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Structural evaluation of pavements applying the MeDiNa Method and FWD and Benkelman beam deflection measurements

Avaliação estrutural de pavimentos com a aplicação do Método MeDiNa e leituras de deflexão com FWD e viga Benkelman

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ABSTRACT
The new Brazilian "National Design Method" (MeDiNa) is an empirical-mechanistic approach for designing asphalt pavements. The article contributes to applying the MeDiNa Method in the structural evaluation of the Rio do Morro Road. It was paved recently and evaluated by deflection basins using FWD and the Benkelman beam in 110 test points. The deflection measurements were compared and elastic moduli were back-calculated by the BackMeDiNa software. It was based on data collected from two compared devices. Subsequently, the MeDiNa software and the elastic moduli, previously back-calculated, were used to predict the fatigue life of the pavement. The results demonstrated the largest dispersion between the collected results from the Benkelman beam deflections and the efficiency of the BackMeDiNa in the back-calculation process from the data and considerations of the research
calculation.

RESUMO
O novo Método de Dimensionamento Nacional (MeDiNa) emprega a abordagem mecanística-empírica para o dimensionamento dos pavimentos asfálticos. O presente artigo contribui com a aplicação do Método MeDiNa na avaliação estrutural da Estrada Rio do Morro, pavimentada recentemente e inventariada com a medição de bacias deflectométricas através do FWD e viga Benkelman para 110 pontos de teste. Para tanto, foi realizado um comparativo entre as medidas de deflexão e os módulos de elasticidade retroanalisados com o *software* BackMeDiNa a partir dos dados obtidos com os dois equipamentos. Na sequência foi empregado o *software* MeDiNa e os módulos anteriormente retroanalisados para a previsão da vida de fadiga do pavimento. Os resultados demonstraram a maior dispersão entre os resultados obtidos com deflexões da viga Benkelman e a eficiência do BackMeDiNa no processo da retroanálise a partir dos dados e considerações de cálculo da pesquisa.

1. INTRODUCTION

Road maintenance is defined through performing an inventory on the pavement, of the functional and structural conditions. The functional evaluation is performed mainly by studying the roughness and surface distresses. Pavement structural evaluation consists of calculating its load capacity according to Magalhães (2015), and it is obtained based on various parameters, such as deflection, which in turn makes the elasticity modulus possible on pavement layers through the back-calculation process.

There are a growing number of research studies on perfecting the evaluation processes of pavements to increase the efficacy of designing pavements (Guzzarlapudi *et al.*, 2016). The majority of research studies address elastic deformation, as the structural capability of pavement is calculated according to stresses and strains, generated internally by each application of load (Gomes, 2012).

The "Método de Dimensionamento Nacional" (MeDiNa) addresses the empirical-mechanistic methodology for designing the implementation and rehabilitation analyses of pavements. Souza Jr. (2018) informs that this method designs pavements based on the deformity of materials, asphalt fatigue curve and fatigue cracking. The MeDiNa method results from over 20 years of COPPE research and other educational institutions and Brazilian entities, according to Lopes (2019).

The MeDiNa software can be downloaded from the “Instituto de Pesquisas Rodoviárias” (Road Research Institute) (IPR) website published by the “Departamento Nacional de Infraestrutura de Transportes” (National Department of Transport Infrastructure) (DNIT). The software includes two additional modules: - BackMeDiNa, employed for performing the back-calculation and determining the elasticity moduli of pavement layers; - AEMC, modulus assigned for the Elastic Calculation of Multiple Layers.

The purpose of this article is to collaborate with the consolidation of the new MeDiNa Design Method. Comparisons were performed between the deflection measurements and the back-calculated elasticity modulus by running the BackMeDiNa software, comparing the results collected from each device to the reference values. Furthermore, the MeDiNa software sought to forecast the studied pavement's useful lifetime before fatigue occurs, cross-checking the collected results for each asphaltic mixture class.

Several software programs were employed for performing back-calculations, including BackMeDiNa. They are set up for inputting deflection basin data collected from FWD devices. Theisen *et al.* (2009) proposed a methodology for employing data collected from the Benkelman beam in the mentioned software programs. This methodology is used and evaluated in this research study, employing the deflection measurements obtained from the FWD and the Benkelman beam. The first device is currently utilized in the roadway technical medium, and the second is traditionally employed in structural evaluations, and therefore investigated on its possible utilization.

2. THEORETICAL FRAMEWORK

2.1. Devices used for the structural evaluation of pavement

The Benkelman beam is a device related to a great deal of experience from the Brazilian technical medium (Borges, 2001; DNIT, 2006 and Gomes, 2012), employed for collecting data on deflections for the design as well as to approve on going pavement layers. It is a low-cost device and manually operated, as it can test an internal track and an external track on the pavement. It is generally employed for specific projects and not recommended for evaluating the network due to the delay of the trial (TMR, 2012 and Guzzarlapudi *et al.*, 2016). The tests employ the static loading of a truck calibrated air load pressure at 8.2 tf in the rear axle (single axle and double wheels).

