Anuário do Instituto de Geociências
Universidade Federal do Rio de Janeiro
https://revistas.ufrj.br/index.php/aigeo/

ISSN 0101-9759
e-ISSN 1982-3908

BR 287 Duplication Designed through the Methods of DNIT and MeDiNa (2020): Structural and Financial Analysis

Análise Estrutural e Financeira da Duplicação da BR 287 Dimensionada pelos Métodos do DNIT e MeDiNa (2020)

Paula Taiane Pascoal, Gabriéli Pires Chiarello, Magnos Baroni,
Deividi da Silva Pereira, Fernando Luiz Zucchi

Universidade Federal de Santa Maria, Santa Maria, RS, Brasil
Emails: ptpascoal@hotmail.com; gabrieli.chiarello@gmail.com; magnos.baroni@gmail.com; dsp@ufsm.br; fernando.zucchi@ufsm.br
Corresponding author: Paula Taiane Pascoal; ptpascoal@hotmail.com

Abstract

The paving field has experienced extensive changes due to the growth of traffic. In order to attend this evolution, it became necessary the implementation of a new methodoly for pavement designing that uses a mechanistic-empirical approach. This paper aims to compare, structurally and financially, three structures, one designed using the DNIT's method and two through "Método de Dimensionamento Nacional – MeDiNa". The three structures were analyzed concerning the behavior in relation to permanent deformation, fatigue life and regarding the necessary investment to pave one-kilometer duplication of an existent highway. Even though the two structures designed through MeDiNa were find to be more expensive than the one designed using DNITs precepts, when considering the cost related to the number of load requests supported by the pavement, structures designed through MeDiNa proved to be more reliable in face of layers damage and presented a good cost per supported requests.

Keywords: Paving; Designed; Cost

Resumo

O campo da pavimentação tem experimentado extensas mudanças devido ao crescimento do tráfego. Para atender essa evolução tornou-se necessário a implementação de uma nova metodologia para dimensionamento de pavimentos, que use uma abordagem mecanistica-empírica. Este artigo tem por objetivo comparar, financeira e estruturalmente, três estruturas, uma dimensionada pelo atual método do DNIT e duas pelo Método de Dimensionamento Nacional – MeDiNa. As três estruturas foram analisadas em respeito ao comportamento em relação a deformação permanente, vida de fadiga e em relação ao investimento necessário para pavimentar um quilometro de duplicação de uma rodovia já existente. Apesar das duas estruturas dimensionadas pelo MeDiNa serem mais onerosas que a estrutura dimensionada a partir dos preceitos do DNIT, quando considerado o desempenho e ao avaliar o investimento em relação ao número de solicitações suportadas pelo pavimento, as estruturas dimensionadas pelo MeDiNa demonstram ser mais confiáveis quanto ao dano das camadas e apresentam um bom custo por carregamento suportado.

Palavras-chave: Pavimentação; Dimensionamento; Custo

Received: 01 June 2021; Accepted: 27 September 2021

1 Introduction

The existing transportation infrastructure in Brazil find itself obsolete and with many discontinuities, being the road mode responsible for one of the sectors with the greatest deficiency in final product delivery. Although this is the main responsible for cargo and passengers transport, only 12.4% of the Brazilian road extension is paved, of which 47.6% of these sections presents pavement problems and 75.7% have road geometry flaws (CNT 2020).

Due to the 2.3% infrastructure investments reduction, made by the federal government in 2020, when compared with 2019, and 31.7% compared to 2010 (CNT 2021), the management of resources have a great emphasis on the area and will carried out to be executed in the best way. So, when designing a road pavement, it seeks to deliver good operational and economics conditions, aiming to provide the user with rolling comfort and safety (Bernucci et al. 2010). The flexible pavement design method of the "Departamento Nacional de Infraestrutura de Transportes" (DNIT), still in use in Brazil, was adapted in 1966 from the United States Army Corps of Engineers (USACE's method) and updated in 1981 (DNER 1981). The method applies an empirical methodology, using the rupture due to granular and soil layers shearing and excessive deformation in the rutting as design criteria. In addition to being an empirical method and having been adapted, the methodology does not consider the particularities of tropical soil behavior and does not include the fatigue effects on the flexible pavement structure (Franco 2007), which is one of the main mechanisms of pavements deterioration.

With a road fleet growth of 59.5% compared to 2010 (CNT 2020), combined to changes in vehicle characteristics, it would be incipient to think that the method adapted 40 years ago will serve this expansion in an impassive manner. Therefore, it was essential to reformulate the priorities regarding the structure's behavior exposed to these load demands. With that in mind, it has been under development for some years, and is currently in the transition phase, a new pavement design named "Método de Dimensionamento Nacional (MeDiNa)".

The mechanistic-empirical methodology insertion and MeDiNa's calculation framework to design Brazilian pavements, aims to increase the reliability of the projects (DNIT 2020a), seeking a reduction in maintenance costs, associating the particularities and characteristics of the materials used in the structure as well as the local environmental conditions and the traffic demand (Fritzen et al. 2019).

This paper aims to present the structural analysis and the financial viability of three pavement structures designed by different methodologies. Thereby, a comparison will be made regarding the deterioration mechanisms, permanent deformation (rutting) and fatigue failure (cracked area), of a pavement structure designed through DNIT method, that will be evaluated using the structure performance routine present in MeDiNa, along with two structures designed and evaluated directly through MediNa, where the variant of these two will be the type of asphalt mixture.

The three pavement structures were designed considering the duplication of an existing highway located in the state Rio Grande do Sul, Brazil. The analyzed concession lane is located on BR 287, between the cities of Santa Cruz do Sul and Tabaí, and it was designed based on the Equivalent Single Axle Load (ESAL), also called number "N", corresponding to the load requests obtained by the Venâncio Aires toll plaza. In addition to comparing the structural behavior of the three proposed structures, as to the cracked area and the rutting, a cost projection for each structure will be presented, in order to assess the financial viability presented by them, considering the two design methodologies.

