Adaptation of the French pavement design to countries in South America

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Adaptation du dimensionnement des chaussées française aux pays d Amérique du Sud

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Résumé

En France, le LCPC (maintenant l'IFSTTAR) a développé une méthode rationnelle de dimensionnement des différentes structures de chaussées. Cette méthode prend en compte les propriétés de la plateforme, support de chaussée, en fonction de sa portance, contrôlée sur chantier et celles des matériaux de chaussée. Les performances des matériaux sont mesurées en laboratoire, selon des essais conventionnels, répétables, reproductibles et pertinents avec le comportement réel, des matériaux, observé sur le terrain. Les conditions de trafic et de climat sont évaluées à partir de l'agressivité des charges, traduite en notion de trafic équivalent (les différents silhouettes et charges sont ramenées en nombre d'essieux conventionnels de 130 kN) et pour une température équivalente (soit 15°C de température moyenne annuelle).
Après un rappel, des méthodes de formulation des matériaux bitumineux, matériaux les plus performants et les plus employés actuellement, et de la méthode fondamentale de dimensionnement des chaussées, tels que pratiqués en France, l'article s'intéresse aux conditions d'adaptation de ces méthodes, et plus précisément aux paramètres essentiels, pour des applications dans les pays d'Amérique du Sud. Ainsi, la sensibilité à l'eau des enrobés est très forte en Colombie, où des recherches ont conduit à la mise au point d'essais complémentaires et à la définition de seuils d'acceptation. De même, les notions de température équivalente et d'agressivité des charges doivent être définies pour les conditions d'usage dans le pays considéré. Des recherches et études sont en cours au Brésil. Les premières réflexions et les premiers résultats sont présentés, montrant les possibilités et difficultés restantes pour valider la méthode de dimensionnement.
L'intérêt de ces méthodes d'études, très ouvertes, prenant en compte les principaux facteurs d'influence, est leurs adaptations aux innovations sur les matériaux et les structures, et aux conditions d'usage, propre à chaque pays. La difficulté reste, bien entendu, la transposition et le calage des méthodes de calcul, par des expérimentations en vrai grandeur. Mais cela ouvre aussi de nouvelles perspectives, pour le développement des matériaux et pour une meilleure durabilité de la route.

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Abstract

In France, LCPC (now the IFSTTAR) has developed a rational pavement design for pavement structures. This method takes into account the properties of the platform, support of pavement structure, with the bearing capacity, controlled on site and those of road materials. The performance of road materials are measured in the laboratory, according to conventional, repeatable, reproducible and relevant tests with real, of road materials, observed behavior in the field. Traffic and climate conditions are evaluated from the aggressiveness of the loads, translated into concept of equivalent traffic (different silhouettes and loads are reduced in number of conventional axles of 130 kN) and for an equivalent temperature (15 ° C of average annual temperature).
After a reminder, the mix design methods for bituminous materials, the materials the most perform and the most used currently, and the fundamental pavement design method, such that performed in France, article is interested in the conditions of adaptation of these methods, and the essential parameters for applications specifically in the countries of South America. Thus, the sensitivity to water mix is very strong in Colombia, where research led to the development of additional tests and the definition of thresholds of acceptance. Similarly, the concepts of equivalent temperature and aggressiveness of the charges must be set for the conditions of use in the country. Research and studies are underway in the Brazil. The early reflections and the first results are presented, showing the opportunities and challenges remaining to validate the method of sizing.
The interest of these studies, very « open" methods, taking into account the main factors of influence, is their adaptations to innovations in materials and structures, and the conditions of use, in each country. Difficulty remains, of course, valve timing of the calculation methods, by experimentation and the transposition in true size. But it also opens new perspectives for the development of materials and for better durability of the road.

1 - Overview and main principles of French bituminous hot mix design

The Marshall method also called recipes, used until the late 50's, showed his failure, in conjunction with empirical methods, where during exceptional winter of 1962-63, the entire national road network, which had under-sized, was completely destroyed. Since then, to take into account the differences of stresses, both climatic and mechanical, and the big variability of the constituents (aggregates and asphalt), the Directorate of Roads decided to develop their own French bituminous hot mix design mixtures were based on a focus on behavior or the final product quality.

