The PCN Runway Strength Rating and Load Control System

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ABSTRACT: The Aircraft Classification Number / Pavement Classification Number (ACN/PCN) system has been adopted by ICAO as the standard for the international reporting of airfield pavement bearing strengths. The ACN, a relative number expressing the relative damage caused by an aircraft can be calculated using a prescribed ICAO method. By contrast with ACN, PCN assignment is not fixed by a prescribed technical method. At the instigation of CROW's Coordinating Committee on Airfield pavements, a study into PCN assignment has been undertaken (Ref. 1). The objective of the study is twofold. First to clarify on ICAO's ACN/PCN reporting system for civil airports, and present the status on ACN/PCN. The second objective is to investigate PCN assessment methods currently utilized by member states. The investigation has lead to a number of recommendations which can ultimately result in a standard method for PCN assessment for usage within the Netherlands and/or NATO practice. The assembled information can also be used by NATO nations or regulatory be prescribed by a nations Civil Aviation Authority to arrive at realistic and comparable PCNs.

KEY WORDS: Load classification, ICAO, ACN/PCN, PCN Assignment, Guidelines, NATO

1. THE ACN-PCN METHOD

1.1 Introduction

The Aircraft Classification Number / Pavement Classification Number (ACN/PCN) system has been adopted by ICAO as the standard for the international reporting of airfield pavement bearing strengths. The ACN-PCN system of rating airport pavements is designated by the International Civil Aviation Organization (ICAO) as the only approved method for reporting strength. The ACN-PCN method came into use in 1981. Although there is a great amount of material published on how to compute an ACN (Ref. 2 and 3), ICAO has not specified regulatory guidance as how an airport authority is to arrive at a PCN, but has left it up to the authority as to how to perform this task. This is a result of member states reluctance to agree on an international standardized method of pavement evaluation, but rather to rely on their own internally developed procedures. Acceptance of the ACN-PCN method itself resulted only from the omission of a uniform evaluation standard in that many states felt that their method was superior, and a change to another method would be costly in terms of study, research, development, field training, staff familiarity, and all other attendant concerns. As a consequence, there is a great amount of uncertainty among ICAO states that do not have well established evaluation methodology as to exactly how to arrive at a PCN and still be within the boundaries of whatever ICAO guidelines might exist. Additionally, without published ICAO standard recommendations on this subject, the determination of PCN has most certainly been anywhere from inconsistent to erroneous. To provide guidance on a national level, this paper discusses a study undertaken by CROW to explain the rating process and its principles.

1.2 The classification method

The engineering system used for the control of aircraft loadings on airside surfaces is the ACN-PCN method. The International Civil Aviation Organization (ICAO) (DOC 9157-AN/901 and Amendment number 35 to Annex 14, Ref. 2) devised the ACN/PCN method as an effective, simple, and readily comprehensible means for reporting aircraft weight-bearing capacity of airfields. The ACN-PCN is a reporting method for weight-bearing capacity introduced for world wide civil use in the mid-1980's. ICAO requires that the strength of pavements for aircraft with mass greater than 12,500 lb (5,700 kg) be made available using ACN-PCN method by reporting all of the following information (Ref. 2):

- Pavement Classification Number
- Pavement type
- Subgrade strength category
- Maximum allowable tire pressure category or maximum allowable tire pressure value
- Evaluation method

The ACN-PCN system is simple to use. Each aircraft is assigned a number that expresses the structural effect on a pavement for a specified pavement type and a standard subgrade category. Each airport operating authority reports site pavement strengths using the same numbering system. The pavement is capable of accommodating unrestricted operations provided the aircraft load number is less than or equal to the pavement strength number. Maximum tire pressure limitations may also be applied to some pavements which may further restrict certain aircraft operations. The ACN is based on the static application on aircraft loads to the pavement surface making them somewhat conservative in nature. Member States to ICAO are required to evaluate and publish the strength of airport systems using the ACN/PCN system. The national CAA publishes weight bearing limits in terms of ACN/PCN in a Flight Information Publication for civil and international use. The intent is to provide planning information for individual flights or multi-flight missions which avoid either overloading of pavement facilities or refused landing permission. The ACN and PCN are defined as follows:

1. ACN is a number that expresses the relative structural effect of an aircraft on different pavement types for specified standard subgrade strengths in terms of a standard single-wheel load.
2. PCN is a number that expresses the relative load-carrying capacity of a pavement in terms of a standard single-wheel load.
3. The system is structured so that a pavement with a particular PCN value can support, without weight restrictions, an aircraft that has an ACN value equal to or less than the pavement's PCN value.
4. ACN values will normally be provided by the aircraft manufacturers at maximum and minimum operational gross weight. The ACN has been developed for two types of pavements, flexible and rigid, and for four levels of subgrade strength.
5. The PCN value is for reporting pavement strength only. The PCN value expresses the results of pavement evaluation in relative terms and cannot be used for pavement design or as a substitute for evaluation.