2 Theoretical Reference

2.1 DNIT Design Method

Developed by Engineer Murillo Lopes de Souza, based on the Design of Flexible Pavements Considering Mixed Loads and Traffic, of USACE, the DNIT method also known as the DNER (1981), has as design principle, by means of parameters, constructive thicknesses of granular layers to protect the subgrade.

According to Bezzera Neto (2004) this method is divided into three fundamental stages, being those the materials definition, traffic determination and designing itself.

One of the designing parameters is the California Bearing Ratio (CBR) of the soil that composes the subgrade, obtained through penetration and expansion tests at certain conditions, that has the function of evaluating the soil resistance in face of significant displacement (Bernucci et al. 2010). DNER (1981) pointed out some considerations that should be used regarding the materials' CBR, in addition to determining granulometric ranges in which the granular materials should be included. Thus, the subgrade material`s CBR must be superior to 2% and the expansion coefficient lower than 2%. In the eventual need for subgrade reinforcement, the material used must have CBR higher than the subgrade and limited expansion by 1%. For subbase and base, the CBR must be superior to 20% and 80%, with an expansion of less than 1% and 0.5%, respectively.

Regarding the traffic demand determination, which the pavement will be subject throughout its project period, the N, that represents the load repetition number of the standard axle (single axle single wheel loads of 8,2 t), and the EALF of USACE, must be obtained (DNIT 2006).

2.2 Método de Dimensionamento Nacional - MeDiNa

In view of these needs of the Brazilian road environment, the designing flexible pavements methodology present in MeDiNa, which considers the mechanistic-empirical model, seeks to associate data related to the materials used in paving and the traffic applied. In it, the pavement is designed based on the stress efforts that it will be subjected, evaluating the stiffness and layers damage, in order to verify the asphalt mixture fatigue behavior and granular and soil layers permanent deformation.

By correlation means and multi-layer elastic analysis routine, the best materials and their respective layer thicknesses are defined in order to calculate the stresses and strains, relating their critical values to the damage that loads repetition can cause to the pavement (Franco & Motta 2020). Finally, the calculation framework checks the thicknesses and analyses if they satisfy the conditions imposed in the designing.

In order to validate the structural design using MeDiNa, it becomes necessary to choose constituent materials and make a laboratory characterization of them, in addition to inserting a broad set of information in the software (Franco & Motta 2020). In reference to subgrade, reinforcement subgrade, subbase and base layers it is necessary to know the constituent materials, inserting resilient parameters (DNIT 2018a) and permanent deformation (DNIT 2018b), as well as the basic characterization and MCT classification (DNER 1996). Regarding to the asphalt mixture, it is inserted information such as Poisson's ratio, granulometric range (ABNT 2003), asphalt content (ABNT 1993), Los Angeles abrasion of the mixture's mineral aggregate (DNER 1998), void content (ABNT 1993), bulk density (ASTM 2007), permanent deformation obtained through the Flow Number (ABNT 2016) and the material's fatigue curve, obtained through the diametral compression test (DNIT 2018c).

2.3 Pavement Costs

According to the *Lei nº 8.666* (1993), the budget is a basic component of any project that will be auctioned. The high cost to pave a highway kilometer is a relevant factor when it comes to the allocation of resources, so it is extremely important that the budget is carried out in the best way and within the parameters required by DNIT.

The road network investments, federal and private, are decreasing year after year. Concerning the public resources, the shortage of it and the budgeting lake of space are the motives. In relation to private ones, the difficulty is explained based on the concessionary investments in the third part of the road concessionary program (CNT 2021).

The asphalt pavements budget in Brazil, for projects and bidding, is based on Sistema de Custos Rodoviários' (SICRO) cost composition. This system has parameters that serve as an aid tool for determining the necessary inputs in the work, both qualitatively and quantitatively (DNIT 2017). To obtain each service unitary costs, presented in SICRO's spreadsheets, DNIT conducts average prices regional surveys, with periodic updates.

3 Method

This paper aimed to compare a flexible pavement performance designed by the current DNIT's methodology (DNER 1981) and two structures designed by MeDiNa's mechanistic-empirical methodology, which is in the transition process (DNIT 2020a), using version 1.1.5 calculation framework of December 2020. In addition, the structures cost was calculated, based on one highway kilometer, using SICRO, and the overall cost was assessed in relation to their performance, associating it with traffic request in each solution indicated.

For this purpose, the designing was performed considering the BR 287 highway duplication, between the cities of Santa Cruz do Sul and Tabaí, both in the state of Rio Grande do Sul, Brazil, where a traffic study of Venâncio Aires toll plaza has been conducted since January 2013 until December 2020 (Empresa Gaúcha de Rodovia 2021). Within this period, the monthly traffic volume and the corresponding load requests were analyzed in order to obtain the location N value, considering the USACE's EALF. From this study, an annual N was obtained, and an 2.5% increase was projected, defined through the region's Gross Domestic Product (GDP), for the ten-year project period, obtaining the project solicitations number.

In order to compare the thickness influence and/or addition of new layers, as well as the structure's performance, it was chosen a standard pavement structure composed of subgrade, subbase and base of granular base and asphalt concrete as coating layer. In item 3.1 the materials that compose each layer will be presented.

For the flexible pavement structure designing following DNIT's methodology, that is in use in Brazil, named "Structure 01", the CBR obtained in laboratory was considered along with the solicitations number. The base and coating layers thicknesses were determined according to the DNER (1981) and DNIT (2006) precepts.

Two other structures were designed based on the mechanistic-empirical methodology present in MeDiNa. In the structure named "Structure 02", the same constituent materials as Structure 01 were considered. In "Structure 03" the asphalt mixture type was modified.

