GeoAmericas2020
4th PAN AMERICAN CONFERENCE ON GEOSYNTHETICS
26-29 APRIL 2020 • RIO DE JANEIRO • BRAZIL

Study of the influence on the lowering oh the water table in the execution of the subway in Line 4 of Rio de Janeiro

Silva, L.R, Pos Graduating University UNISUAM, Rio de Janeiro, Brazil
Souza, G.L.A, Professor University UNISUAM, Rio de Janeiro, Brazil
Leite, I.C.S, Professor University UNISUAM, Rio de Janeiro, Brazil

ABSTRACT

Aiming to ensure the durability and continuous improvement of a building, groundwater lowering techniques have become fundamental and have evolved over the years to meet the new demands of construction. For the construction of line 4 of the Rio de Janeiro subway, it was necessary to carry out a provisional system of lowering the water table at the Jardim Oceânico station. In all there were six stations (Oceanic Garden, São Conrado, Gávea, Antero de Quintal, Jardim de Alah and Nossa Senhora da Paz).
In this work, the main function of the temporary groundwater lowering system was to significantly reduce lateral thrust on the side retaining walls used for excavations, eliminating water pressures (by pressure) on them, and to ensure the stability of the excavations. for the bottom rupture without having to deepen the walls the retaining walls (diaphragm walls), which in turn have a thickness of 80 cm. Geotechnical profile under study showed a sandy substrate with depths in the order of 35m to 40m, with free water source (Marapendi channel) very close to the excavation site where it can considerably increase the drained flow rates. A pumping test was performed prior to the installation of the water table pumping system where it was possible to obtain the average subsoil permeability of the region, with adequate precision to achieve a more efficient and economical setting for the lowering system from the water table.

1. INTRODUCTION

Water is a fundamental element for maintaining all life forms on our planet. Of all fresh water available for consumption, 96% is proven to be groundwater. These waters were used to accumulate underground reservoirs over time and form or draw the groundwater that can be activated when the soil is excavated. With the growth of the construction market, opting for the smallest use of space and greater utilization, has made it increase and build in height and depth requiring more and more ground excavation, allowing the water table to be reached. Large buildings are usually dug below the water table.

These excavations require groundwater drainage.There are several methods to drain water that is saturating or subsurface. Only after the preliminary analyzes are performed, can the methods be defined. Based on the arguments presented above, this study presents the objective of presenting a study on the Flatbed Drawdown System, the procedures performed and the implementation challenges of the Rio de Janeiro Subway Line 4. In order to define the beginning of the water table lowering system, it is essential to consider a cost / benefit ratio of the system in function of the technical and other constraints, the alterations of each work, such as schedule, risks of slope ruptures and / or retaining walls of excavations, etc.

In this work, the main function of the provisional water table lowering system was to significantly reduce the horizontal thrust on the sidewalls of the excavations, eliminating the water pressures on them, and to ensure the stability of the excavations in relation to the excavation. bottom rupture without deepening the retaining walls (diaphragm walls).
When the design of a water table lowering system is done only from the drillhole results, it is actually an initial estimate of a system with the possibility that further adjustment may be required after the actual results are obtained. the lowering of the water table and the flow pumped into the wells.

The definition of aquifers and their permeability is also always very inaccurate (extent, thickness, etc.), factors that decisively influence the design of a water table lowering system. In the particular case of this work, a pumping test was performed, before the start of the work, to obtain local soil permeability values much closer to reality, and after designing the water table lowering system.

2. CASE STUDY - LINE 4 METRO RIO DE JANEIRO

2.1 Geological Description Geotechnica

The local soil consists of sediments of sandy layers (with aquifer behavior) to great depths, varying between 30 and 35 m. Below this sandy layer there is a clayey material (with "impermeable" behavior).

Regarding the material permeability, two hypotheses were considered because the sandy material does not clearly have the behavior of the aquifer. Thus, a single aquifer with average permeability of k = 6.5 x 10-2 cm / s was admitted and another hypothesis was to consider two aquifers adopting different permeabilities, being k1 = 1.0 x 10-1 cm / s and k2 = 1. .0 x 10 -2 cm / s for the second aquifer. The soil profile is presented below:

2.2 *Cold Sheet*

According to IBGE, the Southeast Region of Brazil is composed of a geological framework that encloses a great diversity of hydroestratigraphic units, ranging from the Cenozoic Archean, so that groundwater is spatially distributed according to different aquifer systems and patterns of potentiality. and can be grouped to these criteria.