The Falling Weight Deflectometer (FWD) is a more expensive device than the Benkelman beam, although it is more modern and versatile. The FWD device uses a falling weight for pavement loading through a circular loading plate. The pavement loading can be varied, and geophones are used for measuring deformities in specific points from the applied load point, thereby guaranteeing increased precision for defining the deflection basins (TMR, 2012).

The main advantages of utilizing FWD compared to the Benkelman beam are greater practicality, quicker trials and more precise results, especially in measuring a deflection basin from a specific pavement point. According to Pinto *et al*. (2013), the shape of a load pulse generated by the device is similar to what is measured from a moving wheel load; thereby, due to dynamic loading, FWD reproduces more precisely pavement deformations. According to Zheng *et al.* (2017) and Franco *et al.* (2019), the use of deflections measured by FWD made it possible to improve the diagnosis of the pavement's structural condition and a more adequate pavement rehabilitation design.

2.2. Determining the elasticity modulus by back-calculation

Back-calculation is a mechanistic evaluation procedure and employed as a basis the elastic linear calculations of pavement deflections. The on-site measured deflections are compared with the calculated deflections and the moduli necessary for this estimation are determined, characterizing the back-calculation process (Lopes, 2019).

Franco *et al.* (2019) mentioned that pavements with different structures could present the same maximum D_0 deflection value (in the center of the applied load), but with different deflectometric basin curvatures. Thus, the complete basin calculation makes it possible to perform a more precise diagnosis on structural pavement conditions. According to Zheng *et al.* (2017), the deflection basin form factors have been widely utilized in the conception and evaluation of highways.

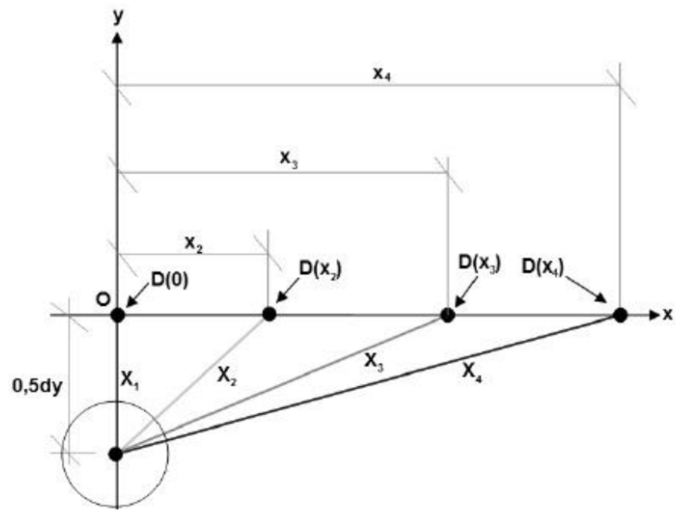

Figure 1. Calculation of the "X" distances by measuring the "x" distances according to the Theisen *et al*. methodology (2009)

Several software programs employed for performing the back-calculation are configured for the input of deflection basin data obtained from FWD devices by informing the circular load plate radius and the applied loading. Theisen *et al.* (2009) mentioned that in the case of deflectometric measurements performed by the Benkelman beam, there is the performance of the single axle load with double wheels (8.2 tf) and in this case, they proposed a methodology for employing data collected from the Benkelman beam and using the back-calculation programs obtained by FWD. This methodology is based on the principle of an overlying effect, as each one of the loads (double wheels) is responsible for half of the pavement deflection. Hence, the actuation of only one load can be applied to the back-calculation. However, new "X" distances measuring the respective load's geometric center must be calculated based on the "x" distances between the deflection basin points, utilizing Equation 1. Figure 1 illustrates the necessary adjustments for the deflection basin distances.

$$Xi = \left[\left(xi \right)^2 + \left(0.5dy \right)^2 \right] ½ \qquad (1)$$

where Xi: the calculated distance;
xi: distance between the deflection basin points;
dy: distance between the geometric center of the loaded plates.

2.3. The MeDiNa design method

MeDiNa is defined as the Brazilian Design Method, named in homage to Professor Jacques de Medina due to his notable contribution to Brazilian pavement.

According to Chiarello *et al*. (2019) and Knabben and Carpio (2020), the MeDiNa software program seeks to calculate the stresses and strains on the structure and verify if the number of the applied load will cause excessive fatigue cracking on the asphalt surface or cemented layers or if they will provoke deformation permanent in a degree exceeding the established limit. And finally, the software will verify the layers' thickness and calculate if they adhere to the critical design conditions.

Pavement implementation design specifications and the reinforced design are detailed in the software program. Franco and Motta (2020) mentioned it is necessary to perform laboratory trials for a new paving project to obtain the resilient modulus and plastic deformation modulus for the subgrade, reinforced subgrade, subbase and base.

In the case of asphalt mixtures, Souza Jr. (2018) and Lopes (2019) inform four theoretical asphalt mixtures found in the MeDiNa database, named Class 1, Class 2, Class 3, and Class 4, where Class 1 mixture is considered the least resistant to fatigue and Class 4 mixture is the most resistant. According to Flores and Specht (2019), the asphaltic mixtures display a broad range of fatigue parameters, varying from 5764 MPa in Class 1 to 10492 MPa in Class 4 in their resilient modulus.

