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Reporting the Bearing Capacity of Airfield Pavements Using PCR Index

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Abstract: Airfield pavements are important assets that have to secure the safe operation of an airport. On this basis, assessing and reporting the bearing capacity of an airfield runway pavement is a critical task. Recently, the Aircraft Classification Rating-Pavement Classification Rating (ACR-PCR) system has been introduced, which uses the PCR index for expressing the bearing capacity of an airfield pavement. In order to accurately determine PCR, the mechanical characteristics and the thicknesses of the individual layers of a pavement are required. For this purpose, it is not seldom that in the absence of resources dedicated to detailed pavement evaluation procedures, assumptions for the material characteristics of the pavement considering typical materials may be made, while pavement thicknesses may be derived by pavement design records. The present paper highlights the importance of using Non-Destructive Testing (NDT) for accurately assessing the in-situ condition of a flexible runway pavement and determining the PCR index. In order to achieve the goal of the investigation, measurements were performed along the flexible pavement of an airport runway. In addition, the paper focuses on the impact of the variation of the thickness and of the mechanical characteristics of the asphalt concrete layers on the PCR index and on the interpretation of the results considering the acceptance of aircraft operations by airport authorities.

Keywords: NDT; Airfield pavements; bearing capacity; ACR-PCR

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1. Introduction

Assessing the structural condition of an airfield pavement is of paramount importance for the proper operation of an airport since airfield pavements have to ensure the safe transfer of people and goods. On this framework, the use of practical systems for classifying and reporting the bearing capacity of airfield pavements can act supportively to the decision-making of airport authorities, regarding the acceptance of aircraft operations.

The basis of reporting systems includes the development of indexes for expressing the effect of aircraft loading on a pavement structure and also the bearing capacity of the pavement under investigation. The comparison between these two elements may provide valuable information considering the ability of a pavement to handle aircraft operations without the need of imposing related restrictions [1–3]. Although it is believed that these techniques cannot replace the detailed pavement evaluation procedures, they may still provide a simple tool for facilitating communication practices between airport authorities and aircraft manufacturers. In addition, reporting systems are usually used in order to encounter pavement overloading phenomena, which can result either from aircraft loads that have not been considered during the initial pavement design, or from aircrafts exhibiting more operations than the ones foreseen [4,5]. Moreover, the expression of the bearing capacity of a pavement through indexes may be beneficial, in cases where there are unexpected and emergency needs that have to be confronted considering the allowable traffic volume of an airfield pavement [6].

The official reporting system that has been used during the last four decades is the Aircraft Classification Number-Pavement Classification Number (ACN-PCN), introduced by the International Civil Aviation Organization (ICAO) in 1983 [7]. However, recently a new system has been developed, the Aircraft Classification Rating-Pavement Classification Rating (ACR-PCR) [8], which is expected to be fully applicable by November 2024.

The implementation of both systems requires at minimum the determination of the characteristics of the pavement under investigation, which include the estimation of the mechanical properties of the individual layers of the pavements and the related thicknesses. However, the application of the so far developed methodologies for estimating the indexes that express the bearing capacity of the pavement, which are the PCN and PCR indexes, is usually based on assumptions for the material characteristics of the pavement, considering typical materials and design thicknesses, especially when there are limited resources dedicated to detailed pavement condition evaluation procedures. On this basis, the use of Non-Destructive Testing (NDT) for assessing the properties of a pavement may provide adequate data for the proper determination of pavement condition and consequently for accurately reporting the bearing capacity of an airfield pavement. More specifically, through the NDT testing, the mechanical characteristics (modulus of elasticity) and the thicknesses of the individual layers of the pavement can be precisely determined, which are the core elements for the estimation of PCN and PCR indexes.

Based on the above, in the present investigation, an assessment of the structural condition of a flexible runway pavement is carried out using field and laboratory data, in order to highlight the importance of using accurate data for reporting the bearing capacity of an airfield pavement. The methodology followed is briefly presented in Figure 1.

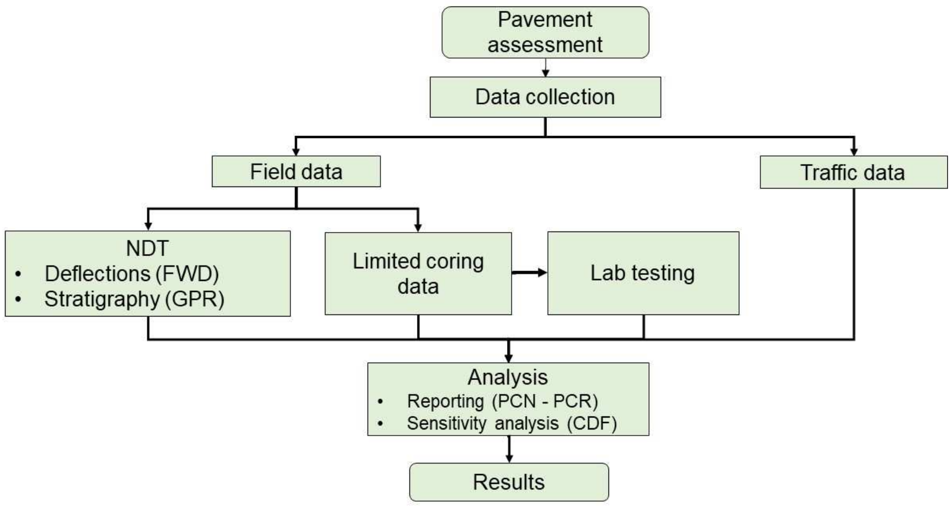

Figure 1. Methodology followed.

Field measurements and laboratory testing along with traffic data were used. The research process included data collection with NDT equipment. More specifically, measurements were carried out with the Falling Weight Deflectometer (FWD) and the Ground Penetrating Radar (GPR), which also constitute the standard practice for the assessment of airfield pavements [9–14]. Moreover, limited cores were extracted to provide supportive information to the NDT testing, considering mainly the estimation of the thickness and of the mechanical characteristics of the Asphalt Concrete (AC) layers. In addition, laboratory tests were carried out on the cores to determine the mechanical characteristics of the asphalt mixtures. Data collection was followed by a combined analysis of the pavement behavior also taking into account traffic data.

