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Influence of Moisture Content on Tropical Slope Soils

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ABSTRACT: This paper aims to analyze the influence of subgrade moisture variation on the structural performance of a road section, through deflectometric data, in dry and post-rainy periods. For the sections analyzed, it was found that the rainy period resulted in increased by 4.53% of the subgrade moisture, causing variations of up to 25.60% in deflection data in mixed section. For the embankment and cut sections, the influence of moisture was negligible, given the efficiency of the drainage system. It was also possible to observe that, when the ground and pavement elevations are relatively equal, the water table directly affects the subgrade, preventing accurate analysis of the rainy period with relation to deflection. Thus, it is evident the need to implement drainage devices that allow the reduction of the impact of moisture variation on the structural performance of a pavement, enabling the maintenance of its service life.

KEYWORDS: Pavements, Deflection, Drainage, Soil plasticity, Variation of moisture.

1. INTRODUCTION

The climatic conditions of a given region influence the properties of the materials used in the construction of the pavement layers. Knowledge of the effects of humidity, for example, is important for a more detailed analysis of the properties of these materials. Environmental variations in the course of the pavement's service life can significantly alter the moisture content of the subgrade and its components and thus modify its structural performance.

Bastos (2013) points out that during the construction phase of pavements the moisture of the layers and the subgrade may suffer variations as a result of inefficient technological control or when the execution control criteria are not met. Bastos (2013) also analyzed moisture variations of ±2% in the compaction moisture of soils A-4 and A-2-4. When the moisture was reduced by 2%, there was a 21% decrease in the values of the surface deflections compared to the surface deflections analyzed at the optimum moisture. When the moisture content was increased by 2%, there was a 16% increase in this deflection compared to that observed at the optimum moisture. For the subgrade with soil A-4, the moisture showed more accentuated variations in deflections in the post-construction process.

Takeda (2006) reports that when rainwater reaches the subgrade due to a deficient drainage system or by infiltration through fissures and joints in the pavement surface, its structural response may be affected. That said, the performance and condition of the materials become conditioning factors of the service life of a pavement. According to Thadkamalla and George (1995), after construction, the subgrade experiences variations in its moisture content, leading to changes in its resistance.

Medina and Motta (2015) describe that, between 1979 and 1984, the Brazilian Highways Research Institute carried out a research to study the influence of seasonality on deflections measured in load tests on experimental stretches of Brazilian highways, verifying that the humidity variations observed in the deflection would be insignificant. Only in one of the stretches evaluated was verified the direct relationship between the increase in moisture and deflection. However, in the other stretches analyzed there was no correlation between the elevation of deflection and in situ humidity in the rainy season in relation to the dry season.

However, Oliveira et al. (2000) describe moisture content and temperature as factors that influence the resilient properties of materials, relating directly to the response of pavement under the effect of dynamic traffic loading. The load-bearing capacity of granular pavement layers may decrease if the moisture content increases, especially during rainy periods. Thus, the characteristic deflection at the center of load application is directly influenced, as it depends on the characteristics of all layers (Rocha Filho and Rodrigues, 1996; apud Cavalcante, 2005).

Therefore, it is indicated that the most appropriate time to perform the deflection measurements is immediately after the rainy season, due to the subsoil condition being the most unfavourable, due to its high humidity. However, in cases where it is not possible to take measurements in this period, a seasonal correction factor is adopted, aiming to correct them for the most adverse season. These values vary from 1.00 to 1.40, depending on the type of subgrade soil and the climatic situation (DNER, 1979a, b).

Araújo et al. (2019) developed a method that enables the connection of different variables and models that integrate transport infrastructure in the urban environment, in the face of hydric conditions, verifying the influence of rainfall on pavements. The authors observed that, for the conditions studied, the moisture of the pavement layers can vary more than 78%, as a result of the rainy season, which can contribute to the reduction of the structural performance of these structures.

