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

Bartosz Świerzewski
Mgr inż.
Urząd Lotnictwa Cywilnego, Departament Lotnisk

DOI: 10.35117/A_ENG_18_12_06

A concrete prefabricated slab as a technology for reconstructing damaged, local airfield pavements

Abstract: The age of currently operated concrete airfield pavements in Poland exceeds 30 years operation period many times. Such a long working life of airfield pavements forced to search for the efficient and fast technologies of their reconstruction. The article described in detail the technologies of fast reconstruction of airfield concrete slabs using prefabricated slabs. The addressed technology guarantees the reconstruction and even the improvement of the condition of load-bearing capacity of mentioned airfield slabs which was confirmed during laboratory tests, field tests and practically verified in the real operation in the International Airport Kraków-Balice.

Keywords: Airfield pavements; Cement concrete; Deterioration of concrete pavements; Load-Bearing capacity of airfield pavements made of cement concrete; Prefabricated slab

Introduction

In the majority of national airports, the airfield pavements are made of cement concrete. Their basic task is a safe transfer of operational loads of aircraft and thermal loads (natural and forced) on the soil subbase. Concrete airfield pavements used in our country encompass newly constructed pavements, operated pavements and pavements which will shortly undergo the overhaul. Operated pavements and these pavements which exceed the designed utilization age require special attention due to the fact that it is possible to detect on them the basic failures characteristic for concrete airfield pavements. 13 types of failures were identified, including surface failures (e.g. spalling, hairline cracks), local failures (e.g. pop-outs, corner cracks), linear failures (e.g. meander cracks, decrements of the pourable sealing compound in expansion gaps). The presented technology of reconstructing the technical condition of single, deteriorated concrete slabs of airfield pavements utilizes prefabricated slab elements. The developed solution ensures the reconstruction of a structural form with the adopted physical and mechanical properties, which was confirmed by the obtained results of laboratory tests and field tests. A huge advantage of the presented technology is a very short time of its execution. The efficiency of the solution was confirmed in the night during operational breaks in the aircraft traffic.

Evaluation of deterioration degree of airfield pavements made of cement concrete

Technical condition of airfield pavement undergoes periodic inspection, the so-called stocktaking of failures which includes every airfield functional constituent (EFL). The stocktaking covers both the existing failures as well as these which were subject to overhaul because they affect the deterioration degree of pavements of airfield functional constituents. The stocktaking system of failures, developed in such a way, enables to determine their size and allows to define the overall index of pavement deterioration. Deterioration degree of pavement, described by index D, is estimated on the basis of the results of tests obtained during conducted visual inspections of pavements of airfield facilities. Deterioration degree of pavements of airfield functional constituents is calculated in accordance with formula [1]:

$$\boldsymbol{D = w_{BC}^{U} \, x \, W_{BC}^{U} + w_{BC}^{N} \, x \, W_{BC}^{N}} \qquad (1)$$

where:

w_{BC}^{U} – statistical weight coefficient of failures in the estimation of deterioration of EFL pavements;

W_{BC}^{U} – index characterizing failures of airfield functional constituents made of cement concrete;

w_{BC}^{N} – statistical weight coefficient of failures in the estimation of deterioration of EFL pavements;

W_{BC}^{N} – index characterizing the repairs of AFE made of cement concrete.

Estimation of the condition of slabs made of cement concrete, which belong to basic constituents of airfield pavements is done based on indices characterizing its failures. The arithmetic average value of the index of deterioration of slab $\overline{W_{BC}^{U}}$, which is a basic element of airfield pavement made of cement concrete is calculated on the basis of formula (2) [1]:

$$\overline{W_{BC}^{U}} = \left. \begin{matrix} W_{Ap}^{U} + W_{Bg}^{U} + W_{Pm}^{U} + W_{Pw}^{U} + W_{Op}^{U} + W_{Now}^{U} + W_{Ug}^{U} + \\ W_{Ps}^{U} + W_{Psszer}^{U} + W_{M}^{U} + W_{Pr}^{U} + W_{O}^{U} + W_{Wp}^{U} \end{matrix} \right/ 13 \qquad (2)$$

The average index of failures is the mean sum of indices characterizing all 13 failures on the slab made of cement concrete.

