Monitored deep excavations in Santiago (Chile) and Lima (Peru)

Fouilles profondes surveillées à Santiago (Chile) et Lima (Peru)

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ABSTRACT: The soil conditions of Santiago and Lima are similar but each city has different typical retaining wall systems which are used to execute deep excavations (currently up to 30 meters). In Santiago, the retaining system is a discontinuous wall consisting on reinforced concrete piles (either hand-excavated or drilled), laterally braced by ground anchors. In Lima, the typical solution is an anchored wall built in a descendent sequence using the basement wall of the final structure with some extra reinforcement. In this paper we present the main characteristics of each system and their performance, as measured during the construction of several sites both in Santiago and Lima.

RÉSUMÉ : Les conditions de sol de Santiago et de Lima sont semblables mais chaque ville a différents systèmes typiques de mur de soutènement qui sont employés pour exécuter les fouilles profondes (actuellement jusqu'à 30 mètres). À Santiago, le système de retenue est une paroi discontinue constituée de pieux en béton armé (soit par excavation manuelle soit par forage mécanisé), latéralement renforcé par tirants d'ancrage. À Lima, la solution typique est un mur ancré construit dans une séquence descendante utilisant la paroi de sous-sol de la structure finale avec un certain renforcement supplémentaire. Dans cet article, nous présentons les principales caractéristiques de chaque système et leur performance, mesurée lors de la construction de plusieurs sites à Santiago et à Lima.

KEYWORDS: Deep excavation, discontinuous pile wall, ground anchors, anchored wall, monitoring

1 INTRODUCTION

The city of Santiago, Chile, the country's capital with more than six million inhabitants, has been developing its buildings and underground spaces, changing the standard excavation from 10-15m in the 2000' to 20-30m nowadays. Ground anchors took a big part as a technological tool, being introduced in the building industry in 1996 by Pilotes Terratest. The accumulated expertise gained over the years and the improved knowledge of the performance of the deep excavations of the time, was fundamental for the optimization of the system and the achievement of significative cost reductions.

Figure 1. Deep excavation of 28 meters in Santiago.

A similar trend occurred in Lima, Peru, a city with more than seven million inhabitants. Ground anchors played a big role as a technological means for developing underground space and excavations up to 20-30m nowadays.

The geological formations of both cities has similarities being both gravel formations from quaternial aluvial-fluvial-glacial deposits with excellent geomechanical characteristics. In fact, parto the experience obtained in deep excavations in Santiago ("Ripio de Santiago") was employed in Lima ("Conglomerado de Lima"), and finally correlated after confirming that both soils have similar behaviour.

2 DEEP EXCATION IN SANTIAGO

The typical retaining wall system used to execute excavations in Santiago corresponds to a discontinuous wall consisting on reinforced concrete piles, laterally braced with ground anchors. The piles can be dug manually (usually in a rectangular shape), or by a rig. Square piles initially were of one meter side and its separation was about 2.0-2.2m. Then the section turned rectangular and more efficient and with separations of 3.0-3.5m with up to 5.0m recorded.

The norm NCh3206.Of2010 defines the requirements for excavations. Usually, the key issue in the design of a deep excavation is the deformation of the surrounding ground. Estimates are obtained by modelling the excavation and its construction phases, defining the most suitable earth pressure redistribution diagrams, and factored earth pressure coefficients where applicable. Being a highly active tectonic region, seismic conditions play an important role in the design, usually approached with a pseudo-static analysis, such as the proposed by Kuntsche (EAU 1990) or Mononobe-Okabe.

A basic acceleration 0.30g applies to Santiago (Zone II, after NCh433.Of2009). For temporary works, loads can be reduced depending on the level of expected post-seismic plastic deformation (in function of the characteristics of the neighbour structures to be protected or the level of risk to be assumed). For a very stiff soil as the "Ripio de Santiago", a reduction factor of 0.50 applies to streets and 0.60 to constructions.

The ground anchors length is dealt either by the simplified method of the seismic wedge analysis or by the Ranke-Ostermeyer deep seated stability analysis.

