INTERNATIONAL SYMPOSIUM 11TH FIELD MONITORING IN GEOMECHANICS

Landfill behaviour on the soft soil of the Itapoá Port's expansion (Phase 2), Brazil

Andre SILVA[1],

[1]Teknier Engenharia, Sao Paulo, Brazil
Corresponding author: Andre Silva (andre@teknier.com.br)

Abstract

The seaports on the coast of Santa Catarina state are considered essential points of the state's economic activity, in addition to being considered one of the most agile and efficient terminals in Latin America. At the end of 2016, work began on expanding the cargo terminal at the Port of Itapoá, in a total area of 105,000 m2 (Phase 1) and at the beginning of 2019 with an additional 30,000 m2 (Phase 2), both with a strong presence of soft soils, which required the execution of CPTU tests for an adequate layer characterization. The present work aims to present and analyze the behaviour of the Phase 2 landfill of the expansion of the container terminal at the Port of Itapoá through the geotechnical monitoring implemented during the period of execution of the geodrains, preload landfill and monitor the behaviour of the underlying soft soil and check if consolidation process occurred according to the design premises.

Keywords: Ports, Soft soils, Landfills on soft soils, Geotechnical monitoring, Piezometers

1. Introduction

This publication aims to present the geotechnical monitoring of the expansion project of the second phase of expansion of the port of Itapoá, located in the city of Itapoá in Santa Catarina, Brazil. At the end of 2016, work began to expand the cargo terminal, in a total area of 105,000 m2 (Phase 1) and at the beginning of 2019 with another 30,000 m2 (Phase 2), with a strong presence of soft soils.

The work consisted of a new expansion of the operational area and storage of the Port of Itapoá by implementing a landfill on soft soil. The existence of soft soil usually results in the occurrence of deferred settlement in time, which often require the use of artificial processes of acceleration of the consolidation of these layers. In this specific case, the solution envisaged considered the application of a preload and the installation of vertical drains.

Figure 1: Itapoá Port Expansion Project

A comprehensive plan of geotechnical site investigation was established to generate representative geological profiles and estimate relevant quantities for the sizing of vertical drain meshes and the overload landfill.

Preload is a method that allows carrying out a landfill that transmits to the massif a load higher than that intended to be transmitted in the final phase of the work. The excess of load will only be withdrawn when there has been any settlement of similar magnitude to those foreseen.

The use of vertical drains is a practice usually combined with preload. It is a process that consists of the introduction, in the layer to consolidate, of vertical drains of material of high permeability, which allows, in addition to vertical flow to the draining borders, a radial flow to the drains shortening the path that water has to travel to abandon the clay layer.

It should be noted that the consolidation also results in another beneficial consequence, which is the increase in the resistance to soil shear since the consolidation process implies a reduction in the content of voids and water content of the clay soil. (Fernandes, 2006)

Figure 2: Aerial view of the port expansion area during overload landfill movement*.*

2. Geological and geotechnical characterization

2.1 Geotechnical survey campaign

The geotechnical survey campaign consisted of the performance of piezocone tests of the CPTu type.

Thirteen electric piezocone (CPTu) tests were performed within situ pore pressure measurement and dissipation tests in layers of cohesive and very soft nature to estimate the horizontal consolidation coefficient (ch).

The performance of tests using the electric piezocone allowed the continuous restitution throughout the vertical of the values of tip resistance (qt), lateral resistance (fs), friction ratio (Rf) and pore pressure (u), of which, through correlations established by the bibliography, it was possible to obtain the lithographic succession and estimate the calculation parameters that govern the phenomena of settlement and consolidation of the soil.

The research campaign allowed the generation of representative geological profiles by subdividing the area of total expansion into representative regions, in which it is possible to make the respective design of the vertical drains and estimation of the settlement.

