A study of the Hot-Mix Asphalt layer thickness reduction when applied over lateritic soils cement base in airfield

Alex Alves Bandeira
Professor Doctor – Department of Constructions and Structures –
Federal University of Bahia – UFBA.
Bahia – BA [Brazil]
alex_bandeira@terra.com.br

Rita Moura Fortes
Professor Doctor – Department of Civil Engineering –
Mackenzie Presbyterian University.
São Paulo – SP [Brasil]
rmfortes@terra.com.br

João Virgilio Merighi
Professor Doctor – Department of Civil Engineering –
Mackenzie Presbyterian University.
São Paulo – SP [Brasil]
jmerighi@terra.com.br

In tropical region, in upper layers, soils having red or yellow coloration are generally found and are denominated lateritic soils. They are rich in aluminum hydroxides and ferric hydrates that give an elevated mechanic resistance. When the lateritic soils are used as a construction material in the structural pavement, the exceptional mechanical characteristic reduced the cost over 50% when associated with the sub-base and base layers, or over 25% when the lateritic soil is treated with cement. In São Paulo State, it was made more than ten thousands kilometers of roads where the base or sub-base was made using lateritic soils or lateritic soils treated with cement. In this study, it is showed, through Finite Element Method, a critical analysis of the sub-base and base of airfield pavement using lateritic soils cement base course and Hot-Mix Asphalt thickness surface less than recommended for critical area in according to Federal Aviation Administration (1996). Considering the results, it is possible to propose a reduction of thickness Hot-Mix Asphalt layer, resulting in a reduction of the final cost of implantation of hundreds of airfields in South America.

Key words: Airports. Cost of implantation. Finite element analysis. Soil cement. Tropical soils.

1 Introduction

On recent years, the people and companies/governor point of view has changed in terms of costs and benefits applied in the infrastructure, because of the environmental conscious. The recycling technology is transforming the innumerous typical solutions of projects and, in many places, there are financial incentives for the companies that use the green stamp or, in another meaning, keep an environmental respect.

Associated to the higher cost of production and transportation of aggregate, in particular in the north of the country, where there is not this kind of raw material, the utilization of tropical soils have been encouraging by the geotechnical engineers, because of the exceptional mechanical and hydraulic characteristics, specially, the soil denominated sand lateritic soil.

In São Paulo State, it is common to use flexible surface over a base constructed only using the lateritic sand soil for low traffic roads or cement base when the traffic is around of 1.0×10^7 of equivalent single-axle load in ten years. The experience with lateritic soil began in 1950 and in 1970 have made more than 10 thousands kilometers of soil with cement base or only with soil lateritic base. Many of these roads, after 30 years, still are in excellent conditions. Part of these roads receives more than 2 thousand vehicles per day, being 30% bus and trucks. Considering the experience in the last 50 years, there are encouragements to use the soil cement technology in base of airfield, reducing Hot-Mix Asphalt (HMA) layer thickness.

Nowadays, there are more than seven hundreds airports/airfields in Brazil. Motivated by economic increase in the last five years, there is a strong demand for construction of regional airport. The typical aircraft is a jet for a 100 passengers at most.

Naturally, to attend the regional airport demand, for this big challenge is necessary money to obtain an architecture project, airport layout and airfield construction.

However, as affirmed by the Federal Aviation Administration (FAA) through the document AC No: 150/5320-6D (1996), the design of airport pavements have a complex solution in terms of engineering problem and involves several considerations motivated by a large number of interrelated variables.

As a consequence of this challenge, the main objective of this paper is not only to propose a change of a granular base by a soil cement base, considering its exceptional characteristic in terms of mechanical and hydraulic performance, but to investigate the possibility of reduction of the asphalt layer thickness in the case of regional airports construction.

2 Airport flexible pavement design

In Brazil, the methodologies used for pavements design are based in the American Association of State Highway and Transportation Officials (AASHTO) and U. S. Army Corps of Engineers (USACE) methods for the roads, and in the FAA method for airports.

The Advisory Circular is AC N° 150/5320-6D (1996). In this document, Chapter 3, it is affirmed that the design of pavements for airport is a complex engineering problem and relates that there are elevated interacting variables in the process and the curves of design presented have its origins on the California Bearing Ratio (CBR) method of design for flexible pavements.

