Transportation Engineering 8 (2022) 100117

Contents lists available at ScienceDirect

Transportation Engineering

journal homepage: www.sciencedirect.com/journal/transportation-engineering

Preliminary evaluation of the ACR-PCR system for reporting the bearing capacity of flexible airfield pavements

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ARTICLE INFO

Keywords:
Airfield pavement reporting
Bearing capacity
ACN-PCN
ACR-PCR
Decision-making

ABSTRACT

Assessing and reporting the bearing capacity of airfield pavements have always been significant tasks in airport engineering, since they support the decision making procedure, which is a core element of Airport Pavement Management Systems (APMS). The official reporting system utilized worldwide during the last four decades is the Aircraft Classification Number – Pavement Classification Number (ACN-PCN) system. However, recently an updated system has been introduced, aiming to overcome the defects of the ACN-PCN system that have been observed during its implementation. This system, referred as the Aircraft Classification Rating – Pavement Classification Rating (ACR-PCR), aims to incorporate the latest advances in airfield pavement design and evaluation and is expected to be fully applicable about 2024. Since this is a transfer period, the current investigation aims to identify any critical aspects arising from the application of the updated system, based on recent Federal Aviation Administration (FAA) airfield pavement evaluation techniques. On this basis, the transferability between the two system is examined, providing useful commentary and remarks for airport authorities, who would like to implement the ACR-PCR method to its full extent. The analysis shows that the transferability between the two systems seems not to be feasible and the implementation of the updated ACR-PCR may present several issues, such as the modification of the existing reported bearing capacity.

1. Introduction

Airfield pavements consist one of the most important transportation infrastructures, since their key role is to ensure the safe operation of aircrafts utilizing an airport. The main goal of airfield pavements is to provide adequate load-carrying capacity, in order to ensure the appropriate operation of airport facilities. Otherwise, maintenance interventions and rehabilitation actions are time-consuming and may affect pavement serviceability with a significant impact on airport financial resources. As such, the implementation of a globally utilized system for classifying and reporting the bearing capacity of airfield pavements has always been an important issue in airport engineering, since it supports the decision making process in terms of pavement management. The importance of the implementation of this system becomes even more profound, considering the introduction of new aircraft types and their ability to safely land on existing runway airfield pavements.

The official reporting system that has been extensively used for the past 40 years, is the Aircraft Classification Number – Pavement Classification Number (ACN-PCN) method, which has been introduced by the International Civil Aviation Organization (ICAO) [1]. The ACN-PCN method is still used worldwide, since it is a practical tool for facilitating communication practices between airport authorities and aircraft manufacturers. Moreover, it is also useful in cases where there are limited resources dedicated to the management of airport pavements. As stated in [2], this method may be beneficial when there are unexpected and emergency needs that have to be confronted considering the allowable traffic volume.

The simplicity of this system was outstanding, which justifies the duration of its applicability. However, there were indications that it contains several assumptions and inconsistencies that have to be considered carefully during its implementation [3,4,5,6,7]. Moreover, since several different methods have been developed worldwide for determining the PCN value of an airfield pavement, a critical task arises, given that the PCN value could not be uniquely defined [2]. Apart from the abovementioned deficiencies, it must be noted that the ACN-PCN

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https://doi.org/10.1016/j.treng.2022.100117
Received 29 March 2022; Received in revised form 10 May 2022; Accepted 10 May 2022
Available online 14 May 2022
2666-691X/

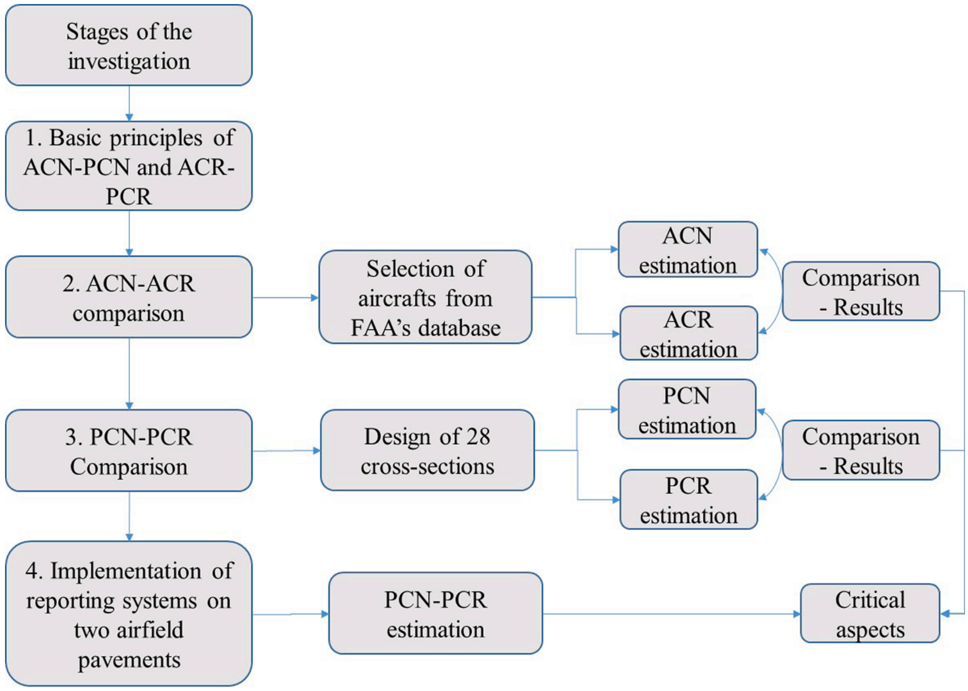

Fig. 1. Methodology followed.

method is based on traditional empirical design methods. However, the development of advanced analytical theories for pavement analysis observed the last decades has been also incorporated in airfield pavement design and evaluation techniques. Since these theories are nowadays used in practice, the update of the system used for reporting the bearing capacity of airfield pavements was considered indispensable. With this in mind, the Aircraft Classification Rating – Pavement Classification Rating (ACR-PCR) method has been currently introduced by ICAO and is expected to be applicable as of November 2024.

Since there is a transfer period between the full applicability of the updated ACR-PCR system, it is believed that it is of particular interest for airport authorities internationally, to be aware of potential critical issues arising from this evolution [8]. The present investigation aims to provide useful commentary and remarks for airport authorities, who would like to implement the ACR-PCR method to its full extent. For this reason, initially potential correlation between the ACN and ACR indexes expressing the impact of aircrafts is investigated, along with the potential transferability of the expression of pavement bearing capacity from the existing ACN-PCN system to the upcoming ACR-PCR system. The investigation is completed with practical applications, which are considered useful for airport authorities. With the analysis phase of the investigation completed, the aim of the investigation was achieved. In the current paper, the overall procedure followed is presented in detail and the related findings are discussed.

2. Methodology

In order to meet the research aim, the methodology illustrated in Fig. 1 was followed. Initially the basic principles of the two reporting systems ACN-PCN and ACR-PCR are briefly described and compared in order to indicate the main differences on a theoretical basis. Then the numerical values of ACN and ACR indexes for several aircrafts selected from the Federal Aviation Administration (FAA) database are compared in order to investigate potential correlation between them. The next stage of the investigation includes estimation of the PCN and PCR index for 28 flexible airfield pavement cross-sections designed using the most resent pavement design techniques of the FAA [9]. Then, the two reporting systems were implemented on two flexible airfield pavements in order to derive useful practical remarks.

Critical aspects arising from each stage of the analysis are presented and useful findings are discussed.

2.1. The ACN-PCN method

The ACN-PCN method is a practical tool that has been used for airfield pavement management for many years. The ACN number is a unique number that is utilized in order to express the relative effect of individual aircrafts on a pavement structure for a specified standard subgrade strength. This number varies according to pavement type (flexible or rigid) and subgrade strength. In order to define the landing gear-pavement interaction a Derived Single Wheel Load (DSWL) is utilized. The DSWL is considered to imply equal stress to the pavement structure with that of a given aircraft landing gear, eliminating the need to specify pavement thickness for comparative purposes, as stated in [10]. For flexible pavements, this is achieved by equating the thickness derived for 10000 coverages of a given aircraft landing gear to the thickness derived for the DSWL at a standard tire pressure of 181 psi (1.25 MPa). It is noted that aircraft coverages refer to the passages required to apply one full load application to a unit area of the pavement. The ACN is then defined as two times the DSWL (expressed in thousands of kilograms). Especially for flexible pavements, thickness determination is based on the California Bearing Ratio (CBR) method. For rigid pavements, thickness is determined by the Westergaard solution for a loaded elastic plate on a Winkler foundation, assuming a concrete stress of 399 psi (2.75 MPa) [10].

The PCN expresses the load carrying capacity of the pavement and uses a five-coded format in order to optimize the provided information for the pavement. More specifically, the PCN code includes: the PCN numerical value, the pavement type, the subgrade category, the allowable tire pressure and the method used to determine the PCN. The type of pavement can be characterized as either flexible (F) or rigid (R). As far as the pavement strength category is concerned, the method includes four pavement subgrade categories based on the CBR of the subgrade for flexible pavements or the modulus of subgrade reaction (k) for rigid pavements. Particularly for flexible pavements the corresponding categories are: A (High, CBR $\geq$13), B (Medium, 8<CBR<13), C (Low, 4<CBR≤8) and D (Ultra Low, CBR≤4). For the maximum allowable tire pressure there are four categories: W (High – No pressure limit), X (Medium - Pressure limited to 1.75 MPa), Y (Low- Pressure limited to 1.25 MPa) and Z (Very Low- Pressure limited to 0.5 MPa). As far as the method used is concerned, 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 for unrestricted operations. It is noted that there is not a unique method for PCN determination, since ICAO has not specified any guidance on how to determine PCN. So it is up to the airport authorities to decide on the method to be used. There are many procedures accepted worldwide for PCN determination, which may lead to different PCN values, as stated in [2]. One of the procedures used worldwide for PCN determination is the one developed by the FAA [10].

2.2. FAA method for PCN determination

The most recent FAA methodology for reporting the bearing capacity of airfield pavements was introduced in 2014 [10]. This method is based on the CBR method and it is implemented through the COMFAA 3.0 software. COMFAA contains an aircraft library with the majority of commercial and military aircrafts currently in operation, while new aircraft configurations can also be added.

According to the FAA, the traffic mixture is converted to equivalent annual departures of one representative aircraft. For this reason, the Cumulative Damage Factor (CDF) concept is utilized, which is derived from Miner's Rule and assumes that the damage developed in pavement is proportional to the number of imposed load applications, divided by the number of load applications until failure. It must be noted that during airfield pavement design and evaluation procedures, load applications are considered in terms of coverages.