The indices characterizing certain failures are calculated according to individual formulas. As an example, two formulas were exhibited which concern shallow spalling and meander cracks. The index characterizing failures caused by shallow spalling[1]:

$$W_{Ap}^{U} = w_{Ap}^{U} p_{Ap}^{U} \frac{Ap^{U}}{F} 100 = w_{Ap}^{U} \frac{Ap^{U} \times 1}{F} 100 \qquad (3)$$

where:

Ap^{U} – failures in the form of shallow spalling for the slab which is the basic constituent of airfield pavements [m^2];

$w_{Ap}{}^{U}$ – statistical weight coefficient of the importance of failures in the form of shallow spalling in the estimation of the deterioration of pavements of airfield functional constituents;

$p_{Ap}{}^{U}$ – conversion factor for failures in the form of shallow spalling for the slab which is the basic constituent of airfield pavements on the surface.

---

1 P. Nita, M. Wesołowski, P. Barszcz and others, *Demonstrator technologii stanu technicznego nawierzchni lotniskowych. Dobór parametrów i wskaźników charakteryzujących stopień zdegradowania płyt stanowiących elementy nawierzchni lotniskowych wykonanych z betonu cementowego w oparciu o dane uzyskane z eksploatowanych obiektów ('Demonstrator of the technology of technical condition of airfield pavements. Selection of parameters and indices characterizing the deterioration degree of slabs which belong to constituents of airfield pavements made of cement concrete based on data obtained from operated facilities*') *– stage IV*. Elaboration. Instytut Technicznych Wojsk Lotniczych, Warsaw 2016.

Index characterizing failures resulting in meander cracks[2]:

$$W_{Ps}^{U} = w_{Ps}^{U} p_{Ps}^{U} \frac{Ps^{U}}{F} 100 = w_{Ps}^{U} \frac{Ps^{U} \times 0{,}02}{F} 100 \tag{4}$$

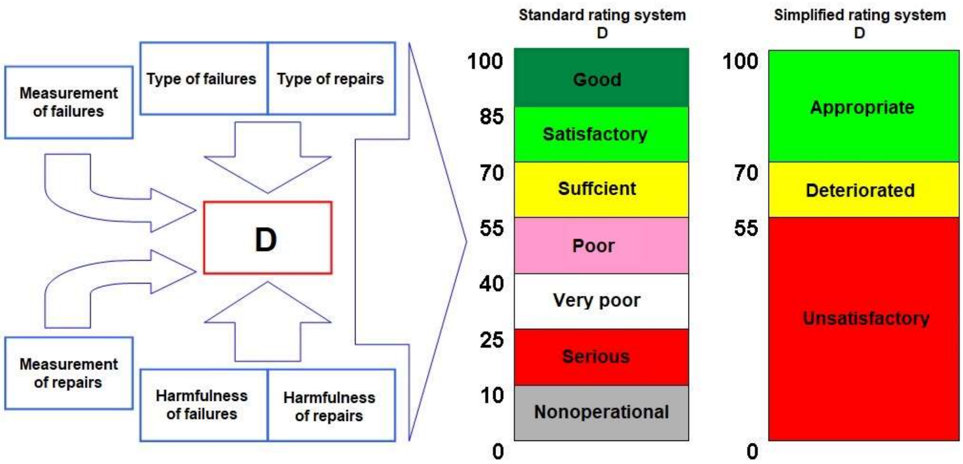
where:

- Ps^U – failures in the form of meander cracks for the slab which is the basic constituent of airfield pavements [m];
- $w_{Ps}{}^{U}$ – statistical weight coefficient of the importance of failures in the form of meander cracks in the estimation of the deterioration of pavements of airfield functional constituents;
- $p_{Ps}{}^{U}$ – conversion factor in the form of meander cracks for the slab which is the basic constituent of airfield pavements on the surface.

Deterioration of the technical condition is a slow and long-lasting process. In general, it consists in worsening of structure properties due to the impact of external factors, which eventually entails irreversible alterations in the structure.

The influence of different failures and repairs on the safety of the operation of aeroplanes is considered in calculations by adopting the estimated weight coefficients based on the expert method.

