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# Comparative Study of French and Chinese Asphalt Pavement Design Methods

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ABSTRACT

This study deals with the comparison of French and Chinese approaches for the design of flexible pavement. The Finite Element Analysis (FEA using ANSYS) was used to compute and compare the mechanical responses in four typical pavement structures used in France and China, for respective axle type and loads. The study concluded that the maximum deflection in typical structure of stabilized asphalt pavement in China is greater than that obtained in the typical treated bases asphalt pavement in France. Therefore, the high modulus materials used in the French method allows the structure to have a high rutting resistance compared to Chinese pavement structures whose the values of the elastic modulus of materials are relatively lower. The results also shown that, the Chinese methodology is advantageous for the design of semi-rigid asphalt pavement, in terms of the mechanical response at the bottom of treated base layer. There are considerable differences between the equivalent axle load conversion methods and the reference axles loads used in France and in China and both methodologies pavement design indexes are established on the criterion of fatigue at the bottom of asphaltic concrete layer for acceptable pavement performance at the end of the design period (i.e., acceptable levels of rutting, fatigue cracking and thermal cracking).

**Key words:** Asphalt pavement, evaluation analysis, structural design, fatigue criteria

## INTRODUCTION

The pavement design systems used in both France and China consist in verifying that a calculated flexible pavement structure can provide, over a particular subgrade, a good mechanical response in specific loading conditions, i.e., a given level of traffic accumulated over a specified lifetime (20 years in France and 15 years in China). Although linear elastic models have been extensively used in flexible pavement design and performance evaluation in the recent years (Huang, 2003), the design methodologies still differ from one country to another and hence the design parameters. The structural deterioration of flexible pavement being associated with cracking in HMA and development of ruts in wheel path (Von Quintus, 2001), the design indexes adopted in each methods must anticipate and prevent optimally the various failure modes (fatigue cracking, rutting) the structure will experience during its service life. Charkroborty and Das (2003) indeed reported that the elastic modulus is an important parameter for pavement structure analysis and design. Analyses were carried out for the surface deflection and the tensile stress at the bottom of base layer. Knowledge that in practice, the stress and deflection distributions in asphalt concrete and portland concrete pavements depend on the relative stiffness of these layers with respect to those of underlying granular layers (Papagiannakis and Massad, 2008).

This study is aimed at, on one hand comparing the specifics of each design method of the asphalt pavement system used in China and that implemented in France and on the other hand to see the influence of said methodologies, in terms of design indexes and materials modulus, on pavement mechanical response.

## MATERIALS AND METHODS

**French asphalt pavement design approach:** The practice of new pavement structure design in France (specification NF P98-086) is based on a rational method which integrates the subgrade bearing capacity, pavement materials and the traffic as main input parameters. Laterally, this method also rests on catalogs of typical structures which have been developed to enable to easily choose the practical structural design for a road. The traffic analysis includes a probabilistic approach, consisting of anticipating the possibility of structural degradation on the pavement surface, by taking into account a risk value related to the life-span of the structure. The mechanical design of the structure is based on the calculation of the stresses induced in the structure by the reference load using Burmister's model. This reference load of a dual wheel axle of 65 KN (32.5 KN per wheel) is defined by a pressure wheels 0.662 MPa unit and distance between axes d = 3R, where R = 125 mm represents the radius of a wheel. In the French design methodology, The conversion in equivalent axles load (Eq. 1) is established on the product of total number of heavy vehicle NPL (Eq. 2) by a coefficient of equivalence called, traffic average aggressiveness coefficient (CAM), the value of which depends on the nature of the pavement structure and classes of heavy vehicles. Traffic due to light vehicles is assumed to have a negligible impact. These equations are:

$$NE = N_{PL} \times CAM \tag{1}$$

With:

$$N_{PL} = 365 \times TMJA \times \frac{(1-\tau)\,d-1}{\tau} \tag{2}$$

Where:

NE = Number of reference equivalent axles
CAM = Average coefficient of aggressiveness of heavy vehicles, as indicated in the Table 1
NPL = Calculated number of heavy vehicles for the design period
d = Design period
τ = Annual geometric growth rate of traffic
TMJA = Annual average daily traffic (times/day)

