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Design Methodologies of Asphalt Pavement Used in China and Mozambique

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Abstract: This study discusses and compares Asphalt Concrete (AC) pavement design methodologies used in China and Mozambique (based on South African Transportation and Communication Commission (SATCC) methodologies). The SATCC design methodologies use California Bearing Ratio (CBR) and catalogues methods. The South African catalogues are basically used for roads with traffic less than 30 million ESAs. The design catalogues method give small thickness than CBR and Chinese methods. The Chinese and the South African design methods give nearly the same thickness; this study concludes that these methods can be used in both countries; China and Mozambique. The results also show that the strong point of Chinese method is verifying the tensile stress and allowable displacement on the pavement calculated from computer program APDS.

Key words: Road construction, pavement design, structural design, evaluation analysis

INTRODUCTION

This study presents asphalt pavement design methodologies used in Mozambique and China. First reason was to study the influence of the two methods in thickness design of roads built of AC largely used in road construction in Mozambique and China due to the following advantages: 1) initial lower cost and 2) easier to repair or to recycle. Second, was to compare the difference between the two design methods of AC. The disadvantage of AC pavement is that it has a shorter service life than Portland Cement Concrete (PCC) pavement and frequently requires significant rehabilitation measures (overlay or surface treatment) due to age hardening and loss of fatigue resistance (CDT, 2004). Generally, AC is built of an asphalt layer that is placed over a treated or untreated base layer and over an untreated subbase layer. The function of the pavement structure is to support load imposed by vehicles and distribute it over a large area of the natural soil (Huang, 2004; Caputo, 1985; Croney and Croney, 1997).

PAVEMENT DESIGN METHODS USED IN MOZAMBIQUE AND CHINA

Pavement design methods used in Mozambique: Until 2000, Mozambique used Portuguese standards to design highway pavements. In 1999, many countries located in Southern Africa Region agreed to incorporate into the SADC (Southern African Development Community) Protocol that the regional road network should be designed to accommodate the same upper limits of axle-load and Gross Vehicle Weight (GVW) throughout the region (David, 2002). Since this period, in Mozambique, a designer may use a number of existing design methods (e.g., Portuguese standards, US standards and those based on SATCC, etc.), such as: a) The South African Mechanistic Design Method (SAMDM); b) The Dynamic Cone Penetrometer (DCP) method; c) The Elasto-Plastic Design Method (S-N method); d) CBR design methods; e) AASHTO Guide for Design of Pavement Structures; f) Design catalogues indicated in SATCC (1998 and 2001) design methodologies and standards (and g) Other design methods indicated in TRL (2004a and 2004b). This study discusses the SATCC design methodologies and standards (origin from South Africa (SA)) grouped in two codes; code for structural design of new asphalt pavements and code for the pavement rehabilitation (overlay).

Code for structural design of new asphalt pavements: The current code for designing new roads is based on the use of design catalogues which enable the designer to rapidly select possible pavement structure that should meet the design criteria. The criterion is based on matching the factors: a) the traffic class in terms of expected future traffic and b) subgrade class in terms of CBR of foundation and climatic region (CSRA, 1996). The SATCC (1998 and 2001) design methodologies and standards take into consideration the traffic loading as the one very important factor in the pavement design. The total ESAs

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(Equivalent Standard Axle of 80 kN) for one direction is computed by Eq. 1 from an estimate average annual daily number (T) of ESAs on one lane at the opening of the new road to traffic, projected at a selected growth rate (I) and cumulated to the total traffic over the design period.

$$T_y = T * 365 * G_f * EF \qquad (1)$$

where, G_f is a growth factor computed by Eq. 2. G_f rates normally ranges between 2 to 15% per annum.

$$G_f = \frac{[1 + 0.01 * i]^y - 1}{0.01 * i} \qquad (2)$$

where, F is a conversion factor to standards axles in ESAs per vehicle in each direction for each vehicle class, calculated from axle load survey by Eq. 3.

$$EF = \left(\frac{P}{80}\right)^n \text{ (for loads P, in kN)} \qquad (3)$$

where:
P = vehicle axle load;
y = design period (10-20 years);
n = damage factor.

The road categories and traffic used for pavement design in Mozambique are from the SATCC (2001) design methodologies and standards and are classified as A, B, C and D, which correspond to a total equivalent traffic loading per lane (E80/lane) over design period (in million), 3-100, 0.3-10, <3 and <1, respectively.