In order to estimate the PCN of a flexible airfield pavement the thickness of the pavement under investigation is converted to a standard flexible pavement cross-section, consisting of an asphalt surface layer and an aggregate base layer with defined thickness and a subbase layer with variable thickness. Depending on the landing gear configuration of the aircrafts expected to use the pavement under investigation, two standard reference sections have been defined. In case the pavement under investigation has excess thickness than the defined for the asphalt surface layer and the aggregate base, the total pavement thickness may be increased by converting the excess material into an equivalent thickness, using the procedure presented in [10]. To facilitate the procedure, the FAA has developed an application that incorporates the procedure presented above for determining the pavement evaluation thickness.

2.3. The ACR-PCR method

The ACR-PCR method is structured on the same basis used for the development of the ACN-PCN method. In accordance with the ACN-PCN, the ACR is utilized in order to express the effect of individual aircraft on different pavements while the PCR expresses the load carrying capacity of the pavement.

Especially for flexible pavements, ACR is determined by Layered Elastic Analysis (LEA) method for each subgrade category. For ACR determination, a reference thickness for the given aircraft mass is estimated. It is noted that there are different reference pavement structures used, based on the aircraft landing gears. Especially for aircrafts with two or fewer wheels on all legs of the main landing gear, the reference structure consists of asphalt concrete layers of 76mm, a variable base course of crushed aggregate and the subgrade. For aircrafts with more than two wheels on any leg of the main landing gear the asphalt concrete layer thickness increases to 127mm. The thickness of the variable base layer is adjusted until the cumulative damage factor of the subgrade

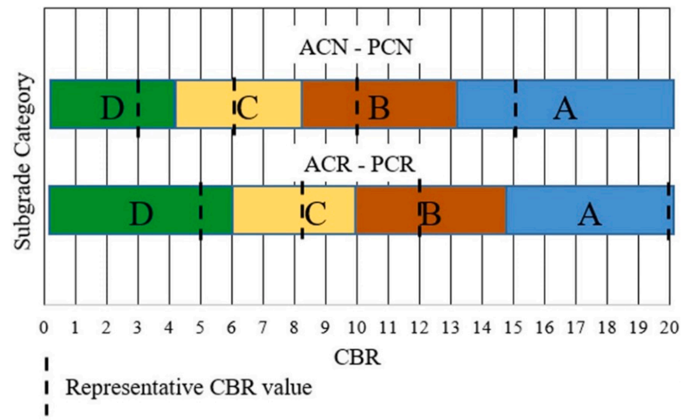

Fig. 2. Subgrade CBR categories for ACN-PCN and ACR-PCR systems.

(CDFsubgrade) is equal to 1.0 for 36500 coverages of the aircraft. The resulting thickness is the reference thickness for ACR. Using the above reference thickness and maintaining the constant tire pressure of 218 psi (1.50 MPa), the DSWL load magnitude is adjusted until the damage of the subgrade is equal to 1.0. The ACR is then defined as two times the DSWL (expressed in hundreds of kilograms). The ACR value of an aircraft can be estimated using the ICAO-ACR 1.32 tool [9].

The five-coded format of the PCR differs from that of the PCN mainly to pavement strength category. More specifically the method includes four pavement subgrade categories based on the modulus of elasticity (E) of the subgrade. Particularly for flexible pavements the corresponding categories are: A (High, E ≥150MPa), B (Medium, 150MPa-<E<100MPa), C (Low, 60MPa ≤E<100MPa) and D (Ultra Low, E<60MPa). Using the equation E(MPa) = 10 × CBR, the range of these categories may be expressed in terms of the subgrade CBR. Fig. 2 shows the different CBR ranges for each subgrade category using the ACN-PCN method and the ACR-PCR method. For each category the representative CBR value for each category is noted using a dashed line.

2.4. FAA method for PCR determination

In the framework of the present investigation, the methodology proposed by the FAA for PCR determination is used [11]. According to this, the PCR is estimated by converting the aircraft traffic mix using the pavement to an equivalent aircraft at maximum allowable gross weight, which will then produce a CDFsubgrade of 1.0 on the evaluated pavement. 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 CDFsubgrade of the aircraft mix is determined and the aircraft with the highest contribution to the maximum CDFsubgrade is considered as the critical aircraft. The annual departures of the critical aircraft are modified until the maximum aircraft CDFsubgrade is equal to the total CDFsubgrade. The critical aircraft weight is adjusted to obtain a maximum CDFsubgrade of 1.0 for this number of annual departures. This is the Maximum Allowable Gross Weight (MAGW) for the critical aircraft at which the ACR of the critical aircraft is then determined. The value obtained is the PCR. The above procedure has been incorporated in the analytical tool FAA Rigid and Flexible Iterative Elastic Layer Design (FAARFIELD) released in 2021 (version FAARFIELD 2.0) [12].

It must be noted that the CDF index calculated in terms of PCR, numerically is different from the CDF index used in the PCN method which is based on the CBR method, since it presents different theoretical background. According to analytical design and evaluation methodologies, for flexible pavements two modes of failure are considered. These are combined with the corresponding critical strains: a) the horizontal tensile strain at the bottom of the asphalt concrete layers and b) the vertical compressive strain at the top of the subgrade. For each mode of

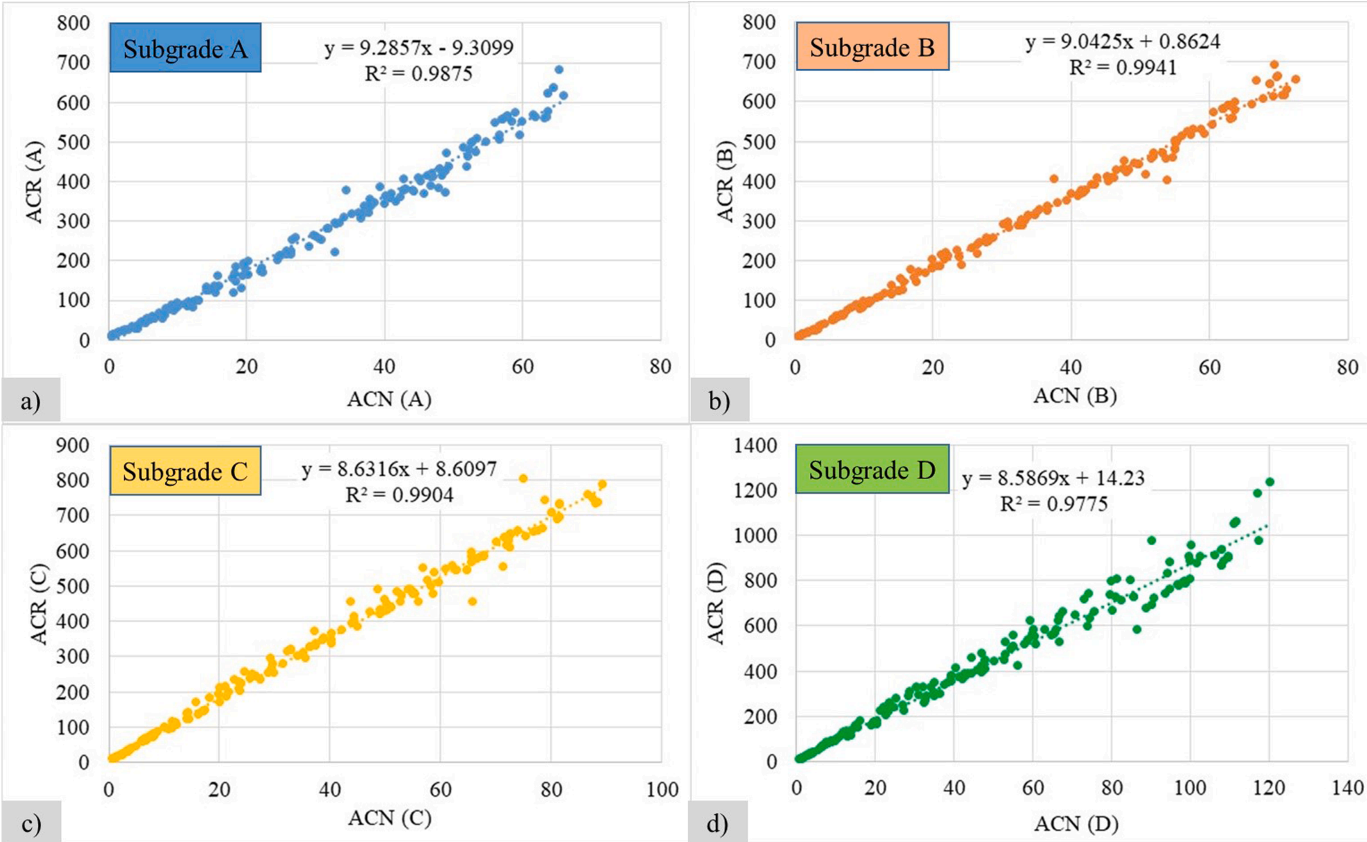

Fig. 3. Correlation between ACN and ACR for subgrade category: (a) A, (b) B, (c) C and (d) D.

failure, the CDF index is estimated using Eq. 1:

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

The applied coverages correspond to the traffic expected to use the runway's pavement for the design or evaluation period, while coverages to failure correspond to the number of allowable repetitions to failure. Coverages are defined from expected aircrafts passages using the pass-to-coverage (P/C) ratio that refers to the passages required to apply one full load application to a unit area of the pavement.

The Bleasdale failure model [13] used to estimate the number of coverages to failure for a given vertical strain at the top of the subgrade is given by Eq.2 when C > 1000 coverages and by Eq.3 when C ≤ 1000 coverages.

$$\log_{10}(C) = \left(\frac{1}{-0.1638 + 185.19 \times \varepsilon_z}\right)^{0.60586} \tag{2}$$

$$C = \left(\frac{0.004141}{\varepsilon_z}\right)^{8.1} \tag{3}$$

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

Although the PCR method is based on the CDFsubgrade, in the framework of the present investigation also the CDF of the asphalt concrete (ac) layers (CDFac) has been considered. In order to calculate the coverages to failure for the asphalt concrete layers, FAARFIELD 2.0 utilizes a model developed by Shen & Carpenter [14], which is based on the Ratio of Dissipated Energy Change (RDEC) concept. RDEC can be represented as:

$$RDEC = \frac{DE_{n+1-}\ DE_n}{DE_n} \tag{4}$$

where DE_n: the dissipated energy produced in load cycle *n*, and DE_{n+1}: the dissipated energy produced in load cycle *n*+1.

