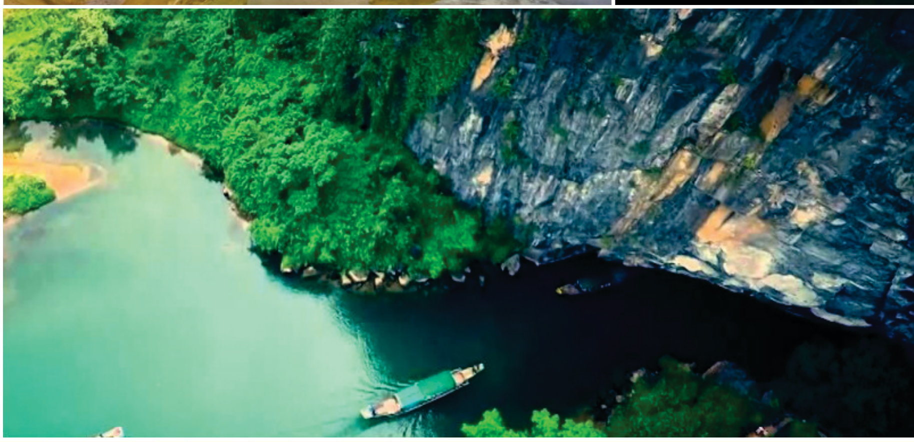
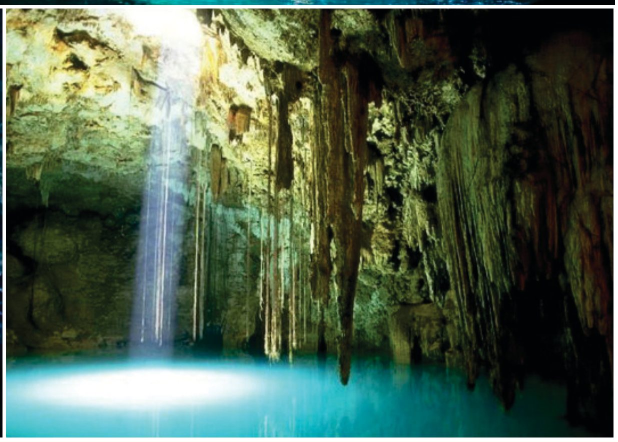
PROCEEDINGS OF THE 4th INTERNATIONAL CONFERENCE
VIETGEO 2018, QUANG BINH, 21-22 SEPTEMBER, 2018

GEOLOGICAL AND GEOTECHNICAL ENGINEERING IN RESPONSE TO CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT OF INFRASTRUCTURE



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Quang Binh, 21&22 September 2018

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TABLE OF CONTENT

SESSION 2
GEOTECHNICS FOR SUSTAINABLE DEVELOPMENT OF INFRASTRUCTURE

SESSION 3
GEOTECHNICAL MONITORING AND MATERIALS

SESSION 4
GEOHAZARDS AND SLOPE STABILITY

SESSION 5
TECHNICAL NOTES

COMPARISON OF NUMERICAL MODELING AND FIELD MONITORING OF DEEP FOUNDATION OF HIGH-RISE BUILDING

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Abtract: In the trend of urban development in Vietnam, the construction of high-rise buildings is indispensable. Due to the limited construction area, these works often have to develop underground space, also known as basement (deep foundation). In fact, the construction of deep foundations have occurred many incidents. There are many causes leading to incidents, including causes of errors in the geotechnical investigation, resulting in not enough data on the physical-mechanical properties of rock and soil. Therefore, the simulation of the actual working condition of the ground around the foundation is not accurate. This paper analyzes the effect of geotechnical survey results on the calculation of the deep foundation in a particular project and compares it with the actual observation results.

Keywords: deep foundation; Mohr-Coulomb model; inclinometer.

1. Introduction

In the trend of urban development in Vietnam, the construction of high-rise buildings is indispensable. Due to the limited construction area, these works often have to develop underground space, also known as basement (deep foundation). There are some typical projects in Ha Noi such as: Pacific Place, 83 Ly Thuong Kiet, Royal City Building, Mo Shopping Center, Lotte Center Hanoi with 5 basements, Tan Hoang Minh D'.Palais de Louis with 4 basements ... In fact, the construction of deep foundations have occurred many incidents, such as: The construction of the basement of Pacific Building, Nguyen Thi Minh Khai Street in 2007 has collapsed the building of the Southern Institute of Social Sciences; Construction of the basement of Saigon Residences building in 2007 has tilt Cosaco apartment building, 5 Nguyen Sieu, ... There are many causes leading to incidents, including causes of errors in the geotechnical investigation, resulting in not enough data on the physical-mechanical properties of rock and soil. Therefore, the simulation of the actual working condition of the ground around the foundation is not accurate. Therefore, it is necessary to improve the quality of geotechnical investigation to reduce the difference in the results of design calculations and actual construction.