It is noteworthy that for the main arterial system, highway type under analyses, which has 95% reliability in its analyses, fatigue cracking is limited to 30% and the maximum permanent deformation is 10 mm (Franco & Motta 2020). Thus, the analyses presented in chapter 4 will be carried out based on these values.

3.1 Structures Constituent Materials

The subgrade layer constituent material is a lateritic clayey soil, according to MCT methodology, evaluated by Santos et al. (2019) and Zago et al. (2021). This material was classified as a low and medium plasticity inorganic clay, with low colloidal activity and clay predominance in its composition, according to Unified Soil Classification System (USCS), and characterized as a material with high volume change, framed in the group A-7-6, according to the classification of Transportation Research Board (TRB) (Santos et al. 2019). The optimum moisture content, maximum dry unit weight, the CBR of the subgrade layer soil, obtained through the DNER ME 049/94 regulations (DNER 1994), are shown in Table 1 (Zago 2016).

To evaluate the Structure 01's performance, designed through DNIT's method, over the ten-year project period, it was used the tool "Evaluate Structure" present in the MeDiNa's framework. To make use of this tool it was necessary to introduce parameters related to the resilient behavior and permanent deformation. Zago et al. (2021) evaluated this behavior based on the repeats load triaxial tests performance used to obtain the resilient modulus (RM) and permanent deformation (PD), which are shown in Table 1.

Table 1 Subgrade parameters (Zago et al. 2021).

Subgrade of clayey soil	
Optimum moisture content - Standard proctor (%)	19.60
Maximum dry unit weight - Standard proctor (kg/m³)	1.67
California Bearing Ratio – CBR (%)	11.00
Resilient Modulus - regression coefficient - k_1	215.02
Resilient Modulus - regression coefficient - k_2	0.23
Resilient Modulus - regression coefficient - k_3	-0.29
Permanent Deformation - regression coefficient - ψ_1	0.87
Permanent Deformation - regression coefficient - ψ_2	0.01
Permanent Deformation - regression coefficient - ψ_3	1.21
Permanent Deformation - regression coefficient - ψ_4	0.04

For the subbase and base, it was use granular base. Within MeDiNa's calculation framework there is an already characterized granular materials database to be used in these layers. "Brita Graduada – C6" was used to compose the subbase and "Brita Graduada - C5" for the structures base. These materials parameters are shown in Table 2.

Finally, for the asphalt layer, it was used two types of asphalt mixture, as shown in Table 3, where one is named, within the MeDiNa's database, as "Class 1", used in Structure 01 and 02, and the other is named "Class 4", used in Structure 03 to represent mixture with modified binder, so it became possible to verify the asphalt mixture influence on costs and project life.

Table 2 Base and subbase parameters.

Parameters	Base (C5)	Subbase (C6)
Poisson's ratio	0.35	0.35
Contact	Unbound	
Compaction energy	Modified proctor	
Los Angeles Abrasion (%)	43.00	43.00
Bulk Density (g/cm³)	2.22	2.02
Optimum Moisture Content (%)	5.00	7.50
Resilient Modulus (MPa)	381.00	278.00
Permanent Deformation - regression coefficient - ψ_1	0.08	0.13
Permanent Deformation - regression coefficient - ψ_2	-0.28	-0.06
Permanent Deformation - regression coefficient - ψ_3	0.89	1.10
Permanent Deformation - regression coefficient - ψ_4	0.09	0.07

Table 3 Asphalt mixture parameters.

Parameters	Class 1	Class 4
Poisson's Ratio	0.30	0.30
Contact	Bound	Bound
Bulk Density (g/cm³)	2.40	2.40
Resilient Modulus (MPa)	5764	10492
Fatigue - regression coefficient - k1	$5.49E^{-11}$	$1.91E^{-5}$
Fatigue - regression coefficient - k2	-3.25	-1.90

3.2 Designed Structes Cost

After designing the structures and evaluating its structural performance, the three composition proposals were budgeted, based on DNIT's SICRO, of October 2020. For this purpose, after the standard budget spreadsheet development, made through the compositions available from DNIT, created to satisfy the project's need, the structures were budgeted considering one highway kilometer data, with basic geometry of 7.2 m of main track and 5.0 m of shoulder.

Within the budget subsequently presented, only the direct highway implementing costs were considered, being those: earth movements, granular bases execution, bonding and priming layers, asphalt layers and signs to be placed along the road.

The Indirect Benefits and Expenses (BDI) and the construction site cost were not considered in the budget. The main services considered, along with their unitary costs are shown in Table 4. Some items, that were not included in SICRO, were consulted on the Agência Nacional do Petróleo (ANP)'s website, where an estimate was made considering April 2019 as a month reference, due to the lack of state values for Rio Grande do Sul.

In possession of the budgets, two types of analysis were made: the first one refers to the total cost per kilometer, for each of the three structures, comparing them with each other; the second analysis considered the total cost per kilometer divided by the solicitations number that the pavement would remain without suffering excessively damage from fatigue - cracked area (Nfat) and permanent deformation - rutting (Npd), considering the limits imposed on this type of road.

Table 4 Unitary costs per service (DNIT 2020b; ANP 2019).

Service	Unitary Cost
Regularization of Subgrade	0.59 R$/m²
Subgrade Reinforcement with Deposit Material	23.85 R$/m³
Subbase of Granular Base with Produced Stone	102.21 R$/m³
Base of Granular Base with Produced Stone	115.91 R$/m³
Priming with Diluted Asphalt	4.92 R$/m²
Binding Painting	0.92 R$/m²
Asphalt Concrete-track C- extracted sand, produced stone	289.78 R$/t
Asphalt Concrete with Polymer asphalt-track C- extracted sand, produced stone	326.81 R$/t
Convencional Asphalt Mixture	2635.70 R$/t
Asphalt Mixture with Polymer Modified Binder	3295.47 R$/t
Signaling Cost - horizontal painting	25.04 R$/m²
Signaling Cost - warning signs	551.77 R$/unit
Signaling cost - bidirecional reflective tack	15.27 R$/unit

4 Results and Discussions

Hereafter, the results and main discussions will be presented, starting with the traffic study, in which it was possible to obtain the number N for a ten years period of use. In sequence, the three structures and their performance will be presented, as well as the economic viability of each one of the designs.