Initially the bearing capacity of the pavement was reported based on both the existing PCN index and the upcoming PCR index, for reasons of completeness of the investigation, since PCN is still the official index for reporting the bearing capacity of a pavement. The two indexes were primarily estimated, based on related methodologies developed by the Federal Aviation Administration (FAA) [15,16] considering the typical materials of the FAA and pavement thicknesses derived by pavement design records. However, it is worth mentioning that the common practice used for pavement construction may deviate from pavement design, leading to differences between the data of the pavement coming from the design procedure and those found in the field. With this in mind, the impact of the variation of the in-situ thicknesses of the individual layers of the pavements, as occurred from the analysis of the GPR data, on the estimation of the two index was investigated.

The investigation was then extended, considering the impact of the assumption of the in-situ mechanical characteristics of the pavement on PCR, with emphasis on the modulus of elasticity of the AC layers (E_{AC}). For this reason, deflection records from FWD measurements were used for back-calculating the modulus of elasticity of the individual layers of the pavement. In addition, a sensitivity analysis was performed in order to investigate the impact of the variation of the thickness of the AC layers and of the E_{AC} on PCR, in relation to the typical FAA material characteristics and the design assumptions. In order to achieve this goal, laboratory data were also considered, which supported the characterization of the AC layers derived from NDT data. For the analysis, the concept of the Cumulative Damage Factor (CDF) was used, as presented in the recent developments of the FAA airfield pavement design and evaluation principles [17].

The analysis showed that the determination of the real condition of the pavement may significantly impact the PCR index and consequently the expression of the bearing capacity of the pavement, which may be substantially different than the bearing capacity considered during the initial design.

2. Materials and Methods

2.1. Reporting Systems

2.1.1. Method ACN-PCN

The ACN-PCN method, is a method that has been widely used for about 40 years as a practical tool for airport authorities, in order to report the bearing capacity of airfield pavements. ACN is a number that expresses the relative effect of an aircraft on a pavement for a specified standard subgrade strength. For flexible pavements the subgrade category is determined through the California Bearing Ratio (CBR) of the subgrade, where Category (A) corresponds to CBR $\geq$ 13%, Category (B) to 8% < CBR < 13%, Category (C) to 4% < CBR $\leq$ 8% and Category (D) to CBR $\leq$ 4%. For each subgrade category, an ACN index is reported, while for most of the aircrafts ACN values can be calculated with the aid of the ICAO-ACN software developed by ICAO.

The calculation of the ACN of an aircraft is based on the determination of a Derived Single Wheel Load (DSWL), which is considered to imply equal stress to the pavement with the considered aircraft. This is achieved by equating the thickness derived for a given aircraft landing gear for 10,000 coverages to the thickness derived for a single wheel load (DSWL) at a standard tire pressure of 1.25 MPa. The ACN is defined as two times the DSWL (expressed in thousands of kilograms).

PCN expresses the bearing capacity of an airfield pavement and is characterized by a five-coded format which includes the PCN numerical value, the pavement type, the subgrade category, the allowable tire pressure and the method used to determine the PCN. The pavement type can be characterized as flexible (F) or rigid (R). The subgrade categories follow the characterization of the ones developed for the ACN index. As far as the maximum allowable tire pressure is concerned, there are the following four categories: for Category (W) there is no pressure limit, for Category (X) the pressure is limited to 1.75 MPa, for category (Y) pressure is limited to 1.25 MPa while the limit for category (Z) is 0.5 MPa. Moreover, there are two pavement evaluation methods: the Technical evaluation method (T) and the Using aircraft method (U).

The ACN-PCN method is structured so that a pavement with a particular PCN value can carry the loading of an aircraft having an ACN value equal to or less than the pavement's PCN value. There are several methodologies that have been developed internationally for PCN determination. In the framework of the present investigation, the most recent methodology developed by FAA has been used [15], which is supported and implemented through the COMFAA 3.0 software.

According to FAA, in order to estimate the PCN, the aircraft traffic mix is converted to equivalent annual departures of one representative aircraft. Moreover, the thickness of the pavement under investigation is converted to a standard flexible pavement cross-section, consisting of AC layers and an aggregate base layer with defined thickness and a subbase layer with variable thickness. In case the pavement has excess thickness than the thickness defined for the AC layers and the aggregate base, the excess material is converted into an equivalent thickness. Initially the Maximum Allowable Gross Weight (MAGW) for each aircraft on that pavement at the equivalent annual departure level is calculated and then for each aircraft the ACN is calculated at its MAGW. The PCN is then selected from the calculated ACN data of all aircrafts [15].

2.1.2. Method ACR-PCR

The ACR-PCR method is an update of the existing ACN-PCN method, which includes the latest advances in airfield pavement analysis techniques and moves away from the previous empirical reporting procedures. The ACR expresses the effect of an aircraft on a pavement, while the PCR expresses the load-carrying capacity of the pavement. PCR, likewise PCN, uses a five-coded format to express the bearing capacity of the pavement. More specifically the method includes four pavement subgrade categories based on the modulus of elasticity (E) of the subgrade. For flexible pavements the categories are A (High, $E \geq 150$ MPa), B (Medium, 150 MPa < E < 60 MPa), C (Low, 60 MPa $\leq$ E < 100 MPa) and D (Ultra Low, E < 60 MPa). For each subgrade category, an ACR index is reported, while for most of the aircrafts ACR values can be calculated through the ICAO-ACR software developed by ICAO.

For flexible pavements, the ACR is determined based on the calculation of the reference thickness for the given aircraft mass. The reference pavement structure used consists of the subgrade, a variable base course of crushed aggregate and an AC layer of defined thickness, which differs according to the aircraft landing gear. The thickness of the variable base layer is adjusted until the CDF of the subgrade ($CDF_{subgrade}$) is equal to 1.0 for 36,500 coverages of the aircraft. The total thickness of the pavement that results from the above procedure corresponds to the reference thickness for ACR calculation. Using the above reference thickness, a DSWL is obtained which has a constant tire pressure of 1.50 MPa and produces a $CDF_{subgrade}$ equal to 1.0. The ACR is then defined as two times the DSWL (expressed in hundreds of kilograms).