Franco and Motta (2020) stressed that traffic parameters are vital for the correct operation of the MeDiNa software program, considering the utilized models have proved to be sensitive to small variations in the number of repetitions of the 8.2 tf standard axle, the number N.

3. METHODOLOGY

The methodology employed included the performance of on-site trials using the FWD devices and the Benkelman beam on 110 test points, back-calculation elasticity modulus, and estimate the fatigue life of the pavement.

The selected road for the research is named Rio do Morro Road. It is located in the municipalities of Joinville and Araquari, in Santa Catarina State. The total length is 9.4 km. Figure 2 identifies the stretch of the road being studied. One can see an urban segment in Joinville and then the road passes predominately in a rural zone towards Highway BR-280.

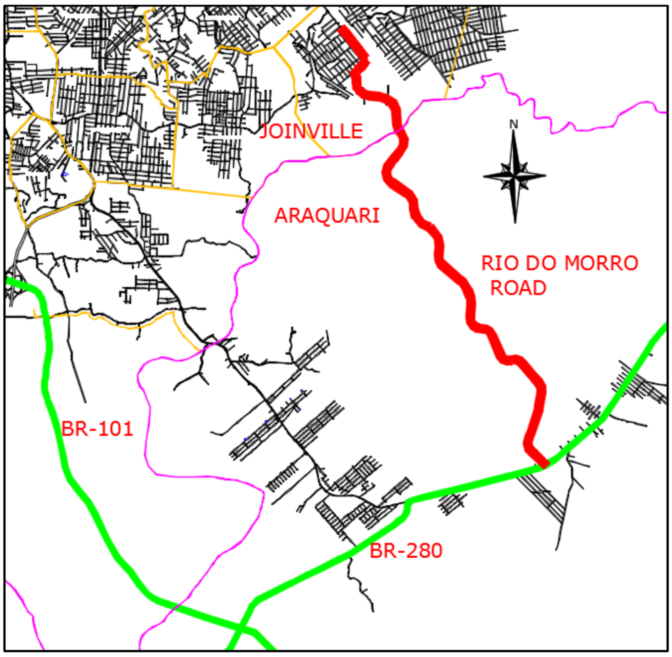

Figure 2. Rio do Morro Road located in the municipalities of Joinville and Araquari

3.1. Defining the study point locations

Through the Engineering Project (DEINFRA-SC, 2009) on the roadway and Monthly Worksite Reports (DEINFRA-SC, 2014 and 2019), it was possible to identify segments with similar structural characteristics and select the trial points. The choice of the locations is related to two pavement structures. Structure 01 is composed of a reinforced subgrade with sand and Structure 02 is composed of a reinforcement made of stone (granitic gneisses), in a minimum thickness of 50 cm, as shown in Figure 3. The other pavement layers are similar: a 30 cm subbase of dry macadam, 18 cm simple graded gravel (BGS) and 5 cm of asphalt mixture made of conventional CAP 50/70, according to the specified range VI granulometry as stated in DEINFRA-SC (2016).

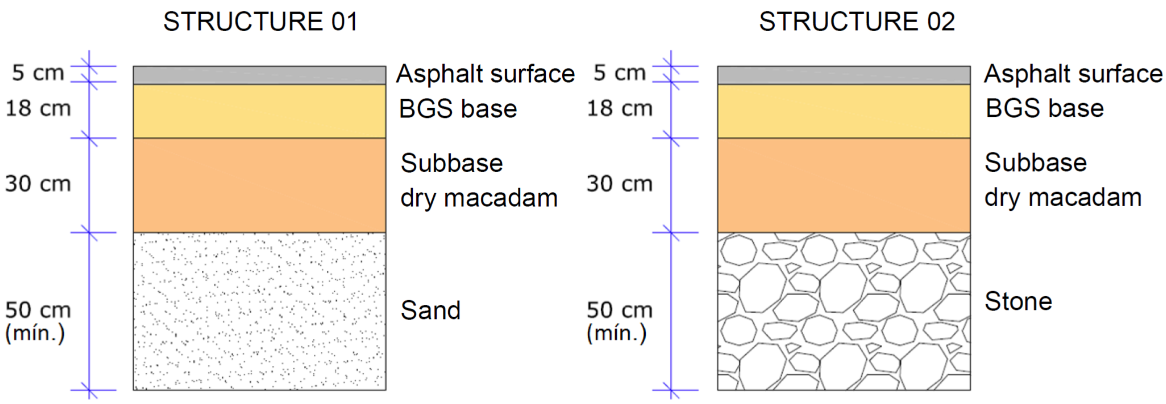

Figure 3. Pavement layer details

A total of six segments were identified with similar characteristics, where the test points were distributed. Table 1 displays the placement of the segments based on the type of region (urban or rural), structure (reinforced subgrade with sand or stone) and the year of paving (from 2014 to 2019).

