Analysis of the Effect of the Deep Excavation of a High-Rise Building on the Deformation of the Ground Surface and Diaphragm Wall

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Abstract Study on the influence of the deep excavation by top-down construction method on the deformation of the adjacent ground surface and diaphragm wall has been analyzed in detail for a deep foundation pit of a high-rise building at 27 Lang Ha, Hanoi. The analysis was implemented by the finite element method. The influencing factors such as wall stiffness, wall depth, ground surface load, and initial groundwater level were carefully investigated by applying a parametric study, taking two cases of short-term and long-term working conditions. The simulated results show that the settlement of the ground surface adjacent to the deep excavation depends significantly on the surface load and the initial groundwater level. Under the long-term condition, the calculated ground surface settlement has a larger value than that under the short-term condition. The simulated horizontal displacement and the bending moment of the diaphragm wall depends significantly on the initial groundwater level and the large surface load.

Keywords Deep Excavation · Finite Element · Settlement · Diaphragm Wall · Bending Moment

1 Introduction

Working analysis of a deep foundation pit constructed by top-down method was performed in this study. The selected project for analysis is the 27 Lang Ha building. The foundation pit of the building includes 2 basements, with a depth of 8.9 m. The plan size of the foundation pit is 30 × 40 m. The building consists of 27 floating floors. The construction method in the form of top-down. A typical design cross-section is shown in Fig. 1 [1].

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G. Feng (ed.), *Proceedings of the 9th International Conference on Civil Engineering*, Lecture Notes in Civil Engineering 327,
https://doi.org/10.1007/978-981-99-2532-2_52

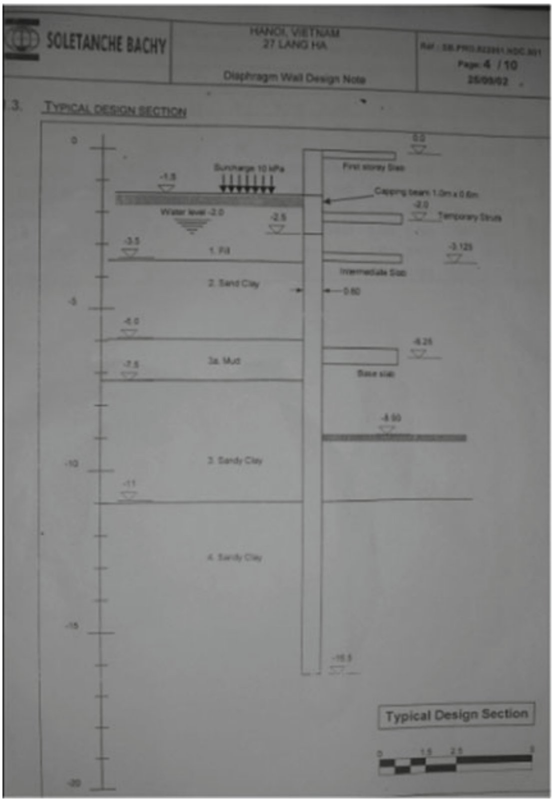


Fig. 1 Typical design section

In order to consider the working of the above-mentioned foundation pit, a parametric study has been implemented in detail considering the influence of factors such as diaphragm wall depth, diaphragm wall stiffness, surface load, and initial groundwater level. The results of numerical simulation analysis, combined with field monitoring data, are the basis for evaluating effective design and construction solutions.

2 Modeling

The finite element method was used to study the problem. The software Plaxis 2D version 8.6 [2] was employed to simulate the problem according to the plane strain problem model.

