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Flexible pavement overlay design of UFJF ring road based on the new Brazilian mechanistic-empirical pavement design method

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Abstract

The procedures for design and reinforcement projects regarding flexible pavements available in Brazil are mostly based on empirical models developed from studies carried out in specific localities, and therefore, should only be used in cases where equivalent climatic and traffic conditions are observed. The national highway agencies in partnership with universities and research centers have been working to change this scenario through the development of a mechanistic-empirical method that is more compatible with the Brazilian geographic and technical-scientific realities. The first outcome of this task force is the computer program MeDiNa, which is still under assessment. In this present study, the new flexible pavement software in Brazil (MeDiNa) was used by the Federal University of Juiz de Fora to calculate the overlay asphalt of its the ring road, aiming to recover its functional proprieties. This pavement was evaluated functionally by Computerized Continuous Visual Survey (CCVS) and tests of longitudinal cracks, and structurally by survey deflection measurements (FWD) and shaft sinking. With the data collected from the structural evaluation, the homogeneous segmentation of the stretch and the back-calculation of the data was carried out, aimed at the acquisition of needed parameters for the calculation. After the appropriate design, it was concluded that the best solution for the overlay is resurfacing along its entire length, with the use of the project's asphalt mixture with single thickness of 5.0 cm, observing the application of the anti-reflective cracking layer in some stretches.

Keywords: Mechanistic-Empirical Method, overlay, back-calculation.

1. Introduction

In a transport infrastructure system, the pavement is regarded to be the most important component, both on financial and operational issues, meaning a heritage, whose management is crucial to the total cost reduction. The conservation and maintenance of the pavements must be treated as investments, allowing an economic and social return, ensuring that the pavement maintains its functionality

The structure of a pavement undergoes a degradation and wear process, resulting in a reduction of its structural condition. Such process is due to climate change actions, the traffic movement, and physical or chemical changes of the materials. Compared to other types of structures, the deterioration velocity tends to be greater in pavements, due to their wide exposure to weather and intense traffic (Mikolaj, *et al.*, 2019).

Therefore, it is acceptable to state that a pavement management system is fundamental for the routine monitoring of their functional and structural conditions. This process, influences not only the maintenance and rehabilitation direct costs, but also the other fractions of the total cost, such as operating costs of vehicles, accidents, disruption of traffic, etc.

The maintenance of a pavement includes all operations which modifies, directly or indirectly, the actual pavement condition. The purpose of this practice can be either the functional return of the pavement characteristics, or the prevention of damage to its structural components, ensuring thus, an extension of its life-cycle.

Both the current method of flexible pavement design (DNER method, developed in 1996, by the Engineer Murillo de Souza), and the procedures of overlay design existent in Brazil today are, in general, based on totally empirical methods.

In view of this, the road agencies along with the universities and research centers have recently set up a task force to create a new method of pavement design, founded on a machanistic-empircal method that is more suitable to technical-scientific and geographical realities. This method strives for theoretical analysis specifically for pavement mechanics, and becomes independent of the empirical parameters of materials, although it requires calibrations with experimental data.

2. Materials and methods

The stretch which was analysed in this study was the flexible pavement of Federal University of Juiz de Fora ring road. According to Machado (2016), its construction started in the 1960s, and since then, only one rehabilitation was carried out (in the 1991, a resurfacing was executed with approximately 4.0 cm of thickness). This ring road represents the main access road of the campus, linking the different faculties to the central area (rectory, central library, civic square, etc.) and the southern area of Juiz de Fora to the upper city.

The staking of the road stretch was carried out taking as a base the intern-al lane of the ring. Then, over the 2,140m of extension, 107 stakes were placed, with spacing of 20 m between them. However, over the FWD surveys, the deflection measurement had to be displaced in some stretches due to the presence of a calm traffic system, which resulted in the listing of 98 stakes. With regards to shaft sinking, due to the logistical and enforcement difficulties, it was possible to implement only one shaft (in the parking lane), along all the extension (Figure 1).

