Numerical Study of Anchored Piles Using Geostudio Sigma/W Modeling

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Abstract: This study describes the analysis of machine drilled piles that are anchored and placed discontinuously. The main advantage of this method is its faster and safer execution compared to hand-dug piles (rectangular cross-section), which is the most widely used method for retaining walls on gravel soils in Santiago. This paper shows the results of displacement versus height obtained using numerical modeling (Geostudio Sigma/W software). In the case of the anchored machine drilled pile used for the construction of the Faculty of Physical and Mathematical Sciences, Universidad de Chile. The modeling results carried out using Geostudio Sigma/W were compared with the modeling results carried out by previous researchers on other software as well as the measured field values. In stage 2 the results obtained were not much different from the results of previous research. There are quite significant differences in stages 6 and 8 between Geostudio Sigma/W modeling and other modeling due to the lack of more detailed information regarding available research data.

1 INTRODUCTION

In urban areas it is usually not possible to use non-vertical slopes to support excavations due to limited space (Abramson et al., 2001), so vertical supports are required. For discontinuous or discontinuous bored piles, the clearance between the piles is three times the width (for hand-dug piles) or diameter (for machine-drilled piles). Retaining walls between piles is possible due to the arc effect.

Retaining wall is a structure that supports soil on steep slopes, which can be vertical (Terzaghi et al., 1996). Among the types of retaining walls, we can distinguish between anchored piles and unanchored piles or hand-dug piles.

Piles are built by digging a hole in the ground (Candoğan, 2008), installing a reinforcing frame in it, and pouring concrete from the surface. During excavation, steel casing can be used to avoid wall collapse in the hole, and is also used as a guide in the drilling process (Weissenbach et al., 2003).

One of the advantages of using drilled piles compared to driven piles is that there is no significant vibration (Weissenbach, Hettler, & Simpson, 2003) and greater excavation depths can be achieved. Drilling of hand-dug piles is done manually, taking workers into holes, which can be so deep that they are frequently exposed to excavation wall collapse caused by local instability, surface vibrations, or earthquakes. In the case of using piles, all processes are carried out from the surface (Raddatz & Taiba, 2017).

The method most widely used in Santiago to support deep and temporary excavations is hand-dug piles anchored and placed discontinuously (Sáez & Ledezma, 2012). In recent years, the use of anchored piles has been incorporated to fulfill the same function as hand-dug piles.

This study takes reference from previous research (Raddatz & Taiba, 2017), describing the anchored pile method as a soil retaining system, and the characteristics of a newly constructed engineering building at the Universidad de Chile. A study of the geotechnical and structural parameters of the project located in downtown Santiago was conducted, in order to build a numerical analysis model through software. Raddatz and Taiba (2017) used Plaxis 2D, GGU-Retain and CYPE software: Embedded Retaining Walls.

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In the research carried out by the author, research data by Raddatz and Taiba (2017) were input into GeoStudio software: Sigma/W in numerical analysis.

2 METHODS

The new building of the Faculty of Physical and Mathematical Sciences at the Universidad de Chile, is located between Beauchef, Club Hipico, Blanco Encalada and Tupper Streets in the commune of Santiago, Metropolitan area (Pilotes Terratest, 2021b). This building has seven floors and six underground floors, with a building foundation height of 27.5 m or a depth of 29 m from the zero line, which is located close to the natural ground level in this sector.

2.1 Anchored Retaining Walls

The sheet piles are considered to be 1 m in diameter around the perimeter where there is sufficient space for installation. The sheet pile piles are located at the factory every 2.5 m between the pile axes (the building foundation is at a depth of 29 m) or 2.95 m between the pile axes (the building foundation is at a depth of 27.5 m). On the northern boundary there is an existing University building, so there is not enough space for installing piles because the pile machine does not fit into the existing building. So rectangular piles are placed under the existing foundation of the building as supporting piles.