Each property of the bituminous mix are evaluated by a unique test and compared to different level of specifications established in the product standards. All the standards used, even for the tests to characterize the behavior of mix in laboratory (according to French method) and the threshold product regarding the different nature of bituminous hot mixes are nowadays European standard. **This demonstrates the value, quality and reliability of the method**.

However, all the features of mix are not established by the performance test results, especially the durability against wear surface or the low temperature resistance of the mixtures, thus some requirements still remain on the components (type of aggregate and/or bitumen), and the minimum binder content (previously the thickness of film binder was determined in French standard, but no choice in European standard, this value translates into a minimum richness modulus, which takes into account the volumetric and mass variations of minerals, it stay an excellent indicator for the designer).

Thus in the study of the formulation, defines the following criteria:
Level 1 :

- The workability of mix (void content vs energy of compaction) through the Gyratory Shear Compactor Press (old NFP 98-252, NF EN 12-697.31 European standard),
  This GSC test is the central test of the mix design, because it is well in accordance with the compactibility in place (see the last paragraph of mix design guide, where correlations between lab/field are established);
- Water resistance by using “Duriez test” (old NFP 98-251.1, NF EN 12-697.12 method B European standard)

Level 2 (level 1 added rutting test):

- Resistance to plastic deformation, by testing laboratory track LPC (old NFP 98-253-1, NF EN 12-697.22, equipment designed “large apparatus”, especially used for heavy traffic (equal or up to 130 kN, European standard),

Level 3 (level 2, added modulus) :

- The mechanical performance: direct traction modulus (uni-axial direct tension (old NFP 98-260-1)) or dynamic bending mode frequency at two points; designed complex modulus (old NF 98-260-2), NF EN 12-697.26) European standard (direct tension or complex modulus in flexion 2 points),

Level 4 (level 3, added fatigue) :

- Resistance to fatigue bending test by two points (old NF 98-253-2, NF EN 12-697.24 European standard), see figure 3 for the presentation of device.

The level of mix design is determined by the road owner in the market, according to the solicitations and the class of risk of the network.

This mix design is performed in the laboratory on materials representative of those that will later be used in the work. Their results show that the mix proposed by the company verifies the requirements of the contract work and specifically the kind of quality chosen in the product standard. This study is performed by the company contracted for the work. The period of validity of the study is 5 years, if no significant changes in the composition.

The minimum level, level 1 (workability and water resistance), is mandatory for all the bituminous mixes. When traffic is important (heavy, channeled, ramps) generally is found to rutting resistance (level 2), especially on wearing course (sometimes on binder courses). Finally, when the owner road wants to control the mechanical properties, for example in the case of high modulus mixes (EME), this test must one part of Level 1, because it is necessary to prove the essential feature that distinguishes the classification of high modulus compare to a classical gravel treated with bitumen. In this case you can also check with the fatigue behavior (level 4) and take into account the values of these mechanical properties in the pavement calculation of the final structure of a variant, always respecting the rules of the guide of the variants [1].

The network of laboratories LPC has met the know-how and experience gained during 35 years of practice in a manual called French method of preparation of the mixtures, development of the formulation (a Spanish version of the guide is available in IFSTTAR "manual LPC de ayuda en la formulacion de mezclas bituminous en caliente" [2], also an electronic file available). The purpose of this manual is to guide the technician performing the formulation stages of commissioning, providing indications on the choice of the constituents in the interpretation of trial results in recommendations to adjust the composition of mixtures so as to comply with the specifications selected.

This procedure prior laboratory study of the development of bituminous mixtures has proved particularly useful and effective because it allows:

- Choose a solution that fits well to a technical-economic situation, for example in the case of a work of variant, it let free the process to rich the performance fixed,
- Optimize formulations based on the mechanical properties and resistance to rutting,
- Make test qualities in materials obtained by criteria chosen by the director of the play in a standard based on behavior,
- Modelize the structures with real characteristics, expected to achieve in work,
- Facilitate the controls of work, limited to examining whether the compositions and density are correct, as these features are related to the mechanical properties evaluated in the previous study of formulation.

