v. 2, n. 28, 2022

Journal of
Engineering
Research

INFLUENCE OF MOISTURE CONTENT ON THE TEST OF RESILIENCE MODULES IN BR-319/AM SUBGRADE SOILS

Vinícius Silveira Levay
Department of Civil and Environmental Engineering at the: ''Faculdade de Tecnologia da Universidade de Brasília"
Brasília, Brazil
lattes.cnpq.br/4006167192472182

Michéle Dal Toé Casagrande
Department of Civil and Environmental Engineering of: ''Faculdade de Tecnologia da Universidade de Brasília"
Brasília, Brazil
lattes.cnpq.br/2689915812155389

Luiz Guilherme Rodrigues de Mello
Department of Civil and Environmental Engineering of: ''Faculdade de Tecnologia da Universidade de Brasília"
Brasília, Brazil
lattes.cnpq.br/2607319033421081

Abstract: In view of the BR-319 implementation scenario, with the execution of Lot Charlie and the contracting of projects in the middle section, and the introduction of the new national dimensioning method (MeDiNa), the present work sought to evaluate the influence of the behavior of the resilience module with the gain of ±2% of moisture in soils of BR-319. Soil characterization tests were carried out, such as Atterberg limits, granulometry by sedimentation, and real density, in addition to the resilience module according to the DNIT 134/2018 standard. As expected, the results showed that the moisture gain generated a reduction of more than 50% in the average resilience modulus. The confining stress-dependent model presented a low frame, and the deviation stress-dependent model showed a better frame, but the composite model used in MeDiNa proved to be the most suitable for this type of soil, regardless of moisture.
Keywords: BR-319, Resilient Modulus.

INTRODUCTION

The BR-319/AM highway was built under the military government, during the 70's and8 0's, to foster the 885 km land connection between the cities of Manaus and Porto Velho and promote region's economic development. Fearnside and Graça (2009) state government policy was to build the highways without asphalt coating, and to coat them over time if there was a significant traffic flow increase. However, the BR-319 was an exception to the policy as asphalt was applied during the construction.

Many challenges were encountered during the construction process due to areas prone to flooding, watercourses, the lack of rocky material, and high precipitation levels. In addition to those challenges, the urgency for the highway was such the hat road was built during a period of rain. Therefore, to protect the pavement structure from heavy rainfall, the engineers used a construction technique that consisted of applying kilometers of canvas to the pavement and road structure during the implementation stages of the project, as shown in Figure 1 (Neto and Nogueira, 2014 and Fearnside and Graça, 2009).

Because of the physical conditions of the site, a lack of maintenance, vehicles exceeding weight limits, and high precipitation, the highway became impassable within a decade, owing to a series of holes that were more hazardous to vehicles than in an unpaved road.

The highway reconstruction has been planned and postponed repeatedly. Currently, the highway has two paved road sections, the first section from km 0 to km 198 (counting from Manaus) and the second section from km 622 (BR-319/AM/RO) to km 64.90 (BR-319/RO), as shown in Figure 2.

Reconstruction is currently being done by the National Department of Infrastructure and Transport (DNIT) on lot C (198-250 km) in the BR-319/AM. In addition, a preliminary environmental license was also granted to DNIT by Ibama (Brazilian Institute of Environment and Renewable Natural Resources) in July 2022 for the middle section, which encompasses 405 kilometers of the highway.

The moisture content of the composite layers on the pavement may change in response to variations in the water level, infiltration through cracks, and uncoated edges (Franco, 2007). Several studies have been conducted to investigate the moisture content "in loco" (Nazarian and Yuan, 2008; Khoury et al., 2009; Freitas, 2019). It was observed that the resilience modulus increased as the soil dried out, due to suction, whereas the RM decreased as the water content increased. During the initial phase tests, in which the subject is the moisture content variations, Guimarães (2009) verified permanent excessive deformation in

Figure 1 - BR-319 Highway construction

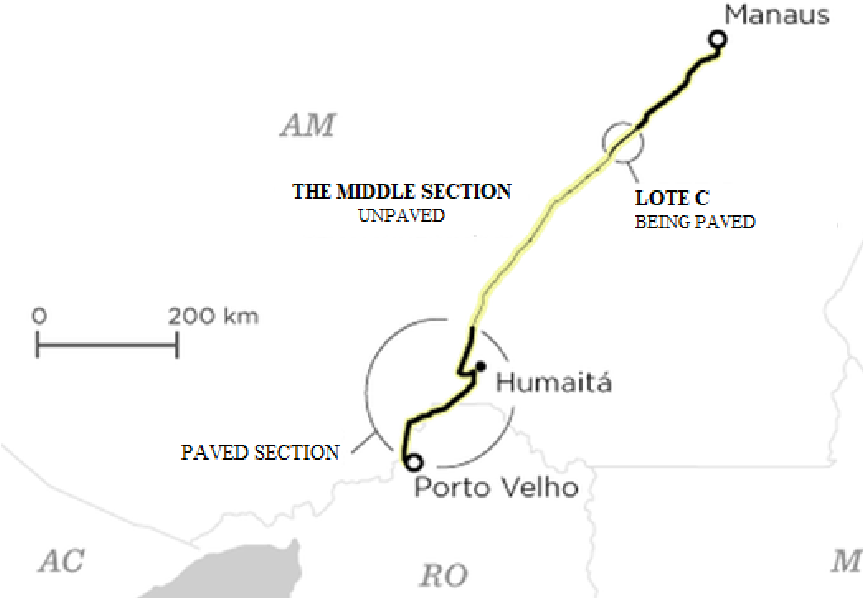

Figure 2 - BR-319 map that shows the patch from Manaus - AM to Porto Velho - RO (Infrastructure Minister of Brazil, translated from Portuguese)

laterite from Rondônia, when the moisture content was increased from the optimum moisture value.

In the context of the BR-319 implementation scenario, the reconstruction of lot C, the contracting projects for the middle section of the highway, and the revised National Dimensioning Method (MeDiNa) employed in new DNIT projects, the purpose of this research is to understand the effects of moisture variation in subgrade soils, thereby, helping in the Structural Analysis of Pavements in the region.

MATERIALS AND METHODS

The experimental program was developed at Trafecon Engineering Soil Laboratory, using repeated load triaxial equipment. All soils were characterized in the laboratory using sedimentation granulometry, Atterberg limits, real densities, HRB classification, and MCT classification.

Furthermore, compaction was carried out in the tripartite mold, because according to Zucchi et al., (2017), using the tripartite mold results in moisture contents and maximum dry densities different from the compactions performed in the CBR cylinder. The compactions were therefore performed in the tripartite mold, however because of a lack of research material, a curve with 3 samples was obtained rather than a normative 5 samples curve.

The resilience modulus test was performed for each soil sample according to 132 standard (DNIT, 2018). The conditioning was done with stress levels ($\sigma 3$ = 0.07 MPa and σd = 0.07 MPa), at 500 repetitions. After conditioning, a series of 12 stress level tests were conducted. For each subgrade, the test was performed at two moisture levels: Wot and Wot±2%. Therefore, the influence of moisture on the resilient behavior of soils was confby determining whether the elastic response is altered when the soil is subjected to short-duration repeated load bursts.

