

Semi top-down method combined with earth-bank, an effective method for basement construction.

Tuan B Q ¹, Tam Ng M ²

¹ Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, VietNam

² Faculty of Civil Engineering, Ho Chi Minh City University of Technology, Ho Chi Minh City, VietNam

buiquangtuan@tdt.edu.vn (Tuan B Q)

Abstract. Choosing an appropriate method of deep excavation not only plays a decisive role in technical success, but also in economics of the construction project. Presently, we mainly base on to key methods: “Bottom-up” and “Top-down” construction method. Right now, this paper presents an another method of construction that is “Semi Top-down method combining with earth-bank” in order to take the advantages and limit the weakness of the above methods. The Bottom-up method was improved by using the earth-bank to stabilize retaining walls instead of the bracing steel struts. The Top-down method was improved by using the open cut method for the half of the earthwork quantities.

1. Introduction:

The author's article limits the analysis from the Dung Tien contractor experience with deep excavation pits in HoChiMinh city and graduate thesis in HoChiMinh city University of Technology.

Nowadays, with high-speed development of major city, constructing high-rise buildings which has basements in inbuilt condition is exigent. Basement Construction Units meet two main difficulties in choosing construction method: *high cost for retaining the excavation and complicated excavation procedure in enclosed space*.

From manufactured reality, in order to improve these two difficulties, the authors propose “Semi Top-down combined with Earth-bank construction method”: use open cut method for half of earthwork quantities and stabilize excavation's retaining walls with Earth-bank instead of internal bracing struts.

2. Summary about two popular basement construction methods:

Nowadays, there are two main methods for constructing basements: Bottom-up and Top-down. The following are explanations and some observations of the two methods:



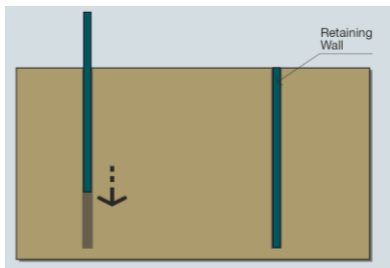


Figure 1. Stage 1- Installation of Retaining walls

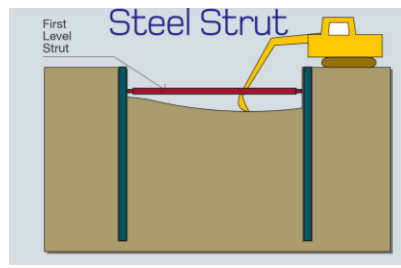


Figure 2. Stage 2- Excavation and bracing steel strut installation

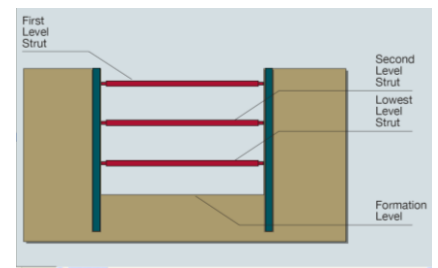


Figure 3. Stage 3- Excavation and bracing steel strut installation

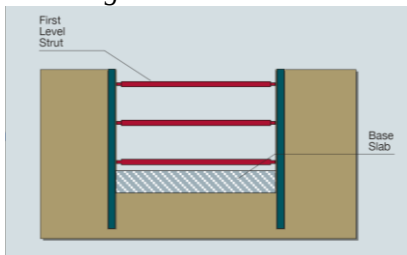


Figure 4. Stage 4 - Substructure construction.

