v. 2, n. 22, 2022

Journal of
Engineering
Research

GEOTECHNICAL FIELD INVESTIGATIONS TO MEASURE SOIL RESISTANCES ON THE CONTORNO OESTE HIGHWAY IN BOA VISTA/RR AND SOLUTION TO LANDFILLS ON SOFT SOILS

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Abstract: Among other challenges, embankments on soft soils have been inspiring to geotechnical engineers, designers and executors, to seek challenging solutions. On this subject, Professor Márcio Almeida, one of the greatest experts on the subject, mentions that these challenges have already resulted in successes and memorable ruptures in works based on soft soils. In general, soft soils are considered, materials of high plasticity, in some cases rich in organic matter, with Nspt ≤ 4. Thus, brief considerations on soft soils are presented, but also results with analyzes and discussions of geotechnical studies carried out on the Highway West Contour of Boa Vista (BR 174), in the State of Roraima, aiming at the determination of soil resistance by means of in situ Palheta Tests (Vane Test), according to ABNT NBR 10905: 1989 (MB-3122). The studies consisted in the execution of "Geotechnical Field Investigations" in sections comprised by 11 piles of the aforementioned Highway. Considering the results, it was found that the soft soil layers in the studied sections have variable "average" thicknesses from section to section with minimums close to 2.0 meters and maximums that exceed 6.0 meters. Furthermore, the existing embankments of the old track, located in the studied sections, indicate the presence of soils of low bearing capacity under the body of the embankments. In addition to the studies, solutions are proposed for landfills on low bearing capacity soils.

Keywords: Contorno Oeste da Boa Vista Highway; landfill; Soft soil; Resistance.

INTRODUCTION

This work presents the results of geotechnical studies carried out on the Contorno Oeste Highway in Boa Vista, state of Roraima (RR), with a view to determining soil resistance by means of in situ reed tests (Vane Test), according to with ABNT NBR 10905: 1989 (MB-3122). Additionally, to support the analysis of the reed tests and also to better understand the geotechnical properties of the materials for the embankment project on soft soils, tests were carried out with a Light Dynamic Penetrometer (PDL) according to the recommendations of DIM 4094 and ISSMFE, from 1989, and in compliance with the procedure of the former National Department of Roads and Highways (DNER-PRO 381/98) Shelby sample collection, layer thickness determination, characterization tests and soil resistance. However, this work presents and analyzes the "in situ" reed tests carried out in the area in question.

INITIAL CONSIDERATIONS

In the development of this work, an extensive bibliographic survey of landfills on soft soils was sought, as well as information that could more faithfully represent the geotechnical knowledge of the region studied.

Soft soils are materials rich in organic matter, with high plasticity and Nspt ≤ 4, deposits of organic soils, very soft sand, peat or hydromorphic soils, in general, likely to occur in low-lying wetlands; mangroves and marshes; floodplains of rivers with low hydraulic gradient; old watercourse beds; marine or lake sedimentation plains. They have physical properties that can vary, resulting in behavioral changes within the same deposit. As characteristics there is great compressibility, low resistance, small permeability and low consistency. The characterization of soft soil deposits aims to guide and support road projects in order to avoid future burdens such as excessive deformations, cracks and slope ruptures.

In general, landfills on soft soils are defined in three classes: Class I, II and III (DNER 381, 1998), according to specific characteristics.

IN SITU REED TEST (VANE TEST)

Its purpose is to measure the undrained shear strength of purely cohesive soils. In Brazil, the standard that governs the test is ABNT NBR 10905:1998.

According to Almeida (1996), the "in situ" reed test is the most used to determine the undrained strength Cu of soft soil, consisting of a constant rotation of 6° per minute of a cruciform reed at predefined depths. The measurement of torque versus rotation allows the determination of Cu values. Table 1 presents the consistency states for soils as a function of the penetration resistance index "N" obtained in the SPT tests, based on Annex "A" of NBR 6484/2020.

To determine the undrained soil strength (Cu), Equation 1 is used:

$$Cu = \left[\frac{T}{\pi . \left(D^3 + \frac{D^3}{6} \right)} \right] . \frac{1}{100} \quad (1)$$

Where: Cu = Undrained soil strength, in kPa; T = Maximum soil torque in kgf.m; D = Blade diameter; π = 3,1416.

