Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Permeability profile of a planosol based on in situ falling head permeability tests

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ABSTRACT: The present paper show the results of in situ falling head permeability tests conducted in a planosol formed above the coastal quaternary deposits in south of Brazil. An excavation was planned to be performed to drainage of a road constructed nearby. The influence of this excavation on the seepage behavior of the marshy ground of this region was important to be considered in order to protect the habitat of endangered fish species. Results showed that for the depth up to 2.0 m, the value of permeability coefficient decreased (from 2.4×10^{-5} to 4.1×10^{-6} cm/s) and then it increased to 4.4×10^{-5} cm/s. The results are in agreement with the concentration of clay in subsurface, resultant of the pedogenesis of the planosol. This study will subsidize a numerical analysis of the flow resulting from excavation and therefore an indication of the best solution to minimize the project impacts on the surrounding environment.

1 INTRODUCTION

The water behavior of the land has great relevance in environmental studies, particularly in assessing the impact caused by engineering works. In roadworks, drainage structures and the highway embankment itself modify the water surface behavior and seepage characteristics in adjacent land.

The area of the study are located in southern Brazil, between the cities of Pelotas and Turuçu in the state of Rio Grande do Sul, where road works on the BR 116 highway doubling are being carried out. In this area, close to the km 510 + 500, will be performed a drainage gallery that crossing the road under the pavement (Figure 1).

The excavation works, required for the gallery construction, are located around 70 m of a marshy ground with a 230 m length that is a habitat of a fish specimen called Rivulideos. The rivulideos fish or annual fish (Figure 2) has the characteristic to be a small fish and lives in shallow water environments or temporary ponds. The fish lay eggs in the substrate of ponds, where they remain inactive during the dry phase and return to develop after the flooding. The Chico Mendes Institute for Biodiversity Conservation (ICMBio) approved on 20 June 2013, the National Action Plan for the Conservation of Rivulideos Fish Threatened with Extinction. One of the actions of this Plan, it is to protect the remaining habitat of these animals, preventing them from being deleted, impacted or handled incorrectly (DNIT 2013).

Aiming at the fulfillment of that plan within the environmental management goals of the roadworks, it was necessary to assess the impact of the gallery excavations in the seepage behavior in this marshy ground. For this purpose, it was necessary to assess the parameters of this site in terms of the geotechnical characterization and the permeability profile of the soil with depth.

This paper presents the procedures and results of the geotechnical characterization and determination of the permeability profile using a series of in situ falling head tests.

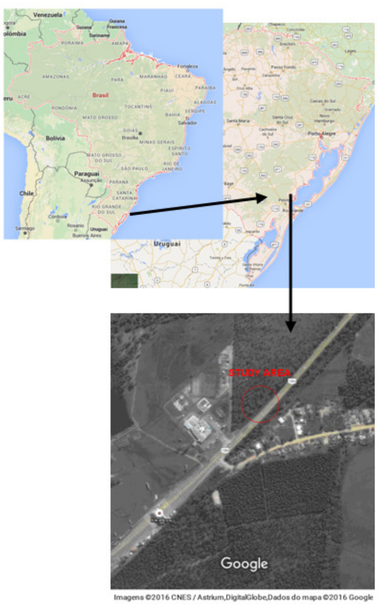

Figure 1. Location of the study area (Google Maps 2016).

Figure 2. Rivulídeos or annual fish found in highway work (DNIT 2013)

2 MATERIALS AND METHODS

2.1 *Characterization of the study area*

The study was conducted in the marginal area on the left side of the highway BR116 between Pelotas - Turuçu. The excavation of drainage gallery will be executed between the km 510 + 500 (Figure 1) in the transverse direction of the highway axis.

The area investigated has a square area of 5x5 m, where five points were located (with a minimum spacing between points of 3 m). In each point, was performed an auger drilling and collecting samples of the different soil horizons for geotechnical characterization. These holes were used to the falling head tests. The depths of the holes were 0.5, 1.0, 2.0, 3.0 and 4.0 m (Figure 3).

The geology and pedology of the study area have great importance to the interpretation of the geotechnical characterization and the permeability profile. According to segment of the Geological Map of the Sheet Pelotas/Mostardas - SH.22-Y-D / Z-C (IBGE 2003) presented in Figure 4, the study area has the geological substrate TQPg unit, characterized by arkose sandstones weakly consolidated that constitute alluvial fans deposits. The soil formed from this substrate belongs to the class of eutrophic Planosols with texture medium/clay (unit PLe3 in Figure 5) or Subdystric Paraquic Ochric Planosol obtained by the Soil Taxonomy American System. The soil profile is inserted in the geomorphologic unit Lagoon High Plain (Cunha & Silveira 1996).