The standard rating system for the assessment of deterioration degree of airfield pavements includes seven levels. A simplified, three-level rating system can also be used, in which to each level the classes were attributed that define the pavement condition. The first level – desired, contains new pavements, renewed and operated, providing that in the next 5 years no repair works of these pavements will be needed. The second level – warning, identifies the technical condition as such, where it is justified to perform detailed inspections that concern conducting treatments improving the technical condition. The last level, the third level, determines the immediate execution of technical and operational inspections to specify activities aiming at commencement of treatment works improving the technical condition of airfield pavements or shutting the premises down. Fig. 1 presents criteria for assessment of deterioration degree of pavements of airfield functional constituents.



1. Criteria for the assessment of the deterioration degree of pavements of airfield functional constituents (EFL) [1]

[2] Ibid.

Operational requirements for the technology of the exchange of prefabricated airfield slabs

Materials used for repairs of concrete airfield pavements should be distinguished by physico-chemical properties similar to the applied concrete and ensure the reconstruction of operational parameters. Primarily, they should guarantee the safety of air operations [9]. Technologies consisting in the exchange of the whole deteriorated concrete slabs have to ensure the reconstruction of the required load-bearing capacity, evenness and coarseness.

Tear resistance

Tear resistance is one of the basic acceptance criteria for concrete airfield pavements, in compliance with the standard NO-17-A204:2015 „Nawierzchnie lotniskowe. Nawierzchnie z betonu cementowego. Wymagania i metody badań" ('Airfield pavements. Airfield pavements made of cement concrete. Requirements and test methods.') [2]. The assessment of tear resistance should be done based on field tests. These tests are performed also in laboratory conditions and then their results can provide the basis for the initial assessment. The measurement should be taken in accordance with the standard PN-EN 1542:2000 „Wyroby i systemy do ochrony i napraw konstrukcji betonowych. Metody badań. Pomiar przyczepności przez odrywanie" ('Products and systems for the protection and repair of concrete structures. Test methods. Adhesion testing by means of tearing' [3]. Checking the tear resistance should be completed for every airfield functional constituent, in accordance with the methodology included in [2].

Coarseness

Coarseness is a very important operational parameter determining the numerical value of the friction coefficient of aircraft's wheel on airfield pavement, which has a direct influence on safety of air operations. The requirements regarding the coarseness of airfield pavements and the characteristics of measurement methods were defined in the standard NO-17-A501:2015 „Nawierzchnie lotniskowe. Badanie szorstkości" ('Airfield pavements. Coarseness testing.') [4]. Under national conditions, the coarseness testing is most often performed with the use of ASFT (Airport Surface Friction Tester). It is a device used for the continuous measurement of friction coefficient, recommended by ICAO (International Civil Aviation Organization). Measurements are taken on wet airfield pavements. The result of coarseness testing of airfield pavements is the average value of the measured friction coefficient.

Evenness

Evenness of airfield pavements determines not only the comfort of air traffic but it also affects the size of dynamic effect on the pavement. Reaching the required evenness ensures efficient and fast drainage of rainwater from airfield pavements. Even on small irregularities of the surface can appear puddles of water, which in the winter season aggravate the conditions of air traffic safety. Evenness testing is done according to the standard NO-17-A502:2015 „Nawierzchnie lotniskowe. Badanie równości" ('Airfield pavements. Evenness testing') [5]. Measurements are taken with the use of the modernized planograph P-3z in longitudinal and transverse direction, with the frequency of 10 cm. Assessment of evenness is carried out compliant with the defectiveness criterion, described in [5].

Load-bearing capacity

The load-bearing capacity of airfield pavements is assessed using method ACN–PCN (Aircraft Classification Number – Pavement Classification Number), according to the standard NO-17-A500:2016 „Nawierzchnie lotniskowe i drogowe. Badania nośności" ('Airfield and road pavements. Testing of load-bearing capacity') [6]. This method is used to determine the dependence between the impact of the aircraft on pavement and the reaction of pavement on generated load. Testing of load-bearing capacity is employed with a Heavy Weight Deflectometer (HWD). Testing comprises the measurements of elastic deflections of pavements, on the basis of which is determined the value of the index of PCN load-bearing capacity and/or the permissible number of air operations for the adopted type of computational aircraft.

