Evaluation of airfield pavement evenness

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Abstract. The evenness of airfield pavements is one of the basic operating parameters, which characterize them. The evenness determines not only comfort of traffic along an airfield pavement, but also influences the size of dynamic effect on the pavement, hence, the safety of air operations. In addition, the evenness condition changing as a result of dynamic loads, adverse weather conditions or inappropriate airfield pavement construction technology, lead to deviations from the desired condition in the form of longitudinal and transverse unevenness. As a result, systematic and correct performance of tests is a very significant and required factor impacting the improvement of traffic safety on airfield pavements. If the data obtained through the measurements are not sufficiently reliable, they may consequently lead to making incorrect decisions, which can ultimately impact the safety of air operations.

Keyword: airfield pavements, airfield pavement evenness, airfield pavement evenness state evaluation

1. Introduction

One of the main operating features that characterises each airfield or road pavements is its evenness, which as a result of dynamic loads, adverse weather conditions or inappropriate construction technology leads to deviations from the desired condition, in the form of longitudinal or transverse unevenness. Pavement evenness, or rather lack of, 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.

The evenness measurements in the road industry, conducted by the General Directorate for National Roads and Motorways (GDDKiA) are carried out with multi-sensor laser profilometers. The obtained test results are converted into, so called, International Roughness Index IRI expressed in mm/m or m/km, that characterizes the suspension work in conventionally applied computational model [1]. However, in conformity with the International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA) requirements, the measurements may be performed using profilometer or leveling rod and a wedge. Measuring devices differ in their dimensions and acceptable single unevenness on the airfield pavement. In accordance with existing provisions of ICAO, the single acceptable unevenness shall be 3 mm over the length of 3 metres, whereas according to FAA it is 6,4 mm over the length of 5 metres. The example of unevenness measurement device used on road pavements in Poland, as well as the unevenness measurement device used on airfield pavements in The United States of America in accordance to FAA, is presented in Figure 1 below.
In the road industry, in a situation of deviations from the desired surface condition there is a possibility of placing (installing) signs warning about the formed road unevenness and limiting the speed over an entire 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 road standards, requirements or criteria to evaluate the technical condition of airfield pavements.

Trying to meet the presented issue half-way, the author, 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 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. Fig. 2 shows examples of airfield pavement damage regarding their unevenness and having significant impact on the safety of air operations executed by aircraft.
2. General information
The measurement of airfield pavement evenness as per NO-17-A502:2015 Airfield pavements. Evenness testing shall be conducted with the use of a 4 m or 3 m long planograph, which enables unevenness recording. In case the geometrical dimensions of an evaluated AFE make it impossible to use a planograph for the measurements, measuring with a 4 m or 3 m long staff is permitted.

2.1. 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 3 m long staff shall be made with a tolerance of ± 3 mm, and a 4 m with a tolerance of ± 4 mm. The rigidity of the staff should be prepared in a way so that the deflection in the centre, when supporting on the ends, did not exceed 0.5 mm [3,4,5]. A 3 m long measurement staff is shown in figure 3. A 4 m long measurement staff is identical to a 3 m one.
2.2. Measurement with a planograph

A planograph used to measure airfield pavement evenness condition records the displacement of a mobile measuring wheel relative to a fourth-metre or a three-metre 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 4 m long planograph should be placed at a distance (4000 ± 70) mm, in a 3 m 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 4. A diagram of a 3 m long planograph is identical as of a 4 m long one, with the remarks as discussed above.

![Figure 3. A 3 m long measurement staff.](image)

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![Figure 4. A diagram of a 4 m long planograph [3].](image)

Figure 4. A diagram of a 4 m long planograph [3].

