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A204: REEVALUATION OF PAVEMENT CLASSIFICATION NUMBER METHOD FOR RIGID AIRFIELD PAVEMENTS

LIU, Yao-Bin
Pavement Engineer, T.Y.Lin Taiwan, Inc.
12F, No. 136, Sec. 3, Jen-Ai Rd.,
Taipei, Taiwan
ybliu@tylin.com.tw

LEE, Ying-Haur
Professor, Dept. of Civil Eng., Tamkang Univ.
E732, #151 Ying-Chuan Rd., Tamsui, New Taipei City, Taiwan 251
yinghaur@mail.tku.edu.tw

CHAN, Hsun-Kuan
Research Assistant, Dept. of Civil Eng., Tamkang University
E801, #151 Ying-Chuan Rd., Tamsui, New Taipei City, Taiwan 251
chanhsunkuan@gmail.com

LIN, Jyh-Dong
Professor, Dept. of Civil Eng., National Central Univ.
Chung-Li, Taoyuan, Taiwan 320
jyhdongl@cc.ncu.edu.tw

Hsiang-Wei Ker
Associate Professor, Dept. of International Trade, Chihlee Institute of Technology
#313, Sec. 1, Wen-Hwa Rd., Pan-Chiao, Taipei, Taiwan 220
hker@mail.chihlee.edu.tw

ABSTRACT

The ACN/PCN method has been adopted as the standardized method for reporting airfield pavement bearing strength since 1980's. Recently, the FAA developed a draft Advisory Circular 150/5335-5B to provide specific guidance on how to arrive at a PCN. The primary objectives of this study are to investigate its fundamental principles, the reasoning of the newly-proposed revisions, and the effects on the PCN determination. The original development of ACN/PCN methodology was first reviewed. The newly revised approach using cumulative damage factors for computing PCN based on equivalent traffic was also discussed. The concept of a single wheel load was employed to define the interaction of various gear loads and pavement without specifying pavement thickness as an ACN parameter. Thus, subgrade strength can be omitted along with pavement thickness when determining the relative effect. PCN is originally defined as a number expressing the load-carrying capacity of a pavement for "unrestricted operations." In

addition to no weight restriction, unrestricted operations are preferably considered to be able to sustain "unlimited number of load repetitions." Thus, a standard aircraft with 90,000 lbs dual-wheel gear load was introduced. For consistency reasons, interior stress prediction models were used for critical stress estimations. A specific subgrade category "B" was adopted. A modified PCN approach with or without mixed-traffic was subsequently developed. A case study was conducted to illustrate the potential problems of the existing PCN procedures and the benefits of the proposed revisions.

KEY WORDS

ACN/*PCN, rigid airfield pavements, pavement evaluation, equivalent annual departure*

INTRODUCTION

The International Civil Aviation Organization (ICAO) has adopted the Aircraft Classification Number / Pavement Classification Number (ACN/PCN) method as the standardized method for reporting airfield pavement bearing strength since 1980's [FAA, 2006b]. Recently, the Federal Aviation Administration (FAA) has been circulating a draft Advisory Circular 150/5335-5B to provide specific guidance and revisions on how to arrive at a more reliable PCN [FAA, 2009]. The primary objectives of this study are to investigate its fundamental principles, the reasoning of the newly-proposed revisions, and the effects on the PCN determination.

The original development of ACN/PCN methodology and several rigid airfield pavement design procedures were first reviewed. Parameter studies on the effects of ACN/PCN determinations due to different aircraft types, gear loads, subgrade strengths, traffic mix, etc. were subsequently conducted. The newly revised approach by introducing a Cumulative Damage Factor (CDF) method for computing PCN based on equivalent traffic was also discussed.