The ACN-PCN system is not intended for the design nor for the evaluation of pavements, nor does it dictate the use of a specific method for the design or evaluation of pavements. To archive this, the system shifts emphasis from the evaluation of the pavement to the evaluation of aircraft loads. The concept of a single-wheel load has been employed as a means to define the landing gear assembly-pavement interaction without specifying pavement thickness as an ACN parameter. This is done by equation a fictitious pavement thickness, given by a mathematical model for an aircraft gear assembly, to the pavement thickness for a single wheel at a standard tire pressure of 1.25 MPa (181 psi).

The PCN number indicates the suitability of a pavement area for unrestricted operations by any aircraft that has an ACN and tire pressure not exceeding the limits reported in PCN format of stated pavement type and subgrade strength category. The method of PCN pavement evaluation is left up to the airport, under the approval of the regulating CAA. Some guidance to the selection of an appropriate PCN is provided in Chapter 3, ‘Evaluation of pavements’ of the Aerodrome design manual (Ref. 3). Although ICAO does not give specified regulatory guidance on how to determine a PCN, it states that the PCN must represent a relation between allowable load i.e. the ACN of the critical i.e. most damaging aircraft and the structural pavement life.

2. RECENT AND FUTURE DEVELOPMENTS

2.1 The ACN-Method under discussion

Aircraft designers, airliners and airport authorities feel that the present ACN procedure hampers the design of efficient airplanes, leading to downloading the operational mass and not using the aircraft and pavement to a maximum extend. In the early nineties Boeing stated that future aircraft such as B777 due in mid 1995, have ACNs that are significantly higher than that of critical aircraft such as B747-400 or MD12X. Considerably higher ACNs indicate problems with respect to the compatibility and acceptance since most International Airports have PCNs that equal the ACN of those critical aircraft. Under ICAOs rating system, B777 could therefore only operate with restricted operating masses. This problem especially affects flexible pavements, having a low or an ultra low subgrade strength. This message alerted ICAO and an international ACN study group (ACNsg) was formed in 1992. The problem with the current flexible ACN analysis is that it seems to overstate the overlapping stress between widely spaced wheels. Little benefit is given for the extra wheels of heavy modern landing gear designs. In the opinion of the members of the ACNsg, the present ACN procedure is outdated and should be revised completely using multi-layer elastic theory and should be verified by field tests.

In the ACN-procedure an alpha-factor is used to account for the load repetitions and coverage's for various landing gears in flexible pavements. For 10,000 coverage's, this factor is equal to 0,788, resulting in an overestimation of the damaging effect of six-wheeled landing gears. After having studied several options (a/o. Refs. 4, 5), ACNsg recommended in 1995 that an interim alpha factor of 0.72 at 10,000 coverage's is to be used for calculating ACN for 6-wheeled landing gears. Pavement longevity and the number of applied wheel loads are considered via this alpha factor. A reduced alpha-value or load repetition factor results in the ICAO ACN procedure in a smaller reference thickness at 10,000 coverage's. The alpha factor was changed from 0.788 to 0.720. As a result the ACN for B777 at subgrade category D, i.e. CBR 3%, drops from 131 to 106. The ACN of the B747-400 remains unchanged at 101. As a provisional measure and pending justification by full-scale pavement testing, the ACN values for six (6) wheel aircraft configuration including the Boeing B777 airplane, by default are computed using this modified interim alpha factor. The procedure for four (4) wheel aircraft configuration remains unchanged. The ICAO ACNsg has mainly concentrated on flexible ACN. However, an inconsistency can be reported in calculating rigid PCN too. The standard cutoff for rigid pavement is three (3) times the radius of relative stiffness. Wheels placed beyond this distance are left out of the ACN-calculation. This gives inconsistent results with large complex gear configurations such as the C-17 (high strength ACN higher than low-strength ACN). An option is therefore provided to change the cutoff.

A review of the current procedures for pavement design and evaluation undertaken by ICAO in 1997 indicated the inherent limitations of the procedures currently used for the design of aerodrome pavements for some types of new larger airplanes equipped with six or more wheels per strut (e.g. Boeing 777 and A380-800). A review of the other design methods available indicated the need to identify more mature and globally accepted procedures. In this context, full-scale research projects have been undertaken in Moscow, France and the U.S., which will contribute to the development of an alternate procedure, which is likely to be based on a mechanistic-empirical basis using layered elastic design approaches (LEA).

