Investigation of Classification Parameters and Assumptions for Rigid and Flexible Airfield Pavements

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ABSTRACT: Classification of airfield pavement bearing capacity has always been one of the most important tasks for their management and therefore it is important to have a suitable classification and reporting system, which will internationally facilitate the management of airport pavements. Currently the method used for this purpose is the Aircraft Classification Number – Pavement Classification Number (ACN – PCN) of the International Civil Aviation Organization (ICAO) however, practice has shown that there are several difficulties and drawbacks, which encumber the implementation of the method. Theoretical investigations on the method assumptions and background, as well as analyses of field applications have revealed several findings regarding the accuracy and reliability of the reporting system. Related analyses based on data from Greek and international airfield pavement structures have shown that in practice the ACN-PCN system for rigid pavements is less sensitive to background parameters and assumptions, easier to apply and probably more accurate compared to flexible pavements. In addition, critical details which should be considered in order to optimize the accuracy and reliability of the ACN in practice are presented and discussed.

KEY WORDS: Airfield pavements, ACN-PCN, classification, reporting, load rating

1 OBJECTIVES

Evaluation and reporting of pavement bearing capacity has always been among the major tasks of airport engineering, since it supports the decision making process needed for managing of the airport pavements. Modern financing approaches presume the return of capital investments; because of this the airport managers and engineers have always been seeking for a safe way of maximizing the pavement utilization, as well as for a flexible and reliable procedure to classify and continuously check bearing capacity of their pavements.

Early classification methods were very simple (Horonjeff and Mc Jelvey, 1983), but the rapid growth in aircraft types, loads and movements made it necessary to move to more sophisticated systems. The first of them was the well-known Load Classification Number (LCN) (ICAO, 1965) which after 1983 has been replaced with the current system, the Aircraft Classification Number – Pavement Classification Number (ACN-PCN) (ICAO, 1983). Initially, ACN-PCN was considered as vast improvement compared to LCN, however during its implementation in practice over the last 20 years several questions about its suitability have been raised (Loizos et. al, 2002), (Stet et. al., 2002).

In fact, as some researchers claim, it is possible to manage airport pavements without a classification system like ACN-PCN, but in practice the existence of a suitable rating system may significantly facilitate the process and also it make friendlier for the numerous non-pavement experts which are involved in the aviation industry and air transportation. To this end, the investigation of the assumptions and parameters of the official classification system reveals some aspects which might have a significant importance in practice. These findings have come out by the comprehensive investigation of ACN – PCN background, as well as by the evaluation of case studies in flexible and rigid airport pavements. The authors after a long period of systematic work on the subject present their notifications aiming to assist engineers, managers and practitioners to optimize the use of the ACN-PCN in practice.

2 RATING OF THE AIRCRAFT LOAD

The use of a factor for classifying the severity of the aircraft load was probably the most important challenge for the ACN-PCN system. For a variety of obvious reasons the airport managers and engineers need to have a simple but reliable estimation of the damaging impact caused on any pavement by any complicated aircraft gear system and that was one of the most critical problems of the older system (LCN). The vast improvement introduced in ACN concept was the independence of the aircraft load rating from the pavement properties, with the exception of the subgrade strength (table 1). This was achieved by the use of the Derived Single Wheel Load (DSWL), defined by ICAO as the single wheel load with fixed pressure equal to 1.25MPa, which requires the same pavement thickness (reference thickness) as the actual gear system to operate on an unrestricted basis (ICAO, 1983). For flexible pavement structures ICAO suggests to calculate the reference thickness using the CBR method and the 10000 operations as a realistic assumption for the unrestricted operations, whereas for rigid pavements to accept the 2.75MPa as the related critical value for the tensile strain at the bottom of the concrete slab. Detailed investigations on the subject have shown that the suggestion for rigid pavement is acceptable, whereas the validity of the one for flexible pavements is rather questionable, and this is something that will be further discussed in this paper.

Table 1. ACN – PCN subgrade strength categories.

