On the Use of FWD Impact-Stiffness Moduli for Determining PCN in Various Pavement Structures

Moshe Livneh

Department of Civil and Environmental Engineering, Technion-Israel Institute of Technology, Haifa 32000, Israel

Abstract: Various technical studies have shown that impact-stiffness modulus values, defined as the ratio of the FWD (falling-weight deflectometer) impact load to its consequent central deflection, can be used to evaluate the PCN (pavement classification number) of a particular flexible or rigid airport pavement. In a previous study, use was made of the old dynamic stiffness modulus procedure developed by the USCOE (US Army Corps of Engineers), this procedure was correlated with various FWD measurements conducted on several runways and taxiways in Israel, together with in-situ borings and the use of the new COMFAA-3.0 software. The results, obtained only for flexible pavements, were checked against the relevant results of full-scale trafficking tests conducted by the FAA (Federal Administration Aviation) at its National Airport Pavement Test Facility. The present study analyzes new FWD measurements and in-situ borings conducted on additional rigid and all-asphaltic runways and taxiways in Israel in order to formulate an updated correlative equation for these types of pavements. The paper concludes with an updated recommendation for the use of impact-stiffness modulus outputs from FWD measurements in order to determine the PCN of any type of pavement directly on the basis of local experience.

Key words: Aircraft classification number, falling-weight deflectometer, pavement classification number, pavement evaluation.

1. Introduction

It is well accepted that the most conventional method of assigning a PCN (pavement classification number) to a given runway is by conducting an in-depth field study along the runway [1-3]. However, it is not always possible to keep a runway out of commission for an extended period with exploration and boring activities. Thus, a quick PCN assignment is sometimes essential. In this connection, various technical studies around the world indicate that pavement-surface deflections can be considered a predictor of pavement life. Therefore, impact-stiffness modulus values, defined as the ratio of the FWD's (falling-weight deflectometer's) impact load to its consequent central deflection, can be used to evaluate the PCN of a particular flexible pavement.

A correlation study, however, is required in order to calibrate these two methods. A previous paper [4]

utilized field-exploration studies and measurements carried out by the IAA (Israeli Airport Authority) at two of Israel's airports, Ben-Gurion International Airport and Ovda Local Southern Airport, and by the US FAA (Federal Administration Aviation) at the NAPTF (National Airport Pavement Test Facility) in Atlantic City, New Jersey, to conduct such a correlation. All these tested runways are of the flexible pavement type.

With (a) new COMFAA-3.0 software available from the FAA, which is based on new ICAO (International Civil Aviation Organization) repetition factors; (b) new field data that has recently become available from FWD measurements and in-situ borings conducted on additional rigid and all-asphaltic runways and taxiways in Israel, it became essential to analyze both the old and the new data in order to formulate updated correlative equations for these two types of pavements. Thus, the objectives of this paper are as follows:

¶ To summarize the USCOE' (US Army Corps of

Corresponding author: Moshe Livneh, D.Sc., professor, research fields: soil mechanics and pavement engineering. E-mail: moshliv@tx.technion.ac.il.

Engineers') findings regarding ASWL (allowable single-wheel load) evaluations by measuring central deflections with various types of dynamic equipment, such as the USCOE 16 Kip (71.2 kN) Vibratory Machine or any conventional FWD device;

• To correlate the ASWL outputs of old and new field-exploration studies and measurements with the outputs of FWD measurements carried out by (a) the IAA at Israel's Ben-Gurion International Airport; (b) the IAA at Israel's Ovda Local Southern Airport; (c) the FAA at the NAPTF (National Airport Pavement Test Facility) in Atlantic City, New Jersey;

• To establish a workable relationship between ASWL and PCN values, suggesting a modified, routine evaluation procedure for future FAA assignments of a PCN.

The process of meeting these three objectives is elaborated in this paper. This paper also presents a comparison of PCN and ACN (aircraft classification number) outputs calculated by both the old and the new COMFAA software, as reported in Ref. [4].

2. Derivation of ASWL by USCOE

In 1970, an improved vibratory loading device was developed by the USCOE, the so-called WES NDT (waterways experimental station non-destructive testing) tool, in order to assist the NDT evaluation procedure [5, 6]. In this connection, it should be noted that USCOE's primary effort was directed at developing a procedure based on measuring the DSM (dynamic stiffness modulus) of the pavement system and relating this value to pavement-performance data.