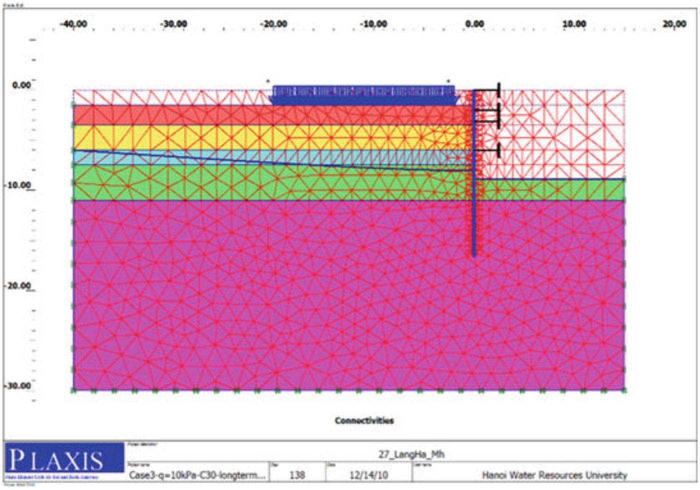


Fig. 2 The simulated section

2.1 Geometry

The analyzed cross section is shown in Fig. 2. A finite element mesh consists of 15 node plane strain elements. The total number of elements is greater than 1000 elements. The number of elements varies depending on the simulation case. Assuming the problem is symmetric, a half of the problem was considered.

2.2 Soil Properties and Initial Groundwater Level

The ground foundation consists of 5 soil layers, from top to bottom, including the filling 1, sandy clay 2, mud 3a, sandy clay 3 and 4. The soil was modelled by Mohr–Coulomb model. The model parameter values are shown in Tables 1 and 2 for short-term and long-term working conditions, respectively. Note that due to incomplete geological data, some parameter values were assumed empirically.

The initial groundwater level is located 2 m below the natural ground (at an elevation of –2.0 m). During the construction of the foundation pit, to ensure that the foundation pit is dry, it is necessary to carry out a suction pump to lower the groundwater level to the bottom of the excavation at each stage.

Table 1 Parameters of Mohr–Coulomb model (short term condition)

Soil and Interfaces Info

Mohr-Coulomb

ID	Name	Type	γ_{unsat} [kN/m^3]	γ_{sat} [kN/m^3]	k_x [m/day]	k_y [m/day]	ν [-]	E_{ref} [kN/m^2]	c_{ref} [kN/m^2]	φ [°]	ψ [°]
1	3a. Mud	UnDrained	16.0	16.0	0.0086	0.0086	0.30	3000.0	15.0	0.0	0.0
2	2. sandy clay	UnDrained	17.5	17.5	0.0864	0.0860	0.25	12000.0	30.0	0.0	0.0
3	3. sandy clay	UnDrained	19.0	19.0	0.0864	0.0864	0.30	18002.0	50.0	0.0	0.0
4	4. sandy clay	UnDrained	19.0	19.0	0.0864	0.0860	0.30	30000.0	85.0	0.0	0.0
5	1. fill	Drained	19.0	19.0	0.0086	0.0086	0.25	15000.0	0.5	25.0	0.0

Table 2 Parameters of Mohr–Coulomb model (long term condition)

Soil and Interfaces Info

Mohr-Coulomb

ID	Name	Type	γ_{unsat} [kN/m³]	γ_{sat} [kN/m³]	k_x [m/day]	k_y [m/day]	ν [-]	E_{ref} [kN/m²]	c_{ref} [kN/m²]	φ [°]	ψ [°]
1	3a. Mud	Drained	16.0	16.0	0.0086	0.0086	0.30	3000.0	0.5	22.0	0.0
2	2. sandy clay	Drained	17.5	17.5	0.0864	0.0860	0.25	12000.0	0.5	24.0	0.0
3	3. sandy clay	Drained	19.0	19.0	0.0864	0.0864	0.30	18002.0	0.5	25.0	0.0
4	4. sandy clay	Drained	19.0	19.0	0.0864	0.0860	0.30	30000.0	0.5	25.0	0.0
5	1. fill	Drained	19.0	19.0	0.0086	0.0086	0.25	15000.0	0.5	25.0	0.0

