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A Geo, as ciências e a tecnologia

**X CONGRESSO  
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Segurança de obras geotécnicas

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## MECHANICAL ANALYSIS OF AN UNPAVED ROAD BY DYNAMIC BEARING CAPACITY TESTS

### ANÁLISE MECÂNICA DE UMA ESTRADA NÃO PAVIMENTADA POR ENSAIOS DINÂMICOS DE CAPACIDADE DE CARGA

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#### ABSTRACT

The type and mechanical characteristics of soils dictate the performance of unpaved roads. Unpaved roads are more influenced by the traffic and natural environment than the paved ones: since earth is a more heterogeneous and fragile surface than bituminous and concrete surfaces from paved roads. As a result, the road users often witness the unpleasant presence of distresses over the way. Thus it is essential to follow up the characteristics of the soils that most affect the performance of unpaved roads, like compaction and bearing capacity parameters which usually are obtained from geotechnical characterization and bearing capacity tests. Therefore, dynamic *in situ* tests are becoming very useful because they allow quick evaluation of the soil subgrade over undisturbed samples and request fewer resources (human and equipment) than conventional *in situ* tests. This paper presents the application results and analysis of Light Falling Weight Deflectometer (LFWD) and dynamic Californian Bearing Ratio (CBR) from different seasons of the year over an unpaved road in Bragança, Portugal. The road is considered a relevant object of study as it connects the two main dams responsible for providing water to the region. The bearing capacity parameters were evaluated in a retrospective analysis and correlations between these parameters were observed in each one of the test seasons.

#### RESUMO

O tipo de solo e as propriedades mecânicas associadas determinam a performance que as estradas não pavimentadas têm quando solicitadas. Estradas não pavimentadas são mais influenciáveis ao tráfego e aos fatores naturais do ambiente do que as pavimentadas: em decorrência do solo servir como uma superfície mais heterogênea e frágil do que as superfícies de concreto e betume das estradas pavimentadas. Como produto disso, os usuários frequentemente têm o desconforto de presenciar degradações ao longo do caminho. Desta maneira, é importante conhecer e monitorar as características dos solos que mais afetam a performance das estradas não pavimentadas, como parâmetros de compactação e de capacidade de carga, normalmente a partir da execução de ensaios de caracterização geotécnica e de capacidade de carga. Com isso, os ensaios *in situ* dinâmicos têm sido cada vez mais úteis visto que permitem a avaliação rápida do substrato sobre amostras indeformadas e requerem pouca mobilização de recursos para serem realizados. Esta pesquisa apresenta a análise de resultados do ensaio Light Falling Weight Deflectometer (LFWD) e CBR dinâmico obtidos em dois períodos distintos sobre uma estrada não

pavimentada em Bragança, Portugal. Essa estrada é considerada um objeto de alto valor de análise por ligar as duas barragens responsáveis pelo abastecimento de água da região. Foi avaliado os parâmetros de capacidade de carga de ambos os ensaios sob uma análise em retrospecto e investigou a correlação entre os mesmos para cada uma das temporadas de ensaios.

## 1. INTRODUCTION

Unpaved roads are a substantial part of the nations road's network. CIA (2012) points that the United States has about 35% of its road network of unpaved roads. Besides the United States, the agency reunites information about this aspect associated with other countries: Australia has 83%; Honduras has 77%; Iceland 56% and Russia 28%. It's notorious that the unpaved roads stake is a huge portion in the roads networks around the world.

There are a lot of approaches that allow the evaluation of the upkeep condition of unpaved roads and the traffic capacity associated with it. Over them, the mechanical evaluation can be highlighted which permits the application of methods that upgrade the actual road in a paved one and permits the monitoring of the structural state (analyses if the road can hold by its structure the volume of vehicles stipulated to pass through it). These actions are only possible by applying bearing capacity tests.

The bearing capacity tests are usually divided into two groups: laboratory tests, like CBR and Triaxial shear test which demand the gathering of soil's samples to do their procedures; and *in situ* tests, like *in situ* CBR, plate loading, dynamic probing that are tests executed over undisturbed soils displaying more accurate results of the material under investigation. Although, a regular barrier to the *in situ* tests mentioned is that all of them demand a huge mobilization of resources: they use big equipment and need a group of people (at least two) to execute the whole process.