Reconstruction of the technical condition of deteriorated airfield pavement using a prefabricated slab

Overhaul technology (repairs, replacements) of deteriorated airfield pavements using prefabricated airfield pavements includes reconstructing very deteriorated concrete slabs and bringing them to such a technical condition which will not pose threat to aircraft during air operations.

Technology description

The technology of the replacement of deteriorated airfield pavements with the use of prefabricated slabs consists in the installation of a slab on the appropriately prepared foundation of the airfield pavement. The prefabricated slab should be placed on the appropriately prepared non-shrink grout [9]. The layer of grout must be of such thickness that height coordinates of the installed slab will be consistent with the coordinates of adjacent slabs. If the surface of the slab will stick out above the existing pavement, then it is necessary to mill its upper surface to the maximum thickness of 20 mm. Then, the milled surface should be covered with agents that will protect the damaged structure of the slab in the near-surface layer. The milled and surface-protected prefabricated slab has to meet the requirements of coarseness stipulated for airfield pavements.

Dimensions of the prefabricated slab of reinforced concrete are as follows: 2,50×5,00 m and thickness 0,21 m. It is made of concrete C35/45 and in its cross-section it has the following primary reinforcement of steel A-III:

- top reinforcement in the form of ribbed rods with ø 14 mm and spacing 30×30 cm,
- bottom reinforcement in the form of ribbed rods with ø 14 lub 16 mm and spacing 15×15 cm.

Airfield prefabricated slab was subject to material testing which was conducted in the laboratory of the Institute of Materials and Building Constructions at the Faculty of Civil Engineering of the Technical University of Cracow and field tests which were carried out by the Airfield Division of the Air Force Institute of Technology (ITWL) at place of its installation, that is on the pavement of a hardstand for aeroplanes in the International Airport Kraków-Balice.

Laboratory tests

The scope of laboratory tests encompassed strength tests of concrete on compression, done in accordance with the standard PN-EN 12390-3 Badania betonu – Część 3: „Wytrzymałość na ściskanie próbek do badania" [7] (PN-EN 12390-3 Concrete testing – Part 3: 'Compression strength of test samples', testing of gravimetric concrete absorption and testing of concrete resistance to frost performed in accordance with the standard PN-88/B-06250 „Beton zwykły" ('Ordinary concrete') [8], item 6.4 and 6.5. The results of conducted laboratory tests were described in subsequent points.

Compression strength

Tests of compression strength (destructive tests) were done for 12 samples (cubes) with the dimensions of 15×15×15 cm and the average value of compression strength amounting to 50,2 MPa was obtained. The results confirmed that cement concrete which was used for the production of a prefabricated slab fulfilled the requirements specified for concrete C35/45.

Absorption
Tests of gravimetric absorption of concrete were done using six cubic samples with the dimensions of 15×15×15 cm. The obtained results were compiled in table 1.

Tab. 1. Results of tests of concrete absorption

Sample No.	Weight of sample [g]		Absorption [%]
	Saturated	Non-saturated	
1	7828	7536	3,9
2	7983	7693	3,8
3	7831	7531	4,0
4	7834	7540	3,9
5	7824	7539	3,8
6	7920	7615	4,0
Average value	7870	7576	3,9

Based on the obtained results the conclusion can be made that cement concrete satisfied the requirements of the above-mentioned standard because its absorption did not exceed the permissible value of 5%.

Concrete resistance to frost
Tests of concrete resistance to frost were done using 12 cubic sample with the dimensions of 15×15×15 cm. There were 150 cycles of freezing and defreezing. The results were summarised in table 2.

