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EVALUATION OF THE CEMENT CONCRETE AIRFIELD PAVEMENT'S TECHNICAL CONDITION BASED ON THE APCI INDEX

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One of the factors that affects the safety of flight operations is to maintain the airport infrastructure in an appropriate condition, due to importance of proper infrastructure management, including funds and human resources management in particular. Currently applicable methods for determination of surface condition are mainly based on visual assessment of surface deterioration. An innovative approach to assessing the cement concrete airport pavement's technical condition based on the APCI (Airfield Pavement Condition Index) is presented in the article. The method of APCI index determination is based not only on the visual assessment of the airfield pavement's surface condition and the calculation of its deterioration, but also includes parameter of load capacity, evenness, roughness and tensile strength of the surface layer. The presented method can be used as a tool for forecasting the technical condition of cement concrete airfield pavements in the context of planning funds for future maintenance purposes. The impact of considering individual model parameters on the value of APCI index, basing on the results of field tests carried out as part of military airports inspections was presented.

Keywords: PCI, deterioration, maintenance, technical condition, airfield pavement, APCI

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1. INTRODUCTION

Both passenger and freight air transport is dynamically developing. Every year, more and more new air connections are made. This is due to the emergence of the low-cost carriers and the constant development of the air connections network [10]. The development of air transport, as well as the related development of airport infrastructure, generates the need for proper quality management. Effective infrastructure management allows rational use of human resources, equipment and economical use of financial resources. This management should be based on verified and reliable information about the current and anticipated airfield's technical condition.

The basic document for majority of air traffic services is the Airport Services Manual [6], Part 2 which describes how to deal with airport pavements. Much more documents were created for public roads, for example [5, 19]. It is also appropriate to control the introduced quality system through audits such as [9]. Surfaces, whether road, airport or parking lots should not only be maintained, but managed as well. Most costs can be avoided by diagnosing the problem, before the surface is significantly deteriorated.

The most common method of airport pavements assessment nowadays is based on the Pavement Condition Index (PCI). There have been numerous modifications to the cited method. The most popular are the PAVER procedure described in [8, 7], or the method used by the Virginia Department of Transportation [12, 13]. Some procedures, apart from visual inventory of surface deteriorations, use other pavement parameters to determine the PCI index. In [1] is presented a method that takes into account the International Roughness Index (IRI) parameter. A more advanced model for determining the PCI index is presented in [4], where individual deterioration types are included in the model with appropriate weight factors. A similar approach is presented in [23] and [25], where authors consider inventoried deteriorations in the pavement degradation model depending on their harmfulness.

The authors suggest a method of assessing pavement condition based on the APCI (Airfield Pavement Condition Index. This type of approach gives a real and broader picture of the actual airport pavement's condition. The main goal of the ongoing work is to develop a methodology for assessing the condition of airport pavements that provides airport services with a reliable and practical tool that will support the process of airport's functional elements management in a sustainable manner.

2. Standard PCI method

U. S. Army Corps of Engineers have developed a method of pavement condition assessment based on the PCI indicator. At the moment, this method is commonly used all over the world by engineers, government institutions and organizations associated with the inspection of airport pavements. In its practice. It was described in detail in the book [20] dealing with the pavements management not only for airports, but also for roads and parking lots. American standards [2, 3] were also created, in which the procedure for determining PCI for airport and road surfaces was systematized.

The PCI indicator can be defined as a dimensionless number between 0 and 100, where the specific value corresponds to the current surface condition in the range from FAILED (0 - unusable surface) to GOOD (100 - new surface). The PCI index is determined based on the pavement's visual inspection, as a result a database containing distress type, quantity and its severity is obtained.

The inventory of airport pavements takes place in a strictly defined manner. The inspection consists of a list of deteriorations observed on the surface of the airport functional element, divided into samples, according to the developed legend. Deterioration is written down in the table describing its type, harmfulness, quantity and approximate location divided into samples. Number of individual deteriorations, their harmfulness and density are determined for each sample. [20] describes how to determine the PCI indicator for a particular sample. The final PCI value for the entire airport functional element assessed is calculated as the arithmetic mean of PCI estimated for a particular sample. In situations where the surfaces of individual samples are not the same size, the final PCI value is the weighted average of PCI estimated for a single sample. The surface values of individual samples are taken as the weight values. Based on the PCI indicator obtained, the technical condition of the pavement is determined, which then allows effective planning of maintenance and renovation investments.