The design method distinguishes three damage mechanisms which are associated with three expressions of admissible stress: (1) Fatigue damage of bituminous materials taken into account through the horizontal strain due to bending deformation at the bottom of bituminous layers $\varepsilon_t$, (2) Fatigue damage of hydraulically bound materials and concrete cement taken into account through the horizontal tensile stress $\sigma_t$ and (3) Damage by accumulated permanent deformations in the untreated materials considered through the vertical compressive stress at the top of the subgrade $\varepsilon_z$. The calculated values from the multi-layer model Burmister, must be less than the allowable values, defined by Eq. 3, 6, 7 and 8, respectively. Equation 3 shows the allowable strain for bituminous materials:

$$\varepsilon_{t\text{-allowable}} = \varepsilon(NE, \theta)\, K_r\, K_s\, K_c \tag{3}$$

With:

$$\varepsilon(NE, \theta) = \varepsilon_6(10°C,\ 25\ HZ) \left(\frac{E(10°C)}{E(\theta)}\right)^{0.5} \left(\frac{N_E}{10^6}\right)^{b} \tag{4}$$

Table 1: Aggressiveness coefficients CAM in France

| Structure's materials | Main national roads and highways (VRS) | Others national roads (VRNS) |
|---|---|---|
| Bituminous materials | 0.8 | 0.5 |
| Soil/untreated materials | 1.0 | 1.0 |
| Bound materials and concrete | 1.3 | 0.8 |

Table 2: Class of subgrade bearing capacity

| Bearing capacity class | Modulus (MPa) |
|---|---|
| PF1 | 20 |
| PF2 | 50 |
| PF3 | 120 |
| PF4 | 200 |

The variable $\varepsilon_6$ represents the tensile strain, at which fatigue failure of a sample of asphalt mix occurs upon $10^6$ loading cycles under particular conditions. From that equation, it was observed that, for a defined load, temperature and material, the number of axle load depends only on the strain value at the base of the bituminous layer (Eq. 5) which is a function of the thickness of the layers:

$$NE = \left[\frac{\varepsilon_6(10°C,\ 25\ Hz)\, K_r \cdot K_c \cdot K_s}{\varepsilon_{t,adm}} \left(\frac{E(10°C)}{E(\theta)}\right)^{0.5}\right]^{-\frac{1}{b}} \tag{5}$$

Equation 6 points out the allowable stress for the materials treated with hydraulic binders:

$$\sigma_{t\text{-allowable}} = \sigma_6 K_d K_r K_s K_c \left(\frac{N_E}{10^6}\right)^{b} \tag{6}$$

Equation 7 and 8 shows the allowable deformation for the untreated material and subgrade, for $N_E$ higher than 250,000 and $N_E$ less than or equal to 250,000, respectively:

$$\varepsilon_{z,adm} = 0.012\ (NE)^{-0.222} \tag{7}$$

$$\varepsilon_{z\text{-}adm} = 0.016\ (NE)^{-0.222} \tag{8}$$

Where:

$K_r$ = Risk coefficient that adjusts the strain value and is calculated according to the slope and the standard deviation of the results from the fatigue test at failure
$K_s$ = Coefficient that takes into account the low bearing capacity of subgrade
$K_c$ = Coefficient of global adjustment between model and observed *in situ* behavior. $K_c$ = 1.30 (1.0 for HMAC)
$N_E$ = No. of standard axle load
$K_d$ = Coefficient of discontinuity and thermal effects
b = -0.2 for all asphalt mixes

The structural characters of the pavement layers depends on thickness and material quality. The design focuses on the thicknesses of base and sub-base which is related to the subgrade bearing capacity (Table 2). Further, the thickness of each layer of material is based on the verification of non-failure criterion of the material involved during the life-span of the pavement. The stiffness moduli of materials

Table 3: Untreated (base and sub-base) pavement structure used in France for traffic class $TC5_{30}$ ($7.3\times10^6 \leq NE < 18.4\times10^6$)

| | Modulus at 15°C, 10 Hz and fatigue at 10°C, 25 Hz | | |
|---|---|---|---|
| Layers | Resilient modulus E (MPa) | Poisson's ratio (μ) | Thickness (cm) |
| Asphalt concrete (BBTM) | 5400 | 0.35 | 2 |
| Asphalt concrete (BBSG) | 5400 | 0.35 | 6 |
| Granular base (GB) | 9300 | 0.35 | 13 |
| Granular sub-base (GB) | 9300 | 0.35 | 13 |
| Subgrade class: PF2 | | | |