However, in a more recent version of that same document, which incorporates recent changes and corrections, it is declared that “the design process considers two modes of failure for flexible pavement: vertical strain in the subgrade and horizontal strain in the asphalt layer" (FAA, 2004, p. 142). In terms of hot mix surfacing, in the related document, it is reported that:

> A minimum thickness of 5 inches (127 mm) of hot mix surfacing is required for traffic mixes that include aircraft with the triple dual tandem (TDT) gear aircraft. The minimum thickness of hot mix surfacing, as shown in Figures 3-2 through 3-15, is required for traffic mixes that do not include aircraft with the TDT gear. (p. 142).

Consulting the mentioned figures and, observing the case of dual wheel gear for gross aircraft weight in the range of 100,000 – 200,000 lb (45,000 – 90,700 kg), the minimum thickness for the asphalt layer in the critical area is 4" or 10 cm, while in the noncritical areas the value is the 3" or 7.5 cm. On the other hand, the Tables 3 and 4, recommends for base course the minimum thickness of 8" or 20 cm.

In relation to the base layer, the related document is clear when recommends the material for base. In Section 2, Flexible Pavement Design, item 311, Base Course, is recommended six kinds of mixtures, but it is not mentioned the soil cement base, which is only recommended for subbase and corresponds at item 301 of the document Standards for Specifying Construction of Airports AC No. 150/5370-10B.

In terms of reflection cracking, the document Airport Pavement Design And Evaluation – AC N° 150/5320-6D (1996) in the item 321, table 3-9, inform that the HMA surfacing course should be at last 4" (10 cm) to minimize reflection cracking in the case of the base to be make of the P-304, Cement Treated Base Course. In resume, this document for pavement design does not recommend the use of soil cement as mixture for base of airfield in the case of gross aircraft weighting more than 100,000 lb.

On the other hand, in tropical region, there is a kind of soil, called lateritic soil, which has an excellent behavior in terms of mechanics resistance, and, in many cases, its performance is better than granular base. Its utilization as material for base opens an opportunity to save money and to minimize the destruction of the environment.

3 Lateritic soils characteristic

Tropical soils are a material that presents exceptional properties as a result of the typical performance of geologic or pedologic processes of humid tropical regions. Tropical soil is a product of climatic conditions, which warrant the necessity to appraise the genetic peculiarities of them. Two soils types are found in tropical regions: lateritic soils and saprolitic soils.

Lateritic soils are found in upper layers, generally having yellow or red coloration due to the presence of aluminum hydroxides and ferric hydrates, are more resistant to erosion and homogeneity. This geologic process of disaggregation and decomposition is very slow and mostly active in the upper layers, which are drained and situated well above the water level thickness of this layer, on the order of meters (FORTES; MERIGHI, 2003).

The use of tropical lateritic soils as a construction material for highways allows more or less 50% of reduction in the cost associated with the sub-base and base layers, or over 25% when the lateritic soil is treated with cement. However, not all types of tropical soils are suitable for use as a stabilized base or sub-base. There are only some types of lateritic soils having particular mechanical and hydraulic properties, which guarantee good performance and long service life. With increased costs due to the long transportation distances and continued reductions in available exploration and borrow areas of materials, it has become more difficult to find new deposits and justify their exploration. Associated with the difficulty in finding material deposits, there is an increase in testing costs, which adds to the total cost and extends project time.

The Miniature Compacted Tropical (MCT) methodology derives from the practice of using small specimens (50 mm in diameter) of compacted tropical soils. Figure 1 shows a schematic of the MCT methodology as described by Villibor et al. (2000). The MCT classification separates tropical soils into classes of lateritic behavior and non-lateritic behavior.

The first group is subdivided into three subgroups: LA – lateritic quartzous sand; LA' – lateritic sandy; and LG' – lateritic clayey. Non-lateritic behavior (saprolitic) soils are subdivided into four groups: NA' quartzous sandy with fine or non-lateritic behavior; NA non-lateritic sand, silts and mixtures and silts with predominance of quartz grain and/or mica; NS' non-lateritic silt, and NG' non-lateritic clayey.

To classify the soils using the MCT Methodology, it is used the chart of Figure 2. The dashed line separates soils of lateritic from non-lateritic behaviors. The properties and relative intention in transportation applications of the soil can be estimated using Table 1.