CBR Category	A- High	B - Medium	C - Low	D – Ultra Low
Range of CBR/K	Above 13% (>120MN/m^3)	8% to 13% (60 to 120MN/m^3)	4% to 8% (25 to 60MN/m^3)	Below 4% (<25MN/m^3)
Characteristic value	15% (150MN/m^3)	10% (80MN/m^3)	6% (40MN/m^3)	3% (20MN/m^3)

Using the above concept the DSWL of an aircraft can be calculated and used without further reference to pavement thickness. This is in accordance with the objective of ACN – PCN method to evaluate the relative loading effect of an aircraft on a pavement, which is rated by calculating the ACN factor through the formula ACN=2*DSWL. The “two” factor in the numerical definition is used to achieve suitable ACNs vs. gross mass scale so that whole number ACNs may be used with reasonable accuracy.

According to the ACN rating system, an aircraft with the higher ACN value is expected to cause more damage on a pavement compared to an aircraft with a lower ACN. Investigations in rigid pavements tend to confirm this, however in flexible pavements this is not always the case; there are several examples where the aircraft load rating is not fully successful. One of them is given by the comparison of the effect caused by the Airbus A300-B4 and the Boeing 707-310C on a variety of typical flexible airport pavement structures.

For the analysis this example (and all other pavements included in this investigation) the structural model of figure 1 was adopted. The modulus values used in the flexible pavements analyses range from 4000 to 6500 MPa for the asphalt concrete, 500 to 250 MPa the unbound integrated base and subbbase and the poisson values used where 0.35 and 0.4. For the subgrade properties several CBR values were examined so as to study all four categories of ICAO and the related poisson ratio value was in all cases 0.45. However it should be strongly noted here that the findings of this study are qualitative and thus they are not depended on the fore-mentioned material properties; any realistic data can be used instead. Finally, it is assumed that critical points of the examined model are the bottom of the intergrated bituminous layers (horizontal stress/strain) and the top of the subgrade (vertical stress/strain).

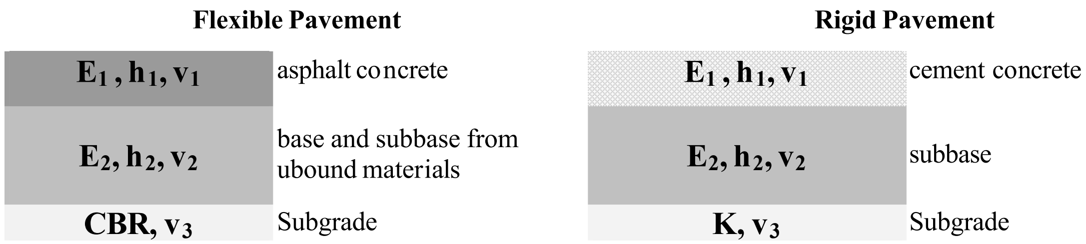

Figure 1. Structural model of a typical flexible / rigid airfield pavement

If the model of figure 1 under the load of A300-B4 and B707-310C is analysed to estimate the stresses and strain values at the critical points using any relevant software such as APSA (Airfield Pavement Structural Analysis) (Loizos and Charonitis, 1999) or APSDS (Wardle and Rodway, 1995) and we get the results of figures 2a and 2b. Judging from the figures, it is clear that A300-B4 is expected to be more damaging for the pavement since it provides higher strain values at both critical positions (points in both figures are “below” the line of equality). However if we have a look at the related ACN values (Table 2) it is noticeable that according to the rating system the A300-B4 should have similar effect with that of the B707-310C. Such results have been noticed in several comparative investigations (using for example A300-600, A300-B4 and B707-310C), implying that in some situations the ACN rating system is not always fully accurate.