The basis for the current ACN-procedure are full-scale pavement test carried out in 1970. The tested pavements and loads were typical for that time era. At the initiative of FAA and Boeing the 1970 Multi Wheel Heavy Gear Load (MWHGL) data were updated with new full-scale pavement tests at the NAPTF in 2002. The National Airport Pavement Test Facility (NAPTF) was built to produce reliable pavement performance and failure data for a variety of pavement structures, subgrade strengths and landing gear configurations. Similar full-scale pavement testing had been performed at the MWHGL, using the same failure mode as in the MWHGL tests (deflection or upheaval at the level of the subgrade interface) was conducted at the NAPTF. The 21 billion USD program is funded and conducted entirely by the FAA and Boeing. Test runs were conducted on four (4) flexible pavements of variable thickness constructed over a CBR 3% subgrade. The Terms of Reference of FAA stated that the goal was to establish a definite alpha factor for six wheel bogies. The 2002 data from the NAPTP indicates by any measure and on any scale that the 6-wheel gear exhibits improved pavement loading characteristics as compared to 4-wheel performance. The resulting alpha factor of 0.679 at 10,000 coverage's is a clear indication of the improved load distribution characteristics of six-wheel gear aircraft.

Table 1 Alpha factor for 10,000 coverage's

Gear type	Alpha factor MWHGL	Interim Alpha factor	Alpha factor NAPTF
1-wheel	0.995		
2-wheels	0.900		
4-wheel alpha	0.825		0.776
6-wheel alpha (inception to 1995)	0.788		
Interim 6-wheel alpha (1995 to present)		0.720	0.679
Current 12-wheel alpha	0.722		

The ICAO ACNsg met in November 2003 to decide on a definite 6-wheel alpha factor. As can be depicted from Table 1, the NAPTF 6-wheeled alpha factor is smaller than the interim factor. Hence the ACN and pavement thickness requirement would also be smaller. Note that the alpha factor of the 4-wheel bogie is also smaller than that of the original MWHGL data too. Considering the lower NAPTF 4-wheel alpha factor, the meeting decided that revision of the 6-wheel interim factor without addressing the 4-wheel factor would lead to inconsistent ACN values. Revision of the latter would have a profound impact on the ACN-PCN system. The meeting adjourned with a new action: an investigative study into the impact that revised ACNs would have on current ACN-PCN method in light of the full-scale pavement load tests conducted by France and the United States.

The FAA responded on their position and recommends that the current alpha factor value for the 4-wheel gear configuration remain at the current value of 0,825 since final analysis from the FAA National Airport Pavement Test Facility (NAPTF) indicates that the current value is consistent with current and historical full scale test results. The FAA has prepared a final report titled "Alpha Factor Determination from NAPTF Test Data" which details the adjustments to total pavement thickness to establish equivalency with MWHGL tests (Ref 6). Based upon the conclusions of this report, the historical performance of real world pavements, and the realization that the test data unavoidable scatter, the FAA further recommends that the 6-wheel alpha factor be permanently established at the current interim value of 0,72 (Ref 7). It was decided that the alpha factors will not depend of the wheel spacing due to the data scatter.

2.2 More fundamental approach to ACN/PCN-procedure

It is now widely recognized that the Corps CBR method cannot adequately compute pavement damage caused by new large aircraft. Although the layered elastic method has been available for more than 20 years, it has not been used as a primary design method for aircraft pavements until recently. The requirement to understand pavement performance has resulted in a demand for accurate site testing systems that will allow accurate prediction of pavement deterioration with time and will ensure that any deterioration of the pavements is identified as early as possible so as to minimize the requirement for major reconstruction work.

It is believed that more advanced structural models are capable of better representing the response interaction from New Generation Aircraft (NGA) landing gears, but these have not been verified with field data. In 1999 the FAA's National Airport Pavement Test Project

Facility (NAPTF) initiated full-scale testing to establish mechanistic-empirical design criteria for the current trend in NGA gears. The FAA are proceeding with a US$ 50 billion pavement research project which includes extensive full scale accelerated tests to quantify the effects of more than four wheels on a strut and interaction effects between closely spaced struts. The (NAPTF) testing vehicle can simulate repeated loading by aircraft weighing up to 800 tons. Data from NAPTF will be used to develop advanced failure models that are applicable to the new generation of aircraft, including the six-wheel B-777 and future models.