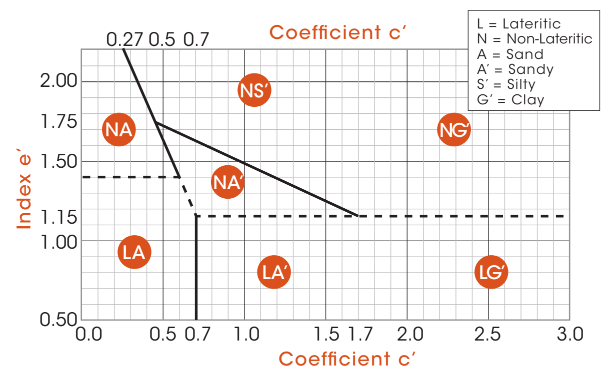

Figure 2: Chart of MCT soil classifications
Source: Nogami; Villibor, 1994.

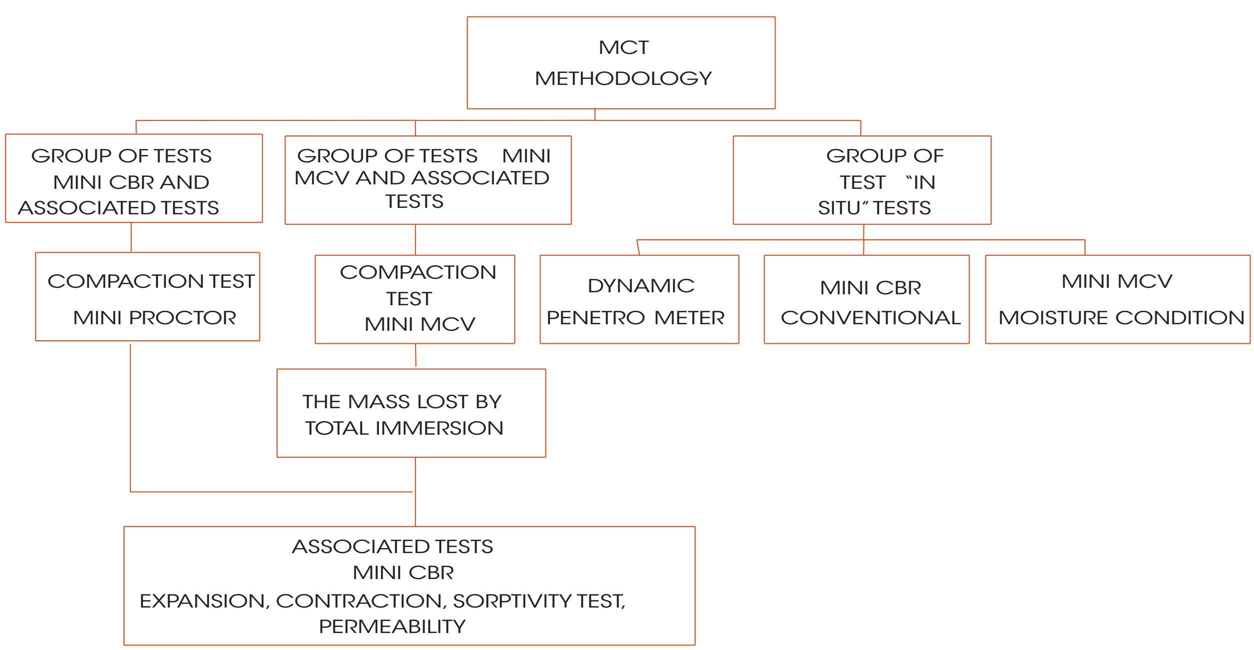

Figure 1: Test groups of the MCT methodology
Source: Villibor et al., 2000.

Table 1: Properties and relative desirability in transportation applications based on MCT soil classification groups