2. Geotechnical conditions of construction site

2.1. Location

Summit Building is located at 216 Tran Duy Hung, Trung Hoa, Cau Giay, Hanoi. The project is is easily connected with the roads such as Nguyen Chanh, Ring Road 3, Lang Road ... and easily move to neighboring districts such as Dong Da District, Thanh Xuan District, Tu Liem District, Fig 1.

- Opposite the Grand Plaza;
- Located 100 meters from Big C supermarket;
- Located 120 meters from the D'Capitale Project;
- Located 200 meters from Thang Long Boulevard;
- Located 300 meters from Amsterdam High School;
- Located 3 kilometers from Royal City.

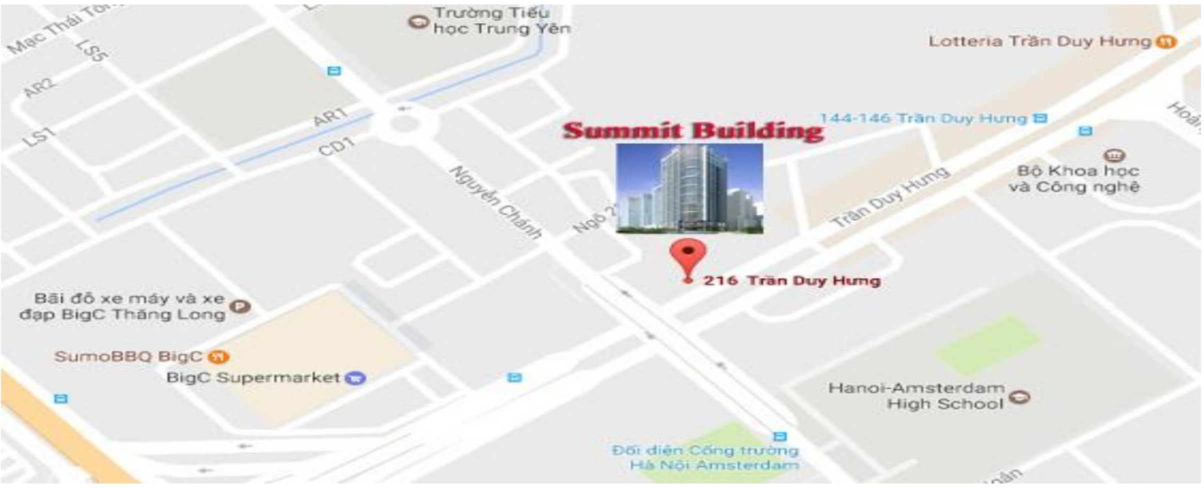

Fig. 1. Location of Summit Building

1.2. Geotechnical conditions of construction site

Based on the results of geotechnical investigation, stratigraphy of the construction site. It is classified into 06 layers and 01 sub-layers, shown on the engineering geological section of the project, Fig 2. Describe layers from top to bottom as follows:

Layer 1: Filled soil: Sand, clay mix

Layer 2: Clay, sandy clay, brownish gray, firm;

Layer 3: Very fine sand, brownish gray, medium dense;

Layer 4: Sandy clay, brownish gray, content organic, stiff;

Layer 5: Very fine sand, brownish gray, dense;

Sub-Layer 5a: Sandy clay, brownish gray, stiff;

Layer 6: Gravel, content coarse sand, very dense.

1.3. Retaining structure

The building uses barretle walls made of reinforced concrete, 28m long. Retaining wall are assembled with prefabricated panels, 80 cm thick, average width of 5 meters, using reinforced Ø25. The wall is also used to make basement wall of high-rise building, Fig 3.

2. Evaluating the horizontal displacement of the retaining wall of Summit building by Inclinometer.

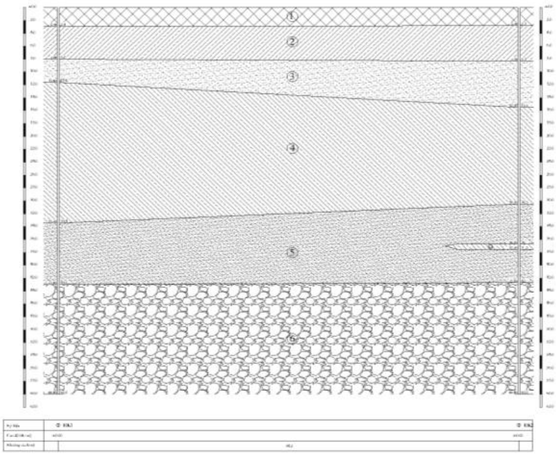
Fig. 2. Engineering geological section of construction site