Accurate analysis of the pavement response to a given aircraft load is necessary but not sufficient for design. In addition, it is essential to have reliable predictions of the failure of a pavement. In the advanced FAA design procedures, failure models are in the form of regression functions relating levels of strain produced by a passing aircraft gear to the number of coverage's to failure. The strain response is based on a mechanistic analysis such as the three-dimensional finite element method, while the failure models are based on traffic tests of full-scale pavement structures. Hence, this methodology belongs to the family of mechanistic-empirical design methods.
Calibrated design criteria are also being developed at the A380 Pavement Experimental Program (A380 PEP) in Toulouse (Ref. 8) and by Progresstech in Moscow which will contribute to the development of an alternate ACN procedure. The results of these full-scale pavement test facilities will also form the basis for a mechanistic-empirical design approach that can lead to a revision of the ACN-PCN rating system.

2.3 Advanced FAA pavement design tools under way

The FAA is currently developing a new generation of PC-based airport pavement design tools that will employ advanced computer programs based on the three-dimensional finite element method (FEM). These procedures will be capable of designing the future airport pavements to serve new aircraft types, including new large aircraft with 6 or more wheels per gear now in the conceptual stages. The three-dimensional FEM can handle greater detail and more complex characterizations of construction materials than can layered elastic analysis. It is particularly useful for modeling rigid pavements, since the slab edges and joints that are often the critical components in rigid pavements can be modeled directly, which is not possible in LEA (LEDFAA, Ref. 9). In addition, 3D FEM can incorporate nonlinear and non-elastic material models not available in LEA.

The FAA plans to produce a 3D FEM based design procedure (called FAARFIELD) as a new design standard for release in 2006. At the present time (2003), the FAA has developed a three-dimensional finite element structural model for rigid pavements (called FEDFAA) that provides automatic discretization of the structure and also incorporates key structural concepts such as finite slabs, joints, multiple structural layers and realistic interfaces between adjacent layers. The model incorporates existing 3D finite element software in the public domain (NIKE3D, originally developed by the U.S. Dept. of Energy's Lawrence Livermore National Laboratory.) This structural model has been extensively verified with in-service field data obtained from the Denver International Airport (DIA) instrumented runway project. A model comprising of an infinitely deep foundation based on special “infinite” elements is currently under development (FAARFIELD). Much work remains to be done before the developed 3D FEM structural model becomes part of a standard design program. Over the next several years FAA will:

- Extend the structural model to cover flexible as well as rigid pavements.

- Incorporate non-linear material models such as stress-dependent moduli for unbound layers.
- Develop suitable structural models for flexible and rigid overlays.
- Target the FEM model size to anticipated PC performance levels for the 2006 time frame.
- Integrate the structural model with suitable traffic models and failure criteria.
- Develop an easy-to-use interactive graphical user interface (GUI) for Windows based on the successful LEDFAA model.

3 NATO REQUIREMENTS AND PERSPECTIVE ON ACN-PCN

3.1 NATO moves towards the ACN-PCN system

NATO is in the transition from the LCN/LCG system to the ACN-PCN system. NATO wishes to determine in a reasonably short time a single methodology for establishing PCN values. NATO defines their military requirements for airfield pavement strength in terms of the Aircraft Classification Number (ACN), following the ICAO international system of load bearing strength reporting. Because ICAO lays down the method of determining ACN for both flexible and rigid pavements, this step has been achieved easily. NATO has published individual ACN values for the range of aircraft likely to use its airfields in Standard NATO Agreement 7131 ACN-PCN (STANAG; Ref. 10). NATO's has replaced the older Load Classification (LCN) system in NATO Criteria and Standards for Airfields with ACN.

NATO considers the reporting of three (3) load bearing strength values. A standard PCN is used to compare bases within NATO. A mission PCN is used to manage pavements at the local base, whereas a contingency PCN is used for mission planning. For NATO nations or individual civilian airport authorities, PCN values are determined as an extension of existing national pavement design and evaluation technologies. Since NATO is an Alliance of nations, such an approach would lead to uneven consequences. Many of its pavements are constructed using common funding provided by the Nations as a whole. The NATO Airfield Services Working Group (ASWG) has discussed on several occasions a NATO wide methodology for determining the PCN. As no NATO STANAG for the evaluation of airfield pavements yet exists, the Netherlands proposed and submitted their national defense standard (Ref. 11) for enquiry as a possible STANAG for pavement PCN evaluation and reporting strength of NATO airfields. Since the military traffic is not precisely known, often a number of passes is used instead. The Dutch PCN is based on 10,000 passes (no lateral wander) of a fictitious PCN evaluation aircraft using a statistical concept to predict damage development. However, the U.S. Army and U.S. Corps of Engineers suggested to consider their evaluation method, which is in fact based on the empirical ICAO methodology for determining ACN (Refs. 12 and 13). The allowable load used for U.S. Air Force airfield evaluations is to be based on 50,000 passes of the C-17 aircraft to a theoretical "first crack". Several nations opposed the underlying design ICAO methodology of Refs. 12 and 13 for determining ACN, as suitable for extension into the determination of PCN. Layered approach is preferred, rather than the empirical Westergaard and CBR relations. The February 2003 ASWG meeting decided to let nations use their own national design theories to determine PCN. Though additional information such as the number of aircraft passes used to make the calculation must be provided (runway only). Nations shall provide the following information:
- Airfield name, runway(s) and PCN value(s);
- Type of aircraft for which the PCN values are based;
- Number of aircraft passes used to make the calculation.