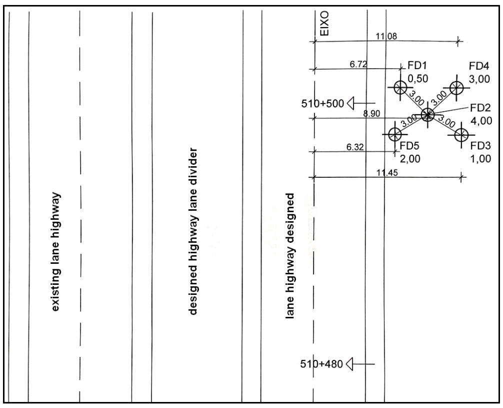

Figure 3. Design of the experimental area with collection points samples and testing

Figure 4. Geological map of the study area

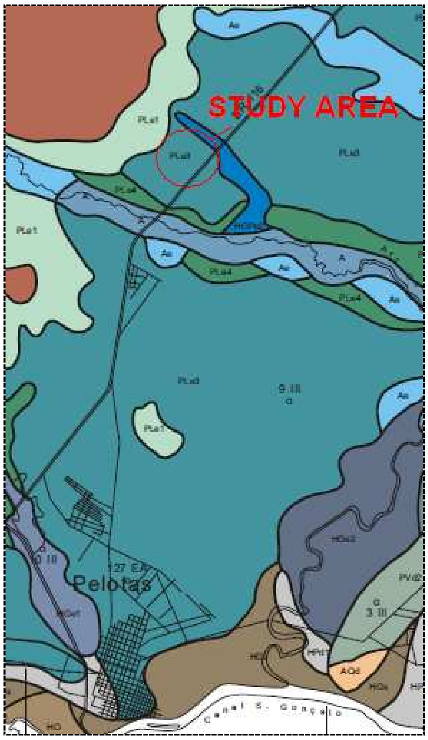

Figure 5: Soil map of the study area

Cunha & Silveira (1996) describe this planosol as a deep soil with imperfect drainage. The superficial horizon has 30-80 cm thick, texture medium (with 6-10% clay), poor structure (massive), strong acidity, color brown to dark grayish. The profile shows an abrupt and flat textural transition to the subsuperficial horizon B, with texture clay (25-40% clay), weak structure (angular or prismatic blocks) and consistency very firm when moist and very hard when dry. The authors indicate in this horizon the presence of a clay-pan, which difficult water penetration, and also reddish and yellowish brown mottled, indicating imperfect drainage. Therefore, the pedological records already indicate poor drainage and water retention by the textural gradient (increase in the clay content) of the horizon B.

2.2 *Geotechnical characterization*

For geotechnical characterization of the soils with depth, the auger samples were collected (Figure 6) at five different depths around 0.5, 1.0, 2.0, 3.0 and 4.0 m (in an amount sufficient for geotechnical characterization in the laboratory tests). The samples packaged and identified were sent to the Laboratory of the Geotechnics and Concrete of the Federal University of Rio Grande - FURG to the geotechnical characterization according the Brazilian standards: NBR 6457/1986 (Soil Samples - Preparation for Compaction and Characterization Tests); NBR 7181/1984 (Soil - Grain Size Analysis); NBR 6459/84 (Soil -Determination of Liquid Limit); NBR 7180/84 (Soil - Determination of Plastic Limit). These results allowed obtain the HRB-AASHTO and USCS classifications.

2.3 *Permeability profile*

The measures of the coefficient of permeability of soil in different depths were performed by a series of in situ falling head permeability tests. The falling head permeability tests followed the procedure indicated in the publication of ABGE (Brazilian Association of Engineering and Environmental Geology) - *Permeability Testing in Soils - guidance for its implementation in the field* - 4th edition (ABGE 2013). This test is considered a variable level test executed in the borehole. In the beginning of the procedure the water level inside the tube is elevated until the initial position of the test. During the test, the downward of the water level is monitored with time. In other words, a PVC tube is positioned in the depth of the test, filled with water until the initial level and then measures of the downgrade speed are performed. Figure 7 shows the test setup.

Before the measures, it was allowed percolation to ensure the saturation condition surrounding the borehole bottom. Furthermore, as the tip of the tube inserted coincides with the bottom of the borehole, the hypothesis adopted was that the water infiltrates the ground through spherical surfaces (Figure 8). In this case the ground permeability coefficient (k) can be estimated by equation 1.

$$k = \left[\frac{D}{8(h1 + h2)}\right] \cdot \left[\frac{\Delta h}{\Delta t}\right] \tag{1}$$

where: D = internal diameter of the tube; $h1$ = height between initial water level and soil surface e $h2$ = height between soil surface and borehole bottom; $\Delta h/\Delta t$ = falling head speed measured.

Figure 9 illustrates the sequence of operations in the assembly and executing the tests on each of the depths.