REVIEW OF ACN/PCN METHODOLOGY

The ACN/PCN method is designated by the ICAO as the only approved method for reporting the bearing strength of pavements. Each aircraft is assigned a number expressing the relative structural effect on a pavement for a specified pavement type (R = Rigid pavement and F = Flexible pavement) and a standard subgrade category (A=High, B=Medium, C=Low, D=Ultra low). The concept of a single-wheel load has been employed to define the landing gear and pavement interaction without specifying pavement thickness as an ACN parameter. This is done by equating the thickness derived for a specified airplane landing gear to the thickness derived for a single wheel load at a standard tire pressure of 181 psi (1.25 MPa). The Westergaard interior loading solution for a concrete pavement resting on Winkler foundation was used for the analysis. A concrete working stress of 399 psi (2.75 MPa) was assumed and the modulus of elasticity was chosen as 4,000,000 psi (27.58 GPa). ACN is then defined as 2 times the derived single wheel load (DSWL) in 1000 kg.

Stet and Verbeek [2005] further discussed the recent and future developments of this methodology. An alpha-factor is used in the ACN procedure to account for load repetitions and coverages for different loading gears in flexible pavements [FAA, 2004a; Hayhoe, 2006]. Due to the inherent limitations of the existing pavement design and evaluation procedure for some new types of larger airplanes (e.g., B-777 and A380-800), full-scale research projects have been undertaken to develop an alternative mechanistic-empirical procedure using layered elastic design approaches. The ICAO ACN study group (ACNsg) has initiated an investigation study into the impact of revising ACNs on the current ACN/PCN methodology based on the full-scale test results.

PCN is a number expressing the relative load-carrying capacity of a pavement. A particular PCN value can support an aircraft that has an ACN value equal to or less than the pavement's PCN value for unrestricted operations without weight restrictions. The PCN value is for reporting pavement strength only and cannot be used for pavement design or as a substitute for pavement evaluation. However, ICAO has not specified regulatory guidance on how to determine a PCN value because many member countries are reluctant to agree on an international standardized method for pavement evaluation [ICAO, 1983; FAA, 2006b; Stet, 1993; Debord, et al., 1998; Stet and Beuving, 2004; Stet and Verbeek, 2005].

PCN assignments are related to design methodologies in which critical edge stress are mostly considered. Since the current ACN/PCN method does not dictate a specific design method for PCN assignment, the technically derived PCN values are likely to vary to a great extent. Many factors which have a profound influence on PCN assignment include: the PCN method used, the use of empirical or mechanistic based methods, the evaluation method used, the pavement structural life, the method to derive an annual traffic volume, the method to backcalculate material properties, and different transfer functions, etc. Stet and Verbeek [2005] also demonstrated the PCN values can vary over 200 percent using different theories and evaluation technologies.

FAA'S RECENT REVISION ON PCN METHODOLOGY

Recently, the Federal Aviation Administration has been circulating a draft Advisory Circular 150/5335-5B to provide specific guidance and revisions on how to arrive at a more reliable PCN [FAA, 2009]. A Cumulative Damage Factor (CDF) method for computing PCN based on equivalent traffic was introduced and the original COMFAA 2.0 program was subsequently revised as COMFAA 3.0. The general steps of using the technical evaluation method for rigid pavements are briefly summarized as follows. More detailed step-by-step procedures are available in the literature.

1. Determine the traffic volume in terms of type of aircraft and number of annual departures of each aircraft.

2. Determine the pavement characteristics including subgrade modulus (k), slab thickness, and flexural strength.
3. Perform the CDF calculations to determine the maximum allowable gross weight for each aircraft on that pavement at the equivalent annual departures.
4. Calculate the ACN of each aircraft based on its maximum allowable gross weight.
5. Select the PCN from the ACN data provided by all aircraft.