So, this paper aims to analyze the influence of moisture on the structural performance of a pavement, comparing the deflection data for dry and post rainy periods, verifying the impact of these periods on the analyzed parameter. This study is also justified, given the gap found in the literature about the action of rainfall on deflectometric data of pavements.

2. RESEARCH METHOD

The study comprised the following stages: (i) probing in the analyzed segments to verify the subgrade moisture, (ii) soil classification according to the American Association of State Highway and Transportation Officials (AASHTO) methodology, (iii) monitoring of precipitation and (iv) reading of deflections using of the Benkelman Beam (Figure 1). Measurements of moisture and deflectometric data were carried out in the dry and post rainy periods.

For this study, a preliminary survey of the conditions and types of drainage was carried out on a section of highway in the southern region of Brazil. Among the criteria for the selection of the area, highlight the visual analysis of the segment, presenting a poor apparent structure with various defects along the route, such as rutting and potholes, also, the variety of sections and drainage devices.

In this study, four sub-segments were chosen with distinct characteristics and each having 80 m, in which five characteristic deflection measurements were taken, distributed as follows,

a) 0+000 and 0+020 stake - deflection measurement;
b) stake 0+040 - measurement of deflection and probing at the edge of the pavement to check the moisture content and collect subgrade material;
c) 0+060 and 0+080 stake - deflection measurement.

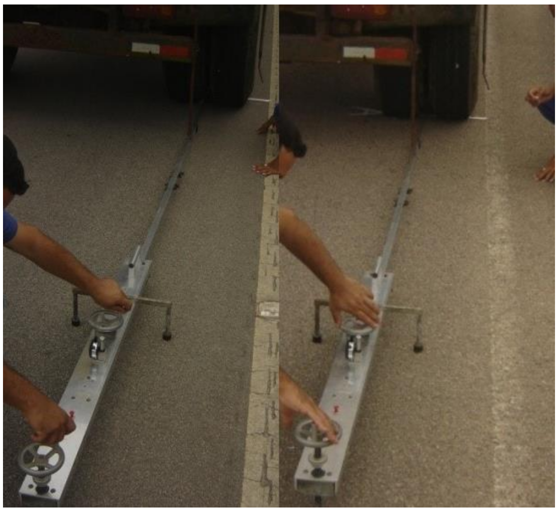

Figure 1 Benkelman Beam used

The characteristics of the segments analyzed with abbreviation, drainage conditions and some defects are as follows (Figure 2):

a) mixed Section (M): gutter and vegetal coating on the right side and non-existent or superficial on the left side. None defects;
b) backfill section (B): embankment protection ditch (EPD), gutters, and vegetal coating on both sides. Rutting, alligator cracks, and crumbling;
c) cut section (C): gutters and vegetal coating on both sides. Few or no apparent defects;
d) glued grade section (G): gutters and vegetal coating on both sides. Rutting.

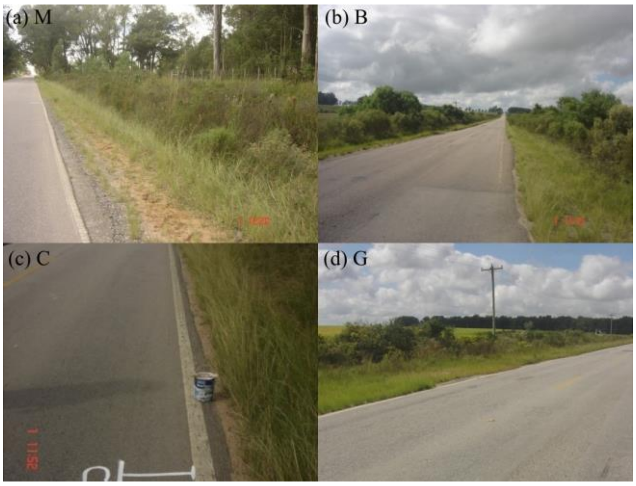

Figure 2 Segments analyzed

The pavement structure verified in the survey consisted of 5 cm of Asphalt Concrete from resurfacing for reinforcement carried out in 2002 on the original pavement surface with 2.5 cm of Double Surface Treatment, 15 cm the on a graded base with limestone and subgrade. The moisture content was obtained in loco with the available materials and also performed in the laboratory with material transported in sealed containers, following the standardized testing method (DNER, 1994a). For the classification of the soils collected in the test borings, the granulometry tests were carried out (DNER, 1994b), Atterberg Limits (DNER, 1994c, d), and followed the AASHTO methodology.