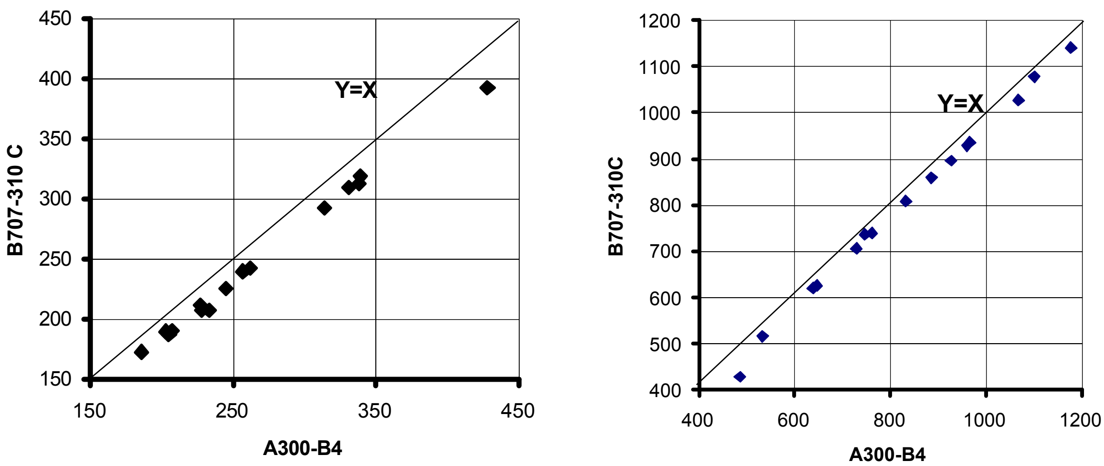

Figure 2.Comparison of the strains that are created at the bottom of the asphalt (a) layer and the top of the subgrade (b) during the pass of A300-B4 and B707-310C.

Table 2: A300-B4 and B707-310C ACN values for flexible pavements (ICAO, 1983)

CBR category	A	B	C	D
A300-B4	43	49	59	76
B707-310C	44	49	60	76

Consequently the airport managers and engineers should be cautious when using the ACN as a factor to assess and compare the damaging effect of different aircrafts on a flexible pavement so as to avoid a wrong estimation in scheduling the maintenance needs and periods. Even though similar tests for rigid pavements confirmed that the ACN system is reliable, experience has shown that such deviations between the different pavement types often result in an oversight of the exceptional cases and treatment the overall procedure as fully accurate. Of course, this might result in potential problems and increase of the life-cycle cost for pavements which do not follow the general rule.

Another interesting property of the ACN that should be notified and used with caution is its relation and deviation with the subgrade strength. Following the standard practice of most classification systems the ACN-PCN has put the emphasis in the establishment of the factor for rating the aircraft load; less importance has been given to the reporting of pavement bearing capacity which is expressed in terms of the maximum allowable load. That is to say a decrease in subgrade strength results in a respective increase of the ACNs (=the expecting damaging impact on the pavement increases). Figure 3 provides a typical example for this.

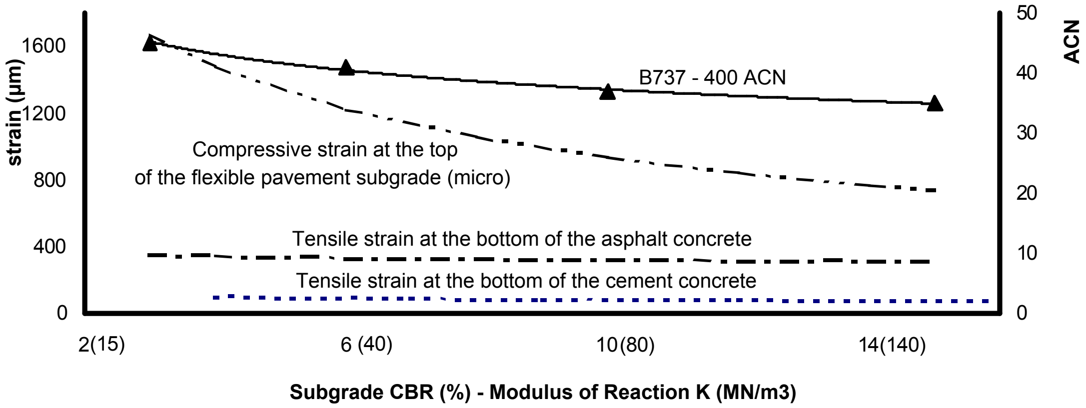

Figure 3.Deviation of ACN and critical strain values in flexible and rigid pavements