A planograph used for measuring airfield pavement evenness is a modernized device made in Poland. The modernization involved adding an assembly recording pavement unevenness, an unevenness sensor, a road increment sensor, a serial interface and an analysis computer. Recently, in order to increase measuring precision, another modernization has been performed, involving changing the rolling wheels, adding a new linear displacement converter transformer, and a new interface and software developed at the Air Force Institute of Technology (AFIT). Figure 5 shows a planograph after the modernization.
Figure 5. A post-modernization P-3Z planography.

This set allows to measure the unevenness present on a pavement, in the form of road length increment, with an accuracy of 0.3 mm and a frequency every 10 cm.

3. Test methodology and evaluation

Airfield pavement evenness, pursuant to the NO-17-A502:2015 standard, should be expressed with the defectiveness degree $W$. This term is understood as a percentage share of the number of 5 m 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.

The 5 m section length adopted for analysis and the developed criteria are not accidental. In [6], the author determined the impact of measurement route length and the variability of the module length on assessed parameters, such as: mean unevenness size, standard deviation or defectiveness. In order to determine their impact, an analysis was conducted, which adopted measuring route lengths of: 100 m, 200 m, 500 m, 1000 m, 2000 m and module lengths: 0.1 m, 0.2 m, 0.5 m, 1.0 m to 10.0 m, with an increment of 1.0 m. An example analysis result is shown in figure 6.

Figure 6. Measurement route length and module relationships [6].
Based on the conducted analyses, a measurement route division into 5 m modules was adopted. The adopted length of 5 m 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 100 m long (1 hectometre) test areas. Pavement areas, which can be assigned a certain rating, are obtained as a consequence of that division. A road structure is evaluated in terms of evenness, by analysing the mean defectiveness value $W$, which is determined from a relationship:

\[
W = \frac{\sum_{i=1}^{n} w_i F_i}{\sum_{i=1}^{n} F_i}
\]

where:

$W$ – defectiveness of the evaluated area or zone [%],

$w_i$ – defectiveness of the $i^{th}$ 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 criteria, which is determined by using a five-grade scale presented in table 1.

### Table 1. Airfield pavement evenness condition evaluation criteria.

| Evenness condition according to defectiveness evaluation | Planograph length | Colours of an evaluated area |
|----------------------------------------------------------|-------------------|-------------------------------|
| Very good                                                | 4 m, 3 m staff    | Green                         |
| Good                                                     |                   | Blue                          |
| Sufficient                                               |                   | Yellow                        |
| Unsatisfactory                                           |                   | Orange                        |
| Insufficient                                             |                   | Red                           |

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

According to [3,7,8] the permissible unevenness for newly constructed pavements and the maximum unevenness values for operated pavements are shown in table 2.

### Table 2. Airfield pavement maximum and permissible unevenness.

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

Moreover, in order to confirm the suitability of a 3 and 4 m planograph measuring system to evaluate an airfield pavement unevenness condition, repeatability and reproducibility coefficients with the use of the Repeatability & Reproducibility (R&R) method were determined. [9] contains an analysis of repeatability and reproducibility, together with the total spread taking into account the impact of individuals operators on the measurement. A block diagram of the R&R method is shown in fig. 7.
The results of a conducted repeatability and reproducibility analysis are shown in table 3.

Table. 3. Common table of calculated values after a conducted analysis.

| Quantity                  | 3 m planograph (%) | 4 m planograph (%) |
|---------------------------|--------------------|--------------------|
| Equipment Variation %EV   | 5.8                | 3.2                |
| Appraiser Variation %AV   | 1.6                | 1.5                |
| %R&R                      | 7.4                | 4.7                |

Based on a conducted analysis of a measurement system suitability, it was concluded that the calculated %R&R indicators fall within a range of up to 10%. It confirmed the fact that both a 3 m, as well as a 4 m long planograph, are suitable for evaluating airfield pavement evenness conditions. However, when analysis the components of individual determined quantities, they indicate a higher suitability of a 4 m long planograph, which in consequence leads to a more accurate reflection of the actual condition of an airfield pavement.

