Reconstruction of the Technical Condition of Concrete Airfield Pavements with the Use of Prefabricated Slab Technology

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Abstract. The rapidly growing civil aviation industry is primarily an increase in the number of air operations, both in passenger and cargo traffic. This leads to an increase in the impact of aircraft on airfield pavement structures and, consequently, to an intensive operation process. Concrete airfield pavements occurring at airports in Poland, but also around the world, cover a wide spectrum, starting from newly built surfaces, used ones as well as those that are subject to renovation. Particular attention should be paid to pavements in the process of operation and pavements which age exceeds the designed useful life and which are already subject to renovation works. Basic types of failures can be identified on concrete airfield pavements including surface failures (e.g. spalling, cracks), local failures (e.g. pop-outs, corner cracks), linear failures (e.g. meander cracks, decrements of the pourable sealing compound in expansion gaps). Currently, where in many cases there is an urgent need to repair damaged pavement, companies and organizations responsible for road/airport construction are looking for new and innovative technologies, including prefabricated concrete pavement technologies, which can ensure effective repairs in a very short time, without closing the given lane or the entire airport. 

Due to the fact that the age of currently used airfield concrete pavements in Poland often exceeds 30 years, it became necessary to search for effective and fast technologies to improve their technical condition. This article summarizes the current state of knowledge in the field of existing prefabricated concrete technologies used at airports in Poland and worldwide. In addition, an innovative technology of using a prefabricated concrete slab has been described, intended for reconstruction of damaged, local airfield pavements in Poland, which were qualified for renovation due to the direct threat to the safety of aircraft operations. The technology guarantees the reconstruction and even improvement of the load capacity of the replaced airfield panels, which was confirmed during laboratory and field tests and verified practically in the process of real operation by air traffic. In addition, the concept of further research on the development of this technology based on cooperation with neighbouring panels using dowel joints will be presented.

1. Introduction

The safety of aircraft operations depends on the technical and operational condition of airport pavements made of cement concrete. Cement concrete intended for the running layer of an airport pavement must meet a number of requirements and be characterized by high bending strength, which depends on the...
numerical size of the PCN load-bearing capacity index, an appropriate level of equality and friction coefficient, limited absorbability, high frost resistance and resistance to the effects of de-icing agents used in winter maintenance period.

Concrete airport pavements exploited both in Poland and in the world include newly built, used surfaces as well as those which are or will be subject to renovation. The exploited surfaces and those that exceed the designed age of use require special attention, because they can identify the basic damages characteristic of concrete airport pavements. The 13 most characteristic types of damage were defined, including: surface damage (e.g. peeling, hairline cracks), point damage (e.g. chipping, corner fractures), linear damage (e.g. crevice cracks, sealing pot loss in expansion joints). Such a range of damage to concrete airport pavements requires having effective and proven technologies for the rapid reconstruction of airport panels in operation [1].

Prefabricated concrete pavement technologies have not been subject to thorough analysis and testing, especially when used at airports. At first, this technology was of technical curiosity, that is to say, whether the precast concrete technology is technically feasible. No serious attempts have been made to fully develop the technology as a cost-effective strategy and implement it into regular production and use. Currently, where in many cases there is an urgent need to repair the damaged surface of the company and organizations responsible for road/airport construction are looking for new and innovative technologies, including prefabricated concrete pavement technologies that can ensure effective repairs in a very short time. Most importantly, this methodology allows carrying out repair work without the need to close a given lane or the entire airport, and this in turn is a very important economic factor considering the volume of civil air traffic.

In recent years, significant development has resulted in the development of precast concrete technologies, and the use of these technologies has become technically feasible and economically justified. The next chapter summarizes the current state of the precast concrete technology used at airports in Poland and worldwide and provides a framework for further consideration of the topic of precast concrete slab.

2. Review of existing solutions for the use of prefabricated slabs at airports in Poland and in the world

2.1. USA, applied technologies

The area of interest in prefabrication in the USA has been broadly included in the Strategic Highway Research Program 2 (SHRP2), which emphasized the need for rapid completion of pavement renovation projects, mainly road surfaces, with minimal inconvenience to users. The aim of the project was to introduce and then apply new methods and materials for repairs and reconstruction of roads and airports as part of the PCP (Precast Concrete Pavement) technology [2].