4.1 Traffic Study

Considering the eight-year data from Venâncio Aires' toll plaza, under Empresa Gaúcha de Rodovia' concession, it was possible to analyze the monthly traffic volumes and the corresponding traffic requests in order to obtain the number N for the ten-years project period, using the USACE's EALF. All the results were obtained following the DNIT (2006). Table 5 presents the axle types, with their respective Vehicle Factor (FV), calculated based on the EALF, for each of the categories. The traffic Average Daily Volume (VDM) obtained was 2631.97. The categories numbers 1, 7, 8 and 12 were not considered in this projection.

This study resulted in an annual N of 6.03×10^6, in the end of the first year's requests. Considering a 2.5% growth rate, in the ten year's requests that were proposed, the project total N was obtained, resulting in $6{,}75 \times 10^7$ load requests number, that were adopted to BR 287 duplication structures designing, section from Santa Cruz do Sul to Tabaí.

Table 5 Vehicle Factor per axle.

	Axle type	FV - USACE
2	Single axle single whell , Single axle double whel	3.57
3	Single axle, Tandem axle double whel	8.83
4	Single axle single whell , Tridem axle- double whel	9.58
5	Single axle single whell , Single axle double whel, Tridem axle double whel	12.87
6	Single axle single whell , Tandem axle double whel, Tridem axle double whel	18.13
9	Single axle single whell , Single axle double whel, Tandem axle double whel, Tandem axle double whel	21.42
10	Single axle single whell , Tandem axle double whel, Tandem axle double whel, Tridem axle double whel	26.68
11	Single axle single whell , Tandem axle double whel, Tridem axle double whel, Tridem axle double whel	27.43

4.2 Designed Structures

The flexible pavement Structure 01 was design considering the DNIT's methodology (CBR's method or late DNER's method), based on a subgrade soil CBR of 11% and the number N presented previously. The Figure 1 presents the structure composed by a lateritic soil subgrade, subbase and base composed of granular base, with 16 and 15 cm respectively, and an asphalt layer of 12.5 cm.

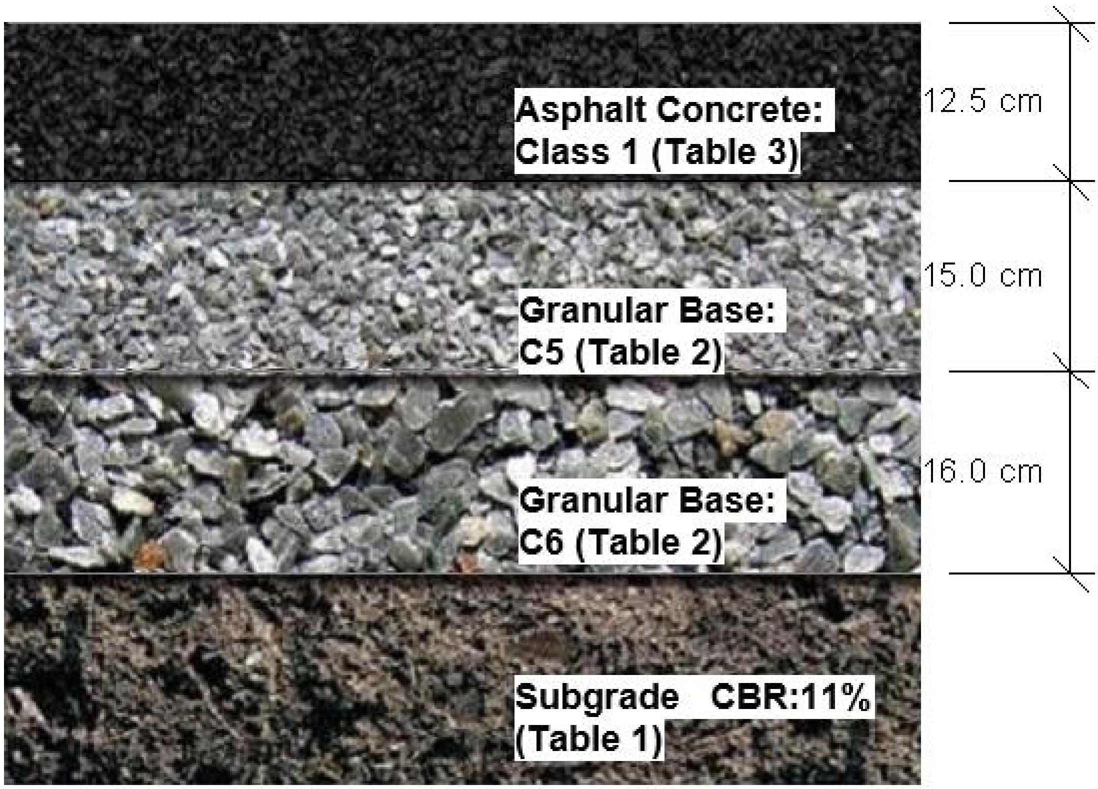

Figure 1 Structure 01, designed using DNIT's methodology.

To verify the structure performance regarding to the rutting and fatigue cracking mechanisms, for the project period, the structure was evaluated by the "evaluate structure" routine calculation framework. The results will be presented in Table 6.

At the end of the 12th month of load requests, the structure will be close to the rutting and cracked area limit, being those 10 mm and 30%, respectively. On the 13th month, in case of the pavement being well executed, it would reach 30.7% of cracked area and then it would suffer the most critical damage assessed, from fatigue failure. The cracked area limit would be extrapolated in the 27th month, when reaching permanent deformation of 10.01 mm. With this analysis, it is possible to conclude that the structure designed following the DNIT precepts, based on DNER (1981) is structurally inefficient for traffic requests, with these constituent materials.