SOIL CHARACTERIZATION

On the BR-319/AM highway, soil samples were collected from 6 piles, 2 soil samples from plot Charlie (km 198 to km 250), 2 soils samples in segment 1 (km 250 to km 346.20), and 2 soils samples in segment 2 (km 346.20 to km 433.10), as shown in Table 1.

Like in the state of Acre, the soil in the Amazon region is known locally as Tabatinga, and its many unique mechanical and mineralogy characteristics can be observed throughout the entire highway. In their report, Barbosa et al. (2018) conclude that structural pavement failures in this type of soil are primarily due to the neglect of the soil's unique mineralogy, physical, and chemical characteristics.

The soil has a fine silty-clayey consistency or a clayey-silty texture, with a low capacity for support, a high expansion quality, and high plasticity. According to laboratory tests conducted for the purpose of studying the increase in moisture by capillarity, the soil displays an effervescent behavior. When in contact with water, it collapses and loses all its capacity to support itself.

Figure 3 shows the attempt of the saturation process. When introducing a water depth of 3mm to the sample, the soil instantly ''effervesced" and collapses under its own weight. This renders the experience impossible. Guimarães (2009) concluded that samples with moisture induced by capillarity show high deformations in the initial cycle of permanent deformation tests. The research is interesting but highly prone to failure.

In the sedimentation granulometry test, it was possible to verify the zero presence of gravel (particles larger than 2mm) or/and the low presence of coarse and medium sand. The percentage of silt.

Identification	Stake	Km	Side	Visual-Manual Soil Classification	HRB Soil Classification
Subgrade 1	190	201.8	Right	Silty Clay Loam	A-7-6
Subgrade 2	310	204.2	Right	Silty Clay Loam	A-6
Subgrade 3	1205	274.8	Axis	Silty Clay Loam	A-6
Subgrade 4	1990	290.5	Left	Pink Clay Silt	A-7-5
Subgrade 5	115	348	Axis	Silty Clay Loam	A-7-6
Subgrade 6	1440	375	Right	Silty Clay Loam	A-7-5

Table 1 - Soils Identification

Figure 3 - Capillarity process

Identification	Gravel	Corse Sand	Medium Sand	Fine Sand	Silt	Clay
Subgrade 1	0.00%	10.80%	16.67%	18.24%	22.33%	31.96%
Subgrade 2	0.00%	6.44%	19.13%	17.01%	25.27%	32.14%
Subgrade 3	0.00%	2.73%	26.63%	28.38%	18.36%	23.90%
Subgrade 4	0.00%	0.80%	4.41%	10.31%	50.04%	34.45%
Subgrade 5	0.00%	1.96%	1.18%	6.13%	39.09%	51.64%
Subgrade 6	0.00%	1.04%	3.09%	20.27%	36.48%	39.12%

Table 2 – Particle proportion in the subgrade composition fraction

The Sedimentation Granulometry results can be observed in Table 3 and Figure 4. It is concluded that the soil composition of subgrade 3 is characterized by the highest proportion of sandy material. Additionally, this can be consistently observed throughout the first half of segment 1, which contains pockets of sandy soil with low plasticity and expansion qualities. Subgrades 1 and 2 had a similar soil composition, with medium and fine sand in the sample.

In subgrades 4, 5 and 6, there is more than 84.5% sandy and granular material (soil material with less than 200 mesh particle size). At last, Segment 2 was primarily composed of extremely fine soils. No sandy and granular soil material present in the sample.

Table 4 presents the results of the real density, Atterberg limits, the maximum dry density, and the optimal moisture content found in the compaction tests in the tripartite mold. It is concluded that the presence of medium and fine sand in sub-grade 3 resulted in a lower optimum moisture content and a lower actual density. Subgrade 5 had the highest moisture content and the lowest maximum dry density, a fact justified by the very low presence of sand (< 10%) and the high percentage of clay and silt in the sample. Subgrades 1 and 2 had a similar maximum density, moisture content, and liquidity limit, however Subgrade 2 presented a lower plasticity limit when in contrast to the Subgrade 1.

Figure 5 shows the soil compaction curves performed in the tripartite mold. Subgrades 1 and 2 showed a small decrease in dry density from the optimum point to the point with +2% moisture content, a phenom that was not observed in other subgrade samples.

MATHEMATICAL MODELS

In order to evaluate the resilient behavior of the BR-319 highway subgrade, three mathematical relationships were established between the resilience modulus and the stress state. For this purpose, the confining stress-dependent model, the deviation stress-dependent model, and the composite model were employed.

The confining stress-dependent model, known as the "k-σ_3" model, was proposed by Hick (1970). In equation 1, the author related the resilience module with the confining stress. The k1 and k2 are representative of the regression coefficients, obtained in laboratory results.

$$MR = k_1 \; x \; \sigma_3{}^{k_2}$$

Furthermore, Svenson (1980) presented a model in which the deviation stress is used as an independent variable, known as the "k-σ_d" model.

$$MR = k_1 \; x \; \sigma_d{}^{k_2}$$

Additionally, several studies have found that the resilience modulus in fine soils depends primarily on stress deviation. (Carmo, 1999) suggests that in granular soils, the resilience modulus depends greatly on the confining stress, and it is not strongly influenced by the deviation stress. The " k-σ_d" model is used for fine soils or other types of soils, in which more than 50% of their soil composition is 200 mesh particles in size. They usually are subgrade lateritic soils or subgrade reinforcement layer.

At last, the revised National Dimensioning Method (MeDiNa), considers and utilizes a Composite Model in its software calculation base. The model utilizes four constants (values) to characterize and understand the material by utilizing the most appropriate model to represent its behavior and properties (Santos, 2021). The Composite Model suggests that the resilience modulus is strongly dependent deviation stress and confining stress.

$$MR = k_1 \; x \; \sigma_3{}^{k_2} \; x \; \sigma_d{}^{k_3} \; x \; \theta^{k_4}$$

According to the MeDiNa User Manual

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3172282202127

Diameter (mm)	Subgrade 1	Subgrade 2	Subgrade 3	Subgrade 4	Subgrade 5	Subgrade 6
	Passed grain (%)	Passed grain (%)	Passed grain (%)	Passed grain (%)	Passed grain (%)	Passed grain (%)
50.8	100.0	100.0	100.0	100.0	100.0	100.0
38.1	100.0	100.0	100.0	100.0	100.0	100.0
25.4	100.0	100.0	100.0	100.0	100.0	100.0
19.0	100.0	100.0	100.0	100.0	100.0	100.0
9.5	100.0	100.0	100.0	100.0	100.0	100.0
4.8	100.0	100.0	100.0	100.0	100.0	100.0
2.0	100.0	100.0	100.0	100.0	100.0	100.0
1.2	98.7	98.6	99.7	100.0	99.2	99.7
0.60	89.2	93.6	97.3	99.2	98.0	99.0
0.420	84.5	87.7	93.1	98.3	97.6	98.5
0.30	76.8	80.7	82.6	96.4	97.5	97.3
0.150	68.3	68.1	58.7	93.2	96.3	94.5
0.0750	61.6	61.2	44.4	85.3	90.6	84.5
0.0649	54.7	58.2	44.5	84.5	91.2	76.8
0.0459	53.1	55.0	36.4	84.5	88.6	71.5
0.03246	50.0	51.9	33.7	74.0	86.0	63.6
0.0229	45.3	50.3	31.0	63.6	83.4	55.7
0.0162	42.9	47.1	31.0	58.3	80.8	50.5
0.0118	43.0	42.1	28.1	50.5	78.3	47.8
0.0084	40.5	40.6	27.9	45.2	70.4	45.2
0.0059	37.3	38.6	27.7	42.6	67.7	42.4
0.0042	35.7	35.3	27.4	39.8	62.5	42.4
0.0012	29.2	29.8	22.8	31.9	45.9	38.7