The study area in question is next to the current container yard, between the CPTU-14 and CPTU17. The remaining CPTU will be used in the following expansion phases

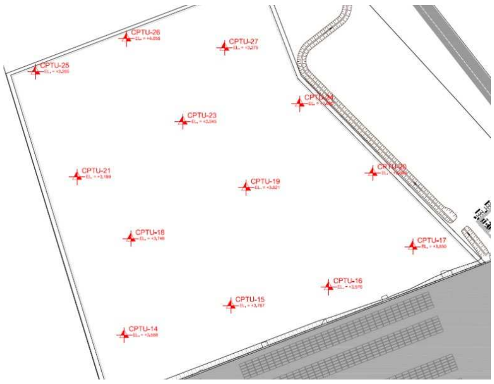

Figure 3: Location of geotechnical investigations (CPTU tests)

2.2 Design criterion

The analysis of the settlements and the dimensioning of the geodrains were made considering each of the 13 vertical CPTs individually and, later, identifying homogeneous areas in terms of the consolidation.

The analyses were performed assuming an average residual base of 5 cm (degree of consolidation U = 90%) and the preload permanence of 4 months.

The overload landfill was defined based on the operational loads due to the expected containers, assuming the same configuration considered for the patio referring to the expansion of the 1st phase.

For the dimensioning of the project preload entity to be applied in the yard, long-term permanent static loads are taken into account, i.e. the loads transmitted to the container blocks in stock. The blocks of design containers are of 6 levels and can be considered a prudent uniform load transmitted to the base of 72kPa.

2.2 Consolidation parameters

From the analysis of all available dissipation tests performed along the 13 CPTu, without considering those not significant, the following calculation values of the ch consolidation coefficient and kh permeability were determined, distinguishing between the most clayey surface soil (clay) and the deepest silty clay (silty clay).

The measurements of the ch consolidation coefficient, obtained from the dissipation tests, are available only for the most superficial clay layer. To define the consolidation coefficient ch and the permeability, from the data available for the most superficial clay layer, a relationship was determined between c_h and the soil type index value, Ic, as shown in Figure 4.

As is evident from the data, as the Ic index increases, the consolidation coefficient decreases as the content of fine material increases.

The option was to interpolate the lower limit (percentage of 15%) in favour of security.

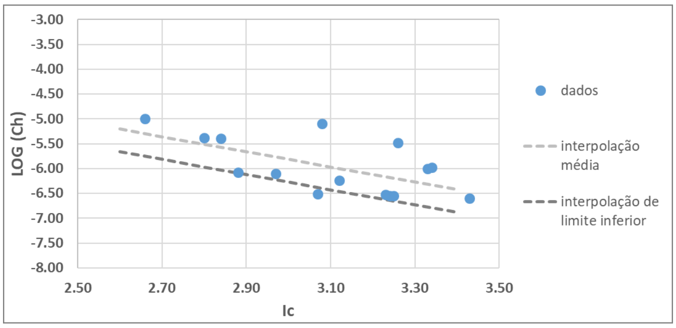

Figure 4: Correlação ch x Ic

Below are the values of the consolidation coefficient for the two layers of clay and silty clay, determined respectively directly and indirectly, and the values of the permeability coefficient, obtained from the CPTu tests.

	Clay		Silty Clay	
Ensaio	$c_h(m^2/s)$	$k_h(m/s)$	$c_h(m^2/s)$	$k_h(m/s)$
CPTU-14	8E-07	2,8E-09		
CPTU-15	9,9E-07	4,7E-09		
CPTU-16	3,1E-07	9,4E-09	5,7E-07	6,1E-09
CPTU-17	8,3E-07	2,7E-09	4,4E-07	7,5E-09

Table 1: Coefficient of consolidation (ch) and permeability coefficient (kh) of clay and silty clay per CPTU of the study area

2.2.1 Vertical drains

Geotechnical investigations allowed the development of geological profiles that led to the subdivision of the total area into five characteristic regions in terms of spacing, depth and typology of drains, as illustrated in Fig.5 and indicated in Table 1