Tab. 2. Results of tests of concrete resistance to frost

<table>
<tr><th rowspan="2">Sample No.</th><th colspan="2">Sample mass [g]</th><th rowspan="2">Mass decrement ΔG [%]</th><th rowspan="2">Resistance R_i [MPa]</th><th rowspan="2">Decline in resistance ΔR_i [%]</th></tr>
<tr><th>Before test</th><th>After test</th></tr>
<tr><td>1</td><td>7940</td><td>7925</td><td rowspan="6">0,22</td><td>51,9</td><td rowspan="12">15,3</td></tr>
<tr><td>2</td><td>7815</td><td>7795</td><td>46,4</td></tr>
<tr><td>3</td><td>7860</td><td>7840</td><td>49,2</td></tr>
<tr><td>4</td><td>7800</td><td>7775</td><td>45,8</td></tr>
<tr><td>5</td><td>7930</td><td>7915</td><td>52,1</td></tr>
<tr><td>6</td><td>7925</td><td>7915</td><td>52,0</td></tr>
<tr><td>7</td><td colspan="3" rowspan="6">samples</td><td>55,7</td></tr>
<tr><td>8</td><td>60,1</td></tr>
<tr><td>9</td><td>56,2</td></tr>
<tr><td>10</td><td>61,4</td></tr>
<tr><td>11</td><td>58,1</td></tr>
<tr><td>12</td><td>59,7</td></tr>
</table>

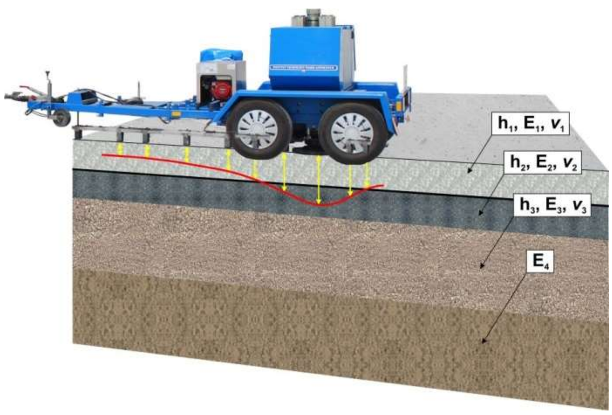
Based on the obtained results it can be established that tested cement concrete met the requirements for the frost resistance level F150 due to the fact that the mass decrement after the test is smaller by 5% and the average decline in compression strength did not exceed 20%.

Field tests

Load-bearing capacity of apron's airfield pavement

The scope of field tests involved the evaluation of the load-bearing capacity of a prefabricated slab installed in the airfield pavement of the apron on the airport Kraków-Balice, which was done on account of recorded results of measurements of elastic deformations of pavement under impact load [6]. Tests of pavements were executed with the application of Heavy Weight Deflectometer (HWD) in compliance with the requirements of the defence standard NO-17-A500:2016 [6].

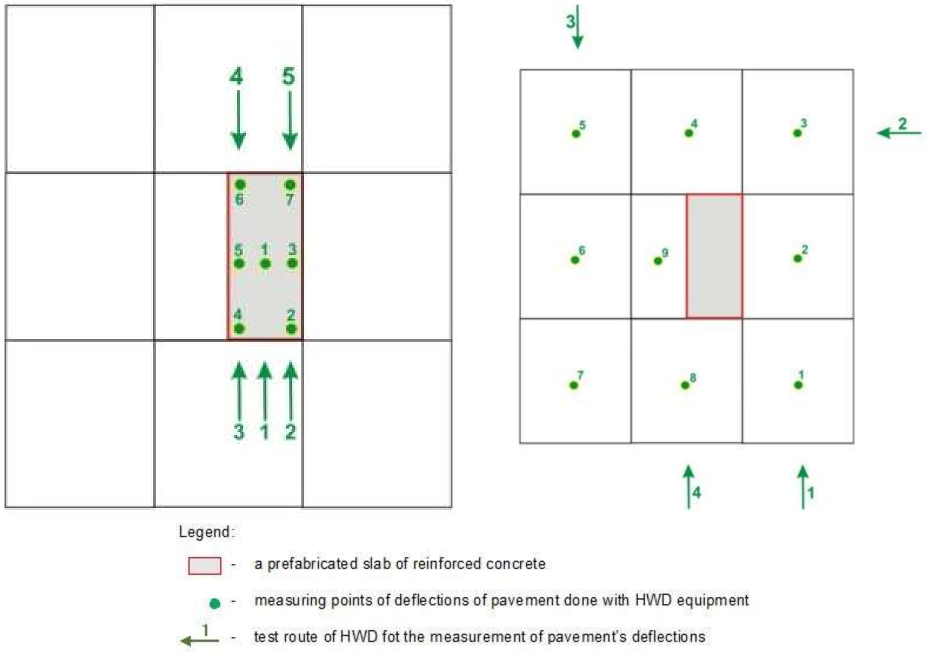
During tests, the airdrops were carried with the force of 200 kN (simulation of pressure of the wheel of a heavy aircraft) on the movable slab with the diameter of 450 mm installed on the airfield pavement. During field measurements, elastic deformations were measured in seven measuring points on the prefabricated slab under test (centre of slab, corner and slab edges) and in the middle of concrete slabs adjacent to the prefabricated slab under test. Diagram of measurement of elastic deformations with the use of the Heavy Weight Deflectometer (HWD) was illustrated in fig. 2.