Table 1 – Road stretch studied characteristics

Segment	Type	Point identification	Number of points	Reinforced structure	Year paved
01	Urban	01 to 21	21	02 (stone)	2014
02	Rural	22 to 40	19	01 (sand)	2014
03	Rural	41 to 48	8	01 (sand)	2019
04	Rural	49 to 70	22	01 (sand)	2019
05	Rural	71 to 100	30	01 (sand)	2014
06	Rural	101 to 110	10	02 (stone)	2019

3.2. Field research

The field research was subdivided into four main activities: topographic location, deflection measured with FWD and Benkelman beam and traffic counting. The work was carried out from May 2019 to March 2020. The test points were previously topographically located in the field so that the trials conducted with FWD and the Benkelman beam could be coincidentally performed in the same locations. This topic will emphasize the procedures for performing the FWD and Benkelman beam tests.

The FWD tests were performed under suitable climatic conditions on June 6, 2019. The average ambient temperature was 22°C and the pavement temperature was 25°C. The performed procedure is described by the 273-PRO standard (DNER, 1996) and, according to this specification, the applied load to the pavement was approximately 40 kN. The device brand used was KUAB, manufactured in Sweden, equipped with a 30 cm diameter load plate for the transference of the loading and seven geophones for deflection readings, placed at 0, 20, 30, 45, 60, 90, and 120 cm from the center of the load applied to the pavement. The device used is illustrated in Figure 4 (a).

The Benkelman beam trials were performed on December 3, 2019, and December 12, 2019; both took place in suitable climatic conditions. Even though the measurements took place in December (just before the beginning of summer), the ambient temperature was verified on the trial days and reached the minimum of 23°C. The Benkelman beam test procedure complied with the described DNER-ME 024/94 and DNIT 133/2010-ME standards. The deformation basin delineation was performed in all the test points; however, the distance was modified between the deflection readings, abiding by the same spacing as employed in the FWD device trials. Figure 4 (b) displays how the Benkelman beam trials were performed in the research study.

(a) (b)

Figure 4. Tests on Rio do Morro Road with (a) FWD and (b) Benkelman beam

3.3. Back-calculation

The deflection basins defined on the field by FWD and the Benkelman beam were back-calculated by the BackMeDiNa software program, version 1.1.0, so that the elasticity moduli for each pavement layer of the six segments were determined by each device. In the Bueno (2016) study, the reinforced subgrade layer was considered as part of the "subgrade system" set, which consists of the natural soil of the land and its reinforcement. In similar case, in this study was determined a single value of the elasticity modulus for the material below the subbase.

The methodology proposed by Theisen *et al*. (2009) was employed to convert the load of the standard axle (a single axle with double wheels) and the utilization of data collected from the Benkelman beam in the BackMeDiNa program. Loading was considered as exerted by only one of the wheels on the axle shaft, the deflections were divided by 2 (representing the effect of only one of the wheels) and the distances between the deflection measurements were recalculated based on the equation derived from the method.

The deflections, air and pavement temperatures, and applied load were imported to BackMeDiNa for the back-calculation process. Subsequently, the materials, pavement layer thicknesses and the Poisson coefficients were input. The initial values were stipulated for the moduli and the adherence "non-adhered" conditions were informed, considering the pre-established conditions indicated by the Method.

The calculations were performed until an approximation was obtained between the measured deflections and the calculated deflections, displayed through the error value (RMS in μm), as values below five μm are sought, as that is an indication of good correlation between measured and calculated deflections. There were also accepted error values ranging from 5 to 10 μm, indicating a reasonable correlation between the field measurements and the calculated deflections, especially for deflection basins obtained from the Benkelman beam due to a lower degree of precision of the device compared with the FWD.

3.4. Prediction of the fatigue life

The purpose of this step is to apply the data obtained from the FWD and the Benkelman beam for pavement empirical-mechanistic calculations. It was performed in the MeDiNa software program, version 1.1.3, and in the "New Pavement (Level A)" project mode. The pavement layer parameters were inserted: materials, thicknesses, back-calculated elasticity moduli from the previous step and the Poisson coefficient.

The Rio do Morro Road was classified as a "primary collector system". The data related to traffic was input in the software that displays a specific screen for calculating the vehicle factor (FV), calculated as 7.027. Then, the N number calculation was performed by MeDiNa, calculated as $7{,}28.10^6$ for the ten-year project period.

The useful lifetime of each pavement was estimated, from segment 01 to 06, through the FWD and Benkelman beam data, based on the number of passes of the standard axle necessary for affecting the asphalt fatigue, considering a maximum of 30% of cracking of the paved area. A fatigue equation was employed corresponding pre-established asphalt class 2 mixtures in the software, as class 2 is defined for project traffics ranging from $6{,}0.10^6$ to $7{,}5.10^6$.

And finally, the required asphaltic thickness was estimated for segments that did not attain their stipulated 10-year useful lifetime design regarding the fatigue criterion, considering all asphaltic mixture classes (class 1, 2, 3, and 4).

