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PAVEMENT EVALUATION OF AIRPORT TAXIWAY AND EFFECT OF INCREASING ACN TO PAVEMENT REMAINING LIFE

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ABSTRACT

This research evaluates the strength of the flexible taxiway pavement. The Cumulative Damage Factor (CDF), which is then expressed in the form of remaining life, is determined by applying the Layer Elastic Design (LED) theory. Strength of the pavement is evaluated by the Aircraft Classification Number - Pavement Classification Number (ACN-PCN) procedure, based on the CBR method. The remaining life of the taxiway causing by the increasing ACN is also evaluated. It is found that the taxiway area ***A5*** provides the lowest remaining lifetime, which is 0.9 years. The taxiway area ***A2*** provides the lowest PCN value, which is 130. It should be noted that, when the ACN aircraft is increase and the ACN/PCN ratio is equal or larger than 0.7-0.8, the pavement remaining life is reduced. In addition, when the ACN/PCN ratio is greater than 1.0 (ACN is overload), the remaining life decreases in the form of an exponential function. The remaining life should be taken into account in the procedure of pavement evaluation.

1. INTRODUCTION

Nowadays, an airport is one of the most popular transportation services used in connecting people around the world. The airport is an important parameter for the economic and social conditions of a country. Since the number of people using an airport for communication is rising up every year, additional traffic volumes and aircraft loads are required. More efficient methods for pavement monitoring and structural evaluation are desired in order to ensure a good serviceability and to provide adequate maintenance solutions for the pavements.

For pavement maintenance planning, one of the main factors needed to be taken into consideration is the structural condition. Load bearing capacity of a pavement can be evaluated by two experimental methods, destructive tests (DT) and non-destructive tests (NDT). Some examples for the DT are core drillings and pits. The examples for the NDT are Heavy Falling Weight Deflectometer (HWD) and Ground Penetrating Radar (GPR). Results from the tests can be analyzed

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by using a mechanistic approach. A structural model of the pavement is required for the estimation of its remaining life. Layer thickness data from GPR and the deflection basin from HWD is used to obtain the elasticity moduli of the pavement layers. The Layer Elastic Design (LED) theory applies the elasticity moduli to determine strain on top subgrade. The Failure model is then used to find the coverage to failure and finally the Cumulative Damage Factor (CDF) that occurs in the structure. The remaining pavement life can be estimated by taking into consideration of the future traffic. Up to the present time, the strength of pavement structure can be evaluated from aircraft carrier capability, which is determined by using the ACN-PCN (Aircraft Classification Number - Pavement Classification Number) method based on the International Civil Aviation Organization (ICAO). The values of the ACN and PCN are obtained by using the CBR method.

Osman (2015) recommended the interpretation of HWD data together with layer thickness data obtained from GPR to propose the methodology for structural airport pavement evaluation. The GRIP Tester was operated to find the friction coefficient of the runway and free computer software (FAARFIELD and COMFAA) were then used to design the new runways. This evaluation presented in a PCN number and an ACN/PCN classification. By comparison these two numbers, it concluded that the PCN is bigger than the ACN. This implied that the pavement can be landed safely.

Qassim (2012) applied the ICAO method in the form of ACN/PCN ratio using different aircraft weights to assess the strength of the airfield pavement at four airports in Iraq. The results suggested to improve the airport pavement which an ACN/PCN ratio is greater than 1.0. Strength of the pavement structure can be improved by either overlaying the surface that is currently use or desiring a new construction. However, in Qassim's study, the lifetime of the pavement structure does not be taken into consideration.

Hayhoe (2010) refered to the Criteria for overload evaluation of airport pavements containing in ICAO documents Annex 14, Attachment A and the Aerodrome Design Manual Part 3. They were presented in terms of the amount the ACN of an overload airplane, which could exceed the listed PCN of the pavement. The relationship between an increment of ACN and an increment of CDF was derived from the ratio between number of applied load repetitions and number of allowable repetition to failure. The overload operations evaluated by a CDF-based design procedure was then compared directly with the ICAO criteria. If the allowable value of the ACN of an overload aircraft relative to the PCN of the pavement was taken by a ratio of 1.1, then an allowable change in CDF was approximately increased 0.5. The sensitivity S_t of the CDF-based design procedure was sensitive to the change of CDF and the change of ACN. The relationship for the CDF-based design procedure could be calibrated if desired.

This research attempts to investigate the strength in term of PCN and predict the remaining life of the flexible taxiway pavement, including the variation range of in the ACN/PCN ratio. Two sets of investigations are considered. The first set is to find the relationship between the CDF and ACN/PCN ratio, while other parameters are constant. The second set is to find the relationship between the pavement remaining life and ACN/PCN ratio, while other parameters are constant. In each set of experiment, different numbers of traffic volume of ACN aircraft are considered.