2. Diagram of measurement of elastic deformations using HWD

- The evaluated airfield pavement was structured in the following way:
- concrete slab – cement concrete B-35 with the thickness of 21 cm,
- sliding layer – sand asphalt with the thickness of 2 cm,
- top subbase – cement concrete B-15 with the thickness of 20 cm,
- bottom subbase – lean concrete B-7,5 with the thickness of 15 cm,
- filtering layer – sand subcrust with the thickness of 15 cm,
- subgrade.

Detailed plans of test scope with the distribution of measuring points were demonstrated in fig. 3.



3. Measurement plan of deflections on the evaluated slab of reinforced concrete and adjacent slabs

The obtained measurement results of elastic deformations of concrete slabs in the specified test area were presented in tables 3 and 4. Substitute modules were calculated according to the following formula:

$$\boldsymbol{E_Z = \frac{2qr}{d}} \tag{5}$$

where:

- E_z – substitute module of structure [MPa],
- q – pressure under movable slab [kPa],
- r – radius of the movable slab,
- d – deflection in slab's axis.

Tab. 3. Test results of prefabricated slab of reinforced concrete

Measuring point	Stress under slab [kPa]	Force of airdrop [kN]	Deflection [μm]	Substitute module [MPa]
1	1254,00	199,41	346,20	1630,0
2	1302,00	207,04	334,20	1753,1
3	1241,00	197,42	394,90	1414,2
4	1436,00	228,31	338,40	1909,6
5	1238,00	196,90	377,80	1474,6
6	1245,00	197,93	326,30	1717,0
7	1285,00	204,37	322,10	1795,2
Average value			348,60	1670,5

Tab. 4. Test results of adjacent concrete slabs from the whole test area

Measuring point	Stress under slab [kPa]	Force of airdrop [kN]	Deflection [μm]	Substitute module [MPa]
1	1252,00	199,17	439,10	1283,1
2	1228,00	195,27	471,00	1173,2
3	1244,00	197,85	442,20	1265,9
4	1275,00	202,70	358,60	1600,0
5	1278,00	203,23	335,70	1713,1
6	1251,00	198,93	340,80	1651,8
7	1255,00	199,57	382,20	1477,6
8	1234,00	196,26	463,20	1198,8
9	1247,00	198,37	440,30	1274,5
Average value			408,10	1404,2

The above-mentioned results confirm that the tested prefabricated slab is distinguished by higher load-bearing capacity in comparison to adjacent airfield pavements. The average value of deflections on the analysed prefabricated slab (348,6 μm) is by **15%** lower from the average values of deflections measured on adjacent slabs. However, the value of the measured substitute module of pavement's structure with prefabricated slab (1670,5 MPa) is by **19%** higher from the substitute module for adjacent slabs. Thus, it can be concluded that the applied overhaul with the use of the prefabricated slab of reinforced concrete contributed to the improvement of the load-bearing capacity of airfield pavements under test. The prefabricated slab built in the airfield's apron at Kraków-Balice airport is depicted in the following image (fig. 4).

4. Prefabricated slab on the apron's airfield pavement at Kraków-Balice airport

Load – bearing capacity of airfield pavement of a runway

Field tests consisting of the estimation and analysis of the condition of load-bearing capacity of prefabricated slabs installed in the airfield pavement of the runway at airport Kraków-Balice were made in accordance with the methodology contained in item 4.3.1. Tests were performed during the last 3 years on the basis of recorded measurement results of elastic deformations of pavements under stress load.