In the Southeast Region, this hydrogeological province mainly encompasses structural discontinuities (faults and fractures) and dissolution cavities decisively modify this scenario, generating a relatively small (micro-pores), its productivity varies around 3 and 10 m3 / hr regional. These flow rates are influenced by geological factors (lithology, fracturing and weathering mantle), tectono-structural and physiographic factors.

It is well known from the geotechnical environment that the position of the groundwater table is quite variable, but in the study in question, the groundwater is located at the 0 (zero) constant level throughout its profile under study.

2.3 *The radius of influence*

Due to the expectation that the effects of the lowering of the water table should cause not very significant repression in the lowered soil layers due to the local soil characteristics, the area in which a precautionary survey was recommended due to the influence of the lowering of the water table to be installed for the construction of the subway line 4, Barra da Tijuca branch, Rio de Janeiro - RJ.

Lowering the water table changes the balance of the lowered ground layers and, depending on the soil type, the layers below the lowered water level has different effects. Changing a layer of soil from the submerged condition to the condition above ground level causes its apparent specific weight to increase by 1 tf / m³.
In sandy layers, this overload causes the sand to compact, reducing its voids. In compact sands, this modification causes practically negligible setbacks and in soft sands, this modification causes small scale but large enough to cause damage to buildings in precarious and / or unfavorable conditions.

In the sandy layers the repression appears in a relatively short time and soon stabilizes. In layers of clay, this overload can cause it to become thicker. In hard and hard clays, this modification causes practically negligible repressions, in medium clay, this modification, depending on the magnitude of the lowering of the water level, can cause small magnitude repressions, but capable of causing damage to buildings in poor conditions. and / or unfavorable and in very soft and soft clays this modification causes significant repressions, which generally generate also significant damage to buildings, even in good condition.

In clay layers, repression is slow and takes a very long time to stabilize.
Evidently, the greater the lowering of water level caused by the implanted system, the greater will be the repression. It is also necessary to consider that stress relief in large excavations will also be capable of causing undesirable deformations in the surrounding soil layers which will also be capable of generating damage to buildings in poor and / or unfavorable conditions.

The local subsoil is presented in sandy layers with increasing compactness with depth. In the specific case of this work, due to the great depth of the excavations, the radius of influence should be relatively high, but the effects of the lowering of the water table should cause not very significant repressions in the lowered soil layers.
Depending on the quality of the boundary constructions and their state of conservation, the effects of lowering the water table on them may possibly be reduced and possibly the damage, if any, will also be reduced. In those constructions where the state of conservation is considered deficient and / or of greater magnitude and closer to the excavations, it is advisable, as a precaution, to monitor repressions.

Irrespective of an optimistic expectation as to the damage to be caused to the adjacent buildings, it is essential to carry out a preliminary inspection prior to the start of the work, in order to make it possible to clearly define any damage actually caused to the buildings due to the execution of the work, as well as to obtain the projects. foundation of all buildings chosen to be monitored.

The influence radius was studied to verify the distance to which the pumping effect is null, ie, it is the limit distance of the cone and the lowering area of this well (Figure 1). Although essentially dependent on the balance between aquifer recharge and well discharge, the extent of the radius of influence (r) can vary significantly depending on geological factors (porosity, permeability, billing, etc.), pumping time, conductivity hydraulics (k) and aquifer parameters (transmissivity, dynamic level, static, drawdown height, etc.).

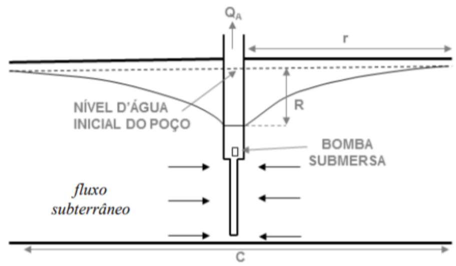

Figure 1: Drawdown wells scheme

The estimated radius of influence of the water table lowering is obtained by Sichardt's formula (1930) as a function of the lowering produced and the permeability of each aquifer.

The definition of water level lowering is relatively precise, on the order of 15 m, but the estimate of permeability is not. The definition of soil permeability varied greatly, in the particular case of the design of the water table lowering system in the executed subsoil was very imprecise.

The size of the sand layer is variable, there are sections with silt present and its compactness increases significantly with depth, generating a large variation in the estimation of permeability.

The solution was to carry out an envelope assessment for various possible permeabilities and then, depending on the other conditions, adopt the area of influence where the precautionary survey was performed.

The initial layer of sand, up to 7m depths, was less compacted and with higher permeability. Due to this characteristic, for this permeability, the influence radius was estimated for a smaller aquifer thickness, which we adopted = 5m.