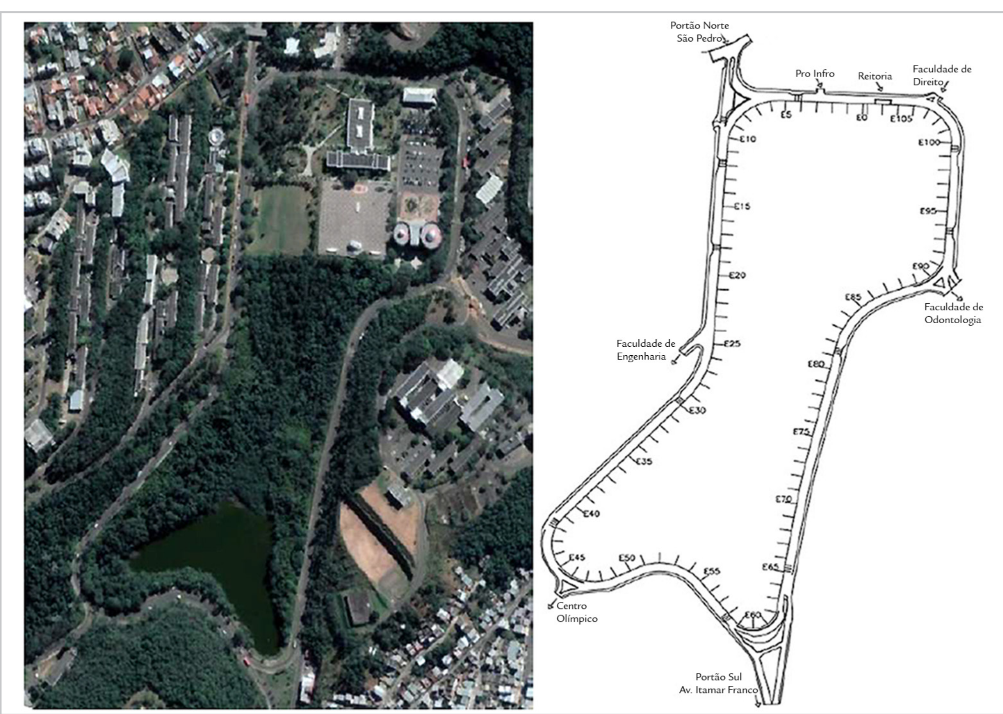

Figure 1 - Satellite imagery and schematic representation of the UFJF ring road.

As to the traffic, one survey carried out in the second semester of 2015 by UFJF Engineering Faculty, pointed out that the Average Daily Traffic on campus during working days corresponded to approximately 9000 vehicles (Machado, 2016). With this datum, and considering a traffic annual growth rate of 1%, the ADT value becomes 9300 vehicles.

For this study, the functional evaluation was carried out through the device "Computerized Continuous Visual Evaluation" by ENGGEOTECH Consultores de Engenharia Ltda company, using the computational software HoleHunter 4.0, drawn and designed by the same, in 2018. This software enables the record preview along with the description of the noted occurrences, while displaying a representative graphic about the relief altimetry of the road stretch, and in a satellite imagery, the covered path (Figure 2).

Figure 2 - HeoleHuntter software screen displaying the video record together with the listed defects, the path and the altimetry.

Although the all defects predicted in standard DNER 005/2003 (intended for overlay design by MEDINA software) have been surveyed, only the data of cracked area percentage are needed. This parameter was obtained by the sum of percentages regarding level 2 cracks (openings greater than 1.0 mm without erosion edges) and level 3 (openings greater than 1.0 mm without erosion edges), verified in situ by LVCI.

With regards to the International Roughness Index (IRI), in the survey carried out by the COPPE staff, a device was used which is suspended and utilizes the tenet of laser lightwaves for the roughness measures. This device was developed by the Cibernética company, and presents 5 laser moduli, installed in a beam connected to the vehicle´s front side. The modules are linked to the central processing unit, which storages the data in a computer inside the vehicle.

In order to carry out the functional evaluation, the KUAB 8833 device, by Konsult & Utvclinkg AB, was utilized, and the deflections were measured through nine absolute deflection transducers. These transducers, known as linear variable differential transformer (LVDTs), are placed one in the center of the plate and the other placed at 20 cm, 30 cm, 45 cm, 60 cm, 90 cm, 120 cm, 150 cm and 180 cm away.

With respect to soil prospection, one shaft survey of 80x80cm was opened in the pavement, close to stake 40, in order to collect the materials and to determine the thicknesses. The material samples collected were tested at the Juiz de Fora Technology Center Foundation, according to the procedures described in the standards for characterization tests and resilient modules.

The next step was the backcalculation. The ring road was divided into homogenous segments aiming to extend the structural parameter validity and traffic measured at some points along the entire extension, in function of the physical characteristic uniformities, degradation state and flow of traffic. The procedures were carried out according Ashto (1993), which utilize the Cumulative Difference Approach and maximum deflection.