4. RESULTS AND DISCUSSIONS

4.1. Deflectometric evaluation

The Rio do Morro Road was paved from 2014 to 2019. In segments 01, 02, and 05, the asphalt surface layer was five years old when measured by deflections while segments 03, 04, and 06, paved in 2019, were measured after six months of vehicle traffic (using the FWD) and 12 months after that (using the Benkelman beam).

The Rio do Morro Road pavement displayed optimal performance regarding deflection measurements. The readings performed by the Benkelman beam, measuring the deflection characteristics for the segments from 26.9 to 52.5 (0.01mm), were lower than a value of 76 (0.01mm) considered as the limit for deflection characteristic as defined in the project design.

The standard deviation values (σ) were verified based on the descriptive statistical calculations of the deflection data that indicated a smaller variation of FWD readings (σ varied from 2.5 to 6.6) compared to the Benkelman beam (σ varied from 3.0 to 10.8). The variation coefficients (CV) also indicated a smaller dispersion in the reading performed by the FWD (CV ranged from 8 to 17) compared to the Benkelman beam (from 10 to 27).

Figure 5 illustrates the comparison between the average deflections measured from each segment. The smaller deflections were measured in segment 05, reinforced subgrade by sand and it has been paved for five years. The largest deflections occurred in segment 03, which was also paved over a sand reinforcement, but that was done more recently, thus possibly it is in a deflection consolidation process, as demonstrated by DNIT (2006).

The individual readings were closer in segments 01 and 02, measured by the FWD and the Benkelman beam. The values obtained from the Benkelman beam were lower than the values measured by FWD in the other segments. Borges (2001), DNIT (2006) and Bueno (2016) informed a contrary trend, that is, the readings performed by the Benkelman beam were greater than the values measured by FWD. However, similar to the deflection behavior in this article, Borges (2001) highlighted a percentage of measured beam values lower than FWD in her research, especially for lower deflection values.

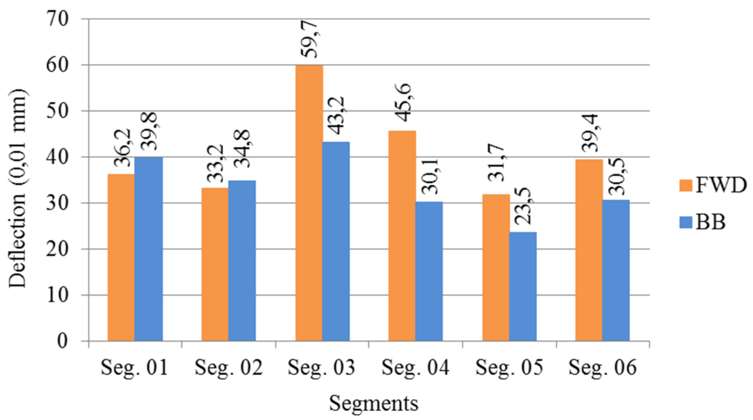

Figure 5. Comparison between the D_0 and FWD and the Benkelman beam (BB) deflection averages

Similar findings were previously reported. The DNIT manual (2006) cites, for example, the authors Fabrício *et al.* (1996), who had chosen to prepare two regression models comparing the Benkelman beam to the FWD, based on the deflectometric level, for values under 85.10^{-2}

mm and values over 85.10^{-2} mm, thereby proving distinct behaviors related to pavement deflection levels. Borges (2001) also cites the authors Pinto and Domingues (2001), who had evaluated 7.5 km of an avenue in Rio de Janeiro, concluding that for low deflections (< 60.10^{-2} mm), the correlation between the two devices is around 1:1, while for high values, the comparison significantly increases.

4.2. Comparison between elasticity moduli

Figure 6 shows the diagram on the calculated elasticity modulus in diverse pavement layers regarding the measured deflection data on FWD and related to segment 02. Similar behaviors were identified for the other segments and the Benkelman beam. Lower deflection values were verified and resulted in better structural response regarding rigidity, resulting in higher elasticity modulus values. Test point example # 35 displayed the best result. On the contrary, test point example # 26 showed higher deflections responsible for lower elasticity modulus values. These behaviors were similar to the researchers Bueno (2016), Machado (2019) and Vieira (2020).

