Comparison between PLAXIS 2D and CYPE to simulate an anchored wall

Guilherme Mello[1], Sara Rios[1], Alexandre Pinto[1], Jesús Ruíz[2], Jorge Barros[3]

[1]*CONSTRUCT-GEO, Dep. of Civil Engineering, Faculty of Engineering, University of Porto, Portugal*
gui.mello1@gmail.com, sara.rios@fe.up.pt, amgcpinto@fe.up.pt
[2]*Universidade da Corunha, Dep. de Ingenieria Civil, Campus de Elvina, s/n, A Coruna, Spain*
jesus.fernandez.ruiz@udc.es
[3]*Mota-Engil Global, R. do Rego Lameiro 38, 4300-454 Porto, Portugal*
Jorge.R.Barros@mota-engil.pt

Abstract. This paper presents a specific case study where a retaining wall necessary to support the construction of a residential building with 4 floors below the ground level and 10 floors above ground was numerically evaluated. The design solution comprised a reinforced concrete diaphragm wall with four levels of ground anchors. Two different commercial software were used to model this case study: PLAXIS 2D ®, and the Cype - StruBIM Embedded walls, v.2023. PLAXIS 2D ® uses the Finite Element Method, allowing the simulation of the soil deformation and comprising the soil-structure interaction. Cype models the soil behaviour by the Winkler theory representing it by fictious springs with a given stiffness related to the soil properties. The results are compared in terms of the deformation of the wall and surrounding soil, as well as the bending moments on the wall. The comparison between the two numerical tools highlights their different assumptions. PLAXIS 2D ® provides the deformation of the surrounding soil, while Cype is more devoted to the estimation of the stresses and bending moments on the wall.

Keywords: diaphragm wall, soil-structure interaction, numerical modeling, finite element method, Winkler theory.

1 Introduction

The rapid expansion of cities and increasing urbanization are bringing new challenges in the field of civil engineering due to the limited space available which is becoming more and more occupied. This trend demands more construction on the underground and sometimes it is necessary to build on soils of poor quality. As the frequency of subterranean projects escalates, the demand for excavations grows in tandem, often leading to deeper and more extensive diggings, which are frequently undertaken within densely populated urban zones and near pre-existing structures. In this challenging scenario, retaining structures have an extremely important role in the current construction projects. They are designed to withstand lateral soil pressures and to ensure the stability and safety of excavations. To minimize potential effects on nearby structures, the evaluation of soil deformations around the excavation is very important. Numerical analysis can support the estimation of those movements, but a thorough understanding of software limitations is crucial for its correct use.

This paper presents a comparative analysis between two software widely used in this field: PLAXIS 2D ®, from Bentley systems, and StruBIM embedded wall, from Cype ingenieros. Although both programs can be used to design retaining structures, their approaches are quite different. While PLAXIS 2D ® uses the finite element method, which allows the simulation of the soil and the interaction between the soil and the structure, StruBIM embedded wall focuses on the structural part of the retaining structure, relying on iterative methods where the magnitude of the soil thrust depends on the displacement of the wall. This latter software uses the Winkler's theory, where the soil is simulated by springs with a stiffness calculated by subgrade modulus coefficients, and uses a pressure-deformation relationship for the elastoplastic behavior (CypeIngenieros, n.d. [1]).

2 Case study description

2.1 Introduction

The retaining wall modelled in this work is composed by diaphragm wall with 4 levels of ground anchors that was built to support the construction of a residential building located in Lisbon with 4 floors below the ground level, and 10 floors above ground. For simplicity, only the results corresponding to a specific wall cross-section are presented.

2.2 Soil Characterization

There are three different types of soils present in the analyzed cross-section, named as Alluvium, Disturbed Miocene, and Miocene. Table 1 provides the soil parameters associated with each layer as well as the elevations at the top and bottom of the layers. These parameters were defined based on the SPT results and laboratory tests.