The tests and, of course, the test equipment used in the mix design must respect the characteristics [3] and procedures fixed by the standard, so that the means of study are, therefore, common to all road community.
The tests are repeatable, relevant as they relate to actual behavior, and selective, to set realistic quality classes in relation to the specifications for classes contained in the bituminous mixtures product standards (for example NF EN 13-108.1 – bituminous mixes for sub-base, base course, wearing course, except porous N° 6 or very thin asphalt mixes N° 2).
The owner of road chooses the thresholds and the class of mix in the product standard, that best suits with the type of work. The company proposes the formulation of the mixture must comply with these performances for such qualities [4].

This mix design is particularly flexible and above all well adapted to technical developments and innovations needed in the road development context (variability of needs, increased stresses, works with guarantee results, ...).

2 - The French rational pavement design for roads and highways

For more than thirty years, the French road authorities have developed a rational approach to pavement design, in the interests of achieving a uniform national roads network. This approach is based on normative stages which focus on materials, their manufacturing processes, implementation and control. It is a rational method, based on mechanistic description of the road behaviour and the computation of the resilient stresses and strains generated by the traffic loads in pavement layers. It presupposes thorough knowledge of the mechanical characteristics of the materials employed, as well as control over their manufacture and implementation. It makes it possible to adjust the thickness of the structure to the local context of bearing capacity of the sub grade and of traffic, according to the materials used and the investment/maintenance policy adopted. Today most of the French road owners take advantage of this uniform approach and apply it to the needs of the traffic their own networks have to carry. The process of new pavement design is described in details in the technical guide Design Manual for Pavements Structures [5 and 9]. In this paper we shall first present the main entry parameters of the method, and then the method of calculation itself.

2 - 1 - Parameters of the French design method

The French design method [9] integrates three entry parameters: the sub grade bearing capacity, the pavement materials and the traffic.

<u>2 - 1 – 1 - The subgrade bearing capacity</u>

The standardization of studies of natural materials and methods of treatment and implementation undertaken since the sixties has made it possible to gain fairly precise knowledge of the long-term behaviour of pavement foundations. Classification of soils and natural materials and their use in pavement foundation, fill and capping layers are detailed in the technical guide entitled “Réalisation des remblais et des couches de forme” [6]. Thus, according to various criteria such as the nature of the soil, its short-and medium-term hydraulic characteristics, its possible treatment techniques, whether a capping layer is laid (with or without a cement binder) the method provides guidance:

- On the short-term bearing capacity during pavement construction;
- On the long-term sub grade behaviour, in the form of a pavement foundation class (PF1 to PF4). A computation module is attributed to each of these classes (table 1).

	PF1	PF2	PF3	PF4
Limits of the classes (MPa)	20	50	120	200
Module for the design (MPa)	20	50	120	200

Table 1 : Classes of sub grade bearing capacity

The pavement foundation class is attributed on the basis of measurements of bearing capacity and/or the deflection carried out in situ, using specific devices as the LPC-Dynaplaque (figure 2).

LPC Deflectometer LPC Dynaplaque

Figure 2: Bearing capacity measurement

<u>2 - 1 – 2 - Materials</u>

Initially, the directives, recommendations and other technical notes published by the Road administration strongly codify the manufacture of the road materials. This codification takes account of choice of constituents, mix design and implementation. It therefore became possible by following these texts, and on the basis of a minimum of preliminary studies, to obtain materials of controlled quality. Today, these texts have been replaced by standards. Concerning the mechanical performance necessary for roads design, materials to be treated with bituminous binders or hydraulic binders are characterized in the laboratory (figure 3). According to the materials considered, this characterization applies:

- In bituminous materials: to their compactibility and, where appropriate, their resistance to rutting, their resilient modulus and their resistance to fatigue.
- In cement treated materials: to their resilient modulus and their resistance to direct traction.

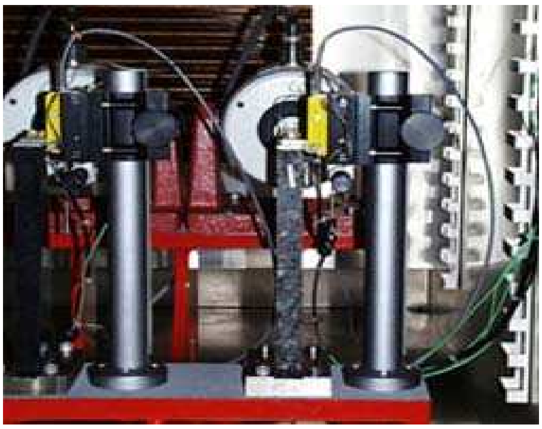


Figure 3: fatigue test on bituminous material (Trapezoidal 2 point beam flexion)

Fatigue curves are expressed in terms of strain for bituminous materials, and stress for concrete and materials treated with hydraulic binders. Untreated materials have mechanical characteristics which are a function of their mode of production and the characteristics of the aggregates. For the structural analysis, in the absence of any specific study on the material considered, standard values from the calculation module and standard fatigue characteristics for the class to which the material belongs are used (table 2).