It is remarkable that in practice this may cause confusion since engineers, managers and practitioners in most cases assume that "a stronger foundation results in a stronger pavement and thus an increased classification number is expected". However, the ACN-PCN concept is "in a stronger foundation the aircraft is less damaging for the pavement, therefore the rating / classification number is being decreased" and therefore a "stronger" pavement may be able to serve aircrafts with lower ACN numerical values compared to a "weaker" one! Notice that we are talking about numerical values, since everything becomes clear when the subgrade strength category is also mentioned.

Therefore the solution to the problems seems simple, it is just a matter of correct reporting. However experience has shown that between different ways of thought, high concentration and caution is needed to avoid confusions and potential incompatibility. Figure 4 presents a sensitivity analysis for the effect of the subgrade strength which is a good example for this comment. A typical flexible pavement structure with 20cm asphalt concrete and 40cm integrated base and subbase (4b), as well as a typical rigid pavement with 30cm cement concrete and 25cm subbase, both founded on a subgrade with variable strength and the PCN (which is actually the maximum allowable ACN) have been estimated using several different approaches (FAA, 1983), (ICAO, 1983), (Directorate, 1990), (ERDC, 2001), (STBA, 2001). In the flexible pavements it is noticeable that the PCN rapidly increases with the increase of subgrade stregth, but given the fact that the ACN of the aircrafts decreases it is questionable whether such an increase is not an overestimation arising by the fact "stronger subgrade ⇒ stronger pavement ⇒ higher PCN". Actually one would expect the numerical value of the PCN to shortly deviate in every step like in figure 4a (rigid pavements) which is acceptable.

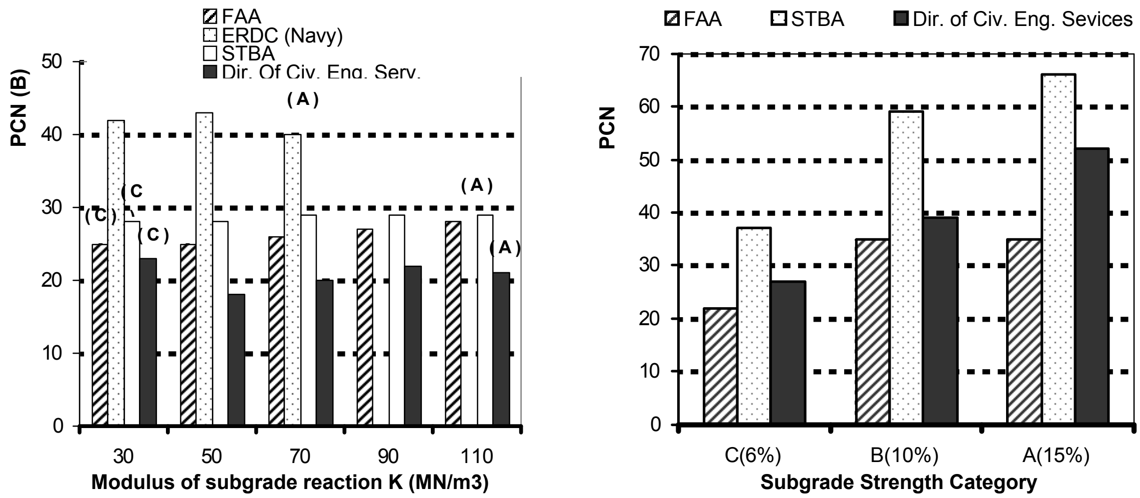

Figure 4: Effect of the subgrade strength deviation

3 STRUCTURAL CLASSIFICATION OF AIRPORT PAVEMENTS

As already mentioned, the ACN-PCN has put little importance in the factor for expressing the bearing capacity of the pavements (the PCN), which is actually an estimation of the typical or maximum ACN allowed to use the pavement. Consequently, since the definition of the ACN is based on specific critical pavement parameters and in order to avoid inconsistencies like those previously presented (figs 2, 4) the airport authorities have to find a methodology to incorporate the effect of all critical parameters in the reporting. That is to say the reported PCN of a pavement should be an outcome by the consideration of the critical failure mechanisms, not only those used for estimating the aircraft ACN. In order to facilitate this, the ICAO has not proposed any specific methodology for classifying airport pavements but has left the authorities of each airport to choose the most suitable for their pavements. This seems to provide the required flexibility to the process, but in practice it might also be a source of additional difficulties, inconsistencies and deviations.