Table 3 – Granulometry by sedimentation

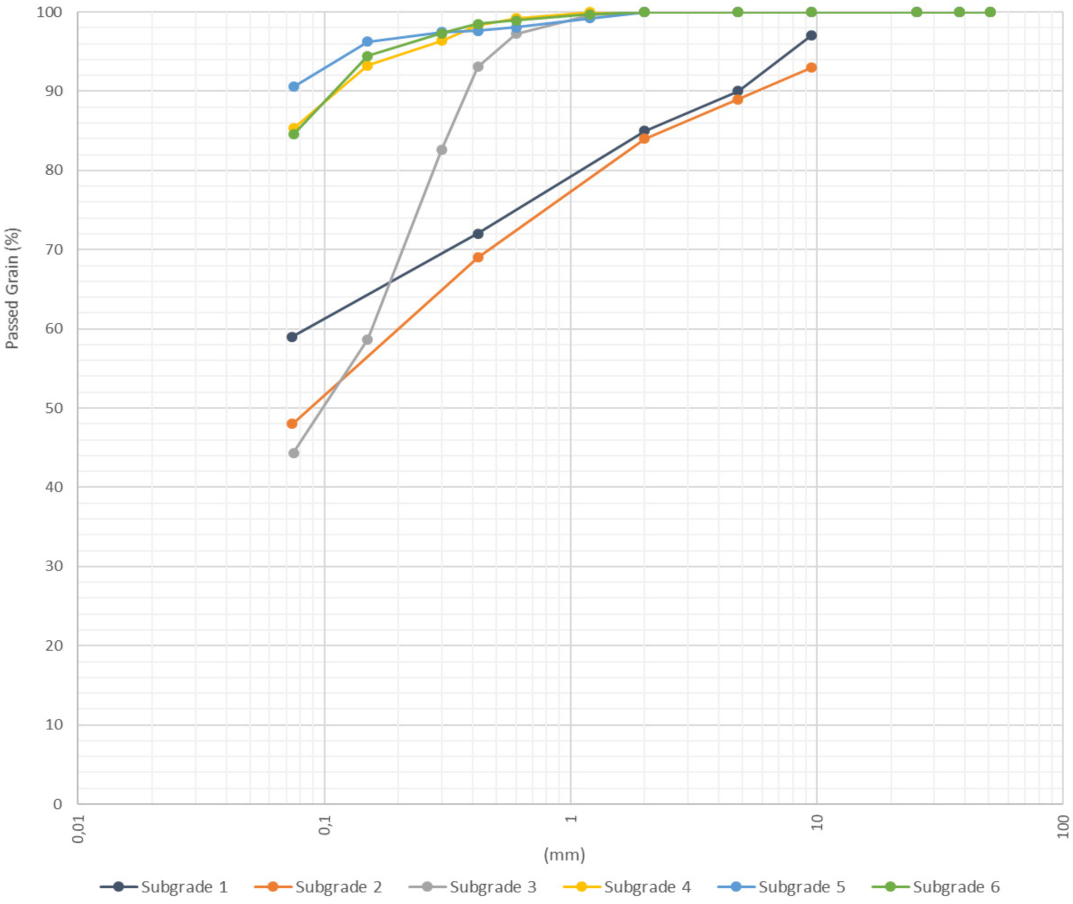

Figure 3 - Granulometry Curves

Parameter	Subgrade 1	Subgrade 2	Subgrade 3	Subgrade 4	Subgrade 5	Subgrade 6
Real Density(g/cm³)	2.578	2.528	2.517	2.614	2.651	2.606
Liquid Limit	42.5%	40.9%	26.67%	42.5%	56.3%	33.95%
Plasticity Limit	29.7%	21.5%	14.22%	20.7%	25.6%	20.08%
Plasticity Index	12.8%	19.4%	12.45%	21.8%	30.7%	13.87%
Max Dry Density (g/cm³)	1.77	1.78	1.78	1.67	1.58	1.66
Optimum Moisture Content	16.6%	16.4%	13.6%	16.4%	20.8%	18.2%

Table 4 – Subgrade soils properties

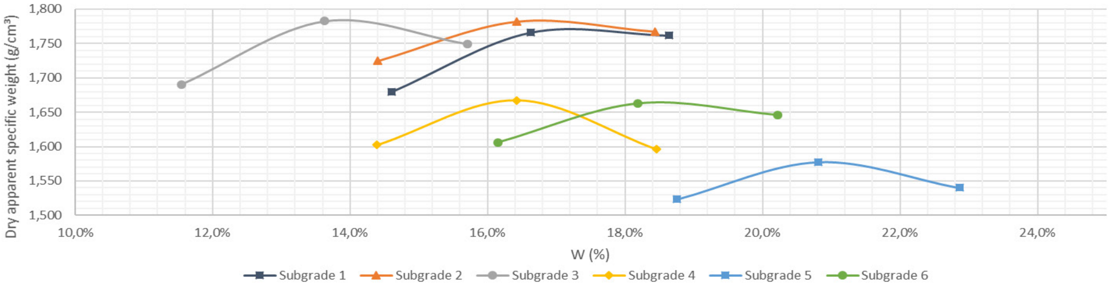

Figure 4 Compactation curve of the tripartite mold

(DNIT, 2020), the users can define which constitutive model best characterizes the resilient behavior of the material. However, if the users choose to, they can also opt for the linear elastic model, exclusively takes into account the resilient modulus average value.

RESULTS AND DISCUSSIONS

The result of the 12 stress level test parameters for each subgrade is presented below. The results of the cyclic triaxial tests allowed generating models that consider the modulus variation as a function of the confining stress and deviation stress. In this context, three models were employed to verify possible changes in soil behavior with a 2% moisture gain.

SUBGRADE 1

Subgrade 1 (Table 5) showed a stress deviation-dependent behavior, with a correlation coefficient (r^2) of 0.68 for Wot soil and 0.86 for Wot±2% soil. Analyzing the stress level parameters, it is possible to observe that the 0.5/0.5 (stress sample) in the optimum moisture soil had a displacement of the trend line. This was consistent with other stress samples, which showed a similar arrangement for both moisture content.

Table 6 and Figure 6 show the resilience modulus reduction was lower in the first 5 stress samples, with an average of 41.5%. This behavior can be explained by the lower load applied to the sample. After the fifth stress sample, the samples had an average reduction of 48.9%, with a 51.1% reduction in the last two stress samples, due to a higher stress ratio (σ_1/σ_3), generating a greater resilient deformation.The composite model showed an excellent fit for both moisture content (with the soil Wot±2% with a coefficient of 0.9 determination).

SUBGRADE 2

Subgrade 2 (Table 7) also showed a behavior dependent on the deviation stress, but the r^2 was closer to 1 for the soil at optimal moisture. It is considered that the higher the value of the regression coefficient, the better the fit of the model (Viana, 2007).