2. OBJECTIVES

The objective of this study is to evaluate the strength of the flexible pavement of a case study in an airport and to investigate the effect of the increase in ACN values on the remaining life of the pavement structure. The details are summarized as follows:

(1) Predict the remaining life of pavement structure and determine the strength in term of PCN of the pavement structure according to the ACN-PCN method.

(2) Study the increasing ACN/PCN ratio affecting the CDF and the pavement remaining life, by considering different numbers of traffic volume of ACN aircraft.

3. STRUCTURAL EVALUATION OF FLEXIBLE PAVEMENT

Strength of the pavement structure can be analyzed by using the data obtained by the Field tests, such as the HWD, GPR, or CBR tests, within the Airside area of the airport currently in use. This case study evaluates the strength of the flexible pavement of the taxiway structure. The typical width of the taxiway is 30 m. The length of the taxiway is approximately 1.6 km. The total area is, however, approximately 109,000 m^2. The pavement structure consists of 4 layers. This includes the surface layer (asphalt concrete, AC), the cement treated base (CTB) layer, the subbase layer (sand with an approximation thickness of 650 mm), and the subgrade (soft clay type CH with a CBR of 3%) as shown in Figure 1. Taxiway ***A*** and ***B*** are divided into eleven areas ***A1***, ***A2***, ***A3***, ***A4***, ***A5***, ***A6***, ***B1***, ***B2***, ***B3***, ***B4*** and ***B5*** as shown in Figure 2.

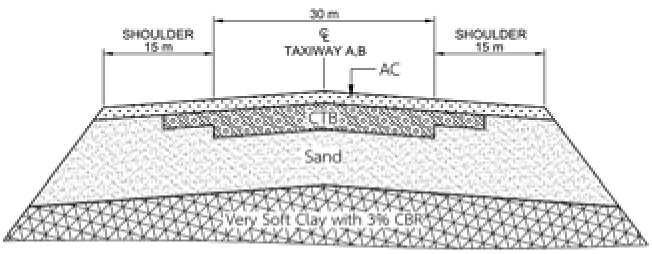

Figure 1: Pavement Structure of taxiway ***A*** and ***B***

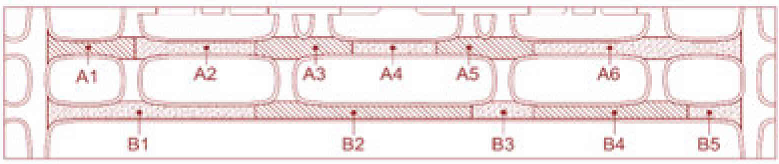

Figure 2: Test areas of taxiway ***A*** and ***B***

3.1 HWD TEST

For HWD test, an impulsive load is applied on the taxiway surface (Sebaaly *et al.*, 1991). The magnitude of the load, duration, and area of loading corresponds to the effect of loading due to the main gear on in-service pavement. According to the recommendations provided by FAA (Federal Aviation Administration, USA), each test location is loaded 3 times with three different load levels along the five different alignments. This includes the alignments at centerline and two lateral offsets of 3.00 m and 6.00 m on either side (left and right) of the centerline. The load is applied through a circular plate. Under each impulse load, the deflections of pavement surface are recorded at various fixed distances measured from the center of the circular loaded plate. The magnitude of the deflection is a function of the pavement layer thicknesses and the material properties. Layer elastic moduli (***E***) can be obtained by performing a back-calculation using the HWD data and layers thickness from GPR test.

3.2 GPR TEST

Setting up the pavement model is one of the difficulties in performing a back-calculation process (Correia, 2014). The layer thicknesses, which is a part of the pavement model, must be defined and inputted in the beginning of the back-calculation programs. Thickness of the pavement can be estimated by several methods, such as by destructive methods (cores) or by nondestructive methods like the GPR. In this study, the GPR is used to perform the tests on the same path as the HWD test. The GPR can provide information about layer thickness and different material encountered. An antenna of 400 MHz and 900 MHz is selected. However, its capability of detecting surface layer down to only the CTB layers thickness.

3.3 BACK-CALCULATION

The elastic moduli (***E***) of the different pavement layers are obtained by performing the back-calculation process. In this process, an elastic modulus value is assumed with using the load from HWD test and the layer thickness from GPR test to calculate a proposed deflection. The proposed deflection is then compared with the observed deflection obtained from the HWD test. If values of the two deflections are not equal, then the value of assumed modulus is adjusted for the next iterative calculation. The iteration continues until the proposed deflection is closely match the observed deflection values. In this study, the back-calculation has been conducted by the commercial software ELMOD, provided by Dynatest. The thickness and elastic moduli of pavement structure in each area are shown in Table 1.