2.3 Diaphragm Wall and Shoring System

The diaphragm wall is made of cast-in-place concrete, using bentonite solution to support the wall. The concrete has a strength of C30. The wall thickness is 0.6 m. The wall is modelled according to a linear elastic model with parameters given as follows: $E = 2.57 \times 10^7$ kN/m^2, $EA = 1.540 \times 10^7$ kN/m, $EI = 4.626 \times 10^5$ kNm^2/m, $w = 9$ kN/m/m, $\nu = 0.2$. Slabs and temporary struts can be simulated by single-ended anchor struts with stiffness $EA = 3{,}500 \times 10^7$ kN.

2.4 Surface Load

The surface load is assumed to be evenly distributed on the ground with strength $q = 10$ kPa.

2.5 Construction Stages

The construction sequence is assumed as follows:

Stage 1: Construction of the diaphragm wall to a depth of −16.5 m.

Stage 2: Construction of the top slab, then digging the foundation pit to elevation –1.5 m, applying surface load q = 10 kPa.

Stage 3: Digging the foundation pit to the elevation –3.5 m, constructing the middle slab and installing a temporary strut system, pumping to lower the groundwater level to the level of the bottom of the foundation pit.

Stage 4: Digging the foundation pit to elevation –6.0 m, constructing the bottom slab, pumping to lower the groundwater level to the level of the bottom of the foundation pit.

Stage 5: Digging the foundation pit to elevation –8.9 m, pumping to lower the groundwater level to the level of the bottom of the foundation pit.

2.6 Parameter Studies

The influence factors such as diaphragm wall stiffness (C30, C40), diaphragm wall depth (H = 13.5 m, 16.5 m, and 19.5 m), surface load (q = 10,20, 50 kPa), and initial groundwater level (−2.0, −3.5, −6.0 m) were studied in detail. The ground soils were considered with two cases of short-term and long-term conditions, corresponding to undrained and drained geotechnical experimental data, respectively (see Tables 1 and 2). The total number of analyzed cases was 30 cases.

3 Simulation Results and Discussion

3.1 Ground Settlement

The results of calculation of ground settlement at the final excavation stage (stage 5) under short-term working condition are shown in Figs. 3a, b, c with values q = 10, 20 and 50 kPa, respectively. We considered the stiffness of the diaphragm wall by employing concrete grades C30 and C40. The results show that the differences in settlement values simulated with two concrete strengths C30 and C40 are not large.

Similarly, under long-term working condition, the results of simulated ground settlement at the final excavation stage are shown in Fig. 4. The results show that the stiffness of the wall does not significantly affect the settlement of the ground surface. Compared with the simulated settlement values under the short-term condition (Fig. 3), those under the long-term condition have larger values.

Figure 5a and b shows the effect of the depth of the diaphragm wall on the surface settlement at the final excavation stage under short-term and long-term working conditions, respectively. The calculation results reveal that the wall depth does not significantly affect ground surface settlement, especially under short-term conditions.

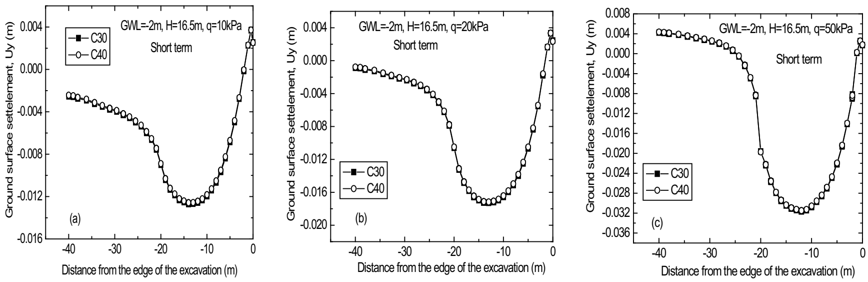


Fig. 3 Effect of wall stiffness on the surface settlement (short term)