3. APCI procedure

The assessment of airport pavements should be carried out in a broader context than just its surface deteriorations. Air traffic safety is influenced by many factors, including roughness and skid resistance of the pavement [24]. Besides the above factors, the surface bond strength parameter plays an important role, in particular at facilities where jet-powered aircraft are moving. Due to the structure durability, the load bearing capacity of the layer package is also an important parameter. In addition, most of the airport pavement's repairs do not restore its initial properties in 100%. Repairs should be considered while pavement is being assessed. A comprehensive approach to airfield pavement assessment in a systemic way guarantees efficient and sustainable pavement management. To meet this goal, the authors developed a method based on the standard PCI procedure, extending the model with the parameters cited above. So the APCI pavement parameter (Airfield Pavement Condition Index) describing the technical condition of the pavement was developed.

Data obtained from various sources may not necessarily provide the same information. In particular, the deteriorations and repairs inventory results. The same area can be interpreted differently by experts. It is caused by human individualized perception, fatigue, surface lighting, time of day or even wetness of the surface. The procedure was standardized by developing a research procedure in order to ensure that the assessment of the surface condition is reliable and largely independent of the human factor.

A diagram of the procedure for assessment of airport functional element's technical condition is shown in Figure 1. The basis of methodology is the individual input parameters assessment based on tests and measurements results. When the minimum limits (in the figure parameters with k index) are not obtained for at least one parameter, the assessment is interrupted until the repair is performed. After repairing the non-compliant area, field and laboratory tests should be carried out again. After obtaining positive test results, the condition of the airport pavement is assessed on the basis of field tests and the technical condition of the airport pavement resulting from the pavement condition and laboratory tests. The subject of this work is the pavement condition assessment with the APCI method, while the assessment of technical condition will be the subject of further work.

Measurements and tests carried out in the field are input data for the process analysis, resulting in output data describing the condition of the airport pavement. The assessment procedure is illustrated in Figure 2. The individual assessment stages, i.e. collection of input data, process analysis and interpretation of output data, are presented in the following sections.

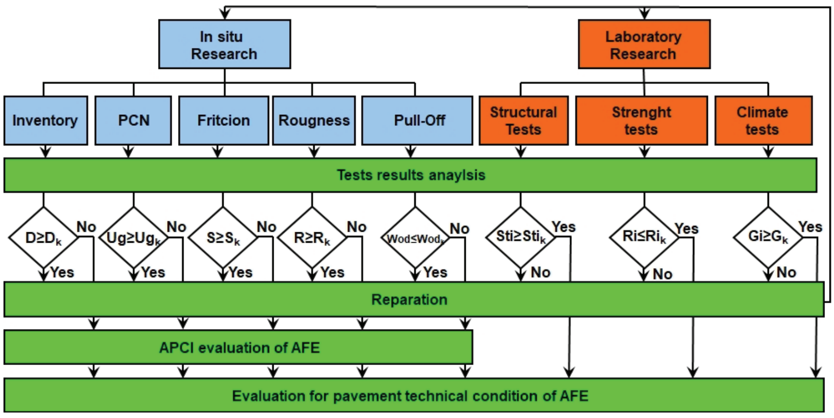

Fig. 1 Assessment of the airport pavement technical condition with the APCI method procedure (PCN – load bearing capacity as a Pavement Classification Number, AFE – Airfield Functional Element)