The ACR-PCR method is also structured so that a pavement with a particular PCR value can carry the loading of an aircraft having an ACR value equal to or less than the pavement's PCR value. It is noted that ACR has been designed to be about 10 times higher than the ACN and the same trend occurs for the PCR and PCN indexes. This was completed in order to avoid potential confusion during the implementation of the upcoming ACR-PCR reporting system. In the present investigation, PCR was determined using the procedure developed by FAA and presented in [16], which is supported by the FAA Rigid and Flexible Iterative Elastic Layered Design system FAARFIELD 2.0 [18].

In order to calculate the PCR of a pavement all relevant pavement data are collected, including layer thicknesses and modulus of elasticity along with the expected aircraft types and number of departures. Initially, the ACR of each aircraft in the traffic mix is calculated at its operating weight and the maximum ACR aircraft is recorded. Then the maximum $CDF_{subgrade}$ of the aircraft mix is determined and the aircraft with the highest contribution to the maximum $CDF_{subgrade}$ is considered as the critical aircraft ($AC_{(i)}$). The number of departures of the critical aircraft are adjusted until the maximum aircraft $CDF_{subgrade}$ is equal to the total $CDF_{subgrade}$ of the aircraft mix. Then, the critical aircraft weight is modified in order to obtain a maximum $CDF_{subgrade}$ of 1.0 for this number of departures.

This weight corresponds to the MAGW of the critical aircraft. The next step includes the determination of the ACR of the critical aircraft at its MAGW, which is considered to be equal to $PCR_{(i)}$. In case this is the maximum ACR aircraft from the ones initially calculated, the PCR is considered to be equal to $PCR_{(i)}$. Otherwise, the $AC_{(i)}$ is removed from the traffic mix and the above procedure is repeated, until the calculated PCR index equals the maximum ACR aircraft [16].

Detailed information and related comparison between the two abovementioned reporting systems, along with basic principles of the implementation of FAA's methodologies for PCN and PCR indexes estimation can be found in [19].

2.2. Data Collection

In the framework of the present investigation, data from a regional airport of Southeastern Europe were used. The field experiment included collecting data with NDT systems (Figure 2) in order to record the elastic surface deflections and estimate the thicknesses of individual pavement layers. Measurements with the FWD [20] were performed with a 30 cm diameter plate and a load of 100 kN, based on international experience and practice. Table 1 presents the configuration of the FWD system used, as far as the geophone distances are concerned. FWD measurements were performed along both sides of the runway centerline at distances of about 2 m left and right of the runway centerline, at 50 m intervals, as this area was expected to carry the majority of the expected aircraft traffic fleet. During FWD testing, temperature measurements in the body of the AC layer were taken.

(**a**) (**b**)

Figure 2. NDT measurements: (**a**) FWD; (**b**) GPR.

Table 1. FWD system configuration.

Geophone	1	2	3	4	5	6	7	8	9
Distance from center (mm)	0	200	300	450	600	900	1200	1500	1800

The GPR system [21] was used to estimate the thicknesses of the individual layers of the pavement. GPR surveys were performed along the same paths of the FWD testing. In order to obtain the required thickness data of the pavement under investigation two horn antennas were used, having a frequency of 1000 MHz and 400 MHz, respectively (Figure 2b).

In addition, the thicknesses of the individual layers of pavement cross-section coming from the airfield pavement design procedure was available (Figure 3). The investigated pavement structure had been designed using the empirical method of the FAA and consisted of 12 cm of AC layers, a base and a subbase of compacted crushed stone granular materials of 28 cm and 80 cm, respectively, and a subgrade layer of natural gravel having a CBR = 3.5% (Figure 3).

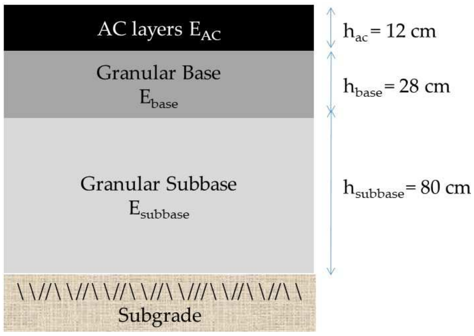

Figure 3. Typical cross-section of runway pavement coming from design procedure.

Regarding the traffic fleet expected to use the airfield pavement, a mix including both civil and military aircrafts was considered. The individual characteristics of the aircrafts and their wheel configuration are shown in Table 2, along with the expected annual departures.

Table 2. Traffic fleet data.

Aircraft	Gear Configuration	Aircraft Weight (ton)	Annual Departures
A320-200	Dual	78.400	2000
B757-300	Dual Tandem	124.058	2000
C-130	Single Tandem	70.307	1000
F-16C	Single	19.187	4000

In addition to the collection of field data through NDT, limited coring was carried out at various locations of the runway. The extracted cores were initially used to support the GPR measurements considering the estimation of the thickness of the AC layers. Figure 4 shows three indicative cores, designated as C1, C2 and C3, along with the thickness of the AC layers.

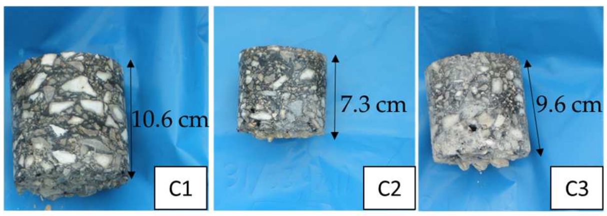

Figure 4. Indicative extracted cores.

In addition, since the long-term performance of the pavement is largely affected by the stiffness of the AC layers, all of the extracted cores were further tested in the laboratory to assess the mechanical characteristics of the asphalt mixture.

2.3. Sensitivity Analysis—CDF

The overall set of the collected data was finally used in a sensitivity analysis, in order to investigate the combined effect of the variation of the thickness of the AC layers and of their mechanical characteristics on PCR index. In order to achieve this goal, the most recent developments considering airfield pavement design and evaluation procedures introduced by FAA [17] were used, which are implemented through the FAARFIELD 2.0 system [18].