The WES NDT tool contains a loading device that exerts a static load of 71.2 kN (16 kip) on the pavement surface and is capable of producing 0-66.7 kN (0-15 kip) vibratory loads at a frequency of 15 Hz. This load is applied to the pavement surface through a 457-mm-diameter (18-in-diameter) steel loading plate. The loading equipment is positioned at each test site, and the dynamic force is varied from 0 to 66.7 kN at 8.9 kN (2 kip) intervals, with a constant frequency of

15 Hz. The deflection of the pavement surface, measured by the velocity transducers, is plotted against the applied load. The DSM (dynamic stiffness modulus) (ton/mm) is the inverse of the slope of deflection versus load plot at the linear portion of the curve. The measured DSM value is later corrected to the standard DSM value, for which the asphalt temperature is 21°C.

Nowadays, the use of the WES NDT tool is rare, in most cases, it has been replaced by the FWD (falling-weight deflectometer). Therefore, ISM (impact-stiffness modulus) values, defined it as the ratio of the FWD impact load to its consequent central deflection, substitute for the DSM values. This substitution is performed with the aid of the following correlation, obtained from the data and references shown in Fig. 1:

For flexible pavement and $ISM \geq 20$ ton/mm:

$$DSM = 0.7147 \times ISM + 16.2 \quad (1)$$

For flexible pavement and $ISM < 20$ ton/mm:

$$DSM = 4.6109 \times ISM^{0.6315} \quad (2)$$

For rigid pavement:

$$DSM = 0.7743 \times ISM \quad (3)$$

where, DSM = dynamic stiffness modulus of the pavement, measured by WES NDT, in ton/mm, and ISM = impact-stiffness modulus of the pavement in ton/mm, measured by any FWD device.

Fig. 1 DSM measured by WES NDT equipment versus ISM measured by any FWD device according to various published experimental data [7-9].

The investigation carried out by Green et al. [6] with the WES NDT tool led to the following experimental relationships obtained in the various types of pavement structures:

For flexible pavements

$$ASWL = 1.110 \times DSM \quad (4)$$

For rigid pavements:

$$ASWL = 0.452 \times DSM \quad (5)$$

For rigid pavements overlaid by asphaltic layers:

$$ASWL = 0.473 \times DSM \quad (6)$$

where, DSM = dynamic stiffness modulus of a given pavement in ton/mm, and $ASWL$ = allowable single-wheel load, with 0.164 m^2 (254 in^2) of tire-contact area for 24,000 departures, in ton, obtained from in-situ exploration and drilling. It is noted that for asphaltic pavements, the measured DSM value is corrected for an asphalt temperature of 21°C by the method detailed in Ref. [4].

The multiplier factors given in Eqs. (4) and (5) are shown in Fig. 2 as a function of the postulated pavement moduli: 500 MPa for flexible pavements, 30,000 MPa for rigid pavements, and 20,000 MPa for combined pavements.

The multiplier factor can be derived from Fig. 2 for an all-asphaltic pavement for which the pavement modulus is postulated to be 3,500 MPa: it is equal to 0.716. Thus, for all-asphaltic pavements:

$$ASWL = 0.716 \times DSM \quad (7)$$

Now, in order to calculate the PCN values from the measured DSM values, it is necessary to develop the relationship between PCN and $ASWL$. This is shown in the next section.

3. Derivation of PCN from ASWL

In Israel, the single critical airplane equivalent is the B747-400, together with its 6,000 annual departures over a period of 20 years (i.e., a total of 120,000 departures). The PCN_H (i.e., the PCN value derived from the thickness of the pavement structure) calculations of a given runway for this aircraft is performed with the aid of COMFAA-3.0 software as explained in FAA's AC 150/5335-5B [10].

Fig. 2 Multiplier factor for Eqs. (4) and (5) as a function of the postulated pavement moduli.

3.1 The Flexible Pavement Case

For the flexible pavement case, this procedure utilizes two calculation stages: first, the MGW (maximum gross weight) value of the given critical airplane is calculated by choosing from the aircraft library the Boeing aircraft group together with the B747-400 airplane (four wheels on main gear) and then inserting the following into the software window: (a) 6,000 annual departures; (b) the calculated total effective equivalent thickness; (c) the subgrade CBR (California bearing ratio) value. For these data, the output value of MGW is obtained by applying the MGW (flexible) computational mode and is shown at the bottom-left corner of the software window.