The software utilized in this study for the back-calculation process was the BackMeDiNa, which calculates the difference between measured and calculated deflection in each sensor, with the final error measured through the deflection root mean square (RMS). Aiming to develop a project as reliable as possible, only outputs whose errors were lower than 10 μm were admitted in this research.

The pavement structure input in the software corresponds to that observed in the prospection, being that the Poisson coefficients of the different layers were estimated with regard to the values usually utilized in the country, listed as follows:

- Surface: 8.0 cm / μ = 0.30;
- Base: 10.0 cm / μ = 0.35;
- Subbase: 20.0 cm / μ = 0.35;
- Compacted subgrade: 40.0 cm/μ = 0.45;
- Subgrade: thickness semi-infinite / μ = 0.45;

The overlay design of UFJF ring road was carried out by software MeDiNa, through the Overlay Mode of the program. In this mode, the user initially enters with information about the pavement structure, such as layer numbers, thicknesses, types of materials, resilient modulus and Poisson coefficient.

Then, the user enters with the complementary data of the existing surface, such as cracked area percentage, the IRI, milling thickness and the pavement age. The asphalt mixture, which is input in the pavement, was designed by the SUPERPAVE method, using a type of asphalt binder commonly utilized in Juiz de Fora, the CAP 50/70, produced by Refinaria Duque de Caxias (Reduc). This design was carried out by Neumann (2018) at UFJF Pavement Laboratory, with optimum content of 5.9%.

After this step, the data about the traffic was input as follows: type of road, Average Daily Traffic (ADT); vehicle factor (VF); percentage of vehicles on project lane; growth rate; and project period. The ADT, as already presented, was established, for the first-year analysis (2018), as 9300 vehicles, considering 90% of saloon cars and 10% of urban buses, and an estimate of 50% of vehicle in the project lane. Table 1 summarizes the traffic data input in the software.

Table 1 - Summary of traffic data.

Traffic Data	
Type of road	Local road
ADT (1 year)	9300
VF	0.095
N (1 year)	3.22e+5
% of vehicles on project lane	50
N (lane)	1.61e+5
Growth rate (%)	1
Project period	10
N (total)	1.69e+6

3. Results and discussions

3.1 Cracked area percentage (CA%)

From the image collected analyses in LVCI, the percentage of areas affected by cracks of level 2 and 3 was defined. In Table 2 a summary of characteristic CA% found is presented (CA% = $\Delta + \sigma$), where Δ presents the arithmetic mean and σ the sample standard deviation.

Table 2 - Characteristic Cracked Area Percentage of homogeneous segments (Author, 2018).

Segment	Δ (%)	σ (%)	CA %	Segment	Δ (%)	σ (%)	CA %
01	24.20	15.75	39.95	05	5.16	8.34	13.50
02	39.58	14.78	54.37	06	13.65	11.97	25.63
03	25.67	10.11	35.78	07	6.25	6.99	13.24
04	18.75	16.58	35.60	08	23.13	7.65	30.77

Tables supplied by the National Agency of Land Transportation (ANTT) were consulted in order to evaluate the functional and structural states of pavement, therefore the homogenous segments 01, 02, 03 and 04 were classified as the "Terrible", the 06 and 08 segments as "bad", while the segments 05 and 07 were "regular".

3.2 International Roughness Index (IRI)

According to the usual procedure of the characteristic International Roughness Index (IRIc), each segment produced the values shown in Table 3:

Table 3 - Homogeneous Segments IRI (Author, 2018).

IRIc (m/km)			
Segment 01	4.31	Segment 05	2.56
Segment 02	4.16	Segment 06	1.87
Segment 03	3.39	Segment 07	2.70
Segment 04	4.14	Segment 08	2.72

The ANTT classifies the road stretch as well, with regard to its characteristic IRIs in four classes. According to that classification, the segments 01, 02 and 04 were classified as "Bad", the segment 03 as "Regular", and the segments 05, 06, 07 and 08 as "Good".

3.3 Laboratory tests

The outcomes of laboratory tests are shown in Table 4:

Table 4 - Summary of characterization and resilience module tests of the material used in the research.

