STRUCTURAL REAHBILITATION OF PAVEMENTS IN PRESETRESSED CONCRETE

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Abstract: The structural rehabilitation design of aeronautical pavements is done based on the knowledge of present conditions and according to a method that best fits the problems at hand. Knowing that, a description is made of the most widely used design methods and the runway is characterized according to tests performed in previous years. By adopting one of the design methods, the calculation of the thickness of the pavement layers is done for three fictitious traffic mixes. As a comparison of the rehabilitation hypotheses considered, the method used by the Portuguese Air Force is applied. Finally, a prediction of life cycle costs is made for the different rehabilitation alternatives in study.

1 Introduction

Since in the Portuguese Air Force (PAF) the patrimony management prevails, rehabilitation is increasing its importance in the organization. Therefore It was proposed by the Infrastructure Department (ID) the study of rehabilitation alternatives for the runways at Air Base Nº 11 – Beja (AB 11).

The runways in study, main (01L-19R) and secondary (01R-19L), are respectively 3450 m long with 60 m wide and 2951 m long with 30 m wide [Portugal, AIP]. Both have a superficial layer in prestressed concrete with slabs 96 m long, 7,5 m wide and 0,16 m thick.

No major interventions were made to date, and since its construction in 1962, the runways didn’t suffer any changes in their constitution.

The objective is to study different alternatives for structurally rehabilitate and to establish as much as possible a reference approach for similar cases.

To this end, first it is presented a general characterization of the different types of pavement frequently found in airfields. Then, some of the existing design methodologies are described. After a choice is made that best corresponds to the problem in question and the characterization of current state of the runways is studied, a compatibility of the structural models previously determined is made to the method of choice and the rehabilitation hypothesis are determined.

Finally, a life cycle cost analyses is performed for the hypothesis studied, since it’s a key factor when choosing possible implementation in the field.

2 Typical Structures and Design Methodologies

The pavement types often applied in transport infrastructures such as roads and airports can be grouped into three major groups according to their characteristics: flexible pavements, rigid pavements and semi-rigid pavements [Branco et al., 2006]. The biggest different between them, beyond the material that constitutes the surface layer, is the way that loads are transmitted through the layers of the pavement, which is represented in Figure 1.

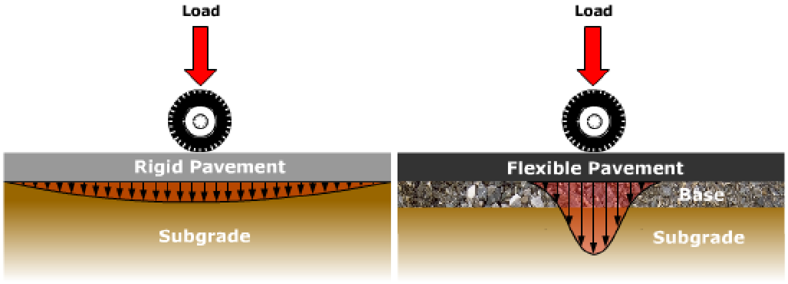

Figure 1 – Distribution of loads on rigid and flexible pavements.

Regarding the pavement design methods, there is a wide variety, with variable dissemination and applicability. The Federal Aviation Administration (FAA) method, supported by a calculation program (FAARFIELD) is one of the most used. The design procedure in this method is based on a layered elastic and three-dimensional finite element-based structural analysis, for flexible and rigid pavements, respectively. The present method takes into consideration the lateral movement of aircrafts on the runway, through the Cumulative Damage Factor (CDF) [FAA, 2009].

Another globally spread method, is the one used by the United States Army Corps of Engineers (USACE), the PCASE method that uses a layered elastic analysis for the design of both flexible and rigid pavements. This method has the ability to make the design accordingly to an empirical or analytical approach.

Both methods allow the design of new pavements and overlays for already existing pavements according to the presented needs.

3 Runway Characterization

The runway of Air Base Nº11 in Beja, when it was designed in 1962, the method used was the one applied by the USACE for rigid pavements, which was based on the type of mission for the airfield and the critical aircraft for that mission [USACE, 1958], being the HHS's prestressing procedure used for its construction [Mello, 1962].