The additional information allows NATO to use the U.S. evaluation method to determine internal common and comparable NATO airfield strength values as required. The ASWG meeting also recognized the layered elastic method as the future NATO evaluation method to be used to determine a common pavement strength value. Hence, AEP-46a (Ref. 12) was ratified for limited time only and does not describe a NATO wide PCN assignment method. According to the U.S. representatives, introduction and implementation of a layered elastic PCN method to NATO will be feasible within a period of five (5) to six (6) years.

3.2 International Questionnaire on design and evaluation

It has been noticed that PCN assessment can be done in several ways. To gain insight in the methods used in the design, evaluation and PCN assessment of airfield pavement, the NATO ASWG and the CROW working group on ACN-PCN prepared a questionnaire. This questionnaire provided insight in the motivation for the choice of a certain design system and the experiences in practice. It should also lay bare a common need for improvement. Information was requested on the design methodology used, the conditions during construction, possible specific problems occurring with solutions etc. In brief: what are your experiences associated to design, evaluation and practice with airfield pavement?
The questionnaire has been distributed to the official NATO ASWG correspondence list and to known national Airfield Pavement Points Of Contact (APPOC's). Also active and corresponding members of CEN TC 227 Ad Hoc Working Group Airfields received the questionnaire. Furthermore this questionnaire was sent to a number of national airfield pavement experts and to airfield administrators. A total of twelve (12) respondents co-operated and replied to the questionnaire: Belgium, Czech republic, Finland, Germany, Hungary, Netherlands (two reactions), Portugal, United Kingdom, US Navy, US Army and Sweden. The questionnaire showed that NATO nations use different PCN procedures, mostly relying on national design procedures. The methods used vary from either fully empirical to mechanistic-empirical. As there is no common agreement to a NATO wide design and/or PCN evaluation standard, some respondents find it important that guidance is given on the characterization and assessment of material fatigue transfer functions as well as on the determination of pavement material properties. An inquiry of the U.S. Corps amongst several nations learned that the pavement design method used by individual nations lead to different pavement thickness (and PCNs). Consequently, different nations get different results. This, and the fact that the PCN reporting system does not reflect the actual pavement life are considered as shortfalls of the ACN-PCN system.

However, with the current World situation there is an increasing need for NATO standards with respect to airfield pavement design to support joint military operations. It is critical to mission planners that methods steps are taken to insure that global methods for reporting the structural capacity of an airfield are available. Several Nations have implemented mechanistic design/evaluation systems with criteria that appear to be yielding reasonable results. Many of these procedures are based on linear, elastic theory coupled with empirical relationships for relating computed stress/strain to allowable aircraft load. This approach is well understood and well documented. The elastic layer mechanistic/empirical methods are also very adaptable to new criteria. For example, it is not very difficult to add/remove/modify the criteria (fatigue relationships or transfer functions). This makes it attractive since results from continuing research and development could be incorporated as necessary. With the current emphasis and requirements for better design/evaluation methods, a NATO standard could be established that would be well accepted among the Nations.

4. DETERMINATION OF PCN

PCN assignments are related to design methologies. Inverse pavement design is often the basis for PCN assessment. In order to appreciate the different PCN methods in use, a brief introduction is presented regarding design concepts. As has been stated previously, the method of PCN evaluation is left up to the airport authority (or regulating CAA). Since the introduction of the ACN-PCN method in the early the eighties, pavement engineering and design has evolved enormously, thus the accuracy of a PCN evaluation rating has improved too. An established and industry recognized engineering method appropriate to the pavement construction type should be used to determine the structural capability of a pavement to support aircraft loads and traffic levels. However, in most states, PCN values are determined as an extension of existing national pavement design concepts and evaluation technologies. Although layered elastic methods has been available for more than 20 years, it has not been used as a primary design method for airport pavement classification and designs until recently. The majority of ICAO states and NATO nations use the empirical derived CBR-method and Westergaard equations for PCN evaluation.