As part of the project, the project team reviewed the state of PCP practice, identified gaps in the technology used, and evaluated the performance of completed projects. A review of USA projects and numerous SHRP2 field tests have shown that sufficient progress has been made in the reliable design and construction of PCP systems to achieve five key attributes for the surface, i.e.:

- construction – techniques and equipment are available to ensure acceptable production efficiency for PCP systems;
- concrete durability – the production of prefabricated slabs ensures excellent strength and durability of concrete;
- load transfer in connections – reliable and economical techniques are available to ensure effective load transfer in PCP connections;
- performance – the boards can be thinner than the standard cast concrete on site and withstand a longer service life due to the prestressing and/or reinforcing elements in the PCP system.

The application of the prefabricated concrete pavement technology, in accordance with the practice used in the USA, can be divided into the following categories:
a) Intermittent repairs of concrete pavements – the use of this type of technology is aimed at performing individual, local repairs using prefabricated concrete slabs. There are 2 types of repair work possible [3]:
  - repairs at full depth – damaged plate joints, corner cracks or adjacent cracks;
  - full plate replacement – to replace cracked or degraded plates.

b) Continuous application – according to this methodology, repairs involving the replacement of the entire concrete or asphalt pavement are subject to repairs, depending on the level of damage and the client's requirements. This prefabricated technology is perfectly suited for the continuous laying of subsequent parts of damaged pavements.

In 2000, the management of New York and New Jersey Airport examined the use of a prefabricated concrete slab to repair the taxiway at Guardia International in New York. Two test sections with a length of 61 m were carried out. On one test section, reinforced concrete panels 3.8 x 7.6 m in size and 400 mm thick were used. The next section is panels with identical dimensions, but 300 mm thick. A unique feature of the system was the use of special screws that were designed to properly position the board in terms of height. A gap under the boards of 13 to 25 mm was used, which was then flooded with a special cement mortar. In addition, the prefabricated panels had designed pockets for the use of dowels (figure 1) [4].

![Figure 1. View of the prefabricated panel used at Guardia International airport in New York [4].](image)

The technology of prefabricated concrete pavements has improved significantly over the last decade. Several prefabricated concrete pavement systems have been developed, including the Fort Miller Super-Slab System, Kwik Slab System, Michigan System or the above-mentioned La Guardia International Airport System, which are implemented in USA production projects. Field experience and load tests indicate that prefabricated systems are real alternatives to the rapid repair and reconstruction of existing surfaces [16].

2.2. Japan
Prefabricated panel technology has been used at airports in Japan since the early 1970s. The first projects were based on installing reinforced boards on previously prepared stable ground. The standard dimensions of panels used at airports are 2.5 m wide and 14 m long. The thickness of the panels, depending on the application, was from 200 to 250 mm. Most often, the slabs were placed on the asphalt layer so as to prevent liquid and other materials from getting under the slab, e.g. on granular material.

The use of prefabricated elements in Japan has increased with the development of a new load technology called "horn device". The plates in this technology were connected by a special compression
link attached at the end of the plates, which was tensioned to a certain force. This method allowed for better load transfer between panels and for faster replacement of damaged panels [3].

2.3. Russia
In the 1960s, as one of the first in the world, the Soviet Union began to use the technology of reinforced prefabricated slabs mainly on roads in the north of the country and where access was difficult and economically attractive (oil fields, industrial and agricultural facilities). Very often the plates were covered with asphalt so as to compensate for differences in height between individual plates.

The technology used in Russia, despite its conceptual simplicity, has been improved a few additional options, such as electrothermal compression, the use of thinner panels and a unique way of joining panels. Technology has been standardized throughout the country. The standard panel had dimensions of 2 x 6 m or 2 x 4 m. The panels were 160, 180, 200 or 220 mm thick. The concrete slab was pre-compressed by stretching the longitudinal rods in an electrothermal process.