2 .1 *Parque Oriente Building*

Parque Oriente excavation was designed, executed and monitored by Pilotes Terratest. The excavation lay-out and cross section is shown in figures 2 and 3. Bored cased piles were executed to guarantee a minimum deviation of the wall due to the big boulders usually present.

The typical section was 21.2m depth; the monitored one was located on the vicinity of the avenue Alonso de Cordova.

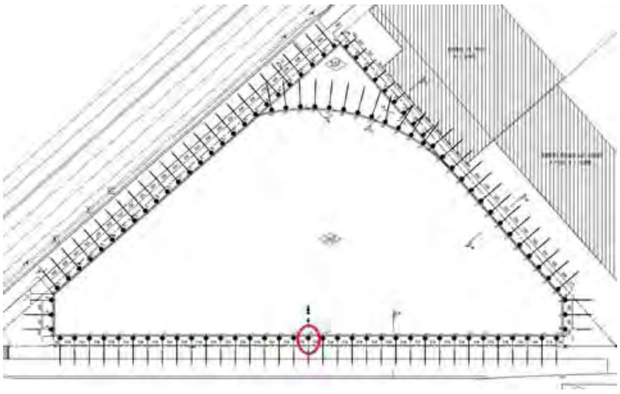

Figure 2. Excavation layout and monitored pile.

An inclinometer casing was installed in one pile attached to the reinforcement cage in its full length, and the two rows of ground anchors were instrumented with load cells. The inclinometer restriction in depth probed, after numerical analysis, not to influence more than 1mm the final stage readings because of the soil high stifness. Piles 880mm diameter were arranged every 3.20 m. In the monitored section, the first row of ground anchors was placed at 4.50m depth and the second one at 13.0 m depth. The service loads of each anchor were 880kN (275kN/m) and 1245kN (389kN/m) for the first and second row respectively. The first excavation stage was carried to 5.50m depth before the first row of anchors was installed.

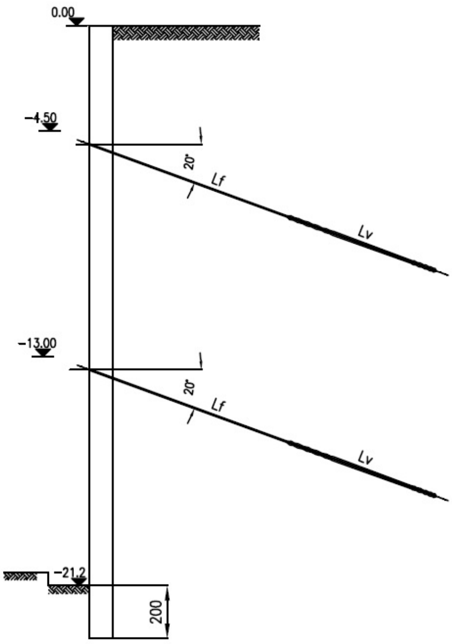

Figure 3. Cross section of the anchored pile wall.

The horizontal deformation of the pile in cantilever was 1.3mm, measured just before the anchor was tensioned. The wall moved 0.75mm backwards after post-tensioning of the anchors. In the second row, the horizontal displacement induced by post-tensioning was 0.45mm.

The second excavation stage was carried to 13.50m depth where the second row anchors where executed. The excavation continued to 15.50 m depth before tensioning the anchor. A berm was left in front of the piles for supporting the jack.

The third excavation stage was carried to the maximum excavation depth. A maximum horizontal deformation of 15mm was measured at the maximum excavation depth.

Anchor loads were measured at the mentioned stages. The anchor load behavior was coherent with the expected very low creep value (k_s) of the set soil-grout-steel and the measured deformation of the pile wall, related to its free length (specific deformation).