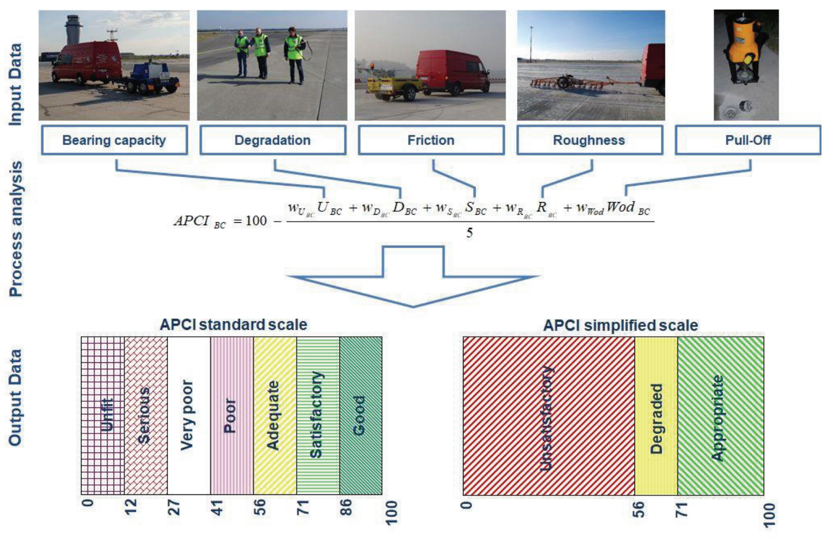

Fig. 2 Assessment of the airport functional element's surface condition with the APCI method

Assessment of pavement deterioration is performed basing on data obtained during the inspection. Experts measure the surface deteriorations and repairs, considering its' type, number and location. Each of the concrete slabs which constitutes the assessed functional element of the airport is subject. In the case of large elements (e.g. runway), the entire hectometer of the pavement, which corresponds to a fragment of a 100 m long element, can be assessed. Slab deteriorations occur in the point, line and area form. Point deteriorations include marl spalls (Op) and fractures / chipping of edges and corners (Now), and their measure is number of pieces. Linear deteriorations consist of slotted cracks (Ps), wide slotted cracks (Psszer), loss of joint sealant mass (M) and thresholds (Pr). Measurements of linear deteriorations are expressed in meters. In the event of cracks, deterioration of not less than 25 cm in length shall be measured. Area deteriorations should include shallow flaking (Ap), deep flaking (Bg), capillaries cracks (Pw), frost cracks (Pm), deep cavities (Ug) and slabs for replacement (Wp). Area deteriorations are measured in square meters. The deteriorations legend corresponds to the repair legend, in which the letter markings are identical to the deterioration.

The load bearing capacity of airport pavement is assessed using the traditional method of elastic deflections with the Heavy Weight Deflectometer (HWD) device. The test is based on the Polish defence standard [15]. The result of the pavement load capacity assessment is the commonly used Pavement Classification Number (PCN) indicator and / or the number of air operations for an aircraft with an ACN (Aircraft Classification Number) indicator.

Skid resistance are determined by airport pavement friction measurement based on the Polish defence standard [16], as well as the international normative documents, such as [6]. The tests are carried out with a device for continuous measurement of the friction coefficient mentioned in the cited documents. The test result is a dimensionless number from 0 to 1, where 0 means no friction force and 1 means friction force equal to the pressure force.

The evenness of the pavement is assessed with the measurements of the surface irregularities. It is performed in accordance with the Polish defence standard [17]. The measure of inequality is defectivity (%). This means the percentage of samples exceeding the requirements.

The strength of the concrete pavement surface layer tensile strength is checked in compliance with the [14]. As a result, a peel strength is obtained then divided by the surface of the sample, resulting in the assessed bond strength.

Pavement parameters collected during field tests are input analysis data. The developed APCI model for cement concrete pavement is shown in equation (3.1).

$$\overline{APCI_{BC}} = 100 - {(w_{U_{BC}}U_{BC} + w_{D_{BC}}D_{BC} + w_{S_{BC}}S_{BC} + w_{R_{BC}}R_{BC} + w_{Wod_{BC}}Wod_{BC})}\Big/{\sum w} \tag{3.1}$$

where:

wi – characteristic weights for the type of parameter,

∑w – weight sum

U – load bearing capacity

D – degradation

S – skid resistance

R – roughness

Wod – bond strength by pull-off.

The weights in the model have been selected using the method of experts, based on many years of research and experience of engineer employees from the airport pavement diagnostics environment. The basis for estimating the weight values were the results of tests performed on airports functional elements in Poland. The tests at both civilian and military airport facilities with various types of operating aircraft. Inspections were carried out on runways, taxiways and aprons. Pavements of different age and surface condition, both new and heavily degraded which require complete restoration, were subjects. Table 1 presents estimated weights. The weights may vary depending on the adopted pavement maintenance scenario and sum of the weights not always have to be equal 1,0.