Table 1: Thickness (Thk.) and Elastic moduli (***E***) of pavement structure

Areas	Thk. from GPR		***E*** from Back-calculation		Areas	Thk. from GPR		***E*** from Back-calculation	
	AC (m)	CTB (m)	***E*** of AC (MPa)	***E*** of CTB (MPa)		AC (m)	CTB (m)	***E*** of AC (MPa)	***E*** of CTB (MPa)
A1	0.352	0.607	582.50	3617.90	***B1***	0.332	0.666	559.97	4555.08
A2	0.344	0.596	519.77	3326.47	***B2***	0.339	0.653	929.06	4455.79
A3	0.337	0.578	539.22	3510.86	***B3***	0.359	0.624	734.31	4628.14
A4	0.307	0.668	604.71	4284.17	***B4***	0.359	0.639	640.61	5244.90
A5	0.360	0.613	532.56	2153.76	***B5***	0.339	0.674	551.59	4451.28
A6	0.346	0.610	456.95	2901.69					

3.4 CBR TEST IN SAND LAYER

Field CBR test is an indirect test to measure the soil strength to resist a standardized penetration piston moving with a specified rate and penetration distance. Based on the ASTM D4429, to avoid the reduction of strength of the pavement structure, the test in the case study is conducted at one position in the sand layer at a depth of 1 meter. The CBR value of the sand layer is 11%, which is related to elastic moduli as $\boldsymbol{E} = 10.341 \times \text{CBR}$ (***E*** in MPa)

4. AIRPLANE TRAFFIC MIXTURE

In the airport pavement design or evaluation procedure, the number of airplane passes is considered by taking into account of only the number of the departure but ignores the arrival aircraft traffic (ICAO, 1983). This is due to the weight with fuel of the most departure airplanes in general are considerably heavier than that of the arrival ones. In the case study, the air traffic volume and the traffic growth of annual departures by different models of aircrafts corresponding to their weight, ACN, annual departure and the percentage of the growth per year are shown in Table 2.

Table 2: Air traffic volume and traffic growth

Model	Gross Weight (tons)	% Gross Weight on Main gears	ACN for Subgrade 3% CBR	Annual Departure	% Growth per year
A320-200	78.40	92.80	53	78,000	3
A300-600	172.60	95.00	85	16,500	3
A330-300	233.90	95.70	100	30,000	3
B777-200LR	348.36	91.68	117	13,000	3
B777-300ER	352.44	92.44	120	14,000	3
B747-400ER	414.13	93.60	100	16,000	3
A380-800	562.00	95.13	106/103 (Body/Wing)	2,000	3

5. PAVEMENT REMAINING LIFE

The properties of the pavement structure (e.g., surface, base, subbase, and subgrade layers) obtained from the HWD, GPR and CBR tests are used to evaluate the flexible pavement. The evaluation method uses the maximum vertical strain at the top of the subgrade to predict the pavement remaining life and CDF.

5.1 ASSUMPTIONS FOR LAYERED ELASTIC MODEL

The layered elastic design (LED) method is originally applied in 1995 and specifies for the heaviest of aircraft (Horonjeff et al., 2010). In 2008, the FAA adopted this method for designing the flexible pavement to support the aircrafts that greater than 30,000 lb. In the layered elastic design theory, the passing loads produce both vertical and horizontal strains and stress in the layers of pavement in the pattern shown in Figure 3. The strain of an elastic structure can be used to determine the deflection of the pavement. Magnitude of the deflection of a given flexible pavement is a function of its elasticity (***E***), which behaves like the Young's modulus obtained by Hooke' law.

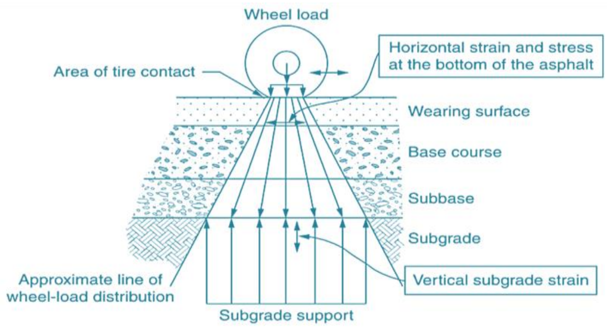

Figure 3: Visualization of layer elastic design theory (after Horonjeff *et al.*, 2010).

