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An Alternative Proposal for Reporting the Bearing Capacity of Flexible Airfield Pavements

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Structural classification of airfield pavements has always been of great importance for the establishment of a comprehensive airfield pavement management system. As the use of a simple and reliable classification procedure can significantly help the airport authorities to monitor the performance of their pavement(s) and plan an effective maintenance program, the existence of a structural classification procedure that can classify, check and estimate the pavement bearing capacity on a long-term basis could be a useful tool. In addition to this, the procedure presented in this work can easily co-operate with modern analytical design and evaluation procedures, in contrast to classical methods used for the structural classification of airfield pavements.

Keywords: Pavement classification, analytical evaluation, pavement management, bearing capacity

1. BACKGROUND AND OBJECTIVES

Because of the large variation between the loads and wheel gear systems of different aircraft types, several methods for measuring and classifying the load ratings of aircrafts and the bearing capacity of airfield pavements have been in use for many years. The existence of such methods is necessary, as it gives the airport authorities the ability to check the structural adequacy of their pavement(s) and therefore estimate if it can serve the demanded traffic with or without problems

Further analysis of the information coming from a structural classification method can provide significant support for the development of airfield pavement management systems.

Up to now, most of the methods used for reporting the bearing strength of airfield pavements have put the emphasis on the development of a procedure for measuring and classifying the load rating of the different aircraft. The bearing capacity strength of the pavement usually is them defined as equal to the load rating of the heaviest aircraft that can use the pavement on an unrestricted basis.

The simpler (and older) methods used to report the strength of a pavement in terms of the maximum gross weight, or maximum gear weight (Horonjeff and Mc Kelvey, 1983), that the pavement can bear.

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These methods were soon withdrawn and were replaced by a better one, which used a standard system for the classification of the aircraft loading and pavement bearing strength. This method is the well-known an the LCN (ICAO, 1965) approach, which was introduced by ICAO at the end of the decade (1940–1950) and soon was applied in almost every country.

Despite its widespread use, the LCN was not without problems and difficulties, especially at the flexible pavement branch. Thus, in order to provide a simpler and more reliable method for reporting the bearing capacity of the airfield pavements, the ICAO introduced the ACN – PCN method (ICAO, 1983).

The major feature of this method is the adoption of a factor which expresses the aircraft loading (ACN) which is not affected by the pavement characteristics (except the CBR of the subgrade). This has allowed the classification of all aircraft types and therefore simplified the method. Yet, the lack of a unique procedure for PCN determination, and the inadequacy (Loizos et. al., 1998), (Loizos and Charonitis, 1998) of the ACN when applied as an equivalent single-wheel model, have prevented the ACN – PCN compatibility with up-to-date analytical methods which are under use for the airfield pavement design and evaluation.

The need for a classification method as simple and flexible as ACN – PCN which would be compatible with both analytical and semi – empirical methods currently used for the airfield pavement design and evaluation, led the authors to investigate the possibility of developing an alternative proposal which is presented in this work.

The proposed procedure classifies the aircraft load ratings in a way similar to the one of the ACN – PCN, but the classification is based on a different factor, the Aircraft Loading Index (ALI) (Loizos and Charonitis, 1998), which can provide a reliable equivalent single wheel model and, therefore supports more applications than the ACN.

2. THE AIRCRAFT LOADING INDEX (ALI)

The Aircraft Loading Index (ALI) is a single wheel model which when applied on a pavement, gives a critical effect similar to the one of the original wheel – gear system of the aircraft. It is defined as the numerical value of the pressure (MPa) of the single wheel load which has a constant radius and when applied to a reference pavement, gives the same tensile stress at the bottom of the bituminous layer, as the original tire system of the aircraft.

Of course the ALI is partially depended of the properties of the pavement materials. To this end there have been developed two pavement categories (Table I). The radius values for the calculation of the ALI is 225mm for category A and 245mm for category B respectively. Practically, any pavement can be used as a reference pavement.