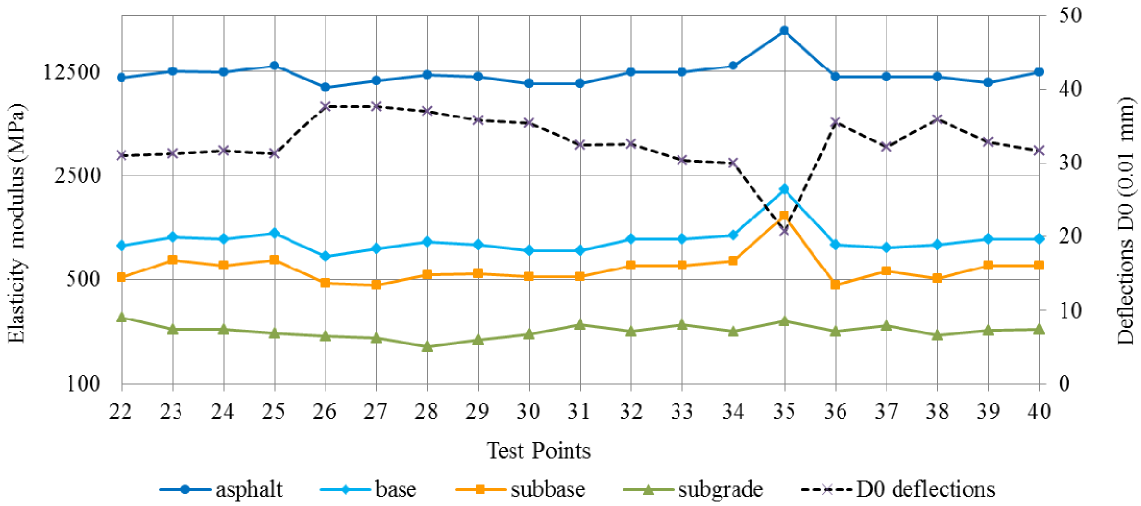

Figure 6. Elasticity moduli from Segment 02 based on FWD data

Based on the calculations in Figure 7 (a), a certain degree of proximity was verified between the calculated modulus's average values for the asphalt surface layer, especially for segment 05, in which there was a greater uniformity between the deflection measurements. Segments 01, 02, and 05 displayed higher values with FWD in the moduli, which were previously paved more five years ago. On the contrary, lower values were obtained in segments 03, 04, and 06, which were recently paved, where they are in an additional consolidation phase provided by traffic over the pavement structure.

Even though the paving has been performed at distinct periods and by different companies, both adhered to the specification for asphaltic mixtures within the granulometric type C range, but recently similar to VI range from DEINFRA-SC (2016). Marshall test specimens were molded for the asphaltic mixture applied to pavements in 2019 and determined the mixture resilient modulus and obtained the maximum value of 11111MPa. The back-calculated moduli values can be concluded as being coherent with the performed lab test.

Figure 7 (b) illustrates the comparison between the calculated elasticity moduli for the base, subbase and subgrade layers. Similar to the previous graph, segment 05 has been verified as displaying the greatest proximity between the calculated values based on the basins generated by FWD and the Benkelman beam. The values obtained from FWD proved to displayed higher values from the base and subbase modulus in segments 01, 02 and 05 (in 5-year-old pavements) and lower values in segments 03, 04 and 06 (recently paved). When the subgrade moduli are evaluated, the average calculation for segment 06 stood out, as it was recently paved. In this case, the subgrade reinforcement material is stone, which contributes by adding greater rigidity and higher modulus values for the subgrade. This situation was also observed by Bueno (2016) in pavements reinforced by stone.