In the second stage, the above calculated MGW value is inserted into the gross weight line in the same software window, leading to an ACN output after applying the ACN (flexible) computational mode. Thus, the PCN value of the given pavement is equal to the ACN value obtained for the given soil group. It is noted that the total effective equivalent thickness is calculated according to the procedure given in Ref. [4].

The $ASWL$, as defined earlier in Eq. (4) (the flexible pavement case), is calculated for the same total effective equivalent thickness by using the well-known CBR equation, given in Ref. [11], in this equation, the single-wheel contact area is equal to

0.164 m² (254 in²) and the repetition factor (α) is equal to 0.94 (compatible with 24,000 departures).

For the thickness and subgrade CBR data of the pavements tested in the study, described in the following section, the relationship between the calculated PCN_H and ASWL values is shown in Fig. 3. This figure indicates that, on the average, the PCN_H value in flexible pavements is equal to ASWL (in tons) multiplied by a factor of 1.460.

3.2 The Rigid Pavement Case

For the rigid pavements case, the PCN_H calculations follow the same procedure as that for the flexible pavement case. Here again, in the first stage, the MGW (maximum gross weight) of the given critical airplane is calculated by choosing the same software window as above, and then inserting the following into the software window: (a) 6,000 annual departures; (b) the calculated total effective equivalent thickness; (c) the combined subgrade reaction (k) value; (d) the concrete flexural strength for a PCC (Portland cement concrete) of 4.5 MPa. For these data, the output value of MGW is obtained by applying the MGW (rigid) computational mode and is shown at the bottom-left corner of the software window.

In the second stage, the above calculated MGW value is inserted into the gross weight line in the same software window. This leads to an ACN output after applying the ACN computational mode (rigid). Thus, the PCN value of the given pavement is equal to the ACN value obtained for the given soil group. It is noted that the total PCC effective equivalent thickness is calculated according to the procedure given at the end of this section.

Similarly, the calculation of ASWL, as defined earlier in Eq. (5) (the rigid pavement case), is performed with the same data for the rigid pavements. This is done by, again, using the COMFAA-3.0 software in order to obtain the MGW of the 1,200 yearly departures of an SWL-50 aircraft (located in the Generic Aircraft Group). This MGW value is equal to the required ASWL. Although the tire

pressure in these MGW calculations retains a constant value of 1,241 kPa (180 psi), thus leading to different values of the wheel contact area, and not to the defined constant value of 0.164 m² (254 in²), the approximation of the above equality of MGW with ASWL seems to be sufficient.

Calculations of PCN_H and ASWL have been conducted for PCC effective equivalent thicknesses of 200, 300, 400, and 500 mm and for combined subgrade reactions of 25, 75, and 125 kPa/mm. The results of these calculations are given in Fig. 4. This figure indicates that, on the average, the PCN_H value for rigid pavements is equal to ASWL (in tons) multiplied by a factor of 1.803.

Finally, the calculation of the effective equivalent thickness is calculated according to FAA's AC

Fig. 3 PCN_H for 120,000 departures of the B747-400 versus ASWL from Eq. (4) (flexible pavement).

Fig. 4 PCN_H for 120,000 departures of the B747-400 as a function of ASWL of Eq. (5) (rigid pavement).

150/5320-6D [12], in which the rate of the slabs condition factor (C_r) is selected. This is done after an extensive pavement condition survey, for which (a) $C_r = 1.0$ for an existing pavement in good condition, (some minor cracking may be evident, but no structural defects exist); (b) $C_r = 0.75$ for an existing pavement containing initial corner cracks owing to loading but no progressive cracking or joint faulting; (c) $C_r = 0.35$ for an existing pavement in poor structural condition, meaning one that is badly cracked or crushed and has faulty joints. Thus, the selection of a condition factor is really a matter of engineering judgment, and its implementation is conducted according to Eq. (8) given in Ref. [12]. This equation, furthermore, takes into account the elasticity modulus of the existing slab [13], which differs from the standard value of 27,500 MPa as defined in COMFAA 3-0.

$$H_{ef} = [H_{ex} \times C_r^{1/1.4}] / [0.213 \times \ln(E_c) - 1.145] \quad (8)$$

where, C_r = condition factor, H_{ex} = existing slab thickness, E_c = elasticity modulus of the existing slab in MPa, and H_{ef} = effective thickness of the existing slab for the standard elasticity modulus of 27,500 MPa.