5.2 CUMULATIVE DAMAGE FACTOR (CDF) FOR FLEXIBLE PAVEMENT

Concept of design the aircraft pavement is referred as the fatigue failure using the word of a Cumulative Damage Factor (CDF). The CDF is concerned with the value of the structural fatigue of a pavement resulting in its remaining life (FAA, 2016). The CDF is expressed as the ratio of applied load repetitions to allowable load repetitions to failure as shown in the following equations:

$$CDF = \frac{(\text{annual departures}) \times (\text{life in years})}{(\text{pass/coverage ratio}) \times (\text{coverages to failure})} \quad (1)$$

If the $CDF = 1$, it means that the pavement has reached the limit of its remaining fatigue life. If the $CDF < 1$, it indicates that the pavement has some remaining fatigue life, and the higher value of the CDF provides the smaller value of its remaining fraction life. If the $CDF > 1$, the pavement has run out of its remaining fatigue life, which may result in structural damage during the airport pavement operation.

The number of coverages to failure, C, for a given vertical strain at the top of the subgrade obtained from the failure model of the full scale flexible pavement tested by the National Airport Pavement Test Facility (NAPTF) and recognized by the FAA for Airport Research is expresses by the following equation:

$$C = \begin{cases} \left(\frac{0.004}{\varepsilon_v}\right)^{8.1} \text{when } C < 12{,}100 \\ \left(\frac{0.002428}{\varepsilon_v}\right)^{14.21} \text{when } C > 12{,}100 \end{cases} \quad (2)$$

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

The pass-to-coverage (P/C) ratio of a specified aircraft is the ratio between the numbers of the specified aircraft passed to the full load application at a certain point of a pavement. In general, the P/C ratio is larger than 1, which implies that the number of actual specified aircraft passing a certain area can be larger than the number obtained from the full load application. This causes by the fact that when an airplane moves along a taxiway, it naturally does not precisely pass along the same accurate line for every trips. The lateral movement found in this situation is defined as the airplane wander and obtained using a statistically normal distribution. Therefore, several numbers of passing along a specific point on the pavement of an airplane are required to reach the capacity of full-load application. The number of passes of an airplane on a certain point of a specified pavement can be taken by observation. However, the number of coverages must be calculated based on the specified P/C ratio of an airplane.

5.3 PROCEDURE FOR FINDING REMAINING LIFE AND CDF

Procedure for finding the remaining life and the Cumulative Damage Factor (CDF) is shown in Figure 4. The gross weight and subsequently the load on the main gear of an aircraft is obtained from specifying the type of the aircraft. The vertical strain on top of the subgrade is calculated by using the theory of Layer Elastic Design (LED). Coverage to Failure is then calculated by specifying the failure mode (FAA).

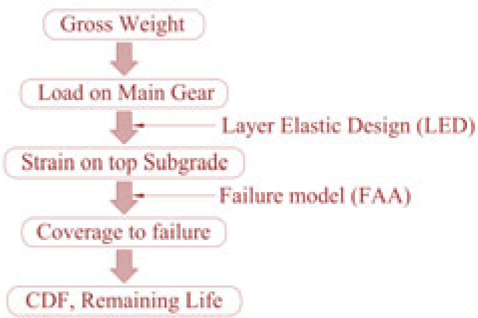

Figure 4: Steps to find remaining life and CDF.

The CDF is finally predicted by using Eq.(1) with the obtained coverage to failure, the annual departure from traffic volume, the specified life in years and the P/C ratio of a specified aircraft. In this case, the specified life in years of the pavement structure is 20 years. On the other hand, the remaining life can be predicted by replacing the life in years in Equation (1). However, in this case, the CDF generated is set to 1.

The evaluation of an airfield pavement is practically computed using a computer program called FAARFIELD (Federal Aviation Administration Rigid and Flexible Iterative Elastic Layered Design), developed by the FAA. The procedure provides the evaluation or design method based on the layered elastic theory and three dimensional structural finite element analysis developed to determine the thicknesses of the airfield pavements. Either the Remaining life or the CDF of a pavement structure in taxiway can be predicted from the thickness and structural properties combining with the traffic volume of the aircrafts.

Table 3: Remaining service life and CDF of taxiway A and B

Areas	Remaining life at CDF=1 (year)	CDF at Remaining life=20 years	Areas	Remaining life at CDF=1 (year)	CDF at Remaining life=20 years
A1	10.8	2.080000	***B1***	667.5	0.003530
A2	2.7	9.120000	***B2***	2665.3	0.000238
A3	2.0	12.440000	***B3***	466.4	0.006970
A4	238.5	0.017400	***B4***	2264.5	0.000328
A5	0.9	29.440000	***B5***	907.7	0.001950
A6	1.6	16.200000			

Table 3 shows the remaining life and the CDF of a pavement structure in taxiway areas ***A1*** to ***B5*** obtained by using the computer program. It is noted that the remaining life is obtained by specify the CDF equals to 1. In contrast, the CDF is calculated by using the remaining life of the pavement structure equals to 20 years. Results from this case study shows that the pavement remaining life of the areas ***A1***, ***A2***, ***A3***, ***A4***, ***A5*** and ***A6*** are lesser than 20 years.