Table 1. Soil properties (Mota Engil, 2020)

Soil	γ (kN/m^3)	c´(kPa)	E(kPa)	ϕ(º)	Top layer elevation (m)	Bottom layer elevation (m)
Alluvium	19	4	8000	28	90.92	82.38
Disturbed Miocene	20	10	30000	28	82.38	77.17
Miocene	21	15	50000	30	77.17	-

2.3 Structural elements

At the selected cross-section, the excavation has 12,27 meters of depth. A diaphragm wall with 0.4 m of thickness was built with C30/37 concrete, and it was braced by 4 levels of temporary ground anchors with an applied prestress ranging from 400 to 750 kN. Each anchor consists of 5 or 6 A500 steel bars with a diameter of 150 mm spaced by 3.6 m. Table 2 summarizes the inclination, free length, applied prestress, fixed anchor length, number of steel bars, and anchor depth.

Table 2. Anchor properties

Anchor level	Inclination (º)	Free length (m)	Fixed anchor length (m)	Number of steel bars	Applied pre-stress (kN)	Depth of each anchor(m)
1st level	30	12	6	5	500	0.35
2nd level	25	10	7	6	700	3.7
3rd level	20	8	7	6	750	6.5
4th level	15	7	7	6	750	9.3

3 Numerical modeling

3.1 Construction sequence

In both software, the construction sequence was the following: 1) construction of the diaphragm wall; 2) excavation to 0.5 m below the next anchor level; 3) installation of the corresponding anchor; 4) repetition of this process until the bottom of the excavation is reached. The difference between software relies on the wall installation, and the generation of the soil in the at-rest state. Although both use the "wished in place" structure, where the soil disturbance associated to wall construction is not taken into account, in PLAXIS 2D ® a previous phase before the first excavation is required to simulate the wall construction, while in Cype-StruBIM Embedded Walls the simulation starts with the wall already installed. The groundwater level was considered at the bottom of the excavation for both numerical models.

3.2 PLAXIS 2D ® numerical model

Figure 1 shows the mesh used in the model that has 1591 fifteen-node triangular elements and 13232 nodes. The model was fully fixed along the xx axis and normally fixed in the lateral boundaries being free on the top boundary. The blue lines represent the location of the excavation stages and the four anchor grout bodies.

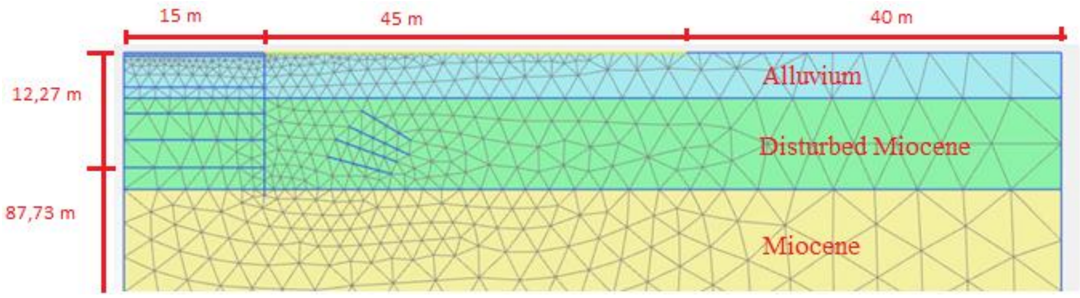

Figure 1. Finite elements mesh adopted

The constitutive model adopted to simulate the soil behavior in PLAXIS 2D ® was the Mohr-Coulomb model using the soil parameters identified in Table 1 and considering a Poisson ratio of 0.3. The embedded wall was simulated using the command "plate" with the given properties indicated in Table 3, considering that the concrete has a Young modulus of 33 GPa and a unit weight of 25 kN/m^3.