3.1 Runway Present Conditions

Nowadays, after many years in service, the runway is still in good conditions without presenting major distresses in the visual inspections carried out in the 2003 [Antunes, 2003]. However, in certain areas of the runway the slip coefficients obtained are below the minimum recommended [ANA, 2010]. Through testes conducted in the years 2003 and 2009, other pavement properties were determined, such as:

- Slab deflections [Antunes, 2003];
- Average concrete compressive stress, induced by prestress, of 2,25 MPa [Antunes, 2003];
- Actual position of the longitudinal and transverse prestress cables [Antunes, et al., 2009];
- Thickness of pavement's different layers [Antunes, 2003];
- Compressive strength and elastic modulus, of soil-cement, of 13,4 MPa and 6,0 GPa, respectively [Antunes, 2003];
- Compressive strength and elastic modulus, of concrete, of 83 MPa and 42 GPa, respectively [Antunes, 2003];
- Concrete's flexural strength of 7,5 MPa [Antunes, 2003].

The analysis of test results enabled the construction of a structural model of the pavement, in the program BISAR 3.0, with the characteristics presented in Table1.

Table 1 – Model of structural behavior deduced from the falling weight deflectometer (program BISAR 3.0) [Antunes, 2003].

Concrete		Interface	Soil-cement		Subgrade		
H1 (m)	E1 (MPa)	K (MPa/m)	H2 (m)	E2 (MPa)	H3 (m)	E3 (MPa)	E4 (MPa)
0,16	42000	8333	0,17	6000	2,00	75	1000

LEGEND:

H_1 , H_2 , H_3 – Thickness of concrete slab, soil-cement layer and upper layer of subgrade, respectively;

E_1, E_2, E_3, E_4 – Elastic modulus of concrete, soil-cement and top and bottom layers of subgrade, respectively;

K – Tangential stiffness in the joint between the concrete slab an the soil-cement layer.

3.2 ACN/PCN Classification

The ACN/PCN classification method is based on assigning values of ACN (Aircraft Classification Number) to aircrafts and values of PCN (Pavement Classification Number) to pavements. The ACN expresses the effect made by a given aircraft to the pavement and the PCN, among other factors, states the load capacity of a given airport pavement in terms of maximum permissible load in a single wheel, acting with a pressure of 1,25 MPa, making 10 000 coverages [ICAO, 1983]. This means that, any aircraft with an ACN value inferior or equal to the PCN value of the pavement, can operate on it without any restrictions.

The calculation of the maximum permissible load for the runway in study was based on the analysis of the structural model of the pavement, using the program BISAR 3.0, of Shell, with the intent of preventing cracks on the slabs. To do so, the tensile stress at the bottom of the prestressed slab was limited to 4,65 MPa. A maximum vertical load of 222 kN was obtained, giving the runway a PCN classification of 45, in terms of pavement's load capacity.

4 Design Solutions

In Beja's Airport Master Plan, prepared by COBA in collaboration with EDAB (2003), is defined, without any reliable estimate of a future traffic mix, that the aircrafts operating will have an ACN classification of approximately 55. For this reason, one of the objectives of the rehabilitation is that the rehabilitated pavement has a PCN classification of, at least, 55.

4.1 Traffic

In the rehabilitation alternatives design for Beja's runways, was considered a traffic mix that seemed to be realistic for futures requests of the airfield. This traffic was divided into civilian and military traffic, since the air base in question will be used by both.

Civilian traffic considered was the traffic from Faro airport, but due to the fact that it can be excessive, only a part of the total traffic was considered and three possible relationships were analyzed:

- 50% of Faro's airport traffic;
- 30% of Faro's airport traffic;
- 30% of Faro's airport traffic, plus a reduction of 50% of the most damaging aircraft to the pavement.

Based on the Annual Traffic Report from Faro Airport (2009), with the information on the number of departures for each airline company and a document with the schedule of regular flights [ANA, 2011], containing the information of the aircraft that each company operates, was defined the civilian traffic to be considered in the design, with the result shown in Table 2.

Table 2 – Total departures for each civil aircraft.