Finally, the effective equivalent thickness accounting for the steel reinforcement applied in the slabs is calculated according the relevant USCOE chart [14], approximately formularized by the following equation:

$$H_{ef} = 1.048 \times H_{final} - 1.078 \times S \times H_{final} \quad (9)$$

where, H_{ef} = existing slab effective thickness calculated according to Eq. (8), H_{final} = existing slab final effective equivalent thickness, and S = percentage of steel reinforcement in the range of 0.05% to 0.1%.

4. Correlation Study of Flexible Pavements

At Israel's Ben-Gurion and Ovda Airports, field exploration and boring studies included determinations of (a) thicknesses of various layers; (b) in-situ strength of the various pavement layers,

including subgrade; (c) a deterioration factor for each pavement layer; and (d) the FWD impact-stiffness moduli of all the tested pavements. The results obtained were presented by the author in Ref. [4]. It should be noted that this reference also contains data from the NAPTF trial sections taken from Ref. [15]. The results of all these field exploration and boring studies concern flexible pavements only.

Fig. 5 presents the calculated values of ASWL for the data of Ref. [4] using, as mentioned before, the well-known CBR equation as given in Ref. [11], here, the single wheel contact area is equal to 0.164 m² (254 in²), and the repetition factor (α) is equal to 0.94 (compatible with 24,000 departures). This figure also presents the accompanying DSM values calculated with the aid of Eqs. (1) and (2) from the FWD measurements.

Fig. 5 indicates that the zero interception linear regression between the two above variables yields a multiplier factor of 1.572, which is higher than that given in Eq. (4) (i.e., 1.110). This discrepancy may be due to the use of mean DSM values that were utilized to obtain Eq. (4), in contrast to the 15th percentile DSM values employed in Fig. 5. Finally, in order to obtain the PCN_H values from the calculated ASWL values, it is necessary to multiply them by a factor of 1,460, as indicated in Fig. 3.

The coefficient of determination (R^2) obtained for the regression of Fig. 5 is rather low: 0.574. Therefore, it was decided to introduce the ratio of DSM/CBR^{0.5} as a new parameter instead of the DSM alone and to look for a direct relationship between the values of this new parameter and the calculated PCN_H values (Fig. 6).

Again, the PCN_H values in Fig. 6 were calculated by the COMFAA-3.0 software for a given effective equivalent thickness and its accompanying given subgrade CBR. Here it should be noted that according to the basic definition of the ACN-PCN system, the number of wheels in the main gear totals four for this software. The regression of Fig. 6 yields, as intended,

Fig. 5 ASWL for 24,000 departures of tested flexible pavements versus their DSM values measured by the FWD apparatus, as reported in Ref. [4].

Fig. 6 PCN_H for 120,000 departures of the B747-400 versus the expression of DSM/CR_E^{0.5} measured by FWD apparatus, as reported in Ref. [4].

a coefficient of determination (R^2) value, of 0.894, higher than that associated with Fig. 5, 0.574.

The regression given in Fig. 6 yields the following equation:

$$PCN_H = 1.4193 \times (DSM/CR_E^{0.5})^{1.4923} \quad (10)$$

where, PCN_H = calculated PCN value according to COMFAA-3.0 for 120,000 departures of the B747-400 aircraft based on the thickness and CBR data given in Ref. [4], shown in Fig. 3 as a function of the following expression: $DSM/CR_E^{0.5}$.

It is important to note that Eq. (10) enables a determination of PCN values only on the basis of

non-destructive measurements, without the need to conduct any in-depth field explorations. This is also true of the subgrade CBR value, which can be obtained from the FWD deflection measurements by utilizing the vertical deflection measured at a lateral distance of 1.8 m. The total pavement thickness is left as an unnecessary input value as suggested by the 1993 AASHTO guide for the design of pavement structures and by others [16].

