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Back calculation of excessive deformation on deep excavation

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Abstract

Excessive lateral deformation occurred during the excavation construction exceeded the design criteria. Scrutiny evaluation should be employed to investigate the factor triggering the problems. The evaluation was conducted using numerical analysis by means of PLAXIS 2D 2011. Back calculation modeling results showed that soil investigation did not capture the field condition properly. The existence of small pound and stream next to the field was not taken into account due to the distance of borehole location. Structural work was proposed to overcome the excessive lateral deformation.

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Keywords: excessive deformation; deep excavation; numerical analysis;

1. Introduction

Deep excavation becomes a necessarily work in infrastructure and building project. Multi stories building should use underground structures for utilization as well as structural purposes. However, deep excavation is critical to both vertical and horizontal ground movement and basal heave as well. They have great influence to adjacent building and its earth structural work. It is therefore deep excavation work requires high precision in design as well as construction process to avoid failure.

The excavation failure can be either total or partial. The collapse of Nicoll Highway MRT is probably the most famous of the total deep excavation failure. It has been extensively investigated and documented. Whittle and his colleagues stated that the use of relatively thin jet grout piles and their specification was a lack along with low shear strength of marine clay to trigger the failure [1, 2]. Ishihara highlighted the requirement of closer spatial distance of

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boring and sounding tests for deep seated deposit to reveal more precision deep soil characteristics [3]. Meanwhile the formal investigation report [4] indicated that the main reasons of failure as described below:

- Under design of the retaining wall.
- Under design of the strut whaler connection.
- Problems with instrumentation and monitoring process causes the incorrect back analysis during construction progress.

Under design that leads to lower factor of safety is typical reason of excavation failure. Three deep excavation failures of soft clay in Taiwan [5], the collapse of deep excavation in sensitive organic clay in Hangzhou, China [6], and two cases of excavation deteriorations in Kuala Lumpur, Malaysia [7] are the examples. They have inappropriate data collected causing misinterpretation of the soil properties. The use of improper soil parameters drives in under design of earth structure

This paper presents the case of the 13 m depth excavation supported by secant piles system. The failure did not yet occur. However, excess lateral deformation has developed on the retaining wall system. Investigation of the reasons and counter measure recommendation is discussed as well.

2. Project description

The construction of the 48 stories multi-purposes building required 12.8 m deep excavation. The site was situated at 120 m x 45 m area. Its layout can be seen in Fig.1. The towers were located in the middle of the site. Meanwhile, three stories basement occupied all the site area. The bottom basement was utilized as raft footing combined with bored pile. It was a single store warehouse building about 50 m from north border. A 3-stories building was neighboring along the South West to the West direction about 20 m from the boundary line. A small pound existed 15 m next to the North West corner continuously draining the water through a small stream along the North border.

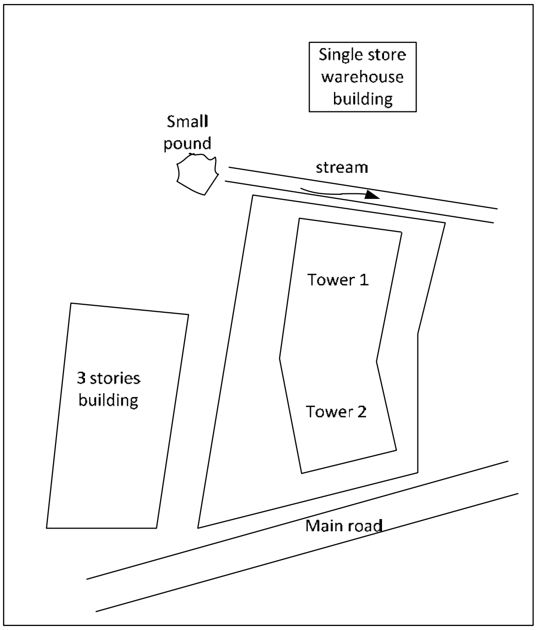


Fig. 1. Layout of the construction site

Four (4) boreholes and six (6) CPT tests were conducted. The location point of the test is presented in Fig.2a. The borehole locations were located along the tower building. The CPT tests were spread out off the borehole space. Fig.2b. and Fig. 2c show the CPT and SPT results respectively. The soil investigation results indicated that three layers were identified. The soft to medium clay existed at 0 – 2 m depth. It was underlain by 13 m medium to stiff clay. This clay can be classified into expansive soil. The last identified stratum was stiff to very stiff clay. The ground water table did not exist along the boring data.