Table 1 Weights used in APCI model

D	**U**	**R_L**	**R_T**	**S**	**Wod**	**∑**
0,7	0,1	0,05	0,05	0,05	0,05	1,0

The assessed airport pavements are classified in accordance to the pavement condition assessment criteria, based on the obtained APCI index values. The criteria were developed on the basis of knowledge and many years of experience of experts from the airport industry. The detailed APCI assessment scale for airport pavements is as follows:

- APCI = 100 ÷ 86 - Good condition - The surface has little or no deteriorations and requires only routine maintenance.
- APCI = 85 ÷ 71 - Satisfactory condition - The surface has minor deteriorations that requires only routine maintenance.
- APCI = 70 ÷ 56 - Adequate condition - The surface has low and medium deteriorations. Routine and major repairs should be carried out in a short time.

- APCI = 55 ÷ 41 - Poor condition - The surface has deteriorations of low, medium and high harmfulness, which probably cause operational problems. Maintenance work should include routine repairs and reconstructions in the near future.
- APCI = 40 ÷ 27 - Very poor condition - The surface has mostly medium and high deteriorations, which causes significant maintenance and operational problems. Immediate intensive maintenance and repairs are needed.
- APCI = 26 ÷ 12 - Serious condition - The surface usually has high damage deteriorations, which cause limitations in its use. Immediate repair is needed.
- APCI = 11 ÷ 0 - Unfit condition - Surface deterioration has reached a level where safe air operations are no longer possible. Complete reconstruction is necessary.

4. Impact of model parameters on the APCI value

An analysis of including in the APCI model (3.1) individual parameters characterizing the assessed surface was carried out. The results for the analysis were used from a database created on the basis of a five-year review of one of the military airport facilities. Two cement concrete airport aprons were chosen. In order to maintain the confidentiality of test results, the aprons were named APRON 1 and APRON 2 for the purposes of the article. The standard size of concrete slabs on aprons was 5 x 5 m. The surface of the standard slab was 25 m2. Both airport functional elements assessed were characterized by a pavement condition at a sufficient level, according to the standard PCI scale. During the field tests, an inventory of deteriorations and repairs was made. The inventory was carried out based on the catalogue of cement concrete airport pavement's deteriorations developed at the Air Force Institute of Technology. This catalogue is widely used to evaluate pavement. Based on the results, the degree of surface degradation (D) was calculated. In addition, longitudinal (RL) and transverse (RT) evenness, skid resistance (S) and structure deflections (U) were measured. In addition, a test of the surface tensile strength with a Pull-Off apparatus (Wod) was performed. Table 1 presents the final results of the assessment of individual parameters. Each of the assessed parameters met the minimum requirements for the assessed airport pavements, which allowed pavement condition assessment with the APCI method.

Table 2 Results of APCI analysis input data assessment

Airfield Functional Element	**D** [%]	**U** [μm]	**R_L** [%]	**R_T** [%]	**S** [-]	**Wod** [MPa]	**APCI** [-]
APRON 1	10	710	18,3	82,7	0,66	6,89	**78**
APRON 2	26	882	26,2	46,3	0,67	8,69	**68**

The APCI for pavement APRON 1 is 78, which means the pavement is in „Satisfactory" condition. It can be say that the surface has minor deteriorations that requires only routine maintenance. In the case of APRON 2 pavement, this index equals 68 and the pavement is in „Adequate" condition, which means the surface has low and medium deteriorations. Routine and major repairs should be carried out in a short time. Degradation has the greatest influence on the APCI result.

The impact of considering each individual input data on the final result of the APCI indicator was analysed by determining the APCI indicator for various combinations of input parameters. The APCI index was calculated for each of the combinations, their results are presented in Figure 3. In addition, the airport surface conditions according to the detailed APCI legend were marked with appropriate colours on the graph.