5. Correlation Study of Rigid Pavements

The concrete slabs of Runway 02-20 at the Ovda airport and those of Taxiway U at Ben-Gurion airport were both field-explored with boring studies that included determinations of (a) H (i.e., thicknesses of the existing slab thickness); (b) S (i.e., percentage of steel reinforcement); (c) C_r (i.e., condition factor of the existing slabs leading to their deterioration factor); (d) k (i.e., combined subgrade reaction, subgrade combined with sub-base); (e) E_c (i.e., in-situ elasticity modulus of the concrete slab); and (f) R_c (i.e., in-situ tensile strength of the concrete slab). The results obtained for these determinations are presented in Table 1. In addition, the DSM results obtained from FWD impact-stiffness moduli are given in Table 2.

The calculations of ASWL as defined in Eq. (5): (a) from the measured DSM value and Eq. (5); and (b) from calculated H_{final} (according to both Eqs. (8) and (9), and k , and R_c values) are shown in Table 2. These calculations indicate that a discrepancy exists in the ASWL outputs between these two kinds of calculations, with a low value for Taxiway U and a high value for Runway 02-20.

The ASWL outputs in Table 2 suggest the following correction to the ASWL versus DSM of Eq. (5):

$$ASWL = 0.398 \times DSM \quad (11)$$

where, DSM = dynamic stiffness modulus of concrete slabs (ton/mm) measured by the FWD apparatus, utilizing Eq. (3).

Eq. (11) is based on very limited measured data, and thus its validity should obviously be verified by

Table 1 Measured values of the existing concrete slabs.

Facility	H (mm)	S (%)	C_r	k (kPa/mm)	E_c (MPa)	R_c (kPa)
U	350	0.07	0.50	45.0	7.0×10^4	7.1
02-20	280	-	0.85	47.0	3.7×10^4	4.1

Table 2 Calculated ESWL for the data of Table 1.

Facility	Eq. (5)		COMFAA 3.0	
	DSM (ton/mm)	ASWL (ton)	H_{final} (mm)	ASWL (ton)
U	66.4	30.0	287	25.5
02-20	53.4	24.1	273	15.0

additional measured data. Finally, the PCN_H value is derived from the multiplication of the corrected ASWL values of Eq. (11) by the ratio value given in Fig. 4 (i.e., 1.803).

6. The All-Asphaltic Case

Recently, new R_1-N_3 taxiways were constructed at Ben-Gurion airport. Some of these taxiways are constructed of a flexible pavement, and others of an all-asphaltic pavement. Both structures have been designed to carry 120,000 departures of the Airbus A380-800 aircraft with a maximum gross weight of 592 tons for a subgrade CBR of 5.0%. The flexible structure, of 1,560 mm thickness (Table 3), was based on the old F806FAA FAA program (i.e., on the old CBR equation), and the all-asphaltic structure of 900 mm thickness (Table 3) on the new FAARFIELD FAA program [17]. The use of these two different programs probably led to a somewhat smaller all-asphaltic final (effective equivalent) thickness (1,494 mm) than that of the flexible structure (1,589 mm). It is noted that in the old FAA method, a flexible structure of 1,560 mm thickness is equivalent to an all-asphaltic structure of 970 mm.

Table 3 summarizes the field-explored data, including the subgrade CBR value of 6.0% (compared with the design CBR value of 5.0% used to calculate the pavement structure thickness) and the DSM value obtained from the FWD measurements corrected for 21°C asphalt temperature. This table also includes the calculated values of ASWL according to the following:

Table 3 Measured values of the recently constructed flexible and all-asphaltic pavements and their calculated ASWL values.

Structure	H (mm)	H_{final} (mm)	CBR (%)	DSM (ton/mm)	ASWL: Eqs. (5) and (7)/COMFAA A (ton/mm)
Flexible	1,560	1,589	6.0	52.5	58.3/99.6
All-Asph.	900	1,494	6.0	73.0	51.6/94.3

(a) Eq. (4) and COMFAA 3-0 for the flexible pavement structure (middle row of the table); and (b) Eq. (5) and COMFAA 3-0 for the all-asphaltic pavement structure (last row of the table).

The calculated values of ASWL shown in Table 3 indicate that the ratio of the software-source value (i.e., the value derived from COMFAA 3-0 software) to that of the equation-source value (i.e., the value derived from Eqs. (5) and (7)) is equal to 1.71 for the flexible pavement structure and 1.83 for the all-asphaltic pavement structure. This finding enables the correction of Eq. (7) by the same ratio of the value of 1.572 (taken from Fig. 5) to the value of 1.110 (taken from Eq. (4)). Thus, the corrected expression that substitutes for Eq. (7) is:

$$ASWL = 1.014 \times DSM \quad (12)$$

where, DSM = dynamic stiffness modulus of all-asphaltic pavement structures (ton/mm), measured by the FWD apparatus utilizing Eqs. (1) and (2).