Table 4: Treated (base and sub-base) pavement structure used in France for traffic class $TC5_{30}$ ($4.5\times10^6 \leq NE < 11.3\times10^6$)

| | Modulus at 15°C, 10 Hz and fatigue at 10°C, 25 Hz | | |
|---|---|---|---|
| Layers | Resilient modulus E (MPa) | Poisson's ratio (μ) | Thickness (cm) |
| Asphalt concrete (BBTM) | 5400 | 0.35 | 2 |
| Asphalt concrete (BBSG) | 5400 | 0.35 | 6 |
| Granular base (GB) | 23000 | 0.25 | 22 |
| Granular sub-base (GB) | 23000 | 0.25 | 20 |
| Subgrade class: PF2 | | | |

and Poisson's ratios for two models of typical asphalt pavement system for a given traffic in France, are provided in the Table 3 and 4. In the untreated bases pavement (Table 3), the minimum foundation layer thicknesses for base course and sub-base are 0.15 m on PF3, 0.25 m on PF2 and 0.45 m on PF1. For the second model, with base and sub-base treated with hydraulic binder, these thicknesses are: 0.20 m on PF2, 0.18 m on PF3 and 0.15 m on PF4.

**Chinese asphalt pavement design method:** Chinese current asphalt pavement design method is based on "Asphalt pavement design specifications" (JTJ D50, 2006), using multi-layered elastic continuous system theory. The design is established on the principle of limiting stresses to minimize fatigue damages. According to this specification, the traffic characteristics are determined in terms of the number of repetitions of a single-axle load applied to the pavement on two sets of dual tires. The standard vehicle axle load, is taken as 100 KN known as BZZ-100 axles. The others standard axle calculation parameters are: The tire pressure (P) of 0.7 MPa; the equivalent diameter (d) of 213 mm and the distance between centers of two wheels of 1.5 d. In this method all axle loads bigger than 25 KN must be converted to equivalent single axle loads of 100 KN, following the two main principles of equivalent axial load: The principle of equal thickness and the principle of equally undermine. That conversion process is provided according to the following situations: (1) When the design deflection value of road surface or the flexural-tensile stress at the bottom of the asphalt surface layer is taken as index, the axle load is calculated in accordance with the Eq. 9:

$$N = \sum_{i=1}^{K} C_1 \cdot C_2 \cdot n_1 \cdot \left(\frac{P_1}{P}\right)^{4.35} \tag{9}$$

Where:

- $N$ = Equivalent standard axle frequency (times/day)
- $n_1$ = Vehicles effect frequency (times/day)
- $P$ = Standard axle load (KN)
- $Pi$ = Converted load of each type of vehicle (KN)
- $C_1$ = Wheel set coefficient, for one-wheeled set, $C_1 = 6.4$; for two-wheeled set, $C_1 = 1$; for four-wheeled set, $C_1 = 0.38$
- $C_2$ = Axle number coefficient

If the distance between the axles is greater than 3 m, the axles are calculated as separate axle loads and the coefficient of the number of axles is equal to the number of axles. If the distance between axles is less than 3 m, the axles are calculated as double axles or multi-axles and the coefficient of the number of axles is calculated in accordance with the following Eq. 10:

$$C_2 = 1+1.2(m-1) \tag{10}$$

When the flexural-tensile stress at the bottom of a Semi-rigid base is taken as design index, the axle load is calculated from Eq. 11:

$$N = \sum_{i=1}^{K} C'_1 \cdot C'_2 \cdot n_1 \cdot \left(\frac{P_1}{P}\right)^{8} \tag{11}$$

Where:

- $C'_1$ = Wheel set factor, for one-wheeled set, $C'_1 = 18.5$, $C'_1 = 1$; for two-wheeled set; for four-wheeled set, $C'_1 = 0.09$
- $C'_2$ = Axle number coefficient

If the distance between the axles is less than 3 m, the coefficient of double axles or multi-axles is calculated following the Eq. 12:

$$C'_2 = 1+2\,(m-1) \tag{12}$$

where, m is the number of axles.

