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CONSTRUCȚII. ARHITECTURĂ

ACTUAL TRENDS IN THE CONCEPTION AND DESIGN OF PAVEMENTS FOR AIRPORT RUNWAY

BY

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Abstract. After the description of types of pavement for airport runway, the paper presents the principle of various modern methods used in structural design, such as French practice, United States of America practice and the Canadian one. Finally based on their performance, the French and the Canadian one are selected in order to be used for the study of new durable runway pavements in comparison with the classical ones.

Keywords: airport runway; durable pavement; design structures.

1. Introduction

In recent years, air travel has seen a tremendous increase and with it infrastructure has been constantly developing and upgrading in order to synchronize with air traffic dynamics, with the performance of new, larger, more economical and faster aircraft, weighing over 400 t.

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Air transport has the following features: safety, speed, efficacy and comfort. Rapidity is a fundamental feature in air transport, regardless of geographical conditions, and has the potential to avoid unfavourable weather conditions.

Each airport has a reference code consisting of a number and a letter, the code number is correlated with the reference distance of the aircraft and the code letter is correlated with the wingspan and the overall width of the main train. These elements are presented in Table 1. This code is not used in the structural design calculation or when determining the length of the runway.

Table 1
Specific Data for the Airport Code (Horia *et al.*, 2010)

Code no.	Reference distance of aircraft, [m]	Letter code	The wingspan m	The total width of the main train, [m]
1	< 800	A	< 15	< 4.5
2	800…1,200	B	15…24	4.5,…,6.0
3	1,200…1,800	C	24…36	6.0,…,9.0
4	≥ 1,800	D	36…52	9.0,…,14.0
		E	52…65	9.0,…,14.0
		F	65…80	14.0,…,16.0

The airport transport infrastructure is compiled according to Fig. 1 from: runway, taxiway and traffic area (apron).

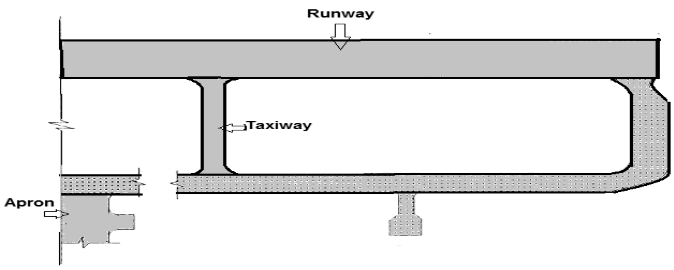

Fig.1 – Airport infrastructure (ICAO - Doc 9157).

The location, orientation and number of runways are determined according to: the specific weather conditions, expressed in particular by the coefficient of utilization determined by the mist incidence and wind distribution, the topographic situation of the land, the air traffic intensity, the performance parameters of the aircraft and the impact on the environment. The length of the runway is determined by: the specific aircraft type, the sea level atmospheric pressure (1,031 millibars), the standard temperature (t = +15°C) and the longitudinal profile of the runway. Table 2 show the necessary length for taking off/landing over for different types of aircrafts.

Table 2
The Necessary Length for Taking Off/Landing over for Different Types of Aircraft
(Andrei & Andrei,, 2003)

Aircraft types	Necessary length for taking off, [m]	Necessary length for landing over, [m]
B 727 - 200	853	2,215
DC 10 - 10	1,777	2,800
TU 154	2,217	2,420
AN - 24	880	2,000

The width of the runway shall be taken according to the airport code number/letter as shown in Table 3.

Table 3
The Width of Runways, [m] (Andrei & Andrei, 2003)

Code number	A	B	C	D	E
1	18	18	23	–	–
2	23	23	30	–	–
3	30	30	30	45	–
4	–	–	45	45	45

The main features of the aircraft that condition the elements of the airport infrastructure are as follows:

i) landing gear;
ii) the wingspan;
iii) take off/landing performance.

The landing gear is located at the front of the aircraft and consists of a number of main landing gear and a secondary landing gear, Fig. 2 shows configurations for different landing trains, namely:

a) single;
b) dual;
c) two single in tandem;
d) two dual in tandem;
e) three dual in tandem.