Figure 6. Sampling auger for geotechnical characterization of materials

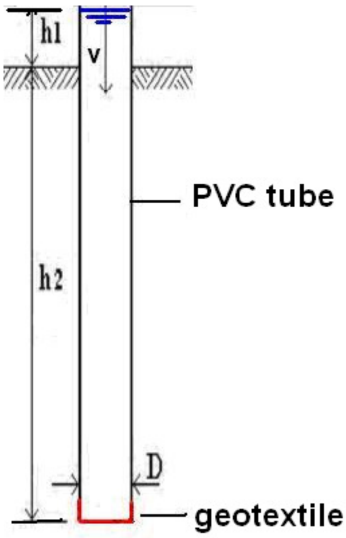

Figure 7. Test setup

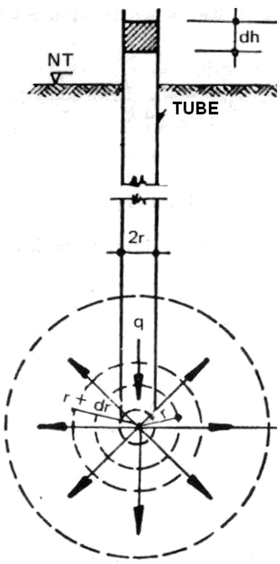

Figure 8. Flow hypothesis by circular concentric surfaces

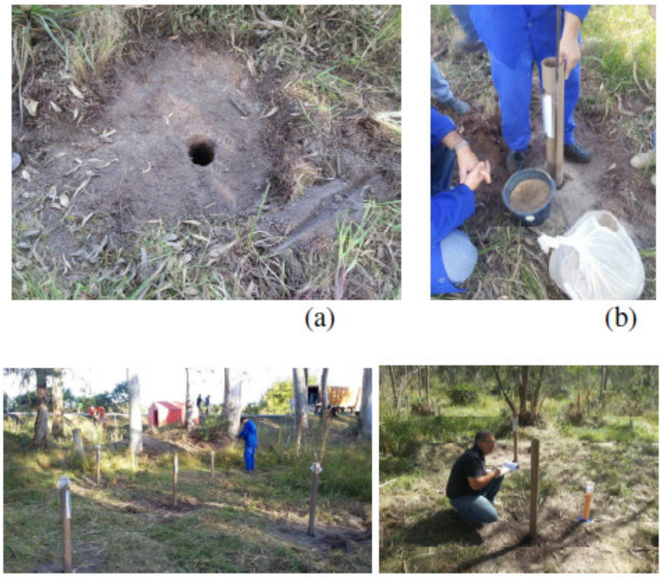

Figure 9: Sequence of operations in the falling head permeability tests. (a) opening borehole; (b) tube installation; (c) tubes installed at different depths; (d) taking measurements

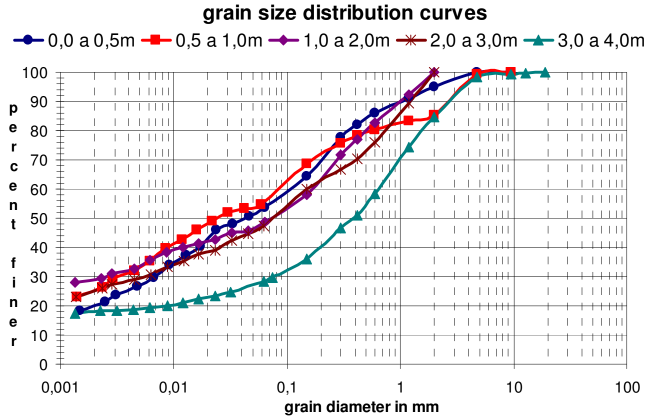

Figure 10. Grain size distribution curves

Table 3. Results of falling head permeability tests

depth test (m)	*D* (cm)	*h1 + h2* (cm)	*Δh / Δt* (cm/s)	*k* (cm/s)
0.5	7.45	111	0.0029	$2.43.10^{-5}$
1.0	6.60	186	0.0053	$2.35.10^{-5}$
2.0	6.60	285	0.0017	$4.92.10^{-6}$
3.0	6.60	384	0.0019	$4.08.10^{-6}$
4.0	6.60	485	0.0257	$4.37.10^{-5}$

3 RESULTS

The parameters obtained from the grain size analysis tests and Atterberg limits are show in Table 1. The consequent geotechnical classification of the soils is presented in Table 2. The grain size distribution curves are shown in Figure 10.

Table 3 shows the results obtained for the soil permeability coefficients at different depths tested. Figure 11 illustrates the permeability coefficient values along the depth. It is observed that the soil permeability significantly decreased in the depths 2.0 and 3.0 m and returns to reach a much higher value in the depth 4.0 m.