Behavior			N = NON – Lateritic				L = Lateritic		
Mct group			NA	NA′	NS′	NG′	LA	LA′	LG′
Properties (1)	Mini-CBR	Not soaked	M, H	H	M, H	H	H	V, H	H
		Soaked	M, H	M, H	L, M	L	H	H	H
V = very high	Expansion		L	L	H	M, H	L	L	L
H = high	Shrinkage		L	L, M	M	M, H	L	L, M	M, H
M = medium	Permeability (K)		M, H	L	L, M	L, M	L, M	L	L
L = low	Sorptivity (s)		H	L, M	H	M, H	L	L	L
Relative desirability as: N = not suitable	Pavement base		N	4th	N	N	2nd	1st	3rd
	Select subgrade		4th	5th	N	N	2nd	1st	3rd
	Compacted subgrade		4th	5th	7th	6th	2nd	1st	3rd
	Embankment (core)		4th	5th	6th	7th	2nd	1st	3rd
	Embankment (shell)		N	3rd	N	N	N	2nd	1st
	Earth road surfacing		5th	3rd	N	N	4th	1st	2nd
Classification obtained from traditional index properties	USCS/ASTM		SP	SM	SM, CL	MH	SP		MH
				SC	ML	CH		SC	ML
			SM	ML	MH		SC		CH
	AASHTO		A-2	A-2	A-4	A-6		A-2	A-6
				A-4	A-5	A-7-5	A-2	A-4	A-7-5
				A-7	A-7	A-7-6			

Source: Nogami; Villibor, 1994.

4 Brazilian airport demands

The demand for new airports is very expressive. Since 2000, the number of passengers and cargo is enhance, and in the period between 2003 and 2005, there were an annual average of increase, in according to Empresa Brasileira de Infraestrutura Aeroportuária – Infraero –(Brazilian Airports Infrastructure) (2007). It means more 4.9% of passengers and 12.1% of cargo. In the same period, the gross domestic product (GDP) was 3.7%. This scenery is very optimist for this kind of activity and is associated at global business and commerce.

Part of this expansion is linked to insertion of company kind low-cost and regional carriers and increase of salary mass. So, the aviation segment is transforming in a popular form of transport, in particular in some regions, as interior of state of São Paulo, where there is a lot of cities involved in hard growth.

Based on data compiled by Agência Nacional de Aviação Civil – ANAC (Brazilian Civil Aviation Agency) (2007), there are 741 public airports in Brazil and all air carriers, and are transported 102.2 millions passengers and 1.2 billions ton in terms of cargo in 2006. These numbers are associated with 190 millions of peoples and a GDP of US$ 1.1 trillion. Table 2 details total flight, passengers and cargo during the period of 2003 until 2006. Observe that the domestic passengers increased in approximately 50% during the period while international passengers increased around 22.4%.

Table 3 was made based on data from Table 2, using primary statistical method. So, it was possible to estimate the demand of flight and passengers for 2015. It is important to observe that there is an increase around 100% of domestic pas-

Table 2: Shown the increase of flight, passengers and cargo between 2003 and 2006

Year	Flight		Passengers		Cargo (kg)	
	Domestic	International	Domestic	International	Domestic	International
2003	1,649,312	116,283	61,268,864	9,946,946	667,392,497	557,221,095
2004	1,655,757	134,546	71,489,102	11,217,152	717,688,675	640,828,939
2005	1,698,461	142,584	83,483,534	12,595,298	752,299,245	607,840,321
2006	1,781,786	136,752	90,005,151	12,180,225	641,458,849	588,220,426

Source: ANAC, 2007.

Table 3: Estimative of the demand for flights and passenger in 2015

Year	Flight		Passengers	
	Domestic	International	Domestic	International
2006	1,781,786	136,752	90,005,151	12,180,225
2015	2,120,000	205,000	180,000,000	20,000,000
Variation (%)	28	50	100	67
R2	0.867	0.62	0.987	0.785

Source: Merighi et al., 2007.

sengers. As a result, it is expected a strong demand for regional airport. It is important to inform that, in South America, there are a lot of international flight using B727, B737, Airbus 319 and Fokker 100 aircrafts.

Since 2003, total domestic passengers have increased 5.0% per year, and there is a demand for construction of new airports in interior of Brazil. However, the high cost of construction many times does not encourage the investors (state or federal administration). Some efforts had been made to decrease the total costs but these efforts involves a lot of items of airport construction. In preliminary studies developed for road constructions, was observed that the use of lateritic soil cement base allows reducing the total cost of pavement in 25%.

5 Proposal for utilization of lateritic soils cement base course

The peculiarities of lateritic soil mixed with cement Portland permit the reduction of HMA thickness and, consequently, of the final cost. This technology is usual in the Departamento de Estradas de Rodagem (DER-SP) (Department of Transportation of São Paulo State), but in airport pavement it is not. São Paulo State has more than 10 thousands kilometers of soil cement base course. Part of these roads was made in the 1970´s, and after thirty years, the base course is almost intact. The rehabilitation of the road is necessary only in the last layer or, in other words, had been made only an overlay.