The sensitivity analysis was initially performed through the determination of the CDF index, which is expressed as the ratio of the number of applied load repetitions to the number of the allowable load repetitions to failure, as shown in Equation (1):

$$\text{CDF} = \frac{\text{number of applied load repetitions}}{\text{number of allowable repetitions to failure}} = \frac{(\text{annual departures}) \times (\text{life in years})}{\left(\frac{\text{pass}}{\text{coverage}}\text{ratio}\right) \times (\text{coverages to failure})} \quad (1)$$

The number of the applied load repetitions corresponds to the traffic expected to use the runway's pavement for the evaluation period, while allowable repetitions to failure occur from corresponding failure models of the critical layers. The applied coverages are determined from expected aircraft passes that are converted to coverages, using the pass-to-coverage (P/C) ratio, that corresponds to the passes required to apply one full load application to a unit area of the pavement [17]. The effect of multiple aircraft types to total CDF is accounted for using Miner's Rule, as shown in Equation (2):

$$\mathrm{CDF} = \mathrm{CDF}_1 + \mathrm{CDF}_2 + \cdots + \mathrm{CDF}_n \quad (2)$$

where

CDF_i: The CDF of each aircraft in the traffic mix.

n: The number of aircrafts in the traffic mix.

According to the FAA, the CDF is calculated for each 10-inch (254-mm) wide strip along the pavement over a total width of 820 inches (20.8 m). The P/C ratio for each aircraft is estimated for each strip, assuming that 75% of passes occur within a wander width of 70 inches (1778 mm). The CDF corresponds to the maximum CDF value computed over all 82 strips [17], considering the contribution of all aircrafts to total damage. On this basis, the CDF at a lateral offset j from the centerline of a runway pavement can be expressed through Equation (3) [8]:

$$\mathrm{CDF}\left(y_j, z\right) = \sum_{i=1}^{m} \frac{N_i}{(P/C)_j^i} \times D_i(z) \quad (3)$$

where

N_i: The number of aircraft passes.

$D_i(z)$: The damage contributed by a pass of aircraft i.

$(P/C)_j^i$: The P/C ratio of aircraft i at a lateral offset j.

For flexible pavements, the CDF is estimated considering the failure of the AC layer (CDF_{AC}) and the failure of the subgrade as well ($\mathrm{CDF}_{subgrade}$). In case CDF < 1, the pavement is not expected to fail due to the related mode of failure. In the present investigation, emphasis is given on the failure of the subgrade, since that index consists of the base for the determination of the PCR index. Especially for subgrade failure, for the estimation of the allowable coverages to failure the following failure models are used [17,22]:

$$\log_{10}(C) = \left(\frac{1}{-0.1638 + 185.19 \times \varepsilon_z}\right)^{0.60586} \quad C > 1000 \text{ coverages} \quad (4)$$

$$C = \left(\frac{0.004141}{\varepsilon_z}\right)^{8.1} \quad C \leq 1000 \text{ coverages} \quad (5)$$

where C is the coverages to failure, and ε_z is the vertical strain at the top of the subgrade.

3. Results

3.1. Reporting the Bearing Capacity of Runway Pavement Using Design Thicknesses and Typical FAA Materials

The first step of the analysis included reporting the bearing capacity of the runway airfield pavement by considering the pavement cross-section coming from design procedure (Figure 3), along with related assumptions on the material characteristics. Since the pavement had been designed according to the principles of the empirical method of the FAA, the typical FAA materials were considered. As such, the AC layers were considered to present the characteristics of the typical P-401, the granular base the characteristics of the material P-209 and the granular subbase the characteristics of the material P-154. For the reason of completeness of the investigation, the bearing capacity of the pavement was initially reported through both the PCN and PCR indexes. Based on the above and considering the traffic fleet data of Table 2, the PCN was estimated to be equal to 59.3/F/D/X/T (PCN_{design}), while the PCR index occurred 490/F/D/X/T (PCR_{design}).

Table 3 presents the ACN and ACR values of the aircrafts using the airport for the subgrade category D. It is observed that all aircrafts present ACN values, which are less than the reported PCN. On the other hand, the estimation of the PCR based on the same material assumptions may restrict the operation of aircraft B757-300, which presents an ACR value that exceeds the PCR of the runway. Therefore, it occurs that the expression of the bearing capacity may be altered through the implementation of the upcoming ACR-PCR system, compared to the existing ACN-PCN system.

Table 3. ACN and ACR values of aircrafts using the airport for subgrade category D.

Aircraft	ACN (D)	ACR (D)
A320-200	50.2	444.00
B757-300	58.1	516.54
C-130	37.6	340.32
F-16C	18.3	175.21

3.2. Reporting the Bearing Capacity of Runway Pavement Using Insitu Thickness and Typical FAA Materials

In order to investigate whether the in-situ condition of the pavement differs from the design assumptions, an additional analysis was performed considering layer thicknesses values derived from NDT data collection. Figure 5 shows a view of the processing of the GPR data of the two antennas that were used in the present research for a section of the runway. By combining the results of the analysis with the two antennas, the stratigraphy of the hole runway was determined. Figure 6 presents the related results of the measurements performed at the distance of 2 m right of the runway centerline, since this data was used for the analysis. It is noted that 15 characteristic cross-sections of the runway pavement were selected for further analysis, whose exact position is marked in Figure 6.

Figure 7 shows the thicknesses of the individual layers of the pavement as obtained from the processing of the collected data with the GPR for the 15 cross-sections of the runway pavement. In the same figure the positions of the cores of Figure 4 are also marked. It is observed that the in-situ thicknesses of the pavement may be different than the thicknesses coming from the design procedure. More specifically, most of the evaluated cross-sections, with an exception of cross-section 1, are thicker than the design cross-section. It is worth mentioning that the construction of pavements that are slightly thicker than the design cross-section, may be considered as a common practice, in cases that it is desirable to assure the sufficiency of pavement thicknesses during construction. On this basis, the pavements are expected to have higher bearing capacity than the one considered during the design.