Figures 5 and 6 present examples for this possibility. The figures present the PCN values estimated in 6 flexible and 6 rigid airport pavement structures using the experience from several international organizations/authorities (the US FAA (FAA, 1983), the US ERDC (ERDC, 2001), the British Directorate of Civil Engineering Services (Directorate, 1990), the French STBA (ICAO, 1983), (STBA, 2001) and NTUA/Greece (Loizos et. al., 2000)). Tremendous differences among the different procedures are obvious in both flexible and rigid pavements and consequently it is difficult to answer the question "which is the PCN of the pavement?" Undoubtedly, the bearing capacity of each pavement should be almost the same regardless of the method used for its estimation and therefore it is logical to assume that if we have information like those of figs 5,6 the airport engineers cannot get any information about the pavement bearing capacity. Practically, the lack of compatibility between the different PCN estimation procedures can be a significant drawback for the ACN – PCN system and this is something that should be considered by the airport managers and engineers in order to avoid wrong estimations about the airport pavement bearing capacity.

Following this, for the reliable assessment of the pavement bearing capacity it is necessary to have additional information, probably about the local classification experience and the method used for the PCN estimation. Of course this complicates the pavement the management procedure, but if the PCN is the only available information then it is necessary to be very cautious and probably undertake a special analysis of structural properties for confirming the ability of a pavement to serve the traffic and/or load demand, at least until there is an international harmonization of the procedures used for the estimation of the PCN.

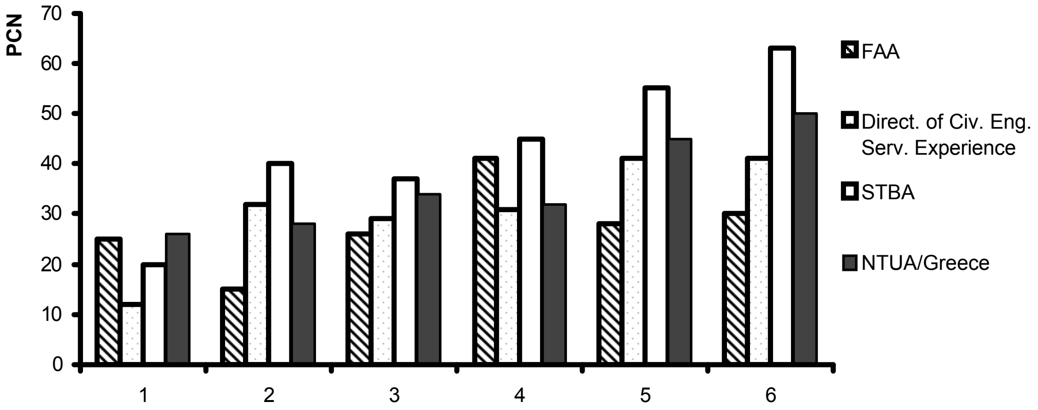

Figure 5. Deviations in flexible pavement PCN estimation using the experience of different countries/organizations.