In order to verify pavement deflection, rainfall monitoring was carried out before the start of the rains and after this period, considering the accumulated rainfall. Thus, the first measurement of the characteristic deflection was performed on April 04th, 2016 and the second on April 26th, 2016.

The admissible deflection was determinate according to DNER (1979): road parameters such as operations number of standard axle (8,2 tf) - Number N of 5×10^6, and the average thickness of the existing asphalt surfacing (5 cm) are used. Obtaining the value of 67×10^{-2} mm for the admissible deflection (Dadm). It is also important to note the minimum acceptable curvature radii for each layer: (i) asphalt concrete: 100 m; (ii) granular base: 80 m; (iii) sub-base: 70 m and (iv) subgrade: 70 m.

3. ANALYSIS AND RESULTS

The rainfall data of the periods that preceded the collection of the deflections were collected, with the accumulated rainfall divided into two periods: 3/29/2016 to 4/4/2016 and 4/5/2016 to 4/26/2016. In the dry period of 6 days that preceded the first reading (on 4/4/2016) a daily rainfall average of 0.34 mm was obtained, being negligible in terms of the subgrade moisture content. In the period of 23 days preceding the post rainfall measurements, a daily average of 13.13 mm was observed. However, the daily average of the 10 days preceding the last stage was 22.26 mm, which made the conditions ideal for taking the measurements.

The granulometry in the sections (M, B, C and G) was analyzed, showing the percentage of boulder, sand, and fines, as well as moisture, the Atterberg limits, and the uniformity and curvature coefficients. Table 1 presents the results of this stage.

Table 1 Classification of the subgrade soil

Properties	**Segment**			
	M	**B**	**C**	**G**
% Boulder	1.1	2.1	1.5	1.2
% Sand	54.4	50.8	39.9	40.5
%Fines	44.5	47.1	58.6	58.3
D10	0.003	0.003	0.002	0.002
D30	0.018	0.015	0.009	0.009
D60	0.430	0.400	0.085	0.080
Coefficient of uniformity	165.4	160.0	42.5	40.0
Curvature coefficient	0.290	0.225	0.425	0.495
Liquidity limit (LL)	43	45	37	41
Plastic limit (PL)	16	19	16	19
Plasticity Index (PI)	27	26	21	22
Natural humidity	2.84	4.12	4.23	4.34
Classification USCS	CS	CS	SM	SM
Classification AASHTO	A-7-6	A-7-6	A-6	A-6
General rating AASHTO	Poor	Poor	Poor	Poor

It is observed that for all segments, the subgrade is composed of a clay material containing a high percentage of sand. It is a plastic material and has intermediate plasticity. Due to these characteristics, it is subject to high volume variations between the wet and dry states, being a poor material for use in road subgrade.

In segments M, B and C, the 0+000, 0+020, 0+040, 0+060, and 0+080 stakes have deflections above the allowable (67×10^{-2} mm) on post rainy period and radius of curvature greater than the minimum allowable (100 m), which is caused by large deflections in the subgrade (Tables 2 and 3). This problem occurs either because of the poor quality of the material used or because of excessive moisture. For segment G, only stakes 0+040 and 0+060 are below the allowable deflection on post rainy period.

Also, in segment M, at stake 0+080 the characteristic deflection is above the admissible one and the radius of curvature is close to the admissible minimum on post rainy period. In this case, it is assumed that the infrastructure is nearing the end of its service life and would require a more detailed investigation of the influence of moisture and its performance on the subgrade soil. In the dry season, the subgrade had a moisture content of 16.55%. After the end of the rainy season, it became 21.08%, thus occurring an increase of 4.53 p.p. in this parameter.