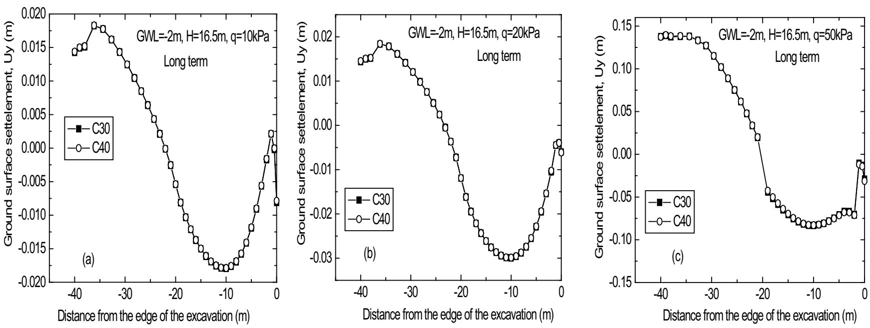


Fig. 4 Effect of wall stiffness on the surface settlement (long term)

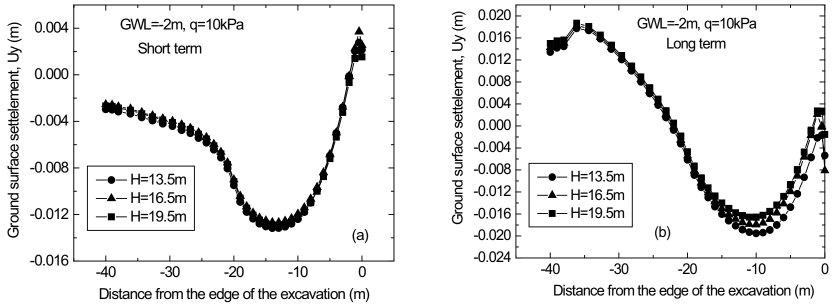


Fig. 5 Effect of depth of diaphragm wall on the surface settlement

The ground surface settlement under the long-term condition (Fig. 5b) is larger than that under the short-term condition (Fig. 5a).

The effect of surcharge load on the surface settlement (final stage) is shown in Figs. 6a and b, respectively, under short-term and long-term working conditions. The calculation results show that the surface load has a significant influence on the ground settlement, especially under short-term conditions (Fig. 6a). The larger the load, the greater the settlement of the ground surface. Under the long-term condition (Fig. 6b), the ground settlement has a larger value than that under the short-term one (Fig. 6a).

Figure 7 shows that the initial groundwater level (GWL) has a significant influence on the ground surface settlement, especially under long-term conditions. The shallower the initial groundwater level, the greater the ground settlement value due to the large distance between the initial groundwater level and the foundation pit bottom elevation. In the long-term condition (Fig. 7b), the ground surface settlement has a larger value than that in the short-term condition (Fig. 7a).