The Wot±2% soil showed a high point dispersion in the confining stress model, with an r^2 of only 0.05. Note that the Wot±2% soil generated a lower r^2 than the optimum moisture content soil for the deviation stress model. In the composite model, both had a high r^2.

The models and regression constants are presented in Table 8 and Figure 7. Despite having a similar granulometry, subgrade 2 had a greater reduction in resilience modulus with the addition of 2% moisture compared to subgrade 1, with an average loss of 64.9%. The reduction of the last stress sample was only 39.6%. This can be justified by the high deformation of the sample in both moisture content.

SUBGRADE 3

The sedimentation test showed that subgrade 3 has the highest percentage of sand of all subgrades. Silva (2020) states that sandy or granular soils, with less than 50% being 200 mesh particles in size, show a behavior dependent on the deviation stress (Table 9). However, this behavior was not demonstrated for subgrade 3 in resilience modulus test, attesting that the soil's fraction of silt and clay is more relevant in its mechanical characteristics.

Table 10 and Figure 8 showed the models and regression constants. The Wot±2% soil did not complete the test, showing a high sample deformation in the last stress level tests. The average reduction was 68.9%. Only the first stress level sample showed a reduction of 66%, which correlates with the low load applied.

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)
0,021	0,021	0,009	238,422
0,020	0,042	0,022	194,302
0,021	0,062	0,035	179,737
0,036	0,037	0,017	211,036
0,036	0,072	0,036	199,346
0,035	0,107	0,060	178,784
0,050	0,052	0,020	255,409
0,050	0,101	0,051	200,568
0,050	0,151	0,099	153,158
0,070	0,072	0,035	203,476
0,070	0,141	0,083	169,898
0,070	0,211	0,152	138,667

(a) Subgrade 1 – Wot

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)	MR Reduction (%)
0,021	0,022	0,016	137,452	42,3
0,020	0,041	0,037	113,340	41,7
0,020	0,062	0,061	100,497	44,1
0,036	0,036	0,027	136,069	35,5
0,036	0,071	0,064	111,041	44,3
0,035	0,106	0,112	94,678	47,0
0,051	0,051	0,040	125,622	50,8
0,050	0,101	0,098	103,580	48,4
0,050	0,151	0,202	74,736	51,2
0,070	0,071	0,062	115,412	43,3
0,070	0,141	0,170	83,065	51,1
0,070	0,211	0,311	67,801	51,1

(b) Subgrade 1 – Wot±2%

Table 5 – Triaxial testing results – Subgrade 1

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 1	Wot	193.6	128.03	-0.12	0.12	109.10	-0.21	0.68	168.60	0.18	-0.28	0.76
	Wot±2%	105.3	48.24	-0.24	0.25	44.80	-0.32	0.86	65.28	0.16	-0.37	0.90

Table 6 – Models and regression constants - Subgrade 1

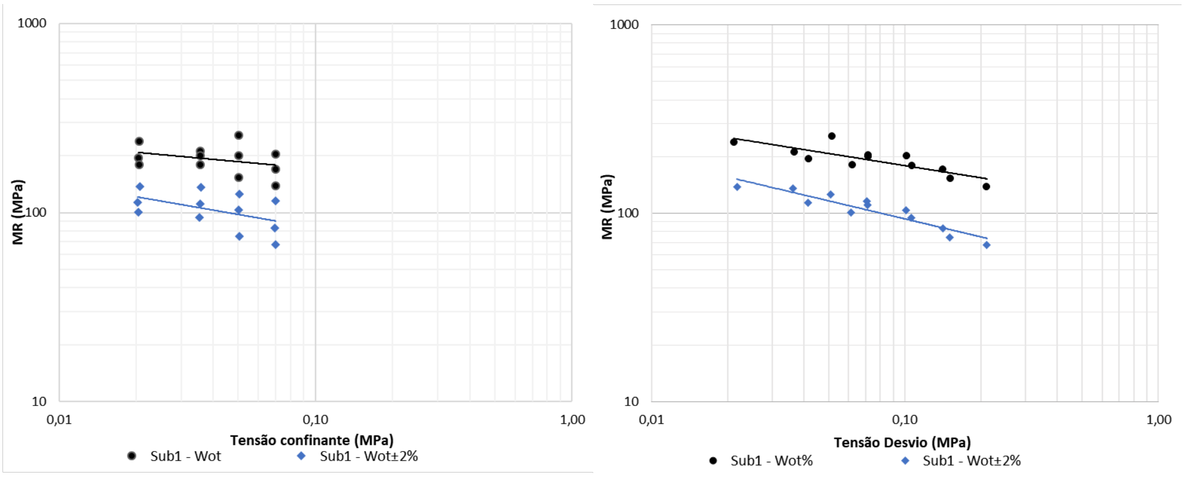

Figure 6 - Resilient Modulus x Confining Stress and Resilient Modulus x Deviator Stress – Subgrade 1

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)
0,021	0,022	0,011	196,958
0,020	0,042	0,023	183,912
0,020	0,062	0,039	159,112
0,036	0,037	0,019	199,438
0,036	0,072	0,043	168,685
0,035	0,107	0,077	137,831
0,050	0,051	0,029	177,919
0,051	0,101	0,070	144,655
0,051	0,150	0,142	105,607
0,070	0,072	0,042	170,812
0,070	0,141	0,117	120,501
0,070	0,210	0,242	86,806

(a) Subgrade 2 – Wot

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)	MR Reduction (%)
0,021	0,021	0,024	85,775	56,45
0,021	0,041	0,073	55,347	69,91
0,020	0,060	0,134	45,162	71,62
0,036	0,036	0,059	60,250	69,79
0,035	0,070	0,146	48,077	71,50
0,036	0,105	0,300	35,000	74,61
0,051	0,051	0,078	64,758	63,60
0,050	0,100	0,245	40,936	71,70
0,050	0,151	0,393	38,421	63,62
0,070	0,071	0,110	63,951	62,56
0,070	0,141	0,327	43,080	64,25
0,070	0,211	0,404	52,373	39,67

(b) Subgrade 2 – Wot±2%

Table 7 - Triaxial testing results – Subgrade 2

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 2	Wot	154.4	53.59	-0.32	0.35	57.22	-0.37	0.86	77.68	0.08	-0.36	0.87
	Wot±2%	52.8	34.95	-0.12	0.05	24.46	-0.28	0.53	33.47	0.32	-0.55	0.92