TABLE I Pavement Categorics

Total pavement thickness						
40–60 cm		*60–80 cm*				*80–100 cm*
Asphalt layer thickness		*Asphalt layer thickness*				
≤17cm	*>17cm*	*≤17cm*	*17cm<h<20cm*		*≥20cm*	
			Moduli (E) of unbound aggregated base and subbase			
			≥700MPa	*≤700MPa*		
A	**B**	**A**	**A**	**B**	**B**	**B B**

TABLE II Reference Pavement structures

Reference Pavement data	*Category A*	*Category B*
Total asphalt layer thickness	15 cm	22 cm
Unbound aggregated base and subbase thickness	40 cm	50 cm
Subgrade thickness	∞	∞
Subgrade CBR	18 % 14 %	14 %

However, if the reference pavement is representative of its category and strong enough (so as to bear a lot of repetitions of the load of the heavy aircraft) the proposed model may obtain higher accuracy and reliability. Thus, in order to specify the ALI of some aeroplanes and check the model, the structures of Table II are recommended. These structures have been used only for the classification of the load of the different aircraft types.

A significant property of the ALI is the fact that the ratio $\frac{\mathrm{ALI}_1}{\mathrm{ALI}_2}$ where 1 and 2 represent two different aircrafts is equal to the respective ratio of the stress/strain values $\left(\frac{\sigma_{rr1}}{\sigma_{rr2}}, \frac{\varepsilon_{rr1}}{\varepsilon_{rr2}}\right)$ caused at the bottom of the asphalt layer(s). This property can be very useful as it can simplify many applications, such as the damage calculation for airfield pavements (Loizos and Charonitis, 1998).

In this work ALI is applied not only for the classification of the load rating of the aircrafts, but also as a "measurement unit" specifying and reporting the bearing capacity of an airfield pavement. In addition, the use of the ALI equivalent single wheel load model ensures the co-operation of the proposal presented in this work (for the structural classification of flexible airfield pavements) with many analytical evaluation/design procedures.

3. THE AIRFIELD PAVEMENT CAPACITY INDEX (APCI)

By making use of the ALI, we can introduce a factor for expressing the bearing capacity of a pavement. To this end, the Airfield Pavement Capacity Index (APCI) is introduced and defined as the numerical value of the ALI single wheel load model that the pavement can serve for a "specific" number of load repetitions. The number of repetitions is depended on the passes (or coverages) that the pavement has to serve and therefore it has to be estimated by the traffic demand of each airport.

It is worth mentioning here that APCI and the evaluation/classification procedure presented in this paper are general ones and in practice they can work with any of the different approaches developed for coverages and pass-to-coverage estimation. This of course means that in practical applications the most appropriate -with respect to the local materials, conditions, etc. can be used so as to provide an APCI index which represents the actual structural condition of the pavement.

In contrast to PCN, the APCI takes strongly into account the performance of the asphalt layers of the pavement. As ACN has been developed on the basis of the empirical CBR method (Turbull and Ahlvin, 1956), which assumes a failure mode consisting of surface deformation caused by overstressing of the subgrade, the classification of a pavement in terms of the ACN – PCN demands a separate checking of the asphalt layer performance. On the other hand ALI and APCI have been developed using a multi-layer elastic structural analysis model (Figure 1), in which the possibility of pavement failure due to fatigue cracking of the bituminous surface is included.