Table 2 Deflection data for the analyzed segments on dry period

General Data		**Dry Period**			
Segment	**Stake (km)**	**Deflections on drought (in 0.01 mm)**		**Radius (m)**	**On-site moisture (%)**
		D0 (20 ºC)	**D25**		
M	0+000	74.64	67.18	418.67	16.55
M	0+020	66.24	55.05	279.11	16.55
M	0+040	67.18	55.98	279.11	16.55
M	0+060	71.84	61.58	304.48	16.55
M	0+080	83.97	70.91	239.24	16.55
B	0+000	74.46	63.43	283.29	18.92
B	0+020	65.27	52.40	242.82	18.92
B	0+040	130.53	107.55	135.98	18.92
B	0+060	102.96	90.09	242.82	18.92
B	0+080	112.15	89.17	135.98	18.92
C	0+000	74.27	53.58	151.10	15.62
C	0+020	74.27	58.28	195.54	15.62
C	0+040	65.80	47.00	166.21	15.62
C	0+060	75.21	59.22	195.54	15.62
C	0+080	104.35	83.67	151.10	15.62
G	0+000	161.64	108.40	58.69	17.15
G	0+020	77.02	54.20	136.94	17.15
G	0+040	66.56	53.25	234.76	17.15
G	0+060	66.56	52.30	219.11	17.15
G	0+080	75.12	59.90	205.41	17.15

Table 3 Deflection data for the analyzed segments on post rainy period

General Data		**Post rainy period**			
Segment	**Stake (km)**	**Rainy season deflections (in 0.01 mm)**		**Radius (m)**	**On-site moisture (%)**
		D0 (20 ºC)	**D25**		
M	0+000	86.31	74.68	268.52	21.08
M	0+020	80.49	66.92	230.16	21.08
M	0+040	84.37	74.68	322.23	21.08
M	0+060	82.43	71.77	292.93	21.08
M	0+080	101.83	84.37	179.01	21.08
B	0+000	76.31	65.55	290.37	18.97
B	0+020	67.51	57.72	319.40	18.97
B	0+040	136.97	106.64	103.03	18.97
B	0+060	106.64	93.93	245.69	18.97
B	0+080	115.45	97.84	177.45	18.97
C	0+000	75.06	53.89	147.61	16.06
C	0+020	77.95	57.74	154.64	16.06
C	0+040	69.29	49.08	154.64	16.06
C	0+060	82.76	59.66	135.31	16.06
C	0+080	108.74	83.72	124.90	16.06
G	0+000	154.90	106.21	64.73	13.39
G	0+020	73.38	53.11	154.11	13.39
G	0+040	58.90	49.24	323.64	13.39
G	0+060	57.94	46.35	267.70	13.39
G	0+080	67.59	56.97	294.22	13.39

The 4.53 p.p. increase in subgrade moisture after the rainy period is linked to some factors, among them the insufficient drainage system. This increase in the subgrade moisture content directly influences its structural capacity, a fact that can be proved by analyzing the variance of the deflections, which increased between 14.74% and 25.60%, with an average increase of 21.27% (Table 4).

The observed reduction of the radius of curvature in the M and C segments may indicate a critical bowing of the deformation basin, revealing a critical structural condition. Negative values mean that there was a reduction, while positive values represent an increase when compared to the dry season values.