6. ACN-PCN EVALUATION METHOD

The International Civil Aviation Organization (ICAO) develops an international method for reporting airport pavement strength. The method is called the Aircraft Classification Number - Pavement Classification Number (ACN-PCN) method. This method can be applied for an aircraft with a mass that greater than 5,700 kg. The Aircraft Classification Number (ACN) is a single unique number which represents the effect of an individual aircraft on different pavements. This number depends on both individual operational aircraft characteristic and the pavement information, such as the aircraft weight, the aircraft configuration (e.g. maximum aft center of gravity, maximum ramp weight, tire pressure, gear geometry or wheel spacing, etc.), the pavement type, and the subgrade strength. The Pavement Classification Number (PCN) is a single unique number representing the load-carrying capacity of a pavement. This number does not specify a particular aircraft characteristic or detailed information about the pavement structure (FAA, 2014).

The ACN number is provided by the airplane manufacturer. Procedure for finding the ACN is shown in Figure 5. The gross weight and subsequently the load on the main gear of an aircraft is obtained from specifying the type of the aircraft. The Equivalent Single Wheel Load (ESWL) is calculated and used to find the thickness at 10,000 coverage. The Derived Single Wheel Load (DSWL) is then calculated before determining the specified ACN number.

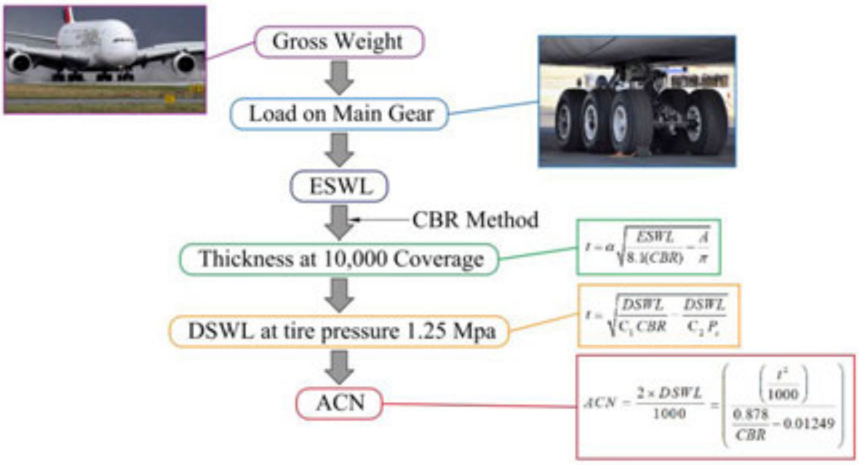

Figure 5: Steps to find ACN number.

The reference thickness at 10,000 coverage for a flexible pavement is calculated by using the formula of the CBR design method shown in Eq. (3).

$$t = \alpha\sqrt{\frac{ESWL}{8.1(CBR)} - \frac{A}{\pi}} \tag{3}$$

where t = reference thickness (inches), α = thickness reduction factor (Hayhoe, 2008), A= contact area of ESWL (in^2), ESWL= Equivalent Single Wheel Load (lbs), and CBR = the CBR of the subgrade layer.

The Derived Single Wheel Load (DSWL) is the mathematical load model for a single wheel load of an aircraft landing gear at a standard tire pressure of 1.25 MPa (181psi). The DSWL is indirectly calculated by using the expression of the referenced thickness provided in SI unit by Eq. (4).

$$t = \sqrt{\frac{DSWL}{C_1\, CBR} - \frac{DSWL}{C_2\, P_s}} \tag{4}$$

where $C_1 = 0.5695$, $C_2 = 32.035$, and $P_s = 1.25$ MPa (ICAO, 1983)

The ACN of an aircraft is defined as two times the DSWL, which expressed in 1,000 kg. By substituting the DSWL obtained from Equation (4) in terms of t and CBR into this definition, the ACN becomes Equation (5).

$$ACN = \frac{2 \times DSWL}{1000} = \left(\frac{\left(\frac{t^2}{1000}\right)}{\frac{0.878}{CBR} - 0.01249} \right) \tag{5}$$

where t is expressed in cm.

A PCN value relates to the allowable load-carrying capacity of a particular pavement. It represents the structural capability of a pavement to support the proposed aircraft loads and traffic levels. The PCN number in this study obtains by using the Technical evaluation method. This method follows the procedure of finding the ACN number except the gross weight and subsequently the load on the main gear of a proposed aircraft is obtained from the maximum allowable gross weight of the aircraft (Tipnis and Patil, 2014). The ACN number which obtained by using this maximum allowable gross weight is referred as the PCN number.

The PCN number is reported using the PCN code format. This includes the pavement type, the subgrade category, the allowable tire pressure, and the method used to determine the PCN, as shown in Table 4.