More efficient *in situ* tests were developed to break on through the limitations of the conventional ones. This way arrives the dynamic bearing tests: in 1984 the Light Falling Weight Deflectometer – LFWD was created in Germany (Nazzal et al., 2007) and later an extension to the LFWD that makes possible the dynamic CBR application. These tests deliver fast results and allow just one person to execute them.

One unpaved road set inside the Montesinho Natural Park was the study object of this paper. The road enables the passage of the park's preservation management entities and also of the tourists interested in the natural beauty of the park, as well as it connects the two crucial dams for the water supply of the city of Bragança in Portugal.

Figure 1 shows the unpaved road studied located in a mountainous region, near the village of Montesinho. The road, which belongs to the city of Bragança in the northeast of Portugal, has elevations between 1220 and 1250 meters regarding sea levels, and coordinates (ETRS89-TM06) M: 109862.46 P: 255612.42 for point A of Figure 1 and M: 109400.55 P: 252673.37 corresponding to point B in the same figure. The entire course totalizes 3016 meters.

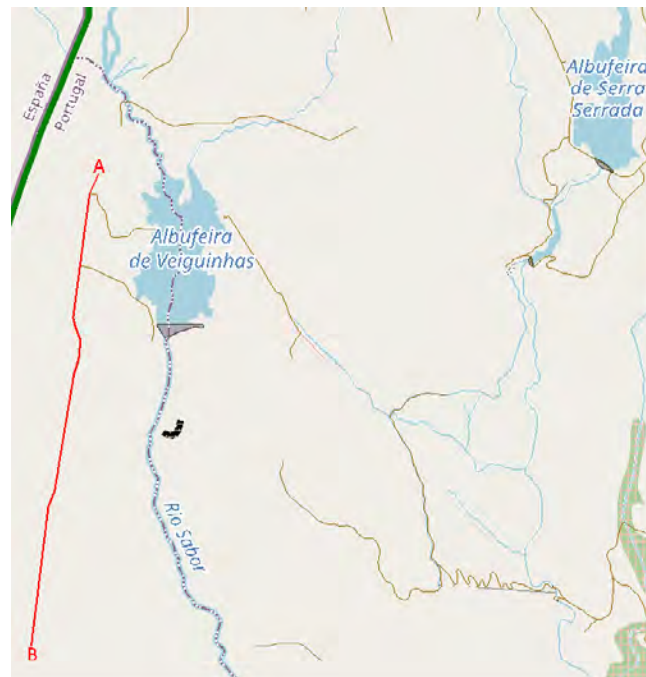


Figure 1 – Location of the Unpaved Road studied

## 2. LITERATURE REVIEW

### 2.1. Light Falling Weight Deflectometer – LFWD

The Light Falling Weight Deflectometer is a new concept of the Falling Weight Deflectometer, traditional *in situ* test encharged of measure the bearing capacity of pavement's layers. Instead of its former design, the Falling Weight Deflectometer - FWD, which is contained in a towable trailer or built in an intended vehicle to execute the test, the LFWD is done using a portable three-part device that can be easily handled by just one person. Although it was developed in 1981 in Magdeburg - Germany, the use of this test spread only at the beginning of the 2000's decade (Elhakim et al., 2013).

The LFWD is used with the main objective of measuring the dynamic elastic modulus ( $E_{vd}$ ) of the foundation soil (in some cases the site's natural subgrade) and mostly granular layers. To sum up, its execution consists of the fall of a mobile mass, along a rod to hit a set of springs at the end of the rod. Each hit causes displacement of the plate, deflections, and propagate vibrations through the material, and the parameters are collected by one or several transducers that can be either internal or external to the plate, which allow the equipment to evaluate the  $E_{vd}$  of the stratum. Figure 2 shows the entire LFWD equipment.