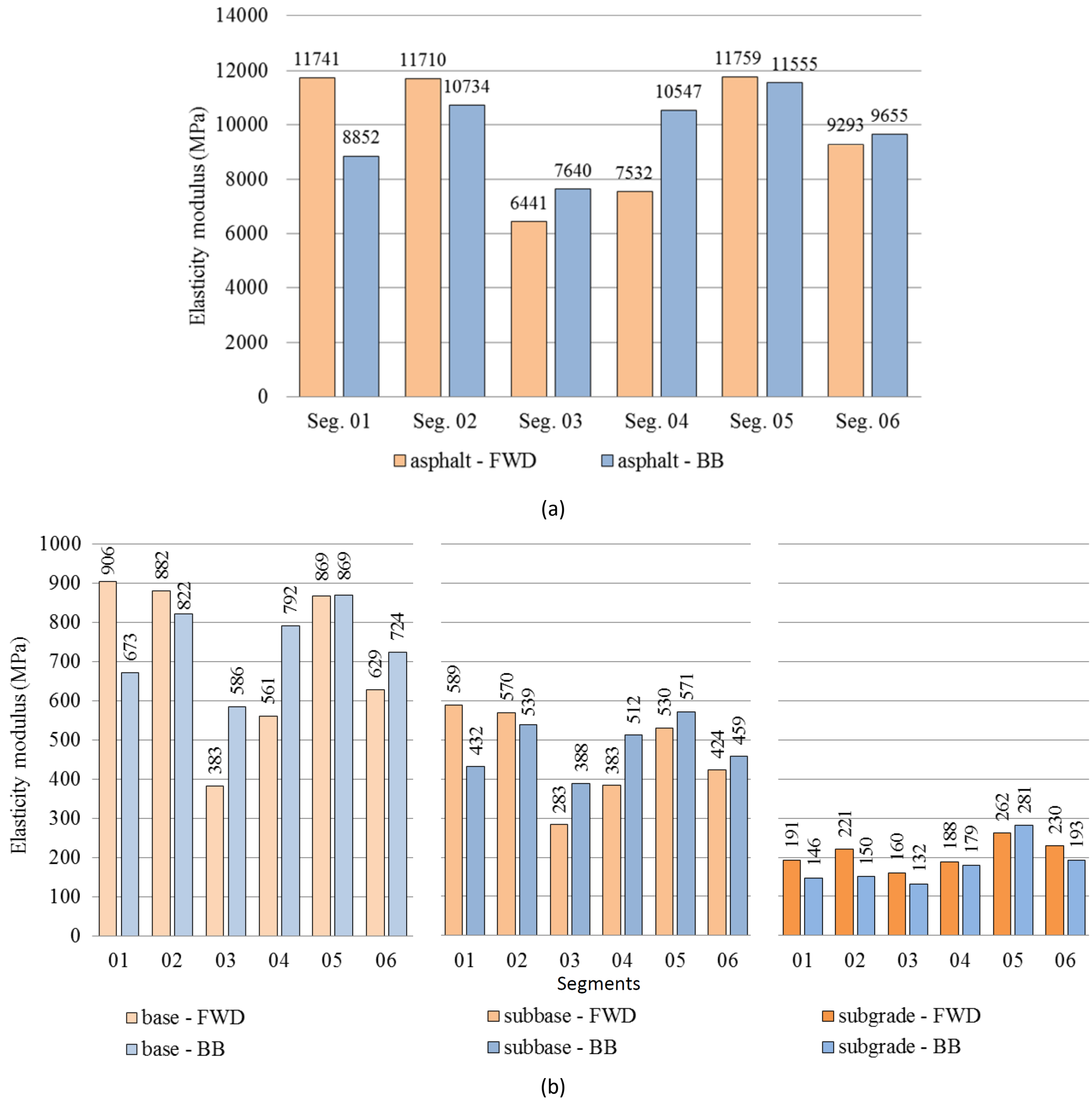

Figure 7. Comparison between the average modulus values (a) for asphaltic surface and (b) for the granular pavement layers

The back-calculated modulus values for the subgrade and subbase layers were among the modulus value ranges obtained by the Franco *et al.* research (2019) for a medium and high-volume road, where lab tests were performed. According to the authors, the resilient modulus ranged from 81 to 468 MPa for the soil layers, and the back-calculated moduli ranged from 52 to 490 MPa. The results found in the lab for the base and subbase ranged from 146 to 744 MPa; through back-calculation, from 78 to 774 MPa. Vieira (2020) calculated the maximum value as 857.7 MPa for the base layer, which displayed greater proximity to the values encountered in this research study.

Increased variability was proven between the measurements of deflection measured by the Benkelman beam, as well as decreased precision in determining the deflectometric basins, a fact that contributed to increased dispersion of the back-calculated elasticity modulus obtained from this device. Thus, when evaluating the graphs between the modulus obtained from both devices, sometimes there is the proximity between the results and sometimes there is a certain distance observed.

Theisen *et al.* (2009) proposed the methodology for converting standard loading and data input from the Benkelman beam in back-calculation programs configured for FWD. In addition to the proximity verified between the moduli's obtained results according to the two devices for specific segments, tests were carried out with the results obtained with the Benkelman beam through the AEMC software. Based on the input of the back-calculated moduli for each deflection basin in the AEMC (Elastic Calculation of Multiple Layers), the theoretical basins were calculated based on the consideration of standard road loading. The RMS_1 error (%) in theoretical basins related to measured basins was very close to the RMS_2 error (%) from back-calculation calculated based on the conversion methodology of Theisen *et al.* (2009). The relative error of RMS_2 related to RMS_1 was an average of 4%.

4.3. Estimate the useful lifetime of the pavement

Table 2 establishes a comparison between the results obtained from the pavement performance calculation related to the fatigue criterion and considering the k1 and k2 parameters of class 2 asphaltic mixtures. Segments 01, 02 and 05 must not exceed the 30% limit of cracked area, based on the calculations performed from data obtained from FWD. This was verified in the columns associated with fatigue cracking by the end of the project period (10 years). The Benkelman beam measurements indicate that segments 02, 04, 05 and 06 must not reach the cracking limit by the end of the project period. There was also a clear-cut verified divergence, when comparing the devices, between the N number values and the time interval (in years) by the time the pavements reach the end of their useful lifetimes regarding the fatigue criterion.

Table 2 – Comparison between the cracking at the end of the project period and the estimated useful lifetime of pavements - Class 2

	FWD			Benkelman beam		
	Cracking %	Fatigue life		Cracking %	Fatigue life	
Segment	after ten years	N	years	After ten years	N	years
01	17.9	$1{,}042.10^7$	13.2	33.2	$6{,}747.10^6$	9.4
02	18.1	$1{,}033.10^7$	13.1	22.1	$8{,}955.10^6$	11.8
03	76.6	$3{,}684.10^6$	5.7	44.7	$5{,}524.10^6$	8
04	44.8	$5{,}524.10^6$	8	22.8	$8{,}707.10^6$	11.5
05	18.2	$1{,}033.10^7$	13.1	17.9	$1{,}042.10^7$	13.2
06	31.7	$6{,}972.10^6$	9.3	27.1	$7{,}741.10^6$	10.5