Table 4: PCN Code Format (after FAA, 2014)

PCN value	Pavement type	Subgrade category	Allowable Tire Pressure	Method Used to Determine the PCN
A number	R = Rigid F = Flexible	A = High (CBR>13) B = Medium (8<CBR<13) C = Low (4<CBR<8) D = Ultra Low (CBR<4)	W = No limit X = to 1.75 MPa Y = to 1.25 MPa Z = to 0.50 MPa	T = Technical U = Using Aircraft

The COMFAA program is developed by the FAA to support the analysis of the PCN using the FAA procedure provided in the FAA Advisory Circular No 150/5335-5C. In fact, the computation of the ACN-PCN used in this study is based on the COMFAA program version 3.0. Input data requested by the COMFAA program for determining the PCN are the thickness and the structural properties (CBR) associated with traffic volume of aircraft. Table 5 shows results from the PCN analysis and ACN/PCN ratios of the pavement structure in taxiway areas ***A1*** to ***B5***. The evaluated thickness is obtained from the thickness taken from the field tests by using the COMFAA support spreadsheet. The PCN values is calculated by the COMFAA program. The ACN_{max} is taken from the ACN of the B777-300ER which is the highest ACN value presented in Table 2.

Table 5: Results of PCN analysis and ACN/PCN ratios

Areas	Evaluated thk.(m)	PCN	ACN_{max} (B777-300ER)	ACN/ PCN	Areas	Evaluated thk.(m)	PCN	ACN_{max} (B777-300ER)	ACN/ PCN
A1	2.220	134/F/D/X/T	120/F/D	0.90	***B1***	2.274	141/F/D/X/T	120/F/D	0.85
A2	2.183	130/F/D/X/T	120/F/D	0.92	***B2***	2.267	140/F/D/X/T	120/F/D	0.86
A3	2.139	131/F/D/X/T	120/F/D	0.91	***B3***	2.264	140/F/D/X/T	120/F/D	0.86
A4	2.221	134/F/D/X/T	120/F/D	0.90	***B4***	2.290	149/F/D/X/T	120/F/D	0.81
A5	2.247	137/F/D/X/T	120/F/D	0.88	***B5***	2.304	151/F/D/X/T	120/F/D	0.80
A6	2.212	133/F/D/X/T	120/F/D	0.90					

The results shown in Table 5 reveals that Area ***A2*** had the lowest PCN value of 130, but this number is higher than the ACN_{max} value of 120, which belongs to the B777-300ER - the highest ACN aircraft in the traffic.

7. EFFECT OF INCREASING ACN TO PAVEMENT REMAINING LIFE

The Aircraft Classification Number (ACN) value can be calculated back to the weight of the aircraft. In addition, the Cumulative Damage Factor (CDF) or the remaining life can be analyzed based on the weight of the aircraft. This study *takes a closer look* at the relationship between the changes in weight of the aircraft in term of the Aircraft Classification Number / Pavement Classification Number (ACN/PCN) ratio and the CDF or the remaining life of the pavement.

ICAO documents Annex 14 and the Aerodrome Design Manual Part 3 suggests that the PCN rating established for a pavement indicates the pavement capability of supporting the aircraft having an ACN of equal or lower magnitude. In the guidance on overload operations, for flexible pavements, the occasional movements by aircraft with ACN not exceeding 10 percent above the reported PCN (ACN/PCN < 1.1) should not adversely affect the pavement. In addition, the annual number of overload movements should not exceed approximately 5 percent of the total annual aircraft traffic movement. It is implied that in general operation the ACN/PCN ratio should be equal or lower than 1. However, in the case of overload operations, the performance of a pavement does not be affected if the ACN/PCN ratio is smaller than 1.1. The annual number of overload aircraft traffic should not exceed approximately 5 percent of the total number of annual traffic volume.

Table 2 shows that the B777-300ER aircraft provides the highest ACN value of 120, with a gross weight of 352.44 tons and the annual departure of 14,000 representing 8.3 percent of total traffic. The ACN/PCN ratios of the B777-300ER in this study however are assumed to be varied with the increase in their values from 0.50 to 1.10. This follows the suggestion of the ICAO that in general the ratio should be equal or lower than 1 or in the case of overload the ratio should be smaller than 1.1. For a selected ACN/PCN ratio, the ACN of the B777-300ER aircraft is considered as a variable, while the PCN is specified as a constant for a specific area. The specified PCN numbers for the pavement structure in taxiway areas ***A1*** to ***B5*** are taken from Table 5. Moreover, as shown in Table 2, the annual traffic volume of the B777-300ER aircraft is 14,000 departures, which is consider as 8.3% of total traffic volume. However, in this study, the traffic volumes of B777-300ER aircraft are assumed to be 1, 2.5, 5 and 8.3% of total traffic volume, which are considered to be 1,569, 3,984, 8,121 and 14,000 departures per year, respectively. The ACN and traffic volume of the other aircrafts are not changed.