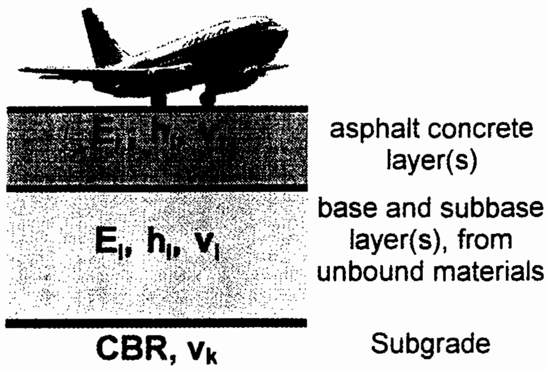

FIGURE 1 Structural model of a typical flexible pavement

Thus, taking into account the superiority of layered elastic design and evaluation methods (as among others LEDFAA (FAA, 1995) and ASPDS (Wardle and Rodway, 1995)) against the traditional CBR method (Wardle and Rodway,1998), it is suggested that the APCI value of a pavement is calculated analytically using the ALI model, a reliable computer software and suitable failure equations for the materials of the pavement. The use of other semi-empirical methods for the calculation of the APCI is not recommended, as they cannot provide reliable results. Despite that, they can be used as a quick, rough estimation of the APCI value.

4. A SIMPLE PROCEDURE FOR EVALUATING FLEXIBLE PAVEMENT STRUCTURES

4.1 Structural model used for the evaluation

As previously mentioned, the adoption of a suitable structural model is necessary in order to establish the properties of any evaluation or/and classification procedure. The model which has been adopted in this work to represent the structure of a flexible airfield pavement comes from the one of the multi – layer elastic theory and it is presented at Figure 1.

Critical points of this model are supposed to be the bottom of the asphalt layer (checking of the fatigue strength of the bituminous material) and the top of the subgrade (checking of the permanent deformation of the subgrade material).

4.2 Evaluation of the asphalt layer(s)

Asphalt concrete usually fails to fatigue after a number of load repetitions, that cause a severe amount of damage on it. Therefore, if the load repetitions cause an amount of damage equal to d and d_d is the maximum allowable damage, then the asphalt concrete layer(s) of a pavement does not fail if:

$$d \leq d_d \Leftrightarrow \frac{d}{d_d} \leq 1 \qquad (4.1)$$

Using a failure equation $(N_{fail} = K_1 \cdot \varepsilon_{rr}^{-k_2})$ developed for bituminous materials, this can be rewritten as an equation for calculating the amount of damage caused in the material by a number of load repetitions (N) (Ullidtz et. al., 1987). In a general form, this equation can be written as:

$$d = \frac{d_d \cdot N}{K_1 \cdot \left(\frac{1}{\varepsilon_{rr}}\right)^{k_2}} \qquad (4.2)$$

$$\text{or} \quad d = \frac{d_d \cdot N}{K_1 \cdot \left(\frac{1}{\sigma_{rr}}\right)^{k_2}} \qquad (4.3)$$

Where:

N is the number of load repetitions (passes).

d_d, d the maximum allowable and the caused damage, respectively

ε_{rr}, σ_{rr} the tensile strain/stress at the bottom of the bituminous layer(s).

k_1, k_2 constants, defined from laboratory experiments.

Further, from equations (4.1) and (4.2) (alternatively one can use equations (4.1) and (4.3) with similar results) we have:

$$\frac{l}{d} = \frac{\frac{d_d \cdot N}{K_1 \cdot \varepsilon_{rr}^{K_2}}}{\frac{d_d \cdot N_d}{k_1 \cdot \varepsilon_{rrd}^{-K_2}}} \Leftrightarrow \left(\frac{\varepsilon_{rr}}{\varepsilon_{rrd}}\right)^{K_2} \cdot \frac{N}{N_d} \leq 1 \qquad (4.4)$$

Where:

N_d is the maximum load repetitions (passes) so as not to have failure of the material and ε_{rrd} the respective tensile strain.

d_d, d the maximum allowable and the caused damage, respectively.

N is the number of (expected) load repetitions (passes), $\varepsilon_{rr}$the respective tensile strain.