Equivalent Traffic Calculations

The determination of traffic volume generally includes past traffic that has occurred since original construction or last overlay and forecasted traffic that will occur before the next planned overlay or major rehabilitation. The normal design life for pavement is 20 years. However, the expected life can vary depending on the existing pavement conditions, climatic conditions, and maintenance practices. In addition to the maximum gross weights of aircrafts, main gear type (single, dual, dual tandem, etc.), and main gear tire pressure, fuel-loading practices at the airport and type of taxiway system (parallel or central) are also needed to determine pass to traffic cycles ratio (P/TC). Nevertheless, no specific guidance on the effect of pavement remaining life on PCN methodology is currently available.

Since the traffic forecast is a mixture of a variety of aircraft having different landing gear types and weights, the "critical airplane" concept was introduced to account for the effects of all traffic in the conventional FAA design methodology. Each aircraft type in the forecast should be checked in order to determine the required pavement thickness using the corresponding design curve with the forecasted annual departures. The critical airplane is the one that produces the greatest pavement thickness and is not necessarily the heaviest aircraft in the forecast. All aircraft must be converted to the same landing gear type as the critical airplane. The general equation for this conversion, which represents an approximation of the relative fatigue effects of different gear types, is as follows [FAA, 1995a, p. 25; FAA, 2006b]:

$$0.8^{(M-N)} \qquad (1)$$

Where, M is the number of wheels on the critical airplane main gear; and N is the number of wheels on the converted airplane gear. After the aircraft have been grouped into the same landing gear configuration, the conversion to equivalent annual departures of the critical airplane is determined by:

$$\log R_1 = \log R_2 \times \sqrt{\frac{W_2}{W_1}} \qquad (2)$$

Where, R_1 is the equivalent annual departures of the critical airplane; R_2 is the annual departures expressed in critical airplane landing gear; W_1 is the wheel load of the critical airplane; and W_2 is the wheel load of the aircraft in question.

Commonly, these equivalencies for the relative fatigue effects of different gear types are defined by a simple ratio of the evaluated total repetitions for the two loadings being compared for a selected pavement structure. However, it is noted that the load equivalencies, presently determined by the aforementioned conversion factors and equation (2), are not single valued and may vary widely for different levels of aircraft departures in this study. This conclusion is similar to the statement by Ahlvin [1991, p. 10-9] that "any simple ratio will be different for different magnitudes of load repetitions so that the adopted practice is arbitrary and unverified." Thus, FAA [1995a, p.25] has also indicated that "much more precise and theoretically rigorous factors could be developed for different types and thickness of pavements."

Consequently, the conventional "critical airplane" concept, conversion factors for different landing gear types using equation (2) have been replaced by the concept of cumulative damage factor (CDF) in the new LEDFAA design methodology [FAA, 1995b]. The cumulative damage effects of multiple aircraft types and departures are accounted for by using Miner's hypothesis. This approach is more mechanistically based and will result in a single valued factor to represent the relative fatigue effects of different aircraft types for a given pavement structure. This single valued factor will vary widely for different aircraft loads, gear configurations and properties of pavement structure but not the magnitude of load repetitions. Such a conversion is more theoretically rigorous than the conventional FAA approach. Nevertheless, the conversion of different aircraft types and departures to equivalent annual departures of a specific aircraft type is no longer necessary.

Existing Fatigue Relationships and Thickness Design Criteria

The conventional FAA thickness design methodology was based on an earlier fatigue curve developed by the Corps of Engineers from test track data and observation of full-scale test pavements. The ratio of the concrete flexural strength (S_c) to the allowable slab tensile stress ($\sigma_a = 0.75 * \sigma_e$) is called a design factor (DF) or analogous to a safety factor. The fatigue curve originally adopted a bilinear relationship between a design factor (DF) and the number of load repetitions (in terms of coverages, C) at the specified failure criteria. However, no explicit fatigue relationship is available elsewhere in the literature [FAA, 1995a]. The method presently adopted for the determination of minimum required slab thickness for design is based on the basic thickness concept. A design factor of 1.3 was chosen to determine the allowable slab tensile stress for 5,000 coverages. The thickness of pavement required to sustain 5,000 coverages of the design loading is considered to be the basic thickness (or 100 percent thickness). The required design thickness for the expected 20-year coverage levels is determined by the product of the basic thickness (h_1) and the percent thickness (or relative thickness, RH). The equations are summarized as follows:

$$\sigma_e = \frac{S_c}{1.3*0.75}$$
$$h_1 = \left[\left(RC0 + RC1 \times \ln(\ell) + RC2 \times (\ln(\ell))^2\right) \times \left(\frac{P}{\sigma_e}\right)\right]^{0.5} \quad (3)$$

$$RH = \begin{cases} 1+0.15603*(\log(C)-3.69897) & if\ C > 5000 \\ 1+0.07058*(\log(C)-3.69897) & if\ C < 5000 \end{cases} \quad (4)$$

Where RC0, RC1 and RC2 are coefficients obtained using influence charts for various aircraft types and are provided along with the R805FAA program. P is the main landing gear load, lbs; σ_e is the critical edge tensile stress, psi; S_c is the flexural strength of concrete, psi; $\ell=(E*h^3/(12*(1-\mu^2)*k))^{0.25}$ is the radius of relative stiffness, in.; E is the elastic modulus of the slab, psi; k is the modulus of subgrade reaction, psi/in; μ is the Poisson's Ratio, and h or h_1 is the slab thickness, in. Note that the above equation is only applicable to the U.S. customary system (English system) unless proper adjustments to the coefficients are made for metric system. For any given pavement structure with known slab thickness, concrete modulus of rupture, elastic modulus of the slab and subgrade modulus, the allowable number of load repetitions (in terms of coverages) of a specific aircraft and wheel load may be determined through a very simple backcalculation process. Thus, the above equations are analogous to a fatigue relationship. However, it is worth of mentioning that the bilinear relationship between a design factor (DF) and coverages (C) derived from the above equations is not a unique curve [Lee and Yen, 2001].

Rollings and Witczak [1990] developed a structural deterioration model for rigid airfield pavements that predicts performance in terms of a structural condition index (SCI), a design factor (DF), the coverages at the onset of structural deterioration (CO) and the coverages at absolute failure (CF). The SCI is derived from the pavement condition index (PCI) considering the distresses associated with tensile fatigue loading only and is on a scale from 0 to 100. The DF is defined as the ratio of flexural strength of concrete (S_c) and the critical tensile stresses (σ) calculated using the layered elastic pavement model. The basic fatigue relationship used to find the number of coverages (C) to failure in the LEDFAA program [FAA, 1995b; 2006a; Rollings and Witczak, 1990] is as follows. Failure is defined as the number of coverages (C_{80}) to reduce the pavement SCI to 80 at any given value of DF or S_c/σ.

$$SCI = \frac{DF - 0.2967 - (0.3881 + 0.000039*SCI)\log(C)}{0.002269} \quad (5)$$
$$DF = 0.4782 + 0.3912*\log(C_{80})$$

The coverages at failure (C_{80}) obtained from the above fatigue equation were implicitly tied to the manner in which critical tensile stress, or consequently the design factor, was determined. To make the layered elastic design procedure compatible with the conventional FAA thickness design procedure, a scaling factor of 0.753 is applied to the calculated layered elastic interior stress to provide an equivalent edge stress. The subgrade is assumed to be infinite in thickness and is characterized by either an elastic modulus (E) or modulus of subgrade reaction (k-value) in the current LEDFAA program. If a k-value is specified, it is converted to an equivalent E-value using a logarithmic relationship.

$$DF = 0.753 \times [0.4782 + 0.3912 * \log(C_{80})] \qquad (6)$$

Fatigue failure expressed in terms of a "cumulative damage factor" (CDF) using Miner's hypothesis is adopted in the new LEDFAA thickness design approach. CDF is the amount of the consumed structural fatigue life and is expressed as the summation of the ratio of applied load repetitions to allowable load repetitions to failure. The LEDFAA program automatically calculates the damaging effects of each aircraft in the traffic mix [FAA, 2006a]. When the damaging effects of all aircraft sums to a value of 1.0, the design conditions have been satisfied and the required slab thickness is determined.