Eq. (12) is based on only one measured case, and thus its validity should obviously be verified by additional measured data from other in-situ cases. Finally, the PCN_H value is derived from the multiplication of the corrected ASWL values of Eq. (12) by the ratio value given in Fig. 3 (i.e., 1.460). Furthermore, it can be concluded that the thickness calculation of an all-asphaltic pavement according to the old F806FAA FAA program leads to overestimated values compared with those derived from the new FAARFIELD FAA program [17].

7. Conclusions

This paper has described the IAA's (Israel Airports Authority's) updated experience with

airport-pavement bearing-capacity evaluations by means of the PCN (pavement classification number) system. Various technical studies around the world indicate that pavement-surface deflections can be considered a predictor of pavement life. Therefore, impact-stiffness modulus values, defined as the ratio of the FWD's (falling-weight deflectometer's) impact load to its consequent central deflection, can be used to evaluate the PCN of any flexible pavement.

For the present study, use was made of the old DSM procedure developed by the USCOE to guide the suggested FWD procedure. For that reason, a correlation was made with various FWD measurements conducted on six major flexible-pavement-type runways and taxiways in Israel, together with in-situ borings. The results obtained, using the new COMFAA-3.0 software, were also checked against relevant results made available from the full-scale trafficking tests conducted by the FAA at its NAPTF (National Airport Pavement Test Facility) in Atlantic City, New Jersey. In addition, various FWD measurements were conducted on a major rigid-pavement-type runway and a taxiway, together with their in-situ borings, and also on a recently constructed all-asphaltic-pavement-type taxiway, together with its DCP (dynamic cone penetrometer) subgrade testing during the construction phase. The conclusions drawn from the tested pavements are as follows:

• For flexible pavement structures, the use of the central deflection to characterize a PCN rating is legitimate. However, the inclusion of the CBR variable in the regression analysis is acceptable;

• For any range of subgrade CBR of the above pavements, Eq. (10) enables a determination of PCNH values (based on 120,000 departures of a B747-400 aircraft) on the basis of non-destructive measurements and without the need to conduct any in-depth field-exploration study, thus allowing a quick PCNH assignment where essential;

• For rigid pavement structures, Eq. (11) enables a determination of ASWL values (i.e., allowable

single-wheel load, with 0.164 m^2 (254 in^2) of tire-contact area, for 24,000 departures) on the basis of non-destructive measurements, thus allowing a quick PCNH assignment by applying a multiplier factor of 1.803 to the ASWL obtained above;

• For all-asphaltic pavement structures, Eq. (12) enables a determination of ASWL values on the basis of non-destructive measurements, thus allowing a quick PCNH assignment by applying a multiplier factor of 1.460 to the ASWL obtained above;

• The two procedures described for determining PCNH in rigid pavements and in all-asphaltic pavements are based on two rigid pavement cases and one all-asphaltic pavement case, thus, these two procedures should be considered only preliminary;

• The thickness calculation of an all-asphaltic pavement according to the old F806FAA FAA program leads to overestimated values compared with those derived from the new FAARFIELD FAA program.

In conclusion, it should be emphasized that the results reported in this paper apply specifically to the traffic and pavements listed, including the limited CBR and k ranges and the ranges of the limited rigid and all-asphaltic pavement cases. For routine use of other sites than those tested in this paper (i.e., those that manifested the local experience), a validation of Eqs. (10), (11) and (12) should be explored with the use of additional structures, subgrades, and air traffic volumes.

Finally, it is worthwhile quoting the conclusion reached in Ref. [4]: (a) the new PCN values for pavements serving aircrafts with four wheels or more on their main gear, as derived from new COMFAA-3.0 software, are higher than their comparable PCN values derived from the old COMFAA software, a difference that may amount up to 20% for heavy flexible structures serving 120,000 departures of B747-400 airplane; and (b) the ACN values for aircrafts with four wheels or more on their main gear, as derived from new COMFAA-3.0 software, these values are lower than their comparable

ACN values derived from the old COMFAA software, the difference, however, being only at a rate of about 10%. These new ACN-PCN outputs are also based on the old definition of ACN-PCN given by ICAO [18].