The system's unique concept was to use special clamps installed along the long edge of the board. These clamps were welded together, and the high quality of the weld used was a prerequisite for using the method. If the distance between adjacent staples was 4 mm or less, the staples were welded together. However, if the spacing was greater than 4 mm, a special rod was used whose diameter was three to four times larger than the gap between the clamps. Then two welds were made to connect the clamps (figure 2) [16].

![Figure 2. View of prefabricated panels used in the Soviet Union (airport panels on the left, clamps connection technique on the right).](image)

2.4. Poland

2.4.1. Airport pavements made of prestressed plates
The origin of the construction of prefabricated airport panels in Poland refers to the 1970s, when airport pavements were built from pre-prestressed panels in domestic conditions at military facilities [12]. Articulated pavement made of prefabricated pre-prestressed slabs (LWS) is a pavement made of individual plates, joined together by welding steel clamps. LWS panels had dimensions: length 6.0 m, width 2.0 m and thickness 140 mm. The steel clamps were a specific connecting element that was placed in properly formed nests of slabs before concreting. The clamps were placed in pairs on the front and side surfaces of the plate, creating characteristic linear hinges that ensured sufficient cooperation between the plates. Plates forming the airport pavement were laid on a properly prepared surface. The design solution for an airport pre-prestressed plate is shown in figure 3 [5].
The basic class of concrete used for the production of LWS slabs was B-40 class concrete, which was characterized by:

- the ability to transfer high compressive loads throughout the entire cross-section of the plate;
- the ability to transmit high tensile stresses due to base load from the aircraft;
- resistance to delamination.

The high class of B-40 concrete guaranteed the transmission of high prestressing loads and had direct benefits in the form of reducing the concrete cross-section in the pavement and thus the weight of the entire structure. For the reinforcement of airport pre-stressed plates, steel with various properties and purposes was used, i.e.: prestressing reinforcement, non-stressing reinforcement and auxiliary reinforcement.

One of the advantages of airport pavements made of pre-stressed panels was the ability to build the pavement regardless of the season and weather conditions. The full adhesion of the panels to the ground, which was checked by a random method, was of fundamental importance for the quality of the pavement made of LWS boards. Another important element of quality control was checking the welded joints, which determined the effectiveness of joints between individual plates.

### 2.4.2. OAT surface prefabricated panels

The technology used by OAT aims to replace degraded concrete surface slabs and replace them with new ones from prefabricated elements. Depending on the panel dimensions, its thickness, length and width, an individual design of the OAT prefabricated surfacing board is made, which is then produced at the prefabrication plant [6].

By default, instead of the old concrete slab with 5.0 x 5.0 m plan, two prefabricated elements with 2.49 x 5.0 plan and 0.25 m thickness are used [13]. The prefabricated surface slab is manufactured in the prefabrication plant according to individual orders. The plate is reinforced and equipped with elements enabling its transport (transport anchors) and subsequent adjustment (mounting anchors). Concrete with a class of min. C40 / 50 and the agreed composition, which ensures the required strength parameters, adequate frost resistance and resistance to de-icing agents. The plate is placed on new or existing ground, where it may be necessary to use an leveling layer, e.g. low-shrink mortar. After mounting the plate, it is necessary to inject through special injection holes. This is to fully support the board (between its bottom and foundation) over its entire surface. For this purpose, injection with the use of, for example, silicate resins is used, which allows for a very fast introduction of movement.

Installation of OAT prefabricated panels on a properly prepared (figure 4) base includes:

- delivery of prefabricated elements on low-loader vehicles;
- drilling holes in the existing surface for dowels and anchors for gluing them.
Figure 4. View of drilling holes for dowels and anchors in the existing surface (left) and installing a prefabricated panel with specially prepared "pockets" (right).

Then the prefabricated slab is applied to the dowels and anchors protruding from the existing surface which have special "pockets". After laying the slab on the ground, leveling is carried out and correct positioning in relation to the adjacent panels while maintaining appropriate longitudinal and transverse slopes. After height adjustment of the prefabricated slab, injection is made through specially prepared injection holes equipped with applicators, through which the resin is pressed under the slab at 5 bar pressure (for stabilization). In order to avoid excessive lifting of the plate, laser leveling indicators or a measuring staff are used. When excess resin appears in adjacent holes or in an expansion gap, the injection should be stopped because it means that the space under the slab is evenly filled.