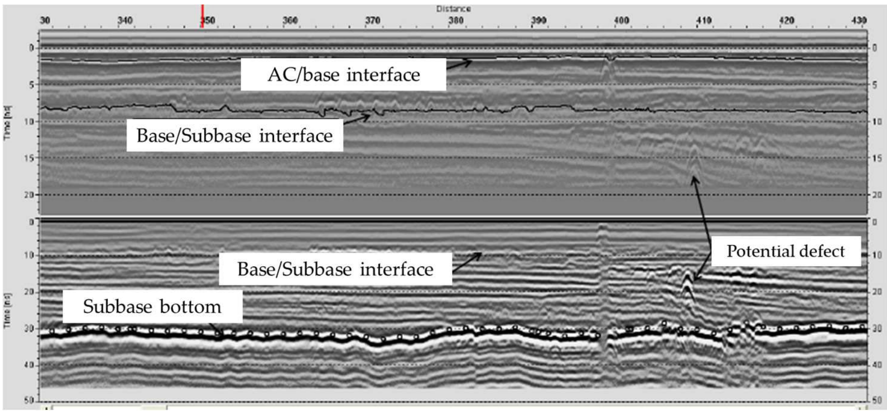

Figure 5. Processing of GPR data using two antennas.

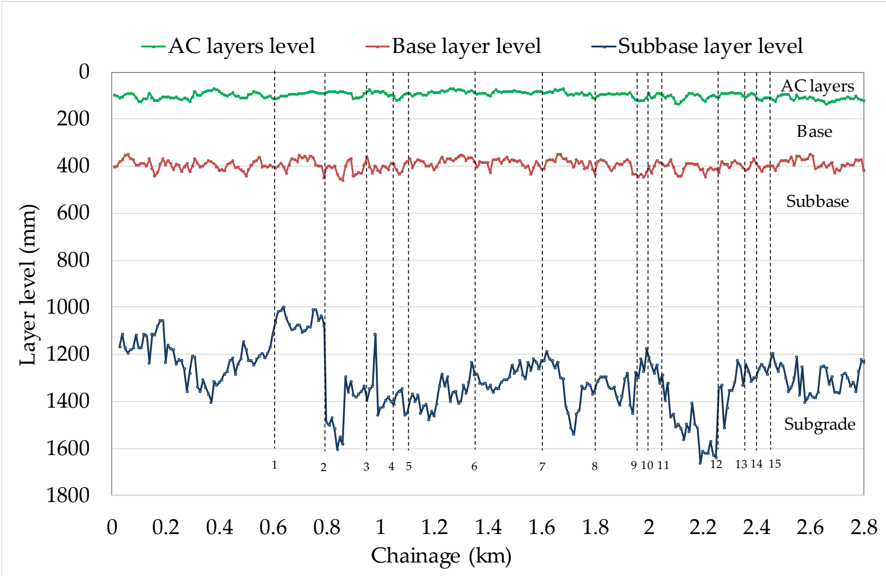

Figure 6. Thickness of individual layers along the runway.

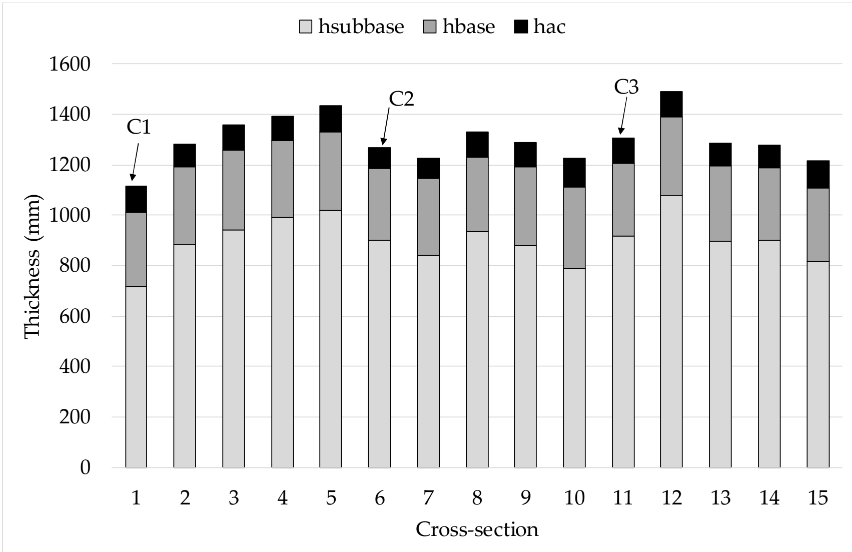

Figure 7. Thicknesses of characteristic cross-sections.

PCN and PCR indices were first estimated for each cross-section considering the typical FAA materials. The related results are shown in Figure 8. It is observed that the variation of the thicknesses leads to a significant variation of the PCN and PCR indexes of the considered pavement, which provide an improved condition of the bearing capacity of the pavement. With the exception of cross-section 1, all the cross-sections present PCN and PCR indexes that are equal or exceed the PCN_{design} and PCR_{design} values, respectively.

From Figure 8 it is also observed that PCN and PCR seem to present a similar trend. For this reason, potential correlation between the two indexes was investigated and the related results are shown in Figure 9. As shown in Figure 9, the two indexes show a strong correlation ($R^2 = 0.98$). Since the R^2 coefficient corresponds to the percentage of the variability in the PCR index that is explained by the regression line, the change in the PCR index can be described by the change in the PCN index. Therefore, it seems that the fit of the regression line to the data in question is excellent. This information could be useful for airport authorities for a preliminary estimation of PCR in the absence of detailed pavement evaluation techniques, during the transfer period until the full implementation of the ACR-PCR system.

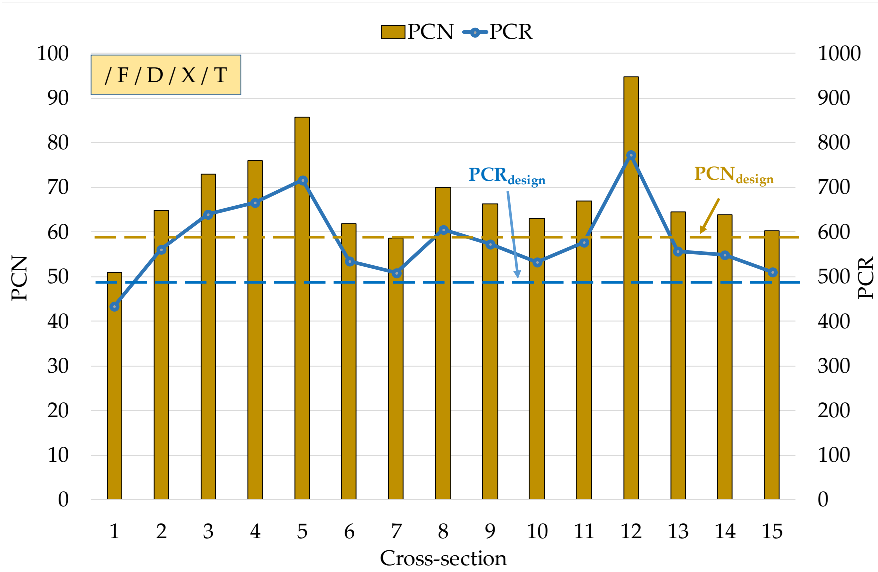

Figure 8. PCN and PCR indexes of characteristic cross-sections.