CLAY SENSITIVITY

The strength of clays depends on the arrangement between the grains and the void ratio in which it is found. The consistency after handling (crushed) may be less than in the natural state (undisturbed). This phenomenon occurs differently and was called clay sensitivity.

Sensitivity can be well visualized through two simple compression tests. The first with the sample in its natural state. The second, with a specimen made with the same soil after complete remodeling, but with the same void ratio. To determine the sensitivity of the clay, Equation 2 is used:

$$S = \frac{Resistance\ in\ the\ undisturbed\ state}{Resistance\ in\ the\ dented\ state} \quad (2)$$

As for sensitivity, clays are classified according to Table 2. It must be noted that the higher the degree of sensitivity, the lower the soil support capacity.

LIGHT DYNAMIC PENETROMETER TEST (DPL)

The DPL, specified in the International Reference for Test Procedures for Dynamic Sounding (DP) (ISSMFE, 1989), is a small hand-held field device designed for use in soundings to a maximum depth of 21 m. Probing suitable for small to medium depth projects, complementing and correlating with other studies. It is ideal for use in hard-to-reach places such as floodplains, slopes and closed spaces. With good penetration in soft/soft and medium hard soils, being possible to use in layers of sand and gravel medium compacted. The test provides lateral friction and edge resistance, allowing a slight tactile-visual evaluation of the soil through grooves present in the rods and identification of the water level.

The DPL aims to characterize and determine the penetration resistance of low-bearing-capacity soil deposits. This test helps to determine soil resistance in areas where the Palheta test becomes technically unfeasible, such as: in granular soils, unsaturated soils and soils with high permeability. Figures 1 and 2 show the components of the Light Dynamic Penetrometer (DPL) equipment.

CHARACTERIZATION OF THE MUNICIPALITY OF BOA VISTA

Boa Vista (Latitude: 2° 49' 10" North and Longitude: 60° 40' 17" West) is a Brazilian municipality, capital of the state of Roraima, in the northern region of the country. It is located on the right bank of the Rio Branco and is located at an altitude of 76 meters. It is the northernmost capital of Brazil and the only one located entirely north of the equator, and the furthest from Brasília, the federal

Soil	N	Designation
Clays and clayey silts	≤ 2	Very soft
	3 a 5	Soft
	6 a 10	Medium
	11 a 19	Stiff
	20 a 30	Very stiff
	> 30	Hard

Table 1. State of Soil Consistency (ABNT NBR 6484: 2020).

Sensitivity	Classification
1	Insensitive
1 a 2	Low sensitivity
2 a 4	Medium sensitivity
4 a 8	Sensitive
> 8	Ultra-sensitive

Table 2. Classification of clays in terms of sensitivity.

Figure 1. Components for the DPL test.

Figure 2. DPL tip for ground penetration.

Figure 3. Pedological map with emphasis on the Municipality of Boa Vista (IBGE, 2005).

capital. It has, according to IBGE, an area of 5,687,037 km² and an estimated population of 399,213 inhabitants in 2019.

STUDY AREA SOILS

Vale Júnior (2005), mentions that the soils of the state of Roraima are related to their geomorphology. Soils have as outstanding characteristics, low natural fertility, low base saturation, and high aluminum saturation. Figure 3 shows a small fragment of the pedological map of the region studied, in which latosol, neosol, plintosol and gleisoil were predominantly found.

WORK METHODOLOGY

The methodology involved an extensive bibliographic survey and results of geotechnical studies carried out in 2008, on the Contorno Oeste Highway in Boa Vista in the State of Roraima, and aimed at determining the soil resistance by means of in situ Palheta Tests (Vane Test), according to ABNT NBR 10905: 1989 (MB-3122), and the Light Dynamic Penetrometer (DPL) according to recommendations from DIM 4094 and ISSMFE, 1989. The studies consisted in the execution of a program of "Geotechnical Field Investigations" in sections comprised by piles 181, 183, 186, 188, 378, 380, 382, 384, 425, 427 and 429 of said Highway. Figures 4 to 9 show test performance locations.

PRESENTATION AND ANALYSIS OF RESULTS OF THE STUDY SOIL PROFILES

In total, 3 (three) sections were studied, as shown in Table 3, in which the approximate length of each section with the corresponding piles is presented.

Figures 10, 11 and 12 present the profiles of undrained strength x depth measured through the reed tests for Sections 01, 02 and 03. Then, in Figures 13, 14 and 15, the undrained strength dented in them depths. In addition, Figures 16, 17 and 18 show results of soil sensitivity x depth.