Layered elastic design was first introduced in the mid 1980's and is quite common in Europe nowadays. It is because of the complexities of structural behavior and material properties that empirical procedures have endured for so long in pavement engineering. However, with the knowledge now available from research, a mechanistic-empirical procedure based on layered elastic design can be applied to asphalt and rigid pavements. Following the load input into the model, the stresses and strains are calculated at the design positions. For flexible pavements these are at the bottom of the bituminous layer (fatigue cracking), the top of the subgrade (rutting) and in a cement bound base at the bottom of this layer (reflective cracking). For concrete pavements the edge-loading position is critical. Stresses and strains are calculated at the edge position using Westergaard incorporating temperature induced stresses and the measured load transfer. By means of fatigue relationships or transfer functions the (residual) allowable number of standard axles and thus the residual pavement life is calculated. The assessment process also corrects the results for seasonal variations (eg. flexible material/concrete temperature, subgrade variations etc). Statistics can be used to predict the development of damage and indicate the reliability of assigned PCN values.

Public freeware and commercial layered elastic programs for pavement design are largely available: a/o NLAYER, NOAH, JULEA, BISAR, WESLEA, ELSYM5, CIRCLY, SPDM, UECSLAB, PAVERS, FEDFAA, LEDFAA, KENLAYER, KENSLAB, APSDS etc, etc, not to mention the huge number of Finite Element programs that are available. Some are special purpose airport pavement design programs (LEDFAA (www.airporttech.tc.faa.gov), winPCN (www.dynatest.com/software/acn_pcn.htm), PCASE (www.pcase.com), APSDS (www.mincad.com.au), UECSLAB (www.crow.nl), and PAVERS (www.pavers.nl), others are general purpose linear elastic design programs for calculating pavement response due to loads. The aforementioned programs must be considered expert tools, which allow the engineer to assign elastic properties to various pavement layers and use or define calibrated failure criteria for all pavement materials. An overview of the capabilities of a number of tools available in the public or commercial domain is presented in Table 2.

Table 2 Overview of capabilities of airport pavement software

Design theory	LED-FAA	WinPCN	PCASE	APSDS	UECSlab	PAVERS
Conventional Design						
- CBR-method [1)]	-	+	+	-	-	-
- Classical Westergaard [2)]	-	+	+	-	+	+
- PCN assessment	-	+	+	-	+	+
Linear Elastic Design						
- Flexible multi-layer	+	-	+	+	-	+
- Rigid multi-layer	+	-	+	-	-	+
- Slab-on-Grade model	-	-	-	-	+	+
- Traffic library	+	-	+	+	+	+
- Fatigue function library	-	-	-	+	+	+
- Back-calculation FWD-data	-	-	+	-	+	+
- Lateral wander	+/-	-	+/-	+	+	+
- PCN assessment	-	-	+	-	+	+

1) ICAO ACN-program based on S-77-1 (Ref. 4); [2)] ICAO ACN program based on PCAs PDILB program (Ref. 5)

5 ASSIGNMENT OF THE PCN

A number of methods (Ref. 14) can be used by an airport authority to determine the rating of a pavement in terms of PCN. The first method discussed, known as the Using aircraft method, can be applied with limited knowledge of the existing traffic and runway characteristics. The terminology Using aircraft simply means that the PCN is based on the aircraft currently and satisfactorily using the pavement, and there are no engineering methods or technical analysis employed to arrive at this sort of PCN. The second method, known as the Technical evaluation method, requires a much more intimate knowledge of the pavement and its traffic, as well as a basic understanding of engineering methods that are utilized in pavement evaluation in order to be successfully implemented. All of the factors that contribute towards pavement analysis, such as existing and forecasted traffic, aircraft characteristics, pavement design parameters, and engineering experience are applied in arriving at an evaluation as a basis for determining PCN based on this method.

5.1 The Using aircraft method

The Using aircraft method is presented in the following steps. As mentioned above, this method can be used when there is limited knowledge of the existing traffic and runway characteristics. It is also useful when engineering analysis is neither possible nor desired. Accuracy of ratings based on using aircraft is by nature less than for a Technical evaluation, but PCNs can be assessed more quickly and with minimal cost. There are two basic steps required to arrive at a Using aircraft PCN:

1. Determine the airplane with the highest ACN in the traffic mix frequently using the runway. This is the critical airplane.
2. Assign the ACN of the critical airplane at commonly used load percentage as the PCN.