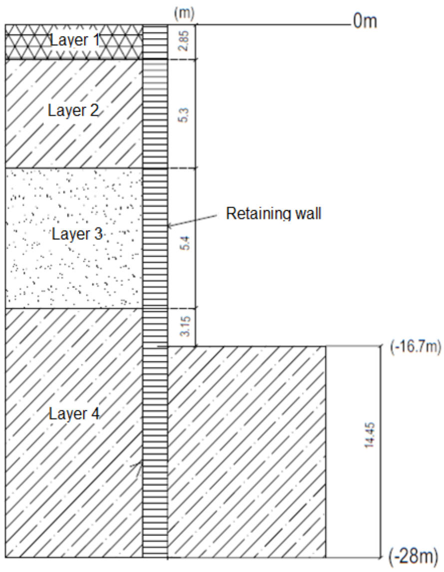

Fig. 3. Cross section of retaining wall

The building needs to observe the horizontal displacement of the retaining wall during the excavation and construction of the underground part of the building.

Measure the horizontal displacement of the retaining wall with Inclinometer: 04 points and observation from top to bottom of observation tube, the distance between measurement points is 0.5m.

Installation depth: Inclinometer is installed at 29.0 meters depth at 04 positions and 35 meters at 01 position, Fig 4. The actual depth after installation is as follows, Table 1.

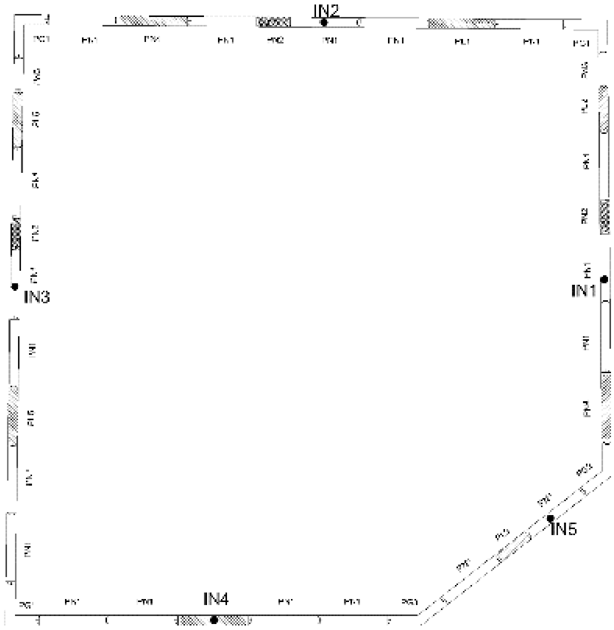

Fig. 4. Location of horizontal displacement monitoring points

Tab. 1. Installation depth and peak height of the monitoring tube

Position	IN-01	IN-02	IN-03	IN-04	IN-05
Installation depth, (meter)	29	29.5	35	29	29