3. Damage to concrete airport pavements

The technical condition of airport pavements is subject to periodic inspections, the so-called inventory of damage, which is related to the destructive processes occurring in concrete and concrete damage that occurs in connection with them. Damaged plates pose a threat to the safety of moving aircraft. Review of damage to airport pavements is carried out directly at the facility, where damage status is recorded on an ongoing basis for each functional element of the airport and individual boards [11]. Usually, a visual method is used and each panel at the airport is inventoried, measuring (usually) 5 x 5 m. Both existing and repaired damages are inventoried. This "double" inventory system allows you to determine the amount of damage at the airport and allows you to determine the overall degradation rate of the object. To assess the technical condition of airport pavements, the damage was divided into three groups: surface failures (e.g. spalling, cracks), local failures (e.g. pop-outs, corner cracks), linear failures (e.g. meander cracks, decrements of the pourable sealing compound in expansion gaps) [1].

4. Innovative technology of using airport prefabricated slab in Poland

The technology of Prefabricated Airport Slabs (PAS) involves the reconstruction of very degraded concrete slabs and bringing them to such a technical condition that will not threaten the safety of aircraft during flight operations.

4.1. Description of the technology

The technology of replacing damaged airport panels with the use of prefabricated airport slabs includes the foundation of the panel on a properly prepared foundation of the airport pavement. The prefabricated panel should be placed on a properly prepared sub-base of non-shrink mortar [7]. The thickness of the mortar layer should be selected so that the elevations of the placed slab match those of the adjacent slabs. If the panel surface protrudes above the existing surface, the upper surface should be milled for max. thickness equal to 20 mm. Then, the milled surface of the plate should be covered with protective measures that will protect the disturbed structure of the plate in the surface layer. The milled and surface protected prefabricated slab must meet the roughness requirements for airport pavements.
The prefabricated reinforced concrete slab has the dimensions: 2.50 x 5.00 m and a thickness of 0.21 m. It is made of C35/45 class concrete and in its cross-section has the following main reinforcement from A-III steel:

- upper reinforcement in the form of ribbed bars of ø 14 mm with a spacing of 30 x 30 cm;
- lower reinforcement in the form of ribbed bars ø 14 or 16 mm with a spacing of 15 x 15 cm. The view of PAS assembly is shown in figure 5.

**Figure 5.** Installation of an prefabricated airport slabs at an airport.

4.2. Laboratory tests
The scope of laboratory tests included tests on concrete compressive strength, carried out in accordance with PN-EN 12390-3 Concrete tests - Part 3: "Compressive strength of test samples" [8], testing of concrete weight absorbability and testing of concrete resistance to frost, made in accordance with PN-88 / B-06250 "Normal concrete" [9], points 6.4 and 6.5. The results of the laboratory tests are presented in the following sections.

4.2.1. Compressive strength
The concrete compressive strength tests (destructive test) were carried out on 12 samples (cubes) of 15×15×15 cm and an average compressive strength value of 50.2 MPa was obtained. The obtained results confirmed that the cement concrete from which the prefabricated slab was made met the requirements for concrete class C35/45.

4.2.2. Absorbability
Concrete weight absorbability tests were carried out on six 15×15×15 cm cubic samples. The results obtained are summarized in table 1. Based on the results obtained, it can be concluded that the cement concrete tested met the requirements of the above standards, because its absorbability did not exceed the permissible value of 5%.

**Table 1.** Concrete absorbability test results.

| Sample nr | Sample mass [g] | absorbability [%] |
|-----------|-----------------|------------------|
|           | saturated       | dry              |
| 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 |
4.2.3. Frost resistance of concrete
Tests of concrete resistance to frost were carried out on 12 cubic samples with dimensions of 15×15×15 cm. The number of freezing-thawing cycles was 150. The results are summarized in table 2. Based on the results obtained, it can be concluded that the tested cement concrete met the requirements for frost resistance grade F150, because the weight loss of the samples after the test is less than 5%, and the average decrease in compressive strength did not exceed 20%.