If equation (4.4) is applied to an airfield pavement, then N_d, ε_{rrd} represent the bearing capacity of the pavement and N, $\varepsilon_{rr}$the load effect of a random aircraft type, both in terms of damage. Thus, by making use of the ALI (APCI) properties, the equation (4.4) can be written (for flexible airfield pavements) as:

$$\left(\frac{\mathrm{ALI}}{\mathrm{APCI}}\right)^{k_2} \cdot \frac{N}{N_d} \leq 1 \qquad (4.5)$$

By using this equation (4.5), one can easily check whether an aircraft can use a pavement for a number of movements (passes) without causing severe damage at the asphalt layer(s). For the evaluation of (4.5), k_2 can be taken by the appropriate laboratory fatigue equation or it can be estimated as a function of (weighted) asphalt temperature, k_2=k_2(T(°C)), using regression analysis approach (Hudson et al., 1976). If a fracture mechanics approach is used instead of the conventionally used "phenomenological" fatigue life prediction, according to the results of (Tseng and Lytton 1990), $k_2$is equal to n, where n is the slope of a log-log plot of the stress integrity factor versus the rate of crack growth. In this situation without suitable experimental results available n (and k_2) can be estimated using the (Mc Leod, 1976) nomograph, or its computerized version (Jayawickrama et. al. 1987), as a function of asphalt cement properties such as asphalt content, viscosity, penetration and temperature.

Yet, in most cases, a pavement has to serve more than one aircraft type. Then, the check has to be done for the total amount of damage caused by the aircraft movements and that is to say:

$$\frac{d_1 + d_2 + \ldots\ldots + d_v}{d_d} \leq 1 \qquad (4.6)$$

or

$$\frac{\sum_{i=1}^{v}(\mathrm{ALI}_i^{K_2} \cdot N_i)}{\mathrm{APCI}^{K_2} \cdot N_d} \leq 1 \qquad (4.7)$$

The numerator of the fore-mentioned equation can include predicted or past traffic damage, or a combination of both. If the past traffic data are not adequate for the calculation then an estimated amount of past traffic damage may be simply added to the numerator of equation (4.7). In the same way damage caused by other factors (i.e. climate) can be also considered. Thus, equation (4.7) provides a quick and easy procedure for examining the adequacy of the asphalt layer(s) of an airfield pavement to serve the traffic demands.

It is worth mentioning here that the above proposed procedure possibly can be used for the completion of existing classification methods such as ACN – PCN, which cannot evaluate and classify the flexible airfield pavements according to the bearing capacity of their bituminous layer(s). Yet, ALI and APCI are quite flexible indexes and therefore they can support evaluation and classification not only for the bituminous layer(s) but also the subgrade of an airfield pavement.

4.3 Evaluation of the pavement subgrade

As the failure mechanism of the subgrade layer materials of a pavement differs from that of the bituminous one and possible failure of its materials is result of excessive permanent deformations, an attempt to develop an equation similar to (4.7) probably wouldn't provide a reliable answer to the problem.

Therefore the checking of the adequacy of the bearing capacity of the subgrade has to be evaluated using the common way, directly from the failure equation and that is to say:

$$\frac{N_{tot}}{N_d} \leq 1 \qquad (4.8)$$

Where:

N_{tot} is the total expected aircraft passes and
N_d is the allowable load repetitions.

The allowable load repetitions can be calculated using a suitable failure equation like (4.9).

$$(N = a \cdot \varepsilon_{ZZ}^{-b}) \qquad (4.9)$$

Where N is the number of load repetitions, a, b are constants defined from laboratory experiments and ε_{zz} is the vertical strain at the top of the subgrade layer. The latter can be easily calculated from a semi-empirical equation developed during the introduction of ALI by (Loizos and Charonitis, 1998) at the Laboratory of Highway Engineering of NTUA which is:

$$\varepsilon_{zz} = \frac{\sigma_{zz\mathrm{APCI}} + 0,04 + y}{E_{sub}} \qquad (4.10)$$

Where σ_{zzAPCI} is the vertical stress caused when during a pass of the APCI single wheel model at the top of the subgrade, E_{sub} is the Young's Modulus of the subgrade material and y is a factor calculated from equation (4.11):

$$y = \frac{\max ALI}{APCI} \Big/ 0,1 \qquad (4.11)$$

As one can deduce, equation (4.10) is a little conservative and that is so because:

a)The possible failure of the subgrade material usually results in an extremely difficult problem as it cannot be easily handled in practice.

b)A relatively strong subgrade generally can serve much more traffic than that of normal traffic volume of existing airports.