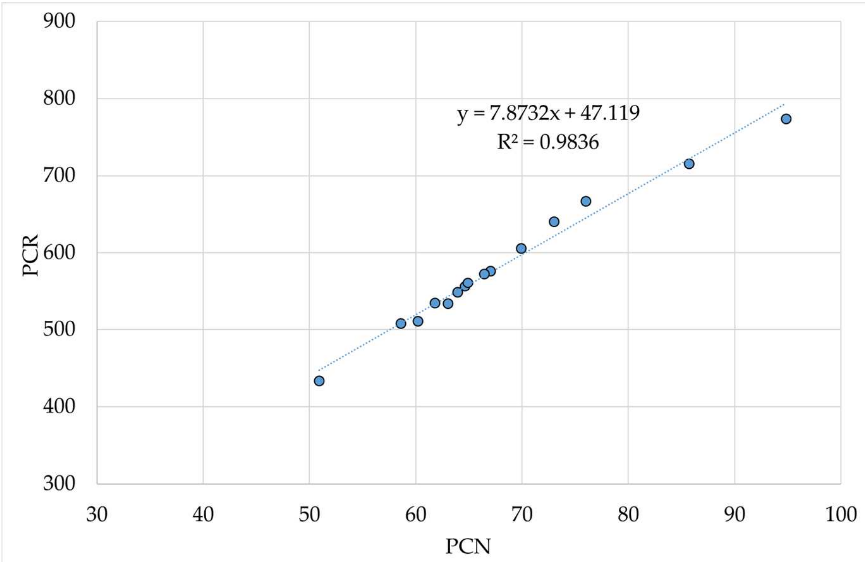

Figure 9. Correlation between PCN and PCR index.

3.3. Reporting the Bearing Capacity of Runway Pavement Using Insitu Thicknesses and Materials

In order to investigate whether the in-situ behavior of pavement materials differs from that of the typical FAA materials considered during the design procedure, an additional analysis was performed considering the modulus of elasticity of the individual pavement layers derived from the processing of FWD data. For this reason, back-calculation of the modulus of elasticity of the individual pavement layers was performed considering also layer thicknesses coming from GPR data analysis. For the back-analysis, the BAKFAA software was used, which has been developed by the FAA.

From the related analysis it emerged that the base and subbase layers exhibited similar characteristics to those of typical FAA materials. However, special emphasis was put on the assessment of modulus of elasticity of the AC layers (E_{AC}), since the assumption of the typical FAA material (P-401 with E_{AC} = 1378 MPa at 32 °C) was considered quite conservative for the mixes used in this area. It is noted that the corresponding mixes were expected to present E_{AC} of about 3000 MPa, adjusted to the temperature of 32 °C. The results of the relevant analysis are shown in Figure 10. In the same Figure, the recorded temperature in the body of the AC layers is also presented, given that this parameter affects the behavior of the asphalt mix and consequently of the pavement.

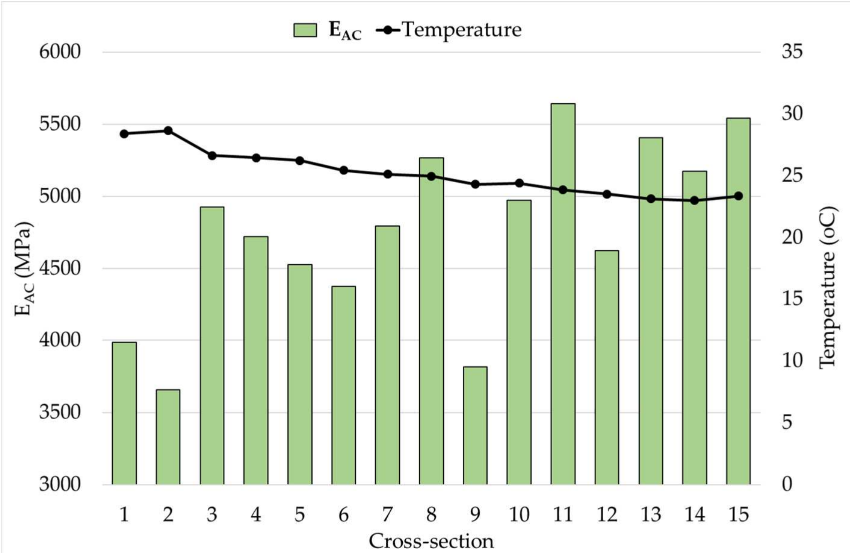

Figure 10. Back-analyzed E_{AC}.

The above data were used to estimate the PCR index of the 15 cross-sections. For comparison reasons, the E_{Ac} values were normalized to a temperature of 32 °C using the conversion algorithm of Equation (6), based on international experience and practice [23].

$$\frac{E_{ref}}{E_{AC}} = \frac{1}{1 - 2.2\log\left(\frac{T_{AC}}{T_{ref}}\right)} \tag{6}$$

where

E_{ref}: Modulus of elasticity of AC layers to reference temperature (°C).

E_{AC}: Modulus of elasticity of AC layers from back-analysis.

T_{ref}: Reference temperature (°C).

T_{AC}: Temperature at 1/3 of AC layer thickness.

From the relevant conversion, it emerged that the mean E_{AC} of the characteristic cross-sections was E_{AC} = 3860 MPa with a standard deviation of 386 MPa, therefore the value E_{AC} = 3475 MPa can be considered as a characteristic value of the sample, which differs significantly from the characteristics of typical P-401 FAA material.