Table 8 - Models and regression constants – Subgrade 2

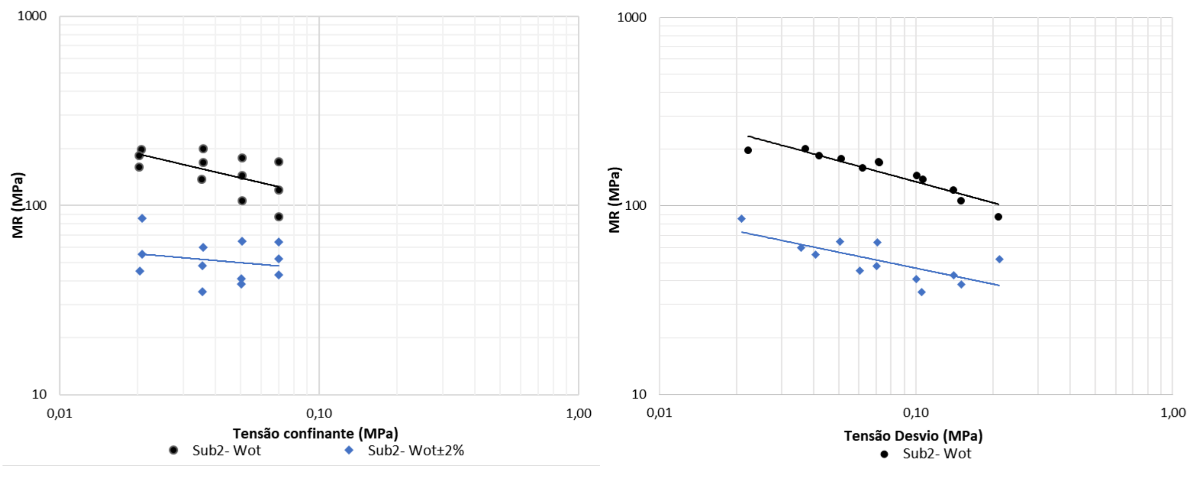

Figure 7 - Resilient Modulus x Confining Stress and Resilient Modulus x Deviator Stress – Subgrade 2

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)
0,020	0,022	0,011	194,835
0,021	0,042	0,024	176,906
0,020	0,062	0,037	165,415
0,036	0,037	0,018	200,512
0,036	0,072	0,041	174,720
0,035	0,107	0,064	167,690
0,050	0,051	0,028	183,978
0,050	0,102	0,061	167,658
0,051	0,151	0,113	133,700
0,070	0,072	0,042	171,610
0,070	0,141	0,095	149,093
0,070	0,211	0,180	116,951

(a) Subgrade 3 – Wot

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)	MR Reduction (%)
0,021	0,021	0,027	78,172	59,9
0,020	0,041	0,069	58,893	66,7
0,020	0,061	0,127	47,915	71,0
0,036	0,036	0,053	67,695	66,2
0,035	0,071	0,135	52,300	70,1
0,035	0,105	0,271	38,856	76,8
0,050	0,051	0,084	60,696	67,0
0,051	0,101	0,224	44,894	73,2
0,050	0,151	0,386	39,202	70,7
0,070	0,070	0,121	58,262	66,0
0,070	0,141	0,317	44,348	70,3

(b) Subgrade 3 – Wot±2%

Table 9 - Triaxial testing results – Subgrade 3

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 3	Wot	166.9	93.86	-0.18	0.29	95.82	-0.21	0.79	121.40	0.06	-0.20	0.80
	Wot±2%	53.7	29.84	-0.17	0.13	20.43	-0.35	0.87	30.43	0.21	-0.45	0.97

Table 10 - Models and regression constants – Subgrade 3

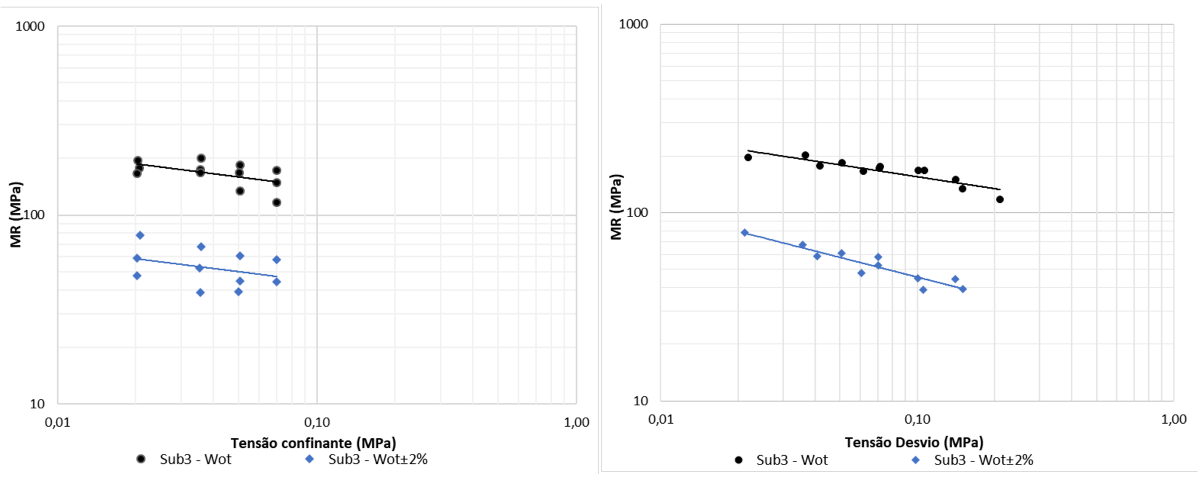

Figure 8 - Resilient Modulus x Confining Stress and Resilient Modulus x Deviator Stress – Subgrade 3

Subgrades 1 and 2, subgrade 3 in the composite model, showed an excellent framework. Nothing worth noting in the Wot±2% soil, the r^2 remained closer to 1.

SUBGRADE 4

Among all the soils studied, subgrade 4 (Table 11) contains the highest silt content. This characteristic was believed to haved a particular result for both moisture content. Soil in wetness did not fit well in any model. And again, the Wot±2% soil showed an excellent r^2 for the deviation stress dependent and composite models.

The average reduction of all stress levels in test samples was 53.8%. The most significant reduction is from the sixth stress test sample. A change in the slope of the moisture content curve can be observed in Figure 9.

SUBGRADE 5

Subgrade 5 (Table 13 and Figure 10) moisture content results did not present a good framework for the stress deviation dependent model and confining stress dependent model. The Wot soil had a better fit in the composite model, with values similar to the other soils studied. Additionally, the Wot±2% soil did not demonstrate a good fit for this model, generating an r^2 much lower than the other soils.

Due to the greater presence of clay (51.64%), the soil had the lowest resilience modulus reduction, with an average of 28.8%. The average reduction in the first 3 stress samples was only 9.9%. Similarly, to subgrade 1, the 0.5/0.5 voltage pair had a low resilient displacement, overall reducing the correlation coefficient, resulting in a high resilience modulus compared to the other samples. It is observed that there was a change in the slope of the trend line in the model depends on the confining stress.

SUBGRADE 6

Subgrade 6 (Table 15) showed a behavior also dependent on the deviation stress, similar to the other soils studied. The average reduction was 68.0% in the stress test samples, a value similar to subgrade 3 in Wot±2%. It is observed that the presence of fine sand does not benefit the resilient behavior of the soil with a gain in moisture.

In addition, subgrade 6 (Table 16 and figure 11) did not complete the last stress test, indicating an excessive strain of the sample, generating a low r^2 for the k-σ_d model. The composite model proved to have a good fit for both moisture content.

GLOBAL ANALYSIS

In order to analyze the behavior of the soils broadly, the 3D graph of the composite model (Figure 12 and 13) was plotted in the OriginLab software (2022). Two images representing different surfaces were merged in each figure, the orange surface referring to the soil at optimal moisture and the blue surface referring to the soil at optimal moisture ±2%. The red and green dots are the three-dimensional representation of the resilience modulus, σ_3 and σ_d.d values.