It is worth mentioning here that because of (b), the checking of the subgrade layer, under certain conditions can be skipped when the CBR value of the material is higher than 8%. Up to now, the results of investigations made by the authors, tend to confirm this suggestion, providing a further simplification to the proposal.

5. FIELD APPLICATION

The first application of the proposed procedure in practice has been in terms of a joint research project between the National Technical University of Athens (NTUA) and the Greek Civil Aviation authority. During this project, there has been a detailed structural evaluation of Rhodes international airport. Rhodes is an island, which had a tremendous tourist development during the 80s and the early 90s. This resulted in a relative increase in the air traffic, which caused severe damage to the pavement of the airport runway.

More specifically, analysis of in situ FWD measurements, laboratory component analysis based on field cores, as well as conventional in situ CBR testing for the subgrade materials, showed extensive fatigue cracking in the bituminous layers (figure 2) and practically no damage of the unbound materials and the subgrade.

FIGURE 2 Typical pavement damage at Rhodes airport runway

In order to strengthen the pavement structure, a rehabilitation procedure has been adopted, which is based on the use of a two-layer asphalt overlay (see Figure 3). In order to classify and monitor the rehabilitated pavement in the future, the airport authorities needed a suitable procedure, as the conventional methods in use until then (based on the ACN – PCN) couldn't be directly linked to the pavement performance. Thus the proposed procedure was adopted which provided the airport authorities with the ability not only to know the aircraft types and passes that the pavement can serve but also to estimate the effects of a possible deviation from the traffic forecast.

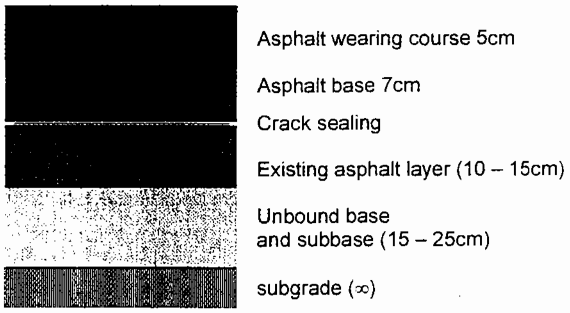

FIGURE 3 Typical cross section of Rhodes airport runway pavement after rehabilitation

6. CONCLUSIONS

As the methods currently used for classifying and reporting the bearing strength of the airfield pavements are (practically) unable to support and co-operate with analytical procedures which are under wide use for design and evaluation, the authors tried to develop an alternative proposal, based on a different index (ALI) for classifying the load rating of the aircrafts and the bearing capacity of the pavements.

The main advantage of this proposal is that the indexes used (ALI and APCI), can be easily incorporated into many analytical procedures currently used for the airfield pavement evaluation. Since there is an international effort to improve the analytical design and evaluation methods, the flexibility of the indexes may prove to be useful in the future. Currently, the implementation of ALI and APCI can provide quite a simple alternative for estimating and checking the adequacy of the bearing capacity of a flexible airfield pavement structure.

A significant feature of the proposed methodology is that it provides the opportunity of checking, in a simple way, whether the bearing capacity of a pavement can withstand the total damage caused by traffic (any combination of different aircraft types) and, optionally, by other factors (i.e. time, climate etc.) whereas other classification methods (i.e. ACN – PCN) cannot support similar procedures.

Further, in contrast to PCN, the classification of a pavement using the APCI index can include information for the performance of the asphalt layers of the pavement.

Since practical applications in Greek Airports tend to confirm the above mentioned properties of the proposal, it is believed that this research work will stimulate the beginning of a procedure (or a number of procedures) for estimating, classifying and reporting the bearing capacity of airfield pavements, using analytical evaluation models. To this end a comprehensive validation / calibration procedure of the proposed methodology is ongoing using data from long-term airfield pavement performance studies. The possible application of the procedure to semiflexible / semi-rigid pavements is also under investigation.

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