Table 1. Results of characterization tests

sample depth (m)	gravel (%)	sand (%)	silt (%)	clay (%)	wl (%)	Ip (%)
0 - 0,5	5	52	23	20	27	10
0.5 – 1.0	15	30	30	25	33	13
1.0 – 2.0	-	56	15	29	40	24
2.0 – 3.0	-	52	23	25	38	24
3.0 – 4.0	15	57	10	18	26	14

wl – liquid limit; Ip – plasticity index

Table 2. Geotechnical classification

sample depth (m)	HRB-AASHTO geotechnical classification	USCS geotechnical classification
0 - 0,5	A4(4)	CL
0.5 – 1.0	A6(6)	CL
1.0 – 2.0	A6(8)	CL
2.0 – 3.0	A6(8)	CL
3.0 – 4.0	A2-6(1)	SC

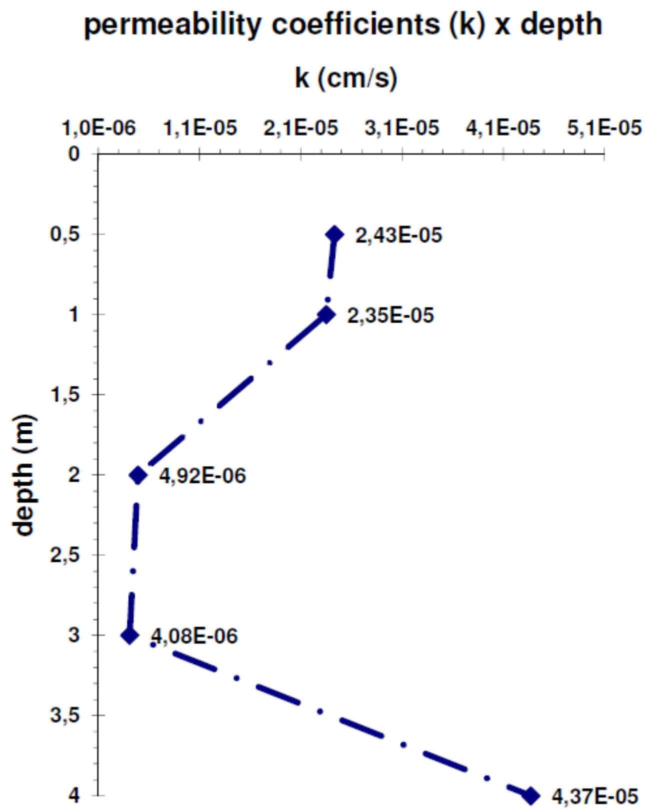

Figure 11. Permeability profile

4 CONCLUSIONS

The in situ falling head permeability tests performed show that the soil profile in the study area has permeability coefficient values consistent with the range between silty clayey sand and sand in agreement with the particle size observed in the geotechnical characterization tests.

According the results presented in Table 3 and illustrated in Figure 11, the permeability (or hydraulic conductivity) of the ground decreases in the clayey subsuperficial horizon (25% to 29% clay between depths 1.0 to 3.0 m) with values of k between $4.0x10^{-6}$ and $5.0x10^{-6}$ cm/s and tendency to increase to have high values in the depth 4.0 m (k = $4.37x10^{-5}$ cm/s), where terrain profile becomes more sandy (72% gravel + sand between depths of 3.0 to 4.0 m).

The results are in agreement with the pedogenesis of planosol profile and confirm the importance of water retention by subsuperficial horizon in the seepage of the marshy ground (ruvilideos fish habitat). This study will subsidize a numerical analysis of the flow resulting from the excavation to be performed and therefore an indication of the best project solution to minimize the environmental impacts.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

Brazilian Association of Engineering and Environmental Geology - ABGE 2013. *Permeability tests on soil: guidelines for its implementation in the field*. São Paulo/Brazil: ABGE (in portuguese).

Cunha, N. G. & Silveira, R. J. C. 1996. *Study of Pelotas city soils*. Documentos CPACT 12/96, Pelotas/Brazil: EMBRAPA/CPACT, Ed. UFPel. (in portuguese)

National Department of Transport Infrastructure – DNIT 2013. BR-392: The DNIT care with annual fish. *Boletim BR-116/392 Gestão Ambiental*, n.19: 2-2 (in Portuguese)

Brazilian Institute of Geography and Statistics – IBGE 2003. *Geological Map Sheet Pelotas/Mostardas - SH.22-Y-D / Z-C*. Florianópolis/Brazil: IBGE (in portuguese)

Google 2016. *BR 116, 510 – Sítio Floresta*. Images CNES/Astrium, Digital Globe, https://www.google.com.br/maps/place/BR-116,+510+-+Sítio+Floresta