Note that subgrades 2, 3, 5, and 6 present a flatter surface in soil Wot±2%. This result is explained by the low standard deviation (<11) of the modulus value during the test. In other words, there was no significant reduction or increase in modulus with the addition of stress deviation and/or confining stress.

The 3D graphic representation of subgrade 5 at the optimum temperature was different from the others. This can be attributed to the applied stress level parameters 0.5/0.5 and 0.7/0.7MPa, which caused a modulus to go above the average. The other soils, however, presented similar surfaces. These surface curvatures demonstrate that with the increase in deviation stress, there is a reduction in

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)
0,020	0,021	0,024	172,010
0,021	0,042	0,053	156,697
0,020	0,062	0,085	146,215
0,036	0,036	0,040	179,617
0,035	0,072	0,079	181,668
0,035	0,107	0,120	176,876
0,051	0,051	0,046	223,551
0,050	0,102	0,106	191,100
0,050	0,151	0,205	146,672
0,070	0,072	0,065	220,052
0,070	0,142	0,177	159,183
0,070	0,211	0,332	126,352

(a) Subgrade 4 – Wot

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)	MR Reduction (%)
0,021	0,022	0,029	149,894	12,9
0,020	0,041	0,078	104,515	33,3
0,020	0,061	0,145	83,552	42,9
0,036	0,036	0,068	106,300	40,8
0,036	0,071	0,172	81,673	55,0
0,036	0,105	0,388	53,816	69,6
0,051	0,051	0,106	95,656	57,2
0,050	0,100	0,333	59,742	68,7
0,050	0,151	0,690	43,057	70,6
0,070	0,071	0,189	73,499	66,6
0,070	0,141	0,599	46,228	71,0
0,070	0,212	0,755	53,466	57,7

(b) Subgrade 4 – Wot±2%

Table 11 - Triaxial testing results – Subgrade 4

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 4	Wot	173.3	202.38	0.05	0.02	131.53	-0.10	0.16	287.80	0.31	-0.20	0.61
	Wot±2%	79.3	12.91	-0.54	0.46	17.29	-0.56	0.92	13.27	0.00	-0.64	0.98

Table 12 - Models and regression constants – Subgrade

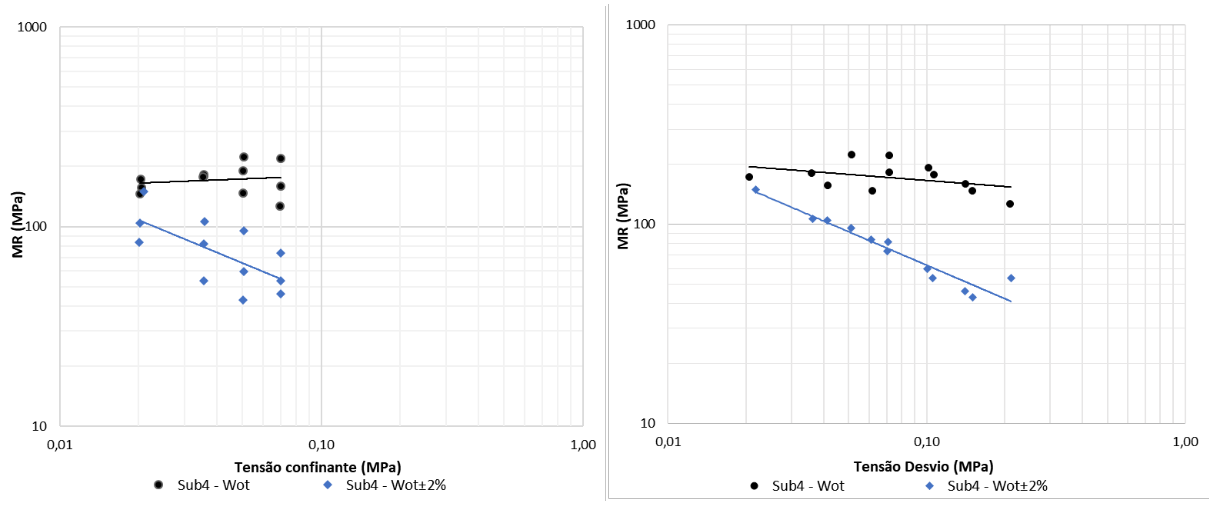

Figure 9 - Resilient Modulus x Confining Stress and Resilient Modulus x Deviator Stress – Subgrade 4

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)
0,020	0,022	0,015	145,568
0,021	0,042	0,029	146,164
0,020	0,062	0,043	143,930
0,036	0,037	0,016	234,527
0,036	0,072	0,036	198,428
0,035	0,107	0,058	185,059
0,050	0,053	0,016	337,650
0,050	0,102	0,047	219,265
0,050	0,152	0,080	190,288
0,070	0,072	0,027	267,451
0,070	0,142	0,069	205,961
0,070	0,211	0,118	178,928

(a) Subgrade 5 – Wot

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)	MR Reduction (%)
0,021	0,021	0,016	133,947	8,0
0,020	0,042	0,032	130,734	10,6
0,020	0,062	0,049	127,538	11,4
0,036	0,037	0,026	143,160	39,0
0,036	0,072	0,048	151,535	23,6
0,035	0,107	0,077	139,100	24,8
0,051	0,051	0,034	149,832	55,6
0,050	0,102	0,072	140,609	35,9
0,051	0,151	0,118	127,718	32,9
0,070	0,072	0,047	151,075	43,5
0,070	0,141	0,097	146,047	29,1
0,070	0,211	0,173	122,142	31,7

(b) Subgrade 5 – Wot±2%

Table 13 - Triaxial testing results – Subgrade 5

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 5	Wot	204.4	620.25	0.35	0.43	220.27	0.04	0.01	856.03	0.65	-0.25	0.75
	Wot±2%	138.6	159.88	0.05	0.09	129.84	-0.02	0.05	186.85	0.14	-0.06	0.58

Table 14 - Models and regression constants – Subgrade 5

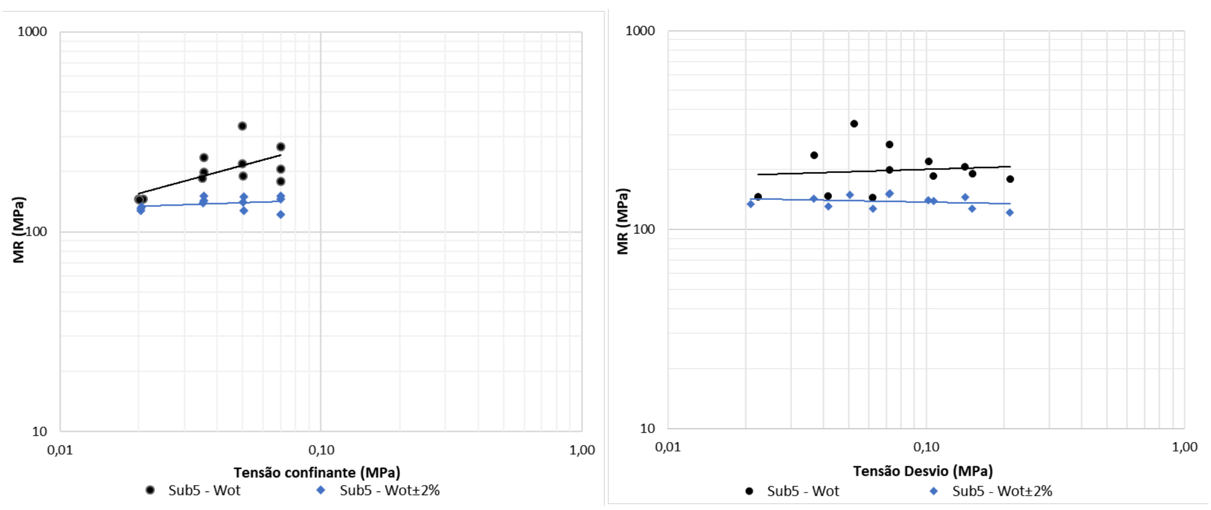

Figure 10 - Resilient Modulus x Confining Stress and Resilient Modulus x Deviator Stress – Subgrade 5