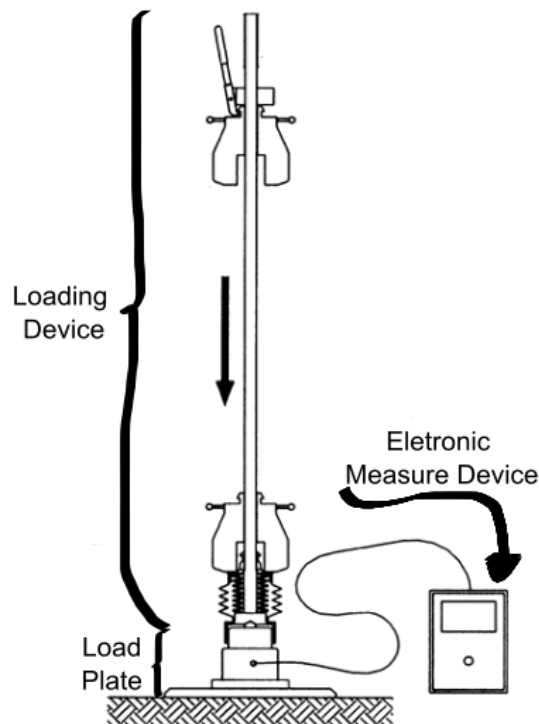


Figure 2 – Light Falling Weight Equipment  
Modified from Adam and Adam (2003)

Like the FWD, its precursor, the LFWD test simulates the effort made by the wheels of a vehicle and also uses the Boussinesq model, which considers the soil as a homogeneous elastic material to calculate its deformability modulus. Equation 1, presented below, stands the calculation of  $E_{vd}$  by LFWD according to Nazzal *et al.* (2007) and Mendes (2013).

$$E_{VD} = \frac{k(1 - \nu^2) \sigma R}{s_m} \quad [1]$$

- $E_{vd}$  as dynamic elastic modulus in (N/m<sup>2</sup>);
- $k$  as rigidity factor (if it is a flexible plate  $\therefore k = 2$  but if is a rigid plate  $\therefore k = \pi/2$ );
- $\nu$  as Poisson's ratio;
- $\sigma$  as applied stress in (N/m<sup>2</sup>);
- $R$  as radius of the loadplate in (m);
- $s_m$  as the mean value of deflection detected in the center of the plate in (m).

The states took from Mendes (2013) and Oliveira (2017) studies conclude this topic. It was found that LFWD is not a suitable test for obtaining the evaluate the modulus of bonded layers. The test application on soils and granular materials must not be under saturation conditions greater than 95%.

## 2.2. Dynamic California Bearing Ratio – Dynamic CBR

The application of dynamic CBR was only possible by the plunger developed after the LFWD that fits between the loading device and the load plate. Figure 3 shows a typical plunger for performing the dynamic CBR test.



Figure 3 – Typical Plunger for dynamic CBR test

The purpose of this test is the same as other CBR tests, the penetration of a plunger over the element in which it is being tested. Penetration in this case is generated by the impact of the drop weight on the set of springs which displace the plunger and it tends to penetrate the ground. It is possible because the load plate has a hole on its lower base that allows the passage of the plunger to the material. Figure 4 presents a characteristic load plate to perform the dynamic CBR test.

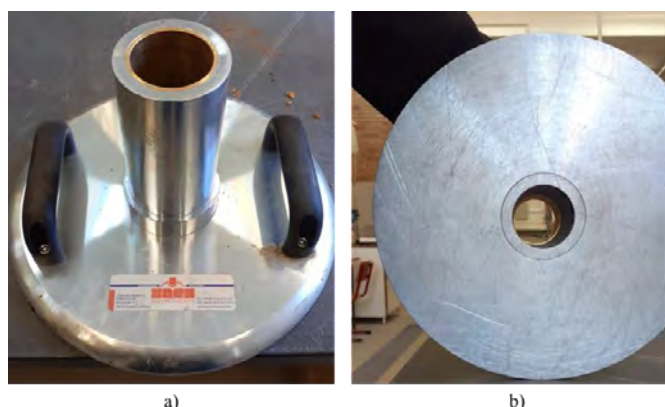


Figure 4 – Different Load Plate for dynamic CBR test

Equation 2 announced by the TIC company presents the dynamic CBR calculation principle (TIC, 2017 apud Oliveira, 2017).

$$CBR_D = \frac{24,26\sigma}{s^{0,59}} 10^6 \quad [2]$$

$CBR_D$  as Dynamic CBR in (%);  
 $\sigma$  as applied stress in (N/m<sup>2</sup>);  
 $s$  as deflection in (m).

**3. METHODOLOGY**

The points submitted to the LFWD and dynamic CBR tests were previously georeferenced, so in both seasons (December/2020 and March/2021) that tests were performed, they had been on the exact points. In the two seasons of tests, first, the LFWD test was done, from the arrival to the end of the road, on all points, and then the dynamic CBR on the return over the same points.