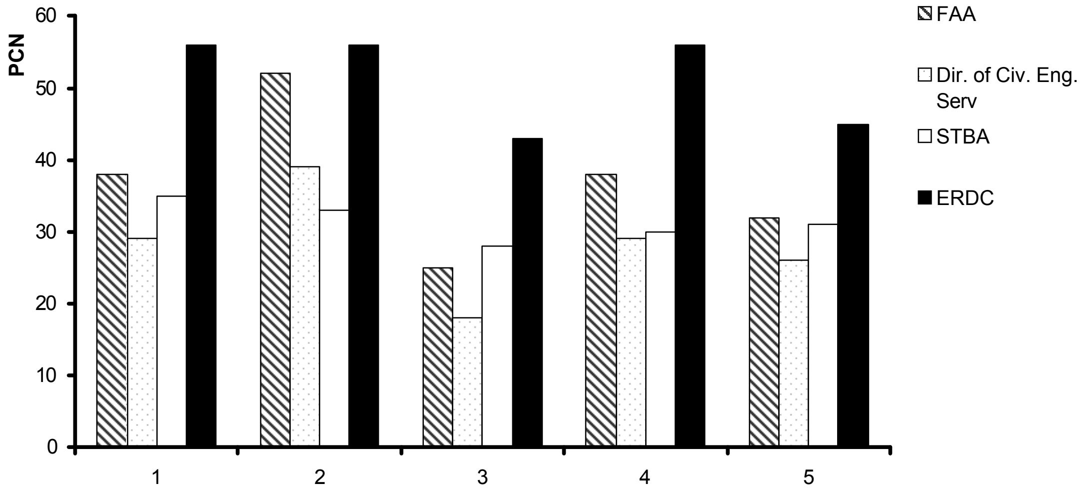

Figure 6. Deviations in rigid pavement PCN estimation using the experience of different countries/organizations.

Towards this, it is interesting to evaluate the possibility of using the DSWL single wheel as a common reference for estimating PCN, since it can be used by almost all the different classification methods. It is remarkable though that ICAO has avoided the suggestion of ACN and DSWL for airport pavement design and evaluation, however some interesting ideas and methods like the one of the British Directorate of Civil Engineering services (1990) have been developed on the subject. Despite that, research has shown that the adoption of the DSWL model may introduce additional problems in some types of analyses (such as the analytical models), especially when studying the effect of heavy airplanes that cause very high stresses and strains on flexible pavement. In these situations, a single wheel of a high radius is needed since the DSWL pressure is fixed; however the possible increase of the radius beyond a maximum value may cause failure of the model because the loaded area becomes too large compared to the thickness of the pavement. Then (after exceeding the maximum point) there is a beginning of one-dimensional compression conditions (Lambe & Whitman, 1969 - Wu, 1969) on the upper (asphalt) part of the pavement and the horizontal strain value starts decreasing towards zero (Lambe and Whitman, 1969 - Wu, 1969), instead of increasing to reach the one caused by the airplane gear.

Figure 7 shows, using the DSWL model, the variation of the tensile strain at the bottom of the aggregated bituminous layer of a typical flexible airfield pavement as well as at the bottom of the concrete slab of a typical rigid pavement. For the first one (flexible) we can notice that if the radius exceeds 290mm the strain values decrease and conditions of one-dimensional compression start, whereas for the second one there is no such phenomenon due to the high modulus of cement concrete. Since these limitations of the DSWL model (pressure constant - radius variable) may significantly affect the evaluation process, they should be taken into account in order to use it for the pavement classification and the PCN estimation.

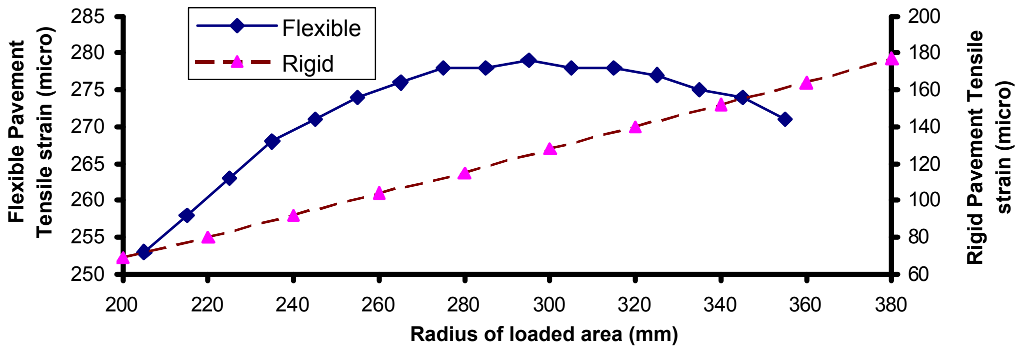

Figure 7. Variation of tensile strain at the bottom of a pavement asphalt layer vs tensile strain at the bottom of a cement concrete layer, using the DSWL model