Table 2. Results of concrete frost resistance tests.

| Sample nr | Sample mass [g] | loss of weight $\Delta G$ [%] | strength $R_i$ [MPa] | decrease in strength $\Delta R_i$ [%] |
|-----------|----------------|------------------------------|----------------------|---------------------------------------|
|           | before the test| after the test               |                      |                                       |
| 1         | 7940           | 7925                         | 0.22                 | 51.9                                  |
| 2         | 7815           | 7795                         |                      | 46.4                                  |
| 3         | 7860           | 7840                         |                      | 49.2                                  |
| 4         | 7800           | 7775                         |                      | 45.8                                  |
| 5         | 7930           | 7915                         |                      | 52.1                                  |
| 6         | 7925           | 7915                         |                      | 52.0                                  |
| 7         |                |                              |                      | 55.7                                  |
| 8         |                |                              |                      | 60.1                                  |
| 9         |                |                              |                      | 56.2                                  |
| 10        |                |                              |                      | 61.4                                  |
| 11        |                |                              |                      | 58.1                                  |
| 12        |                |                              |                      | 59.7                                  |

4.3. Field tests
The scope of field tests included assessment and analysis of the load-bearing capacity of prefabricated airport slabs built into the airport pavement of one of the runways in Poland, which was carried out over a period of 4 years. The tests were carried out on the basis of recorded results of measurements of elastic deflections of the pavement under impact load. Pavement tests were carried out with an airport weight meter HWD (Heavy Weight Deflectometer) in accordance with the requirements of the defense standard NO-17-A500: 2016 [10].

During the tests, discharges were made with a force of about 200 kN (simulation of pressure of a heavy-type aircraft wheel) on a pressure plate with a diameter of 450 mm resting on the airport pavement. The results were recorded in a computer with simultaneous display of deflection and stress over time on the monitor screen [1]. The assessed structure of the airport pavement made of prefabricated panels had the following structural system:
- running layer – prefabricated concrete slab of C35/45 class with a thickness of 21 cm;
- leveling/smoothing layer – asphalt concrete 10 cm thick;
- substructure – cement concrete B-15 class 21 cm thick;
- soil stabilization layer with 15 cm thick cement;
- subgrade.

The results obtained during the measurements of deflections for prefabricated panels selected at random are presented in table 3 and figure 6.
Table 3. Results of elastic deflections for PAS* - comparison 2016, 2017, 2018 and 2019.

| PAS | 2016 | 2017 | 2018 | 2019 |
|-----|------|------|------|------|
| 1   | 311.60 | 270.30 | 300.80 | 256.30 |
| 2   | 358.40 | 245.10 | 392.30 | 382.30 |
| 3   | 391.80 | 332.80 | 340.50 | 385.00 |
| 4   | 304.90 | 362.90 | 389.50 | 290.10 |
| 5   | 305.60 | 405.00 | 393.70 | 279.90 |
| 6   | 344.10 | 318.90 | 387.50 | 278.10 |

*PAS – Prefabricated Airport Slabs.

Figure 6. The course of elastic deflections for PAS - comparison for 2016-2019.

Figure 7 presents a graphic comparison of the average values of elastic deflections determined in 2016, 2017, 2018 and 2019 for prefabricated airport slabs.

Figure 7. Comparison of average elastic deflection values for PAS - comparison for 2016-2019.

4.4. Load-bearing capacity analysis and calculation of the PCN index

The PCN classification number expresses the load-bearing capacity of the airport pavement [14]. It is equivalent to 1/500 of the permissible load (expressed in kg of mass) applied to the pavement by means of a single wheel with a standard pressure of 1.25 MPa. In the ACN-PCN method, the load-bearing capacity of the pavement is described by a group of symbols describing individual construction
parameters and informing about the method for determining the number of PCN (e.g. \( \text{PCN} = 23/F/C/ \ Y/U \)). The interpretation method of the record is presented in table 4 [15].