Material	Young modulus (MPa)	Poisson coefficient	ε6 (µstrain)	-1/b	Kc coefficient
Bituminous materials (*) standard value at temperature 15°C, Frequency 10 Hz					
Asphalt concrete (BBSG)	5 400 (*)	0.35	100 (*)	5	1.1
Roadbase asphalt concrete (GB3)	9 300 (*)	0.35	90 (*)	5	1.3
High modulus asphalt concrete (EME2)	14 000 (*)	0.35	130 (*)	5	1
Materials treated with hydraulic binders					
Material	Young modulus (MPa)	Poisson coefficient	σ6 (MPa)	-1/b	Kc coefficient
Aggregates and cement mix (GC3)	23 000	0.25	0.75	15	1.4
Aggregates and cement mix (GC4)	25 000	0.25	1.20	15	1.4
Aggregates and granular slag (GLg)	15 000	0.25	0.60	12.5	1.5
Aggregates and pre-crushed-slag (GLp)	20 000	0.25	0.70	13.7	1.5
Roller-compacted concrete	28 000	0.25	1.85	15	1.50
Ciment Concrete					
Material	Young modulus (MPa)	Poisson coefficient	σ6 (Mpa)	-1/b	Kc coefficient
Cement concrete for slabs and CRCP (BC5)	35 000	0.25	2.15	16	1.5
Lean cement concrete (BC3)	24 000	0.25	1.63	15	1.5

Material	Young modulus (MPa)	Poisson coefficient	A (low traffic)	A (mean traffic)
Untreated granular materials (*) maximal value in base course				
UGM category 1	600	0.35	16 000	12 000
UGM category 1	400	0.35	16 000	/
UGM category 1	200	0.35	16 000	/

Table 2 : Typical value of materials characteristics for the design

2 - 1 – 3 - Traffic

In the French design method, the cumulative traffic over the service life of the pavement is converted into an equivalent number of passages of a reference axle, which cause the same structural damage to the roadway as the actual composite traffic. The French reference axle is a single axle with dual wheels of 130 kN (3.25 kN per wheel). Thus, the cumulated number of heavy lorries (NPL) intending to drive on the roadway is multiplied by a mean coefficient of traffic aggressiveness (CAM) to obtain an equivalent number of passages (NE) of the reference axle:

$$NE = NPL \times CAM$$

The main coefficients of aggressiveness result from statistical study taking into account traffic survey on road and highway networks (see the values from the 1998 French Catalogue for new structure in table 3). It depends on the mean daily traffic flow, wheel and axle lorry configurations and the nature and the thickness of the pavement material.

Structure:		VRS	VRNS
- bituminous and inverted		0.8	0.5
- Uga/Uga:		1.0	1.0
- composite:		1.2	0.8
- semi-rigid and rigid:		1.3	0.8
- Pavement foundation:	TC2	TC3	>TC3
	0.50	0.75	1.00

VRS : main national roads and highways
VRNS: other national roads

Table 3: Aggressiveness coefficients CAM on the French national network

2 □2 - Thickness design for new roadways

The design of a new pavement begins with a decision on the type of surfacing to be employed. The experience and the application of value analysis to pavement lead to design structures by drawing a distinction between the functions fulfilled by the surfacing and those fulfilled by the structural underlying layers. The choice of surfacing composition is carried out according to local experience and to the objectives pursued with respect to use characteristics of the intended roadway (for example, adherence, noise, comfort in rainy weather, smoothness of ride according to the service level of the road, etc.).