It is also interesting to mention here an example where such conditions may occur in practice and that is the calculation of the DSWL of the B747-200C at very low subbase strength category (according to the ACN - PCN manual (ICAO, 1983), which is:

$$\frac{\text{ACN}}{2} = \text{DSWL} = 460\ \text{KN} \Rightarrow \text{r} = \sqrt{\frac{\text{DSWL}}{\pi \cdot 1{,}25\text{MPa}}} \Leftrightarrow \text{r} = 342\text{mm} \qquad (3)$$

where r is the radius of the equivalent single wheel. The ACN value of the B747-200C was taken from (ICAO, 1983). Using the same procedure, the DSWL radius at the low subbase strength category has been estimated to be equal to 295mm.

Contrary to flexible pavements, figure 8 shows the applicability of DSWL as an equivalent to the actual aircraft gear system. It is noticeable that the model is quite accurate for tensile strain values between 50 and 130 micro and becomes conservative in higher values. Most of the latter cases refer to slab thickness less than 300mm, which means that this model is probably applicable and maybe useful in practice.

Apart from the difficulties and deviations in the estimation of the PCN it is further interesting to study its reliability as a factor for expressing the bearing capacity. Of course, as previously mentioned, since it is practically impossible to reliably estimate the PCN of a random structure investigation focuses on the reference pavements which according to their definition should allow unlimited operations of the examined aircraft and thus their PCN should be equal to the aircraft ACN. According to ICAO a number of 10000 operations has been set for flexible pavements as a realistic value for the unlimited operations; for the rigid pavement the respective requirement is to produce a tensile stress of 2.75MPa at the bottom of the cement concrete layer. Following this, three of the B 727-200 flexible reference pavements are presented in table 3. The necessary calculations were made using the (ICAO 1983) definition and the CBR pavement design method (US Army Engineers, 1977).

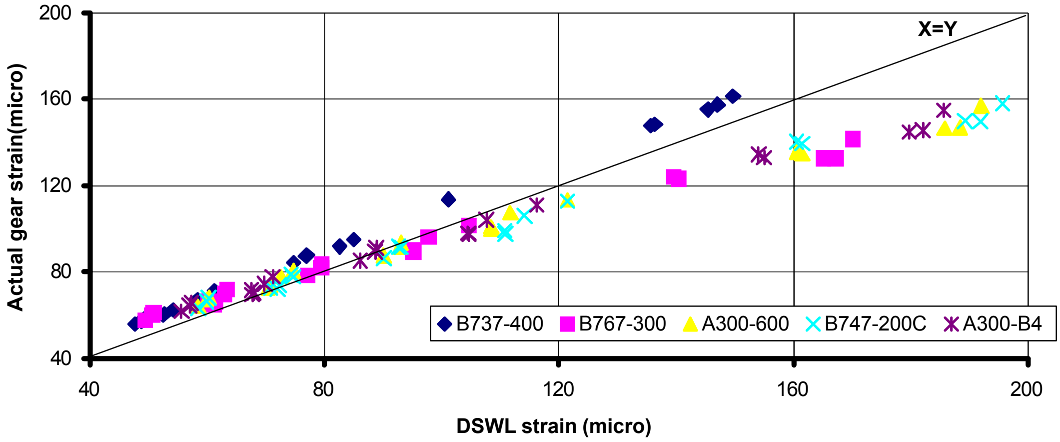

Figure 8. Comparison of tensile strain of the DSWL model and the actual gear at the bottom of the concrete slab of rigid airport pavements

Table 3. Thickness of the reference pavements for the B727-200

Subgrade CBR	6%	10%	15%
Asphalt layer Unbound base and subbase	h_1=13cm, h_2=70cm	h_1=13cm, h_2=45cm	h_1=13cm, h_2=30cm