Aircraft	Total Departures in 2009	50% of Departures	30 % of Departures
A320	5187	2594	1556
B737-800	4626	2313	1388
A321	3358	1679	435
A300-600	1451	726	1007
B757-300	1220	610	366
B757-200	545	273	164
B737-300	387	194	116
Gulfstream V	208	104	62
B737-100	173	87	52
A319	152	76	46
B737-700	63	32	19

The anual militar traffic, is obtained from an arithmetic average of the movement recorded between the years 2005 na 2010 [DINFA, 2010]. Note that touch-and-go's, present in the records of the Portuguese Air Force, were also counted as departures, but with an assign factor of 0,5. This consideration is supported by the fact that the maneuver induces less effort on the pavement in terms of vertical loads than a conventional take-off. On Table 3 is presented the military traffic considered in the design of rehabilitation hypothesis.

Table 3 – Military traffic.

Correspondent Aircraft on FAARFIELD	Type	Total Departures 2005-2010	Annual Average
(An-124)	A124	8	2
(A319-100 opt)	A319	130,5	26
(A320-200 opt)	A320	49	10
(BeechJet 400A)	AJET	14048,5	2810
(Sngl Whl-30)	AMX	6	1
(B747-400ER Freighter)	B747	3,5	1
(C-130)	C130	18,5	4
(C-130)	C160	121	24
(F-16C)	F16	38	8
(P-3)	P3	1450	290
(F-15C)	TORNADO	22	4
(A310-300)	A310	14	3
(C-17A)	C17	4	1
(B707-320C)-350.000lbs	E3TF[1]	53	11
(IL76T)	IL76	10	2

4.2 Rehabilitation Hypothesis

The rehabilitation hypothesis are divided in two groups, new and overlaid construction, and each considers the alternatives of the rehabilitation being done with rigid or flexible pavement, summing a total of four distinct rehabilitation alternatives.

In the new rigid pavement design, all layers are characterized by their thickness and elastic modulus, with the exception of the concrete slab, which is characterized by its thickness and flexural strength (elastic modulus fixed at 27 579 MPa) [FAA, 2009]. On Table 4, is shown the thickness calculated for the different layers, according to the FAA method for the different traffic mixes.

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[1] The E3TF or E-3 Sentry is used as an "Airborne Warning And Control System" (AWACS) and has a fuselage of a Boeing 707/320, but with the particularity of having a revolving radar on top.

Table 4 – Thickness of rigid pavement layers.

	Sub-base (mm)	Base (mm)	Superficial Layer (mm)
Traffic 50%	260	150	400
Traffic 30%	230	150	380
Traffic 30%, plus reduction in 50% of Critical Aircraft	240	150	372

In the new flexible pavement design, it's chosen to combine the asphalt layers into one single layer and determine that layer's elastic modulus, according to the Shell method [Picado-Santos, 1995] [Baptista; Picado-Santos, 1999] [Baptista; Picado-Santos, 2000]. The result of applying this method and the corresponding elastic modulus, are given in Table 5.

Table 5 – Elastic modulus for different thickness of asphalt layer.

Thickness (cm)	16	22	25	28	30	32
Service Temperature (°C)	30	30	29,4	29,4	28,9	28,5
Elastic Modulus (MPa)	4100	4100	4400	4400	4600	4800

The thicknesses of new flexible pavement layers, for different traffic levels, are presented in Table 6.

Table 6 - Thickness of flexible pavement layers.

	Base (mm)	Superficial Layer (mm)
Traffic 50%	400	240
Traffic 30%	450	212
Traffic 30%, plus reduction in 50% of Critical Aircraft	450	203

Designing the, rigid and flexible, overlay requires the prior calculation of an equivalent concrete slab, which has to have the characteristics within the parameters used by the FAA method, in the FAARFIELD program, and has to be true to the existing prestressed concrete slab, therefore keeping the same PCN classification of 45 [ICAO, 1983]. On Table 7, it's presented the equivalent slab properties.

Table 7 – Equivalent slab properties.

Thickness	Flexural Strength (R)	Elastic Modulus (E)
220 mm	4,50 MPa	27 579 MPa

In the rigid overlay design, is used as the underlying layers the ones determined as the structural model of the existing pavement, exception made for the prestressed concrete slab which is replaced by the equivalent slab. The rigid overlay thickness calculation results are presented in Table 8.