Considering the undrained strength of Section 01 (Figure 10), there is some variability in the measured values, with maximum undrained strength close to 130 kPa up to a depth of 4.0 meters in piles 181 and 188.

The undrained resistance for Section 02 (Figure 11), at a depth of 0.50 m, presented values from 39 kPa to 76 kPa with a decrease until close to a depth of 4.5 m, for later increase to a depth of 6.0 m in the stakes 378; 380 and 384. However, in pile 382, the soil presented resistance below those verified in the other three piles. It is possible that the higher values in the 0.5m layer are related to the dryness of the surface layer, not representing reliability in the resistance of this depth, since these layers are subject to resistance variation in the drying and drought periods.

In analysis of stretch 03 (Figure 12), higher resistance is verified in the initial layer, as seen in stretch 02, with a decrease in the lower layers. For piles 425 and 429 + 15, the increase in undrained resistance can be seen from the approximate depth of 3.5m. This fact was not verified in pile 427, in which the resistance was maintained or decreased up to a depth of 6.0m.

In observation of undrained dented resistance for stretch 01 (Figure 13) there is a certain initial trend up to a depth of 2.0 m. Then there is a considerable gain in strength at pile 181, with values close to 130 kPa. For pile 183 there is a certain variability with increasing increase from 4.5 m to a depth of 6.5 m. It is possible that the great variability of strength of piles 181 and 183 is due to the fact that the soil of the studied area is composed of sedimentary soil, which is a transported soil, and subject to considerable variability in strength.

In relation to undrained dented strength

Figure 4. View of stretch 1 (Piles 181 to 188).

Figure 5. Existence of Buritizeiros indicating the presence of soft soil.

Figure 6. Existence of soft soil in stretch 1.

Figure 7. Soil profile of section 1.

Figure 8. Execution of DPL test.

Figure 9. Preparation for performing the "vane-test" test.

Stretch	Approximate Length (m)	Piles
01	160 m	181, 183, 186 e 188
02	140 m	378, 380, 382 e 384
03	140 m	425, 427, 429+15

Table 3. Sections in which the "Vane-Test" tests were performed.

in section 02 (Figure 14) there is a similar behavior for piles 380; 382 and 384 to a depth of 2.5m with a maximum strength of less than 20 kPa. There is also a gain in strength above 70 kPa for piles 378 and 384. This section is generally characterized by a soil considered soft, since most of the piles do not exceed the value of 50 kPa of strength.

Considering the dented undrained resistance for Section 03 (Figure 15), there is some variability in the initial measured values, however, from a depth of 1.0 m onwards, there is a certain tendency with resistances reaching a maximum of approximately 23 kPa, with except for the 429+15 pile, which has a considerable gain in strength from 4.5 m, reaching close to 71 kPa. The average strength of the three piles is 40.67 kPa, thus being characterized as soft soil.

In Section 01 (Figure 16) there is a certain initial tendency of piles 181, 183 and 186 to a depth of 2.5 m, with maximum strengths of 3 kPa, and considerable increase in sensitivity for pile 186, reaching the value approximately 9.5 kPa, indicating ultra-sensitivity of the soil, with a subsequent decrease close to 7 kPa at a depth of 3.5 m and sensitive behavior. On the other hand, pile 188 does not follow the same diposition as the others, as it has a variability of increases and decreases in sensitivity along the depths of 0.5 m and 2.5 m.

In Section 02 (Figure 17) the sensitivity presented values between 3.5 and 5.5 to 1.5 m for piles 382 and 384 with behavior between medium sensitivity to sensitive. Between 2 to 6 m depth, the soil behaved with indicative values up to medium sensitivity.

When analyzing the sensitivity for Section 03 (Figure 18) there is a high value up to 1.0 m for pile 427, reaching a resistance close to 5.2 times greater than the average of the resistances of piles 425 and 429+ 15. From a depth of 2m, the maximum sensitivity value was 5kPa, indicating even sensitive behavior.

FINAL CONSIDERATIONS / RECOMMENDATIONS

NBR 6484 Soil - Simple recognition soundings with SPT - Test method, is considered very soft to soft soil when NSPT ≤ 5, however, in the work in question, soft soil was considered when NSPT ≤ 4 and strengths up to 50 kPa. In this context, the main considerations for the study are presented.

a) Soft soil layer with thicknesses of less than three meters

With the results obtained, it is concluded that the studied soils, in general, have a low bearing capacity, and that to solve the problems with regard to the densification and stability of embankments to be built in areas where compressible soils occur, they need to be removed. Complete removal is recommended, that is, the base of removal must be placed on material with good support qualities, avoiding remnants of compressible soils that can cause future problems.