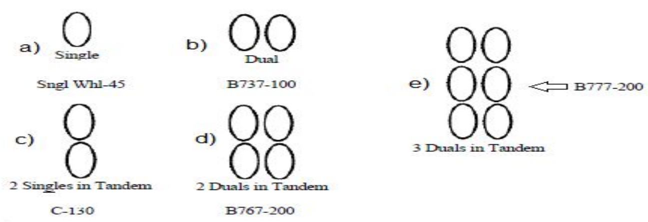

Fig. 2 – Types of landing gear (airport-runway-design).

2. Types of Airport Pavements

For airport pavements, the same types of structure are used as for roads: flexible, rigid and mixed pavement.

However, the types of load solicitation between the two categories differ, due to the mode of operation, of aircraft loads, the exposure to different environmental factors in the case of airport infrastructure as opposed to roads due to position in large areas, lack of vegetation and low slopes. Airport road structures must meet the following conditions: load condition and functional conditions.

Flexible structures have flexible layers made from bituminous mixtures and rigid airport pavements are made up of a set of stabilized layers over which a concrete pavement is used as a finish (Fig. 3).

The rigid structures consists of a concrete (slab) and a foundation of ballast or crushed stone, whether or not stabilized, to ensure the continuity and to resist the weight of the possible rise of the subgrade and to ensure its protection against frost, and also to provide a stable surface (Fig. 3).

The mixt structures are composed mainly of rigid structures, and are coated with a wear layer of bituminous mixture (Fig. 3).

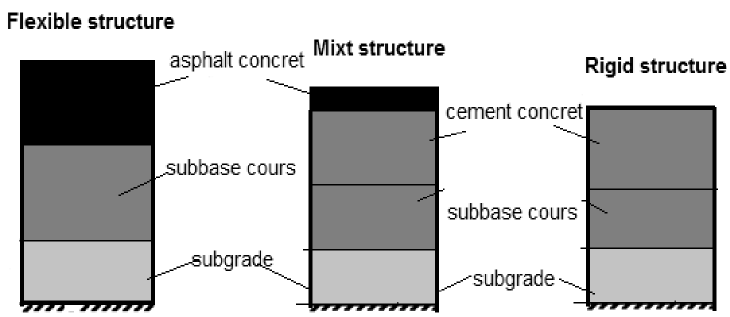

Fig. 3 – Different types of airport structures.

3. Structural Method of Design

Each airport pavement is a particular case due to the diversity of traffic loads and the various types of soil foundation (Andrei & Andrei, 2003).

For the design of the airport pavements, the following methods are detailed: the French method, the Federal Aviation Administration (FAA) method and the Canadian method.

The French design method of flexible pavements can be calculated according to the calculation task by two methods: the general design when considering one type of critical aircraft and the optimized design that takes into account all types of aircraft. The method has 4 steps.

Step 1. According to the French method, proposals are made for structure catalogues according to airport class and the value of CBR (Californian Bearing Ratio) as shown in Table 4.

Table 4
Recommended Thickness for Flexible Pavement (Andrei & Andrei, 2003)

Airport class	ICAO	Load	CBR	Asphalt concrete	Binder	Asphalt mix	Crash stone	Ballast	Subgrade improved
A	4E	Gear 80 tf	3	8	–	30	60	80	–
			6	7	–	18	40	–	–
			10	6	–	15	35	–	Xx
			15	8	8	–	20	–	Xx
B	4D	Gear 60 tf / Dual 40 tf	3	8	–	14	60	60	–
			6	6	–	14	30	30	–
			10	8	–	8	30		xx
			15	7	7	–	20		xx
C2	4C	Dual 20tf	3	6	6	–	40	40	
			6	6	6	–	40		X
			10	5	5	–	20		xx
			15	8	–	–	15		xx
C1, D2	3B 3C	Single whell 5 tf	3	7	–	–	40		X
			6	6	–	–	25		X
			15	5	–	–	15		xx
D1, D3	1A	Aircraft 5.7 tf	3	3,...,5	–	–	15	20	–
	2A		6	3,...,5	–	–	15	15	–
	2B		15	3	–	–	15		xx

Step 2. Choice of the design load, aircraft characteristics affecting the design:

a) aircraft mass;

b) undercarriage leg;

c) distribution of the mass over the undercarriage legs;

d) loads used in the calculation.