RDEC eliminates the dissipated energy that does not produce crack extension damage providing a realistic indication of the damage accumulation from one cycle to another. RDEC exhibits a Plateau Value (PV) after the initial unstable period, which then increases dramatically giving a sign of true fatigue failure. PV is uniquely interrelated with coverages to failure (N_f) through Eq. 5 and it practically implies that a relatively constant percent of input energy is turned into damage thereby representing asphalt concrete fatigue behaviour [15,16,17]. PV is estimated according to Eq. 6.

$$N_{f=}0.4801PV^{-0.9007} \tag{5}$$

$$PV = 44.422{\varepsilon_h}^{5.140}S^{2.993}VP^{1.850}GP^{-0.4063} \tag{6}$$

where: ε_h is the horizontal tensile strain at the bottom of the asphalt layer, S is the initial flexural stiffness of the material, *VP* and *GP* are volumetric and gradation parameters respectively, defined as $VP = V_a/(V_a + V_b)$ and $GP = (P_{NMS\_}P_{PCS})/P_{200}$. V_a is the air void content and V_b is the asphalt content by volume. P_{NMS} is the percent of aggregate passing the nominal maximum size sieve, P_{PCS} is the percent of aggregate passing the primary control sieve, and P_{200} is the percent of aggregate passing the No. 200 (0.075mm) sieve.

3. Results and discussion

The presentation of the analysis results begins with the outcome of the ACN-ACR comparison and proceeds with the remarks from the PCN-

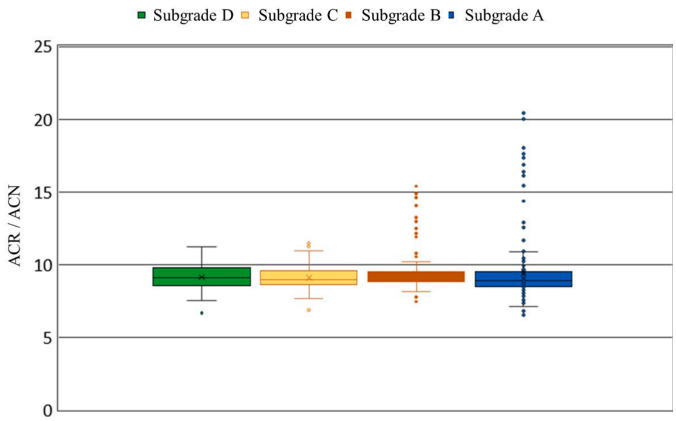

Fig. 4. Ratio of ACR/ACN.

PCR comparison. Then the observations from the practical implementation of ACN-PCN and ACR-PCR reporting procedures on two runway airfield pavements are presented.

3.1. ACN-ACR comparison

In order to investigate any potential relationship between the ACN and the ACR of an aircraft, about 170 aircrafts with different types of landing gear configuration were selected from the database of the FAA. The ACN values of each aircraft were estimated for four subgrade categories (A, B, C and D) using the COMFAA 3.0 analytical tool developed by FAA. Subsequently, for the same aircrafts the ACR value was estimated using the ICAO-ACR 1.32 tool. These values are presented graphically in Fig. 3. The coefficient of determination R^2 was then estimated for each subgrade category. The analysis results showed that there is a strong correlation between the ACN and the ACR values for all subgrade categories since the R^2 ranged from 0.97 to 0.99.

It is noted that the ACR numerical value is expressed in hundreds of kilograms, while the ACN value is expressed in tones, so ACR is higher than corresponding ACN by approximately one order of magnitude. This was intentionally defined in order to avoid confusing the two systems during the period of transition [8]. In the framework of the present investigation the ACR/ACN ratio was also investigated. On this basis, for the same set of the 170 aircraft data, the ACR/ACN ratio was estimated for each subgrade category. The distribution of the ACR/ACN ratio for each subgrade category is presented in Fig. 4 in the form of boxplots, where the internal line of boxplots refers to mean values. The results show that the ratio of the two indexes is not constant for each subgrade category and in most cases it is less than 10. However, there are cases where the ACR may be even twenty times higher than the ACN, as observed in case of subgrade category A.

In order to make an in depth investigation of the relation between the ACN and the ACR indexes, 32 aircrafts from FAA's aircraft library were selected having the same landing gear configuration (dual wheels). The ACN and ACR values for each subgrade category are presented in Fig.s 5, 6, 7, 8, where the aircrafts are ordered by ascending ACN for all subgrade categories. All four Fig.s show that the variation in ACN values does not follow the ACR variation, since it is observed that as the ACN increases, the ACR presents several fluctuations.

For convenience, the ACN –ACR values estimated for one subgrade category (Subgrade category A) were considered for further analysis (Fig. 8). As illustrated in Fig. 8, while the ACN value of the aircrafts increases, the ACR presents several fluctuations. However, it must not be overseen that the ACN is an index expressing the relative damage of an aircraft on a pavement and as such these fluctuations lead to the conclusion that the relative damage of some aircrafts is altered during the implementation of the updated ACR-PCR system. For example, the

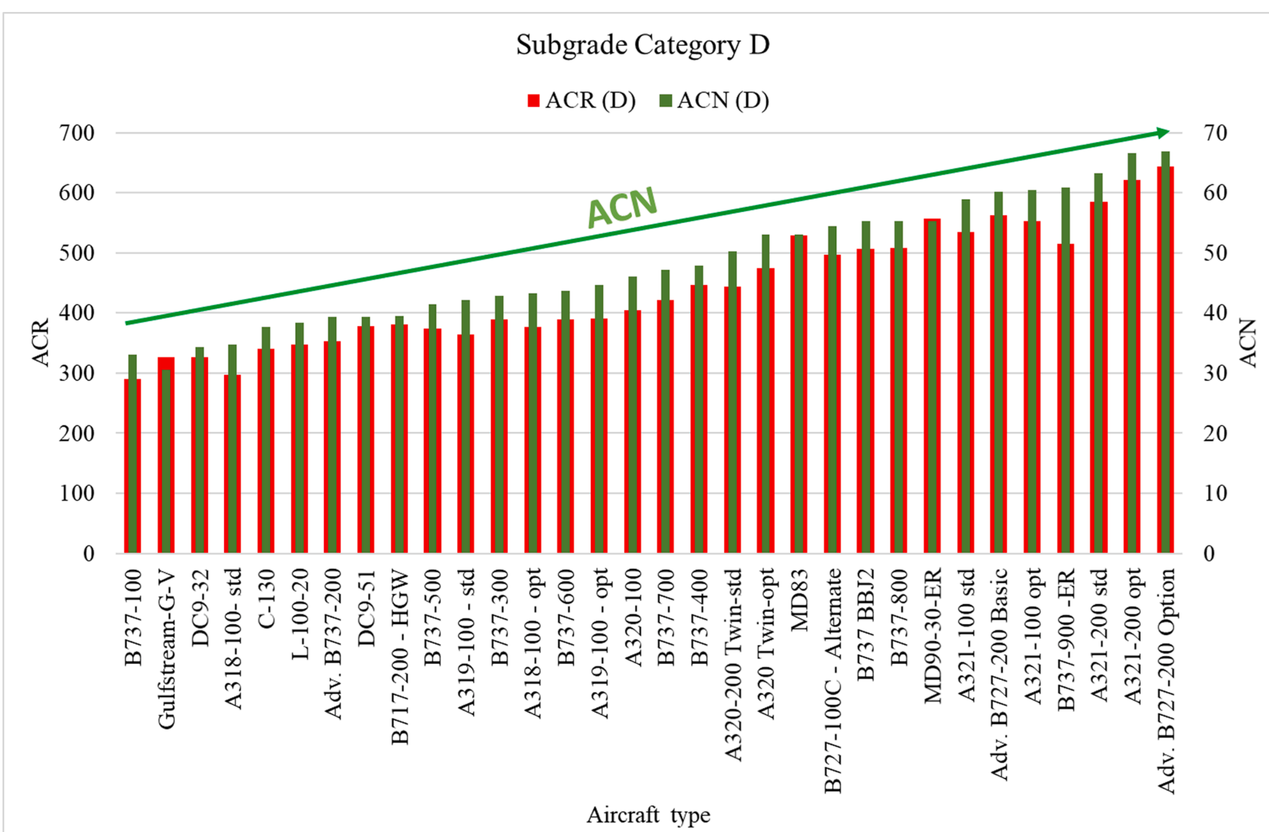

Fig. 5. Comparison of ACN and ACR values of aircrafts with dual wheel configuration for subgrade category D.

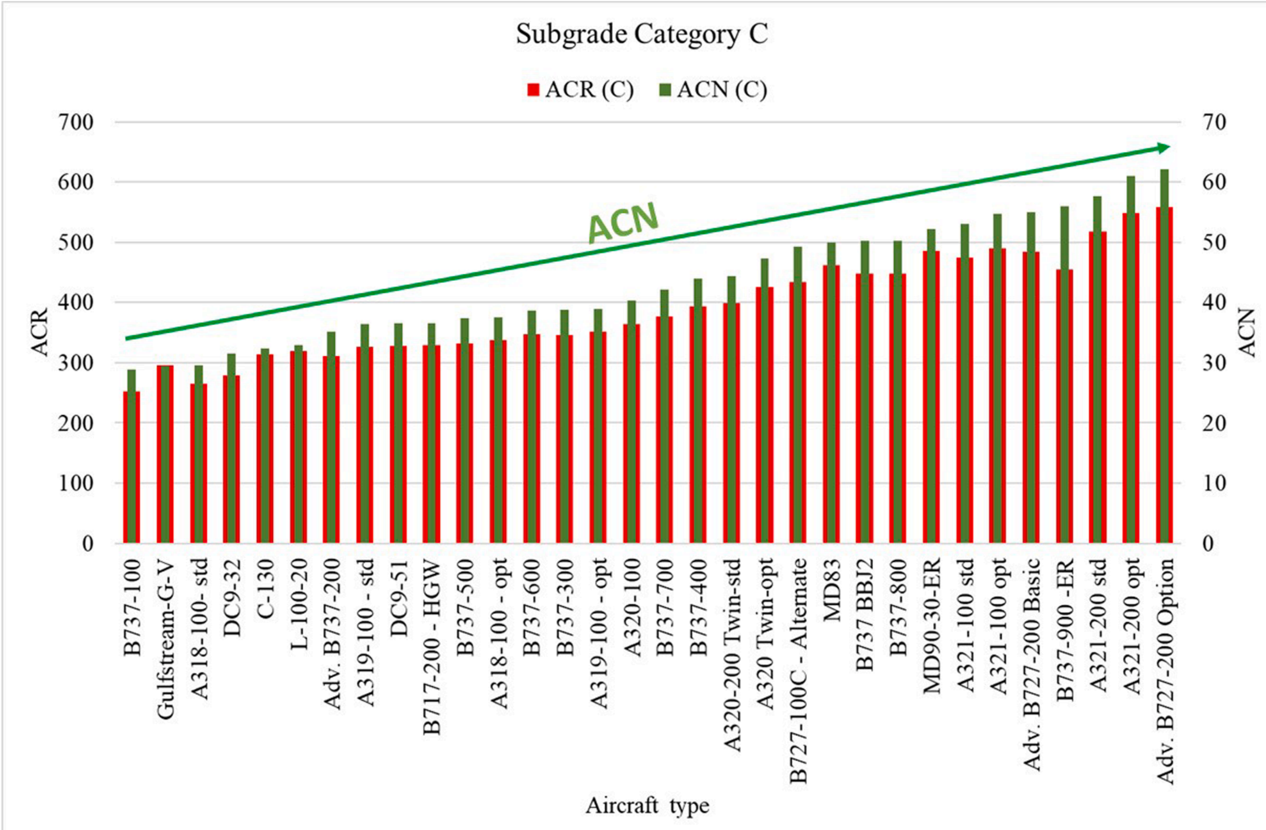

Fig. 6. Comparison of ACN and ACR values of aircrafts with dual wheel configuration for subgrade category C.