In order to stabilize possible pockets of remaining soft soil, it is recommended to lay a layer of rachão stone (stony material of variable sizes, usually up to 20 cm in diameter).

Another important recommendation is the implementation of a drainage system of the draining trench type (1.50 m deep x 0.50 m wide) associated with the draining mattress (0.40 m thick), at the base of the landfill, in which, in addition to the main function (draining) it effectively collaborates with the reduction of differential settlements and increase of resistance by eliminating water. It also reduces capillary rise caused in compacted landfills with silty-clay soils.

b) Soft soil layer with thicknesses greater than three meters

For landfills on low bearing capacity soils and with heights greater than three meters, cleaning and surface regularization of the area is recommended, with light equipment or manually.

Journal of Engineering Research ISSN 2764-1317 DOI 10.22533/at.ed.3172222203102

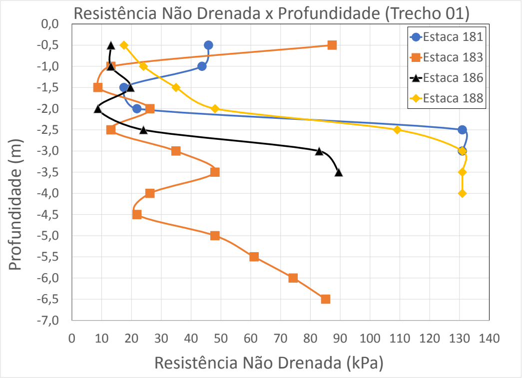

Figure 10. “Vane-Test” for section 01.

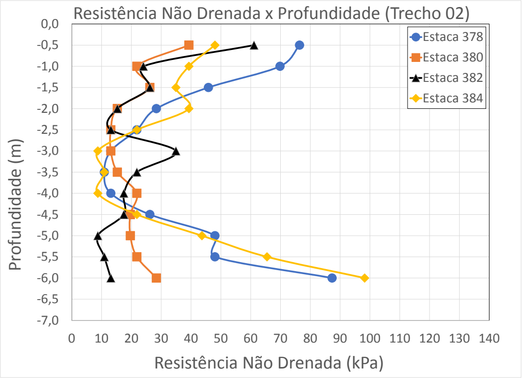

Figure 11. “Vane-Test” for section 02.

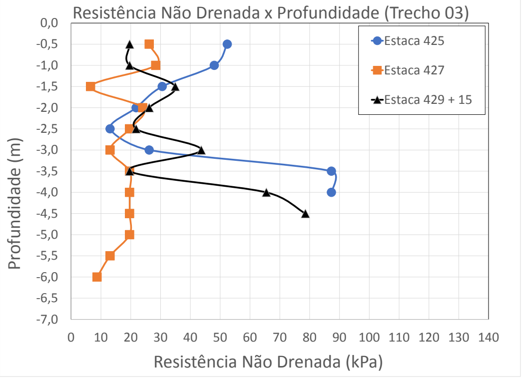

Figure 12. “Vane-Test” for section 03.

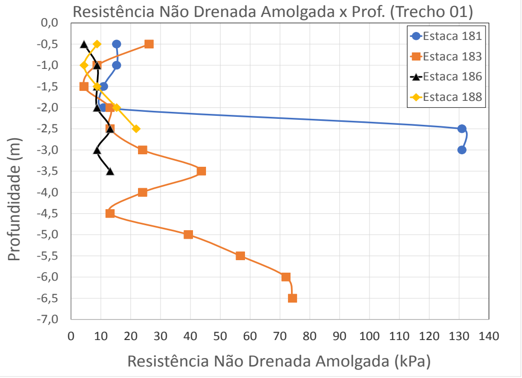

Figure 13. Dented undrained resistance x depth for section 01.