Implementation of the ACN/PCN Determination Procedures

The COMFAA program was developed to facilitate the ACN/PCN determination procedures. The COMFAA 2.0 program adopted the conventional FAA edge stress thickness design methodology (same as the R805FAA program) using the conversion of equivalent annual departures of a critical airplane and the bilinear fatigue relationship as shown in equations (1) ~ (4). The COMFAA 3.0 program adopted the more technically sound CDF method for equivalent traffic conversions. In the CDF method, the number of equivalent traffic cycles of the critical airplane is defined as the number of traffic cycles of critical aircraft that will cause the same amount of damage to the pavement as the number of traffic cycles of the conversion aircraft [FAA, 2009]. The new procedure based on CDF may be more technically correct. The pertinent conversion relationship is as follows:

$$C_1 = \frac{C_{1F}}{C_{2F}} C_2 \qquad (7)$$

Where, C_1 is the equivalent coverages of the critical aircraft; C_{1F} is the coverages to fail the pavement when loaded by the critical aircraft; C_2 is the actual coverages of the conversion aircraft; and C_{2F} is the coverages to fail the pavement when loaded by the conversion aircraft.

The current discrepancies of adopting edge stress for thickness design but using the interior stress for ACN/PCN determination have been well recognized by the FAA and necessary revisions have been made. Thus, in addition to the use of the conventional FAA edge stress design method, the COMFAA 3.0 program also adopts the PCA interior stress design method for equivalent traffic conversions and the determination of maximum allowable gross weight of the critical airplane. The PCA fatigue equation is listed as follows:

$$SR = 0.9725 - 0.03585 \times \ln(LR) \qquad (8)$$

In which, stress ratio (SR) is defined as the ratio of working stress and the concrete modulus of rupture; LR is the allowable load repetitions. For stress ratio below 0.50, the allowable load repetitions are treated as unlimited. Roginski [2008; 2009] discussed the current issues on PCN methodology regarding critical aircraft determination and the edge stress versus interior stress of rigid pavements and also noted that there still exist some technical issues currently being addressed by the PCN working group.

DEVELOPMENT OF AN IMPROVED APPROACH

Verification of the Existing ACN/PCN Determination Procedures

The airport pavement design and evaluation software (R805FAA) was obtained from the FAA website [FAA, 1995a]. A Visual Basic Application (VBA) module was added to the design spreadsheet by executing the COMFAA 2.0 program iteratively to automatically determine the PCN value in this study. Very good agreements have been achieved while comparing the resulting PCN values with the COMFAA 2.0's outputs.

The existing TKUAPAV program [Lee and Yen, 2001] originally written in Visual Basic software package was recoded into an Excel spreadsheet for rigid airfield pavement design. Two additional VBA modules were written to facilitate automatic PCN determinations using both R805FAA's bilinear fatigue relationship and PCA's fatigue equation. The condition when the allowable load repetitions are unlimited for stress ratio below 0.50 in equation (8) was neglected to avoid having an undesired bilinear relationship for such conversion again. The interior stress prediction models developed by Lee et al. [1997] were adopted in this analysis for critical stress estimations. Fairly reasonable agreements have been obtained while comparing those PCN results with the COMFAA 3.0's program outputs using both edge stress and interior stress modes. It is worth mentioning that some technical difficulties and errors have been identified when conducting the analysis using COMFAA 3.0 program. Discussions of these verification efforts will be illustrated in the subsequent case study with more details.