The ZFG 3.00 was the equipment used to execute the LFWD and dynamic CBR tests (along with the plunger and holed plate necessary for the last one). Six hits were executed for LFWD, three for the appropriate settlement of the plate (known as pre-loading), and three to take measures of the point due to recommendations in ASTM E2835 (2011). Only one hit was executed for the dynamic CBR test.

**3.1. Cumulative Differences Approach**

It was used AASHTO’s Cumulative Differences Approach, presented in annex J of Guide for Design of Pavement Structures publication (AASHTO, 1993) to divide the road into homogeneous sections regarding  $E_{vd}$  and  $CBR_d$  parameters. It was originally conceived for paved roads identifying road intervals with similar mechanical behavior, whether to deflection, skid resistance, bearing capacity, and other aspects. It emerged as a solution to analyze quickly extensive road networks which are not feasible to examine each measured response of the points within sets that often comprised tens to thousands of data. The process is described ahead in Tables 1 and 2.

Table 1 – Part one of Cumulative Differences Approach

Interval (1)	Distance (2)	Cumulative Distance (3)	Parameter (4)	Average Interval Parameter (5)
1	$\Delta x_1$	$\overline{\Delta x_1} = \Delta x_1$	$r_1$	$\overline{r_1} = r_1$
2	$\Delta x_2$	$\overline{\Delta x_2} = (\Delta x_1 + \Delta x_2)$	$r_2$	$\overline{r_2} = (r_1 + r_2)/2$
3	$\Delta x_3$	$\overline{\Delta x_3} = (\Delta x_1 + \Delta x_2 + \Delta x_3)$	$r_3$	$\overline{r_3} = (r_2 + r_3)/2$
$N_t$	$\Delta x_{nt}$	$\overline{\Delta x_{nt}} = (\Delta x_1 + \dots + \Delta x_{nt})$	$r_{nt}$	$\overline{r_{nt}} = (r_{nt-1} + r_{nt})/2$

Table 2 – Part two of Cumulative Differences Approach

Actual Interval Area (6)	Acumulative Area (7)	Zx Value (8)
$a_1$	$\overline{a_1} = a_1$	$Z_{x1} = \overline{a_1} - [(\overline{a_{nt}} / \overline{\Delta x_{nt}}) * \overline{\Delta x_1}]$
$a_2$	$\overline{a_2} = a_1 + a_2$	$Z_{x2} = \overline{a_2} - [(\overline{a_{nt}} / \overline{\Delta x_{nt}}) * \overline{\Delta x_2}]$
$a_3$	$\overline{a_3} = a_1 + a_2 + a_3$	$Z_{x3} = \overline{a_3} - [(\overline{a_{nt}} / \overline{\Delta x_{nt}}) * \overline{\Delta x_3}]$
$a_{nt}$	$\overline{a_{nt}} = a_1 + \dots + a_{nt}$	$Z_{xnt} = \overline{a_{nt}} - [(\overline{a_{nt}} / \overline{\Delta x_{nt}}) * \overline{\Delta x_{nt}}]$

The Zx results expressed in graphs facilitate the determination of homogeneous sections. When is verified no change in slope of the line, there is a similar behavior in this stretch. In the other hand, the points which the change in slope occurs, correspond to the change in the homogeneous behavior of the pavement and so a beginning of a new section and the end of the previous one.

## 4. RESULTS AND DISCUSSION

### 4.1. Light Falling Weight Deflectometer – LFWD

The LFWD test reflects a road in different mechanical condition from one season to another one. It can initially be noticed by submitting  $E_{vd}$  results to the cumulative differences method: the graph from the December test has eight well-defined sections while the graph which represents the march test brought six sections that have some erratic points making not-so-clear lines. Figures 5 and 6 stand respectively for the December test graph and for the March test graph using AASHTO's method.