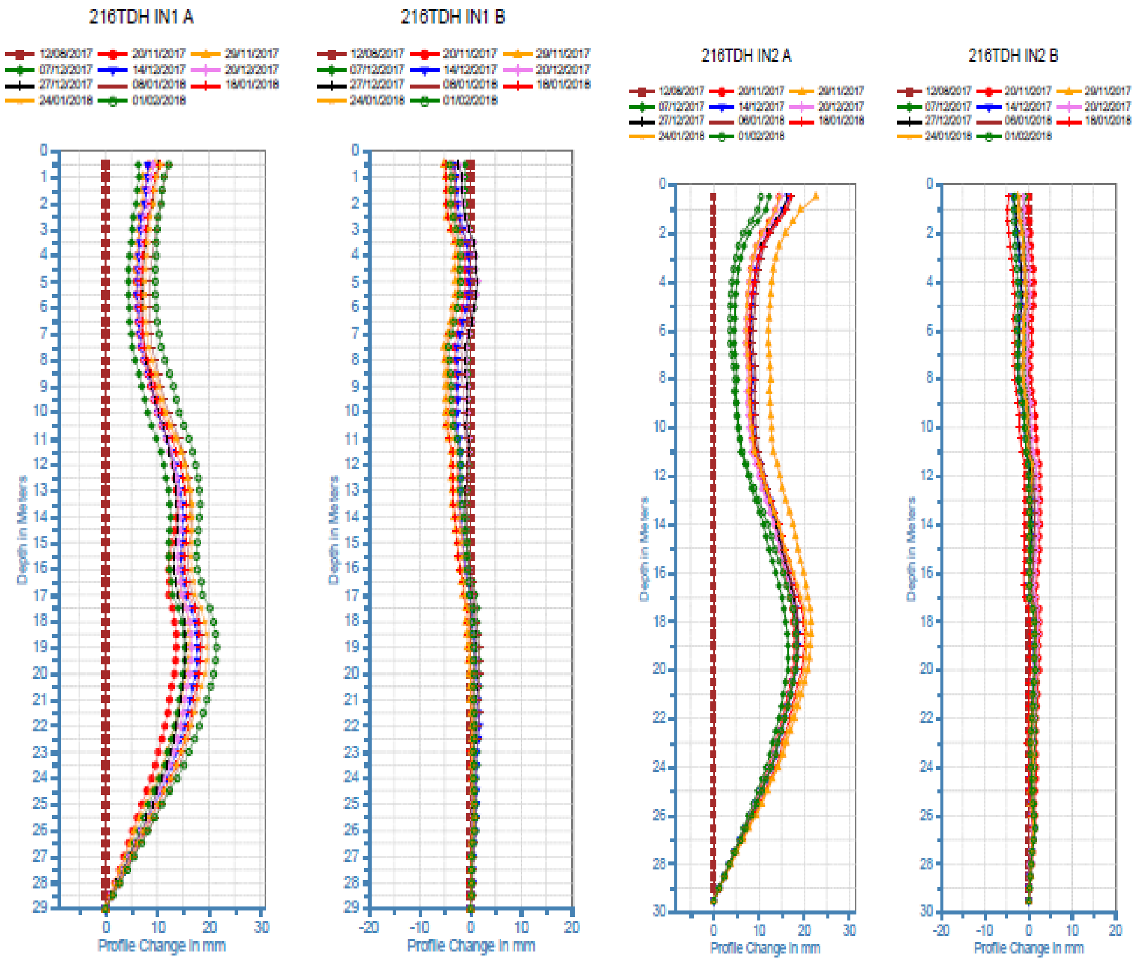

Fig. 5. Movement chart at position IN-01, IN-02

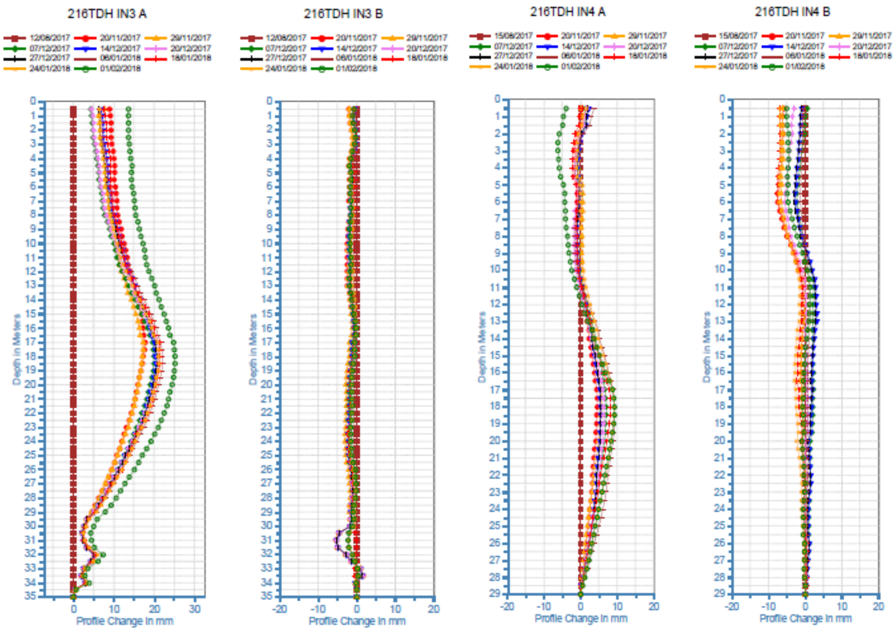

Fig. 6. Movement chart at position IN-03, IN-04

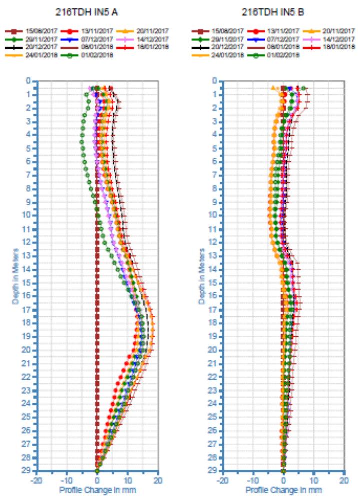

Fig. 7. Movement chart at position IN-05

After 24 observation cycles of nearly 6 months (from 15/8/2017 to 01/02/2018), the horizontal displacement of the retaining wall (Fig 5,6,7) is as follows:

- Position IN-01, the largest displacement in A direction is 21.40mm at depth 19.0m.

- Position IN-02, the largest displacement in A direction is 18.20mm at depth 19.0m.

- Position IN-03, the largest displacement in A direction is 25.17mm at depth 18.0m.

- Position IN-04, the largest displacement in A direction is 9.30mm at depth 18.0m.

- Position IN-05, the largest displacement in A direction is 15.30mm at depth 19.0m.

The results of the observation reflected the movement of the retaining walls in both space and time:

- By space: the most displacement at depths from 14.0 meter to 24.0 meter (9.93mm). The smallest displacement is from the top of the wall to 6.0 meter (0mm).