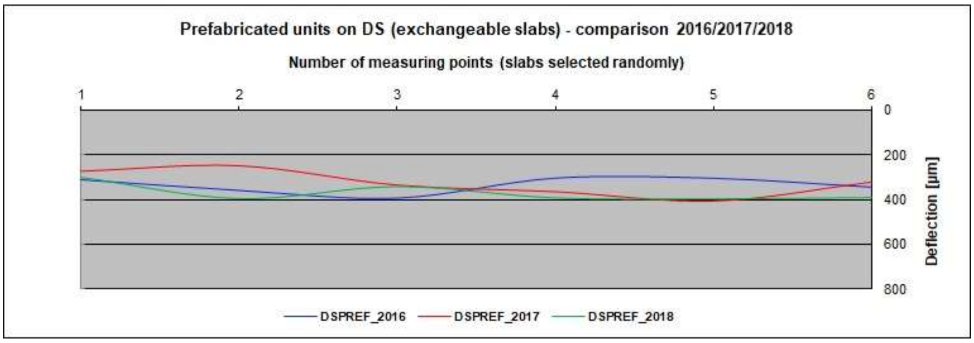
The evaluated structure of airfield pavement made of prefabricated slabs is structured in the following way:

- concrete slab – prefabricated slab C35/45 with the thickness of 21 cm,
- smoothing layer – asphalt concrete with the thickness of 10 cm,
- substructure – cement concrete B-15 with the thickness of 21 cm,
- soil stabilization layer with cement with the thickness of 15 cm,
- subgrade.

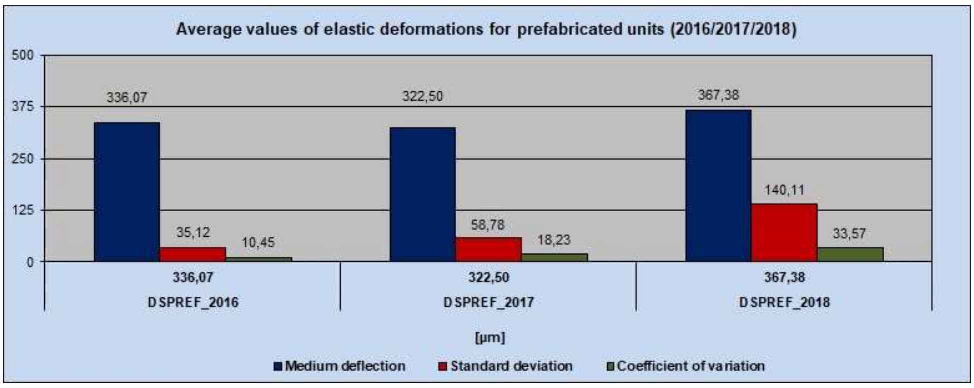
The obtained results of measurements of deflections for randomly selected prefabricated slabs were presented in table 5 in fig 5.

Tab. 5. Results of deflections for prefabricated units – comparison of tests from 2016, 2017, 2018

Slab	2016	2017	2018
1	311,60	270,30	300,80
2	358,40	245,10	392,30
3	391,80	332,80	340,50
4	304,90	362,90	389,50
5	305,60	405,00	393,70
6	344,10	318,90	387,50



5. The waveform of elastic deflections for prefabricated units – comparison of tests from 2016, 2017, 2018



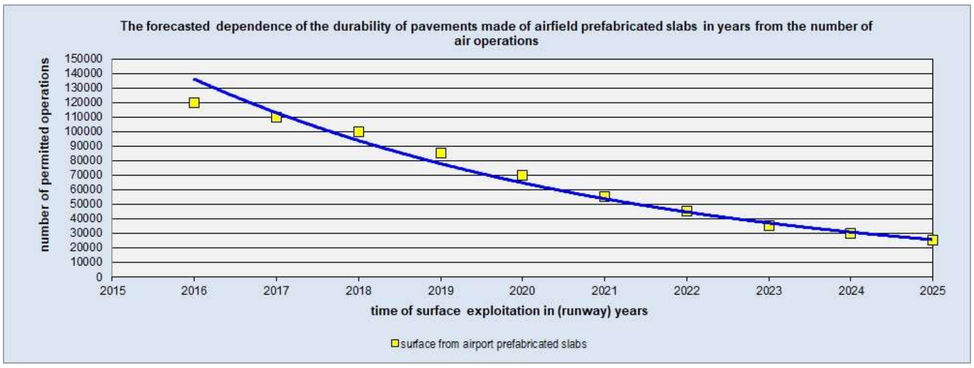
6. Average values of elastic deformations for prefabricated units – comparison of tests from 2016, 2017, 2018

Fig. 6. presents graphically the comparison of the average values of elastic deformations defined in 2016, 2017, 2018 for prefabricated units.