Fatigue, rutting and cracking represent the usual pavement damages taken into consideration during pavement design. Those parameters are equally important than the design indexes. In the asphalt pavement design methodology used in China for many years, the surface deflection has been used as design index and the flexural stress at the bottom of the base layers as principal parameter (Zhang, 2009). The first, related to the accumulative equivalent axles, road grade and the surface layer, represents the stiffness of the entire road surface or a distortion caused by the vertical load on the road surface. The calculated road surface deflection value should be less than or equal to the design deflection value (Eq. 13). The calculation of the maximum deflection value is given by Eq. 14:

$$l_S \le l_d \tag{13}$$

With:

$$l_d = 600 N_e^{-0.2} A_c A_s A_b \tag{14}$$

Where:

- $l_d$ = Design deflection (mm)
- $N_e$ = Design equivalent axle load (times)
- $A_c$ = Road grade coefficient, Highway: class I 1.0, class II 1.1, class III 1.2
- $A_s$ = Pavement layer type coefficient, Asphalt concrete course 1.0; hot-mix and cold mix asphalt macadam, injection treatment macadam, Asphalt surface treatment 1.1, in lower surface 1.2
- $A_b$ = Base course type coefficient, semi-rigid base $A_b$ = 1.0; flexible base $A_b$ = 1.6

Secondly, the tensile stress parameter, is associated to the thickness of the pavement in such a way that the stress developed within the structure is less than the allowable values obtained from Eq. 15:

$$\sigma_m \le \sigma_R \tag{15}$$

With:

$$\sigma_R = \frac{\sigma_{SP}}{K_S} \tag{16}$$

- $\sigma_R$ = Pavement layer material allowable tensile stress (MPa)
- $\sigma_{SP}$ = Ultimate splitting strength of concrete (MPa)
- $K_s$ = Tensile structure coefficient ($K_S = 0.09 N_e^{0.2}/A_c$)

The Chinese design approach gives a relatively thick asphalt concrete surfacing (single, double or triple asphalt layers) according to the road traffic (traffic class considered) and provide a good all-weather surfacing for flexible pavements with granular or cemented base. In the typical pavement structure models, the structure is assumed linear elastic and multilayer system under a dual circular loaded area. The stiffness of the subgrade depends on the CBR of soils and the road class. In such a way that, for CBR (%) of 8, the thickness of the subgrade vary from 0-30 mm. And from 30-80 mm when the CBR (%) is 5. The typical pavement layer systems used in China is presented in Table 5.

Table 5: Stabilized and unstabilized pavements used in China

| | Modulus at 15°C, 10 Hz | | |
|---|---|---|---|
| Layers | Resilient modulus E (MPa) | Poisson's ratio (μ) | Thickness (cm) |
| **Stabilized** | | | |
| Asphalt concrete | 1400 | 0.25 | 4 |
| Asphalt concrete base | 1200 | 0.20 | 6 |
| Cement stabilized base | 1300 | 0.20 | 20 |
| Cement stabilized sub-base | 900 | 0.25 | 30 |
| Subgrade | 50 | 0.40 | - |
| **Unstabilized** | | | |
| Asphalt concrete | 1400 | 0.25 | 4 |
| Asphalt concrete base | 1200 | 0.25 | 6 |
| Cement stabilized base | 600 | 0.30 | 20 |
| Cement stabilized sub-base | 280 | 0.35 | 30 |
| Subgrade | 50 | 0.40 | - |

**Comparison of design methodologies:** The main purpose was to evaluate the pavement responses in French and Chinese pavements over a definite loads using different typical pavement structure models. The four models are studied under normal static loading conditions. Two of them represent two typical pavement system used in China for a class1 highway while the two others refer to those implemented in France for an equivalent traffic conditions. The numerical analysis of the pavement layer is based on the finite element method. ANSYS software package has been used to perform the pavement structure analysis. Table 3-5 shows the material properties of the layers that have been adopted in this case study. So, to calculate the responses at the top of the bituminous layer and responses at the bottom of the base layer, the pavement has been modeled as a multilayer layers system, according to the design approach and consisting of surface layer, base layer, sub-base and subgrade. The pavement structure was carved out using 8-noded solid elements (SOLID 45). The size of the pavement considered is 3000×3000 mm and the depth of subgrade layer has been taken as 10000 mm, considering that the circular or square load surfaces have no influence on the responses if the same contact pressure is applied (Perret, 2002), Finite Element Analysis (FEA) was performed for rectangular dual wheel models defined from the Chinese and French standard axle loads. Figure 1 shows the configuration of the reference axle load considered for calculations in French and Chinese structure models.

