EXCAVATION AND PERIPHERAL RETAINING SOLUTIONS
WHEN INTERSECTING THE GROUND-WATER TABLE LEVEL

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ABSTRACT

The fast evolution of peripheral retaining techniques allied to nowadays' great need of exploring the subsoil even further, especially in the urban areas, is a constant concern to any Civil Engineering company. Moreover, the study of situations where the final excavation level is below the ground-water table level turns out to be quite interesting because:
- Not only the peripheral retaining lessens the stresses caused by the excavation's surrounding ground, but also prevents the water from flowing in the digging pit in order to avoid unforeseen accidents;
- This is the most usual situation since, for historical reasons, metropolis are located on the coast (or on rivers' banks), being Lisbon a good example of this.

For this purpose, a reference will be made to the waterlogged soils, which are defined by the existence of water and air in the gaps left by the solid matrix. This reference aims to study the influence that many features have in the self-stabilization of the ground.
Another determinant aspect is how to select a proper draining system, so the most common ones will be mentioned.
Given this, the essay's body will focus on five of the most used methods when carrying out peripheral retaining systems, which are: diaphragm walls, curtain with bored piles, sheet piling, jet Grouting and deep mixing. These methods will be taken into account not only individually, but also comparatively.
Finally, there will be considered two techniques of usual employment (deep slab and coffer-dam). The “Champalimaud Centre for the Unknown” is an excellent example of the underground water table floors construction using, for this matter, a curtain with bored piles as a peripheral retaining wall. There will also be a further analysis of some resulting values of the work's instrumentation.

Keywords: Peripheral Earth Retaining Wall; Ground-water table level; Ground improvement; Waterproofing.
1. INTRODUCTION

Throughout the years, the densification of construction has suffered a great increase, especially in the urban areas. New constructive technologies and new materials have been developed in order to solve modern engineering problems, taking into account the growing demand of the client who requires low cost and high quality solutions.

This search has also been stimulated by the numerous advantages coming from the occupation of the subsoil space, accomplished by digging floors into a structure. A good example for the use of this technique is the construction of subterraneous parking, which leads to more security and comfort than parking in the public way. Moreover, the underground space can be used for mechanical equipments storage, leaving the upper floors unoccupied, like in hotels, with important environmental advantages.

Through this essay, there will be approached the most common techniques when constructing in depth and, more importantly, in lands where the ground-water table level is intersected. These kinds of solutions play a decisive role because, since Middle Age, metropolis’ development near the coast has made commercial trades easier, being Lisbon a good example of this. This contributes to an increase of the ground-water table level in these areas, leading to the very likely intersection of waterlogged soils when working in depth. For the reasons accounted, an Engineer who owns the necessary skills to choose and dimension a peripheral retaining system in such conditions, where the existence of water is a determinant factor, is also able of designing efficiently an identical system in dry soils.

2. INFLUENCE OF THE GROUND-WATER LEVEL ON THE SOIL

The soil is constituted by a solid phase (minerals and organic matter), a liquid phase (defined by the existence of water) and a gas phase (air). The last two fill the gaps left by the solid particles; the amount of water present in these gaps will define a soil as dry, waterlogged and non-waterlogged.

As known, the soil responds differently to an applied stress field according to a wide range of factors, being one the interactions between the water and the solid matrix. This tension change occurs, for instance, in an excavation.

![Fig. 1 – Location and changes in the tension state of a soil particle.](image)

When such imbalances take place, the solid matrix will be forced to modify its structure in order to acquire a new balance position. This disturbance may cause particle settlements on top of the excavation and, on the worst scenario, destabilize the upright slope
established, and consequently the landslide of the instable surface.
Clearly, these consequences are undesired at any type of work and may result in either material or human damage.

It comes easy to understand the importance of a preliminary study of the digging pit with the aim to conclude the best way to carry out these works without any unpleasant situation.

Following, there will be presented some obtained results concerning the three different possible conditions of a soil. The main goal is to understand the influence that several properties of the ground have in its self support. The comparative criteria of the resistance will be the maximum depth of the free excavation of the ground for which it is in balance.