By the assumption of increasing the values of ACN/PCN ratios of the B777-300ER model from 0.50 to 1.10 with the specified PCN, the new ACN number is obtained. The new load on the main gear and the new gross weight of the B777-300ER is then obtained by using the reversed calculation of the procedure showing in Figure 5 for finding the new ACN numbers. However, in this study, the new gross weights for the B777-300ER aircraft are obtained by trial and error method using the COMFAA commercial software. This is done by substituting different values of the gross weight as the input data to obtain the ACN numbers and checking the equality with the specified ACN values. The obtained solution is the required new ACN number. Then, the CDF and the remaining life are determined by using the procedure showing in Figure 4. In this study, the procedure is carried out by the commercial software called FAARFIELD. Table 6 shows the CDF and the remaining life of the pavement in the area ***A1***. The 1.0%CDF, 2.5%CDF, 5.0%CDF and 8.3%CDF are defined as the CDF values when traffic volume of the B777-300ER aircraft are 1.0, 2.5, 5.0 and 8.3 percent of total traffic volume, respectively. The 1.0%Life, 2.5%Life, 5.0%Life, and 8.3%Life are defined as the remaining life when traffic volume of the B777-300ER aircraft are 1.0, 2.5, 5.0 and 8.3 percent of total traffic volume, respectively.

Table 6: CDF and Remaining Life of pavement structure in area ***A1***

ACN/ PCN	PCN num.	New ACN of B777-300ER	New Gross Weight (tons)	1,569 Annual dep.		3,984 Annual dep.		8,121 Annual dep.		14,000 Annual dep.	
				1.0%CDF	1.0%Life	2.5%CDF	2.5%Life	5.0%CDF	5.0%Life	8.3%CDF	8.3%Life
0.50	134	66.9	234.28	0.83	23.30	0.83	23.30	0.83	23.30	0.83	23.30
0.60	134	80.2	264.44	0.83	23.30	0.83	23.30	0.83	23.30	0.83	23.30
0.70	134	93.6	294.61	0.83	23.30	0.83	23.30	0.83	23.30	0.83	23.30
0.80	134	107.0	323.86	0.84	23.10	0.85	22.90	0.86	22.50	0.89	22.00
0.90	134	120.3	352.44	0.97	20.50	1.18	17.40	1.55	13.90	2.08	10.80
0.92	134	123.0	358.22	1.05	19.30	1.38	15.30	1.95	11.40	2.77	8.40
0.94	134	125.7	364.01	1.15	17.80	1.65	13.10	2.51	9.10	3.72	6.40
0.96	134	128.4	369.86	1.30	16.10	2.02	11.00	3.26	7.20	5.03	4.80
0.98	134	131.0	375.35	1.48	14.50	2.48	9.20	4.19	5.70	6.62	3.70
1.00	134	133.7	381.13	1.72	12.70	3.08	7.60	5.42	4.50	8.75	2.80
1.02	134	136.4	386.91	2.02	11.10	3.84	6.20	6.98	3.50	11.43	2.20
1.04	134	139.0	392.36	2.36	9.60	4.72	5.10	8.77	2.80	14.51	1.70
1.06	134	141.7	398.12	2.80	8.20	5.85	4.20	11.05	2.30	18.46	1.40
1.08	134	144.4	403.92	3.34	7.00	7.20	3.40	13.81	1.80	23.22	1.10
1.10	134	147.1	409.59	3.95	6.00	8.76	2.80	17.00	1.50	28.70	0.90

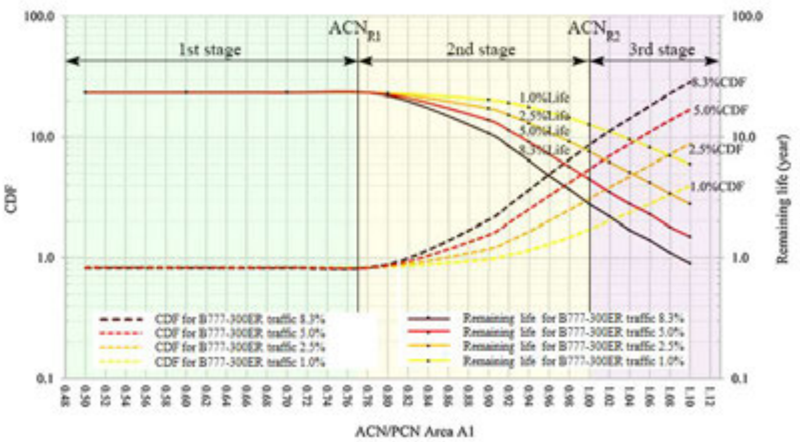

Figure 6: Relationship between CDF, Remaining Life of pavement structure and ACN/PCN ratio at traffic volume in area ***A1.***