On the opposite, the choice of materials and thicknesses for the structural layers is carried out according to a mechanistic approach. First, the materials are selected and the thicknesses are computed with regard to their mechanical resistance beyond the expected traffic. Then it has to be checked that the structure will be able to withstand without damage to the frost period. The design in terms of mechanical resistance consists in verifying that the pavement structure is sufficient to respond to the constraints imposed on it by the traffic cumulated over the whole specified service life. This verification is carried out by comparing:

- the maximal stresses and/or strains created in the different pavement materials by the reference load, which are calculated using the multi-layer linear elastic model (Burmister's model) implemented in the Alizé-LCPC software,
- and the stresses and/or strains allowable for each material, which are determined from the fatigue characteristics resulting from laboratory tests (treated materials) or empirical failure relationships (untreated materials and soils).

The structure is appropriate if the first stress and/or strain values computed by the model are less than or equal to the second one depending of the fatigue or failure criteria of the considered material. Since the damage due to repeated loading is assumed to be caused by fatigue in the treated materials and permanent deformation in untreated layers and sub grade, the relevant failure criteria are:

- tensile strains due to bending deformation at the base of the bituminous layers,
- tensile stresses due to bending deformation at the base of materials treated with hydraulic binders and concrete,
- vertical compressive strains at the top of not treated materials and sub grade.

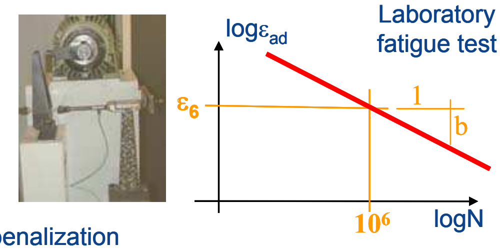
2 3 - Allowable stress and strain values

The allowable value towards the failure criteria suitable for a given material represents the maximum level of stress or strain, applied as many times as the number of traffic load passes, that the material is able to withstand before being subjected to a given level of damage. This level of admissible damage is specified by the road owner, according to the level of service expected for the pavement and is expressed as the risk of failure of the pavement over the whole service life. The effect of the risk parameter on the allowable value is based on a probabilistic approach, which is an original feature of the French design method. It takes into account the dispersed nature of the fatigue mechanism treated material observed both in laboratory and in situ, combined with the dispersion of the layer thicknesses in real pavement.

In the case of bituminous materials, materials treated with hydraulic binders and concrete, the allowable stress or strain value at the base of the layer is thus a function of (figure 4):

- the fatigue behaviour of the material expressed by parameters e6 (or s6) and b which are the characteristics of the fatigue curve obtained in the laboratory;
- the cumulated equivalent traffic NE over the service life of the pavement;
- the sub grade bearing capacity level soil, through a penalization of the allowable value for low bearing capacity: Ks = 1/1.2 for PF1 and 1/1.1 for PF2 sub grade, and Ks = 1 for PF3 and PF4;
- the risk of rupture, as explain above, which parameter specified by the road owner and reflects his road strategy;
- the effects of discontinuities encountered in rigid structures (slabs joints, edges, cracks in CRCP), combined with the curling thermal gradient. They are taken into account through the Kd coefficient (1/1.70 for undowelled slabs and 1/1.47 for dowelled slabs and CRCP), which results from three dimensional FEM computations performed on some French typical rigid and thermal conditions;
- the experimental adjustment of the design model (coefficient Kc) by means of feedback derived from the observation of real pavement behaviour and damage mechanism, and full scale tests performed with the LCPC Accelerated Pavement Testing facility [7].

In the case of the untreated materials and soils, the failure criteria represents the damage due to excessive permanent strains. It does not take into account any risk parameter and the criteria parameters do not depend on the mechanical performance level or the bearing capacity of the considered material.



Bituminous material

$$\varepsilon_{t\text{-allowable}} = \boxed{\varepsilon_6 \left(\frac{CAM \times N}{10^6}\right)^b} \times K_\theta\, K_r\, K_s\, K_c$$

temperature

low bearing capacity penalization

risk

global adjustment between model and observed in situ behaviour K_c=1.30 (1.0 for HMAC)

CAM : Traffic aggressiveness coefficient (equivalence between real traffic loads and the standard dual-wheel 65 kN)

Materials treated with hydraulic binder and concrete

$$\sigma_{t\text{-allowable}} = \boxed{\sigma_6 \left(\frac{CAM \times N}{10^6}\right)^b} \times K_r\, K_s\, K_c\, K_d$$

low bearing capacity penalization

discontinuity and temperature

risk

global adjustment between model and observed in situ behaviour. K_c=1.40 to 1.50

K_d discontinuity effects (edges, joints) and thermal effects. It results from 3D FEM computation and feedback from in service structures

Unbounded granular materials and soils

$$\varepsilon_z = A\ N^{-0.222}$$

Figure 4: General expression of the allowable strain and strain values

3 Adaptation of pavement design to local applications in South America

Concerning researches carried out on asphalt pavement structures design using French methodology for South America climate conditions, BARRA (2009) have developed complex modulus and fatigue studies executing two point bending tests without rest periods, by using trapezoidal specimens [11].