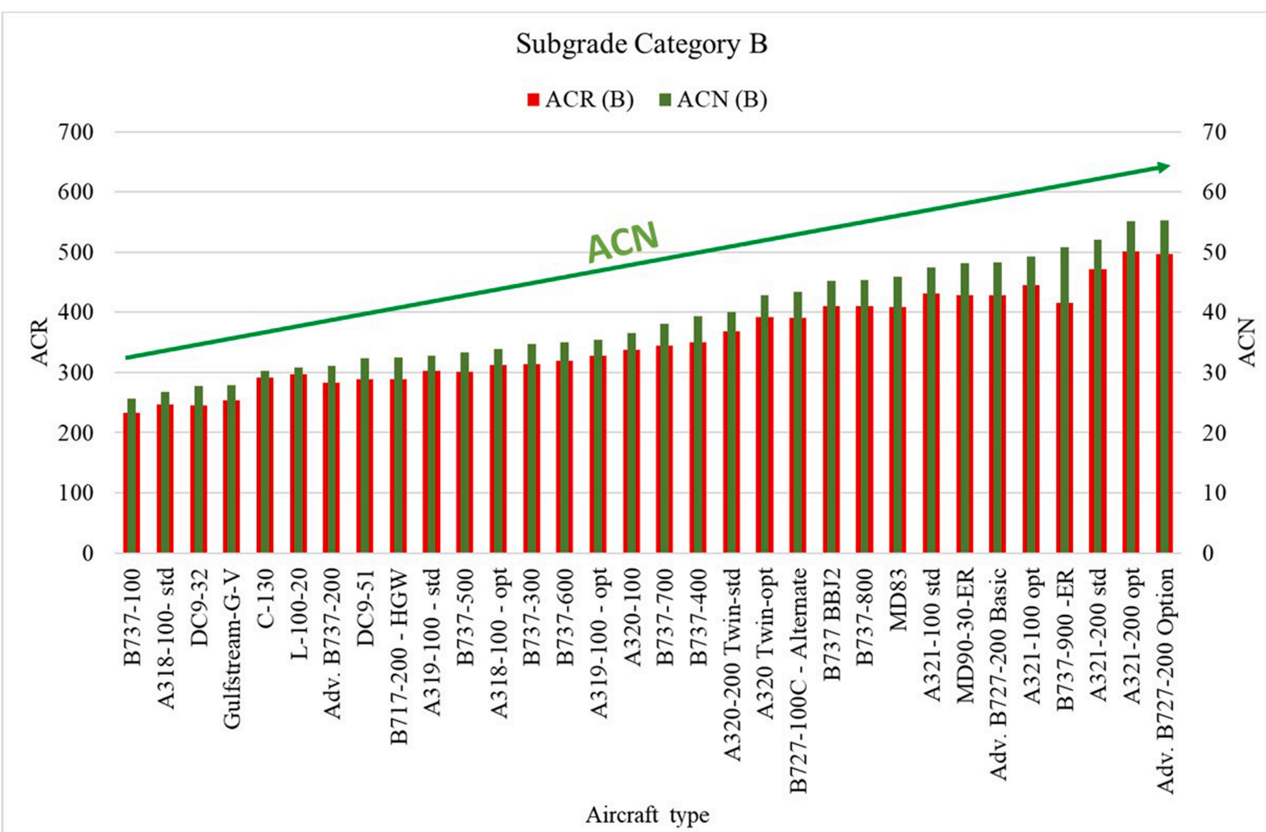

Fig. 7. Comparison of ACN and ACR values of aircrafts with dual wheel configuration for subgrade category B.

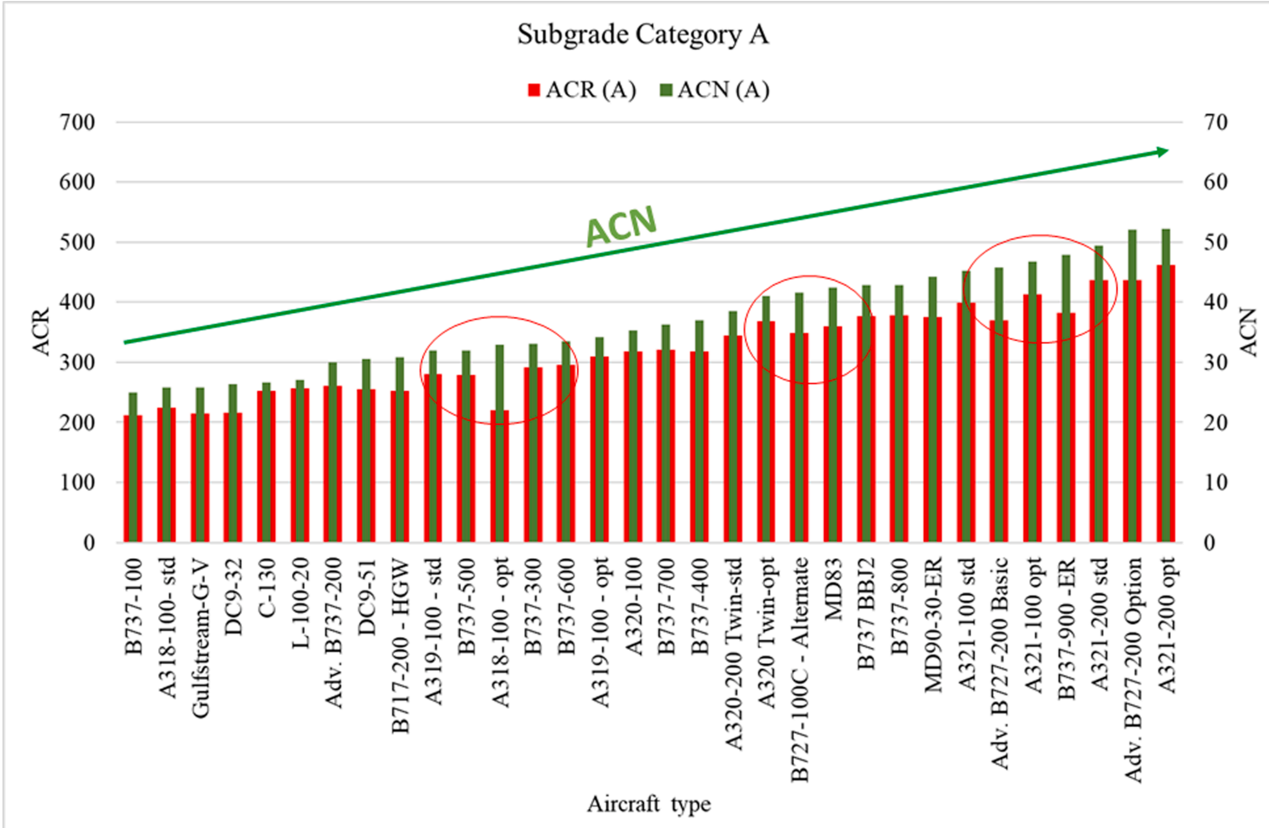

Fig. 8. Comparison of ACN and ACR values of aircrafts with dual wheel configuration for subgrade category A.

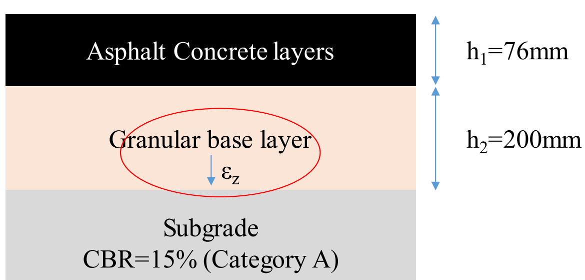

Fig. 9. Pavement cross-section for pavement response and CDFsubgrade analysis.

ACN value of the aircraft A321-100 is less than the ACN of the B737-900, while the ACR value of the A321-100 is higher than the ACR of the B737-900.

The above observations motivated the authors to investigate the ACN and ACR fluctuations in terms of the relative damage of these aircrafts and the related pavement response. In order to achieve this goal, a hypothetical flexible pavement cross-section was used, having the same layering and mechanical characteristics of the reference section used for ACR calculation (Fig. 9). The thickness of the granular base layer, which is variable during ACR calculation, was considered constant and equal to 200mm, in order for the response analysis to be meaningful.

For each aircraft, the vertical strain at the top of the subgrade and the corresponding CDFsubgrade assuming 1 annual departure was estimated, using the most updated analytical evaluation procedure developed by the FAA [9]. Since the CDFsubgrade index is affected by the number of annual departures, this parameter was considered to be fixed and equal to 1, in order to investigate the relative damage of each aircraft. For each aircraft the CDFsubgrade occurs using Eq.1 and Eq.3 along with the P/C ratio of each aircraft provided by FAARFIELD 2.0. The results are presented in Fig. 10, where it is observed that as the ACN of the aircraft increases for the subgrade category A (Fig. 8), there is a variation of the vertical strain which follows the variation of the CDFsubgrade. On the other hand, this variation seems to follow in general the variation of the ACR values of the aircrafts as it is depicted in Fig. 11.

Since the variation of the ACR follows the variation of the critical strain and consequently of the CDFsubgrade, the modelling used for the updated ACR-PCR reporting procedure is more appropriate compared to that used for the ACN. That occurs due to the fact that the ACR is consistent with the basic principles of the analytical design and evaluation procedures.

However, the above observations are not valid for all the aircrafts investigated. By observing Fig. 11 it occurs that the ACR variation does not follow strictly the vertical strain variation. Fig. 12 shows in detail the vertical strain and the CDFsubgrade with ascending ACR for nine aircrafts, where it is observed that aircrafts with higher ACR values may produce lower damage on pavement. For example, the A321-100opt having an ACR equal to 412 for subgrade category A, presents a lower CDFsubgrade than the aircraft B737-900 which has an ACR equal to 382 for the same subgrade category. Since these aircrafts present the same P/C ratio and annual departures, their damage is mainly influenced by the vertical strain at the top of the subgrade. So it is concluded that there are still inconsistencies through the implementation of the ACR-PCR system, as far as the ACR index is concerned.