2.1 ANALYSIS IN UNDRAINED CONDITIONS

\[ h = \frac{3.8c_u}{\gamma} \]

2.2 ANALYSIS IN DRAINED CONDITIONS OF A DRY SOIL

According to Mohr-Coulomb criteria for dry soils:

\[ \tau = \sigma_n \times \tan \varphi \]

As such, it is confirmed that a soil in the referred conditions will arrange in accordance to its friction angle as the excavation takes place, which makes the construction of a vertical slope impossible.

2.3 NON-WATERLOGGED SOILS

The most common soils that Engineers deal with are the waterlogged soils and dry soils, known as non-waterlogged soils. In this kind, as previously mentioned, the gaps between the solid matrix are fulfilled with air. If these gaps are connected, the air has the same atmospheric pressure and the water inside them has a lower pressure due to the capillary tensions. The difference between the pressures of the air and the pressure of the water is called suction \((u_a - u_w)\).

This phenomenon creates an apparent cohesion \((c_a)\) associated with attractive forces, of a hydraulic nature, between the particles of the solid matrix. This cohesion is called apparent because the cement connections disappear as the soil becomes waterlogged.

The analysis made will have as a reference the model for non-waterlogged soils Barcelona Basic Model, formulated by Alonso & al. (1990). [1].
As such, it has created a model calculation in the program GeoStudio in order to determine the value of safety factor associated with engaging more critical rupture.

**Features of the model calculation:**
Rupture criterion: Mohr-Coulomb Model
Type of analysis: Bishop, Janbu and Ordinary
Vertical slope heights: 3 and 6 meters

**Characteristics of the terrain analysis:**
\[ \gamma_h = 20 \, kN/m^2 \]
Suction: variable

After carrying out an iterative calculation in which the suction’s value was varied and the resistant soil characteristics were fixed, was created following the abacus:

3. **PRELIMINARY WORKS AND STUDIES**

The preliminary works and studies concerning a specific job play a decisive role since they provide important information about where it takes place and its features. It is a significant help when it comes to:

1) Adjusting the project to the external constraints (dimensioning, constructive methods, materials, etc.) the best way possible;

2) Explaining the possible phenomena that may occur during the procedures;

3) Foreseeing eventual setbacks throughout the works.

For ground peripheral retaining solutions, the following steps should be taken into account:

- Geological- geotechnical prospection of the site (to examine the type, constitution, mechanical characteristics and other soil’s properties of the local in case);
- Inquire the various methods existent on the Engineering market;

Source: Fig provided by the project director.

**Fig 5 – Deployment local of the “Champalimaud Centre for the Unknown”, before the works beginning.**
- Study the technical limitations of each method;
- Verify in which conditions are the neighbouring buildings, if there are any;
- Analyze the space available for the construction site;
- Study the involving environment (especially the services and accesses which may be affected during the construction works);
- Study the sort of options possible for the work according to the budget set by its owner;
- Estimate the time needed for the job, taking into account the time of the possible technical methods employed and the deadlines settled;
- Other possibilities that will vary from one work to another.

The SPT (Standard Penetration Test) stands out as being the most used in Portugal. This method has become quite popular because of its low cost comparing to others and also because it allows the collection of soil samples from the drilling hole.

4. EXCAVATION DRAINAGE

The installation of an adequate drainage system is vital especially in excavation works that intersect the ground-water table level. Its main purpose is to conduct/remove the water resultant from the rain, for instance, and water infiltrated in the soil. Depending on the case in study, this system may be either temporary or definite.

There are 4 main sets of techniques most commonly used:

I) Superficial water retaining
- It is the first barrier to the superficial water when it comes near the excavation;
- Executed through ditches (or gutters), walls and slopes.

II) Direct captation of water
- The water that emerges to the surface is pumped to its exterior;
- Executed through pump groups and an adequate conducting and reception system.

III) Lowering of the ground-water table level
- A draining is done with the aim to change the ground-water table level position, turning it more convenient for the work execution;
- Executed through pumping wells, well-points, Ejection systems, electro-osmosis and horizontal captation.

![Fig 6 – Scheme of equipment used in a SPT test.](image)
IV) Exclusion methods
- Executed through the creation of physical barriers that make it difficult for the water to reach the excavation;
- There can be used thixotropic muds, sheet piling or soil freezing (more appropriate/feasible for low temperature environments) as temporary barriers;
- As permanent barriers, it is more usual to use Jet Grouting or Deep Mixing columns, but it can also be used framed walls or curtain of piles. This means that, if well dimensioned, a peripheral retaining system should resist the grounds forces and avoid the entrance of water in the excavation.