Step 3. Determination of the bearing strength of the subgrade (CBR) – the foundation soil is characterized by CBR value, the value adopted corresponds to the lowest value obtained on compacted samples and immersed for 4 days. In the case of gravelly soils and pure sand, the CBR value is adopted from Table 5.

Table 5
CBR value of granular soil (ICAO/Doc 9157)

Description of the foundation soil	CBR
Pure well – graded gravel	20
Pure badly – graded gravel	20
Gravel containing silt, Ip < 7	20
Gravel containing silt, Ip >7	10
Gravel containing clay	10
Pure well – graded sand	10
Pure badly – graded sand	6…8

Step 4. Determination of pavement thickness

The normal design load (P'), only valid for a life period of ten years, is obtained by:

$$P' = \frac{P}{c}, \tag{1}$$

where: $c = 1.2 - 0.2 \log n$; P = 47.5% the total mass of the take-off; n – ten movements per day.

In relation with Fig. 4, introducing the design value for P' and CBR1, results the total equivalent thickness of the pavement structure H_{SR}.

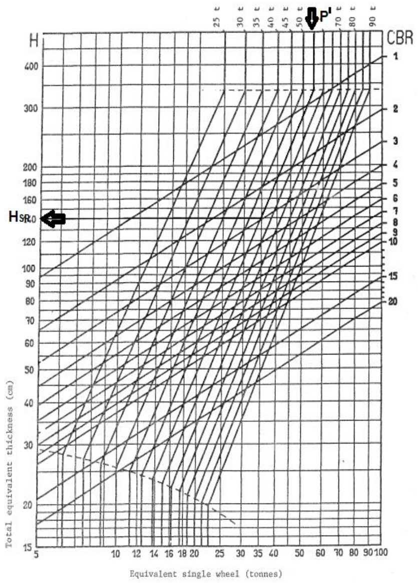

Fig. 4 – Total equivalent thickness H_{SR}, [cm] (ICAO/Doc 9157).

Where is required for an improvement subgrade, this will be taken into account in the calculation of recommended thickness of pavement above this subgrade with:

$$e = h_1 - h\frac{\mathrm{CBR2} - \mathrm{CBR1}}{\mathrm{CBR2} + \mathrm{CBR1}}, \tag{2}$$

where: h_1 is the total equivalent thickness, h – thickness of the improved subgrade, CBR1 – the min value of the subgrade, CBR2 – value of the improved subgrade.

The determination of the equivalent thickness for the airport pavement (H_e) depends on the CBR value of the subgrade and the adopted design load.
The equivalent pavement thickness of a course is equal to its actual thickness multiplied by an equivalence coefficient from Table 6, and the equivalent pavement thickness is calculated with:

$$H_e = \sum_{i=1}^{n} h_i \times c_i, \tag{3}$$

where: h_i is the equivalent pavement thickness of a course, c_i – equivalence coefficient.

Table 6
Equivalence coefficient (ICAO/Doc 9157)

New materials	Equivalence coefficient c_i
Asphalt concrete	2.0
Sand gravel mix bound with bitumen	1,5
Sand gravel mix bound with emulsion	1,2
Sand gravel treated with hydraulic binders (cement, slag, fly-ash)	1,5
Well graded crushed gravel	1,0
Sand treated with hydraulic binders (cement, slag, fly-ash)	1,0
Pea gravel	0,75
Sand	0,5

The minimum equivalent thickness of stabilized granular layers (H_e) is obtained from the diagram presented in Fig. 5, depending on e and CBR of the subgrade.