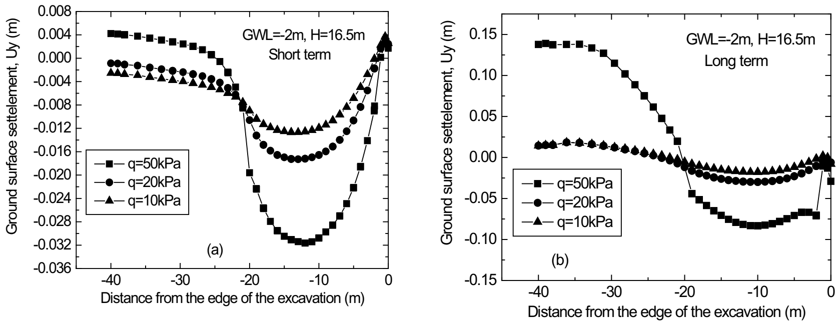


Fig. 6 Effect of surcharge load on the surface settlement

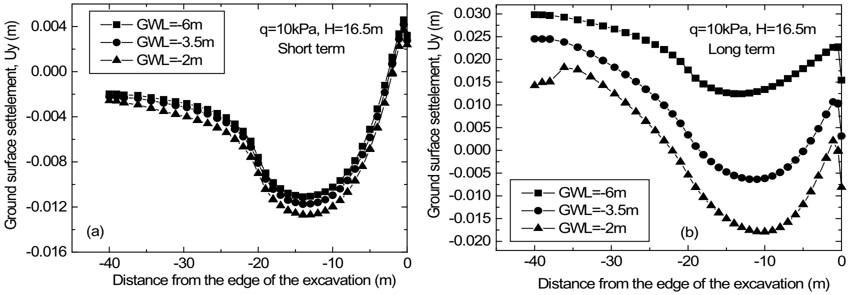


Fig. 7 Effect of initial groundwater level on surface settlement

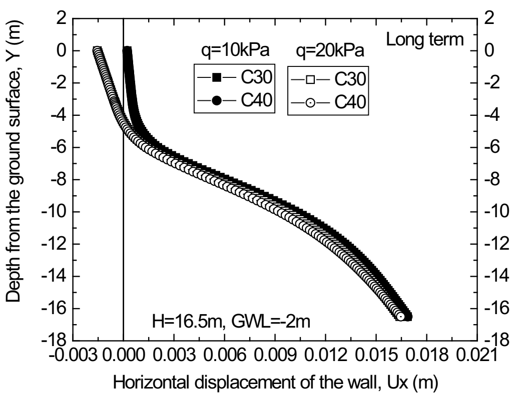
3.2 Diaphragm Wall's Horizontal Displacement

Figure 8 shows that in the comparison of diaphragm walls with different concrete strengths C30 and C40, the concrete strength stiffness has a small influence on the horizontal displacement of the diaphragm wall.

Figure 9 shows that the surface load has a significant effect on the horizontal displacement of the diaphragm wall. However, when the load value is small (q = 10, 20 kPa), there is not too much difference in the horizontal displacement caused by the surface load.

The initial groundwater level has a significant influence on the wall displacement value (Fig. 10) under long-term working conditions. The shallower the initial groundwater level, the larger the horizontal displacement value, especially the wall segment below the elevation of the excavation bottom. It is noted that the horizontal displacement of the diaphragm wall could be reduced if the small strain soil stiffness and its stress state dependency could be taken into consideration.

Fig. 8 Effect of wall stiffness on the horizontal displacement of the diaphragm wall



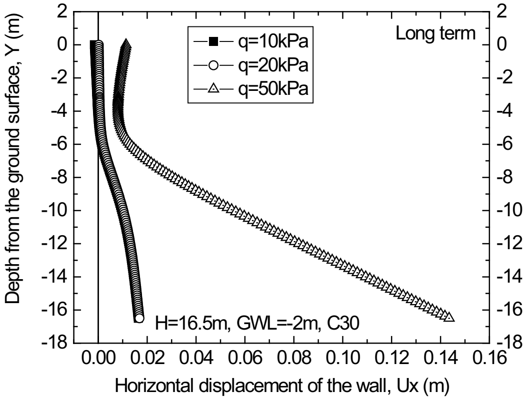


Fig. 9 Effect of surface load on the horizontal displacement of the diaphragm wall

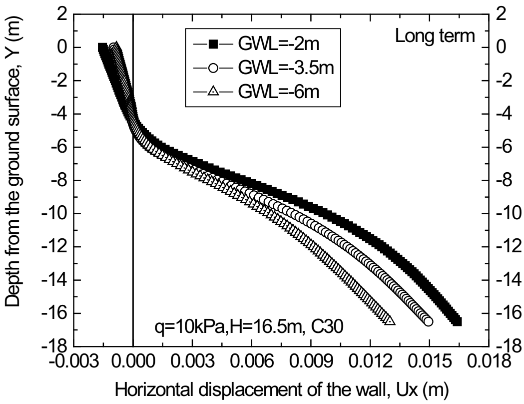


Fig. 10 Effect of initial groundwater level on the horizontal displacement of the diaphragm wall