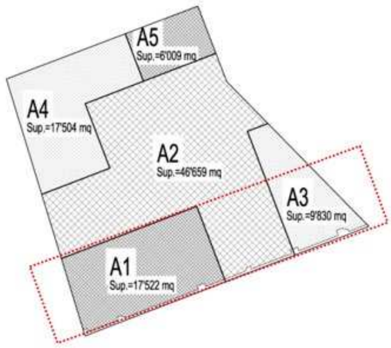

Figure 5: Division into characteristic areas A1, A2, A3, A4 and A5 and highlight the area under study5

		Geodrain			Expected overload time (days)
AREA	CPTU	i(m)	L(m)	Typology	
A1/A5	14-15	1,8	20	T1	120-135
A2	16	1,8	28	T1	120-125
A3/A4	17	2	24	T1	120-125

Table 2: Geometric characteristics of geodrains according to location and expected time of overload

*T1 - geodrains Romadrain 90, drain flow in situ q=1.3 x10-6 m3/s

3. Monitoring plan

The geotechnical instrumentation plan predicted the installation of 4 settlement plates (M1, M2, M3, M4 and M4A), 4 locations(P1, P2, P3 and P4) with 11 electric piezometers at different depths, illustrated in Fig 6 and Table 3. During the eight months of work, the reading campaigns were carried out for piezometers and the settlement plates 3 to 4 times a week.

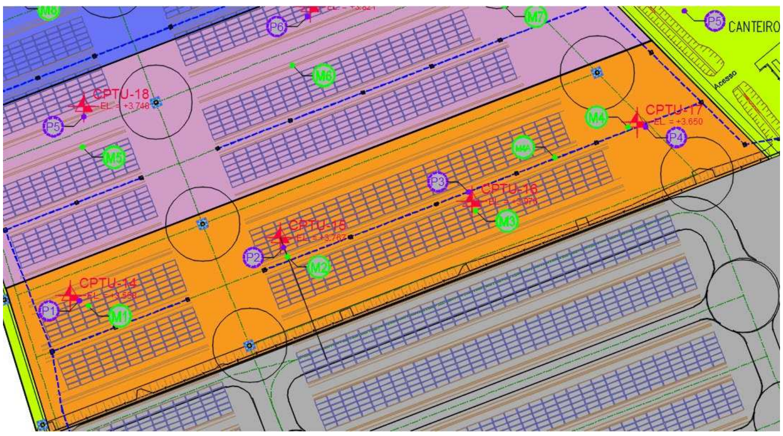

Figure 6: Location of instruments (settlement plates in purple and multilevel electric piezometers in green (M1,M2, M3, M4))

The piezometers were installed by a multilevel methodology, where more than a piezometer were installed in the same borehole to monitor the behaviour of the clay layer at different depths in the generation and dissipation of pore pressure excesses.

	Depth per location		
Piezometer	N1(m)	N2(m)	N3(m)
1	8	14,5	
2	5	10	15
3	13	23	28
4	8	14	20,5

Table 3: Summary table of the installation depths of multilevel electric piezometers

4. Monitoring data

4.1 Settlements

The landfill was raised for about four months between January and mid-April 2018 and monitored during the period between January and August 2018, where it was possible to establish three distinct settlement regions that can be observed in the summary graph of figure 7.

In the graph presented, it is possible to observe that the largest settlement occurred in PR-01 with 71.5cm, and the smallest settlements occurred in the plate region, PR-03, PR-04, PR-04A in the order of 25 to 32cm. PR-02, on the other side, presented itself as a transition region in which there was a settlement of intermediate dimension in the order of 45cm.