So, this fact has encouraged the authors to study the use of soil cement base course for regional airport where the typical aircraft had around 50 ton with capacity for 100 passengers.

The soil used in this research was LA' – lateritic sandy – from experimental test track in construction in São Paulo State, which was accomplished through an agreement between Mackenzie University and Department of Transportation of São Paulo State. The Figures 3(a) and (b) show a view of the deposits and the sub-base construction.

Normally in this region, the lateritic soil thickness is around 3 to 4 m. The first meter in this deposit is an organic soil and its color is

(a)

(b)

Figure 3: (a) Deposit of sand lateritic soil (b) Test track sub-base compaction
Source: The authors.

brown while the sand lateritic soil is red. It is important to say that, in the experimental test track, the basic pavement structure was idealized considering lateritic sandy soil sub-base and soil cement base course. The principal soil and soil cement characteristics are shown in Table 4.

The typical structure proposal, in according to FAA AC 150/5320-6D (1996), is schematized in Figure 4 and was obtained considering the parameters presented in the Table 4. This structure was obtained considering the Embraer 195 jet (Figure 5), a standard aircraft, and the parameters presented in the Table 5.

The research had the follow sequence: firstly, the thickness of the pavement layers was obtained in according to document AC 150/5320-6D (1996) which the principal parameters are presented in the Table 5 and denominated as "case 1", and, in the same layers sequence, demonstrated in the Figure 4. The "case 2" is similar to the "case 1", changing only in the kind of base. While in the

Table 4: Soil and soil cement mix characteristics

Soil characteristic	Value
Soil group in AASTHO system	A-2-4
MCT classification	LA' or sand lateritic soil
Maximum dry density – standard Proctor test (kN/m3)	20.20
Optimum moisture content	10.4
Maximum dry density – modified Proctor test (kN/m3)	20.60
Optimum moisture content	10.0
Contraction – standard Proctor test (%)	0.20
Contraction – modified Proctor test (%)	0.48
Soil cement characteristic	
Compressive strength – 28 days (MPa) 6% MPa	2.52
Compressive strength – 28 days (MPa) 6% MPa	3.85
Resilient modulus (cement = 6%) MPa	3,800
Resilient modulus (cement = 8%) MPa	4,500
Compression test for tensile resistance determination/ Brazilian Test (cement = 6%) MPa	0.33
Compression test for tensile resistance determination/ Brazilian Test (cement = 8%) MPa	0.42

Source: The authors.

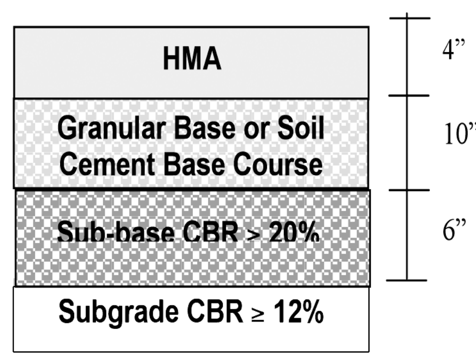

Figure 4: Airport pavement structure studied
Source: The authors.

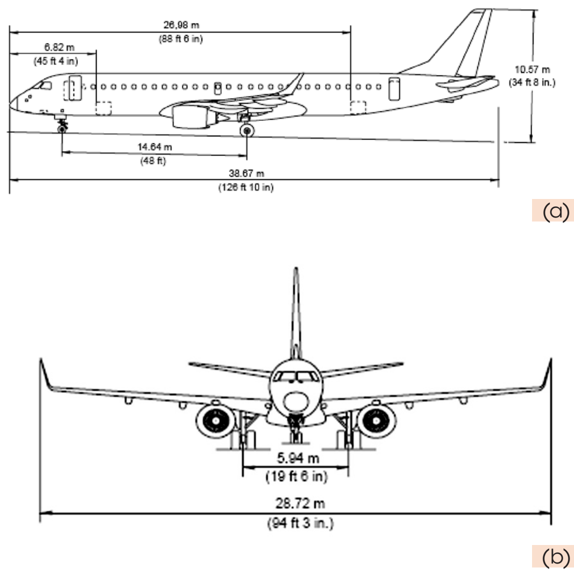

Figure 5: General Aircrafts dimensions
Source: Empresa Brasileira de Aeronáutica S.A, 2007.