The equivalency road categories between SATCC design methodologies and standards (2001) and Chinese standards (JTJ014-97 and Xiaoming, 2001) are: a) A corresponds to Expressway and highway class I; b) B corresponds to highway class II and III; c) C corresponds to highway class III; and d) D corresponds to highway class IV.

Code for the pavement rehabilitation (overlay): In SATCC standards the main pavement rehabilitation are: a) complete pavement reconstruction; b) partial reconstruction; c) asphalt or granular overlay; d) surfacing rehabilitation and; e) provision of drainage or/improvement of the existing facilities (SATCC, 2001).

In this research, the two simplest design methods (Catalogue and CBR), which do not require previous expensive pavement testing will be presented.

Design catalogues: The design catalogues indicated in SATCC (1998 and 2001) design methodologies and standards, include specific pavement structures for either nominally wet or nominal dry regions. To determine the appropriate structures, the following parameters are entered in the design catalogues: a) traffic class; b) subgrade support classification and c) nominal conditions. The SATCC design catalogues are basically used for roads with traffic less than 30 million ESAs. For roads with traffic greater than 30 million ESAs, other design methods must be used, such as UK, US methods and Australian practices (CSRA, 1996). The SATCC design catalogues give relatively thin (< 50 mm) asphalt concrete surfacing due to the current low road traffic and provide a good all-weather surfacing for flexible pavements with granular or lightly cemented bases. But traditionally in wet regions, relatively thick asphalt concrete base pavements are used. The typical design includes a (100 to 120) mm continuously graded asphalt concrete base with a 40 mm semi-gap-graded flexible asphalt concrete surfacing. In the Technical Recommendations for Highways (TRH4) (CSRA, 1996) are presented 5 charts for dry region (D1-D5) and 5 charts for wet region (W1-W5) matching specific base/subbase structure. These catalogues can be found in TRH4 (CSRA, 1996) and Ministry of Works of the United Republic of Tanzania (MWURT, 1999).

California Bearing Ratio (CBR) Method: Different researches conducted over the world show that the CBR method gives a slightly thinner pavement for heavy traffic when compared to other design methods (Yoder and Witczack, 1975; Garber and Hoel, 2002). Over the world, the design curves are presented for different subgrade CBR values. CBR Method is one of the asphalt pavement design method introduced first by Porter in 1929, as indicated by Eq. 4. Later, Eq. 4 was modified by Peltier (French) in order to include the effect of traffic loading as shown in Eq. 5 (Senço, 1980; Caputo, 1985).

$$H = \frac{100 + 150\sqrt{P}}{CBR + 5} \qquad (4)$$

$$H = \frac{100 + \sqrt{P} * \left(75 + 50.\log\frac{N}{10}\right)}{CBR + 5} \qquad (5)$$

where:
P = axle load in each wheel, in ton; CBR-California bearing ratio;
N = No. of daily load repetition for two directions.

For calculation of thickness by Eq. 4, the input data are: CBR and P; but by Eq. 5, the same data including N are inputs. For the case eq. 4, if we represent the total pavement thickness (H) and

H = Asphalt concrete layer (t_1) + Base layer (t_2) + Subbase layer (t_3)

and a = t_1+t_2, then the design of pavement structure may follow the procedures:

$$a)\begin{cases}\text{Input CBR of Subgrade}\\ \text{Get H (tot. thickness)}\end{cases}$$

$$b)\begin{cases}\text{Input CBR of subbase}\\ \text{Get } \alpha \Rightarrow t_3(\text{subbase}) = H - \alpha\end{cases}$$

$$c)\begin{cases}\alpha = t_1 + t_2\\ \text{Assume } t_1 \Rightarrow\ t_2(\text{base}) = \alpha - t_1\end{cases}$$

Pavement design methodologies used in China: Pavement design methods used in China follow the Chinese specifications for design of highway asphalt pavement (JTJ014-97) and it is based on confirmation of the class and type of pavement. In these methods the following factors are considered: regional climate, hydrology, local material, road traffic characteristic and the road user request (quality and comfort of the roads). This method is used mainly to confirm the asphalt layer that should match the design requirements (e.g., serviceability of pavement). Chinese specifications suggest using the pavement thickness indicated in Table 1. These thicknesses were determined taking into consideration the factors: bearing capacity of pavement, weather condition and pavement temperature, pavement material type, reflection cracks and ruts that may appear on the pavement and traffic loading and volume.