Table 4 Comparison of the deflection results for the analyzed sections

Segment	**Stake (km)**	**On-site moisture (p.p)**	**Deflection difference in the rainy season (in %)**		**Radius (%)**
			D0 (20º C)	**D25**	
M	0+000	4.53	15.64	11.16	-35.86
M	0+020	4.53	21.51	21.56	-17.54
M	0+040	4.53	25.60	33.39	15.45
M	0+060	4.53	14.74	16.54	-3.79
M	0+080	4.53	21.27	18.99	-25.17
B	0+000	0.05	2.49	3.35	2.50
B	0+020	0.05	3.44	10.17	31.54
B	0+040	0.05	4.94	-0.84	-24.23
B	0+060	0.05	3.58	4.26	1.18
B	0+080	0.05	2.94	9.73	30.49
C	0+000	0.44	1.07	0.57	-2.31
C	0+020	0.44	4.96	-0.94	-20.92
C	0+040	0.44	5.29	4.41	-6.96
C	0+060	0.44	10.04	0.74	-30.80
C	0+080	0.44	4.21	0.07	-17.34
G	0+000	-3.76	-4.42	-2.01	10.29
G	0+020	-3.76	-4.72	-2.01	12.54
G	0+040	-3.76	-11.51	-7.52	37.86
G	0+060	-3.76	-12.96	-11.37	23.09
G	0+080	-3.76	-10.02	-4.90	43.23

In sub-sections B and C, the moisture content varied by 0.05% and 0.44%, respectively, which can be considered negligible for the subgrade. This indicates that the location has a sufficient drainage system. Also, in an embankment section, drainage is facilitated by the elevation of the pavement structure relative to the natural ground.

The characteristic deflections also had a small percentage variation between 2.49% and 4.94%, with an average value of 3.44% for segment B and between 1.07% and 10.04%, with an average value of 4.96% for the C. It is also possible to see that, for sub-sections B and C, all the stakes present values above the admissible ones and high bending radii. It is worth noting that, at stake 0+040 of sub-section B, the bending radius is very close to the minimum admissible, similar to that observed in the mixed section segment.

Finally, segment G showed a decrease in the moisture content of 3.76 p.p. after the rainy season. After investigating the area, it was found that there was a rice field on both sides of the road, and it was hypothesized that during the dry season it was being mechanically irrigated and that during the excessive rains it suffered rainwater drainage.

For section G, in the 0+040 and 0+060 stakes, we have characteristic deflections smaller than the admissible ones and high radius of curvature, which may mean that these points of the segment have an adequate condition, both in the lower and upper layers. In 0+020 and 0+080 stakes, there are characteristic deflections above the admissible ones and high bending radii, which is caused by high deflections in the subgrade. As it is a segment in glued grade, where the pavement level is equal or close to the level of the natural terrain, its subgrade is directly affected by the level of the water table. Therefore, the analysis of the variation of deflections in the post-rainfall period in segment G is impaired.

It should be noted that the radius of curvature found at stake 0+080 of segment G is very close to the minimum admissible, which means that this point is very close to the end of its useful life. On stake 0+000, the worst situation is found, since there are characteristic deflections greater than the admissible ones and a radius of curvature well below the admissible minimum. This means that this point is close to collapse, that is, both the upper and lower layers do not meet the structural conditions. The reasons may be varied, among them are the low-quality material used in the subgrade and unsatisfactory drainage conditions.

4. CONCLUSIONS

The significant influence of moisture on the structural performance of the pavement can be seen when soils with high plasticity for application in subgrade are analyzed. It was observed that in all segments, the soil is classified as having poor characteristics for use in road subgrade. In the mixed and embankment sections, there was a predominance of sand, while in the cut and glued grade sections the percentage of fines was higher. It was also possible to see that the Atterberg limits are not ideal for use in the subgrade and granular layers.

The analysis of the deflections made it possible to identify that in the mixed section, the impact of the rainy season resulted in an increase in the characteristic deflection, as the subgrade moisture content increased. A deficient drainage system directly contributes to this high variation in the analyzed segments. However, for the embankment and cut segments, due to the efficient drainage system, the moisture increments and, consequently, the characteristic deflection was negligible, since the subgrade. Subsection G did not present the same tendency in the cause-effect correlation, given the circumstances of the surrounding environment and its section in glued grade.

Finally, it can be concluded that the interference of moisture can be mitigated by the introduction of an efficient drainage system, which can also be designed by the geometric configuration of the track section itself. Thus, the pavement will be able to maintain its service life, without being significantly affected by variations in subgrade moisture.

5. ACKNOWLEDGEMENTS

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