The Structure 02, designed with MeDiNa, has its composition shown in Figure 2. This structure has the same constituent materials as Structure 01, however, due to the traffic demand and the materials particularities, it was necessary to add an asphalt layer. Thus, it is composed by a lateritic soil subgrade, granular base subbase and base, with 15 cm each, and two asphalt layers of 15 and 12 cm each.

In order to reduce the asphalt layer thicknesses and to analyze the different materials behavior, Structure 03, also shown in Figure 2, has two asphalts with polymer modified binder layers, with 9 and 14 cm thicknesses, in addition to granular base subbase and base, 15 cm each, and a lateritic soil subgrade. The two structures performance, designed by MeDiNa, is shown in Table 7. Using the Medina's database, the material with the higher characteristic similarity to asphalt with polymer modified binder is the asphalt concrete of Class 4. For this reason, in Structure 3 that was the material used to represent the polymer-modified asphalt layers.

Table 6 Structure 01 performance regarding the rutting and cracked area.

		Structure 01	
Period	Neq	Rutting	Cracked Area
1th month	$4.96x10^5$	8.4 mm	4.4%
6th month	$2.99x10^6$	9.2 mm	12.9%
12th month	$6.02x10^6$	9.6 mm	27.6%
24th month	$1.22x10^7$	9.9 mm	71.3%
36th month	$1.85x10^7$	10.2 mm	99.0%
48th month	$2.50x10^7$	10.3 mm	99.0%
120th month	$6.75x10^7$	10.9 mm	99.0%

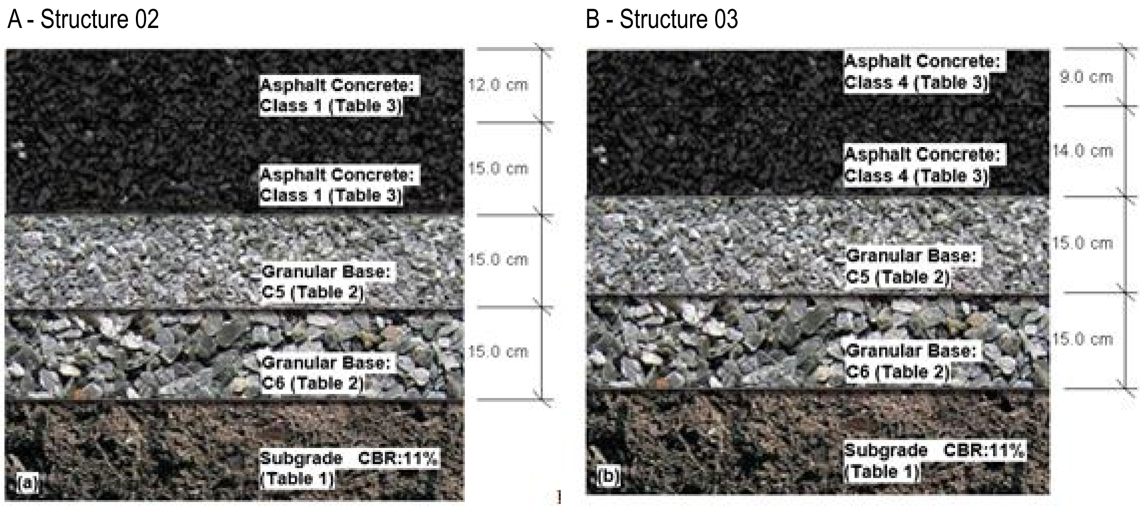

Figure 2 A. Structure 02; B. Structure 03, designed using MeDiNa's software.

Table 7 Structures 02 e 03 performances regarding the rutting and cracked area.

		Structure 02		**Structure 03**	
Period	N eq	Rutting	Cracked area	Rutting	Cracked area
1th month	$4.96x10^5$	3.3 mm	1.8%	3.0 mm	1.8%
6th month	$2.99x10^6$	3.7 mm	3.5%	3.4 mm	3.5%
12th month	$6.02x10^6$	3.8 mm	4.6%	3.5 mm	4.7%
24th month	$1.22x10^7$	3.9 mm	6.6%	3.6 mm	6.7%
36th month	$1.85x10^7$	4.0 mm	8.5%	3.7 mm	8.6%
48th month	$2.50x10^7$	4.1 mm	10.6%	3.8 mm	10.7%
120th month	$6.75x10^7$	4.3 mm	29.7%	4.0 mm	30.0%

Structures 02 and 03 showed satisfactory behavior regarding permanent deformation and cracked area, both within the limits imposed for the type of track, during the 10 years of project. At the end of the 120 months, Structure 02, as long as it was executed correctly, would present 4.3 mm of rutting and 29.76% of cracked area, while Structure 03, would present a final rutting of 4.0 mm and 30% cracked area. What differs this structure from the other are the Structure 02's 27 cm of conventional asphalt mixture coating, and the Structure 03's 23 cm of asphalt mixture with polymer modified binder. The financial viability analysis for each one of the structures will be presented in item 4.3.

Is it possible to visualize the three structures behavior regarding rutting (permanent deformation) and fatigue cracking (cracked area) in Figure 3, and in association with the Table 6 content, it is concluded that the structure designed though DNIT (DNER 1981) will suffer rupture before the end of the period project considered, while the two structures designed based on the new design method, must present an excellent performance since they are well executed. This is due to the design by MeDiNa not only consider the subgrade's ability to withstand rupture shear deformations, but also the properties and characteristics of all structure constituents.