Sichardt's formula for estimating the radius of influence is:

$$R = 300\Delta h\sqrt{k} \qquad [1]$$

Where:

$R = Radius\ of\ Influence$
$\Delta h = Lowering\ of\ water\ level = 15m$
$K = Soil\ permeability$

The shape of the water level lowering water table is considered parabolic, asymptotic with the horizontal plane.

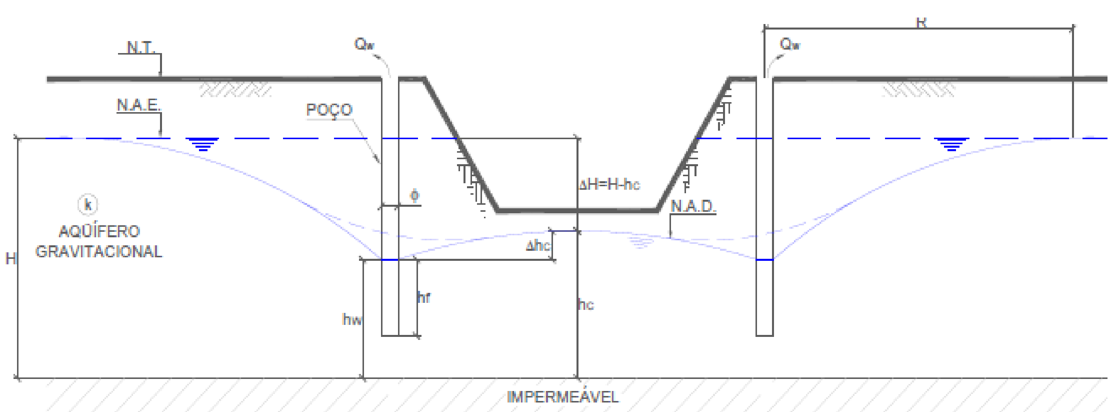

Figure 2: *Schematic sketch*

Table 1: *Estimated Influence Radius*

Estimativa de raio de Influência			
Δh	k	R	$R/2$
$5m$	$5\,x\,10^{-2} cm/s = 5\,x\,10^{-4}\,m/s$	$335m$	$168m$
	$3\,x\,10^{-2} cm/s = 3\,x\,10^{-4}\,m/s$	$260m$	$130m$
$15m$	$2\,x\,10^{-2} cm/s = 2\,x\,10^{-4}\,m/s$	$636m$	$318m$
	$10^{-2} cm/s = 10^{-4}\,m/s$	$450m$	$225m$
	$5\,x\,10^{-3} cm/s = 5\,x\,10^{-5}\,m/s$	$318m$	$159m$
	$3\,x\,10^{-3} cm/s = 3\,x\,10^{-5}\,m/s$	$246m$	$123m$
	$2\,x\,10^{-3} cm/s = 2\,x\,10^{-5}\,m/s$	$201m$	$101m$
	$10^{-3} cm/s = 10^{-5}\,m/s$	$142m$	$71m$

In the table above, it is possible to verify the great variation of the estimate of the influence radius in function of the several hypotheses considered. Since the shape of the water-lowering water table is considered parabolic, asymptotic with the horizontal plane, in the specific case of this work, with a very thick layer of very compact sand, it was assumed that the possible influence of the lowering of the water level. water will be limited to half of the influence radius.

Also, in the specific case of this work, with a very thick layer of very compact sand, the effects of the lowering of the water table should cause not very significant repressions in the lowered soil layers and, depending on the quality of the boundary constructions and the state of conservation, the effects of lowering the water table on them may possibly be reduced and possibly the damage, if any, will also be reduced.

Due to these favorable characteristics, there is an optimistic expectation that the lowering of the water table will cause damage to the boundary constructions and the large area covered by the influence of the lowering of the water table.

2.4 Pumping Test

In a work of this magnitude, with a sandy subsoil to depths of 35m to 40m, with free water source (Marapendi Channel) at a distance from the work that may increase the flow to drain, the expectation is to If well flow rates are relatively high, it is always advisable to perform a pumping test prior to installing the water table lowering system.
The pumping test allows the average permeability of the local subsoil to be obtained, with adequate accuracy to achieve a more efficient and economical setting for the water table lowering system.

It is important to clarify that water table lowering systems are not capable of absorbing and depleting rainwater and that, for this need, a digging system should be provided, independent of the water table lowering system. .
The pumping test consists of measuring the flow rate of a well installed at the site and the stabilized water table caused by it in the aquifers to be evaluated.
This is achieved after stabilization of all water levels in the well installed meter and all installed piezometers and meters.