Based on the data obtained from the back-calculation, the PCR index was estimated, and the results are shown in Figure 11. It is observed that the consideration of the in-situ characteristics of the AC layers E_{AC} (insitu) greatly affects the PCR index which is used for classifying the bearing capacity of an airfield pavement. Moreover, the use of the E_{AC} (insitu) instead of the typical P-401 FAA material, leads to an increase in the reported bearing capacity and consequently on the acceptance of the aircraft operations for the runway pavement. Based on the above it is apparent that all of the investigated pavement cross-sections can accept without weight restrictions the expected traffic fleet.

Then, in addition to the analysis of the elastic deflections for the estimation of the E_{AC}, a laboratory determination of the stiffness measure ITSM (Indirect Tensile Stiffness Modulus) (EN 12697-26) [24] was carried out on the cores obtained. From the testing it occurred that the mean was E_{AC} = 5418 MPa with a standard deviation of 1140 MPa. Therefore, the value E_{AC} = 4278 MPa could be considered as a characteristic value of the sample coming from the laboratory testing. It is noted that this value approximates the value of E_{AC} that has resulted from the back-calculation procedure.

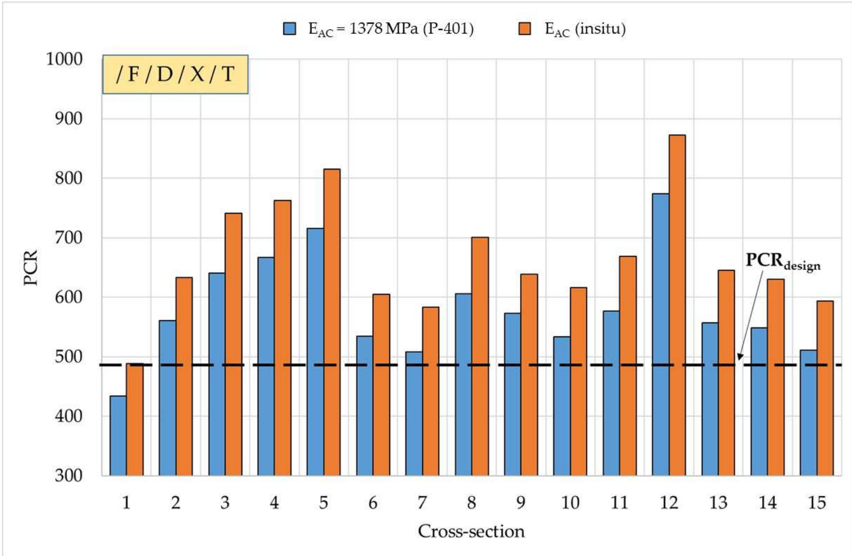

Figure 11. Effect of AC layer mechanical characteristics on PCR index.

3.4. Sensitivity Analysis on PCR

In order to further investigate the effect of the variation of the thickness mainly of the AC layers and the assumptions of the E_{AC} on the evaluation of an airfield pavement and on reporting its bearing capacity, a sensitivity analysis was carried. The main criterion was the $CDF_{subgrade}$, since this index is the basis for PCR estimation.

The related sensitivity analysis included values of the thickness of the AC layers in the range of 7 cm to 12 cm (Figure 12), which occurred from the processing of the recordings with the GPR system and was also confirmed from the limited coring data. It is noted that in all cores the thickness of the AC layers was less than the thickness of the design cross-section.

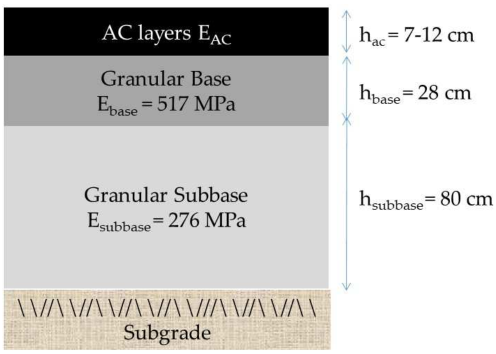

Figure 12. Cross-section used for sensitivity analysis.

Regarding the E_{AC}, three values were considered for the analysis: the value corresponding to the initial pavement design and the typical FAA material (E_{AC} = 1378 MPa), the characteristic value based on the back-calculation procedure (E_{AC} = 3475 MPa) and the characteristic value based on the results of laboratory testing (E_{AC} = 4278 MPa). The rest of the pavement elements (base and subbase thickness and mechanical properties of materials) were taken into account based on the design cross-section. Consequently, the analysis focused on the combined effect of the characteristics of the AC layers on the behavior of the pavement.

The results of the analysis are shown in Figure 13, from which the importance of selecting appropriate data for pavement evaluation emerges. More specifically, the selection of the thickness of the design cross-section (12 cm) and the modulus of elasticity corresponding to the in-situ condition of the pavement (E_{AC} = 3475 MPa) leads to a sufficient bearing capacity of the pavement for the considered traffic. However, the choice of a more conservative approach regarding the thickness of the asphalt layers in combination with the consideration of the E_{AC} leads to high values of the $CDF_{subgrade}$ index.

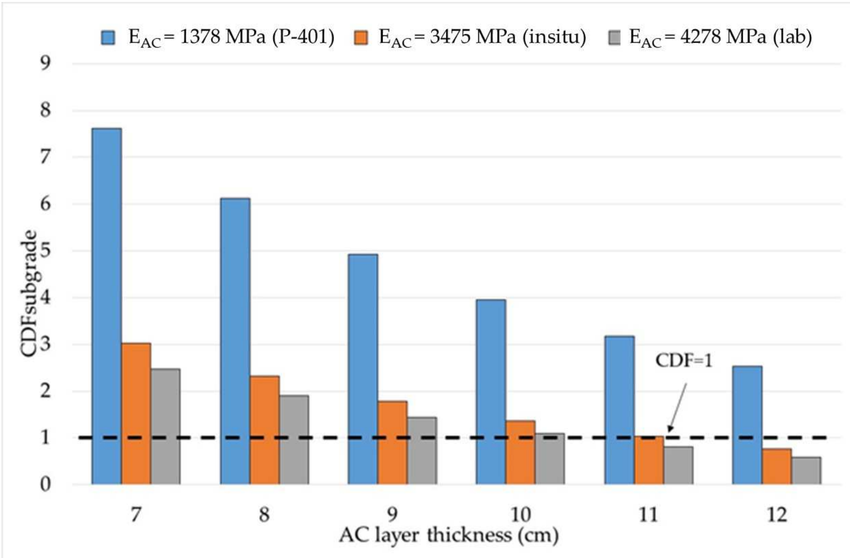

Figure 13. Effect of AC layer thickness and E_{AC} on $CDF_{subgrade}$.