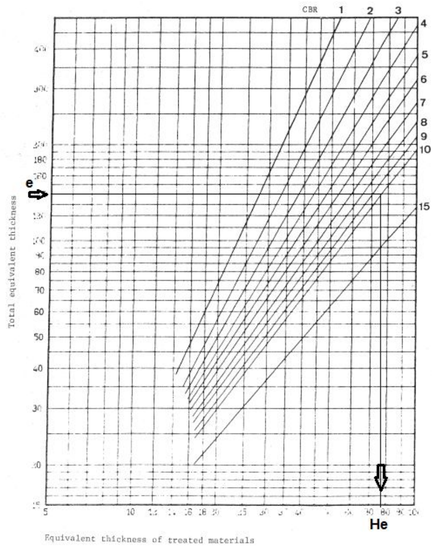

Fig. 5 – Equivalent thickness of treated materials (ICAO/Doc 9157).

The FAA method, according to Federal Aviation Administration Advisory Circular AC 150/5320, takes into consideration the total mass of the aircrafts for different types of landing gears. The FAA method is based on a computing program presented in Fig. 6 and which requires covering 10 steps.

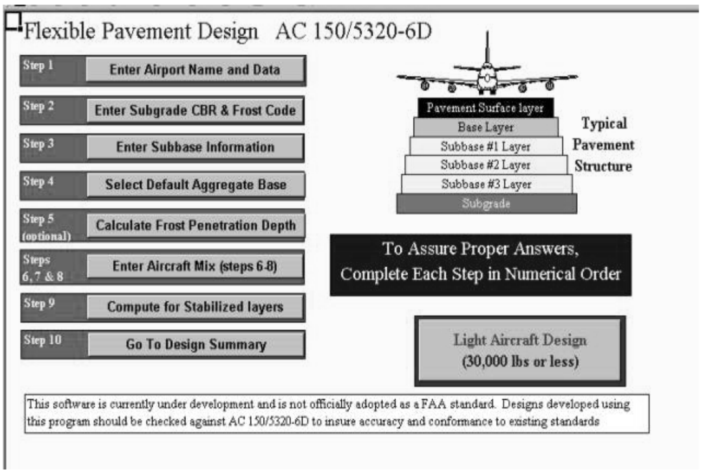

Fig. 6 – Window presentation program F806FAA.xls.

Fig. 7 presents the program window used for the introduction of the general characteristics data (information regarding the airport, value of the CBR1 parameter, number of improved pavement payer, if is the case, and the value of CBR2 index).

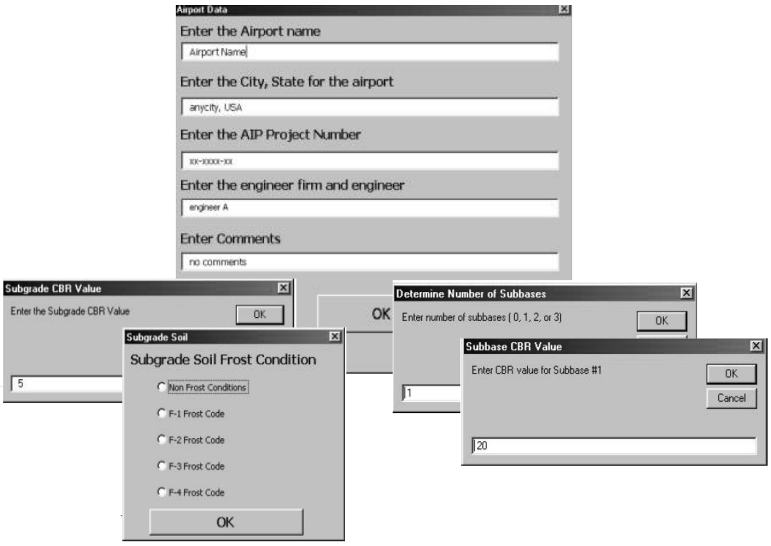

Fig. 7 – Print screen of command windows to enter general data.

The design traffic is considered to be the number of annual take-offs for different types of aircrafts and the aircraft which requires the greatest airport pavement structure thickness is considered to be the critic aircraft.