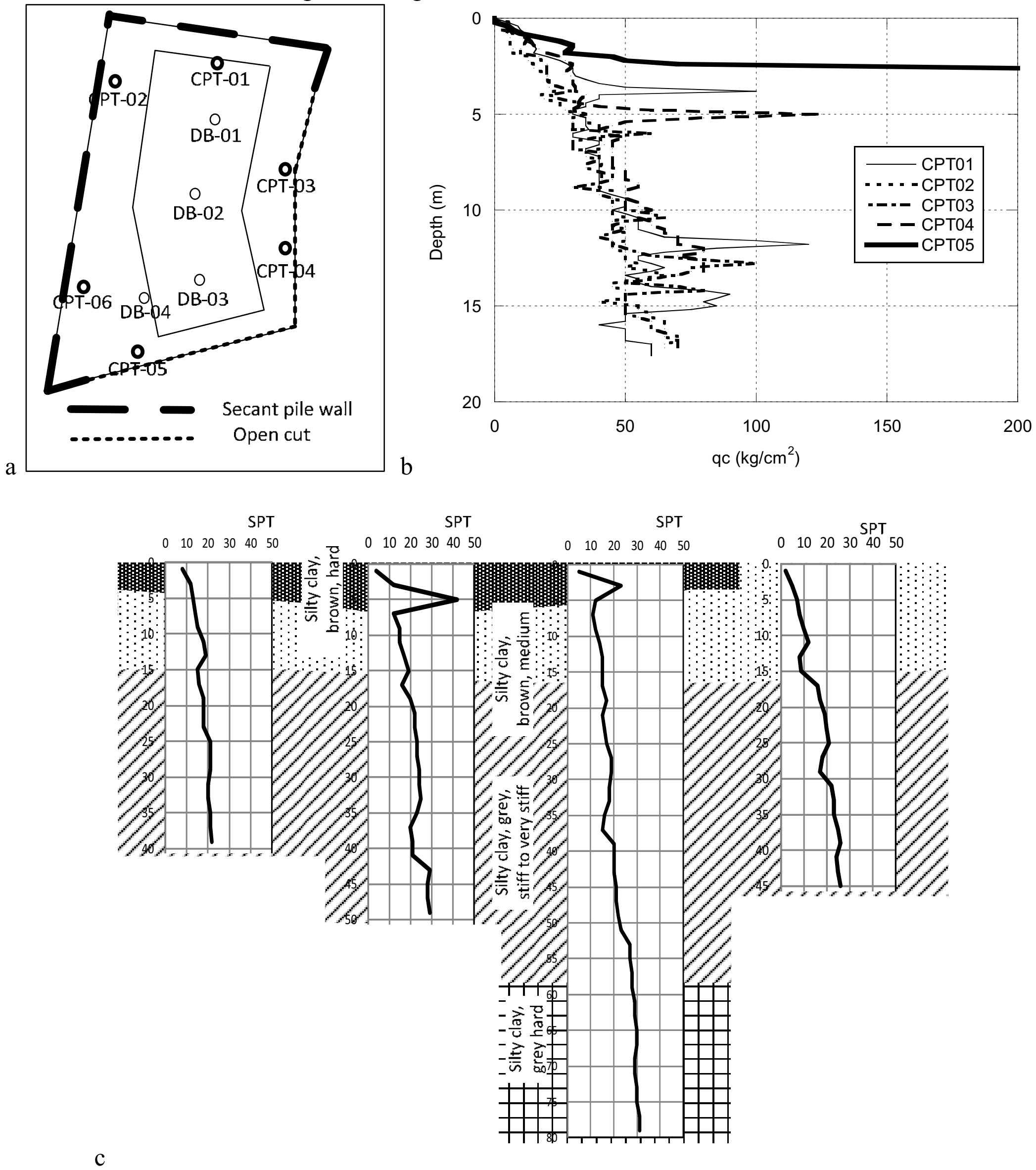


Fig. 2. (a) Location of borehole and CPT tests; (b) CPT results; (c) SPT and borehole results

3. Geotechnical recommendations

Based on the soil condition, the existing geotechnical recommendation related to the deep excavation can be described as follow:

- Excavation in the West and North side required cutting wall. The open cut can be applied in the other sides with the slope of 1.5V : 1H.
- The soldier pile system was recommended. The pile diameter was 800 cm and installed every 1200 cm with 20 m long. The pile should be able to retain minimum 500 kNm bending moment. The maximum design deflection was 120 mm at the top of the pile.
- For first 8 m excavation, a free standing soldier pile system was allowed. 1V:1H Counter front should exist from 8 m depth downward when removal of the ground for the tower was being conducted (Fig.3a.)
- Strut should be constructed before removal of the counter front (Fig. 3.b)
- Strut was permitted to be removed when the construction of the basement wall completed.
- The exposed slope should be immediately covered by minimum 75 mm thick of shotcrete.

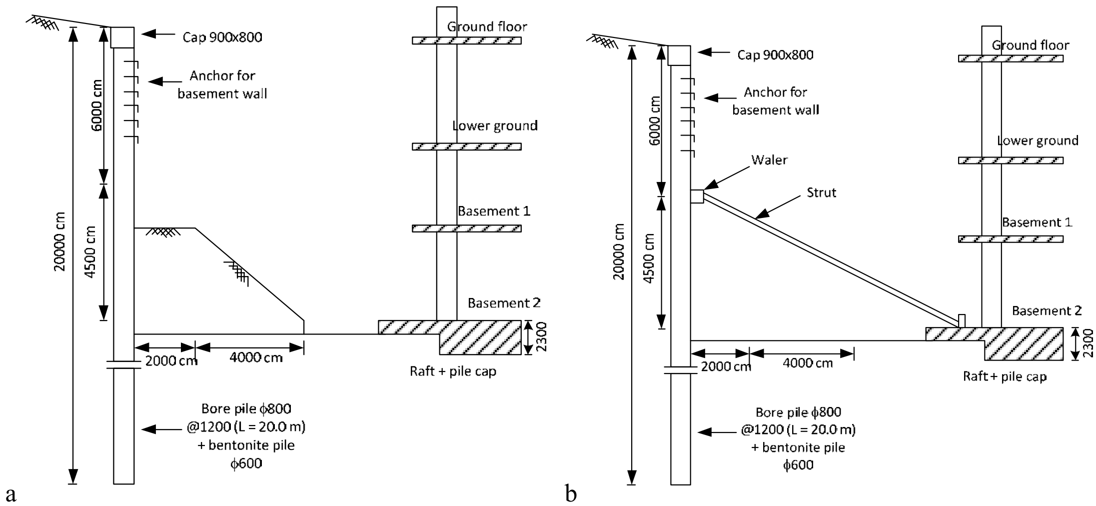


Fig. 3. The cut off wall system: (a) Counter front at 8 m depth; (b) Removal of counter front.

4. What went wrong?

The excavation work was started after soldier pile installation completed. The monitoring sensors were installed at the top of the pile cap according to the layout as described in Fig. 4a. The available monitoring data were started at days 13 after excavation work. The excavation sequence was started from the onset of tower 1 and extended into all direction to get 8 m depth dredging up. The 12.8 depth excavation was conducted by setting the ground counter front along the pile wall. Starting at M6 – M6' was a sloping excavation following arrow direction from – 12.8 m depth at M6 – M6' to ground level at the project boundary.

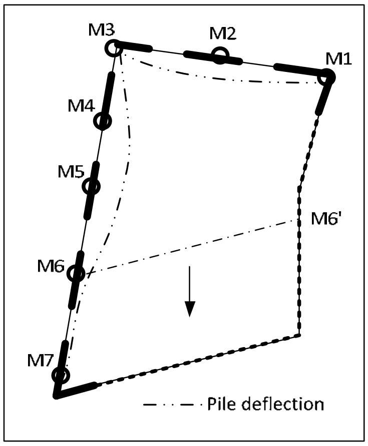
The deflection behavior along the excavation process can be evaluated in Fig.4b. The deflection of the wall exceeded the designed criteria at the middle of the North wall and at the first one-third of the West wall. Even it reached more than twice of the targeted deflection about 30 days afterward. This excessive deformation was a red warning and need a quick counter measure to prevent excavation failure.

5. Back analysis

Excessive lateral deformation of the wall indicated the first stage of the excavation failure. Slow counter measure action can lead to the catastrophic problem. Precise remediation required back analysis based on the recording data of the real condition. Finite element modeling was utilized for back analysis by means of commercial software PLAXIS 2D 2011.