Table 5: Design parameters considered

Parameters	Values
Subgrade CBR (%)	12
Sub-base CBR (%)	20
Granular base (%)	80
Aircraft standard Model IGW	jet Embraer 195
Maximum allowed weight kg (lb)	52,450 (115,632)
Annual departures	3,000
Dual wheel gear	-----
Total thickness cm (in)	50 (20)
Asphalt surface – critical area cm (in)	10 (4)
Granular base thickness cm (in)	25 (10)
Sub-base cm (in)	15 (6)

Source: The authors.

"case 1" was used 25 cm of granular base, in the "case 2" it was changed to 25 cm of soil cement base course with 8% of cement in dry mass.

The "case 3" is similar to the "case 2", except that the soil cement thickness layer was changed to 20 cm and the asphalt thickness, from 10 cm to 5 cm. Finally, the "case 4" is analogous to "case 3", however, there was an increase of 5 cm in the sub-base layer thickness. All four cases are illustrated in the Table 6.

Table 6: Resume of four pavement structures cases studied

Layer	Thickness cm (in)			
	Case			
	1	2	3	4
Hot mix asphalt surface	10 (4)	10 (4)	5 (2)	5 (2)
Granular base	25 (10)	–	–	–
Soil Cement base (8%)	–	25 (10)	20 (8)	20 (8)
Sub-base	15 (6)	15 (6)	15 (6)	20 (8)

Source: The authors.

The investigation of the structural behavior in terms of stresses and strains in the four cases studied was made using the 3D flexible structural pavement tool, illustrated in Figure 6. They are calculated numerically using the finite element methods with frictional contact mechanics under large elastoplastic deformation. On the asphalt concrete surface was applied two aircraft tires classified as H41x 16 – 20 22R, each one with 406 mm width and 104 cm height, the distance between axles is 87 cm. The main gear tire pressure is equal to 1.083 MPa (154 psi). This problem summarizes the model that considers three deformable bodies in contact, i.e., two tires and a top pavement surface.

The pavements and the tires are discretizing using the brick elements with eight nodes. The 3D pavement is modeled as a unique block, but with different materials properties defined by the pavement soil layers. The same is done for the tires. So, this model has three deformable solids. To analyze this model, the contact mechanics is applied. The tires are considered master bodies and the structural pavement slave body.

In this model, the several layers of the pavement structure are discretizing. Each soil layer has its material parameters defined by the elasticity modulus (E), the Poisson ration (ν) and the initial yield stress (σ_{yo}). Here, it is assumed that the pavements should be modeled by a two meters solid, in each horizontal side, and the real thickness of the pavement structure in the vertical direction. Regarding the boundary conditions, the bottom surface layer has its displacements completely restrained. The lateral sides of the pavement model have no restraints on the vertical direction, but they are completely restrained on the other two possible displacements (Figure 6).

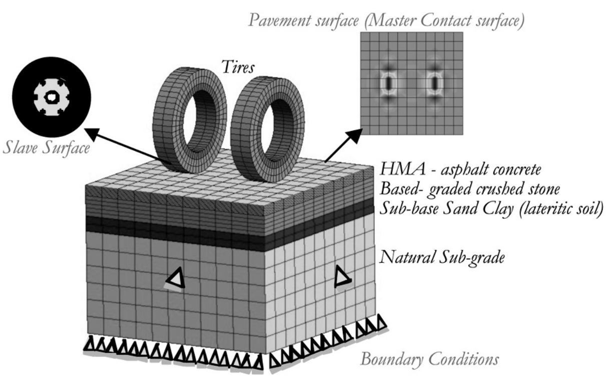

Figure 6: A 3D finite element model of structural pavement
Source: The authors.

The procedure is performed putting the tires on the asphalt surface. In the contact discretization, the asphalt surface is defined as the master surface and the tire surfaces in contact with the asphalt are defined as slave surfaces. Then the simulation is performed and, in the equilibrium configuration, the results lead to the correctly phenomenon. In this paper, four types of structural pavements are analyzed. It is important to mention that only the stresses developed under the tires are plotted over the deep direction.

The results of the numerical structure analysis in terms of stresses and strains are showed in the Figures 7, 8, 9 and 10.