From the above it occurs that further investigation is needed in order to improve the modelling used for ACR estimation. Moreover, as presented in Fig. 3, it seems that there is a strong correlation between ACN and ACR. However, based on Fig.s 5-8 it occurs that the variation of ACN does not follow the variation of ACR. This leads to the conclusion that the impact of several aircrafts is altered when expressed through the

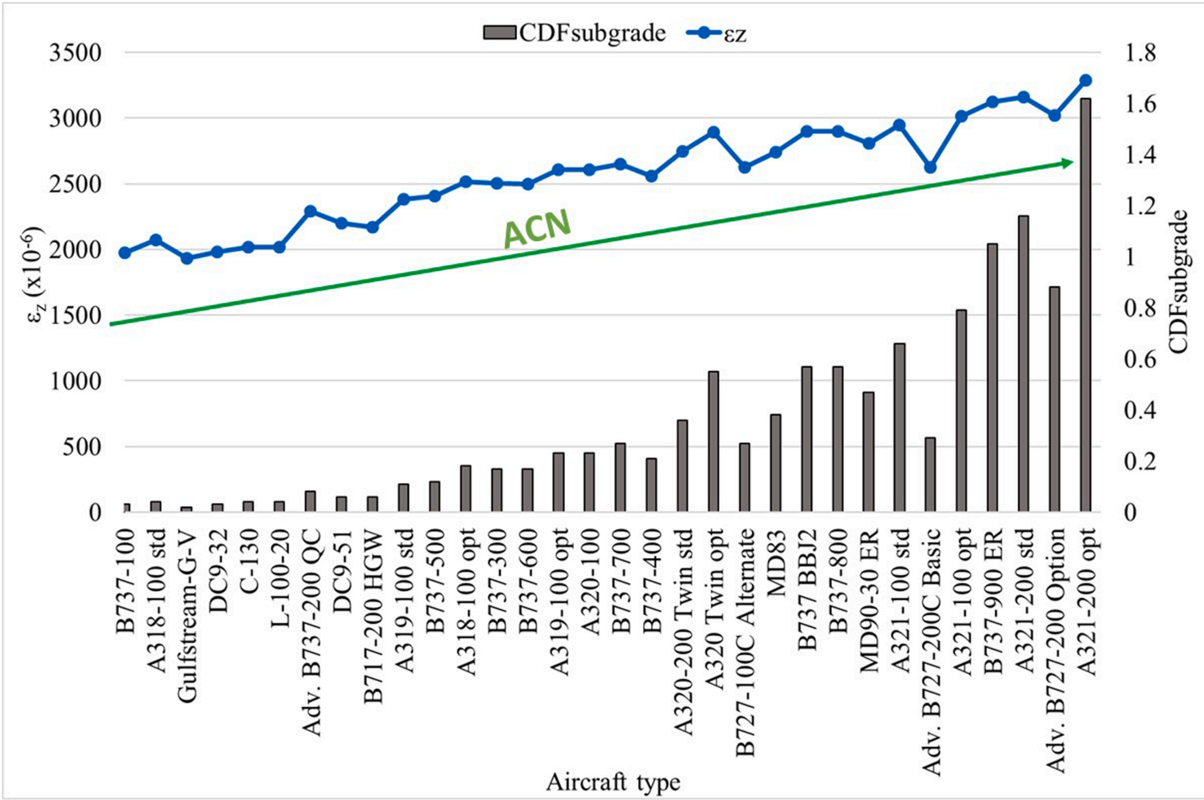

Fig. 10. Variation of vertical strain and CDFsubgrade with ascending ACN.

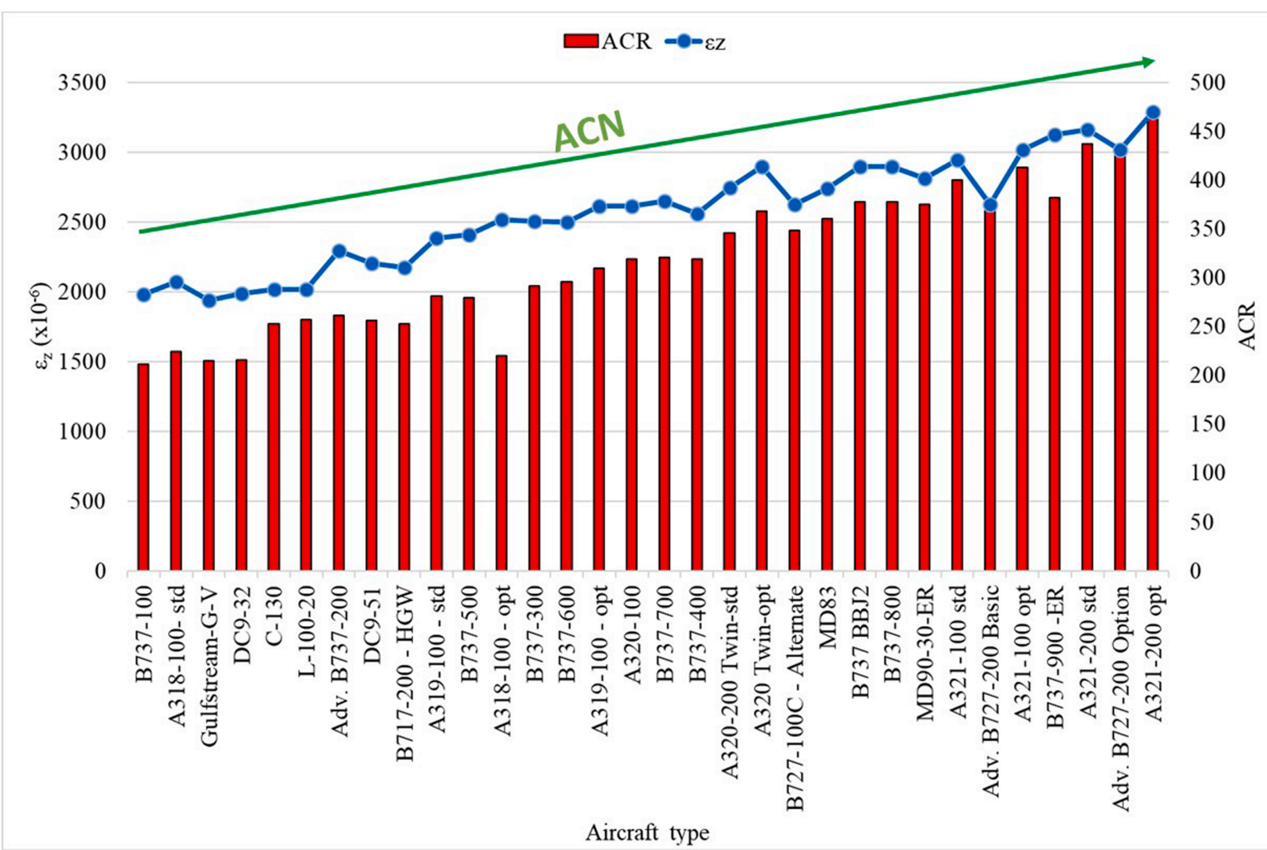

Fig. 11. Variation of vertical strain and ACR with ascending ACN.

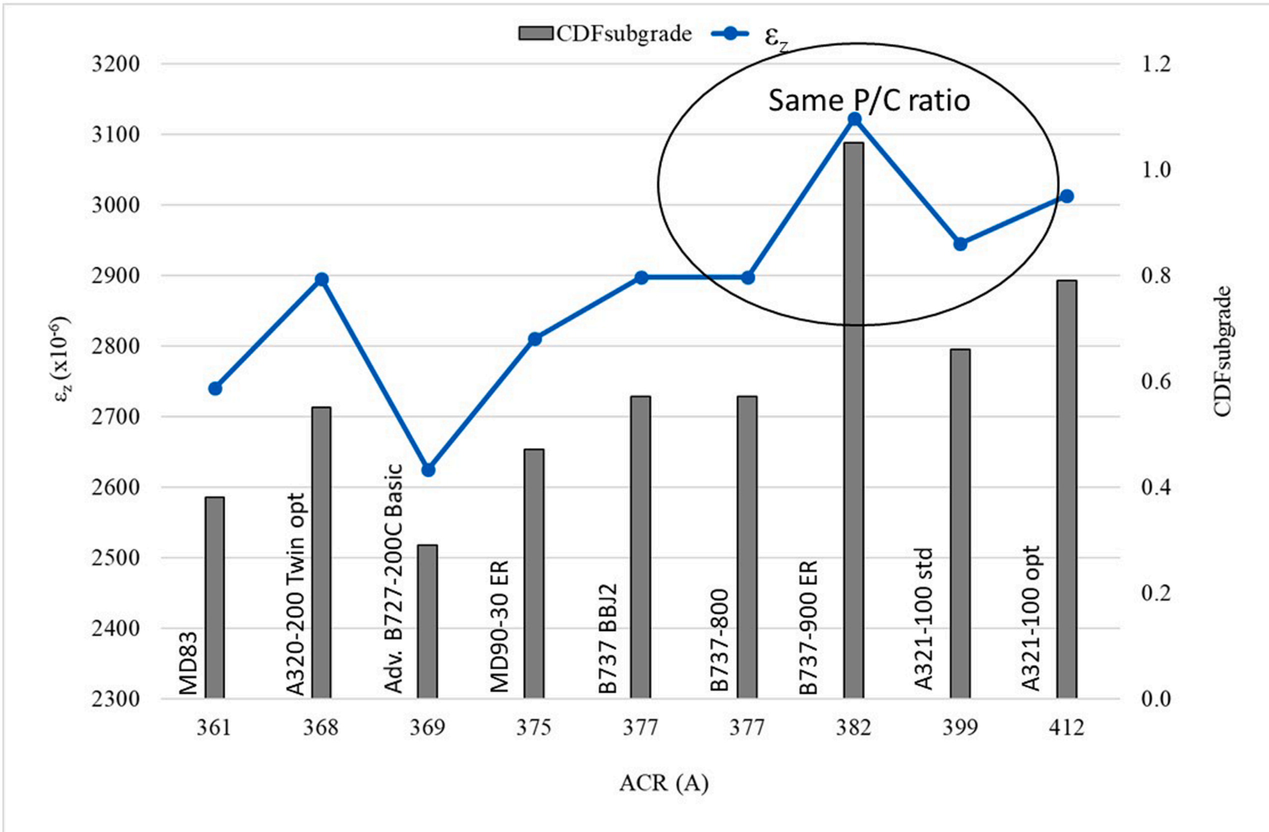

Fig. 12. Variation of vertical strain and CDFsubgrade with ascending ACR.

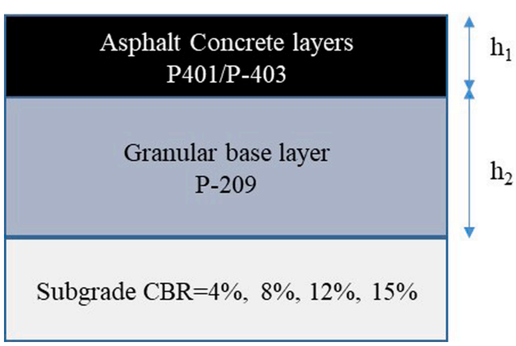

Fig. 13. Pavement cross-section used for sensitivity analysis.