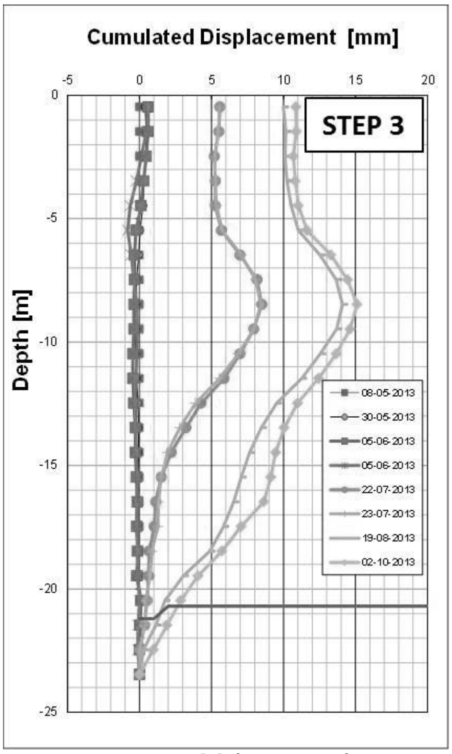

Figure 4. Horizontal deformations of stage 3.

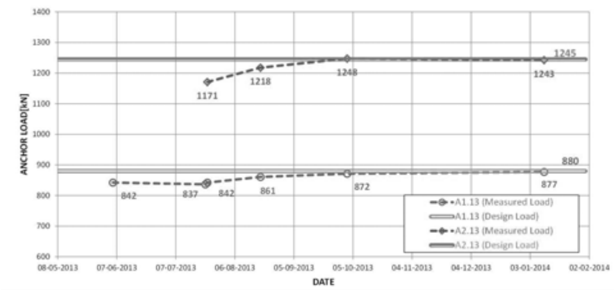

Figure 5. Measured ground anchor loads.

Figure 6. Load cells and instrumented pile.

Figure 7. Parque Oriente building excavation completed.

Figure 8. Deep excavation of 26.5m in Santiago, ramp withdrawal.

3 DEEP EXCATION IN LIMA

The typical retaining wall system used to execute the excavations carried out in Lima corresponds to an anchored wall consisting on the reinforced concrete wall of the building laterally braced with several rows of ground anchors.

Figure 9. Anchored wall in Lima.

The construction involves the construction of wall panels. The height of each stage of excavation (3.0-3.5m) and 4.0-5.0m wide in an alternate sequence. Wall panels have stru ctural conections to each other so the overlap lenght of th e reinforcement has to be accounted for.

Figure 10. Formwork positioning

Also, heavy formworks are used to withstand the concretin g pressure and give a good finish to the wall. After execu ting the concrete panel and postensioning the ground anch or, a nex excavation sequence is carried out to the next le vel until reaching the final excavation depth.

Figure 11. Steel reinforcement being place in an open panel.

A basic acceleration of 0.40g applies to Lima (Zone 3, after E.030). For temporary works, it can be reduced to 0.18g. Design considerations as for Santiago are taken into account, even using the same design software and design procedures.

3 .1 *Office Building*

Office Building is one of the deepest projects in which Pilotes Terratest contract was to perform both engineering design and construction. The excavation lay-out and cross section is shown in figures 12 and 13.

The typical section was 31.8m deep. An inclinometer ca sing was installed one meter behind the wall in a borehole 35.50m long. Eight rows of ground anchors were designe d, having service loads of 800kN to 1155kN. Lenghts vari ed from 12 to 22 meters. The concrete wall was the build ings permanent lateral wall, having a thickness of 30cm - 40cm with aditional reinforcement (flexural and punching) due to the temporal construction stresses.

Reading of the inclinometer involved 18 visits from February 25 to August 28, 2015. The total displacement measured was 9mm. The first stage of excavation, being unsupported, attained a deformation of about 4.5mm, then in a cantilever shape moved in each sequence of excavation with little increments to its maximum.