**Table 4.** Interpretation of symbols describing pavement construction parameters.

|   | The dimensionless number of PCN |
|---|---------------------------------|
| 2 | Surface type                    |
|   | R      | Rigid                        |
|   | F      | Flexible                     |
| 3 | Soil category (for rigid surfaces - \( k \), for flexible surfaces - \( \text{CBR} \)) |
|   | A      | High strength \( k > 120 \text{ MN/m}^3 \) \( \text{CBR} > 13 \) |
|   | B      | Medium strength \( 60 – 120 \text{ MN/m}^3 \) \( 8 - 13 \) |
|   | C      | Low strength \( 25 – 60 \text{ MN/m}^3 \) \( 4 - 8 \) |
|   | D      | Ultra Low strength \( k < 25 \text{ MN/m}^3 \) \( \text{CBR} < 4 \) |
| 4 | Permissible tire pressure       |
|   | W      | Unlimited                    |
|   | X      | High maximum tyre pressure of 1.5 MPa |
|   | Y      | Medium maximum tyre pressure of 1.0 MPa |
|   | Z      | Low maximum tyre pressure of 0.5 MPa |
| 5 | Assessment method               |
|   | T      | Indicates technical evaluation |
|   | U      | Indicates usage – a physical testing regime |

Based on the measured values of elastic deflections, the deflection bowl and then stress in the airport pavement were determined for the tested prefabricated airport slabs. The current PCN load index and the allowable total number of flight operations for the adopted Boeing 737-800 computing aircraft are presented below in table 5.

**Table 5.** Load-bearing results for the PCN 52 indicator - prefabricated airport slabs.

| Airport Functional Element | PCN load index | Total number of air operations |
|----------------------------|----------------|--------------------------------|
|                            | 2016           | 2017     | 2018     | 2019     |
| RWY - PAS                  | 52/R/B/W/T     | 120 000  | 110 000  | 100 000  | 135 000  |

Based on the load capacity tests carried out, it can be concluded that the technology used to replace the plates using prefabricated elements ensures restoration of the load capacity of concrete slabs and its maintenance at a level that ensures the safety of flight operations. It should be noted that the tests were performed for different/randomly selected runway airport panels. Considering that the number of replaced runway plates is constantly increasing, which increases the pavement's load-bearing capacity, therefore the total number of permissible air operations in 2019 also increased compared to 2018. The technology significantly improves the load capacity of the runway pavement structure.

5. **Summary and determination of directions for further research**

Recent passenger statistics show that air transport is one of the most dynamically developing types of transport in Poland and in the world. This, in turn, results in increased aircraft impact on airport pavements.

Cement concrete pavements are the basic type of airport pavements that work very well in Polish climate conditions. They have high frost resistance, resistance to de-icing agents used in winter, high compressive and bending strength, as well as good adhesion of aircraft wheels to the surface [1]. A properly designed and, above all, properly made airport pavement made of cement concrete is characterized by a much longer durability, which is currently assessed for more than 30 years. Currently, concrete pavements are exploited, whose age significantly exceeds the abovementioned life. It should
be noted, however, that these surfaces already have typical signs of damage that are characteristic of concrete surfaces.

The intensive, complex and very long service life of concrete pavements, which are subjected to loads of modern aircraft, has forced the search for effective technologies for the rapid reconstruction of damaged airport panels. Restoration of the load-bearing capacity of individual, degraded concrete slabs using prefabricated airport slab technology has been thoroughly tested in laboratory and field conditions. In addition, the technology presented in the article was practically verified by a four-year process of intensive use of air traffic on the runway one of the airports in Poland. The technology provides fast and effective restoration of the load capacity of degraded concrete airport pavements. Thus, it allows aircraft to safely perform air operations. The special advantage of the discussed technology is the very short practical application time, which does not exceed 4-5 hours and depends on the interruptions in air traffic between implemented air operations.

In order to increase the stability of the airport pavements and to introduce cooperation between adjacent airport panels, and thus to increase its operational capabilities, further research is conducted consisting in modification of the above-mentioned method. The subject of the study is the dowel design for prefabricated airport panels that will be loaded with the main, forward gear of the sample Boeing 737-800 aircraft. The design of the new solution is shown below in figure 8.

![Figure 8. Design of a new PAS using a dowel connection.](image)

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