Table 3. Diaphragm wall properties

Parameters	Diaphragm wall
Axial stiffness EA (kN/m)	13200000
Flexural stiffness EI $(kN.\,m^2/m)$	176000
Wall weight W $(kN/m/m)$	2
Poisson´s ratio ν	0.2

Since PLAXIS 2D ® overlaps the soil and the wall, the wall weight was calculated with equation (1), where e is the wall thickness (e=0.4 m). For simplification, the soil unit weight was assumed 20kN/m^3, which corresponds to the average unit weight of the three soils indicated in Table 1.

$$W = (\gamma_{concrete} - \gamma_{soil}) \times e \times 1. \tag{1}$$

To simulate the soil-structure interaction, a roughness angle equivalent to 2/3 of the friction angle was adopted. The free anchor length was simulated using the command "node to node anchor", with an axial stiffness calculated by multiplying the steel elasticity modulus (210 GPa), by the steel bars area. For the anchors with 5 steel bars, the axial stiffness is 18555031,6kN while for the anchors with 6 steel bars, the axial stiffness is 22266037,9 kN.

The anchor grouted bodies were simulated using the command "embedded beams", considering the parameters indicated in Table 4. In this case, a stiffness of 7 GPa, identical to the one presented at PLAXIS 2D® tutorial manual [2], was considered to simulate the mixture of the soil with the grout. Since the axial skin resistance was not available, a value of 102 kN/m was used, which represents the minimum value for the anchor's geometry that does not cause soil failure.

Table 4. Anchor grout body parameters

Parameters	Anchor grout body
Body weight W ($kN/m/m$)	0.75
Hole diameter	0.15
E(kN/m^2)	7000000
Axial skin resistance (kN/m^3)	102

3.3 StruBIM embedded walls numerical model

The soil strength parameters and unit weight described in Table 1 were also introduced in the software. In addition, the program also requires the saturated unit weight, the active Winkler modulus, the Winkler modulus gradient, and the coefficients of active, passive, and at rest thrusts. As in PLAXIS 2D ®, the same soil unit weight was adopted above and below the groundwater level.
The Winkler modulus, K_h, was calculated using the Selvadura´s formula:

$$K_h = \frac{0.65E}{b(1-\nu^2)}. \quad (2)$$

where E represents the soil elasticity modulus, b represents the width of the wall section, and v represents the Poisson ratio. Table 5 summarizes the Winkler modulus used for each soil. For simplification, the gradient of the Winkler modulus was considered to be equal to zero.

Table 5. Winkler modulus

Soil	Winkler modulus
Alluvium	1843
Disturbed Miocene	6912
Miocene	11520

The parameters used to characterize the anchors are the axial stiffness, the pre-stress applied, the spacing between anchors, and the inclination. Unlike PLAXIS 2D ®, the axial stiffness of the anchors in this program is expressed in kN/m being calculated as a product of the steel Young modulus and the cross-section area of the anchor divided by its free length. Table 6 summarizes the axial stiffness of each anchor level. The other parameters can be found in Table 2.

Table 6. Axial stiffness in each anchor

Anchor level	Axial stiffness
1st level	15462
2nd level	22266
3rd level	27832
4th level	31808

4 Results

4.1 PLAXIS 2D® results

Conversely to Cype, PLAXIS 2D® provides the deformation of the soil which can be observed in Fig XX for the last excavation stage. It is visible that the anchor prestresses were responsible for the surface heave and wall movement toward the supported soil.