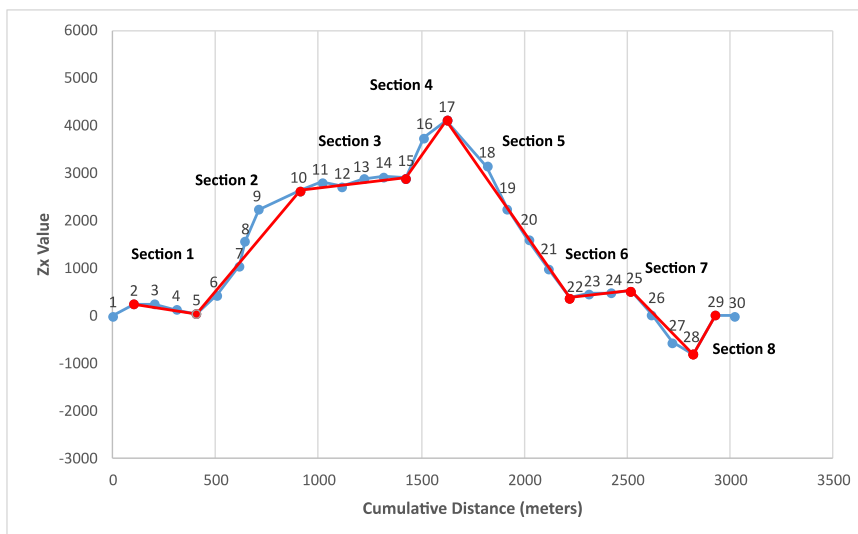


Figure 5 – Cumulative Difference method applied in  $E_{vd}$  results from December

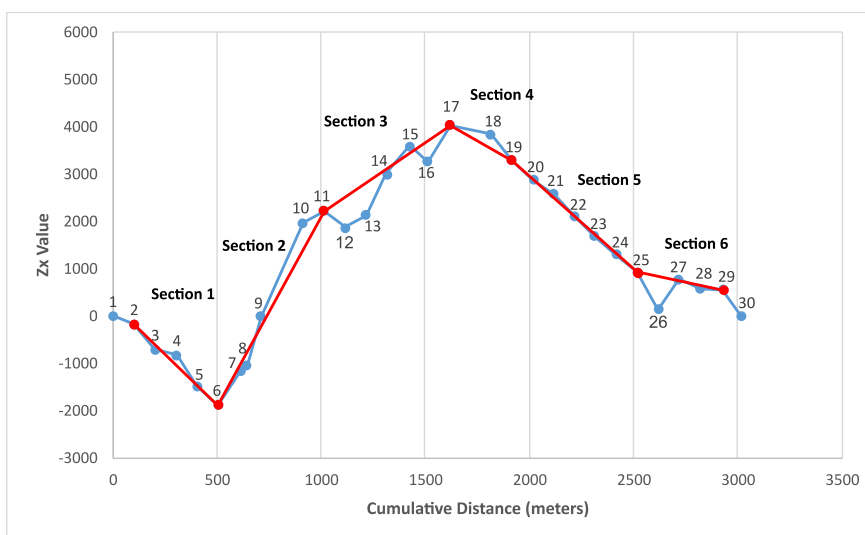


Figure 6 – Cumulative Difference method applied in  $E_{vd}$  results from March

There was a considerable drop in the average value of  $E_{vd}$  from one season to the other: in December was identified 25.32 MPa of average  $E_{vd}$  while in March the value identified was 22.17 MPa which represents approximately 12% of the decrease in the average parameter. Separating the road according to the sections of the most recent test (March) and analyzing the evolution of the  $E_{vd}$  parameter from point to point,

according to percentage difference, it was possible to notice a clear scenario of the parameter along the road. Between sections 3 and 4 an improvement in the parameter and between sections 5 and 6 a generalized worsening of it. The test showed a major decline in the mechanical condition of the road. Figure 7 shows the analysis of the percentage difference of  $E_{vd}$  from one to another along the road.