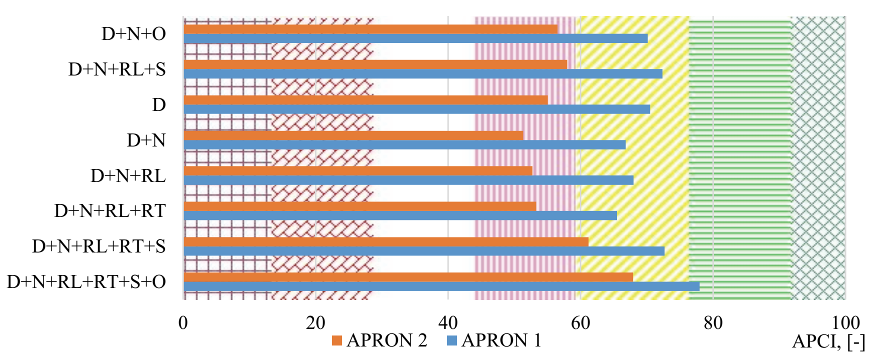

Fig. 3 Values of the APCI indicator depending on the adopted combination of input data

The above analysis indicates that considering additional parameters significantly affects the result of the pavement condition assessment. In extreme cases, the differences between the combinations amounted to almost 20%, which resulted in a change in the interpretation of the surface condition by one level.

5. CONCLUSION

Airport pavement management should be based on reliable information about their current technical condition. Many methods and procedures have been developed to provide data describing the condition of the surface. The vast majority of them are based on the standard PCI procedure. Some add other parameters, such as evenness or load capacity. Besides information about the current surface condition, it is important to be able to predict its future condition. Techniques for assessing indicators, such as Remaining Service Life were also developed here. At the same time, methods which are supported by artificial neural networks that allow predicting the progress of pavement degradation are being developed. All methods will work if the surface information collection system is reliable and complete.

The proposed APCI procedure provides such a spectrum of data. The input data consists of such parameters as: pavement degradation, load bearing capacity (PCN), roughness, skid resistance (friction) and concrete surface tensile strength. Surface degradation is assessed considering both deteriorations and already carried out repairs. Simultaneously with the procedure, a scale for airport pavements condition assessment was created, supported by many years of research as well as the knowledge and experience of experts from the transport construction industry.

The APCI method can be a reliable source of information in the process of estimating the future condition of an airport pavement. It is planned to develop a full method, based on optimization techniques, enabling the most accurate extrapolation of the pavement technical condition in subsequent years of its operation. This will allow rational and effective use of human resources, equipment and financial resources, while ensuring the safety and comfort of performing air operations in the ground maneuvering area. Data entry concerning corrosivity of the atmosphere in the area of the pavement being evaluated is taken into consideration. Such data does not introduce anything new to the current surface condition, but it is an invaluable source of information in the process of forecasting the surface condition. Research regarding standard atmospheric corrosion assessment methods and concrete vulnerability to atmospheric corrosion is being carried out.

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LIST OF FIGURES AND TABLES:

Ocena stanu technicznego nawierzchni lotniskowych wykonanych z betonu cementowego w oparciu o wskaźnik APCI

Słowa kluczowe: PCI, APCI, degradacja, utrzymanie, stan techniczny, nawierzchnie lotniskowe

STRESZCZENIE:

Jednym z czynników wpływających na bezpieczeństwo wykonywania operacji lotniczych jest utrzymanie infrastruktury lotniskowej w odpowiednim stanie, gdzie znaczenie ma właściwe zarządzenie infrastrukturą, w szczególności dysponowanie środkami pieniężnymi oraz zasobami ludzkimi. Obecnie stosowane metody wyznaczania stanu nawierzchni oparte są głównie na wizualnej ocenie uszkodzeń powierzchniowych. W artykule przedstawiono nowatorskie podejście do oceny stanu technicznego nawierzchni lotniskowych wykonanych z betonu cementowego w oparciu o wskaźnik APCI (z ang. Airfield Pavement Condition Index – wskaźnik stanu nawierzchni lotniskowych). Metoda wyznaczania wskaźnika APCI bazuje nie tylko na wizualnej ocenie stanu powierzchniowego nawierzchni lotniskowej i wyznaczeniu jej stopnia degradacji, ale uwzględnia również parametry nośności, równości, właściwości przeciwpoślizgowych i wytrzymałości na odrywanie warstwy przypowierzchniowej. Przedstawiona metoda może posłużyć jako narzędzie do prognozowania stanu technicznego nawierzchni lotniskowych z betonu cementowego w kontekście planowania środków na przyszłe cele remontowe. Ponadto przedstawiono wpływ uwzględnienia poszczególnych parametrów modelu na wartość wskaźnika APCI w oparciu o wyniki badań terenowych przeprowadzonych w ramach przeglądów okresowych lotnisk wojskowych.

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