To start this test, it was necessary to measure the top dimensions of the well meter PVC pipe and all installed meters and piezometers. Then read the water levels prior to pump operation on the well gauge and all installed gauges and piezometers. The readings should be taken at two hour intervals, after 18 hours to evaluate the time x water level curves. Depending on the behavior of the curves, a new time interval will be defined between readings.

Readings should continue until all meters and piezometers stabilize. After stabilization of all meters and piezometers, the pump should be turned off, and immediately after the pump has been turned off, readings should be taken every 5 minutes on the well-installed meter, meters and piezometers within 5 m until complete. 30 minutes. At the beginning of operation the pump should operate at full flow. During this period the flow of the log should be read directly on the meter. After some time the pump will possibly operate intermittently, alternating periods in operation and periods off. In order to determine the pump flow after it starts to operate intermittently, it will be necessary to calculate the weighted average between an operating period and an off period. Pump flow should be calculated as the weighted average between the flow between the period with the pump running and the period with the pump off (flow = 0), as follows:

$$Weighted\ average\ flow = \frac{Pump\ flow\ operating \times Pump\ time\ operting}{Pump\ time\ operting + Pump\ time\ stopped} \qquad [2]$$

The flow to be considered in each reading should be the arithmetic average of the 3 weighted flows.

2.5 Lowering System Sizing

For the design analysis of the lowering of the water table, it considered two hypotheses of aquifers: Gravitational and artesian.

The first dimensioning was the gravitational aquifer, which had a thickness from water level to waterproof of approximately 35m. The diameter of each well is 0.4 m, totaling 66 drawdown wells spaced every 6m. The second dimensioning was of an artesian aquifer, with a water level of 33m and a total of 56 wells spaced every 7m.

The location model of the points where the pumping wells will be installed is shown in the figure below. It is important to note that these wells are monitored through closely installed piezometers.

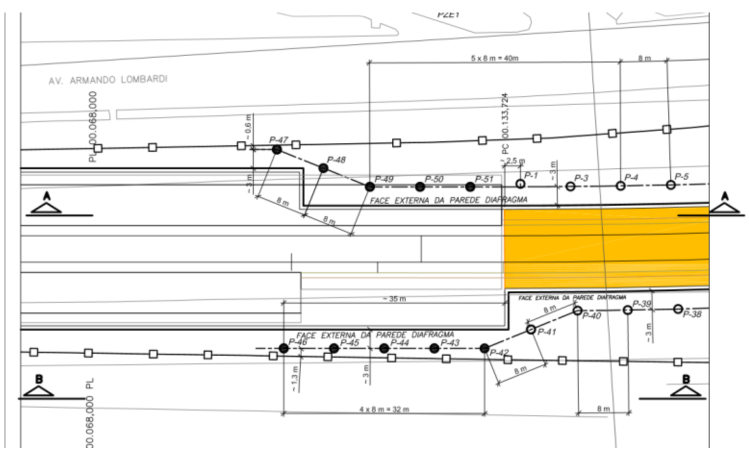

Figure 3: Rental of drawdown wells

Considering that the lowering of the water level varying from 9 to 16m, in the condition for a single aquifer it was found an average flow of 30m3 / h. In the analysis to define the best alternative to be adopted, it was observed that in the hypothesis of adopting only one aquifer with the average permeability of 6.5 x 10 -2 cm / s, it is the most unfavorable, therefore, it was adodated due to be in favor of safety.

The figure below presents the typical schematic of the lowering well of the handkerchief, which is composed of clay soil and washed medium and coarse sand filter, with the pump being installed every 4m.

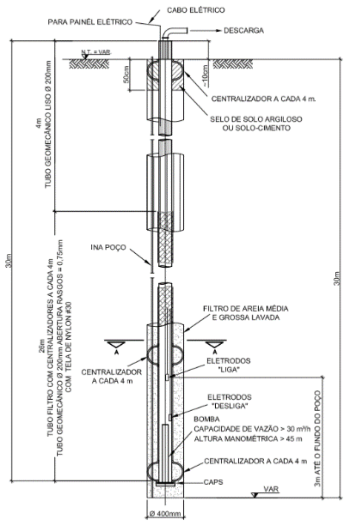

Figure 4: *Typical well installation detail*

2.6 *Dimensioning for discharge of pumped flow by water table lowering system*

In this study it was foreseen the use of reinforced concrete channels. For greater savings on the site, a single channel was adopted for the drainage of rainwater from the jobsite area and for the discharge of the flow pumped by the water table lowering system. For operational reasons, it was envisaged to run a channel on each side of the excavation.