5.1. Soil parameters

Back analysis of the soldier pile wall system was based on finite element analysis. The soil behavior was modeled using Mohr Coulomb model. This model is the simplest one and requires minimum soil parameters. The soil parameter for the existing design based on the soil investigation report is presented in Table 1. The sensitivity analysis based on those parameters was conducted to capture the real deformation in the field.



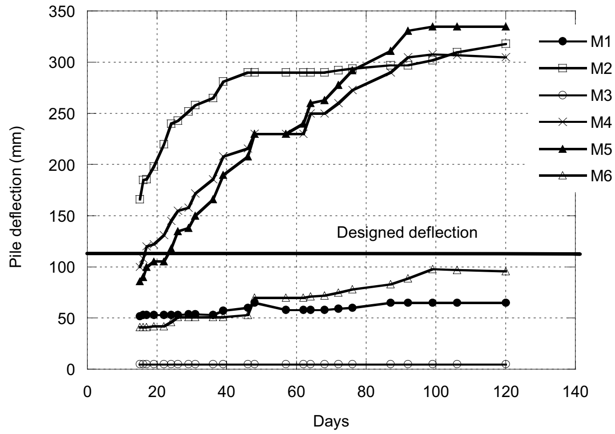


Fig. 4. (a) Monitoring points and deflection plan view; (b) Pile deflection curve.

Table 1. Soil parameters for existing design.

Parameter	Symbol	Layer 1	Layer 2	Layer 3
Name		Soft Clay	Clay	Stiff Clay
Material model		Mohr Coulomb	Mohr Coulomb	Mohr Coulomb
Type of material behavior		Undrained	Undrained	Undrained
Unsaturated unit weight (kN/m^3)	γ_{unsat}	16	16.8	17.2
Saturated unit weight (kN/m^3)	γ_{sat}	17	18	18
Stiffness modulus (kN/m^2)	E	7E3	9E3	12E3
Poisson ratio	υ	0.3	0.35	0.35
Cohesion (kN/m^2)	c	11	21	20
Friction angel (°)	ϕ	12	13	17

5.2. Geometry modeling

Geometrical modeling of the excavation in PLAXIS is presented in Fig.5. The plane strain model was applied with 15 nodes for meshing. The uniform loading was applied to represent the 3 stories building. While fixed strut was installed to prevent continues deformation.

5.3. Model simulation

The simulation was conducted twice. The first was sensitivity analysis to find the appropriate modeling parameters suit to the real deformation. The last one was to find the solution to prevent excessive deformation continuously occurred. Three parameters were utilized for sensitive analysis, namely stiffness modulus, cohesion, and friction angle. The results of the simulation can be seen in Fig.6. The parameters used to obtain field condition in which a 310 mm lateral deformation occurred are described in Table 2. Only layer 1 and layer 2 that significantly have effect of the wall deformation.

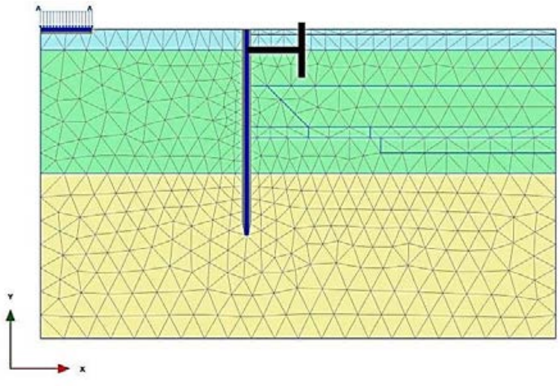


Fig. 5. Geometrical modeling and meshing in PLAXIS

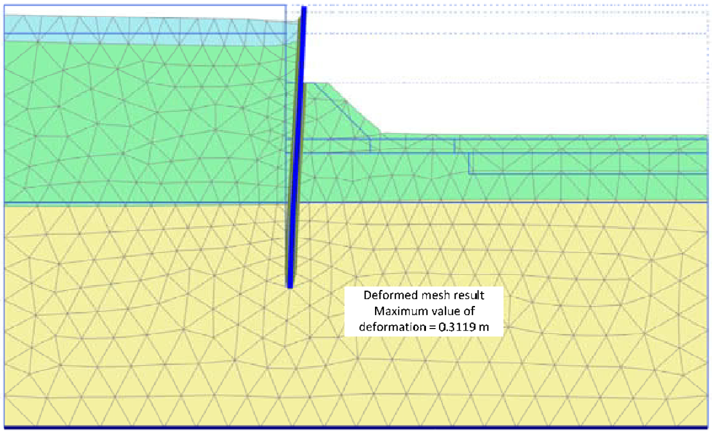


Fig. 6. Back analysis result

Table 2. Soil parameters after back analysis.