In the context of the present research, the effect of the variation of the considered parameters on the PCR index was also examined and the relevant results are presented in Figure 14. In the same figure, the ACR values of the aircraft using the pavement are also marked. It is found that the differentiation of the pavement characteristics identified during the processing of both the in-situ data and through the laboratory test results greatly affects the expression of the bearing capacity of the pavement in question through the ACR-PCR ranking system. Therefore, the combination of reduced AC layer thickness compared to the corresponding value taken into account during pavement design can lead to a limitation of the traffic fleet that the pavement can accommodate.

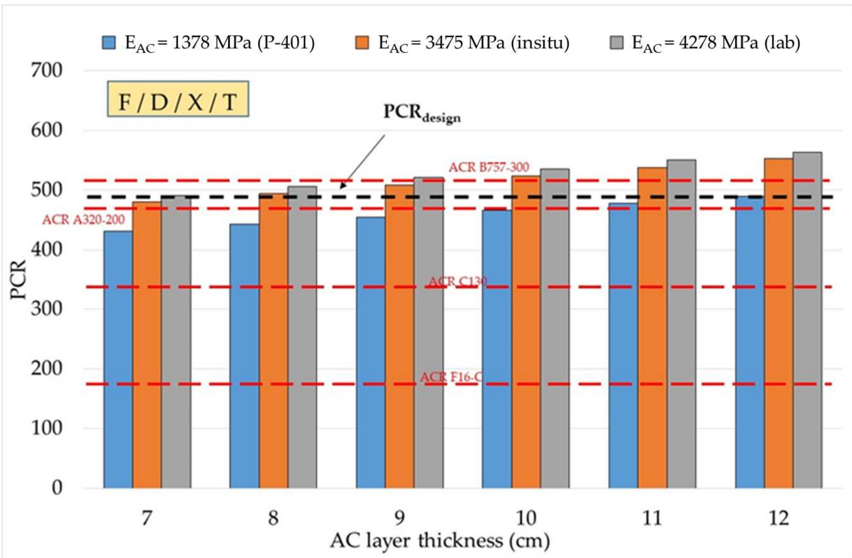

Figure 14. Effect of AC layer thickness and E_{AC} on PCR index.

According to the above, it follows that the combination of field data and laboratory data can provide valuable information for the appropriate management of the operation of an airport's runway pavement.

4. Discussion

The present investigation focuses on the reporting of the bearing capacity of an airfield pavement using the upcoming ACR-PCR system, which is expected to be fully applicable by November 2024. Since this system is expected to replace the so far used ACN-PCN system, it is of paramount importance to highlight the potentials of the new advances in this field, which is of particular interest for several researchers internationally [1,11,17,25]. The implementation of the upcoming ACR-PCR system may be even more critical since it is intended to be also applied in countries that do not mandate prescriptive methods for PCN and PCR determination [1]. On this basis, the use of worldwide accepted methodologies [16], adjusted to the in-situ condition of a pavement with the aid of NDT, may lead to the optimum determination of PCR index, as presented in the present research.

The strong correlation between the PCN and PCR indexes, coming from the current investigation, may provide useful information for airport authorities in terms of a preliminary estimation of PCR, in the absence of detailed pavement evaluation techniques. That information could be especially helpful, during the transfer period until the full implementation of the ACR-PCR system. However, it must not be ignored, that this correlation has occurred for the typical materials of the FAA, and deviations from these material assumptions may alter this finding, especially if one considers the limitations of the empirical procedure for PCN determination, as far as the material characteristics of the pavements are concerned [6,15,19]. The issue of the transferability between the two indexes may become even more challenging, taking into account that there are several methodologies that have been developed internationally for PCN determination, that usually produce different results [6].

Considering future research, it is believed that the investigation of reporting the bearing capacity of airfield pavements through the PCR index may be also extended, considering different types of pavements. Especially for estimating the PCR index of rigid airfield pavements, the investigation of the material assumptions of the typical FAA materials, compared to the in-situ condition of a rigid pavement, could provide valuable information on this field. In this framework, the transferability between PCN and PCR indexes may be also investigated, highlighting potential limitations and deviations of the trend presented in the current investigation for flexible pavements.

5. Conclusions

In the framework of the present investigation a comparison between the PCN and PCR indexes for reporting the bearing capacity of an airfield runway pavement was performed. The analysis showed that the expression of the bearing capacity alters through the implementation of the upcoming ACR-PCR system, compared to the existing ACN-PCN system, a fact that may lead to restrictions considering the aircraft operations that a pavement can accommodate. However, a strong correlation between the PCN and PCR indexes was observed.

Another significant finding of the current research deals with the assumptions usually used during pavement evaluation and reporting procedures. Since it is not seldom to use typical materials of the methods developed worldwide for the assessment of the condition of an airfield pavement, the present research highlights the importance of accurately determining the in-situ condition of the pavement. To achieve this goal, the use of NDT systems, along with appropriate analysis techniques, is fundamental, while limited destructive testing can act supportively to material characterization procedures. In terms of the PCR index, the analysis showed that this index may be significantly impacted by the assumptions made, considering the mechanical characteristics of the individual layers of the pavement. The outcome of the analysis is important, since PCR does not consist of a single number for reference but may provide a tool for managing aircraft operations, especially in cases that detailed pavement evaluation procedures are not feasible due to restricted resources and related means.

In addition, the research highlights the importance of considering potential deficient thickness data obtained during in-situ measurements, in relation to pavement layer thicknesses occurring through design procedures. This information is also important, since the constructed pavement may present reduced thickness compared to the design cross-section. This fact, as occurring from the present study, may impact the damage of the pavement and consequently the PCR index, which will be used for reporting the bearing capacity of the pavement for the following years.

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