Table 1
Aircraft fleet.

Aircraft type	Annual departures	Gross Taxi weight (tns)	Tire pressure (MPa)
B717-200 HGW	275	55.338	1.131
B737-300	518	63.503	1.386
B737-700	498	70.307	1.358
B737-800	12739	79.243	1.407
A319-100std	1116	64.400	1.190
A321-100std	2068	83.400	1.360
A321-200std	532	89.400	1.462
A320-200 twin std	10238	73.900	1.380

ACR compared to the ACN. Moreover, this difference varies with the subgrade category for the same aircrafts. These remarks reaffirm the suggestion of the FAA for estimating the ACR independently from ACN.

3.2. PCN-PCR comparison

Following the ACN-ACR comparison, the relation between the PCN-PCR was investigated. For this reason, 28 flexible pavement cross-sections were designed using the most recent analytical design procedure developed by the FAA [9] and the corresponding analytical tool (FAARFIELD 2.0) [12]. The typical pavement cross-section used for the design consisted of asphalt concrete layers, a granular base layer and the subgrade using typical FAA materials (Asphalt concrete P-401 and Granular base layer P-209) (Fig. 13). Four subgrade CBR values were considered for the design (CBR = 4% (D), 8% (C), 12% (B), 15% (A)). Because of the modification of the limits of each subgrade category with the new ACR-PCR system, the selection of the CBR values was performed in such a way that the CBR belongs to the same subgrade category, irrespective of the reporting system. For each subgrade category seven cross-sections were designed, by assuming that the thickness of the asphalt concrete layers equals to h_1=100mm, 120mm, 150mm, 180mm, 200mm, 250mm, 280mm and estimating the granular base thickness layer in order to achieve a CDFsubgrade=1 for an indicative traffic mix presented in Table 1. The loading characteristics of aircrafts are listed in Table 1, as retrieved from the aircraft library of the FAA.

Then the PCN and the PCR indexes of each cross-section were estimated based on the procedures presented in [10] and [11] respectively and the related results are presented in Fig. 14. The analysis showed that the PCR remained constant for the cross-sections with the same subgrade category and CDFsubgrade=1, while the PCN varied significantly. It is also observed that there is no correlation between the two indexes. Moreover, it occurs that pavement cross-sections with different PCN values, and consequently different strength, report the same bearing capacity based on the updated ACR-PCR reporting system.

Moreover, since it was observed that the PCR remained constant for

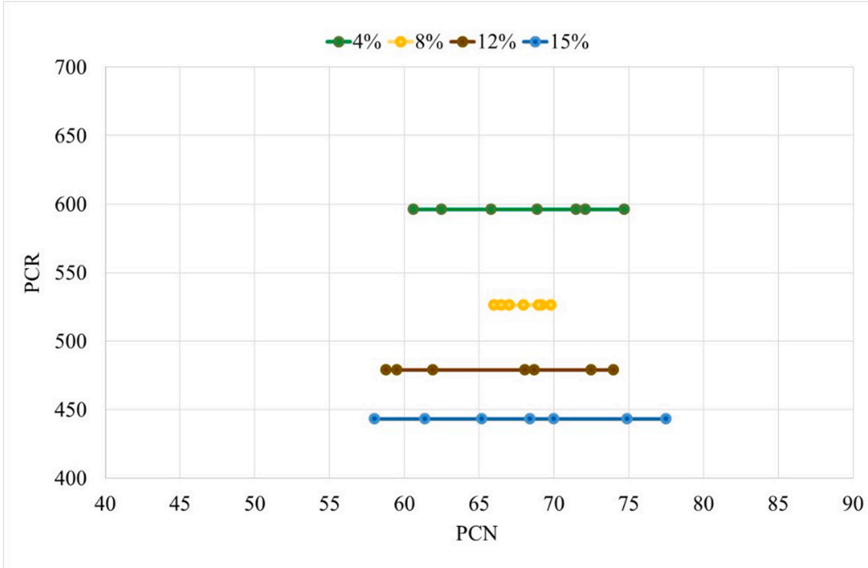

Fig. 14. Comparison of PCN and PCR.

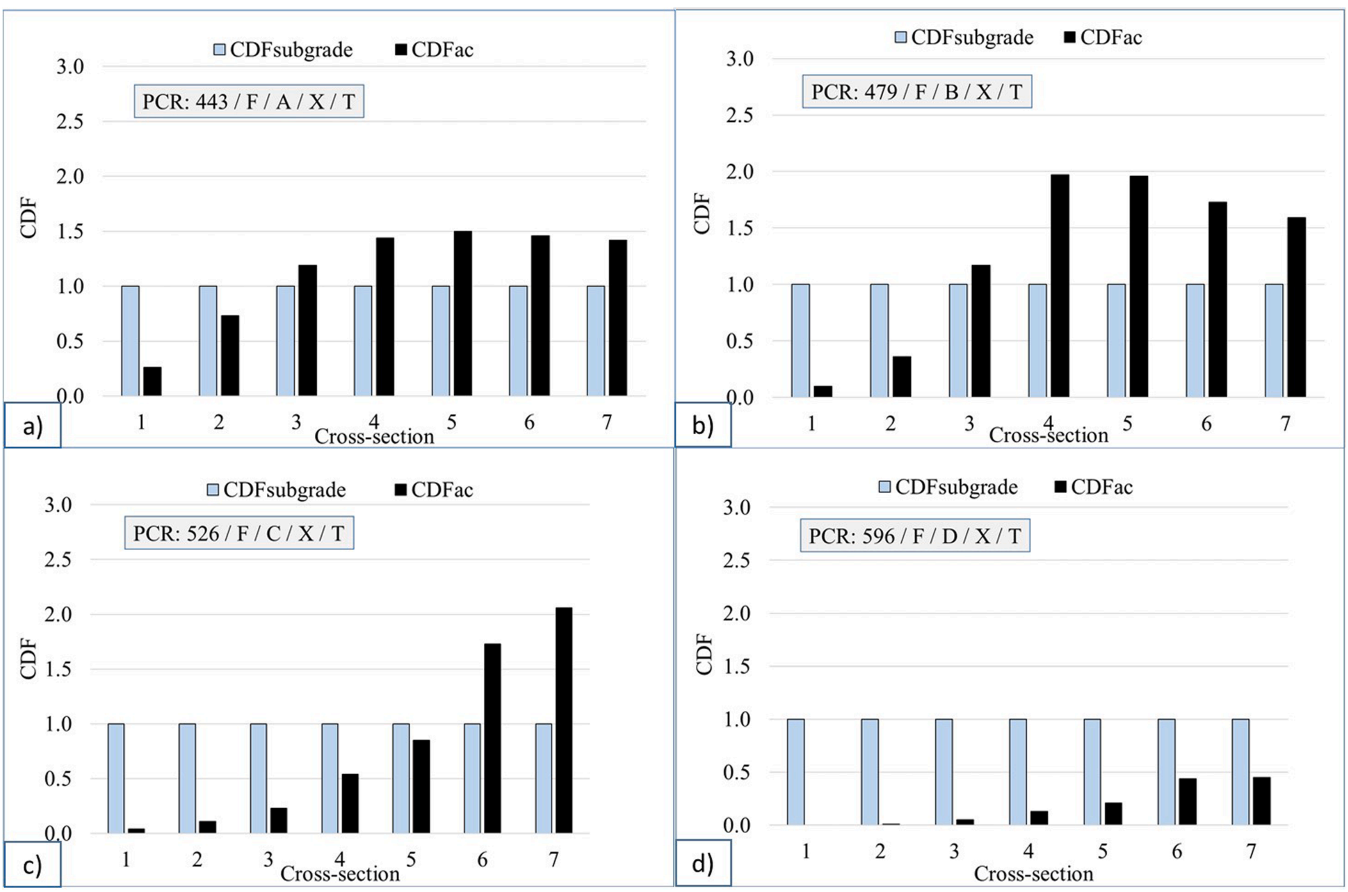

Fig. 15. CDFsubgrade, CDFac and PCR for cross-sections with subgrade category: (a) A, (b) B, (c) C and (d) D.

cross-sections with same subgrade category and CDFsubgrade=1, the CDFac for each cross-section was also estimated in order to investigate that mode of failure using the PCR system as well. The results of the investigation are presented in Fig. 15.

The analysis showed that since the ACR-PCR is structured to be based on failure of the subgrade, there might be sections having the same PCR and consequently reporting the same strength but nonetheless presenting either CDFac<1 or CDFac>1. On this basis, it occurs that the variation of the damage of the asphalt concrete layers cannot be depicted through the PCR index. However, although the ACR-PCR system cannot substitute detailed pavement evaluation procedures, it is intended as a method that airport operators can use to evaluate acceptable operations of aircrafts. Based on the above observations, it occurs that the acceptance of aircrafts having ACR values less than the

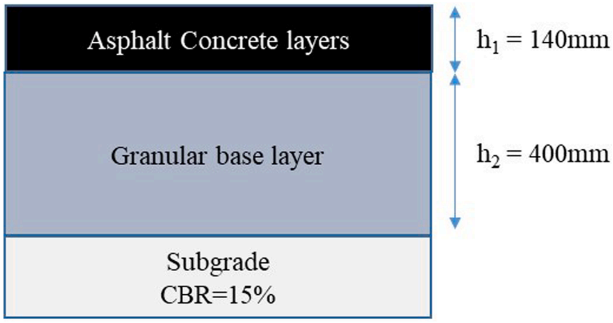

Fig. 16. Runway's pavement cross-section.

Table 2
Aircraft fleet.

Aircraft type	Annual departures	Gross Taxi weight (tns)	Tire pressure (MPa)
B737-300	1522	63.503	1.386
B737-700	3520	70.307	1.358
B737-800	15232	79.243	1.407
A319-100std	5522	64.400	1.190
A321-200std	3251	89.400	1.462
A320-200 twin std	19583	73.900	1.380

reported PCR of a pavement without weight restrictions could lead to potential extensive damage of the asphalt concrete layers, which can be expressed through the CDFac. Having in mind that the CDF index indicates maintenance or rehabilitation needs, one can notice the remarkable importance of detailed airfield pavement evaluation. This issue is considered to be determinant in the framework of decision-making in terms of airfield pavement management.

3.3. Implementation of ACN-PCN and ACR-PCR reporting procedures

In order to make an attempt to quantify the impact of the current evolutions on reporting the bearing capacity of airfield pavements, an additional investigation was performed, including the estimation of the PCN and PCR values for two runway's airfield pavements. Data collection utilised for the purpose of the research came from the flexible runway pavement of two regional airports with strategic importance for the southeast European area. The main criterion for the selection of the two airports was the differentiation of the subgrade category.