Parameters		Surface	Base	Subbase	Compacted subgrade	Subgrade
Tactile-visual analysis		-	Pink silty soil	Beige silty soil	Brown clay	Silt little silty with fine sand
Grain size	d > 4.8mm	-	1%	1%	0%	0%
	4.8 ≤ d < 2.0 mm	-	8%	12%	1%	1%
	2.0 ≤ d < 0.42 mm	-	51%	47%	10%	18%
	0.42 ≤ d < 0.075 mm	-	23%	21%	13%	29%
	d ≤ 0.075 mm	-	18%	19%	77%	52%
Optimum moisture		-	12.90%	18.30%	21.70%	24.60%
Maximum density (g/cm³)		-	1930	1760	1487	1451
Resilient Moduli (MPa)		6447.0	261.8	212.2	153.4	126. 0

A suitable uniformity was observed for the value set found in the resilient modulus tests; fact evidenced by the low variation coefficient (16%). With regards to the asphalt mixture, the resilient modulus and fatigue test outcomes are shown in Table 5.

Table 5 - Results of resilient modulus and fatigue tests for the asphalt mixture (Author, 2018).

Resilient Moduli (MPa)	5963.00
k1	7.40E-11
k2	-3.3104

3.4 Backcalculation

The estimate of resilience module seeds, which are inputs to the software, were defined according to resilient modulus test outcomes realized with the 12 samples extracted from pavement and with the samples molded in the laboratory.

Table 6 shows figures of resilient modulus obtained in backcalculation, with values corresponding to simple arithmetic means of the modulus value set, regarding the deflection bowls of each stake.

Table 6 - Modulus values obtained in Backcalculation (MPa).

Segment	Surface	Base	Subbase	Compacted subgrade	Subgrade
1	6045	465	661	466	324
2	4879	434	373	374	322
3	9115	715	874	707	396
4	3994	497	432	289	267
5	3805	457	682	433	321
6	4024	419	413	318	299
7	4825	545	609	396	266
8	5197	367	276	241	205

Observing the outcomes, it was found that the surface of the flexible pavement achieved a high mean resilient modulus (5235.5 MPa), but lower than the module from laboratory test. Besides this, the data of modulus obtained for the Compacted subgrade layers showed, in the majority of cases, higher values than those found in base and subbase layers. With regard to standard deviation values and the variation coefficients among the deflection bowls, the procedure did not result in significant values, symbolizing low dispersion of values.

3.5 Overlay design

In the overlay design of homogeneous segments, all data of the pavement structure were initially input with its physical parameters considered the same for all homogeneous segments.

After this step, in which all necessary data were input, the overlay calculation was automatically executed. Table 7 shows the obtained thicknesses for each one of the 8 segments, as well as the cracked forecasted area percentage at the end of the project period.

Table 7 - Results obtained on the overlay design of all homogeneous segments for 50% of traffic in the project lane (Author, 2019).

Segment	Overlay Thickness (cm)	CA% in the project period end	Segment	Overlay Thickness (cm)	CA% in the project period end
Segment 01	5.0	6.8%	Segment 05	5.0	6.8%
Segment 02	5.0	8.3%	Segment 06	5.0	9.9%
Segment 03	5.0	5.4%	Segment 07	5.0	7.0%
Segment 04	5.0	9.8%	Segment 08	5.0	9.4%

It has also been noted that, for all the segments, the MeDiNa software indicated the overlay minimum thickness (5.0 cm). This fact was rectified by forecasted percentages of the cracked area, which presented figures quite bellow of the limit of 30% (accepted by the software for the last project month).

In order to evaluate the upper limits of the project thicknesses, a new design was carried out considering 100% of the traffic passing in the project lane, which consists in the most critical situation. Besides this, in two stretches of the ring (stakes 6 to 9 and 59 to 62) the right lane joins the left lane, and therefore, in these cases, it would be the correct analysis to do. Table 8 shows the outcomes.

Table 8 - Results obtained on the overlay design of all homogeneous segments for 100% of traffic in the project lane (Author, 2019).

Segment	Overlay Thickness (cm)	CA% in the project period end	Segment	Overlay Thickness (cm)	CA% in the project period end
Segment 01	5.0	18.8%	Segment 05	5.0	18.8%
Segment 02	5.0	24.2%	Segment 06	9.4	28.4%
Segment 03	5.0	14.1%	Segment 07	5.0	19.6%
Segment 04	9.4	29.2%	Segment 08	8.8	29.5%

As can be seen, only 3 segments presented different thicknesses than previously calculated. However, all segments show a significant rise in the percentage values of cracked area. The software MeDiNa does not analyse the propagation of cracks from the old to the new pavement, whereby the user suggests alternatives to prevent or to delay this process. Considering this scenario, proposed was a new design for the segments with overlay thicknesses higher than 5 cm and/or with a cracked area higher than 20% (in the situation which was taken into account 100% of traffic in the project lane).