Following the recommendations of the document 150/5320-6D (FAA, 2004), item 706, to verify the vertical strain in the subgrade and horizontal strain in the asphalt layer, are presented in the Table 7 the principal points where there are more probability to begin a deterioration of

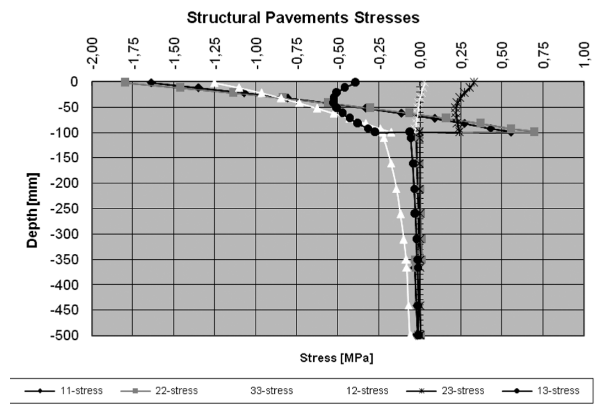

Figure 7: Traditional solution in flexible pavement – case 1
Source: The authors.

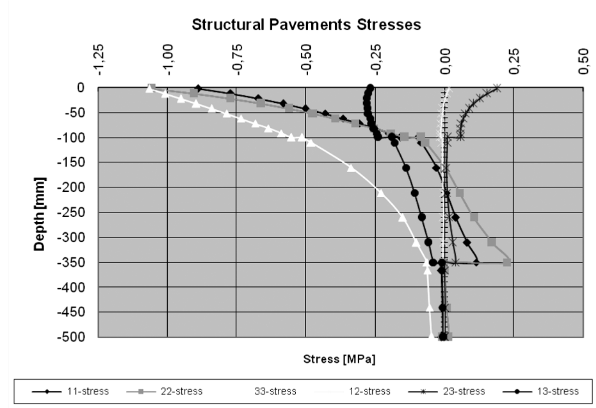

Figure 8: Soil cement base course – case 2
Source: The authors.

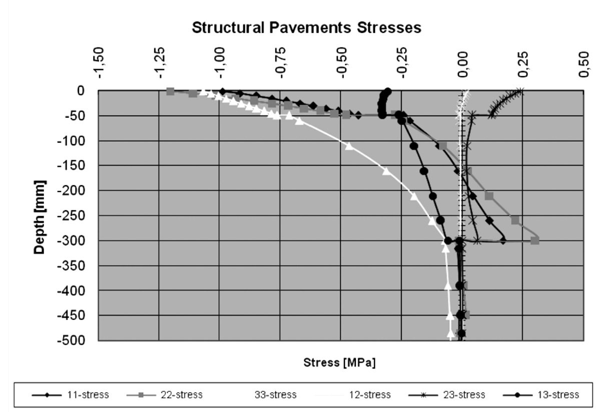

Figure 9: Structure with 5 cm asphalt thickness – case 3
Source: The authors.

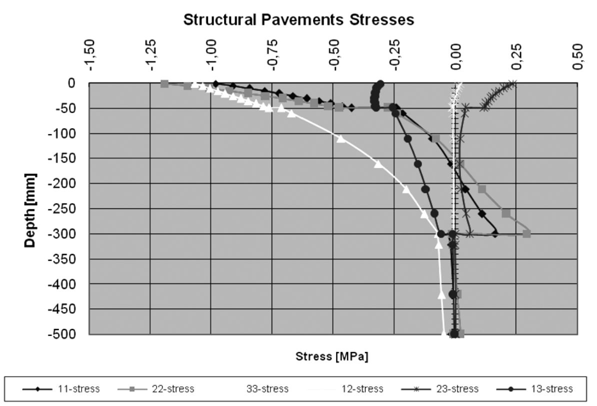

Figure 10: Increase of 5 cm in the subbase thickness
Source: The authors.

pavement or, in other words, points that are considered trustful.

Analyzing the Table 7, it is possible to observe that the critical situation occurs in the bottom of soil cement base layer, in cases 3 and 4. In these situations, the tension stress is very high and corresponds, approximately, to 71% soil cement stress rupture.