The thickness of the asphaltic surface (hr) necessary for assuring the pavement's 10-year-useful lifetime was also sought and continued in the calculations, considering a minimum of 5 cm and a 30% cracking limit. The obtained results are shown in Table 3. It is necessary to adjust the asphaltic layer's thickness for all the classes (class 1 to class 4), depending on the device employed for measuring deflections and on the segment. The necessary thicknesses for the asphaltic layer (besides 5 cm) are highlighted in the table. Divergences are verified again between the values calculated with the FWD data and the Benkelman beam. FWD was considered a reference due to its precision. Failures can be made when evaluating pavement based on deflections and back-calculated moduli from Benkelman beam, for example: class 1 and segment 04, which confirmed the need for a 9.4 cm asphaltic layer by the FWD to comply with the useful lifetime of the pavement; in comparison, the Benkelman beam displayed compliance at 5 cm. Regarding the asphaltic mixture characteristics, decreased thickness was verified for employing class 4 parameters, with improved fatigue resistance.

Table 3 – Surface thickness (hr) for the useful lifetime of 10 years

Seg.	Class 1				Class 2			
	FWD		BB		FWD		BB	
	hr (cm)	TR (%)	hr (cm)	TR (%)	hr (cm)	TR (%)	hr (cm)	TR (%)
01	5.0	20.6	7.5	28.8	5.0	17.9	6.9	28.6
02	5.0	20.8	5.0	24.6	5.0	18.1	5.0	22.1
03	11.9	29.7	9.4	29.6	11.7	28.4	8.8	30.0
04	9.4	28.4	5.0	25.3	8.8	28.7	5.0	22.8
05	5.0	20.9	5.0	20.6	5.0	18.2	5.0	17.9
06	6.9	28.3	5.0	29.2	6.3	28.1	5.0	27.1

Seg.	Class 3				Class 4			
	FWD		BB		FWD		BB	
	hr (cm)	TR (%)	hr (cm)	TR (%)	hr (cm)	TR (%)	hr (cm)	TR (%)
01	5.0	16.6	5.0	29.3	5.0	15.4	5.0	20.2
02	5.0	16.8	5.0	20.1	5.0	15.5	5.0	16.9
03	10.7	29.9	8.2	28.9	6.3	28.5	5.0	23.1
04	7.9	29.0	5.0	20.8	5.0	23.1	5.0	17.2
05	5.0	16.9	5.0	16.6	5.0	15.6	5.0	15.4
06	5.0	28.1	5.0	24.3	5.0	19.9	5.0	18.5

5. CONCLUSIONS

The main advantages of collecting the structural data by FWD were the rapid data collection, decreased road interference, enhanced evaluator safety, greater sensitivity in the differentiation of deflections among the calculated segments and more precision in the results from back-calculation, resulting in less disparity in the response among the calculated elasticity moduli.

The deflection measured with the Benkelman beam was nearly equal or lower than the values measured by FWD due to the lower level of deflectometry of the pavement, less than 60.10^{-2} mm, abiding by the studies of other authors for the same level of deflection.

The methodology proposed by Theisen *et al.* (2009) proved to be adequate for converting standard 8.2 tf loading employed in the Benkelman beam tests and inputting the data from this trial in the BackMeDiNa back-calculation software program. It achieved results close to the calculations performed from FWD for the research data from segment 05, for example. In the segment 05 was identified as the most similar among the elasticity back-calculated moduli by both devices. Satisfactory results were obtained in the verifications performed with AEMC through the back-calculated moduli using the Benkelman beam data.

The BackMeDiNa software program proved to be an efficient tool in back-calculation based on the research data and calculation considerations, as values were found close to the lab trial results for the asphaltic surface modulus, as well as the identified modulus values in studies conducted by other authors.

The results showed the importance of mechanistic calculations for designing a pavement structure, as already verified by Souza Jr. (2018) and Lopes (2019). In this research study, depending on the fatigue curve of a bituminous mixture and specific segments, the stipulated 10-year-useful lifetime did not comply with the fatigue criterion, caused by excessive cracking of the pavement, over the 30% limit.

Through the research data and considerations regarding the fatigue equation, it is not advisable to employ the Benkelman beam device in the empirical-mechanistic calculations of pavements, considering the results can cause the design to be excessive or less than necessary. Exception is made when there is a large degree of homogeneity and repetitiveness of deflection measurements, as verified in the 05 segment, where the calculated data was similar to FWD.

It is fundamentally essential to characterize the asphaltic mixture regarding the fatigue curve. The results obtained in the MeDiNa software program in the calculation of the useful lifetime of pavement were substantially modified according to the equations used.

It is recommended to continue monitoring Rio do Morro Road, based on a new set of deflectometric trials at coincident points in the test locations of this research study, calculating the pavement's performance related to the elastic responses of the requests. It is also recommended to follow up on the appearance and propagation of cracks in the pavement, comparing the field results to the simulations performed in the MeDiNa software program. It is suggested to perform lab trials using asphaltic materials which make up the pavement to obtain the k1 and k2 regression parameters of the fatigue equation.

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