 2002.
[10] Załącznik 14 ICAO do Konwencji o Międzynarodowym Lotnictwie Cywilnym, *Lotniska Tom I - Projektowanie i eksploatacja lotnisk*, wydanie 6 *[Annex 14 ICAO to the Convention on International Civil Aviation, Aerodromes Volume I - Design and operation, issue 6]*, 6 July 2013.