The diaphragm walls are executed *in situ*, previously to the excavation, through the execution of ditches. Not until the setting of the concrete does the excavation begins in the area confined for the retaining.

Anchorages are employed in order to guarantee the stability of the walls whilst all this process takes place. Most of the times, these anchorages are temporary since the structure built inside is dimensioned according to the forces transferred from the retaining systems, turning the use of this technique useless.

Fig 7 – Two well-points levels working simultaneously (lowering of the ground-water level).

Fig 8 – View of the framed wall executed in Sotto Mayor Palace, in Lisbon.

CURTAIN WITH BORED PILES
The reinforced concrete curtain of piles fits in the peripheral retaining of soils, where the piles are the structural elements, which are carried out inside the ground, in an earlier stage of the excavation.

Due to the easiness, the speed of execution and the equipments’ development, this method has become more popular, opposed to other old fashioned techniques, in which concerns the retaining of soils, either in buildings’ construction or other kind of construction.

5. MAIN TYPES OF PERIPHERAL RETAINING SYSTEMS

DIAPHRAGM WALLS
These elements in reinforced concrete are usually constructed using as a reused thixotropic muds which have a double structural function: retaining wall (they resist the external forces from the ground, containing the excavation’s walls during the execution stage) and “inclusion” (they are part of the final construction super-structure).
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The solution, resides mainly in a discontinuity front of framed piles on the ground around the area being excavated, which, in a following stage of the project, will have an open spot, due to the excavation labor.

This kind of solution is used mainly in buried constructions contiguous to communication via and medium or large buildings, with less deep foundations, with hardly any abnormality. This is also quite common when building tunnels in urban areas. The curtain of piles technique is also used when supporting upright slopes.

CURTAIN OF SHEET PILLING

With an extended period of usage such as 100 years, this method was being used at the end of the 19th century, though made of wood or melted iron. Nowadays, made of hot rolled steel not quite rigid, the curtain of sheet piling is a quite competitive solution in any construction. Allied to a huge flexibility and quickness in executing, this kind of technology has been commonly used in specific constructions all around the world.

The steel curtain of sheet piling market offers a wide range of options, allowing to use the best method in all kinds of constructions, such as those in maritime environments (rivers, harbors, etc.), roads, tunnels or road passageways.

Another important aspect, which will be discussed further in the essay, is the fact that this technique is widely used when executing cofferdams.

JET GROUTING

The Jet Grouting is a ground treatment in situ technique used to improve the soil. It is executed directly in the ground, not being necessary a previous excavation.

A small diameter drilling is made at the surface, in which cables are placed, which will lead the grout injection, applied on the ground through horizontal jets at high speed (at about 200-250 m/s). The grout’s strong kinetic energy, when in contact with the soil, causes the initial solid matrix degradation, starting a new solution in which the solid particles get into the ground and the grout is injected. This mixture is much better in terms of mechanical skills and much less permeability ($1 \times 10^{-8}$ to $1 \times 10^{-11}$ ms$^{-1}$) compared to natural soil.
DEEP MIXING

The Deep Mixing (DP) is another ground improvement in situ technique. In this case, the mixture enforcement of concrete-soil is made using stirring vertical axis tools (Deep Soil Mixing, DSM) or horizontal ones (Cutter Soil Mixing, CSM). This procedure allows the increase of ground’s bearing capacity and allows a less water inflow, ideal to suite the peripheral retaining in excavations which intersect the groundwater table level. In short, this technique may be seen as a Jet Grouting’s mechanical variant.

Its origin lies in two countries, two approaches which used DSM as a method to revise the deficit of its soils which were an obstacle to construction. In Sweden, in the Nordic approach, the using of lime and a low resistance soil binder mixture allows the decrease of the water content in soft soils and its decontamination. Whilst in Japan, the Japanese approach prefers using cement and high resistant mixtures, in order to reduce the liquefaction potential in sandy soils, a much usual phenomenon given the high risk of seismic activity in the country.

The Deep Mixing techniques (DSM and CSM) are quite flexible and with great performance of execution levels, being also quite economic. Therefore, these methods have become widely used in the construction industry, such as in peripheral retaining and in foundations.