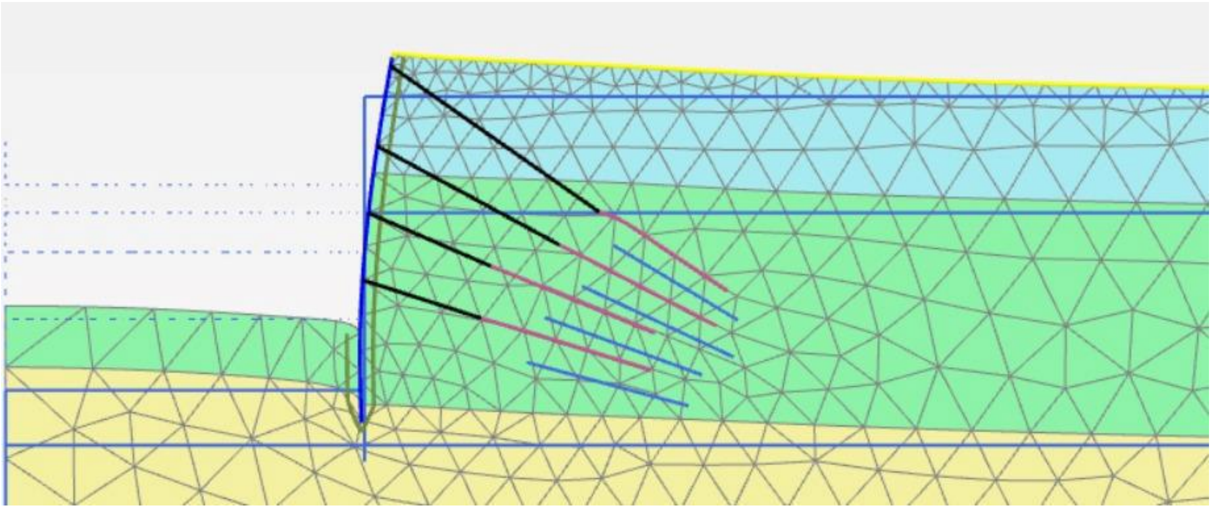

Figure 2. Deformed mesh at the last excavation stage (the full dimension of the model was not presented to zoom the area around the retaining wall)

4.2 Comparison between PLAXIS 2D ® and Cype- StruBIM embedded walls

Considering the Cype is a structural software, its main outputs are in terms of stresses and displacements on the structural elements, namely on the wall. Figure 3 shows the comparison between wall bending moments obtained by both software. Although the obtained values are different, especially for the deeper levels, the shape of the bending moments profile is similar in both software, with the maximum and minimum values at approximately the same depth. However, the maximum bending moment used for wall design is quite different between the two software. In addition, it is clear from the graph that the number of points where Cype provides data is much smaller than PLAXIS 2D ®, which can explain some of the differences.

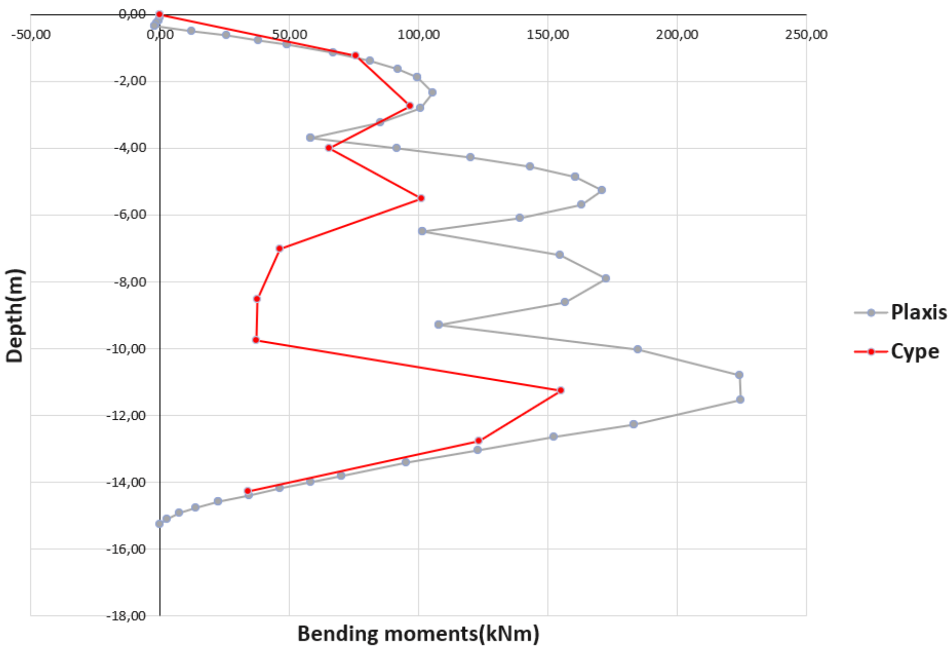

Figure 3. Retaining wall’s bending diagram obtained by PLAXIS 2D ® and Cype-StruBIM Embedded Walls

Figure 4 compares the accumulated horizontal displacements on the wall obtained in both software used. As observed in Figure 2, the accumulated displacements show a movement towards the supported soil as a result of the pre-stress applied in the anchor system. The maximum displacements are at the top, where PLAXIS 2D ®

estimates 60 mm of displacement, conversely to 35 mm predicted by Cype. Notwithstanding, the shape of the displacement profile is similar in both cases.