The pavement should tentatively be rated at the PCN of step 2, assuming that the pavement is performing satisfactorily under the current traffic. If the pavement shows obvious signs of distress, then this rating must be adjusted downward at the discretion of the airport authority. If the rating is lowered, then one or more of the aircraft will have maximum ACNs that exceed the assigned rating. This may require a restriction in allowable gross weight for those aircraft or consideration of pavement strengthening.

5.2 The Technical evaluation method

The Using aircraft method should be considered as, at best, a close approximation. This method was introduced in the ACN-PCN method for general world-wide acceptance of the method. The Technical evaluation method of determining PCN should be used when there is reliable knowledge of the existing traffic and pavement characteristics or when heavier aircraft are expected. No need to mention that accuracy of ratings based on a technical evaluation is better than based on the using aircraft method, but at a greater cost in terms of financial expenditure and time. The PCN better reflects existing conditions when based on the technical evaluation method.

The PCN numerical value for a particular pavement is determined from the allowable load-carrying capacity of the pavement. Once the allowable load is established, the determination of the PCN value is a process of converting that load to a standard relative value. The allowable load to use is the maximum allowab1e load of the most critical aircraft that can use the pavement for the number of equivalent passes expected to be applied for the remaining life.
No matter how good the pavement and load models might be, mechanistic-empirical data is still required to tie the life of a pavement to the computed stress or strain response. It is important to carefully calibrate the function so that the predicted distress can match with field applications. Implementation of calibrated design criteria into modern software tools allow the designer to access the full advantages of the layered elastic method, including treatment of wander, and quickly produce designs for complex aircraft mixes and layered structures that are consistent with the original design concept.

A summary list of the steps required for flexible pavements as based on the Technical evaluation method is as follows:

1. Determine the traffic volume in terms of type of aircraft number of operations of each aircraft that the pavement will experience over its life.
2. Convert that traffic into a single critical airplane equivalent.
3. Determine the pavement characteristics, including the subgrade CBR and pavement thickness.
4. Calculate the maximum allowable gross weight of the critical aircraft on that pavement.
5. Look up or calculate the ACN of the critical aircraft at this maximum allowable weight.
6. Assign the PCN to be the ACN of the critical aircraft at the allowable weight.

5.3 Showcase of PCN deviation

The table below shows that technical derived PCNs are based on different design theories. Consequently, different design methods give different PCN results. Note that according to these design methods, the evaluated pavement cannot adequately support the traffic mix (In case flexible PCN is lower than 64 and for rigid pavements PCN is lower than 75). Therefore it must be borne in mind, that the PCN is not only related to the origin of the design method used, but also to the experience of constructed pavements, the assigned pavement material properties and skills of the pavement engineers.

Table 3 Overview of PCN values

Origin Method	PCN	Code
Flexible Pavement		
- CBR method S-77-1	55	FBWT
- PCASE-CBR	78	FBWT
- PCASE-LEA	69	FBWT
- Shell 85%	86	FBWT
- Barker et al	56	FBWT
- U.S. Corps of Engineers	64	FBWT
- APSDS –MWHGL-data	43	FBWT
Rigid Pavement		
- PCA-PDILB	77	RCWT
- PCASE-Westergaard	75	RCWT
- PCASE-LEA	79	RCWT
- UEC (Ref. 36)	78	RCWT
- Domenichini (Ref. 38)	66	RCWT
- Corps of Engineers	81	RCWT
- Vencon 1992	71	RCWT

Note: Flexible ACN of B747-400 at MTOW/OEW is 64/22; Rigid ACN of B747-400 at MTOW/OEW is 75/25

6 DISCUSSION ON PCN ASSIGNMENT AND REQUIREMENT FOR HARMONIZATION

ICAOs ACN-PCN system does not dictate a specific design method for PCN assignment. Therefore, technical PCN values are often determined as an extension of existing national pavement design and evaluation technologies. As a consequence, the technical reported PCNs are likely to vary to a great extend.

There are a great number of sources that do have a profound influence on a technical derived PCN. Depending on the choice made in the technical PCN assignment, the PCN can vary over 200 per cent!. The list below is by far not complete, but merely gives an impression on the degrees of freedom in a PCN calculation:

- The PCN method used (either using aircraft or technical evaluation) for design or reconstruction;
- The use of empirical or analytical-mechanistic based methods;
- The evaluation method used in relation to the pavement damage and the preferred transfer relation;
- The pavement structural life accounted for in the PCN assessment i.e. level of traffic as well as the period of time to review PCN;
- The method to derive an annual traffic volume;
- A method to assign load pulses to account for stress or strain cycles due to multiple wheel arrangements with closely spaced wheels;
- The correctness or (lack of) fit of the design, or better say, evaluation method used (how well are our design methods);
- The test methods used to define pavement material characteristics and transfer functions;
- The method used to calculate statistical reliability.