- Typical pavement layers used in France for Highway class TC530 on subgrade class PF2 (LCPC and SETRA., 1998)
- Typical pavement layers used in China for Class 1 Highway (NE>4.106)

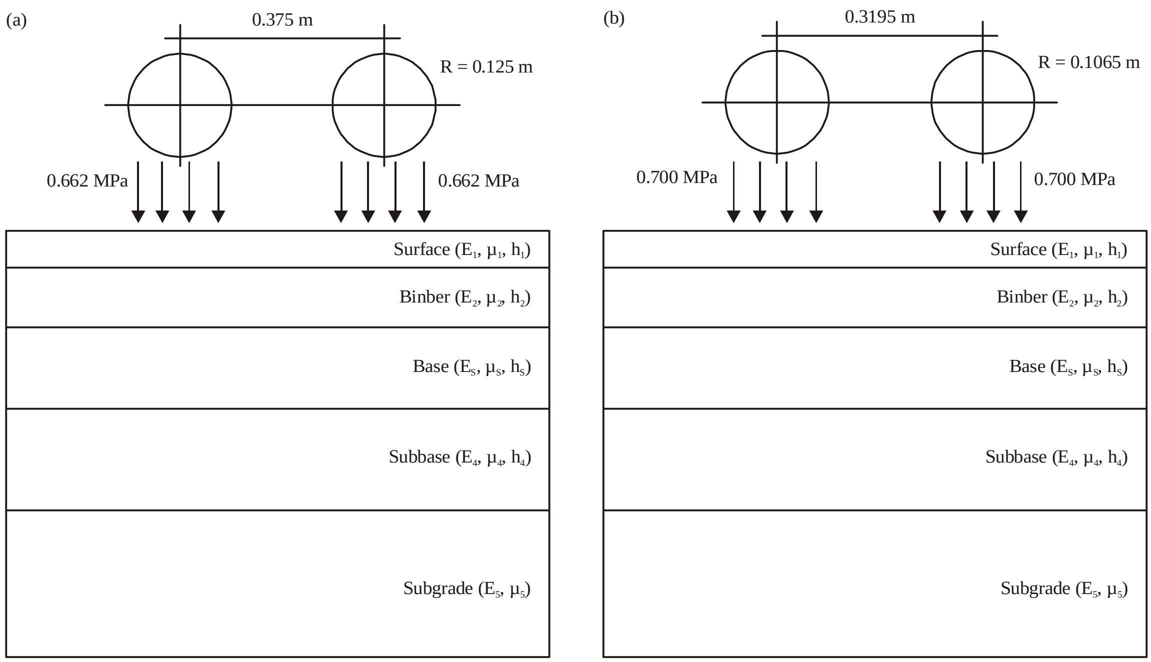


Fig. 1(a-b): Loading configuration used for (a) French and (b) Chines typical pavement structures

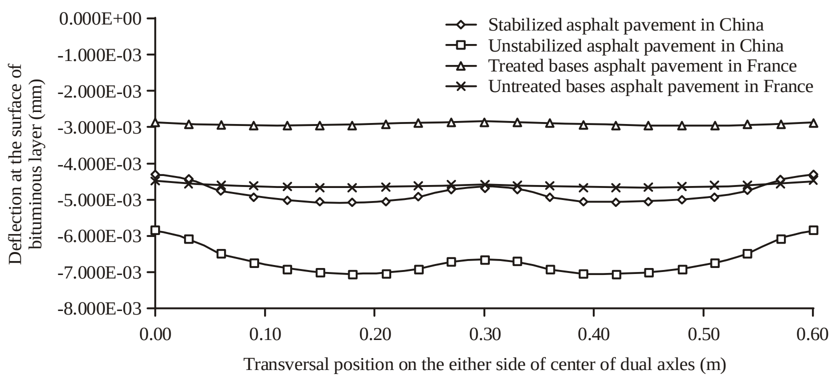


Fig. 2: Deflection at the surface of bituminous layer for Chinese and French typical structures