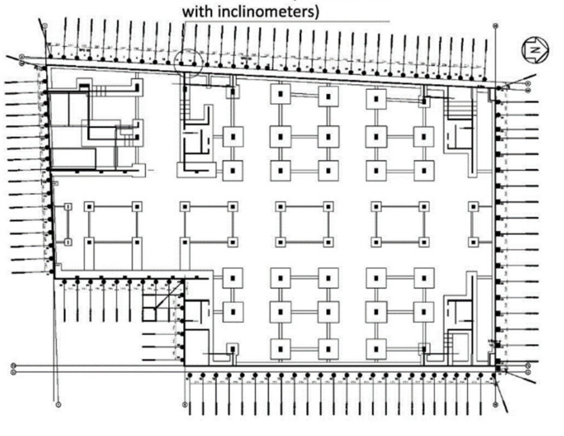

Figure 1: Plan of a retaining wall project with instrumented piles (Pilotes Terratest, 2021b).

The pile is considered to be embedded at 2.5 meters so that the end of the pile is -30 meters or -31.5 meters. The pile head is considered to be at an elevation of -1.5 m to comply with various city regulations, using a small slope from the pile head to the ground level. Anchors on steel cables are used as lateral strengthening elements, each cable has a yield force of 235 kN and a diameter of 15 mm. The number of cables depends on the anchor service load.

Inclinometers were installed on two piles to measure displacement at different stages (Manterola & Carlos, 2012). The piles installed with inclinometers are positioned in an area with a gap between the piles of 2.95 meters between the pile axes and the building foundation elevation of -27.5 meters. Measurements are carried out at the second stage (before installing the first anchor), fourth stage (before installing the second anchor), sixth stage (before installing the third anchor) and eighth stage (final stage of excavation). For the fixed anchor length, soil is used to pull the grout with a reduced resistance of 250 kN/m. This value is usually used on all projects where Santiago gravel is located.

Table 1: Properties of Piles.

Properties	Value
Length (m)	28,5
Diameter (m)	1
Elastic modulus (kN/m^2)	23875200
Cross-sectional area (m^2)	0,7854
Moment of inertia (m^4)	0,049
Axial stiffness (kN)	18751540
Flexural stiffness (kN.m^2)	1169884

Source: Raddatz and Taiba, 2017

Table 2: Characteristics of Angkur.

Sifat-sifat	Pertama	Kedua	Ketiga
Depth (m)	-5,00	-13,00	-21,00
Free length (m)	16,1	12,8	7,9
Fixed length (m)	4,1	5,2	5,4
Service load (kN)	1004	1297	1331
Free-length stiffness (kN)	191100	245700	245700
Fixed-length stiffness (kN)	307500	390000	

Source: Raddatz and Taiba, 2017

The project is placed on the typical Santiago gravel, which has been studied in depth. The high cohesion values for gravel were confirmed in previous analysis of triaxial results on this soil

(Ortigosa & Hidalgo, 1997). The two fine soil layers identified in the soil mechanics report were considered in the model created by Pilotes Terratest for pile design (Pilotes Terratest, 2021). Fine soil layers have been considered in all numerical models carried out for this research project.

Table 3: Soil Properties.

Layer 1 (Depth of 0 to 6,5 m)	Fluvial gravel: second deposit Friction angle = 45º Cohesion = 23,0 kN/m² Unit weight = 22,0 kN/m³
Layer 2 (From a depth of 6,5 m)	Fluvial gravel: first deposit Friction angle = 45º Cohesion = 35,0 kN/m² Unit weight = 23,0 kN/m³
Interlayer (From a depth of 21 m to 22 m and 26 m to 27 m	Fine soil: interlayer Friction angle = 26º Cohesion = 55,0 kN/m²) Unit weight = 18,0 kN/m³

Source: (Raddatz & Taiba, 2017)

A background review for the Santiago gravel has been carried out, and for deformation increases with depth, where depth “z” is in meters.

$$E = 45000\sqrt{z} \quad [kN/m^2]$$

This equation is similar to that used by many experts in Santiago based on the research results of (Ortigosa & Kort, 1997) which stated that the relationship between deformation modulus and depth was found through plate load tests at different depths.