Proposed Simplification of ACN/PCN Definition

The ACN/PCN system is only intended to serve as a method for reporting relative pavement strength such that airport operators can evaluate the acceptable operations of different aircrafts. ACN is originally defined as a number expressing the relative effect of an airplane at a given weight on a pavement structure for a specified standard subgrade. The concept of a single wheel load was employed to define the interaction of various gear loads and pavement without specifying pavement thickness as an ACN parameter. The ACN numerical values are generally larger for heavier aircrafts and weaker subgrade categories. Since pavement thickness generally has much higher structural effect than subgrade strength, one may consider subgrade strength as part of a pavement structure and it certainly can be eliminated from being treated as an ACN parameter while defining aircraft's relative effect. To avoid unnecessary complication, a specific subgrade category (say "B") was proposed in the subsequent ACN determination in this study.

PCN is originally defined as a number expressing the load-carrying capacity of a pavement for "unrestricted operations" and a concrete working stress of 399 psi (2.75

MPa) was also assumed in this ACN/PCN approach. Thus, the PCN numerical values are generally larger for a pavement resting on weaker subgrade categories. The proposed simplification of adopting only one specific subgrade category for ACN definition will certainly eliminate such unnecessary complications.

Furthermore, what were the "unrestricted operations" in the definitions of ACN/PCN methodology really meant? If the ratio of critical stress and flexural strength (or the stress ratio) is relatively small, the allowable number of load repetitions is unlimited according to the specified concrete fatigue relationship [Huang, 2004]. Thus, in addition to "no weight restriction" (up to maximum takeoff weight), unrestricted operations are preferably considered to be able to sustain "unlimited number of load repetitions" as well. In other words, the airport can allow unlimited traffic repetitions, if a certain stress ratio was specified for all aircraft types. In the current methodology, an elastic modulus of 4,000,000 psi (E_{PCC}) was assumed. A concrete working stress of 399 psi (2.75 MPa) is roughly equivalent to a stress ratio of 0.60 using the following relationship:

$$S_c = 43.5 \times \left(\frac{E_{PCC}}{10^6} \right) + 488.5 \qquad (9)$$

Thus, it is proposed that the allowable working stress of 399 psi is adjusted proportionally according to the modulus of rupture of the existing pavement in order to calculate the maximum allowable gross weight of the critical airplane instead of using COMFAA's pavement thickness design mode to do so. The resulting PCN value will be more directly related to pavement characteristics rather than the mix of different aircraft types. Since the traffic repetitions are unlimited, the conversion to critical airplane departures can be no longer necessary.

Implementation of the Proposed Approach

The proposed revisions to the existing ACN/PCN calculation procedure based on the COMFAA 2.0 and 3.0 programs have been implemented in an Excel spreadsheet. For consistency consideration, interior stress prediction models developed by Lee, *et al.* [1997] was used for critical stress estimations. The PCA interior fatigue equation, LEDFAA edge and interior fatigue equations were adopted. A specific subgrade category (say "B") was adopted. A modified PCN determination approach either with or without traffic mix consideration was subsequently developed. A standard aircraft with a dual wheel main gear load of 90,000 lbs was introduced in this study to facilitate such conversions. The basic information of the standard aircraft is listed in Table 1. More detailed information regarding the verification of the proposed approach is illustrated in the subsequent case study.

Table 1 Basic Information of a Standard Aircraft

Aircraft	Gross Weight (lb)	Gear Type	% Gross Weight on Main Gear	Tire Pressure (psi)	Dual Spacing (in.)	Tandem Spacing (in.)	Tire Width (in.)	P/C Ratio
Std. Aircraft	189,473	D	47.5	200	34	0	13.75	3.24

A CASE STUDY FOR TECHNICAL EVALUATION OF RIGID PAVEMENTS

To illustrate the potential problems of the current technical evaluation method and the advantages of the proposed approach in determining PCN values for rigid pavements, the following case study was conducted. Suppose a rigid airfield runway pavement with an effective subgrade k-value of 250 pci and a slab thickness of 14 inches. Assume the concrete has a modulus of rupture of 700 psi, an elastic modulus of 4,000,000 psi, and a Poisson's ratio of 0.15. The runway has a parallel taxiway, and additional fuel is generally obtained at the airport before departure. The pavement life is estimated to be 20 years from the original construction. The traffic data as given in Table 2 was obtained from the literature [FAA, 2006b, Appendix 2].