As recommended in Chinese specifications for design of highway asphalt pavement (JTJ014-97) and Xiaoming (2001), the standard vehicle axle load (P), is taken as 100 kN called as BZZ-100 axles. The standard axle calculation parameters for this vehicle are: a) the tire pressure (p) of 0.7 MPa; b) the distance between centers of two wheels of 1.5d and c) the equivalent diameter (d) of 213 mm. In this method all axle loads bigger than 25 kN must be converted to equivalent single axle loads of 100 kN. The number of standard axle load in life cycle can be calculated by Eq. 6.

$$N_e = \frac{365N_1\left[(1+\gamma)^t - 1\right]}{\gamma}\eta \tag{6}$$

where:

N_e = No. of standard axle load in life cycle for one traffic lane (times);
t = design period (years);
N_1 = average daily traffic in the first year for 2 directions (times/day);
γ = average assumed annual growth rate (%);
η = lane distribution coefficient are: 1.0 for the single lane, 0.5 for the separated double lanes, 0.6-0.7 for the not separated double lanes, 0.4-0.5 for the four lanes and 0.3-0.4 for the six lanes.

Thickness design: The thickness of pavement is calculated according to the multi-layer elastic theory, that defines the pavement as a continuous system and the deflection of the pavement under loading at the center between the wheels should be less than or equal to allowable road surface deflection, as presented below by Eq. 7.

$$l_s \le l_d \tag{7}$$

Pavement deflection is calculated according to the Eq. 8.

$$l_s = 1000\frac{2p\delta}{E_0}\alpha_c F \tag{8}$$

$$\alpha_c = f\left(\frac{h_1}{\delta}, \frac{h_2}{\delta}, \cdots \frac{h_{n-1}}{\delta}, \frac{E_2}{E_1}, \cdots \frac{E_0}{E_{n-1}}\right) \tag{9}$$

$$F = 1.63\left(\frac{l_s}{2\delta}\right)^{0.38}\left(\frac{E_0}{p}\right)^{0.36} \tag{10}$$

where:

l_s = deflection of reality pavement (0.01 mm);
p = tire pressure (Mpa);
δ = equivalent tire radius (cm);
α_c = coefficient of theory deflection from Eq. 9;
F = deflection comprehensive correction coefficient from Eq. 10;
E_0 = resilience modulus of subgrade (Mpa);
E_1, E_2¡–E_{n-1} = resilience modulus of materials of i^{th} structural layers (Mpa);
h_1, h_2¡–h_{n-1} = thickness of i^{th} structural layer (cm).

The Chinese design methodologies and standards include the following steps:

a Calculation of allowable deflection for whole pavement and
b Calculation of allowable tensile stress at the bottom of asphalt and base layers.

Table 1: Recommend thickness of asphalt pavement (JTJ014-97 and Xiaoming, 2001)

Highway class	Class of highway: Expressway	Class I	Class II	Class III	Class IV
Standard axel loads for each lane in design period ($\times10^6$)	> 4	> 4	1~4	0.1~1	< 0.1
Thickness (cm)	12~18	10~15	5~10	2~4	1~2.5

According to the specifications for design of highway asphalt pavement, the thickness of the asphalt pavement is determined by the allowable road surface deflection, Eq. 11.

$$l_d = 600A_cA_sA_bN_e^{-0.2} \quad (11)$$

where:

- l_d = allowable road surface deflection (0.01 mm);
- N_e = No. of standard axle load in service life (times);
- A_c = coefficient of the road class: for expressway and highway class I = 1.0, highway class II = 1.1, highway class III = 1.2;
- A_s = coefficient of wearing course: for asphalt concrete pavement = 1.0, asphalt macadam and asphalt penetration pavement = 1.1, asphalt surface treatment = 1.2;
- A_b = coefficient for semi-rigid base = 1.0 and for flexible base = 1.6.

In the asphalt pavement, the tensile stress of structure σ_m at bottom of each layer in analysis should be less than or equal to allowable strength according to Eq. 12 and allowable strength along the extension of layer can be calculated according to Eq. 13.

$$\sigma_m \le \sigma_R \quad (12)$$

$$\sigma_R = \frac{\sigma_{sp}}{K_s} \quad (13)$$

where:

- σ_R = allowable strength along the extension of pavement layer (Mpa);
- σ_{sp} = cleavage strength of pavement layer material (MPa), cleavage strength of asphalt concrete measured at 15°C and K_S -structural coefficient.