4.3 Construction Costs of Pavement Structures

After the design of the three structures, the implementation costs of the highway duplication were calculated based on SICRO. It is noteworthy that the costs here are referred to the direct costs within the pavement construction, without considering the indirect costs such as Indirect Benefits and Expenses and administration costs. Figure 4 shows a cross-section schematic of the structure left side, however, it does not show the layers thickness, which was presented in Figures 1 and 2.

In relation to costs, Structure 01, designed through DNIT's empirical methodology, would require R$ 1.698.360,50 investment for the one highway kilometer execution. It is possible to analyze that this value is, approximately, the standard value when referring to paving mileage costs.

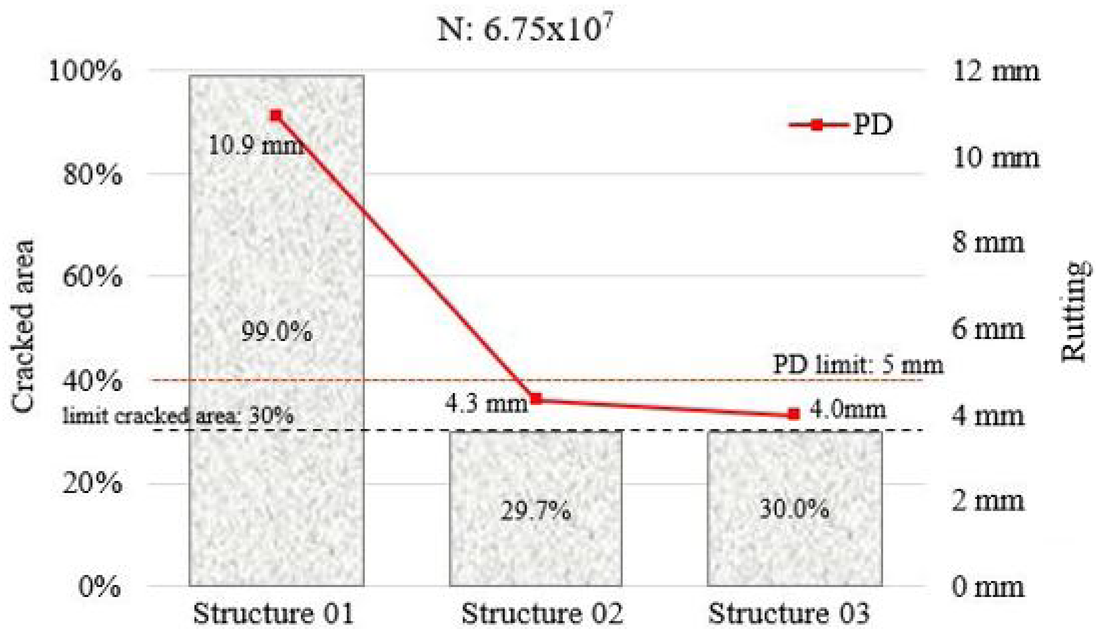

Figure 3 Comparison of three structures structural performance in the face of permanent deformation and fatigue.

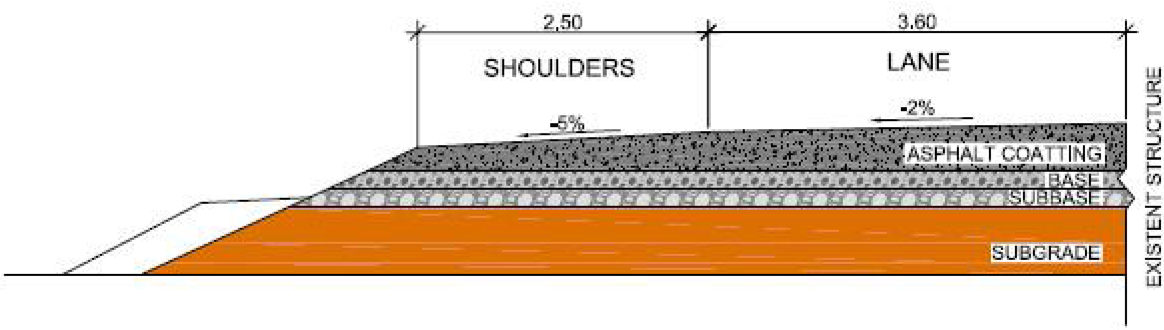

Figure 4 Pavement left cross-section of the duplication.

Structure 02, designed through MeDiNa, which has conventional asphalt mixture, would require R$ 2.978.422.46 investment per kilometer, including factors such as the increase in bonding paints due to the two asphalt coating layers. When comparing with Structure 01, in addition to Structure 02 resisting 10 years of efforts, the difference in the budget is notable, due to the 14.5 cm asphalt coating thickness addition, there is a better structural performance and a significant increase in the capital to be applied.

Aiming to reduce the coating thickness and make a comparison, the third structure was designed considering the use of asphalt with polymer modified binder. Structure 03 presented satisfactory structural behavior and would require R$ 2.859.620,82 investment, which is lower than Structure 02. Although the asphalt with polymer modified binder ton value is higher than the conventional asphalt mixture ton, the fact that requires 4 cm less asphalt coating, favors the budget of Structure 03.

Table 8 shows the percentage that each executive stage composes in the total cost per kilometer for each structure. Excavation, loading, transportations and compaction services are included in the Earth moving item; the item paving includes regularizing the subgrade, base and subbase, priming with dilutes asphalt, bonding paint services and all asphalt layer components. In the signaling item were included the horizontal signaling, reflective bidirectional stud, in addition to the complete vertical signaling.

When analyzing the highway global cost per kilometer, it appears that Structure 02 and 03 had an increase in the budget by 75.4% and 68.4%, respectively, when compared to Structure 01. Apparently, the investment for structures designed through MeDiNa initial costs is much higher cost when compared to the current DNIT values. However, when going through these values by number of load requests supported in face of the damage, it should be noted that Structure 01 would resist only through the first year of use, as in the 13th month, it would exceed the conservation limits and suffer from fatigue failure. To assess the cost in relation to N, it is considered the 13th month of use equivalent N, that is 6.56×10^6, and the structure cost per kilometer. Thus, the cost of the Structure 01 would be R$ 0.26 per Nfat. If performed the same analysis, however, considering the month's Neq that the structure reached the limit for permanent deformation, in this case, the 27th month of use, the cost per Neq would be R$ 0.12, considering the Npd of 1.38×10^7.