Since additional fuel is generally obtained at the airport, and there is a parallel taxiway, thus, passes to traffic cycles (P/TC) = 1; traffic cycles to coverages (TC/C) = pass to coverages (P/C); and coverages (C) = annual departures ∗ 20 years ÷ TC/C. The resulting coverages for each airplane are also listed in Table 1. The required thickness for each airplane at the operating weight and frequency is determined using the COMFAA 2.0 program [FAA, 2003; 2006b]. Based on the required thickness for each airplane, the critical airplane was determined as the B747-400. All departures of the other traffic were converted to the B747-400 equivalent and the total equivalent annual departures of the critical aircraft are 7,424. Since, P/TC = 1; P/C = 3.46; TC/C = 3.46; thus the anticipated total coverages of the critical aircraft = 7,424 ∗ 20 years ÷ 3.46 = 42,913.

By adjusting the gross airplane weight iteratively until the known pavement thickness (14 in.) is obtained, the maximum allowable gross weight of the critical aircraft (B747-400) is determined as 813,000 pounds. In which, the following additional parameters were assumed: percent weight on the main gear = 95 %, tire pressure = 200 psi, and tire contact area = 260.4 in^2. By switching the COMFAA program back to the ACN mode and entering in the allowable gross weight, an ACN of 56.5/R/B/W/T is obtained. The final recommended runway rating is PCN 56/R/B/W/T. Note that the tire pressure code for rigid pavement is normally set as W. It is apparent that the pavement is adequate to accommodate most of the existing traffic except for the A300-B4 aircraft; the operating weight of which has to be restricted.

Table 2 Rigid Airfield Pavement Traffic Example

Airplane	Grear Type	Operating Weight, lbs	Tire Pressure (psi)	ACN (R/B)	** P/C	Annual Departures	Coverages
B727-200	D	185,000	148	52	2.92	400	2,740
B737-300	D	130,000	195	36	3.79	6,000	31,662
A319-100	D	145,000	173	38	3.18	1,200	7,547
B747-400	2D/2D2	820,000	200	57	3.46	3,000	17,341
B767-300ER	2D	370,000	190	49	3.60	2,000	11,111
DC8-63	2D	330,000	194	53	3.35	800	4,776
A300-B4	2D	370,000	205	58	3.49	1,500	8,595
B777-200	3D	600,000	215	55	4.25	300	1,412

** Rigid P/C determined at 95 percent of gross load on main gear

Table 3 Comparison of PCN Results Using Different Approaches

Convert to Critical Airplane Type	PCN Value based on Edge Stress			PCN Value Based on Interior Stress		PCN Value Based on the Proposed Approach			
	COM-FAA 2.0	COMFAA 3.0		COMFAA 3.0		PCA interior fatigue eq.	LED-FAA edge fatigue eq.	LED-FAA interior fatigue eq.	Unlimited traffic
		CDF edge	Verified using R805FAA fatigue eq.	CDF interior	Verified using PCA fatigue eq.				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
B727-200	43.4	48.5	50.1	57.7	**49.3**	64.6	61.5	62.0	
B737-300	33.3	36.5	36.1	**43.8**	**35.0**	61.2	61.7	62.1	
A319-100	35.1	36.9	37.0	**44.3**	**35.9**	62.5	61.6	62.0	
B747-400	**56.6***	**55.1***	**55.4***	**65.6***	**67.0***	59.8	60.1	60.8	
B767-300ER	52.8	48.2	47.3	57.5	56.9	60.2	53.8	60.8	**62.5***
DC8-63	51.4	49.3	51.1	59.0	58.2	60.3	58.4	61.0	
A300-B4	53.5	55.7	56.5	65.9	65.3	59.7	57.0	60.9	
B777-200	70.3	54.5	53.4	**65.6**	**35.7**	56.3	57.3	60.4	
STD. Aircraft	--	--	--	--	54.6	**60.7***	**61.6***	**62.0***	