To equivalent number of annual aircrafts take-offs is determined depending on the wheel mass of the critic aircraft using the mathematical relation 4, or using the equivalent coefficients presented in Table 8.

$$\log R_1 = \log R_2 \times \left(\frac{W_2}{W_1}\right)^{\frac{1}{2}}, \tag{4}$$

where: R_1 is the equivalent annual take-off for the critic aircraft type; R_2 – the equivalent annual take-off depending on the landing gear type for the design aircraft; W_1 – wheel loading for the design aircraft; W_2 – wheel loading for the take-off aircraft (95% of the operational weight of the aircraft or the total mass is allowed).

Table 8
Equivalence coefficients of landing types (Zarojanu 2010)

Type of landing gear	Aircraft lander estimate	Equivalence factor
Single wheel (S)	Dual (D)	0,8
	Dual in tandem (DT)	0,5
Dual (D)	Single wheel (S)	1,3
	Dual in tandem (DT)	0,6
Dual in tandem (DT)	Single wheel (S)	2,0
	Dual (D)	1,7

Fig. 8 presents the program window with the aircraft types database (limited to 21 positions), the required thickness of the airport pavement structure for each aircraft type and resulting critic aircraft type.

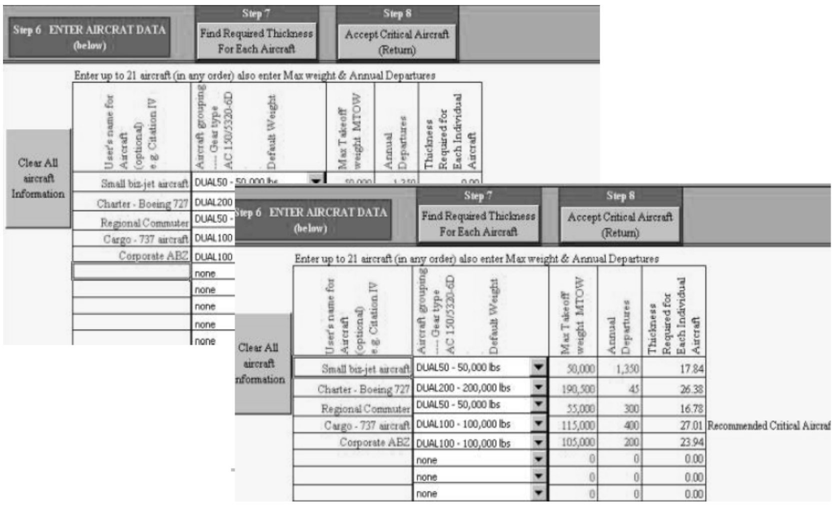

Fig. 8 – Print screen of windows for aircraft data.

Finally, a print screen example with the results obtained on the first running of the program, are presented in Fig. 9.

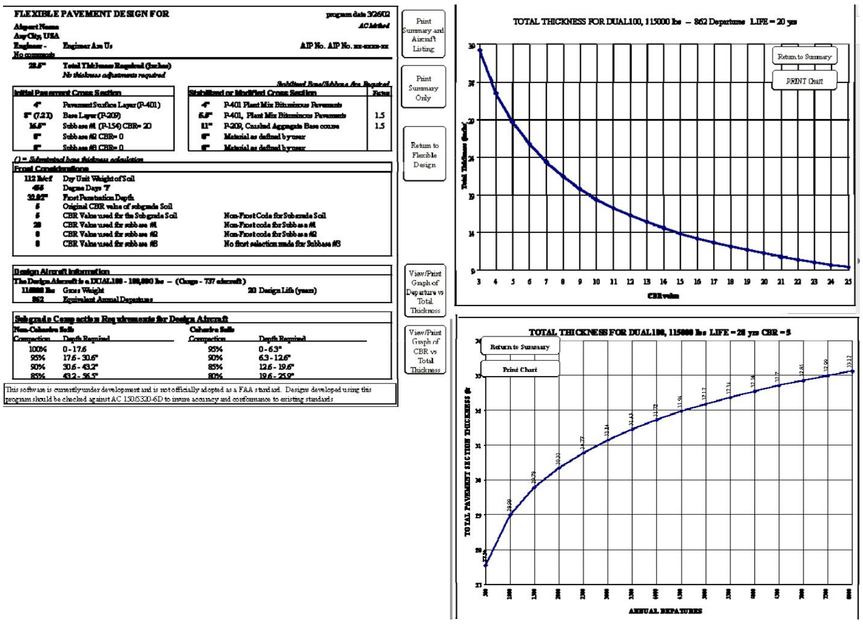

Fig. 9 – Print screen results at first run of the program F806FAA.