When carrying the same analysis for Structure 02 and 03, considering that both were designed through MeDiNa and would support requests during the 10 years project, being the Neq the one of the 120th month of load request, the cost in relation to N is R$ 0.044 for Structure 02 and R$ 0.042 for Structure 03. In this context, at first, can be questioned the structures designed through MeDiNa have high global implementation cost, considering that they are almost 70% more expensive than the structure designed by the DNIT method. However, when the global cost is exposed according to the load requests number supported by the pavement, this investment proves to be necessary and effective.

Table 8 Percentage of cost divided in stages of construction.

Stage	Structure 01	Structure 02	Structure 03
Total cost per km	R$ 1.698.360,50	R$ 2.978.422.46	R$ 2.859.620,82
Earth moving	15.45%	9.03%	9.41%
Paving	83.61%	90,42%	90.02%
Signaling	0.94%	0.55%	0.57%

5 Conclusion

Considering that all layers composing the flexible pavement structure must withstand traffic demands and in view of the development and transition of the new Brazilian design method, the study aimed to present a comparative analysis between structures designed through the design method on force for years (DNER 1981) and the method that is in transition (DNIT 2020a), in addition to comparing the investment from one methodology to another.

Based on the verifications carried out, it is concluded that the structure designed by DNIT's designing method, even though meeting all project requirements, would support traffic for only one year, as it would reach the fatigue limit in the 13th month of use. In addition to that, the structure would suffer from the damage caused by permanent deformation, presenting defects with values that overreach the imposed site type limits.

As for the structures designed by MeDiNa's mechanistic-empirical method (Structure 02 and Structure 03), there was a good performance in terms of cracked area and rutting during the ten years of service. The two structures designed through this method have a performance forecast, which would likely provide their users with comfort and rolling economy, besides security, achieving the basic principles.

Increasing the asphalt layer thickness, applying a higher quality coating, or even the need to apply larger granular layers makes the structure more expensive. When analyzing the DNIT's designed structure cost, considering that is does not present a good structural behavior, the cost becomes very high when compared to the structures designed through MeDiNa. At first, the MeDiNa structures overall value per kilometer is surprising, but when analyzing the load requests and the structure quality, this value becomes acceptable and promising, also considering the low maintenance over the 10 years project. Among the stages that involve the highway execution, paving is the one that requires the higher investment, due to the more expensive input demands.

In front of that, it is concluded that the DNIT's method has fulfilled its purpose in the road sector and attended brilliantly all the past decades necessities.

Therefore, due to the increase in load requests, and carrying capacity, the traffic growth and new technologies in the area, the introduction of MeDiNa in the paving field is necessary, being that it considers a mechanistic-empirical methodology, bringing a design project evolution by realizing the project based on whole constituent properties and the damage caused to the pavement.

6 Acknowledgments

The authors are grateful to the ANP/PETROBRAS and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for their support and the reviewers for their valuable contributions.

7 References

ABNT – see Associação Brasileira de Normas Técnicas.

Agência Nacional de Petróleo 2019, *Preços médios ponderados mensais (produto/estado) de distribuição de produtos asfálticos*, viewed 16 March 2021, <https://www.gov.br/anp/pt-br/assuntos/precos-e-defesa-da-concorrencia/precos/precos-de-distribuicao-de-produtos-asfalticos>.

ANP – see Agência Nacional de Petróleo.

Associação Brasileira de Normas Técnicas 1993, *NBR 12891 - Dosagem de Misturas Betuminosas pelo Método Marshall*, Rio de Janeiro, Brasil.

Associação Brasileira de Normas Técnicas 2003, *NBR NM 248 - Agregados - Determinação da Composição granulométrica*, Rio de Janeiro, Brasil.

Associação Brasileira de Normas Técnicas 2015, *NBR 16505 - Misturas Asfálticas - Resistência à deformação permanente utilizando o ensaio uniaxial de carga repetida*, Rio de Janeiro, Brasil.

America Society for Testing and Materials 2007, *C127 - Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate*, ASTM International, West Conshohocken.

ASTM - see America Society for Testing and Materials.

Bernucci, L., Motta, L.M.G., Ceratti, J.A.P. & Soares, J.B. 2010, *Pavimentação asfáltica: formação básica para engenheiros*, Editora Abeda, Rio de Janeiro.

CNT - see Confederação Nacional do Transporte.

Confederação Nacional do Transporte 2020, *Anuário CNT do transporte: estatísticas consolidadas*, viewed 10 April 2021, <https://anuariodotransporte.cnt.org.br/2020/>.

Confederação Nacional do Transporte 2021, *Conjuntura do Transporte: Investimentos da União e das Concessionárias em infraestrutura de transporte*, viewed 10 April 2021, <https://www.cnt.org.br/agencia-cnt/investimentos-da-unio-e-das-concessionrias-em-infraestrutura-de-transporte>.

Departamento Nacional de Estradas de Rodagem 1981, *Método de Projeto de Pavimentos Flexíveis*, Rio de Janeiro. https://www.gov.br/dnit/pt-br/assuntos/planejamento-e-pesquisa/ipr/coletanea-de-manuais/vigentes/667_metodo_de_projeto_de_pavimentos_flexiveis.pdf

Departamento Nacional de Estradas de Rodagem 1994, *Método de Ensaio 049 - Solos - Determinação do índice de Suporte Califórnia utilizando amostras não trabalhadas*, Rio de Janeiro.