3.3 Diaphragm Wall's Internal Forces

The results of bending moment in the diaphragm wall at the final construction stage (excavating to the bottom elevation of the foundation pit) are shown in Figs. 11, 12, 13 for the walls with different concrete strengths of C30 and C40. Comparisons are also made considering different surface loads q = 10, 20 and 50 kPa, for both short-term and long-term working conditions. In general, in all comparison cases, the more rigid the wall, the larger the bending moment in the wall. However, the difference in bending moment values is not large for walls with the aforementioned stiffness. The effect of wall stiffness will be further investigated with employing a wider range of strength values.

As can be seen in Fig. 14a, the surface load has a negligible influence on the desired moment value in the wall (C30) under short-term conditions. However, under long-term conditions, a large surface load (q = 50 kPa) has a significant effect on the

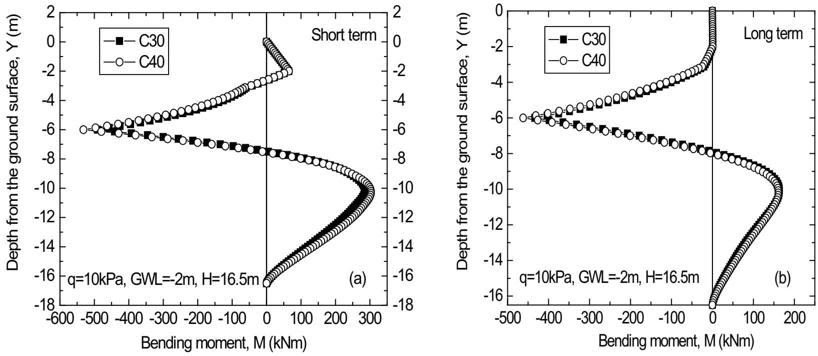


Fig. 11 Effect of the concrete strength of diaphragm wall on the bending moment (q = 10 kPa)

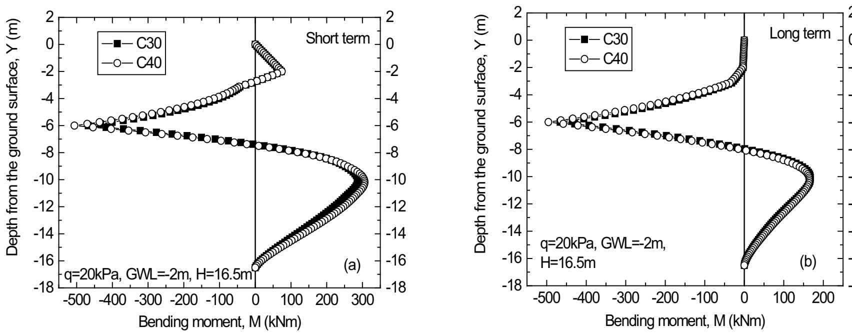


Fig. 12 Effect of the concrete strength of diaphragm wall on the bending moment (q = 20 kPa)

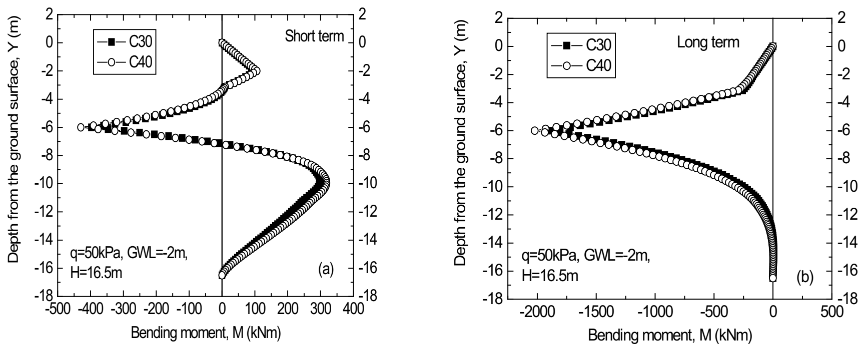


Fig. 13 Effect of the concrete strength of diaphragm wall on the bending moment (q = 50 kPa)