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References

- [1] K.J. DeBord, Precise Methods for Estimating Pavement Classification Number, D6-82203, Boeing Commercial Airplane Group, Airport Technology Organization (B-B210), USA, 1998.
- [2] CROW, Guideline on PCN Assignment in the Netherlands, Guideline on Airport Strength Rating and Directive for Reporting, Technology Platform for Transport, Infrastructure and Public Space, CROW-Report 05-06, USA, 2005.
- [3] M. Livneh, Proposed development in the determination of pavement and aircraft classification number, The IJP (International Journal of Pavements) 7 (1-2-3) (2008) 2-14.
- [4] M. Livneh, Further developments in the use of FWD impact-stiffness moduli for determining PCN in Israel, in: Proceedings of the 7th International Conference on Maintenance and Rehabilitation of Pavements and Technological Control (MAIREPAV 7), Auckland, New Zealand, 2012.
- [5] FAA, Use of Nondestructive Testing Devices in the Evaluation of Airport Pavements, FAA Advisory Circular AC 150/5370-11, Federal Administration Aviation, Office of Airport Safety and Standards, Washington D.C., 1976.
- [6] J.L. Green, J.W. Hall, Nondestructive Vibratory Testing of Airport Pavements, Experimental Test Results and Development of Evaluation Methodology and Practice, Vol. 1, Report No. FASA-RD-73-205-1, US Army Corps of Engineers Waterways Experiment Station, Washington D.C., 1975.
- [7] G. Wiseman, J. Greenstein, J. Uzan, Application of Simplified Layered Systems to NDT Pavement Evaluation, Transportation Research Record No. 1022, Transportation Research Board, 1985, pp. 29-36.
- [8] A.J. Bush III, D.R. Alexander, Pavement Evaluation Deflection Basin Measurements and Layered Theory, US Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, 1981.
- [9] R.A. Bentsen, S. Nazarian, J.A. Harrison, Reliability Testing of Seven Nondestructive Pavement Testing Devices, in: A.J. Bush III, G.Y. Baladi (Eds.), Nondestructive Testing of Pavements and Back-Calculation of Moduli, ASTM STP 1026, American Society for Testing and Materials, Philadelphia, 1989, pp. 41-58.
- [10] FAA, Standardized Methods of Reporting Airport Pavement Strength-PCN. FAA Advisory Circular AC 150/5335-5B, Federal Administration Aviation, Office of Airport Safety and Standards, Washington D.C., 2011.
- [11] M. Livneh, The use of impact-stiffness modulus outputs from FWD measurements to determine PCN in Israel, in: Proceedings of the 8th International Conference on Bearing Capacity of Roads, Railways, and Airfields, Vol. 2, University of Illinois at Urbana-Champaign, 2009, pp. 777-787.
- [12] FAA, Airport Pavement Design and Evaluation. Advisory Circular AC 150/5320-6D, Federal Administration Aviation, Office of Airport Safety and Standards, Washington D.C., 2004.
- [13] R.S. Walker, M.J. Adolf, Pavement-Transportation Computer Assisted Structural Engineering (PCASE): User Manual, Version 2.08, US Army Corps of Engineers, Engineer Research and Development Center, Vicksburg, MS, 2005.
- [14] USCOE (US Army Corps of Engineers), Airfield Pavement Evaluation, Unified Facilities Criteria, UFC 3-260-03, USA, 2001.
- [15] N. Garg, W.H. Marsey, Comparison between falling weight deflectometer and static deflection measurements on flexible pavements at the National Airport Pavement Test Facility (NAPTF), in: Proceedings of the 2002 Federal Aviation Administration Airport Technology Transfer Conference, Atlantic City, NJ, 2002.
- [16] A. Sides, J. Bonjack, G. Zoltan, Overlay Design Procedure for Pavement Management Systems, Transportation Research Record No. 1374, 1992, pp. 63-70.
- [17] FAA, Airport Pavement Design and Evaluation Pavements, FAA Advisory Circular, AC 150/5320-6E, Federal Administration Aviation, Office of Airport Safety and Standards, Washington D.C., 2009.
- [18] ICAO (International Civil Aviation Organization), Aerodrome Design Manual: Pavements, 2nd ed., Pennsylvania State University, USA, 1983.