Parameter	Symbol	Layer 1	Layer 2	Layer 3
Name		Soft Clay	Clay	Stiff Clay
Stiffness modulus (kN/m^2)	E	2500	6E3	12E3
Cohesion (kN/m^2)	c	10	21	20
Friction angel (°)	ϕ	2	2	17

5.4. Structural counter measure

To prevent continuous deformation, strut is the most favorable structural counter measure. Strut can be installed without time consuming and the material is easily found in the surrounding construction site. The finite element modeling is also utilized to predict the behavior of the excavation system when the strut is installed. The results of the simulation can be examined in Fig.7. It can be seen clearly that the excessive deformation is blocked at about 300 mm. it means that no additional deformation occurs.

6. Discussion

Back analysis simulates condition for different value of stiffness modulus, cohesion, and friction angle. The proper values of those parameters to get the real deformation are less than ones of the soil investigation results. However, those values still comply with the handbook of geotechnical design tables [8]. The very low value of friction angle can be understood as those two layers have very small portion of coarse soil. It means that the soil has no friction angle.

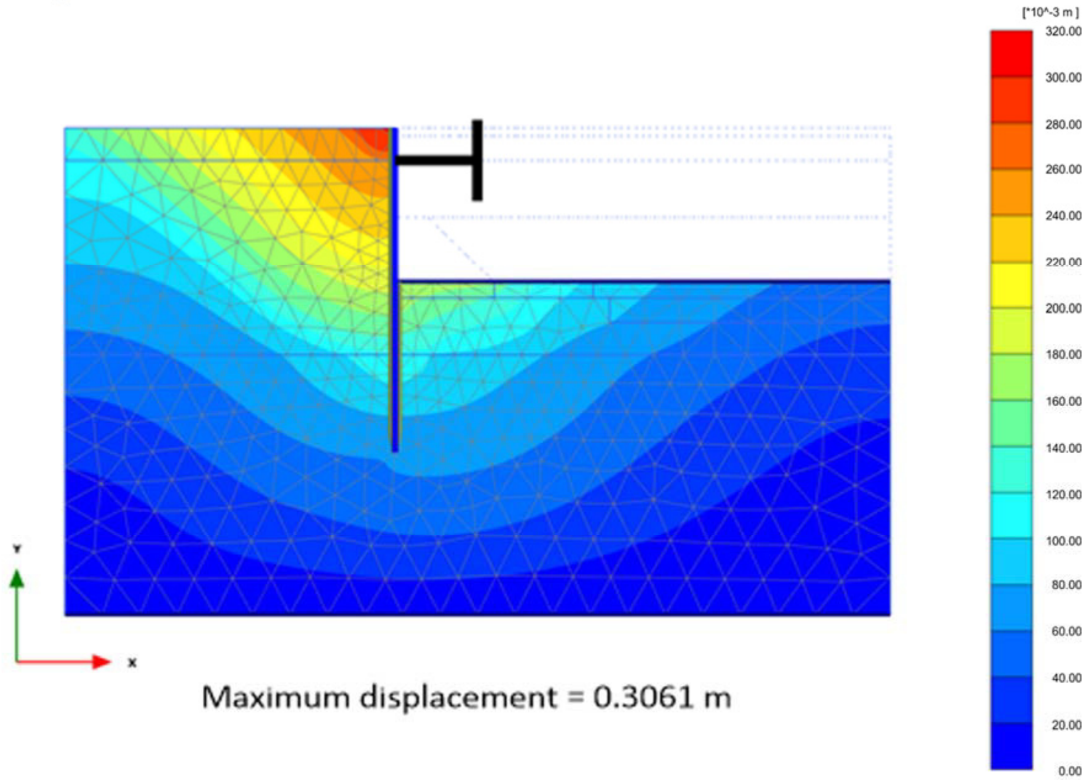


Fig. 7. Displacement distribution after strut installation

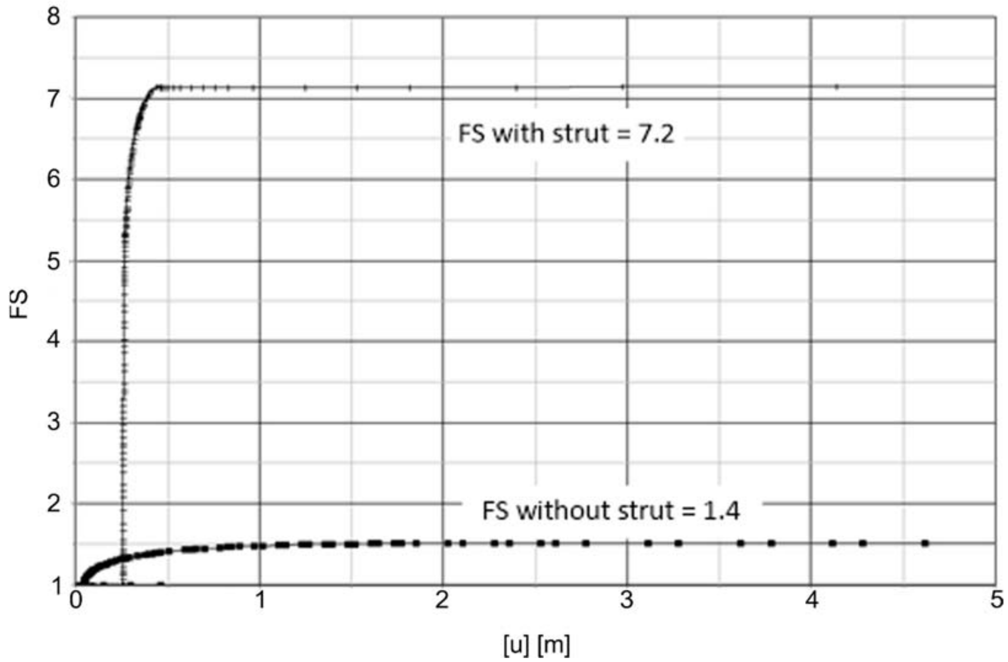


Fig. 8. Factor of Safety FS of the retaining wall system before and after back analysis