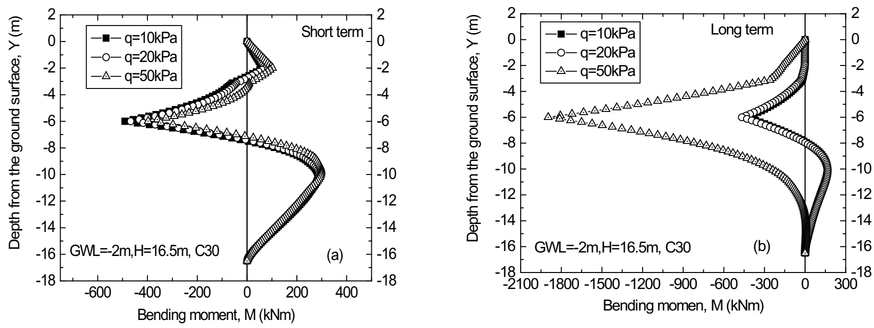
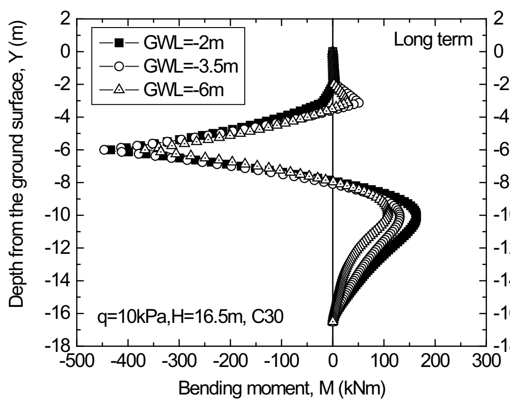


Fig. 14 Effect of surcharge load on the wall bending moment

Fig. 15 Effect of initial groundwater level on the wall bending moment (long term)



bending moment in the wall with the same stiffness (Fig. 14b). The above results are also suitable for walls with greater stiffness (C40).

The influence of the initial groundwater level on the bending moment in the wall is shown in Fig. 15. In general, the shallower the groundwater level, the greater the value of the bending moment in the wall, especially for the part of the wall below the elevation of the bottom of the pit.

4 Conclusions

Study on the influence of the deep excavation of the 27 Lang Ha high-rise building by top-down construction method on the deformation of the adjacent ground surface and the diaphragm wall has been analyzed in detail.

The analysis was implemented by the finite element method, employing the plane strain problem. A parametric study has been carefully analyzed, by considering influencing factors such as wall stiffness, wall depth, ground surface loading, and initial groundwater level, with considering two cases of short-term and long-term ground working. The total number of analyzed cases was 30 cases. Following are the analysis results.

The settlement of the ground surface adjacent to the deep excavation depends significantly on the surface load and the initial groundwater level. In particular, the larger the surface load and/or the shallower the initial groundwater level, the larger the settlement of the ground surface. Under the long-term condition, the surface settlement has a larger value than that under the short-term condition. Within the scope of the present study, the depth and the concrete strength of the diaphragm wall did not largely affect the settlement of the adjacent ground surface.

The horizontal displacement and the bending moment values in the diaphragm wall depends significantly on the initial groundwater level and the large surface load. In general, the shallower the initial groundwater level, the greater the horizontal displacement and the greater bending moment values in the wall, especially the part of the wall located below the bottom elevation of the foundation pit.

References

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