- By the time: The displacement of the wall increases and stabilizes, the displacement is small.

- The observation results clearly reflect the changing law of the retaining wall.

- The level of variation is within the allowable limit (horizontal displacement allowed is H/500, with H is the depth of the retaining wall (TCVN 9381: 2012, item 5.2.5.4).

- The retaining wall system of deep foundation is completely stable, ensuring the durability of the building and safety during construction.

3. Evaluating the horizontal displacement of the retaining wall of the Summit building using the Plaxis 2D

3.1. Construction sequence, Fig 8

Construction method: Top - Down method

Construction phases (ground level is 0m):

- Phase 1: Construction of retaining wall.

- Phase 2: Lowering the groundwater level to -5.4m, excavate to the elevation -4.4m, then executing the floor B0 at 0.0m

- Phase 3: Lowering the groundwater level to -7.9m, excavate to the elevation -6.9m, then executing the floor B1 at -4.9m.

- Phase 4: Lowering the groundwater level to -10m, excavate to elevation -9.5m, then executing floor B2 at -7.5m

- Phase 5: Lowering the groundwater level to -13m, excavation to elevation -12.7m. Then executing B3 floor at -10.7m

- Phase 6: Lowering the groundwater level to -17m, excavate to elevation -16.7m, then executing B4 at -12.7m and B5 at -14.7m.

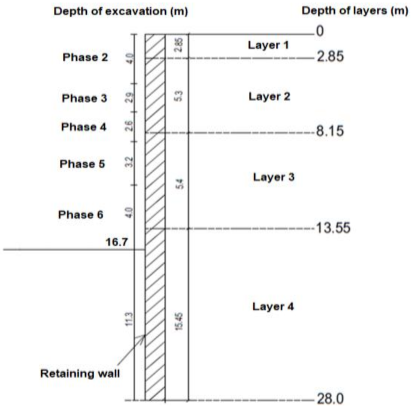

Fig. 8. Retaining wall and excavation phases.

3.2. Input parameters of the model, Table 2,3,4

Due to inadequate geotechnical survey data, we used the Mohr - Coulomb model to calculate the deep excavation for this case. This model has the advantage of being simple, just the basic physical-mechanical characteristics of the land to calculate. However, this model does not accurately simulate the work of soil and structures.

In the deep foundation, the soils works in σ_3 reduction condition. So, in order to simulate the ground conditions, the parameters must be obtained from the trixial compression test (σ_3 reduction). However, for this work, only the results from the uniaxial compression test, so the parameters used to run the model will reduce the accuracy of the results.

Based on previous studies, we propose modifying the elastic modulus values in the model to verify the results of the calculation with the actual observation results.

According to Nguyen Truong Huy, (2015). E_{ref} was obtained according to the results of the 3-axis compression test (σ_3 reduction); or $E_{ref} = (3 \div 5)\ E_{oed}$.

So, the problem is realized with two modulus values of the ground plane:

- Case 1: $E_{ref} = E_{oed}$
- Case 2: $E_{ref} = 5E_{oed}$

Tab. 2. Input parameters of soil layer ($E_{ref} = E_{oed}$)

Layer	1 MC drained	2 MC undrained	3 MC drained	4 MC undrained	5 MC drained
Thickness (m)	2.85	5.3	5.4	18.4	10.5
γ_{unsat} (kN/m^3)	18	18.37	13.25	18.55	13.18
γ_{sat} (kN/m^3)	18.5	18.63	15.24	18.90	15.29
C (kN/m^2)	10	12	0	11	0
φ $^{(o)}$	30	11.17	19.35	14.28	29.18
ψ $^{(o)}$	0	0	0	0	0
E_{ref} (kN/m^2)	42500	6270	27500	7770	5700
υ	0.3	0.31	0.3	0.32	0.3
R_{inter}	0.9	0.7	0.9	0.7	0.9

Tab. 3. Input parameters of soil layer ($E_{ref} = 5.E_{oed}$)

Layer	1	2	3	4	5
	MC drained	MC undrained	MC drained	MC undrained	MC drained
Thickness (m)	2.85	5.3	5.4	18.4	10.5
γ_{unsat} (kN/m^3)	18	18.37	13.25	18.55	13.18
γ_{sat} (kN/m^3)	18.5	18.63	15.24	18.90	15.29
C (kN/m^2)	10	12	0	11	0
φ $^{(o)}$	30	11.17	19.35	14.28	29.18
ψ $^{(o)}$	0	0	0	0	0
E_{ref} (kN/m^2)	42500	31350	27500	38850	5700
υ	0.3	0.31	0.3	0.32	0.3
R_{inter}	0.9	0.7	0.9	0.7	0.9

Tab. 4. Input parameters of retaining wall

Element	Properties	Symbol	Index	Unit
Retaining wall d =800mm M500	Normal stiffness	80%EA	2.3 x 10^6	kN
	Flexural rigidity	80%EI	1.23x10^5	kN/m
	Poisson index	ν	0.15	

Tab. 5. Input parameters of reinforced concrete floor

Element	Properties	Symbol	Index	Unit
Reinforced concrete floor d=0.3m M500	Compression rigidity	80%EA	8.64 x 10^5	kN
	Flexural rigidity	80%EI	6.48 x 10^3	kN/m

The results obtained in each phase are as follows, Fig 9-13.