K_S can be calculated according to: Eq. 14 for asphalt concrete, Eq. 15 for inorganically binder and granular materials and Eq. 16 for inorganically binder and fine granular soils.

$$K_s = 0.09A_a \cdot N_e^{0.22} / A_c \quad (14)$$

$$K_s = 0.35N_e^{0.11} / A_c \quad (15)$$

$$K_s = 0.45N_e^{0.11} / A_c \quad (16)$$

where:

- A_a = grade class coefficient: for asphalt concrete, fine particle and medium-grained particles = 1.0 and for coarse grained particle = 1.1.

Computer program APDS: Chinese design methods, normally, are made by computer program APDS (Southeast Jiaotong University, 2000). The input data are the elastic modulus for surface, subbase and subgrade layer and respective coefficient of Poisson's ratio. The program is based in iteration method; it computes the elastic modulus for the second layer, the thickness for all layers and the allowable tensile stress at bottom of surface and base layers. Additionally, the program computes the allowable displacement for the whole pavement structure. If the computation is not verified, the user, manually, must input different material parameters until the design condition is satisfied.

COMPARISON OF PAVEMENT STRUCTURAL DESIGN METHODS USED IN CHINA AND MOZAMBIQUE

Problem statement example: Determine a pavement structure for the road to be built in Mozambique, in a rural area with dry climate taking into account the following parameters: The design vehicle has a load in each wheel of 6500 kg, the estimate average annual daily traffic (AADT) for design vehicles is 280 vehicles per day in one direction, the CBRs of subgrade is 7, granular sub-base is 20 and soil cement base is 80, the design period is 10 years, the growth rate 3.5% and the average equivalent factor for commercial vehicles is 1.5.

Computation and input data required for SATCC and Chinese design methods: The input data for both design methods (SATCC and Chinese) are presented in Table 2. The CBR values can be converted to E = Elastic modulus or M_R = Resilient modulus using Eq. 17 transformed from Huang (2004).

Table 2: Input data for SATCC and Chinese methods

	SATCC methods		
Design parameters	Use Catalogue	Use CBR method	Chinese method
Daily traffic (T)	280	280	280
Equivalent standard axle load	80 kN	6.5 ton(*)	100 kN
Total traffic on one direction	$1.8*10^6$ ESA (by Eq. 1)	Not required	$1.68*10^6$ ESA (by Eq. 9)
Traffic class	T4	Not required	Not required
Chart	D4	Not required	Not required
Material pavement specification	Cement base/granular subbase	CBR (base, subbase, subgrade)	Base, subbase, subgrade
Elastic modulus or California Bearing Ratio (E or CBR)	Subgrade (CBR≥7)	Cement Base (CBR≥80) Granular subbase (CBR≥20) Natural Subgrade (CBR≥7)	Concrete E1≥1000 MPa Asphalt cement Base E2≥ Granular subbase E3≥206 MPa Subgrade E4≥36 MPa
Poisson's ratio (μ)	Not required	Not required	Asphalt layer, $\mu_1 = 0.25$ Cement base, $\mu_2 = 0.35$ Granular subbase, $\mu_3 = 0.35$ Natural subgrade soil, $\mu_4 = 0.4$
Region	Dry	Not required	Not required

* The weight of heaviest vehicle, SATCC-South African Transportation and Communication Commission, ESA-Equivalent Standard Axle, T4-Traffic class 4, D4-Dry region 4 chart

Table 3: The output data from SATCC and Chinese methods

	Methods used in SATCC			Methods used in China (BZZ-100)		
		Thickness (mm)				Thickness (mm)
Layers	E*(MPa)	Catalogues method	CBR method	E*(MPa)	μ	APDS program***
Asphalt concrete	1000**	20	50	1000**	0.25	40
Cement base (CBR≥80)	824	125	140	1300	0.35	157
Granular subbase (CBR≥20)	206	200	210	206	0.35	210
Subgrade (CBR≥7)	36	8	8	36	0.4	8
Total		345	400			407

* Elasticity or resilient modulus calculated from formula 6.,** Assumed, *** Southeast Jiaotong University, Nanjing (2000)

$$E \text{ or } M_R = 10.3 \text{ CBR (MPa)} \quad (17)$$

Output data: The output data for both design methods (SATCC and Chinese) are presented in Table 3. Using the Chinese design method and computer program APDS, this research has found the following: The tensile stress σ_m at bottom of asphalt layer is 0 which is less than allowable $\sigma_R = 0.92$ and σ_m at bottom of base layer is 0.5012 which is less than allowable $\sigma_R = 0.516$. The computed displacement for whole pavement is $l_s = 0.6829$ mm which is less than allowable $l_d = 0.6831$ mm. The deviation of error between computed and allowable displacement (l_s and l_d, respectively) is 0.03% less than 5%. Thus by both methods, the pavement will efficiently support the predicted loads in the design period.