6. CHAMPALIMAUD, CENTRE FOR THE UNKNOWN

The Centre, in the waterfront of Pedrouços, near Lisbon’s old fishing dock, reify the goal of Champalimaud’s Foundation in building a multidisciplinary investigation centre in the Biomedicine field, that could give the ideal resources to national or foreign researchers and academics to develop distinct projects with clinical application (prevention, diagnosis and treatment) in areas such as neuroscience and oncology.

Hence, the complex has two buildings, A and B, of 3 and 2 uppers floors, respectively, plus an underground floor. Beneath the space between the buildings, there’s a parking lot, at the building’s basement level.
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CONDITIONINGS
The construction’s location was the main constraint, because the ground water-level in that area was quite high (3 meters below ground surface), given that it was located near the Tagus’ river right bank.

The existing soils were predominantly sandy and muddy, with average thickness between 6 and 8 meters. Still, there were, punctually, areas where the ground was clayed or clayed-sanded (these last ones were stiffer) with thicknesses between 7 and 15 meters.
These formations, rested over a layer of basaltic rock (Lisbon’s Volcanic Complex), with great thickness, considered bedrock to project conditions.

FOUNDATIONS’ SOLUTIONS
Taking into account all the requirements needed in the construction and external limitations, the complex was founded over bored piles of 12 meters length. The piles, of circular crossed-section reinforced concrete, were drilled, with a diameter around 600 and 800 mm. Those, as it was said by an engineer working on the ground, go across all strata of surface of weak features of resistance, penetrating into the bedrock. In structural terms, the mobilized resistance will be predominantly the base one.

SOLUTION TO PERIPHERAL RETAINING
Most likely to benefit from the equipment used to carrying out the foundation piles; it was determined to perform a curtain of piles. It consists in 1208 units’ secant bores piles, of 800mm diameter, with lengths varying between 7 and 9 meters.

SOLUTION TO EXCAVATION DRAINING
To complement the work of the curtain of piles, in order to prevent the water inflow within the excavation, it was used, in some sensitive points, a
well points system, arranged meter by meter, allowing the lowering of groundwater level in those areas.

It has been verified that in the non waterlogged soils the suction influences the self-stabilization of the ground. There is a similarity between this physical phenomenon and the consequences of the pre-effort of the cables in a reinforced concrete beam. Suction also has an effect in the rate internal friction angle-soil capacity the greater is the suction the more considerable is the effect caused by the increase in the internal friction angle in the self-stabilization of the ground. On the other side, for low tensions this effect is almost unperceivable.

The draining systems market has suffered a great evolution as well, giving numerous options for draining in depth and at surface consisting with each kind of soil. In most of the excavations that intersect the ground-water table level it is primary to have a perfect adjustment between the peripheral retaining walls, draining and excavation solutions.

In the matter of peripheral retaining walls techniques, there is an outstanding complementarily and applicability in these methods. A good example is the execution of spaced curtains of piles, complemented with jet grouting columns, enabling the structure with a watertight capacity (hard-soft system). On the other hand, the deep mixing methods have a distinct physical principle and proceed mechanically from jet grouting.

In the case study, the “Champalimaud Centre for the Unknown”, due to the functional demands of the building and the soil’s features, it was necessary to execute a type of foundation that did not need to mobilize the superficial layers, since these layers could enlarge the seismic signal, leading to the structure breakdown. This way, there were built piles with

7. CONCLUSIONS

The quick evolution of technology in the last few years, particularly in the execution of excavations/peripheral retaining walls, has made it possible for the today’s engineering market to offer quality solutions well designed and built. This last assignment is for the Civil Engineer to accomplish, who should opt for the best solution and, at the same time, minimize the cost of the work and its execution time.

The soil, as a foundation element, should be studied in a concerning and competent way. This analysis should be materialized through a set of recognition and prospection techniques that aim to acknowledge every detail of the work avoiding incidents during its carrying out.

In Portugal, the most used technique is the SPT, which allows the identification of the soil’s various layers passed through the drilling hole (lithostratigraphy) and the corresponding mechanical properties, like the depth of the ground-water table level.
enough depth to reach the Lisbon’s volcanic complex, with geological features appropriate for this purpose.
The retaining curtain performed, according to the data of the instrumentation employed (inclinometers and piezometers), has played its role amazingly confining its perfect application in these situations.

BIBLIOGRAPHY