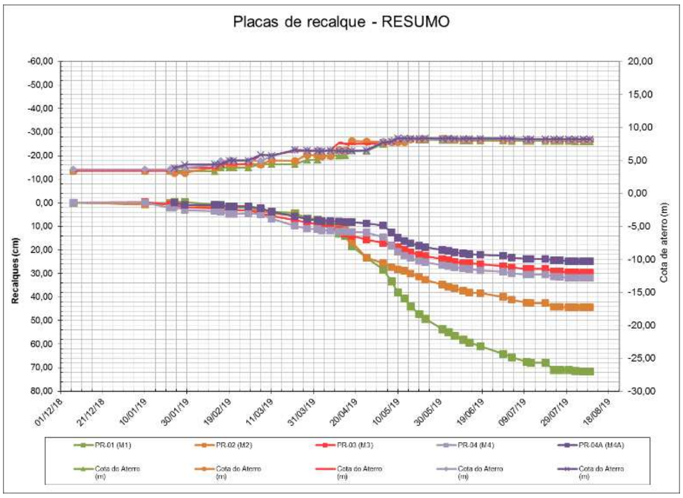

Figure 7: Evolution of settlements during the application of the overload landfill in the area with sandy soil outcrop

4.2 Piezometers

The following shows the graphical monitoring results of some landfill monitoring points, where individual plots of each piezometer vs evolution of the landfill (see Figure 8) are available to better visualize the pore pressure variations with the landfill embankment.

Figures 8 and 9 represent 2 of the 4 points monitored by electric piezometers at different depths. All of which are reactive to the moments of landfill rise with a record of pore pressure excesses. Dissipations occurred during the maintenance of the landfill level quota, although with the generation of new overpressures during new heights, as can be observed in the case of PZ-01. On the other hand, PZ-04 showed lower generated overpressures, certainly because the landfill region showed smaller accumulated settlements.

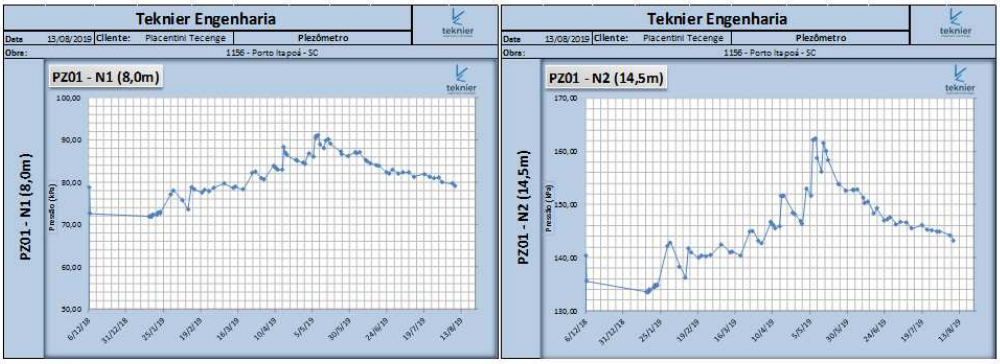

Figure 8: Monitoring piezometric data in PZ-01 at a depth of 8.0m and 14.5m.

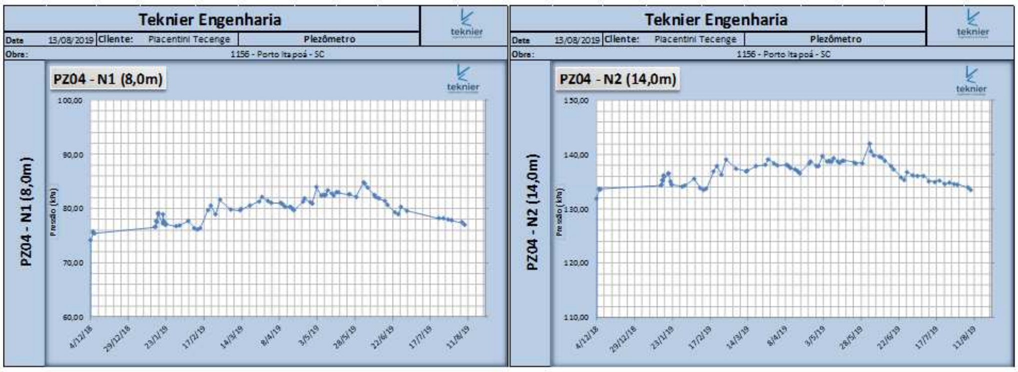

Figure 9: Monitoring piezometric data in PZ-04 at a depth of 8.0m and 14.0m

The piezometer readings showed variations between 10 to 30kPa associated with the landfill rise in these points or neighbouring areas. The most significant variations occurred in the first level, between 8.5 and 14.5 m deep, probably because they were located in more superficial strata, susceptible to the greater influence of stress bulbs from overload. The other two levels, found at higher depths between 14.5 and 28m, showed lower variations in 10 kPa.