## RESULTS

The results were analyzed on either side of the center of dual wheel (near the load) and in the bituminous layers. The results were compared, one component after the other, for the deflection and tensile stress respectively using a Cartesian plane and at two different depths: (1) At the top of surface layer (Fig. 2) and (2) At the bottom of base layer (Fig. 3) which correspond to the traditional position for the evaluation of fatigue resistance.

## DISCUSSION

Perret (2002), observed that the maximum amplitudes for the deflection at the top of surface layer in considered structures were always obtained under the wheels path. Moreover, the maximum deflection in typical structure of stabilized asphalt pavement in China (5.076 mm) is greater than that obtained in the typical treated bases asphalt pavement in France (2.956 mm). Likewise, the maximum deflection in the Chinese unstabilized asphalt pavement (7.048 mm) is bigger than that obtained for the conventional untreated bases asphalt pavement in France (4.674 mm). This result demonstrates particularly that the properties of materials used in the different structures, singularly the elasticity modulus, significantly affect the degree of deflection of the structure and hence its susceptibility to rutting. Indeed, the Poisson's ratio and the Young's modulus were identified as the materials properties that control their behavior, added to the fact that the elasticity modulus of particular importance, may positively contribute to the good performance of the pavement (Charkroborty and Das, 2003; Austroads, 2010; Diogo *et al*., 2007). The results also shown that the tensile stress at the bottom of base layer is maximum under the wheel paths for

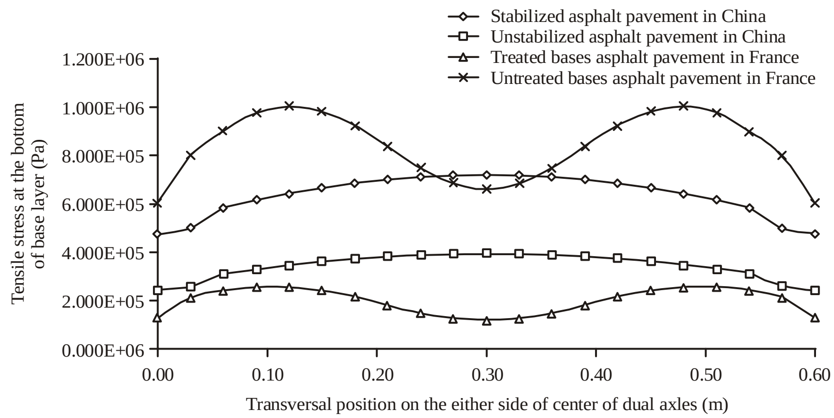


Fig. 3: Tensile stress at the bottom of the base layer for Chinese and French typical structures

French typical pavement and contrarily, this stress is maximum between the two axles in Chinese typical structure of asphalt pavement. The tensile stress in stabilized asphalt pavement in China is $7.238\times10^5$ Pa while that in typical structure of treated base asphalt pavement in France is $2.593\times10^5$ Pa. Given that the two criteria which have been established to prevent fatigue failure of cement-treated materials are maximum tensile strain and maximum tensile stress (Hernando and del Val, 2013), these values are important to the extent that the Chinese method indeed enables to anticipate the effect of fatigue cracking by taking into account, from the basis of calculations (conversion in equivalent axles), the impact of the vehicle loads on the value of tensile stress at the base of the treated layer. This allows us to state with Diogo *et al*. (2007) that the strong point in Chinese method is centered in verifying the tensile stress and allowable displacement on the pavement.

## CONCLUSION

This study first established that there are considerable differences between the equivalent axle load conversion in French and Chinese methods. Then, the materials used in French pavement structures are high modulus materials which allows these structures to be less susceptible to rutting compared with Chinese typical structures whose values of the elastic modulus of materials are relatively lower. And also, the Chinese methodology is more advantageous for the design of semi-rigid asphalt pavement.


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