4. 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 50 m in the transverse direction. A 100 m 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 constitute separated long runway pavement surface areas, 100 m (1 hectometre) long and usually 5 m wide (strip or slab width).

Measurements on taxiways and aprons are performed in all strips in the longitudinal directions and every 50 m in the transverse direction (transverse measurements on taxiways up to 25 m 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 common assessment is presented. The final rating of a road structure, apart from the mean defectiveness value, contains average unevenness, standard deviation, percentage share of individual exceedings and unevenness profiles in the road increment function [12].

An example analysis of test results, together with the manner of their presentation is shown in figures 8-11 and table no. 4.

![Figure 8. Longitudinal unevenness profile on a strip example.](image)

**Table 4.** 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" up to -5.0 mm | Number of slabs with max. unevenness from -5.1 to -9.0 mm | from -9.1 to -12.0 mm | above -12.0 mm |
|-----------|---------------------|------------------------|--------------------------------|----------------------------------------------------------|------------------------|----------------|
|           | [mm]                | [mm]                   | [%]                           | [%]                                                      | [%]                    | [%]            |
| Longitudinal unevenness | | | | | | |
| 1         | -2.4                | 1.5                    | 6.8                           | 93.2                                                     | 6.6                    | 0.0            | 0.2 |
| 2         | -1.9                | 1.2                    | 2.8                           | 97.2                                                     | 2.6                    | 0.2            | 0.0 |
| 3         | -2.1                | 1.2                    | 2.8                           | 97.2                                                     | 2.6                    | 0.2            | 0.0 |
| 4         | -2.2                | 1.3                    | 3.2                           | 96.8                                                     | 2.6                    | 0.4            | 0.2 |
| 5         | -2.3                | 1.3                    | 3.4                           | 96.6                                                     | 2.8                    | 0.6            | 0.0 |
| 6         | -2.7                | 1.3                    | 5.8                           | 94.2                                                     | 5.4                    | 0.4            | 0.0 |
| 7         | -2.4                | 1.5                    | 5.4                           | 94.6                                                     | 4.4                    | 0.6            | 0.4 |
| 8         | -2.1                | 1.4                    | 4.0                           | 96.0                                                     | 3.6                    | 0.4            | 0.0 |
| 9         | -2.1                | 1.3                    | 4.8                           | 95.2                                                     | 4.8                    | 0.0            | 0.0 |
| 10        | -2.4                | 1.3                    | 5.6                           | 94.4                                                     | 5.6                    | 0.0            | 0.0 |
| Mean      | -2.3                | 1.3                    | 4.5                           | 95.5                                                     | 4.1                    | 0.3            | 0.1 |
| Transverse alignment | | | | | | |
| Mean      | -3.3                | 1.5                    | 9.4                           | 90.4                                                     | 9.2                    | 0.2            | 0.0 |
5. Final conclusions

Evenness is one of the most important operating parameters, which each airfield pavement is characterised by. It determines not only the comfort of an aircraft movement over an airfield pavement, but also impacts the size of dynamic loads on it. Achieving required evenness is also a prerequisite for a quick and efficient drainage of rainwater or defrosting agents from airfield
pavements. 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 lost of adhesion between a wheel and a surface.

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 reflecting 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 belong on them.

Having regard to the foregoing, there is a constant need of monitoring the condition of airfield pavement evenness, which will enable the segregation of zones (areas) with the fastest degradation, and forecast its course over time. Furthermore, information about the airfield pavement condition collected from measurements performed in accordance with defence standard NO-17-A502:2015 Airfield pavements. Evenness testing are crucial for the facility Manager, who may take action to enable determining the causes of its forming due to exact diagnostics, thereby reducing the degradation tempo by adjusting the proper repair technology.

Further publications regarding the discussed operational parameter of airfield pavements will present the results with the analysis of evenness condition analysis, coming from the conducted field tests utilizing the new testing instruments.

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