5. Data review

After completing the landfill and subsequent overload removal, the data set resulting from the settlement monitoring allowed the comparison of the forecasts in the project with what occurred at the site.

Considering the main areas highlighted in previous points, the two main comparable quantities are the magnitude of settlement and overload application time.

The maximum settlement obtained, among all plates, occurred in PR-01 at around 71.5cm, representing 132.4% of the predicted in a project at the plate site. The remaining monitored plates presented accumulated settlements in 29.4cm to 44.4cm, representing between 41.5% and 67.7% of the predicted total. Although the consolidation process is still due, the piezometer and settlement plate plots indicated an apparent stabilization of the settlement at the site, which allowed the early removal of the overload landfill.

Given the results (see table 4), it can be seen that the project overestimated the settlements for PR-02, PR-03 and PR-04 (41.5% to 68% of the forecast) and, on the other hand, underestimated the settlement in the PR-01 region that exceeded by more than 30% the total expected value. All this in about 80% of the expected time of the planned project overload.

These differences may be associated with the overestimation of critical parameters for studying this type of phenomena, such as permeability coefficients and consolidation of clayey strata and the use for approximation and calculation purposes in different intervention areas. As mentioned in point 2.1, the calculation of vertical was carried out on the safe side.

Settlement plate	CPTU Ref.	Predicted settlement (cm)	Real settlement (cm)	Ratio (Predicted/Real)
PR-01	14	54	71,5	132,4%
PR-02	15	107	44,4	41,5%
PR-03	16	49	29,4	60,0%
PR-04	17	47	31,8	67,7%

Table 4: Comparison between settlements foreseen for total consolidation and actual settlements

However, the representativeness of these parameters is a relevant and recurrent issue in several projects of this kind due to the difficulty of their determination. (Schnaid et al. 2010)

6. Conclusions

Geotechnical instrumentation is an essential tool to monitor landfill projects on soft soil because they are projects with several variables that can influence the final results. Therefore, it became necessary to understand the consolidation process and validation or adjustment of the assumptions considered in the project phase, becoming an iterative process of execution and analysis to reduce the associated geotechnical risks.

In summary, the behaviour observed between piezometers and laying plates reflects the heterogeneity and complexity of the consolidation process, demonstrating its dependence on several factors, such as:

- Stratigraphy and draining borders (existence of soft soil, boundary conditions, stress history, heterogeneity of layers, thickness, permeability and strata consolidation coefficients, such as the existence of sand lenses between clayey layers)
- Vertical drain mesh density
- Overload (overload landfill height, variations in landfill specific weight due to heavy precipitation and landfill rising speed)

The ability to predict the behaviour of soft soils remains one of the greatest geotechnical challenges, even having at the disposal more advanced methods of characterization and geotechnical modelling, proving that the observational method (implicit to geotechnical instrumentation) remains the basis of understanding this type of cases.

Acknowledgements

Special thanks to Piacentini Tecenge Brasil and Teknier Engenharia for the opportunity to participate in such a relevant and exciting geotechnical instrumentation project that enabled the publication of this article.

References

Almeida,M., Marques,M.E.S, (2014) – Aterro sobre solos moles – projeto e desempenho 2ªed,Oficina de textos, São Paulo, Brasil

Fernandes,M.M (2006) – Mecânica dos solos – Conceitos e princípios fundamentais Vol.1,FEUP Edições, Porto, Portugal

Schnaid, F., Consoli,N.C.,Dalla Rosa, F.,Rabassa, C. (2010) – The role of in situ testing on interactive design on soft clay deposits. *Sysmposium on New Techniques for Design and Construction in Soft Clays*, Guarujá, Brazil.