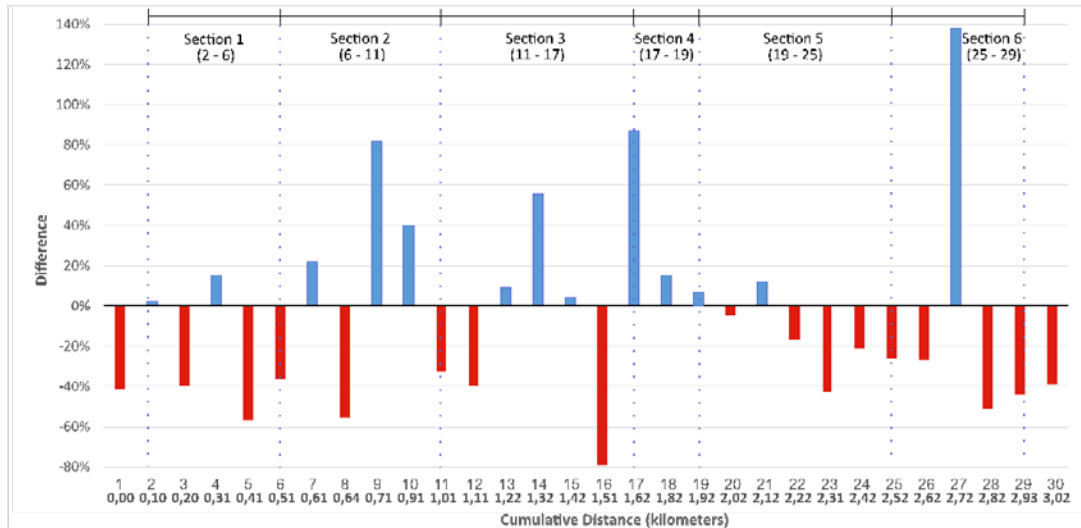


Figure 7 –  $E_{vd}$  Percentage Difference between the two seasons measured

#### 4.2. Dynamic Californian Bearing Ratio – Dynamic CBR

The dynamic CBR also conveys two different conditions from one season to another. As the application of LFWD results on the cumulative difference method, the dynamic CBR results from both seasons separate the road into eight sections in December and six sections in March. Although in the LFWD graphs was possible to identify a certain similarity between lines, dynamic CBR graphs are unlike when it comes to geometry resemblance. Figures 8 and 9 present the cumulative difference graphs for the dynamic CBR test.

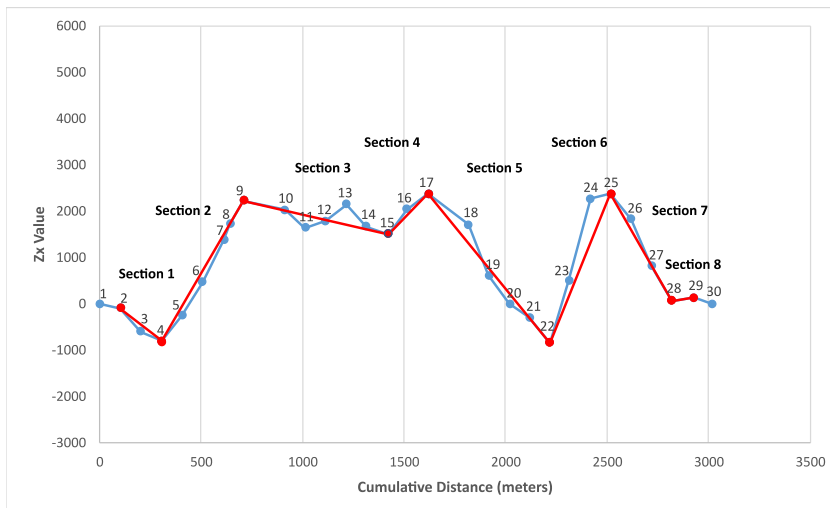


Figure 8 – Cumulative Difference method applied in  $CBR_d$  results from December

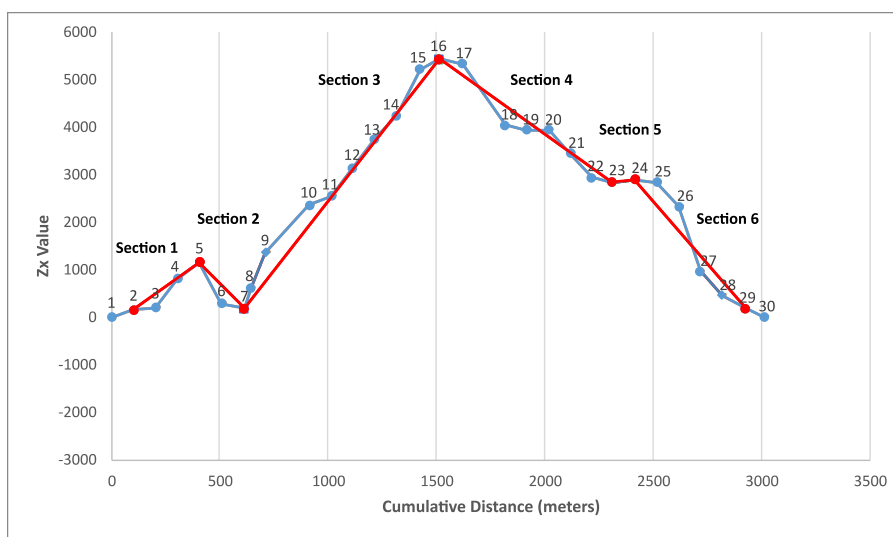


Figure 9 – Cumulative Difference method applied in CBR<sub>d</sub> results from March