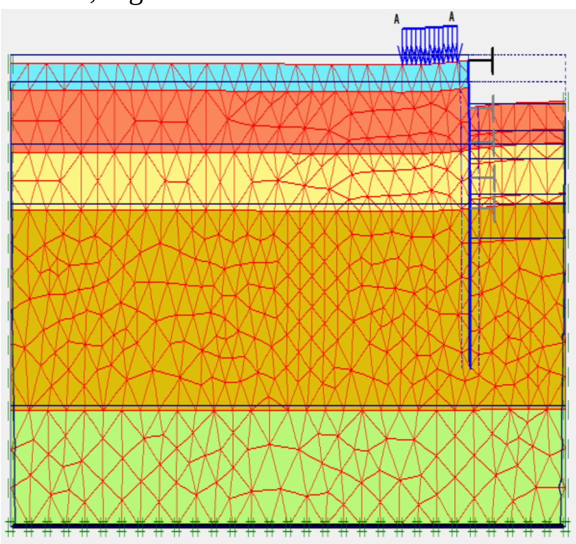

Fig. 9. The displacement of the wall and the soil after phase 2

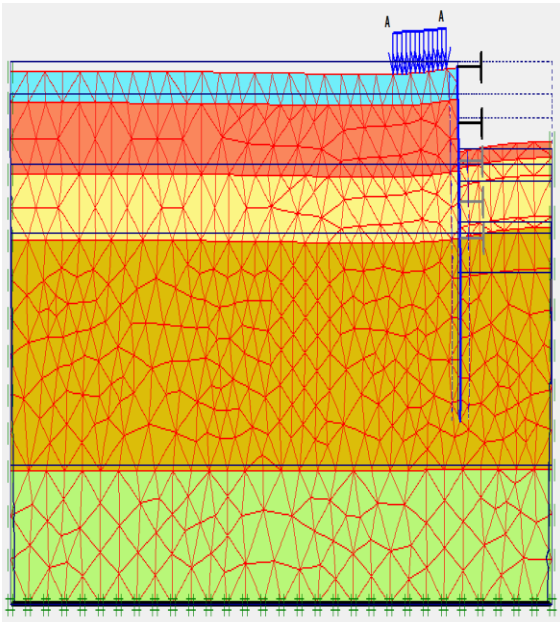

Fig. 10. The displacement of the wall and the soil after phase 3

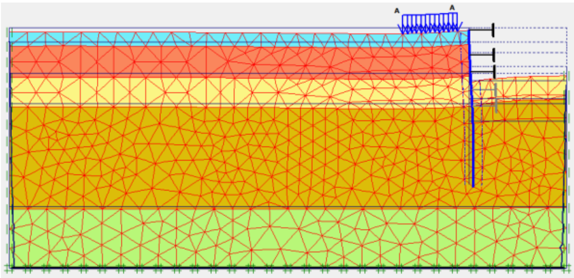

Fig. 11. The displacement of the wall and the soil after phase 4

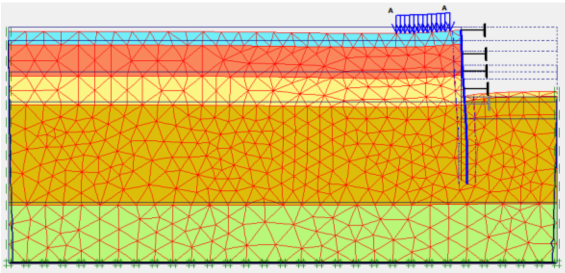

Fig. 12. The displacement of the wall and the soil after phase 5

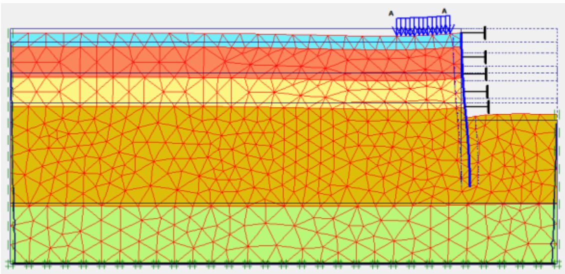

Fig. 13. The displacement of the wall and the soil after phase 6

Tab. 6. Comparison of the largest horizontal displacements from MC model and observation ($E_{ref} = E_{oed}$)