In this context, the complex modulus and fatigue tests were performed on specimens in 3 different states: dry, continuously immersed in water, and continuously immersed in water after a preconditioning process. These are referred to as states 1, 2 and 3, respectively, hereinafter. The preconditioning of the specimens tested in state 3 consisted of submitting them to a specific environmental conditioning cycle: 5 days immersed in water at 60 ºC and 3 additional days without water in an oven also at 60 ºC. Prior to starting the tests, all specimens tested in state 3 were submitted to a series of 3 repetitions of the mentioned preconditioning process, which means that each specimen spent 15 days (360 h) immersed in water and 9 days (216 h) in the oven in total, before being tested.
Furthermore, in the case of states 2 and 3, the specimens were submitted to a saturation process in water using a vacuum pressure of 350.0 mm/Hg ± 5.0% immediately before the

beginning of the tests, in order to achieve a saturation degree of 60% related to the air void content of each specimen.

Also, determining the action of water in terms of the mechanical behavior of the asphalt mixes is very pertinent, given that heavy rainfall characterizes the climate of many countries and regions worldwide, mainly in places defined as tropical or equatorial, i.e., the South America, reaching amounts as high as around 2500–3000 mm/year (INPE, 2012), besides high temperature gradients and moisture levels, being environmental conditions that increase the climate severity. The parameters obtained from the tests applied in pavement design simulations are shown in Table 4.

Asphalt Mix	Complex Modulus (MPa)			Fatigue		
	IE*I (10ºC, 10Hz)	IE*I (15ºC, 10Hz)	IE*I (10ºC, 25Hz)	ε_6 (x 10^{-6})	Residual Standard-Deviaton (SN)	Slope of the Fatigue Equation (b)
CTB_{DRY}	9030	8227	9854	141,46	0,44	-0,13
$CTBPC_{DRY}$	9750	8490	10782	155,09	0,37	-0,15
$CTB_{PRECONDIONED}$	10358	9220	11008	105,59	0,52	-0,13
$CTBPC_{PRECONDITIONED}$	10155	8843	10808	118,38	0,35	-0,20

Table 4 - Parameters determined for the asphalt mixes (BARRA, 2009).

Note: the asphalt mix named CTB is entirely formulated with granitic particles, while the asphalt mix CTBPC contains limestone powder as filler fractions.
Considering the parameters presented in Table 4, they were calculated the admissible strains for the asphalt mixes (εt) (Equation 1), considering 106 cycles of loading (ε6), in accordance to French pavement design methodology (GUIDE TECHNIQUE, 1997).

$$\varepsilon t\text{-allowable}(NE, \theta_{eq}, f) = \varepsilon_6(10°C, 25Hz).[E(10°C)/E(\theta_{eq})]^{0,5}.(NE/10^6)^b$$

(1)

where:

$\varepsilon_{t\text{-}allowable}(NE, \theta eq, f)$ = admissible strain considering the number of equivalent loading axles (NE), equivalent temperature (θeq) and frequency of loading application (considered as 8.2 kN in this research; officially adopted in Brazil);
ε6(10ºC, 25Hz) = strain for 106 cycles, based on the fatigue results of the material;
E(10ºC) = complex modulus measured at 10ºC and 10Hz;
E(θeq) = complex modulus measured under the equivalent temperature (considered as 15ºC and 10Hz);
NE = number of equivalent loading axles (assumed as 1,95 x 106);
b = slope of the fatigue curve.