CONCLUSIONS

- South African methods are modified formulas from those used in US and UK, taking into account local materials, environment and low volume traffic.
- South African catalogues are basically used for roads with traffic less than 30 million ESAs.
- South African catalogues suggest that if the traffic is higher than 30 million ESAs, other methods such as US, UK and TRLL should be used.
- In South Africa, asphalt pavements are subdivided into thin (asphalt surface thick less than 50 mm) and thick asphalt (asphalt surface thick more than 75 mm).
- In South Africa there are developed catalogues and CBR design curves for different CBR subgrade values.
- The catalogues methods give small thickness than CBR and Chinese methods.
- The elastic modulus for the second layer in Chinese method is higher than in the South African method, which may positively contribute to the good performance of the pavement.
- The strong point in Chinese method is centered in verifying the tensile stress and allowable displacement on the pavement.
- The most important remark is that the results from Chinese and South African design methods gives nearly the same thickness; so this study conclude that these methods can be used in both countries; China and Mozambique.

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REFERENCES

California Department of Transportation (CDT), 2004. Asphalt concrete structural section-Design examples. Pavement Techn. Notes, California.

Caputo, H.P., 1985. Soil Mechanics and its Applications. 5th Edn., Technical Books and Scientific Editors, Rio de Janeiro, pp: 438-452 (in Portuguese).

Committee of State Road Authorities (CSRA), 1996. TRH4: Structural design of flexible pavements for interurban and rural roads. CSIR, Pretoria, pp: 50-59.

Croney, D. and P. Croney, 1997. Design and Performance of Road Pavements. 3rd Edn., McGraw-Hill, New York, pp: 15-33.

David, J.M., 2002. 9th Regional Seminar for Labour Practitioners. In: Proc. of the Ninth Regional Seminar for Labour Based Technology-Review of Current Practices, David, J.M. (Ed.), Maputo, 2002. ILO Publications Branch, Harare.

Garber, N.J. and L.A. Hoel, 2002. Traffic and Highway Engineering. 3rd Edn., Bill Stenquist, Pacific Grove, pp: 955-1014.

Huang, Y.H., 2004. Pavement Analysis and Design. 2nd Edn., Prentice Hall, New Jersey, pp: 286-329.

Ministry of Works of the United Republic of Tanzania (MWURT), 1999. Pavement and materials design manual. Ministry of Works of the United Republic of Tanzania, Dar es Salaam.

Senço, W., 1980. Pavement. 3rd End., Camara Brazileira do Livro, Sao Paulo, pp: 104-119. (In Portuguese).

South African Transportation and Communication Commission (SATCC), 1998. Draft: Code of Practice for the Design of Road Pavements. CSIR, Pretoria.

South African Transportation and Communication Commission (SATCC), 2001. Draft: Code of Practice for the Rehabilitation of Road Pavements. CSIR, Pretoria.

Southeast Jiaotong University, 2000. APDS program. Southeast Jiaotong University, Nanjing.

Specifications for Design of Highway Asphalt Pavement-JTJ014-97 1997. Specifications for Design of Highway Asphalt Pavement. China Communications Press, Beijing (In Chinese).

TRL Limited, 2004a. Overseas Road Note 40: A guide to axle load surveys and traffic counts for determining traffic loading on pavements. UK Department for International Development (DFID) for the Benefit of Developing Countries, Crowthorne.

TRL Limited, 2004b. Performance of low volume sealed roads: Results and recommendations from studies in Southern Africa. UK Department for International Development (DFID) for the Benefit of Developing Countries, Crowthorne.

Xiaoming, H., 2001. Principles and design methods of pavement. China Communications Press, Beijing (In Chinese).

Yoder, E.J. and M.W. Witczack, 1975. Principles of Pavement Design. 2nd Edn., John Wiley and Sons, New York, pp: 243-265.