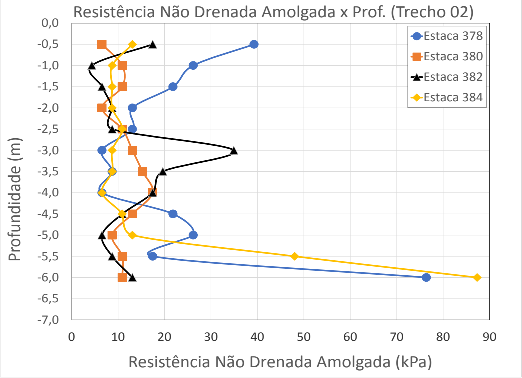

Figure 14. Dented undrained strength x depth for stretch 02.

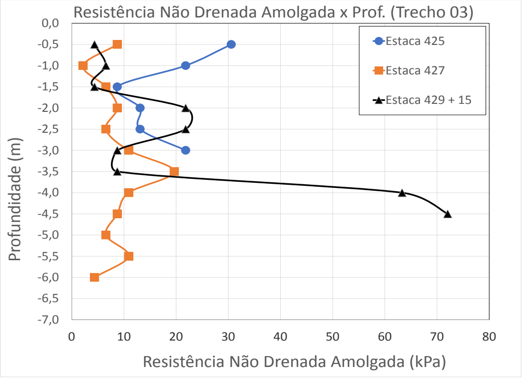

Figure 15. Dented undrained resistance x depth for section 03.

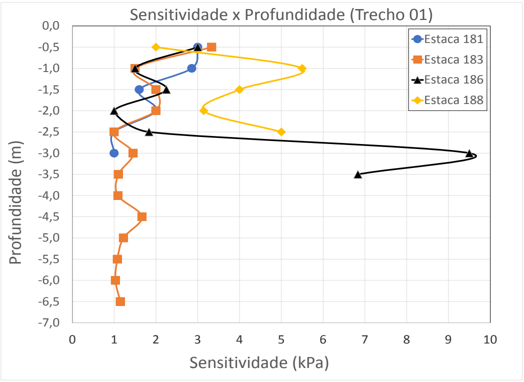

Figure 16. Sensitivity x depth section 01.

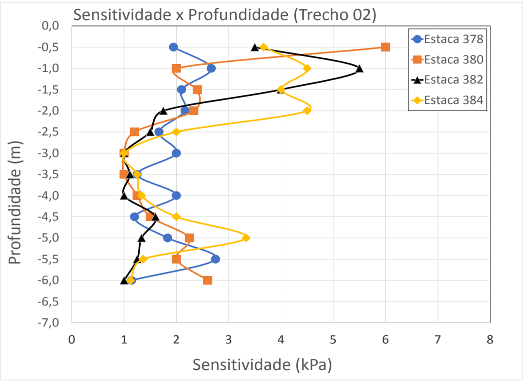

Figure 17. Sensitivity x prof. stretch 02.

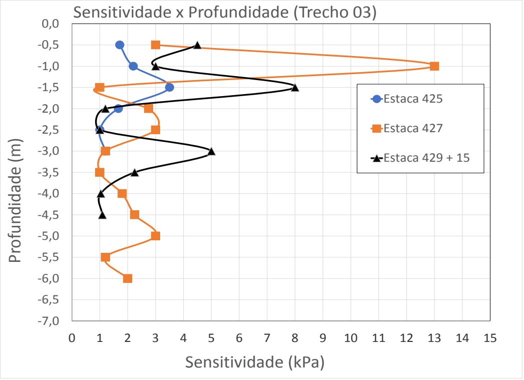

Figure 18. Sensitivity x depth section 03.

On the regularized layer, it is recommended to lay a layer of rachão stone until stabilization. On the already stabilized layer, it is recommended to carry out a drainage system composed of a draining mattress (0.40 m thick), using a non-woven geotextile with a minimum tensile strength of 31 kN/m as a filter and a draining trench on the perimeters (1.50 m deep x 0.50 m wide), associated with the draining mattress. Another layer of non-woven geotextile with a minimum tensile strength of 31 kN/m must be placed on this draining mattress before launching the compacted backfill.

Depending on the need, in relation to the execution time of the compacted embankment, vertical drains (geodrenos) can be executed with the objective of accelerating the settlements and/or the use of geogrids to minimize the differential settlements. Furthermore, it must be noted that there are other solutions that can be analyzed depending on particular situations. Such solutions include the use of lightweight embankments with expanded polystyrene (EPS), balance berms, temporary overloading, construction in stages, among others technically possible and economically viable.

THANKS

The Universidade Católica de Brasília (UCB), Centro Universitário de Brasília (UniCEUB) and Reforsolo Engenharia, which made this work possible with important contributions.

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