Table 8 – Rigid overlay thicknesses.

	Rigid Overlay (mm)
Traffic 50%	382
Traffic 30%	356
Traffic 30%, plus reduction in 50% of Critical Aircraft	347

In the flexible overlay design, the underlying layers considered are the same as the ones considered in the rigid overlay design. The elastic modulus of the overlay depends of his thickness, and the same calculation, using the Shell method, needs to be done to determine it. On Table 9, is shown the thicknesses calculated for the flexible overlay.

Table 9 – Flexible overlay thicknesses.

	Flexible Overlay (mm)
Traffic 50%	329
Traffic 30%	304
Traffic 30%, plus reduction in 50% of Critical Aircraft	294

After calculating the different alternatives, it’s determined the load capacity that each one will have, translated by the respective PCN value. The measurement of this value is done using the BISAR 3.0 program, of Shell. Note that when calculating the PCN for the rigid overlaid pavement, two limit stresses are taken into account, one at the bottom of the overlay and other at the bottom of the prestressed concrete slab, which are different. In the flexible overlaid pavement the limit considered is the stress at the bottom of the prestressed concrete slab and not the strains at the flexible overlay or the top of the subgrade, due to the high stiffness of the existing pavement, even before the overlay is applied.

Table 10 shows the load capacity calculation results for the different rehabilitation alternatives considered for various traffic mixes.

Table 10 - PCN values of pavements designed with FAARFIELD.

	New Rigid Pavement	New Flexible Pavement	Rigid Overlay	Flexible Overlay
Traffic 50%	112	94	112	153
Traffic 30%	102	90	98	139
Traffic 30%, plus reduction in 50% of Critical Aircraft	98	86	96	135

4.3 Economic Analysis

The life cycle cost analysis requires the knowledge of maintenance and rehabilitation schedule to take place over the pavement’s life. That information is obtained consulting records and forecasts of some american airports [ARA, 2011].

A decision is made to only make the life cycle cost analysis of the four alternatives for a traffic mix that has 30% of civilian traffic and a reduction in critical aircraft departures (third traffic hypothesis), since the analysis with the remaining traffic levels would not affect the relations between the different rehabilitation alternatives costs. The initial construction costs and life cycle cost for the different rehabilitation alternatives, are presented in Table 11.

Table 11 – Rehabilitation alternatives costs.

Alternative	Initial Cost (€/m^2)	Actual Value of Life Cycle Cost (€/m^2)
New Rigid	176,80	178,49
New Flexible	40,05	46,19
Rigid Overlay	138,80	140,55
Flexible Overlay	29,40	38,02

Analyzing the table above, it can be concluded that the most economically advantageous structural rehabilitation is the flexible overlay. The total costs presentation is done by adding and subtracting 10% to the average life cycle cost, therefore, for a runway 3450 m long and 60 m wide (main runway in BA11), the application of this alternative would have an excepted cost between 7.083.126 € and 8.657.154 € [FAA, 2009].

5 Conclusions

In this paper four structural rehabilitation hypothesis were studied for the concrete prestressed runway of BA11, for different traffic levels and were designed, according to the FAA method, using the FAARFIELD program.

Knowing the dimensions of the new pavements and overlay layers, their load capacities were calculated and a PCN classification was assigned to each one. By this calculation it was observed that all the hypotheses, calculated using the FAARFIELD program, were rated higher than the classification determined for the operation of aircraft for the new mission that the runway is intended, and it seems that twenty years passed, the required PCN value of 55 would be largely fulfilled.

Perhaps the consideration of a traffic coordinated with the airport's operation would lead to less conservative rehabilitations, since the overlay thickness calculated seems to be overdesigned.

The economic analysis of the four rehabilitation alternatives, only for one traffic level, showed that the most advantageous hypothesis, both from initial cost and long-term cost point of view, is the rehabilitation through the application of a flexible overlay.

It was considered that the objectives of this work were reasonably achieved, since the study of different possibilities of rehabilitation has been made with some success, although some hypothesis should be further explored in future investigations.

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