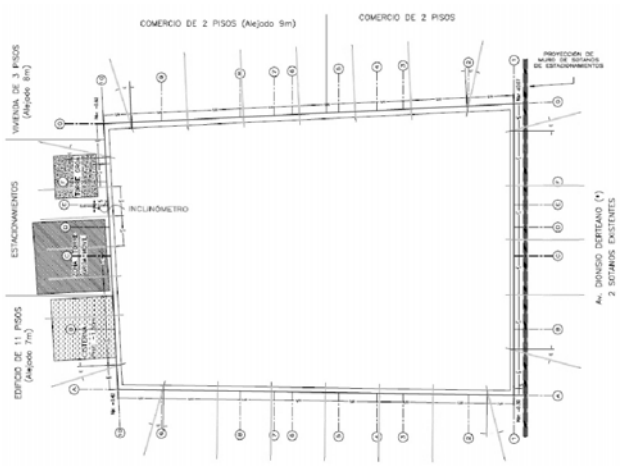

Figure 12. Excavation layout and monitored section on the left side.

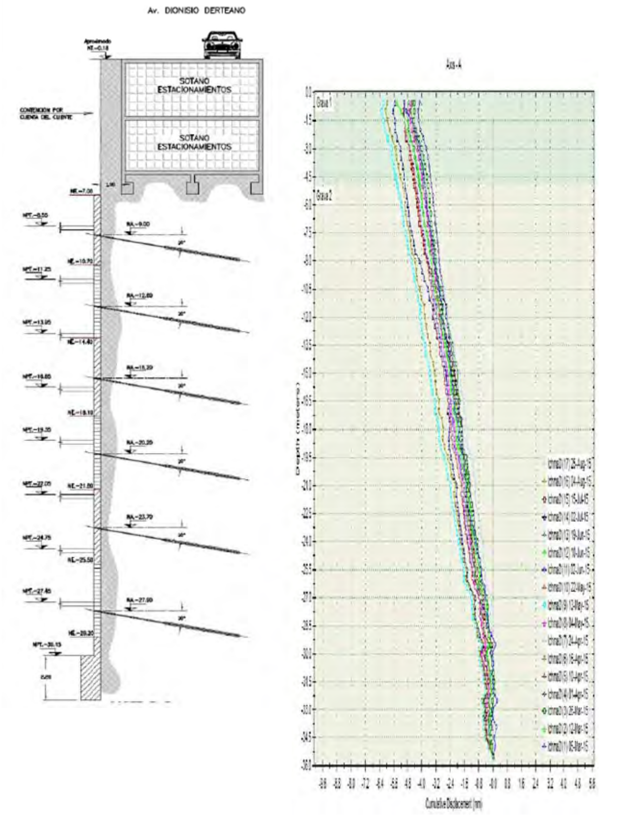

Figure 13. Cross-section of the wall and inclinometer readings.

Figure 14. Ground anchors execution.

The construction sequence of the excavation was modeled in order to calibrate the soil model parameters for the Lima gravel “conglomerado”. Altough some simplifications are involved in the 2D model of the 3D process, a good agreement could be reached.

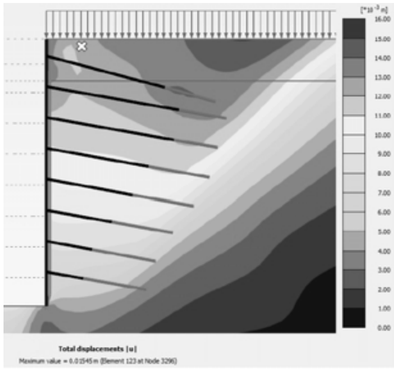

Figure 16. Open excavation completed.

Figure 15. Republica Building with 28 m depth excavation.

4 CONCLUSIONS

The instrumentation of excavations in Santiago and Lima provided material for predicting the performance in other jobsites and for exploring other configurations for deep basement solutions. It was observed that the mean geomechanical behaviour of both geological formations was better than expected, based on published data.

The monitoring of geotechnical works confirmed the expected deformation perfomance, and allowed for the development of a robust expertise to safely approach deeper excavations in the future in order to provide the solutions that society demands from a geotechnical contractor specialist.

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