2.2 Numeric Analysis

In previous research conducted by Raddatz and Taiba (2017), numerical analysis was carried out using the Plaxis 2D, GGU-Retain and CYPE computer programs. Research carried out by the author added numerical analysis using the Geostudio Sigma/W computer program. The analysis is carried out in stages to represent the problem well.

Geostudio is software that uses numerical analysis developed by Geoslope International for geo-engineers and earth-scientists. Geostudio consists of several applications, specifically TEMP/W, SEEP/W, SLOPE/W, AIR/W, CTRAN/W, Sigma/W and QUAKE/W. In this research, the application used is Sigma/W.

Geostudio Sigma/W is a program based on the finite element method. The function of this program is to calculate displacement, resistance, etc. based on material coating conditions. This program automatically determines the center of moment by looking for the minimum point. Then, the anchored retaining wall is modeled and it is determined whether the anchored retaining wall is appropriate to the existing soil conditions.

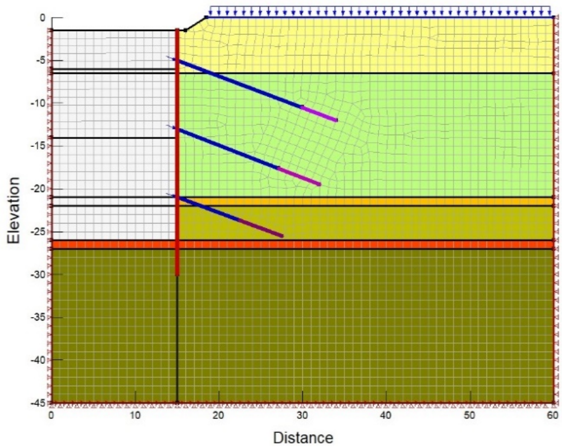

Figure 2: Geostudio Sigma/W model. Source: Prepared by the author, 2023.

3 RESULTS AND DISCUSSION

The following figures show graphically the comparison between field measurements and numerical modeling results. The numerical modeling results by previous researchers are included and compared with the modeling results performed by the author. The graphs correspond to the fourth (before installation of the second anchor), sixth (before installation of the third anchor), and eighth (final stage of excavation) stages. The first data recorded in the field is the second data, hence all model results consider the displacement reduction of the second stage.

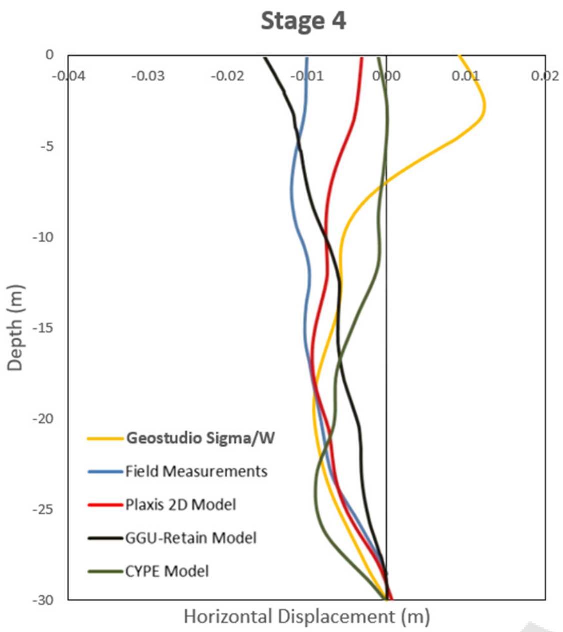

Figure 3: Comparison between measurement and modeling for stage 4 (before installing the second anchor).