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)
0,021	0,020	0,011	180,013
0,020	0,042	0,027	155,193
0,021	0,062	0,044	140,930
0,036	0,037	0,023	161,909
0,036	0,072	0,047	153,566
0,035	0,106	0,084	127,211
0,051	0,051	0,030	173,026
0,051	0,101	0,077	132,144
0,050	0,151	0,162	92,829
0,070	0,071	0,048	147,866
0,070	0,141	0,134	105,273
0,070	0,211	0,271	77,740

(a) Subgrade 6 – Wot

σ_3 (MPa)	σ_d (MPa)	Resilient Deformation (%)	MR (MPa)	MR Reduction (%)
0,021	0,021	0,037	55,589	69,1
0,021	0,040	0,102	39,580	74,5
0,020	0,060	0,175	34,529	75,5
0,036	0,036	0,075	47,345	70,8
0,036	0,070	0,189	37,242	75,7
0,035	0,105	0,346	30,505	76,0
0,051	0,051	0,105	48,363	72,0
0,050	0,101	0,303	33,234	74,9
0,050	0,151	0,389	39,072	57,9
0,070	0,070	0,131	53,917	63,5
0,070	0,141	0,341	41,319	60,8

(b) Subgrade 6 – Wot±2%

Table 15 - Triaxial testing results – Subgrade 6

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 6	Wot	137.3	48.76	-0.31	0.33	53.44	-0.35	0.82	73.71	0.08	-0.34	0.81
	Wot±2%	41.9	48.66	0.05	0.01	24.59	-0.19	0.34	50.83	0.38	-0.38	0.78

Table 16 - Models and regression constants – Subgrade 6

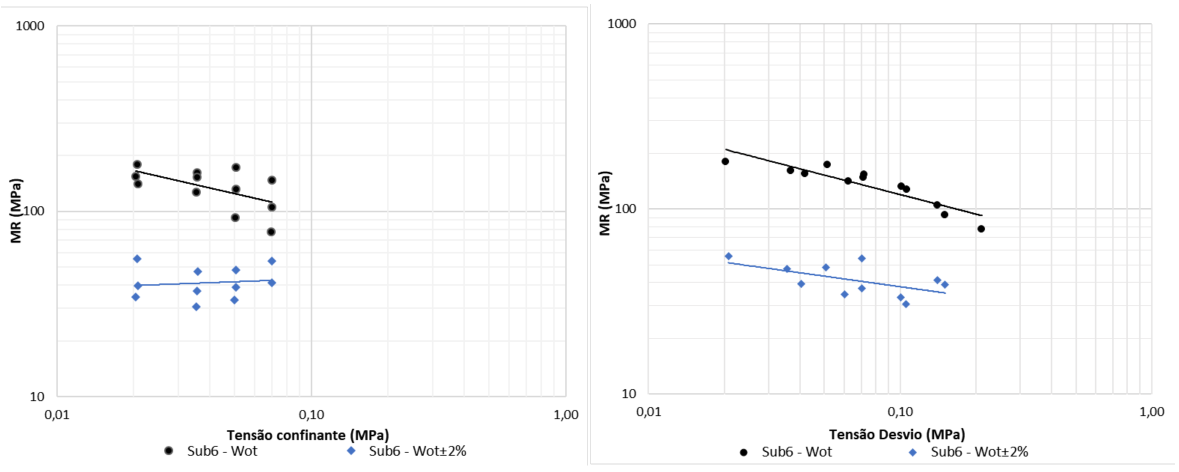

Figure 11 - Resilient Modulus x Confining Stress and Resilient Modulus x Deviator Stress – Subgrade 6