The Canadian method allows the design of the airport pavement structure using the equivalent single wheel loading (ESWL). To determine the asphalt pavement thickness, the following steps are required:

Step 1. Determination of the subgrade Bearing Strength (S), calculated using the mathematical relation 5.

$$S = \mathrm{ESWL}\left(c_1 10^{-c_2 t}\right), \tag{5}$$

where: S is the subgrade bearing strength, [kN]; ESWL – equivalent single wheel load, [kN]; t – pavement equivalent granular thickness, [cm], c_1 and c_2 factors depending on contact area of ESWL.

The ACN/PCN classification number is using four standard reference values for the subgrade bearing strength (CBR) according to Table 9.

Table 9

Strength of Foundation Soil (AC302-011)

Soil resistance	Low	Normal	Good	Very good
CBR, [%]	3	6	10	15
S, [kN]	50	90	130	180

Step 2. Determination of the equivalent granular thickness of an airport pavement structure

To determine the equivalent granular thickness of an airport pavement structure, equivalence factors presented in Table 10 must be used. Each layer of the airport pavement structure is multiplied with the equivalent factor specifically for the material from which the layer is constructed, and the granular equivalent thickness represents the sum of these converted layer thicknesses.

Table 10.
Granular Equivalent Factor (AC302-011)

Pavement material	Granular equivalence factor
Selected granular subbase	1
Crushed gravel or stone base	1
Macadam base	1,...,1/2
Bituminous stabilized base	1,...,1/2
Cement stabilized base	2
Asphaltic concrete (good condition)	2
Asphaltic concrete (poor condition)	1,...,1/2
Portland cement concrete (good condition)	3
Portland cement concrete (fair condition)	2,...1/2
Portland cement concrete (poor condition)	2

Step 3. Determination of the ALR/PLR (Aircraft Load Rating/ Pavement Load Rating) for the airport pavement structure

Aircraft load rating (ALR) is a number which indicates the relative effect of the aircraft loading on the airport pavement structure, PLR is a number expressing the bearing strength of a pavement for unrestricted aircraft operations and is determined according to Fig. 10, depending on the bearing strength of the subgrade and the thickness of the airport granular pavement structure.

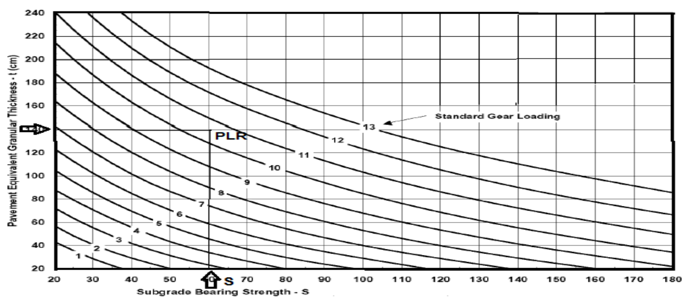

Fig. 10 – Flexible pavement design curves for standard gear loadings (AC302-011).

The ALR/PLR system (Aircraft Load Rating/ Pavement Load Rating) is commonly based on a group of aircrafts with similar loading characteristics rather on a single aircraft loading characteristics.

Step 5. Determination of the limit tire pressure

In Table 11, the values of the tire pressure limit are presented, depending on the asphalt and base layers thickness.