Hence, using the computerized tool Alizé developed by IFSTTAR (ex-LCPC), the following initial pavement structure was considered for simulating numerical analyses on the pavement performance: 5.0 cm (dense graded asphalt mix; BBSG), 25.0 cm (unbound granular layer; GNT) and 30.0 cm (fine cohesive soil). The main objective of these simulations was to determine which thick of asphalt mix would be suitable to the pavement

structures, in order support the traffic loading along 10 years of serviceability, comprising as dry (1) as environmental-conditioning (3) states.
After series of simulation comparing the results obtained by using the computerized tool (ε6) to those calculated by Equation 1 (εt), the results are presented in Table 5.

Asphalt Mix	Layer Thickness (cm)	Strain after Computerized Simulation ε_t (x 10^{-6})	Calculated Strain $\varepsilon(NE, \theta_{eq}, f)$ (x 10^{-6})	Conclusion
CTB_{SECA}	**5.0**	180.42	150.0	Refused
	9.0	149.55		Aproved
$CTBPC_{SECA}$	**5.0**	177.14	165.0	Refused
	8.0	156.70		Aproved
$CTB_{CICLADA}$	**5.0**	176.35	113.0	Refused
	12.0	112.68		Aproved
$CTBPC_{CICLADA}$	**5.0**	177.05	122.0	Refused
	11.0	121.34		Aproved

Table 5 - Results obtained after comparing ε6 to εt (BARRA, 2009).

According to BARRA (2009), after have analyzed and observed the mechanical behavior of the asphalt mixes during the tests and the results provided by computerized simulations, it is possible to infer the following conclusions [12 and 13]:

- The environmental-conditioning process applied to the asphalt mixes by alternating immersion in water and heating into an oven, both at 60 ºC, despite generate an increase of the complex modulus stiffness IE*I, provoke significant decreases of the (ε6), being a decisive factor for harming the mechanical behavior of them;

- Hence, the increasing of the complex modulus stiffness IE*I does not occur by improvements of the physical characteristics regarding the asphalt mixes, but due to the aging process of the material, which despite contribute to the hardening of the samples, become them more fragile. Thus, they get more susceptible to the traffic loading applications;

- For all test states proceeded, in can be inferred that the asphalt mix CTBPC presented a better fatigue resistance in comparison to CTB. This trend can be attributed to the fillers comprising minerals with electropositive characteristics (e.g., the calcite) adsorbing (by chemisorptions) the molecules of the asphalt binder. During this process the filler particles start to react chemically with the naphthenic acids of the asphalt binders, forming the compound calcium nafphthenate, which is insoluble in water (SANTANA, 1992) and protects the asphalt binder film that covers the aggregate particles.

- The action of the water is very harmful on the mechanical behavior of the asphalt mixes and have a direct influence on the pavement design, in which the environmental-conditioning process led to obtain approved asphalt layers more than 20% thick than those evaluated in dry state, as presented in Table 2.

Conclusion

As the man walks on two feet, in France, the principle of pavement construction rests on two pillars:

-the bituminous hot mix design, in the laboratory, to control all the production parameters, consistent with the terms of realization of the site, and have the real mechanical performances of mixes,

-the rational pavement design, taking into account these characteristics and their variability by dispersion of the test results, the probability attached to the risk of degradation, the aggressiveness of the traffic and its evolution, and the quality of the support platform.

Learning from experience and therefore the effects of mechanical and climatic solicitations on the field conditions are well taken into account by the determination of the global adjustment coefficient, in the equations of equilibrium of the available constraints and deformations by the mixes.

These simplified methods to the complexity of the field reality required many researches and developments, in the 1970s to 1980. They have demonstrated their effectiveness, by the establishment of “standard” pavement catalogue for national roads and highways, covering 90% of the needs, by the development of standards on bituminous materials and on the pavement design [10], and especially by the good behavior of the road network for more than 35 years of use.
They allow developing innovation, in relying on goals of performance, while leaving free ways to achieve these goals. Development of high mechanical performance mixes (EME : high modulus asphalt mix for sub base and base courses (in 1985), BBME: high modulus asphalt concrete for wearing courses (in 1990) layer), with the thickness reduction of the layer (near 15 to 35% less) is an example of the use of these principles.

It is essential to respect the terms of mix design, including the fatigue test in the method chosen, and to adapt the pavement design to the climatic conditions suffered by the pavement, as the reference temperature for bituminous materials and the effects of heavy rainfall over the durability of materials and layer interfaces. It will be necessary to continue the research to optimize the use of the French mix and pavement design for better durability, quality and sustainability of road works in the South American context.

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