Table 7: Stress resume obtained in the simulation of the 4 cases studied

Layer: stress/ strain	CASE 1	CASE 2	CASE 3	CASE 4
Asphalt surface: horizontal stress - botton (MPa)	0.72 tension	0.25 compression	0.28 compression	0.26 compression
Soil cement base: horizontal stress – botton (MPa)	–	0.23 tension	0.30 tension	0,30 tension
Subgrade: vertical stress (MPa)	0.04 compression	0.06 compression	0.065 compression	0.06 compression

Source: The authors.

6 Final considerations

Initially, it is very important to say that this research is recent and, according to the authors' point of view, the results obtained are very optimistic and encourage continuing the studies. The reduction of 5 cm in the thickness of the HMA resulted in a small increase in the tension stress on the bottom of the soil cement base course. On the other hand, in case of increase, the thickness of the sub-base, that represents a small cost compared to the other layer sand, almost did not reduce the tension stress.

Considering that, in some regions of Brazil, as Amazon region, for example, where the aggregate deposits spend more than 42 days to transport, the use of soil cement base course is an interesting solution and permits to reduce the cost and, obviously, to attend more regional airports.

The results obtained in terms of traction in the bottom of soil cement base are values in order of 71% of the rupture stress. So, it is possible to use this technology presenting usual values found in the literature.

It is constructed an experimental test track using that technology and it is intended to do a deflectometric evaluation.

References

AGÊNCIA NACIONAL DE AVIAÇÃO CIVIL (ANAC). *Sistema Aeroportuário*. Disponível em: http://www.anac.gov.br/estatistica/estat27.asp#. Acesso em: 20 dez. 2007.

EMPRESA BRASILEIRA DE AERONÁUTICA S. A. *Airport planning manual embraer 195*. APM-1997 - 28 JULY 2006. REVISION 3 - 22 OCTOBER 2007 São José dos Campos, Brasil. Disponível em: http://www.embraercommercialjets.com.br/english/content/ejets/emb_195.asp?tela=apm. Acesso em: 20 dez. 2007.

EMPRESA BRASILEIRA DE INFRA-ESTRUTURA AEROPORTUÁRIA. INFRAERO. Disponível em: http://www.infraero.gov.br/movi.php?gi=movi. Acesso em: 20 dez. 2007.

FEDERAL AVIATION ADMINISTRATION (FAA). Advisory Circular No: 150/5320-6D. Airport pavement design and evaluation, 1996. Available at: http://www.faa.gov/airports_airtraffic/airports/resources/advisory_circulars/index.cfm?template=Document_Listing. Accessed in: dec. 20th, 2007.

FEDERAL AVIATION ADMINISTRATION (FAA). Advisory Circular No: 150/5320-6D Change 3. Airport pavement design and evaluation, 2004. Available at: http://www.faa.gov/airports_airtraffic/airports/resources/advisory_circulars/index.cfm?template=Document_Listing. Accessed in: dec. 20th, 2007.

FORTES, R. M.; MERIGHI, J. V. The use of MCT methodology for rapid classification of tropical soil in Brazil. *IJP – International Journal of Pavements*, v. 2, n. 3, p. 1-13, Sep. 2003.

MERIGHI, J. V. et al. Proposta para implantação de aeroporto industrial internacional em São Paulo. In: CONGRESSO DE INFRA-ESTRUTURA DE TRANSPORTES, 2007, São Paulo: Associação Nacional de Infra-estrutura de Transportes (Andit). São Paulo, Brasil, 19 a 22 jun. 2007.

NOGAMI, J. S.; VILLIBOR, D. F. A new simple method for classification of lateritic and saprolitic soils. In: INTERNATIONAL IAEG CONGRESS, 7., 1994, Balkema, Rotterdam, Netherland. *Proceedings*..., Balkema, Rotterdam, Netherland, 1994. p. 3391-3399.

Villibor, D. F. et al. *Pavimentos com solos lateríticos e gestão de manutenção de vias urbanas*. In: 10ª Reunião anual de Pavimentação Urbana da ABPv – Associação Brasileira de Pavimentação e Universidade Federal de Uberlândia, Faculdade de Engenharia Civil, Uberlândia, Brasil, 2000.

Recebido em 26 nov. 2008 / aprovado em 20 dez. 2008

Para referenciar este texto

BANDEIRA, A. A.; FORTES, R. M.; MERIGHI, J. V. A study of the Hot-Mix Asphalt layer thickness reduction when applied over lateritic soils cement base in airfield. *Exacta*, São Paulo, v. 7, n. 1, p. 121-131, 2009.