Phase	Mohr-Coulomb (mm)	Inclinometer (mm)	Difference (%)
2	42.48	16.00	62.33
3	64.24	17.86	74.51
4	Soil body collapses	17.80	
5	Soil body collapses	18.50	
6	Soil body collapses	25.17	

Tab. 7. Comparison of the largest horizontal displacements from MC model and observation ($E_{ref} = 5E_{oed}$)

Phase	Mohr-Coulomb (mm)	Inclinometer (mm)	Difference (%)
2	12.80	16.00	-25
3	18.15	17.86	1.6
4	23.74	17.80	25
5	29.56	18.50	37.4
6	40.85	25.17	38.38

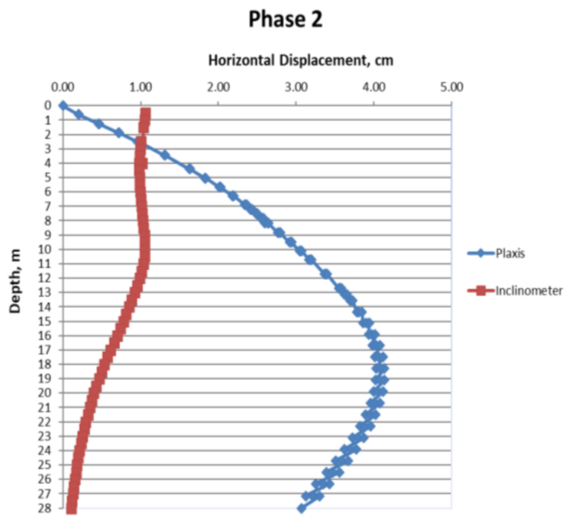

Fig. 14. Horizontal displacements in Phase 2 (Case 1)

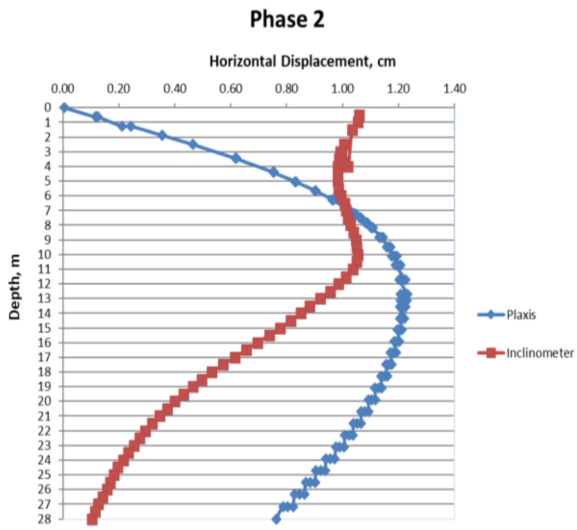

Fig. 15. Horizontal displacements in Phase 2 (Case 2)

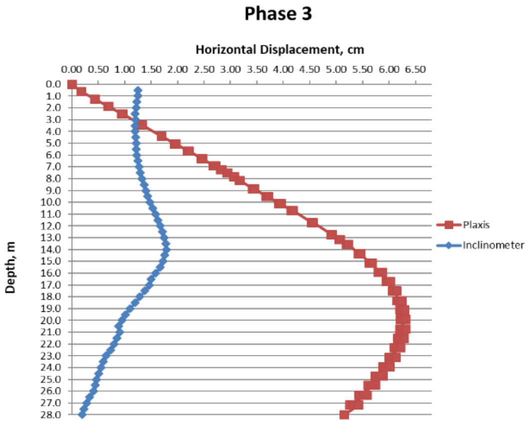

Fig. 16. Horizontal displacements in Phase 3 (Case 1)

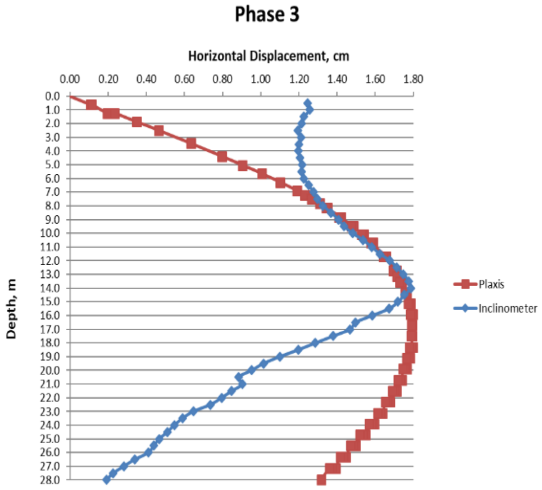

Fig. 17. Horizontal displacements in Phase 3 (Case 2)