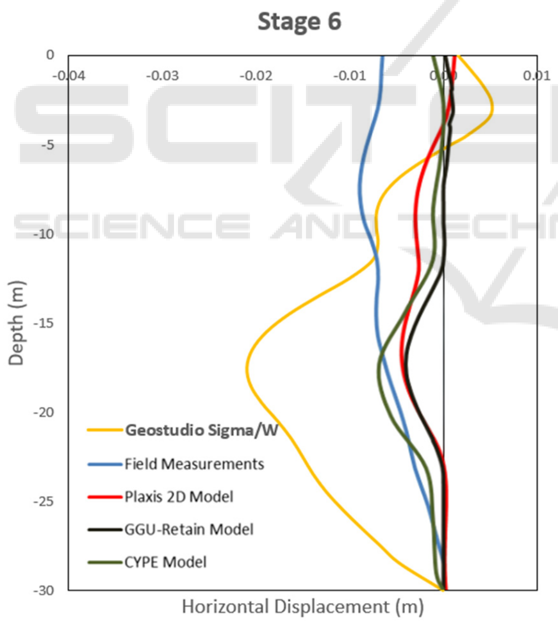

Figure 4: Comparison between measurement and modeling for stage 6 (before installing the third anchor).

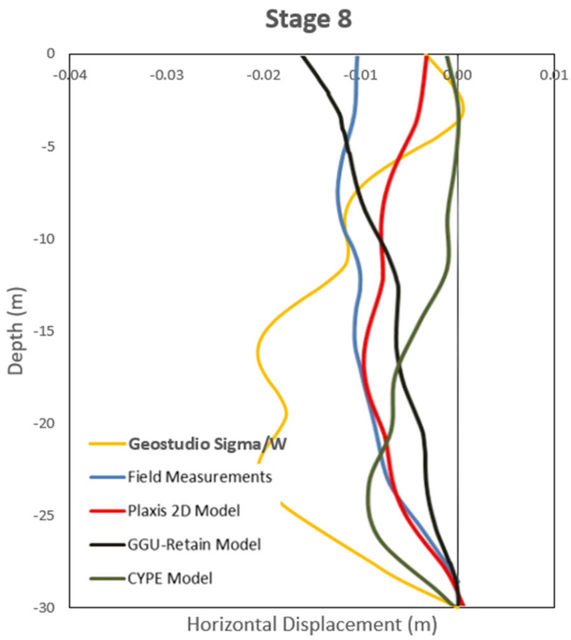

Figure 5: Comparison between measurement and modeling for stage 8 (final excavation stage).

The graph shows that the results obtained from the modeling are of the same order as the field data, but the field measurements have a larger displacement at the top of the pile, which develops significantly in the early stages of excavation (fourth stage).

The graph obtained from Geostudio Sigma/W in stage 4 is similar to the graph obtained in modeling using other software. However, at stage 6 and stage 8, the Geostudio Sigma/W graph at a depth of -15 meters to -25 meters experienced a horizontal displacement that was quite significantly larger than the displacement that occurred in other software. This significant difference could occur due to a lack of more detailed information regarding previous research data, especially anchor data. Thus, the difference is getting bigger, where at stages 6 and 8 the second and third anchors have been installed.

4 CONCLUSIONS

The measurements obtained from the inclinometer are unusual, as high displacements in the early stages are not expected to occur because the pile stiffness and anchor working loads are designed for the higher-pressure conditions that will occur in the final stages. That is what happened in the Geostudio Sigma/W results which showed high displacement in the early stages. There are quite significant differences in stages 6 and 8 between Geostudio Sigma/W modeling and other modeling due to the lack of more detailed information regarding available research data. In other design codes such as EAB (German Geotechnical Society, 2013), various pressure redistributions are provided depending on the type of wall, the number of anchor levels and their location. In the case of three levels of anchorage, the redistribution is triangular in the length of the pile top. Therefore, the results will be very different for the top of the wall depending on the type of design code to be used (pressure distribution used).

As a recommendation for further research, it can complement the data that is still missing in this paper so that better results can be obtained. In addition, other analysis applications can be used to compare with existing results.

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