Table 11

Tire Pressure Limit (AC302-011)

Standard gear load ratio	Standard gear loading characteristics							
	Single wheel gear		Dual wheel gear			Dual tandem wheel gear		
	Gear load kN	Tire pressure MPa	Gear load kN	Tire pressure MPa	Dual tire spacing cm	Gear load kN	Tire pressure MPa	Dual tandem tire spacing cm
1	20	0.30	–	–	–	–	–	–
2	30	0.35	–	–	–	–	–	–
3	45	0.40	–	–	–	–	–	–
4	60	0.45	80	0.50	50	–	–	–
5	80	0.50	110	0.60	55	–	–	–
6	110	0.55	130	0.65	60	–	–	–
7	140	0.60	170	0.70	65	–	–	–
8	–	–	220	0.85	70	–	–	–
9	–	–	290	1.05	75	440	1.10	65×115
10	–	–	400	1.15	90	660	1.20	90×150
11	–	–	–	–	–	900	1.55	110×165
12	–	–	–	–	–	1,120	1.80	115×165
13	–	–	–	–	–	1,380	1.80	115×165

Step 5. Determination of ACN/PCN number

ACN represents the classification number of the aircraft and indicates the relative effect of the aircraft on the airport pavement structure, for a specified foundation terrain, and PCN represents the classification number of the airport pavement structure which indicates the load bearing capacity of a airport pavement structure, used without exploitation restrictions towards a reference traffic.

Depending on S, the conversion from PLR (Pavement Load Ratio) to the PCN number can be done, according to Table 12.

Table 12
Conversion from PLR to the PCN (AC302-011)

Canadian PLR value	Flexible Pavements ICAO subgrade strength category code letter Flexible pavement subgrade strength – *S*, [kN]			
	A (High) >160 180	B (Medium) 160,...,110 130	C (Low) 110,...,70 90	D (Ultra low) <70 50
2	–	–	–	4
3	–	–	–	6
4	–	–	–	9
5	–	–	12	13
6	–	–	16	19
7	–	16	21	27
8	–	23	29	37
9	24	32	39	50
10	38	43	43	64
11	53	57	57	81
12	68	72	72	101
13	80	88	88	124

According to the AC 302-011 norm, the PCN number is determined based on the foundation terrain category, the PLR number and the base equations for different regression curves in Table 13.

Table 13
Determining PCN number (AC302-011)

The letter code for the foundation soil strength	Relationship for PCN number
A	$1{,}000.000 - (46.9401\times PLR) + (6.0420\times PLR^2) - (0.1963\times PLR^3)$
B	$75{,}000 - (24.7528\times PLR) + (2.7623\times PLR^2) - (0.0603\times PLR^3)$
C	$15{,}000 - (3.7769\times PLR) + (0.5096\times PLR^2) + (0.0230\times PLR^3)$
D	$5{,}000 - (1.3799\times PLR) + (0.4657\times PLR^2) + (0.0264\times PLR^3)$

4. Conclusions

The evolution of the characteristics of aircraft and materials in the composition of the airport pavement leads to the current concern to move from empirical design methods to methods whose calculation scheme is based on the behaviour of road materials. In the case of airport pavement, the trend is to develop calculation schemes using the elastic multilayer theory.

Acknowledgements. This paper present the principle of various modern methods use for structural design, in order to be used for the study of new durable runway pavements, in the frame of the doctoral thesis: "Research of airport flexible pavements" commonly worldwide used, undertaken by the author under the guidance of Radu ANDREI, PhD, PE, Associate Professor of Civil Engineering with Technical University „Gh. Asachi" of Iaşi.

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TENDINȚE ACTUALE ÎN CONCEPEREA ŞI DIMENSIONARE STRUCTURILOR AEROPORTUARE

(Rezumat)

Se prezintă descrierea principalelor metode de dimensionare structurală a structurilor aeroportuare flexibile, şi anume metoda Franceză, metoda Federal Aviation Administration şi metoda Canadiană. În final, pe baza performanțelor acestora, metoda franceza si cea canadiana sunt selectate pentru a fi utilizate pentru studierea noilor structuri aeroportuare flexibile durabile în comparație cu cele clasice, în cadrul studiilor aferente tezei de doctorat "Cercetări privind sistemele flexibile pentru pistele aeroportuare".