The comparison of PCN results using different approaches is summarized in Table 3. By convert to different critical aircraft types, the resulting PCN values using the COMFAA 2.0 program is shown in column (2). The PCN values are very different from each other probably due to the use of the bilinear fatigue relationship in such conversions. Since the critical aircraft is B747-400, the runway PCN rating is 56.6, though the resulting PCN value is higher after converting all traffic to B777-200 repetitions. Columns (3) and (4) are the results of using COMFAA 3.0 program with edge stress fatigue relationship as well as the verifications conducted in this study. Fairly good agreements have been achieved. The minor differences may be due to the default specifications of contact areas and tire pressure used by the COMFAA 2.0 and 3.0 programs. By using the CDF method, the resulting PCN value for B777-200 conversion became more reliable, though the runway PCN may be set to 55 or 56 for this case.

Columns (5) and (6) depict the results of using COMFAA 3.0 program with PCA interior stress design equation and the verifications conducted in this study. In general, reasonably good agreements have been achieved with the exception for those shaded PCN values. A detailed manual calculation on the conversion to B777-200 aircraft repetitions was conducted and the results indicated that there still exist some technical difficulties and errors conducting the analysis using COMFAA 3.0 program. The resulting PCN values are very different from each other probably due to the use of the bilinear PCA interior fatigue relationship in such conversions. This observation also agrees with Roginski's comments [2008] that "dual wheel aircraft should not be the critical airplane based on low stress ratio and insufficient range in ACN values to cover all aircraft in traffic mix." In Roginski's case study, the B777-200 (3D) aircraft is also problematic. Nevertheless, a PCN value of 65 or 67 may be used for this runway which is much larger than the PCN value determined using edge stress design method.

Columns (7) ~ (10) summarize the results of using the proposed approach. The PCA interior, LEDFAA edge and interior fatigue equations were used in this analysis, i.e., equations (8), (6) and (5). The maximum allowable gross weight of the critical airplane for this pavement was determined based on the pre-specified stress ratio (SR = 0.60) for unlimited traffic repetitions and the allowable working stress of 399 psi is adjusted proportionally according to the modulus of rupture of the existing pavement. No pavement thickness design using the converted traffic repetitions was required to check with the existing slab thickness. Thus, the resulting PCN values are fairly stable when converting to different aircraft types. In fact, converting to a standard aircraft type may well serve the purpose. A PCN value of 60 to 62 may be adequate for this pavement.

CONCLUDING REMARKS

This study strived to investigate the fundamental principles of the ACN/PCN methodology, the reasoning of the newly-proposed revisions, and the effects on the PCN determination. The concept of a single wheel load was employed to define the interaction of various gear loads and pavement without specifying pavement thickness as an ACN parameter. Thus, subgrade strength can be omitted along with pavement thickness when determining the relative effect. PCN is originally defined as a number expressing the load-carrying capacity of a pavement for "unrestricted operations." In addition to no weight restriction, unrestricted operations are preferably considered to be able to sustain "unlimited number of load repetitions." The maximum allowable gross weight of the critical airplane was determined based on the pre-specified stress ratio (SR = 0.60) for unlimited traffic repetitions and the allowable working stress of 399 psi is adjusted proportionally according to the modulus of rupture of the existing pavement. Thus, a standard aircraft with 90,000 lbs dual-wheel gear load was introduced. For consistency reasons, interior stress prediction models were used for critical stress estimations. A specific subgrade category "B" was adopted. A modified PCN approach with or without mixed-traffic was subsequently developed. A case study was conducted to illustrate the potential problems of the existing PCN procedures and the benefits of the proposed revisions.

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