The same analysis made with LFWD results was done with dynamic CBR results: the average in the first season (December) was 40.3% which lowered to 32.6% in the second season (March). This difference stands for 19.1% of the first season’s average which is higher than the average difference noticed in LFWD results. The higher difference of this test shows that CBR<sub>d</sub> is probably more sensible than E<sub>vd</sub> which justifies the decrease of the first parameter in almost all points over the road when the retrospective analysis is done. Besides some exceptions, from the second half of the road until the end of it all points decreased in CBR<sub>d</sub> which is showed in Figure 10.

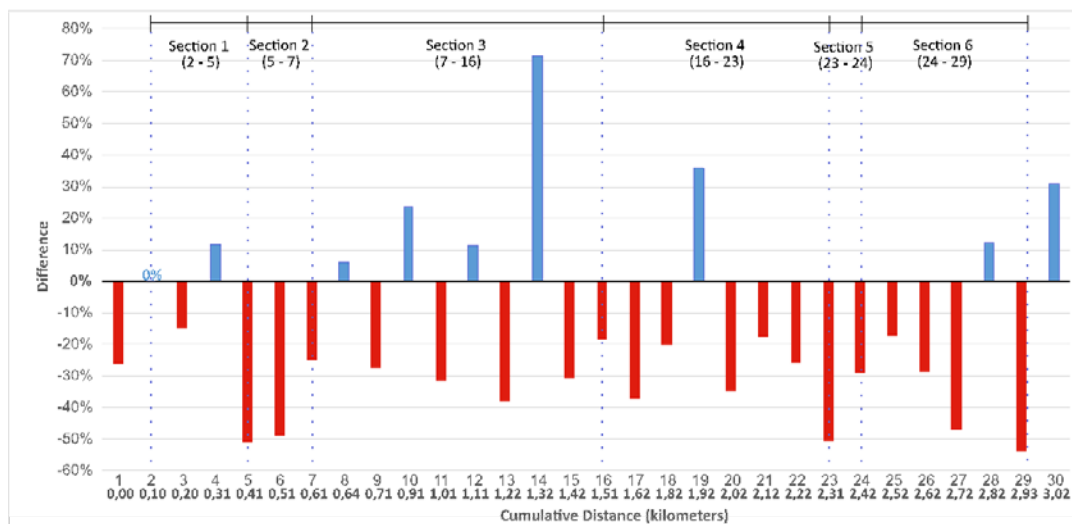


Figure 10 - CBR<sub>d</sub> Percentage Difference between the two seasons measured

### 4.3. Correlations

Although both tests showed a deteriorated condition of the road, the correlations found for the 30 pairs of E<sub>vd</sub>/CBR<sub>d</sub> did not have high a affinity. The December E<sub>vd</sub> and CBR<sub>d</sub> results when correlated (the two whole sets) reached a maximum R<sup>2</sup> of 0.4282 for a natural logarithm equation. By decreasing the range of results to the section level, for December there were natural logarithm correlations in the order of 0.9 for R<sup>2</sup> in

sections 5 and 6. For the results of March, correlations reached  $R^2$  even lower for the whole set, and at the section level, the maximum was in the order of 0.5.

## 5. CONCLUSIONS

The study presents how to evaluate an unpaved road by performing bearing capacity tests on the road's earth bed and how to use the data to analyze the road's mechanical condition.

Based on the analysis carried out, using AASHTO's accumulated differences method on the results of  $E_{vd}$  and  $CBR_d$  parameters of each period, a greater divergence of the test in charge of the last parameter is noted than the one responsible for the other, conveying a test more sensitive to changes occurred on the road. Although, both evidenced a road in decaying mechanical capacity suggesting that the road needs repairs, that it probably has more distresses from one season to another under its surface (which affects the surroundings of their spots) and is prone to have more of them.

The correlative try showed that, despite not reaching a satisfactory global expression between  $E_{vd}$  and  $CBR_d$ , it may be interesting in future analyzes to restrict the correlation dataset to the section level, verify which of them have a high index, and find out what makes this possible.

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