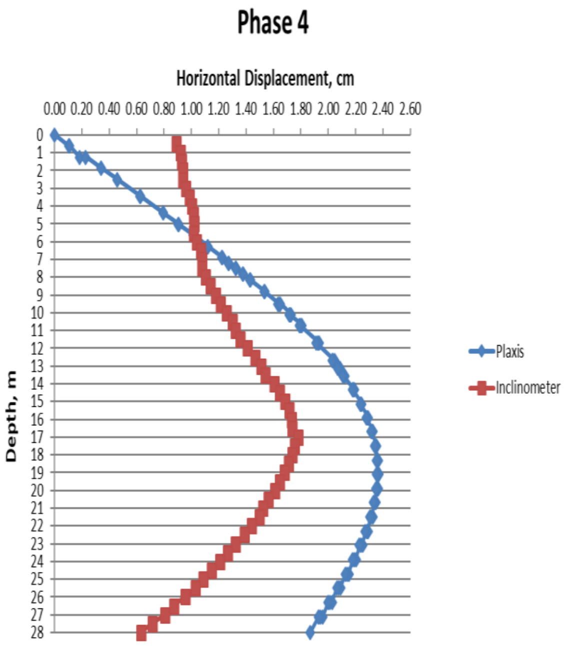

Fig. 18. Horizontal displacements in Phase 4 (Case 2)

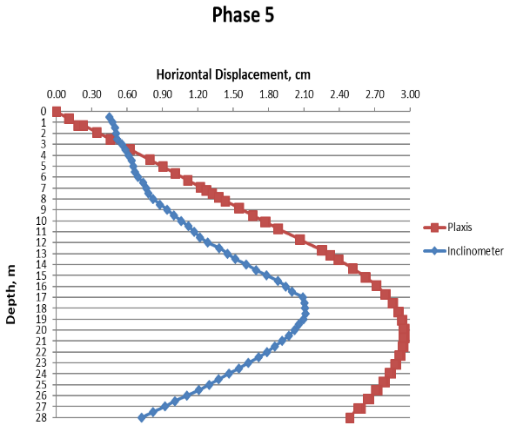

Fig. 19. Horizontal displacements in Phase 5 (Case 2)

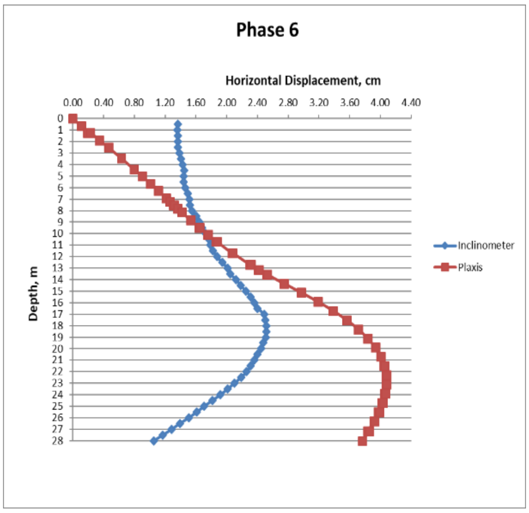

Fig. 20. Horizontal displacements in Phase 6 (Case 2)

Analytical results (Table 6,7; Fig 14-20) show that when changing the E_{ref} value will change the behavior of the soils in the foundation.

The $E_{ref} = E_{oed}$ value incorrectly simulates the displacement of the soil in the foundation pit, leading to the ground being damaged in Phase 4. This is not consistent with the observation results, foundation and retaining walls are stable.

The shape of the deformation graph is also significantly different from the deformation graph of the Inclinometer. When using the $E_{ref} = 5.E_{oed}$, the displacement of the soil in the foundation is more consistent with the actual observation. However, the difference in deformation increased with the depth of the foundation, the shape of the graph is not really consistent with the results of the observation.

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The analysis has demonstrated the influence of the results of the survey to the results of design calculations

4. Conclusion

The analysis results show that the horizontal displacement in the Mohr-Coulomb model is much larger than the Inclinometer observation (average 20 ÷ 40%) and the difference increases with depth. There are differences in horizontal displacement graphs in the two methods. This difference is due to:

- The retaining wall of Plaxis was retained, while the Inclinometer was installed deeper than the wall and fixed, so that the foot of the retaining wall was not displaced as the Mohr-Coulomb model.

- The parameters of the MC model are taken from simple laboratory experiments that do not accurately reflect the actual behavior of the ground.

- MC model is the model of elastic behavior, not showing the process of unloading - reloading of soil during construction.

- The most important parameter for the deep foundation calculation is the E_{ref} obtained from a uniaxial compression test with a constant value of effective stress during the loading process.

Nomenclature

The following symbols are used in this paper

c = cohesion, kN/m^2
E_{ref} = Young's modulus, kN/m^2
MC = Mohr-Coulomb
γ_{sat} = saturated unit weight of material, kN/m^3
γ_{unsat} = unsaturated unit weight of material, kN/m^3
φ = friction angle, ^{o}
ψ = angle of dilation, ^{o}
ν = Poison's ratio

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