The maximum flow rate for the discharge pumped by the lowering system on one side of the ditch was estimated at ~ 1,500m³ / h and the maximum flow rate for rainfall drainage on only one side of the ditch was estimated at ~ 200m³ / h, resulting at a total flow rate adopted for the channel size of 1,700m³ / h.

The design was performed for a 0.3% trim and flow rate Q = 0.47m³ / s. The section sized for the maximum flow (spreadsheet), which only occurs at the end of the channel, was of width = 80 cm and maximum height of the water line = 50cm.

2.7 *Pinch reading*

In parallel to the execution of the pumping test, all discharge pins installed in neighboring constructions located within the influence of the reduced model pumping test shall be read. The installation dimension and the coordinates of the harness pins shall be determined 24 hours after installation by precise topographic survey from the existing milestones on the site. Precision pin reading is done by precision optical leveling from the nearest level reference. The procedure allows you to determine the current dimension of the pinout pin. The repression is calculated by the difference between the current quota and the installation quota. Initially, during the pumping test, four measurements should be performed. The first reading should be done ten days after the start of the test, the other three should be spaced every 15 days. After each reading a specific pressure rating should be made for each construction until stabilization of the pressure is observed. If necessary the time interval between readings can be changed and more readings can be programmed or the number of readings reduced, this for each building individually.

3. CONCLUSIONS

The groundwater lowering procedure aims to facilitate the excavation and construction of structures below the

groundwater. However, certain structural pathologies may occur in neighboring buildings and in the enterprise itself. Whatever the system used to lower the water level, we will always have a decrease in neutral ground pressure, and consequently a considerable increase in effective tension. Thus, the increase in effective soil pressure causes the thickening of soft clay and soft sand layers, causing undesirable but predictable settlements on the foundations or floors of neighboring buildings that are within or near the area of influence of the lowering.
Because of this problem, it is very important to analyze, plan and minimize the behavior of structures that are close to the area of influence of the groundwater drawdown by means of pressure pins, piezometers and inclinometers.
Knowledge of the stratigraphic profile of the soil should precede the elaboration of the architectural project and the integration of engineering and architecture in the architectural design conception process eliminates most of the complications that occur at the construction site.
It is important to manage water during the construction process which is a big challenge. Provisional lowering of the sheet as well as site logistics are aspects that need to be addressed through a project to be designed prior to excavation and the water table should not be underestimated as its presence can make foundation and containment systems considerably more expensive.
It is inferred from this study that the prior planning of the entire construction model, observing the items highlighted above, will provide the association of safety in the execution of services with the safety of the structure. Thus, it is concluded that the considerations presented will enable an effective reduction of the risks attributed to projects of similar complexity.

ACKNOWLEDGEMENTS

First of all, to **God**, being essential in my life, author of my destiny, my guide, present help in the hour of anguish.

To my advisors **Giana Lapor**t and **Igor Leite**, for their attention and support in the short time they carry, for their corrections and incentives.

To my friend **Bruno Lott**, for the encouragement and constant support.

LITERATURE REVIEW

ALONSO, U. R., *Temporary Lowering of Aquifers*. Sao Paulo, Tecnogeo and Geofix.

ALMASSY and BUZAS, *The Century of Scarcity: A New Culture of Water Care: Deadlocks and Challenges*, Editora Claro Enigma, São Paulo. ISBN 9788581661285.

CARVALHO, J. C., *Unsaturated Soils in the Geotechnical Context*, São Paulo: Edidora. ISBN 9788567950037.

CAMPOS, G. C. de, *Lower Aquifers, In Geotechnical Lesson Notes and Foundations, Anhembi Morumbi University*, São Paulo, 2004.

FRANCIS, F. O. and Rocha, H. C., *Civil Underground Works, In Engineering Geology, Brazilian Association of Engineering Geology - ABGE, 1st edition*, São Paulo, 1998.

GRANDIS I., *Demotion and Drainage In Foundations Theory and Practice*, 2nd Edition, Pini, São Paulo, 1998.
HEINEN, C .; BRINCKMANN, W. E .; BRINCKMANN, C. A., *UNISC Water Resources Center Newsletter*, Santa Cruz do Sul: v. 4n. 2, Feb. 2001. Available at: <https://online.unisc.br/seer/index.php/redes/article/viewFile/10722/pdf>

TRAILERS, A. C .; BRAGA, B .; TUDINISI, J. G., *Sweet Waters in Brazil: Ecological Capital, use and conservation*. 2.ed**.** rev. and ampl. Saint Paul: Scriptures, 2002. 702p
TENGEL, Procedures Manual. Available at: <http://www.tengel.com.br/>