The excessive deformation maybe associated with the expansive characteristic of the soil. The water flow from the pound develops swelling effects on the soil that squeeze the wall away of the soil. Moreover, the stream next to the retaining wall will reduce the soil strength significantly. It agrees with the result of the back analysis. The soil investigation results do not capture the effect of water to the soil strength since the point of the field test is relatively far from the pound.

The proposed solution to prevent continuous excessive deformation works well. It can be seen in Fig.8 that safety factor increases significantly when the strut is installed, even with very weak soil parameters. The excessive deformation does not continue to occur. In the field, excessive deformation and strut installation have changed the construction methods. The use of the building column to support the strut requires top down basement construction process (Fig.9). The lower basement should be constructed after the upper basement completed.

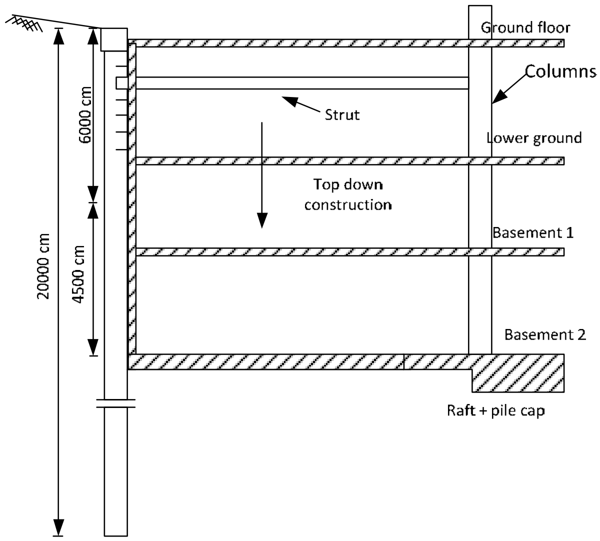


Fig. 9. Top down basement construction process

7. Concluding remarks

Deep excavation requires careful examination when designing the supporting system. The information of the field is very important to interpret the soil investigation report. Lack of combining the field condition and soil investigation report interpretation can lead to construction failure.

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