The primary pavement cross-section under investigation consisted of asphalt concrete layers of about 140mm thickness, a granular base layer of about 400mm and a subgrade layer of natural gravel. For the asphalt concrete layers, the typical FAA material (P-401) has been used for the analysis. For the granular layer, which presented a rather low modulus of elasticity value of 290MPa, the typical FAA material (P-154) was considered. Fig. 16 presents a representative cross-section of the pavement under investigation. The runway was expected to carry annually the aircraft fleet presented in Table 2 for a 20-year period.

Initially, since the subgrade CBR of the runway's pavement was equal to 15%, the subgrade was classified as belonging to subgrade category A. Then, following the technical evaluation procedure presented in [10], the PCN of the runway was estimated. In order to estimate the PCN of the flexible airfield pavement the thickness of the pavement under investigation (Fig. 16) was converted to a standard flexible pavement cross-section, consisting of an asphalt surface layer and an aggregate base layer with defined thickness and a subbase layer with variable thickness. Since none of the aircrafts in the traffic mix had four or more wheels on a main gear, the FAA recommends a reference structure assuming 3inches of asphalt concrete material (P-401) and

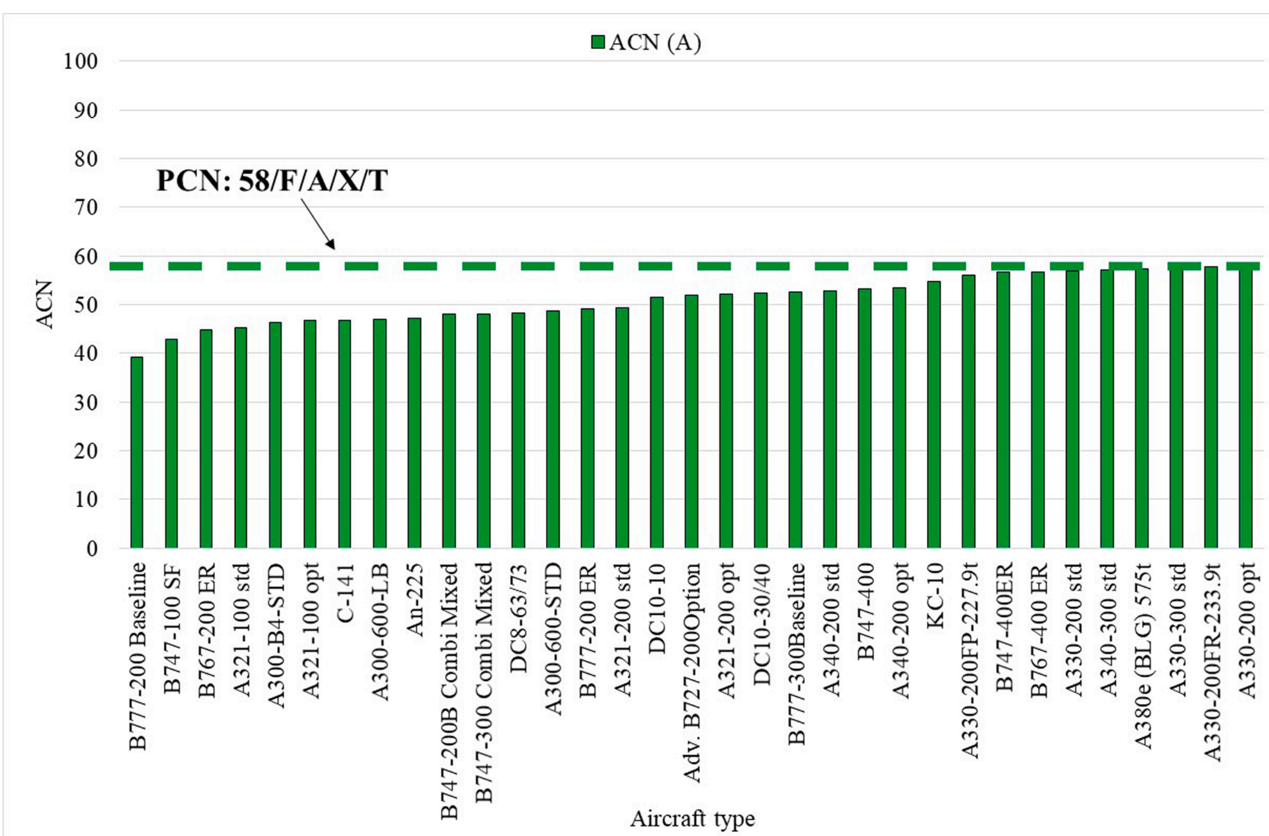

Fig. 17. Aircraft ACN values for subgrade category A compared to PCN.

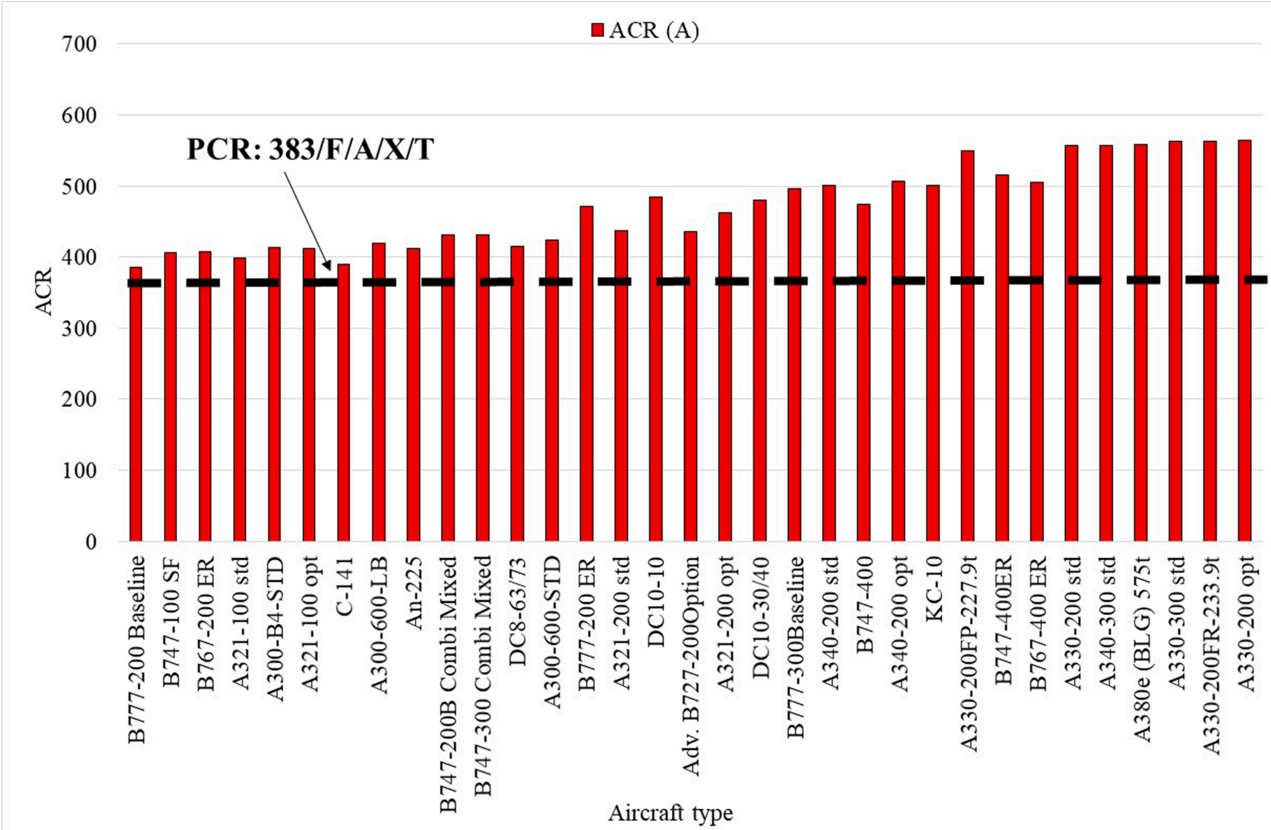

Fig. 18. Aircraft ACR values for subgrade category A compared to PCR.

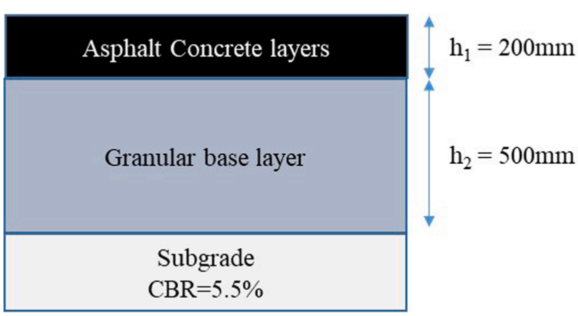

Fig. 19. Runway's pavement cross-section.

6inches of crushed aggregate base course (P-209) for equivalent thickness calculations [10]. Based on the above assumptions and following the related procedure developed by FAA, the runway's pavement cross-section of Fig. 16 was converted to an equivalent evaluation pavement thickness of 558mm. Based on this thickness, the subgrade CBR=15%, the traffic mix of Table 2 and using COMFAA 3.0, the PCN of the pavement was determined to be: 58/F/A/X/T. The critical aircraft for the calculation was the A321-200std having an ACN(A)=49.4.

Then the PCR of the pavement cross-section of Fig. 16 was estimated using FAARFIELD 2.0 and the technical evaluation procedure presented in [11]. By making the same assumptions considering the types of the materials and the traffic mix of Table 2, the PCR was estimated to be 383/F/A/X/T. In order to investigate the equivalence of these two indexes in terms of reporting the bearing capacity of the runway's pavement, the possibility of accepting the landing of several aircrafts was considered. For this purpose, 33 types of aircrafts having ACN values less than the reported PCN were selected, which means that the pavement could carry their loading without weight restrictions according to the PCN. The types of the aircrafts along with their ACN values are illustrated in Fig. 17. For these aircrafts, their ACR values were estimated and are presented in Fig. 18 along with the corresponding runway's pavement PCR value. The analysis showed that the ACR values of these aircrafts exceeded the reported PCR, meaning that according to the new system the runway pavement cannot accept operations of these aircrafts without restrictions. So it is illustrated that the PCR is not equivalent to the PCN and it seems to be more conservative during its implementation for this specific case.

Similar analysis was performed for another runway's flexible pavement having the cross-section of Fig. 19 and expected to carry annually the traffic mix presented in Table 1 for a 20-year design period. The pavement cross-section under investigation consisted of asphalt concrete layers of about 200mm thickness, a granular base layer of about 500mm and a subgrade layer of natural gravel. For the asphalt concrete layers, the typical FAA material (P-401) has been used for the analysis. For the granular layer, which presented a modulus of elasticity value of 520MPa, the typical FAA material (P-209) was considered.