Departamento Nacional de Estradas de Rodagem 1996, *DNER-CLA 259 - Classificação de solos tropicais para finalidades rodoviárias utilizando corpos-de-prova compactados em equipamento miniatura*, Rio de Janeiro.

Departamento Nacional de Estradas de Rodagem 1998, *DNER-ME 35 - Agregado - Determinação da abrasão Los Angeles*, Rio de Janeiro.

Departamento Nacional de Infraestrutura de Transporte 2006, *Publicação IPR – 719, Manual de pavimentação*, Rio de Janeiro.

Departamento Nacional de Infraestrutura de Transporte 2017, *Manuais de Custos de Infraestrutura de Transportes,* Rio de Janeiro.

Departamento Nacional de Infraestrutura de Transporte 2018a*, Norma DNIT 134 - Pavimentação - Solos: determinação do módulo de resiliência: método de ensaio*, Rio de Janeiro.

Departamento Nacional de Infraestrutura de Transporte 2018b, *Norma DNIT 179 - Pavimentação - Solos: determinação da deformação permanente: instrução de ensaio*, Rio de Janeiro.

Departamento Nacional de Infraestrutura de Transporte 2018c, *Norma DNIT 183 - Pavimentação asfáltica: ensaio de fadiga por compressão diametral à tensão controlada: método de ensaio*, Rio de Janeiro.

Departamento Nacional de Infraestrutura de Transporte 2020a, *DNIT inicia procedimentos para transição do método de dimensionamento de pavimentos*, viewed 16 March 2021, <https://www.gov.br/dnit/pt-br/assuntos/noticias/dnit-inicia-procedimentos-para-transicao-do-metodo-de-dimensionamento-de-pavimentos, 2020>.

Departamento Nacional de Infraestrutura de Transporte 2020b, *Relatório analítico de composição de custos-região sul*, viewed 18 March 2021, <https://www.gov.br/dnit/pt-br/assuntos/planejamento-e-pesquisa/custos-e-pagamentos/custos-e-pagamentos-dnit/sistemas-de-custos/sicro/sul/rio-grande-do-sul/2020/outubro/outubro-2020>.

DNER - see Departamento Nacional de Estradas de Rodagem.

DNIT - see Departamento Nacional de Infraestrutura de Transporte.

Empresa Gaúcha de Rodovia 2021, *Volumes de tráfego da praça de pedágio de Venâncio Aires*, viewed 2 March 2021, <https://www.egr.rs.gov.br/conteudo/1716/volume-de-trafego>.

Franco, F.A.C.P. 2007, 'Método de dimensionamento mecanístico empírico de pavimentos asfálticos - SisPav', PhD thesis, Universidade Federal do Rio de Janeiro. http://www.coc.ufrj.br/pt/teses-de-doutorado/151-2007/1107-filipe-augusto-cinque-de-proenca-franco

Franco, F.A.C.P. & Motta, L.M.G. 2020, Execução de estudos e pesquisa para elaboração de método de análise mecanístico-empírico de dimensionamento de pavimentos asfálticos: manual de utilização do programa MeDiNa, Versão 1.1.4, viewed 3 March 2021, <https://www.gov.br/dnit/pt-br/assuntos/planejamento-e-pesquisa/ipr/medina/medina-1-1-4-manual-de-utilizacao.pdf>.

Fritzen, M.A., Ubaldo, M.O., Lima, C.D.A., Motta, L.M.G. & Franco, F.A.C.P. 2019, 'Estudo de projeto de reforço utilizando o método de dimensionamento nacional – MeDiNa', *9º Congresso Rodoviário Português*, Lisboa, Portugal.

Lei nº 8.666 1993, Brasil. http://www.planalto.gov.br/ccivil_03/leis/l8666cons.htm

Santos, T.A., Specht, L.P., Pinheiro, R.J.B., Ceratti, J.A.P. & Brito, L.A.T. 2019, 'Avaliação da resistência e da deformação resiliente de quatro solos de subleitos rodoviários no estado do Rio Grande do Sul', *Revista Transportes*, vol. 27, no. 1, pp. 48-64. https://doi.org/10.14295/transportes.v27i1.1531

Zago, J.P. 2016, 'Estudo da deformação permanente de três solos típicos de subleito rodoviários de Santa Maria – RS', Master thesis, Universidade Federal de Santa Maria. https://repositorio.ufsm.br/handle/1/12036

Zago, J.P., Pinheiro, R.J.B., Baroni, M., Specht, L.P., Delongui, L. & Sagrilo, A.V. 2021, Study of the permanent deformation of three soils employed in highway subgrades in the municipality of Santa Maria – RS, *International Journal of Pavement Research and Technology*, vol. 14, pp. 729-39. https://doi.org/10.1007/s42947-020-0129-6

Author contributions
Paula Taiane Pascoal: conceptualization; methodology; formal analysis; writing – original draft; review and editing. **Gabriéli Pires Chiarello:** conceptualization; methodology; formal analysis; writing – original draft; review and editing. **Magnos Baroni:** advisor; supervision; validation; writing – review e editing. **Deividi da Silva Pereira:** supervision; validation; writing – review e editing. **Fernando Luiz Zucchi:** writing – review e editing.

Conflict of interest
The authors declare no potential conflict of interest.

Data availability statement
All data included in this study are publicly available in the literature.

Funding information
Cooperation agreement between ANP/PETROBRAS and UFSM (5850.0106353.17.9).

Editor-in-chief
Dr. Claudine Dereczynski

Associate Editor
Dr. Márcio Fernandes Leão

How to cite:
Pascoal, P.T., Chiarello, G.P., Baroni, M., Pereira, D.S. & Zucchi, F.L. 2022, 'BR 287 Duplication Designed through the Methods of DNIT and MeDiNa (2020): Structural and Financial Analysis', *Anuário do Instituto de Geociências*, 45:44094. https://doi.org/10.11137/1982-3908_45_44094