As a continuation of this study, harmonization of the degrees of freedom in the analytical methods to be used is thought necessary. Harmonization is needed for standardization of the pavement models, the calculation steps, the assessment and/or selection of material characteristics (strength, transfer functions), the structural pavement life, the design criterion in relation to the true pavement damage, reliability concept as well as traffic and wander. Since sophisticated design tools already exist, it is recommended to concentrate on harmonization rather than developing software which is already available. In order to arrive at a comparable PCN strength rating on a national level, mutual agreement on the aforementioned engineering 'error' sources is necessary. The calculation steps, given in the previous paragraphs can be seen as a first step to a more uniform PCN reporting method for usage in the Netherlands. Such an agreement or Guidance will ultimately lead to an unambiguous PCN assignment method. The Netherlands Civil Aviation Authority can regulatory prescribe the PCN assignment method to be used by national experts and consultants.

Harmonization of PCN derivation must be addressed on a national level first. However, NATO also is moving towards a PCN method based on linear, elastic theory coupled with empirical relationships for relating computed stress/strain to allowable aircraft load. This offers the possibility for a joint development. This option should be pursuit towards the upcoming CROW European Airport Pavement Workshop to be held in 2005.

7 CLOSURE

It is important to have an unambiguous, generally accepted methodology for computing pavement damage, to allow airport pavement engineers to adequately design pavements to accommodate new aircraft, and to allow airlines to anticipate airport pavement weight restrictions in planning their operations and in deciding which aircraft to purchase. An established and industry recognized engineering method appropriate to the pavement construction type should be used to determine the structural capability of a pavement to support proposed aircraft loads and traffic levels.

ICAO does not dictate a specific design method for PCN assignment. As a consequence PCNs can vary depending on the evaluation method used. However, ICAO does relate PCN to the structural pavement life and the volume of traffic to be encountered. The PCN can function as a pavement management tool, and its selection is largely a business decision by the airport authority. However, since ICAO does give guidance on assessing a relation between PCN and pavement life this is not a license for the airport to assign a desired PCN. It is recommended that when an airport authority reports a PCN to CAA, they must also submit the underlying structural pavement life to the responsible CAA. The reported PCN should be reviewed, re-affirmed or re-determined at least every ten (10) years. As part of the review process, consideration should be given to re-testing the strength of the pavement. If the review results indicate that pavement strength values have changed, the airport authority should make the appropriate revisions to the PCN code reported in the AIP manual.

The PCN requirement for NATO differs from civilian use. NATO-PCN reporting requirement considers standard use, mission use and contingency. The NATO nations can use existing national pavement design and evaluation technologies to report PCN. Only one PCN per runway has to be reported, where the type of aircraft and number of passes for which the PCN value is based, must also be provided. The additional information allows NATO to derive the aforementioned requirements for NATO-PCNs from nations reported PCN data.

The standard ACN calculation, particularly in case of flexible pavements, is suspected to improperly model pavement loading of multiple wheel heavy loading landing gear of heavy aircraft. A more fundamental approach which shifts emphasis from CBR subgrade criteria to Linear Elastic Design seems appropriate. One of the benefits is that pavement-load interaction is analyzed for each aircraft and each layer rather than using equivalent passes of a critical airplane, giving more realistic results. As pavement design and evaluation technology evolves using Layered Elastic Analysis and calibrated failure criteria derived from material testing and full-scale pavement tests, pavement prediction performance, design and technical PCN improve. Nevertheless it should be borne in mind that, although layered elastic based procedures, a considerable amount of engineering judgment is still required. It also implies that the bearing strength should be determined by a professional engineer or engineering consulting firm experienced in the analysis of the bearing strength of airfield pavements with a proper understanding of the (local) pavement materials used, in determining their ability to support airport loads, and in assessing the effect that aircraft loads are likely to have on the future performance and condition of the pavement.

As a continuation of this study, the PCN study team felt that harmonization of PCN calculation method and its degrees of engineering freedom, as well as the analytical methods to be used is thought necessary. Harmonization is needed with respect to the pavement models, the calculation steps, the assessment or selection of material characteristics (transfer functions), the structural pavement life, the design criterion in relation to the true pavement damage, reliability concept as well as traffic and wander. Since sophisticated design tools already exist, it is recommended to concentrate on harmonization to arrive at PCNs, rather than developing already available software. The guidance can regulatory be prescribed by national Civil Aviation Authorities to arrive at reproducible and realistic pavement designs and comparable PCNs.

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