Since the subgrade CBR of the runway's pavement was equal to 5.5%, the subgrade was classified as belonging to subgrade category C according to the ACN-PCN method, while based on the ACR-PCR method it was classified to subgrade category D. In order to estimate the PCN of the flexible airfield pavement the thickness of the pavement under investigation (Fig. 19) was converted to a standard flexible pavement cross-section, consisting of an asphalt surface layer and an aggregate base layer with defined thickness and a subbase layer with variable thickness. Since none of the aircrafts in the traffic mix had four or more wheels on a main gear, the FAA recommends a reference structure assuming 3inches of asphalt concrete material (P-401) and 6inches of crushed aggregate base course (P-209) for equivalent thickness calculations [10]. Based on the above assumptions and following the related procedure developed by FAA, the runway's pavement cross-section of

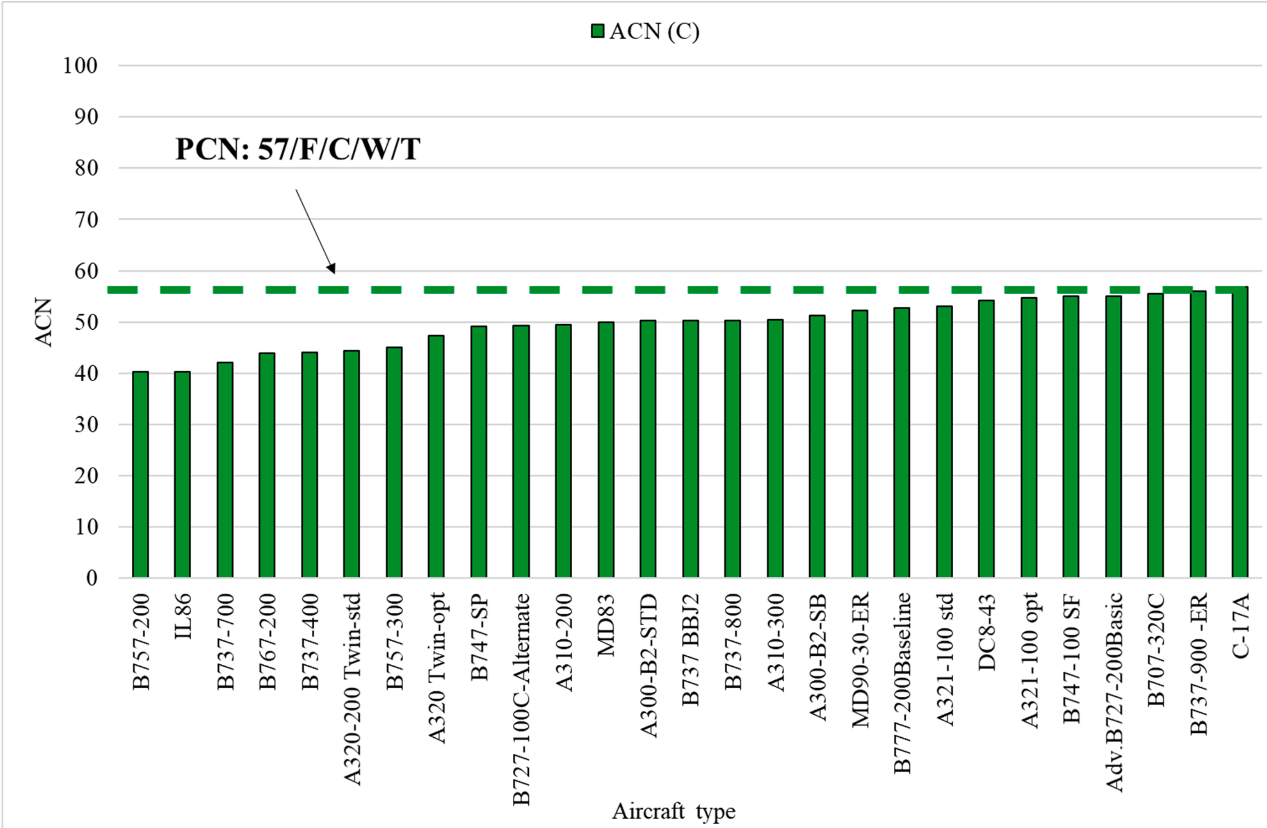

Fig. 20. Aircraft ACN values for subgrade category C compared to PCN.

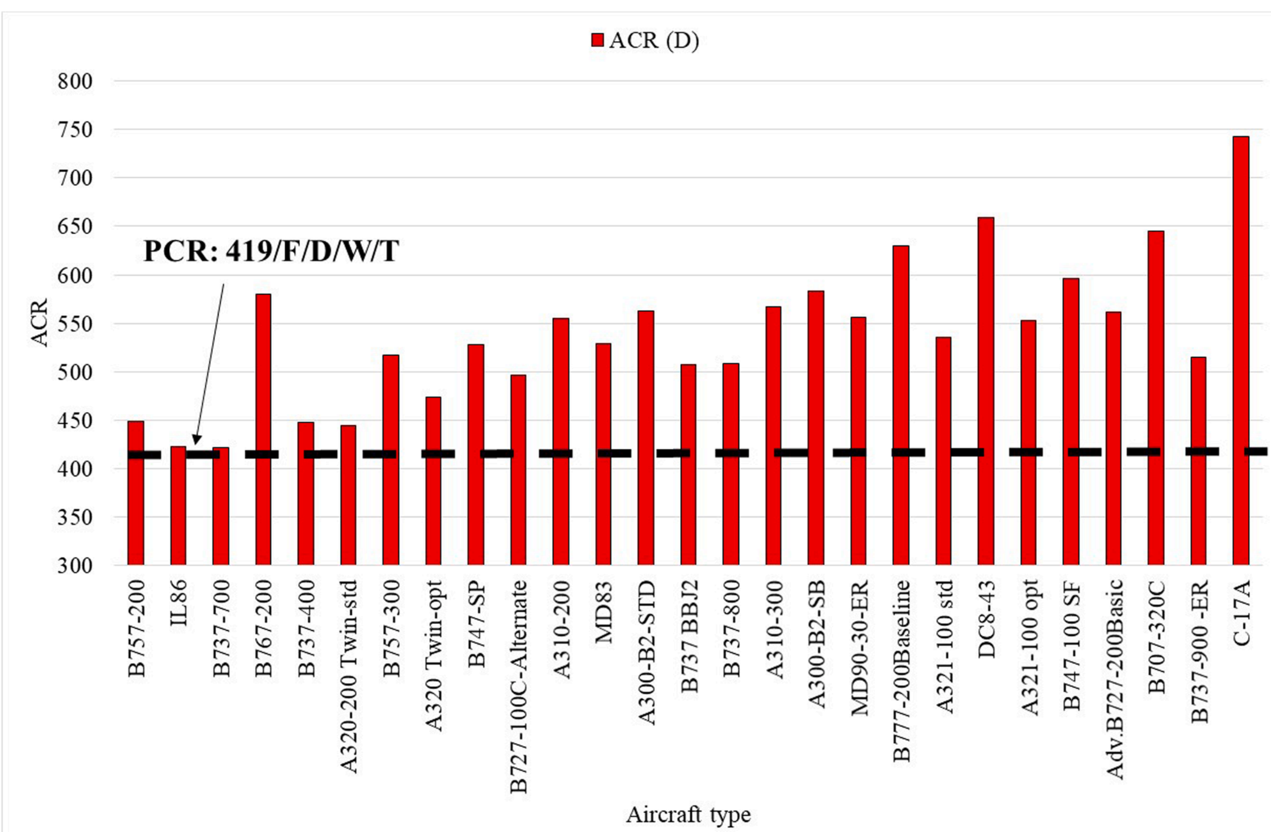

Fig. 21. Aircraft ACR values for subgrade category D compared to PCR.

Fig. 19 was converted to an equivalent evaluation pavement thickness of 992mm. Based on this thickness, the subgrade CBR=5.5%, the traffic mix of Table 1 and using COMFAA 3.0, the PCN of the pavement was determined to be: 57/F/C/X/T. The critical aircraft for the calculation was the A321-200std having an ACN(C)=57.6.

Then the PCR of the pavement cross-section of Fig. 19 was estimated using FAARFIELD 2.0 and the technical evaluation procedure presented in [11]. By making the same assumptions considering the types of the materials and the traffic mix of Table 1, the PCR was estimated to be 419/F/D/X/T. For this purpose, 27 types of aircrafts having ACN values less than the reported PCN were selected, which means that the pavement could carry their loading without weight restrictions. The types of the aircrafts along with their ACN values for subgrade category C are illustrated in Fig. 20. For the same aircrafts, the ACR values for subgrade category D were estimated and are presented in Fig. 21 along with the corresponding runway's pavement PCR value.

The analysis showed that the ACR values of these aircrafts exceeded the reported PCR, meaning that according to the new system the runway pavement cannot accept operations of these aircrafts without restrictions. Moreover, the ACR values of subgrade category D for these aircrafts presented significant fluctuations compared to the increasing trend of the ACN values of the same aircrafts for subgrade category C. It seems that the differences of the two indexes may be more intense for CBR values that correspond to different subgrade categories according to the updated subgrade clustering. From the above it occurs that the implementation of the reporting system plays an important role for airfield pavement management and decision-making, in terms of the acceptable operations of aircrafts.

4. Conclusions

The current research study investigates several aspects arising from the implementation of the upcoming ACR-PCR system, which is intended to fully replace the currently used ACN-PCN system for reporting the bearing capacity of airfield pavements. From this specific investigation it occurred that the ACR-PCR system is more consistent with the latest airfield pavement evaluation techniques, since detailed analytical procedures are incorporated for pavement evaluation. The index ACR used for expressing the impact of aircrafts on airfield pavements has been significantly improved, however further investigation might be needed in order to improve the modelling used, since this index still presents some inconsistences.

Considering the transferability between the two systems, although it seems that there is a strong correlation between ACN and ACR, the ACR must be estimated independently from ACN. Moreover, it seems that there is no correlation between the PCN and the PCR indexes and pavement cross-sections with different PCN values and consequently different strength, report the same bearing capacity based on the upcoming ACR-PCR reporting system.

Moreover, from the estimation of the PCN and PCR values of the runway flexible airfield pavement of two airports, it occurred that the PCR approach may be more conservative compared to PCN, in terms of the amount of aircraft loading that the pavement can carry. The above observations may create a useful path for further investigation, which can be extended, considering also different pavement cross-sections, aircraft fleets and material characteristics in order to be able to strengthen the above finding.

The analysis also showed that since the ACR-PCR is structured to be based on failure of the subgrade, the variation of the damage of the asphalt concrete layers cannot be depicted. However, it is believed that particular focus should be given on the asphalt concrete failure mode, since it may be crucial in terms of airfield pavement performance.

Since this is a transfer period until the full implementation of the updated ACR-PCR system, it is believed that the present investigation could be a useful tool in terms of airfield pavement decision-making practices. The present investigation may be also extended considering the implementation of the ACR-PCR system on rigid airfield pavement structures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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