Results in Table 6 are displayed on a semi-log graph, plotting the ACN/PCN ratio on the *x* axis using a linear scale. For comparison, both the CDF and the remaining life are plotted on the left and right sides, respectively, of the *y* axis using a logarithmic scale as shown in Figure 6. The graph is divided into three stages by two vertical lines, ACN_{R1} and ACN_{R2}. Location of the lines ACN_{R1} depends on the specified area of the Taxiway ***A*** and ***B***. The line ACN_{R2}, whose ACN/PCN ratio is equal to 1, is the maximum value suggested by ICAO for general operation. In addition, the third stage finishes when the ACN/PCN ratio is equal to 1.1, which related to the limitation suggested by ICAO for overload operations. In the first stage, both the CDF and the remaining life have constant values. Each graph is a horizontal line which parallels to the x-axis until it reach the line ACN_{R1}. For the area ***A1***, as an example, the CDF and the remaining life are 0.83 and 23.30, respectively. The graph shows that when the ACN/PCN ratio exceeds the line ACN_{R1}, the CDF value has been increased, but the remaining life value has been decreased. The rate of change or slope of the graphs increase or decrease in the beginning similar to a linear relationship. However, for higher values of the ACN/PCN ratio especially in the third stage, the graphs behave in exponential rate growth or exponential decay. Slope of different graphs changes in different rate depending on different traffic volumes, which are 1.0, 2.5, 5.0 and 8.3 percent of total traffic volume. Table 7 presents function type of the graphs including values of the ACN_{R1} and ACN_{R2} in all areas investigated in this study, ***A1***, ***A2***, ***A3***, ***A4***, ***A5***, ***A6***, ***B1***, ***B2***, ***B3***, ***B4*** and ***B5***. The ACN_{R1} values of all areas range from 0.70 to 0.80.

Table 7: Function of Graph and values of ACN_{R1}, ACN_{R2}

Areas	Function before ACN_{R1}	ACN_{R1}	ACN_{R2}	Function after ACN_{R2}
A1	Horizontal line. (no slope)	0.77	1.00	Exponential
A2	Horizontal line. (no slope)	0.76	1.00	Exponential.
A3	Horizontal line. (no slope)	0.76	1.00	Exponential.
A4	Horizontal line. (no slope)	0.80	1.00	Exponential.
A5	Horizontal line. (no slope)	0.70	1.00	Exponential.
A6	Horizontal line. (no slope)	0.76	1.00	Exponential.
B1	Horizontal line. (no slope)	0.70	1.00	Exponential.
B2	Horizontal line. (no slope)	0.80	1.00	Exponential.
B3	Horizontal line. (no slope)	0.70	1.00	Exponential.
B4	Horizontal line. (no slope)	0.78	1.00	Exponential.
B5	Horizontal line. (no slope)	0.70	1.00	Exponential.

The ICAO suggests that the ACN/PCN ratio should not be equal or lower than 1 for the pavement to support aircraft in general operation. Under the methodology using in this study, the results show that the CDF and the remaining life of pavement structure are affected in all areas when the ACN/PCN ratios large than a specific value, ranging from 0.70 to 0.80 (after the line ACN_{R1}). This may cause damage to the taxiway by increasing the CDF or reducing the remaining life. Different rate of effect depending on the different traffic volume of the aircraft. Therefore, the remaining life should be taken into account in the procedure of pavement evaluation.

8. CONCLUSION

This study evaluates the strength in term of PCN of the flexible pavement and investigates the effect of the increase in ACN values on the remaining life of the pavement structure. The strength of pavement structure is determined according to the ACN-PCN method. The analysis reveals that all areas have an ACN/PCN ratio less than 1.0. The area ***A2*** has the lowest PCN value of 130, but it is higher than the highest ACN value of the B777-300ER, which was equal to 120. It is found that, the taxiway area ***A5*** provides the lowest remaining lifetime, which is 0.9 years. However, the pavement remaining life of the areas ***A1***, ***A2***, ***A3***, ***A5*** and ***A6*** is less than 20 years, which need to be strengthen to meet the standard requirement.

The pavement remaining life of the study area responds to an increase in ACN value. By using an equivalent aircraft using the proposed model, if the ACN/PCN ratios larger than a range from 0.70 to 0.80, the CDF increases while the remaining life decreases. This may cause damage to the pavement structure. In addition, when the ACN/PCN ratio is greater than 1.0 (ACN Overload), the CDF increases, while the remaining life decreases in the form of an exponential function. ICAO criteria does not refer to the CDF and the remaining life in their suggestion. Results from this study, however, express that the remaining life should be taken into account in the procedure of pavement evaluation.

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