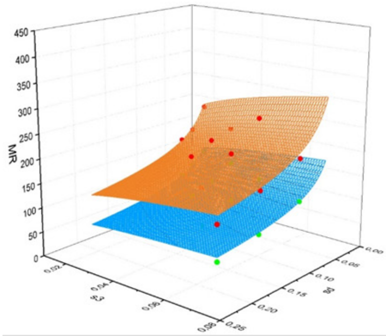

Figure 12a- Subgrade 1

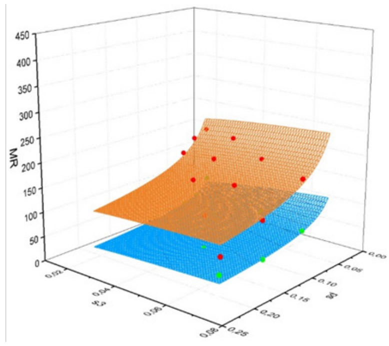

Figure 12b - Subgrade 2

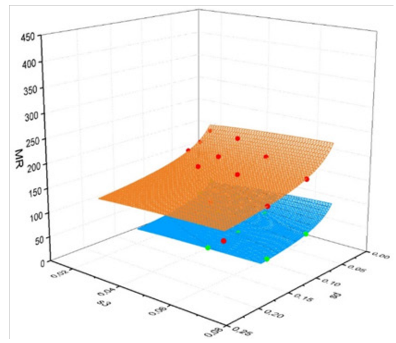

Figure 12c - Subgrade 3

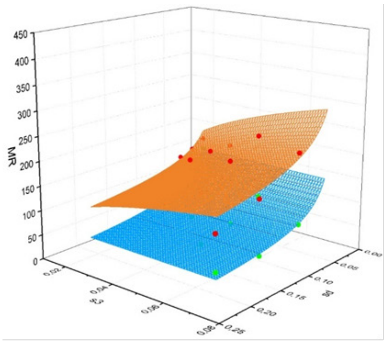

Figure 13a- Subgrade 4

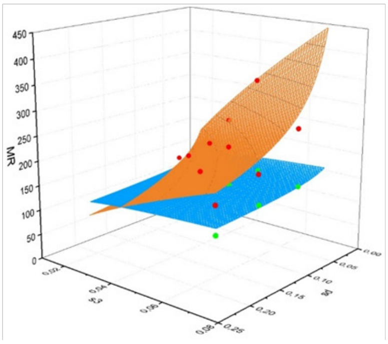

Figure 13b - Subgrade 5

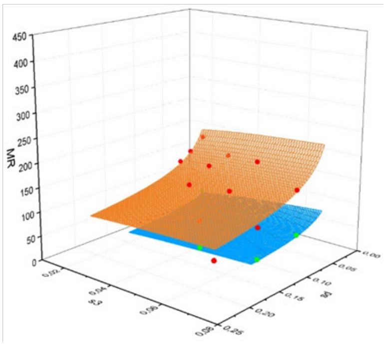

Figure 13c - Subgrade 6

Soil		Medium Modulus	Model Dependent on Confining stress			Model Dependent on Deviator stress			Composite Model			
			K_1	K_2	R^2	K_1	K_2	R^2	K_1	K_2	K_3	R^2
Subgrade 1	Wot	193,6	128,0	-0,1	0,12	109,1	-0,2	0,68	168,6	0,18	-0,2	0,76
	Wot±2%	105,3	48,24	-0,2	0,25	44,80	-0,3	0,86	65,28	0,16	-0,3	0,90
Subgrade 2	Wot	154,4	53,59	-0,3	0,35	57,22	-0,3	0,86	77,68	0,08	-0,3	0,87
	Wot±2%	52,8	34,95	-0,1	0,05	24,46	-0,2	0,53	33,47	0,32	-0,5	0,92
Subgrade 3	Wot	166,9	93,86	-0,1	0,29	95,82	-0,2	0,79	121,4	0,06	-0,2	0,80
	Wot±2%	53,7	29,84	-0,1	0,13	20,43	-0,3	0,87	30,43	0,21	-0,4	0,97
Subgrade 4	Wot	173,3	202,3	0,0	0,02	131,5	-0,1	0,16	287,8	0,31	-0,2	0,61
	Wot±2%	79,3	12,91	-0,5	0,46	17,29	-0,5	0,92	13,27	0,0	-0,6	0,98
Subgrade 5	Wot	204,4	620,2	0,35	0,43	220,2	0,0	0,01	856,0	0,65	-0,2	0,75
	Wot±2%	138,6	159,8	0,05	0,09	129,8	-0,0	0,05	186,8	0,14	-0,0	0,58
Subgrade 6	Wot	137,3	48,76	-0,3	0,33	53,44	-0,3	0,82	73,71	0,08	-0,3	0,81
	Wot±2%	41,9	48,66	0,05	0,01	24,59	-0,1	0,34	50,83	0,38	-0,3	0,78

Tabela 3 - Table 17 – Models applied in each soil resilience modulus.

Due to the fact that subgrades 3 and 6 did not complete the last applied stress test, the graphical representation of the composite model was reduced, as shown in Figures 12c and 13c. Furthermore, the behavior of the two soils is analogous for both moisture content, both the 3D representation of the 3D composite model and the percentage of resilience modulus reduction (67% and 69%).

Table 17 presents a compilation of all coefficients for all models. For the composite model, the k1 obtained was higher for all soils at optimum moisture content. The k2 obtained was less than 0.65, and the temperature variation did not significantly change the coefficient. The k3 calculated for all soils was negative. With subgrade 4 Wot and subgrade 5 Wot±2%, the exception value of r^2 for the composite model was ≥ 0.75, showing a good framework.

CONCLUSIONS

The main objective of this article was to verify, through resilience modulus tests, the influence of moisture on soil behavior. It is concluded that, in general terms, the gain of 2% of moisture in the soil of the BR-319 generates an average reduction of 55%. Subgrade 5 however, showed a smaller reduction, of 32% due to a greater amount of silt and clay and a greater optimum moisture content compaction.

The confining stress dependent model was unsuitable for this type of soil, due to the low presence of sand and the great influence of the fine fraction on soil behavior. The stress-deviation-dependent model showed a higher r^2, but in some cases, the r^2 was less than 0.34, as in subgrade 5.

The composite model, used in MeDiNa, proved to be the most satisfactory for the soil at both moisture levels, with an average value of 0.81.

REFERENCES

Barbosa, V. H. R., Marques, M. E. S., & Guimarães, A. C. R. (2018). Caracterização mineralógica de um solo do Acre visando à produção de agregados artificiais de Argila Calcinada para uso em pavimentos. Matéria (Rio de Janeiro), 23.

Carmo, C. A. T. D. (1998). **A avaliação do módulo de resiliência através de ensaios triaxiais dinâmicos de dois solos compactados e a sua estimativa a partir de ensaios rotineiros** (Doctoral dissertation, Universidade de São Paulo).

Cordão Neto, M. P. (2005). **Análise hidro-mecânica de barragens de terra construídas com materiais colapsíveis.** (Doutorado em Engenharia Civil) Departamento de Engenharia Civil e Ambiental, Universidade de Brasília.

Fearnside, P. M., & de Alencastro Graça, P. M. L. (2009). BR-319: **A rodovia Manaus-Porto Velho e o impacto potencial de conectar o arco de desmatamento à Amazônia central.** Novos cadernos NAEA, 12(1).

Franco, F. A. C. P. (2007). **Método de dimensionamento mecanístico-empírico de pavimentos asfálticos–SISPAV**. 2007. 294. Tese (Doutorado em Engenharia Civil) –Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Freitas, J. B. (2019) **Análise de parâmetros para projetos mecanísticos-empíricos de pavimentos asfálticos em Goiás.** Dissertação de Mestrado. Universidade Federal de Goiás. Goiânia, GO.

Guimarães, A. C. (2009). **Um método mecanístico-empírico para a previsão da deformação permanente em solos tropicais constituintes de pavimentos**. Universidade Federal do Rio de Janeiro. Rio de Janeiro, 367.

Hicks R. G.; Monsmith, C. L. **Factors influencing the resilient properties of granular materials.** Highway Research Record, n. 345, p. 15-31, **1971.**

Khoury, N.; Brooks, R.; Zaman, M.; Khoury, C. (2009) "Variations of resilient modulus of subgrade soils with post-compaction moisture contents." Transportation Research Record: Journal of the Transportation Research Board, (2001). pp. 72-81.

Nazarian, S. e Yuan, D. (2008) "**Variation in modulus of base and subgrade with moisture".** GeoCongress 2008: Geosustainability and Geohazard Mitigation. New Orleans, EUA

Neto, T. O., & Nogueira, R. J. B. (2016). **Geopolítica e rodovias na Amazônia: um debate necessário**. Revista de Geopolítica, 6(2), 166-186.

Silva B. D. A. (2003). **Aplicação das metodologias MCT e resiliente a solos finos do centro-norte do Mato Grosso.** Dissertação de Mestrado em Engenharia de Transportes, IME, Rio de Janeiro.

Silva, N. A. B. D. S. (2020). **Desempenho de um compósito solo-polímero para aplicabilidade em obras geotécnicas e de pavimentação.** Dissertação de Mestrado - Universidade de Brasília. Faculdade de Tecnologia.

Viana, H. M. F. (2007). **Estudo do comportamento resiliente dos solos tropicais grossos do interior do Estado de São Paul**o (Doctoral dissertation, Universidade de São Paulo).

Viana, H. M. F. (2007**). Estudo do comportamento resiliente dos solos tropicais grossos do interior do Estado de São Paulo** (Doctoral dissertation, Universidade de São Paulo).

Zucchi, F. L., Pascoal, P. T., dos Santos, T. A., Mendes, T. C., Baroni, M., & Pinheiro, R. J. B. (2017). **Análise Comparativa Entre as Metodologias de Compactação da ABNT (2016) e REDE (2010) para Solo Argiloso e Arenoso do Estado do Rio Grande do Sul.** ANPET-Associação Nacional de Pesquisa e Ensino em Transportes.