In this design, the execution of one layer to reduce propagation of cracks between the new and old surface was considered. The chosen material was an asphalt mixture particularly designed to absorb the stress, with 1.5 cm of thickness, resilient modulus of 3000 MPa, Poisson Coefficient of 0.25 and specific mass of 2.4 g/cm³. The obtained outcomes are shown in Table 9.

Table 9 - Overlay outcomes of segment 02, 04, 06 and 08 with layer to reduce propagation of cracks for 100% of traffic in the lane (Author, 2019).

Segment	Overlay thickness (cm)	CA% in the project period end
Segment 02	5.0	15.6%
Segment 04	5.0	19.0%
Segment 06	5.0	19.0%
Segment 08	5.0	18.2%

With these three incurred simulations, it was observed that the best solution of overlay for the UFJF ring road flexible pavement is the execution of a resurfacing with a layer of unique thickness of 5.0 cm (asphalt mixture), besides the application of a layer to reduce propagation of cracks in the stretches corresponding to segments 02, 04, 06 and 08.

4. Conclusion

In this study, a research was carried out regarding a method of flexible pavement maintenance, known as overlay, which consists of the implementation of a new asphalt mixture over the existing surface, aiming at the re-establishment of certain functional properties, as well prevention of future damages.

The outcomes of international roughness index support with the fact of UFJF ring road pavement presents suitable traffic conditions, since the IRI values found for the distinct segments were admissible for the most part of the ring. This also indicates low levels of permeant deformation, especially of the subgrade, which is the most susceptible layer to the appearance of type of defect.

With regards to the cracked surface area percentage determination, even though the LVCI is a relatively new measurement method, it presented good effectiveness and accuracy. Even with the high extension of the analyzed ring road, the utilization of high-resolution images and pre-defined scales, the software showed agility in the measurements of affected areas.

The high values of the cracked area verified by the method are related to prolonged exposure of the structure to dynamic loadings, enforced by vehicles, and to adverse weather effects, caused by climatic agents, as well as by the road's own chemical properties inherent to the materials.

Looking at the high values of effective elastic modulus and of UFJF ring road asphalt surface resilient moduli, it can be said that, despite advanced age, the ring still has a good capacity for supporting the exposure demands.

The overlay design based on the New Brazilian Mechanistic-Empirical Method was carried out in three situations: 1) asphalt material overlay considering 50% of the traffic in the project lane; 2) asphalt material overlay considering 100% of the traffic in the project lane; and 3) asphalt material overlay and layer to reduce propagation of cracks in some segments, considering 100% of the traffic in the project lane.

In the first situation, the overlay minimum thickness, allowed by software MeDiNa (5.0 cm), was determined for all the analyzed segments, and the forecasted cracked area percentages for the last month of analysis were between 5.4% and 9.9%. These outcomes allowed to conclude that those thicknesses could be even lower if the cracked area limit of 30% was taken into account. Nevertheless, the overlay execution with thicknesses inferior to 5.0 cm is neither usual nor recommended by DNIT.

In order to establish an upper limit for the overlay thicknesses in a critical scenario, it was decided to carry out the design according to the second situation (whose returned values were quite high for the overlay thicknesses in the segments 02, 04, 06 and 08, while maintaining the other thicknesses at 5.0cm). The percentages of the forecasted cracked area rose significantly for all the segments, with emphasis in the segments 02,04,06 and 08, whose values exceeded 24% of cracked area.

The even segments become evident, as they are those that require more attention by the user. With this in mind and considering the fact that MeDiNa software does not analyze the propagation of cracks from the old to the new pavement, the design was developed regarding a third situation. Due to presence of the crack propagation layer, the overlay thicknesses of those segments went back to having the minimum value of 5.0 cm, and its forecasted cracked areas presented values inferior to 20%.

Considering the simulations made, it is possible to conclude that the best solution for the UFJF road ring pavement overlay is to adopt a resurfacing with 5.0 cm of the project asphalt mixture (M_R = 5963 MPa) throughout the entire extension, paying attention to the utilization of an anti-crack propagation layer with 1.5cm of thickness (M_R = 3000 MPa) in the segments 02, 04, 06 and 08.

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