Assuming that the material modulus (not really an important value since this is a qualitative investigation) is 6000MPa for the bituminous and 350MPa for the unbound materials and the poisson ratio is 0.35 and 0.4 respectively, analysis with APSA provided the critical strain values at the critical positions. The calculated strain values were incorporated into allowable operations using equation 1 for the bituminous and 2 for the subgrade:

$N=4.3 * 10^{-14} * (\varepsilon_r)^{-4,831}$ (LCPC, 1991) (1),

$N=1.02 * 10^{-7} * (\varepsilon_{zz})^{-4.167}$ (PIARC, 1987) (2)

where N= the number of the allowable load repetitions without failure of the material and ε_r and ε_{zz} represent the maximum horizontal strain at the bottom of the bituminous layer(s) and the vertical strain at the top of the subgrade, respectively. Both equations have been extensively tested and verified in Greece, but of course their adoption is by no means essential; any relevant failure equation suitable for the local conditions and materials can be used instead and provide similar conclusions.

Evaluation of equations 1 and 2 showed that a possible failure of the asphalt materials in less than 10000 load repetitions is possible in some circumstances. Consequently, at least according to the experience of the authors, if the PCN is related with the pavement bearing capacity then the reference pavement of the B727-200 should have a PCN less than the ACN of the aircraft, something that cannot be accepted. Even if this may not really be an important problem for practical applications, further analyses undertaken in NTUA (using different aircraft types, material properties and failure equations) have confirmed the existence of such strange cases and underlined the question whether it is possible to have a PCN which would represent the strength of the different pavement layers.
Similar investigations in rigid pavements show that there is no such problem since after the examination of more than 50 reference pavements the deviation between the values obtained by analytical calculations and the requested tensile stress of 2.75MPa was less than 10%. This of course assures that the reference pavements practically do not fail under the load of the related aircraft.

4 CONCLUDING REMARKS

Since the classification of airport pavements can be a very important tool for their management, it is necessary to adopt a suitable and reliable system for this purpose. Investigation of the official method currently under use, the ACN – PCN of ICAO, has shown that airport managers and engineers should be cautious because some of the assumptions adopted by the method are different from the commonly used in pavement design and evaluation. In other words, it is necessary to have in mind the background of the classification system so as avoid inaccurate reporting of the pavement bearing capacity which may be risky and result in an unexpected increase of the maintenance cost.

In order to maximize the benefit from airport pavements, it is important to remember that the classification system puts the emphasis on rating the effect of the aircraft load and thus the strengthening of the pavement foundation is expressed as a relative decrease of the damaging impact of the aircrafts. Practice has shown that this problem is more likely to be met in flexible pavements, where the damage/failure mechanisms are not always the same with those adopted by the ACN-PCN. The fact that the aircraft rating system for flexible pavements is not fully accurate is also important and should be taken into consideration if the PCN is used for estimating the remaining life and the pavement maintenance needs.

Evaluation of international experience on the PCN calculations in airport pavements indicates that there is a large deviation among the results of the different methods. In fact, if the results from more than one approach are considered, it may practically impossible for airport engineers to estimate a suitable PCN for a pavement. Moreover this incompatibility of the results makes it difficult to evaluate information received by different sources and therefore hardens the international co-operation between airport authorities, managers and engineers since in reality they do not use the same index for reporting the bearing capacity of their pavements. Probably it is necessary to further investigate this towards the harmonization of the different methods used worldwide for the PCN estimation.

For the above reasons, research on the subject is ongoing in the NTUA Laboratory of Highway Engineering, focusing on proposals for pavement classification in terms of the ACN-PCN (Loizos, et. al., 2000), (Loizos and Charonitis, 2004) as well as on the introduction of effective alternative classification approaches for airport pavements (Loizos and Charonitis, 2005). Results of first applications were very promising and thus monitoring and appreciation of further field implementation is currently in progress and more findings are expected to be publicized in the future.

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