Based on the measured values of elastic deflections, for the examined prefabricated airfield pavements, a deflection bowl was determined and then, stresses in the airfield pavement. The defined current index of load-bearing capacity (PCN) on this basis and the acceptable, total number of air operations for the adopted computational aircraft Boeing 737-800 was presented in table 6 below. However, in fig. 7 were illustrated the results of load-bearing capacity from performed field tests in 2016–2018 as well as the estimated forecast of the dependence of durability of prefabricated airfield slabs from the time of their operation.

Tab. 6. Results of load-bearing capacity for index PCN 52 – airfield prefabricated slabs

Airfield functional constituent	**Index of load-bearing capacity (PCN)**	**Total number of air operations**		
		2016	**2017**	**2018**
DS (airifeld prefabricated slabs)	52/R/B/W/T	120 000	110 000	100 000



7. The forecasted dependence of the durability of pavements made of airfield prefabricated slabs in years from the number of air operations

Based on conducted tests of load-bearing capacity it can be estimated that the technology of the replacement of slabs with the application of prefabricated elements ensures the reproduction of the load-bearing capacity of concrete slabs and their maintenance on the level guaranteeing safety of air operations. This technology substiantially affects the improvement of the load-beating capacity of the pavement structure of the runway [10].

Summary

In the Polish climatic conditions, the airfield pavements made of cement concrete are best suited due to the fact that they are distinguished with a high frost resistance, resistance to the activity of anti-frost agents applied in the winter season, high compression and deflection strength as well as high adhesion of wheels of aircraft to the pavement.

Intensive and very long operation period of airfield pavements, sometimes longer than the expected application period, forced to search for new, efficient and fast reconstruction technologies of deteriorated airfield pavements. The reconstruction of the load-bearing capacity of single, deteriorated concrete slabs using prefabricated slabs was subject to precise control in laboratory and field tests. The described technology ensures fast and efficient reconstruction of the load-bearing capacity of deteriorated concrete airfield pavements. Thus, the performance of air operations is safe. The particular advantage of the technology in question is a very short execution time, which does not exceed 4–5 hours and depends on breaks in air traffic between performed air operations.

Source materials

[1] Barszcz P., Blacha K., Wesołowski M., Zieja M.: *The evaluation method of degradation degree of runway pavement surfaces constructed from cement concrete.* Safety and Reliability – Theory and Applications, Čepin, Briš (eds). Taylor & Francis Group, London 2017.

[2] NO-17-A204:2015 Nawierzchnie lotniskowe. Nawierzchnie z betonu cementowego. Wymagania i metody badań.

[3] PN-EN 1542:2000 Wyroby i systemy do ochrony i napraw konstrukcji betonowych. Metody badań. Pomiar przyczepności przez odrywanie.

[4] NO-17-A501:2015 Nawierzchnie lotniskowe. Badanie szorstkości.

[5] NO-17-A502:2015 Nawierzchnie lotniskowe. Badanie równości.

[6] NO-17-A500:2016 Nawierzchnie lotniskowe i drogowe. Badania nośności.

[7] PN-EN 12390-3 Badania betonu – Część 3: Wytrzymałość na ściskanie próbek do badania.

[8] PN-88/B-06250 Beton zwykły.

[9] Wesołowski M., Poświata A., Jakubek M.: *Szybkie technologie odtwarzania stanu technicznego uszkodzonych nawierzchni lotniskowych z betonu cementowego*, IX Konferencja Dni Betonu, Wisła 2016.

[10] Wesołowski M., Świerzewski B., Kowalewska A., Jakubek M.: *Lotniskowa płyta prefabrykowana – skuteczna technologia odtworzenia stanu nośności zdegradowanych nawierzchni lotniskowych z betonu cementowego*. X Konferencja Dni Betonu, Wisła 2018.