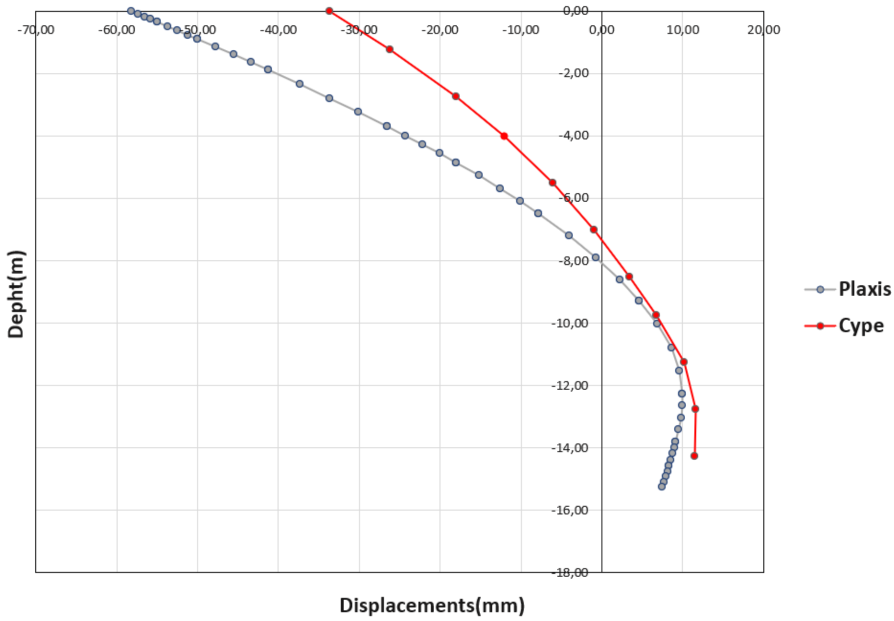

Figure 4. Comparison between PLAXIS 2D ® and Cype-StruBIM Embedded Walls in terms of accumulated horizontal displacement on the wall

5 Conclusion

In this work, a specific case study of a diaphragm wall with four levels of ground anchors was modeled with two different software, PLAXIS 2D ® and Cype-StruBIM Embedded Walls, which have different numerical approaches. While PLAXIS 2D® enables the simulation of soil deformation and accounts for the soil-structure interaction, Cype uses the Winkler theory to simulate the soil stiffness and an iterative procedure to adjust the soil thrust depending on the wall deformation. The comparison between PLAXIS 2D ® and Cype was performed in terms of wall accumulated horizontal displacements and bending moments. In general, the shape of the wall deformation and bending moment profiles is similar in both software. However, PLAXIS 2D ® indicated higher wall displacements at the top and higher maximum bending moment than Cype. This is especially important as Cype results are not conservative.

References

[1] Cype Ingenieros S.A. (n.d). Embedded retaining walls - user manual https://www.cype.net/documents_en/manuals/pananc09.pdf. Accessed on 18/07/2023

[2] Plaxis (2023a). Plaxis 2D 2023.1 Tutorial Manual. https://communities.bentley.com/cfs-file/__key/communityserver-wikis-components-files/00-00-00-05-58/PLAXIS_5F00_2D_5F00_2023.1_5F00_2D_5F00_1_5F00_Tutorial.pdf

Cype Ingenieros S.A. (n.d). Elementos de contención: Cálculo de empujes.Alicante, Spain: Cype Ingenieros S.A.