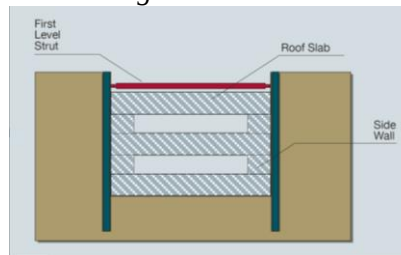


Figure 5. Stage 5- Substructure construction

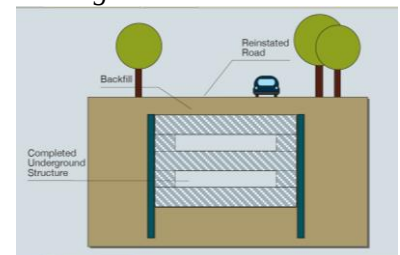


Figure 6. Stage 6- Backfilling and superstructure construction

- Stage 1- Installation of Retaining walls: Retaining walls are installed before excavation commences. Depending on site condition, soil type and excavation depth, retaining walls can be concrete walls, concrete bored piles or steel sheet pile walls.
- Stage 2- Excavation and bracing steel strut installation: The soil is excavated to the first strut level. The first level struts must be installed before excavation proceeds further
- Stage 3- Excavation and bracing steel strut installation: The soil is excavated to the next strut level and second level struts are installed. This process progresses until it reaches the final depth or formation level. The number of strut levels depends on the excavation depth
- Stage 4- Substructure construction: At formation level, base slab is constructed, then the lowest level struts are removed and side walls are constructed.
- Stage 5- Substructure construction: Next basement level slab is constructed and the struts at that level are removed. This process progresses upwards until roof slab of the basement is constructed.
- Stage 6- Backfilling and superstructure construction: After finishing roof slab construction, the soil is backfilled to the first strut level before removing first level struts or continuing superstructure construction.

2.1 Bottom-up construction method:

This method is popular and simple in design and construction. Excavation depth requirement depends on foundation base depth and lowest basement's floor level. After the soil was excavated, the building is constructed from the bottom or the lowest level of basement to the top (from foundation to roof).

While shallow cutting excavations can be stabilized by natural earth-bank, deeper excavations at narrow construction sites (inbuilt condition) require using retaining walls (concrete walls, concrete bored piles, steel sheet piles walls...) combined with internal horizontal section steel struts for ground stabilizing in construction process.

a. Construction procedure:

b. Advantages:

- Open cut method: simpler than other earthwork construction methods.
- Giving facilities for lowering groundwater level and constructing foundation.
- Basement waterproofing and technology infrastructure installation are more convenient.

c. Disadvantages:

- In inbuilt condition, it will be very hard to obtain required excavation depth and could cause adverse effects to adjacent buildings if the top soil layer is soft.
- The cost for resisting horizontal displacement along excavation boundary is high. This is also the major disadvantage.



Figure 7.
Excavation and
bracing steel
strut installation
in Bottom-up
method

2.2 Top-down construction method:

This method assumes, that retaining walls (usually concrete walls), and bored piles are constructed firstly. Temporary support piles (section steel piles) and bored piles are simultaneously installed at roof slab level. After that basement floor beams are constructed on top of temporary raking struts. Natural soil surface is used as floor beam formwork. According to this, the soil is excavated to just below basement roof slab level with retaining walls and horizontal bored struts, which is necessary for high height basements. Stairwells are used for excavation and soil transportation from lower floors. After constructing formation level slab, side walls are constructed (or retaining walls are also used as side walls), and horizontal bored struts are removed. The access openings on the roof slab are sealed when superstructure is constructed. The basement will continue to be constructed along with superstructure construction.

a. Construction procedure:

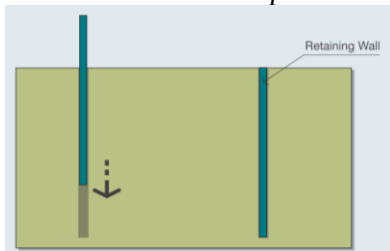


Figure 8. Stage 1- Installation of retaining walls

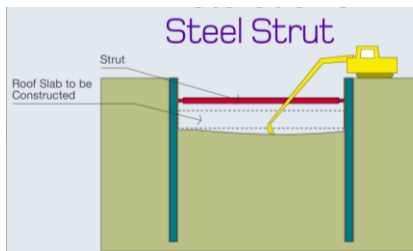


Figure 9. Stage 2- Excavation and steel bored strut installation

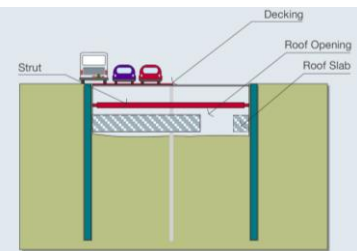


Figure 10. Stage 3- Substructure construction

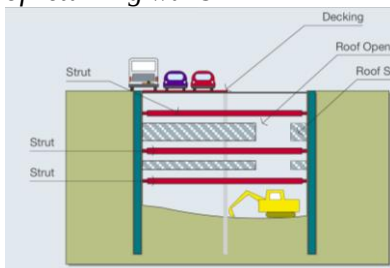


Figure 11. Stage 4- Substructure construction.

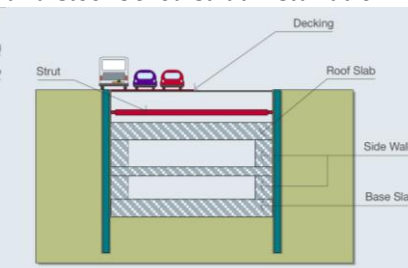


Figure 12. Stage 5- Substructure construction

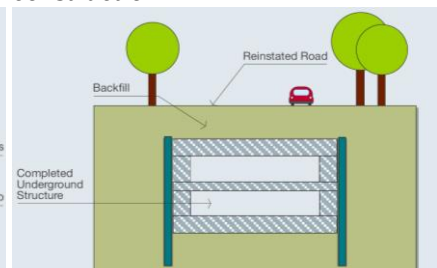


Figure 13. Stage 6- Backfilling and superstructure construction

- Stage 1- Installation of retaining walls: The retaining walls, which are usually concrete walls, is installed before excavation commences.
- Stage 2- Excavation and steel bored strut installation: The soil is excavated to just below roof slab level. Bracing struts are installed to retain the soil at the sides (when basement height is high).
- Stage 3- Substructure Construction: Roof slab and roof openings are constructed in order to proceed downwards. Roof slab not only resists horizontal displacement but also reduces the noise in construction progress
- Stage 4- Substructure Construction: This process progresses downwards until base slab is constructed. The operations on roof slab can keep working normally due to decking systems.
- Stage 5- Substructure Construction: The side walls are constructed upwards, after removal of struts between level slabs. Then the access openings are sealed.
- Stage 6- Backfilling and superstructure construction: After constructing basement, the soil is backfilled to the top strut level (for Metro station) before these struts are removed or superstructure construction is proceeded (for high-rise building).

b. Advantages:

- Economize scaffolds, struts and formwork frames by using natural soil surface.
- Use structural slabs for resisting horizontal displacement of retaining walls.
- Superstructure and basement construction can be simultaneously progressed due to pillar support.

c. Disadvantages:

- Support pillar designing process is more complicated: these pillars have to bear not only up loads but also different lateral loads in each stage of construction process, and also subordinate to computational scheme of the whole building.
- Detailing and constructing the connections for columns, beams and walls are more complicated.
- Sanitary facilities and labor safety conditions is hard to obtain (lighting, ventilation...).
- This semi-mechanical excavation mostly take place in enclosed spaces, therefore this method can only be used at soft soil layer sites.



Figure 14. Kingpost (Decking) in Top-down method.



Figure 15. Access openings for excavating in Top-down method.

3. Proposal of improving method:

In order to take advantage of the strengths and improve the disadvantages of these two methods, the authors propose to apply “Semi Top-down method combined with Earth-bank” in construction of a specific project: Sacombank building, 266 Nam Ky Khoi Nghia, District 3, Ho Chi Minh city.

- Improvement from Bottom-up method: Earth-bank is used to stabilize retaining walls instead of bracing section steel struts.
- Improvement from Top-down method: Using open cut method for half of the earthwork quantities.

3.1 Construction progress based on Semi Top-down method combined with Earth-bank:

Presentation of the construction process:

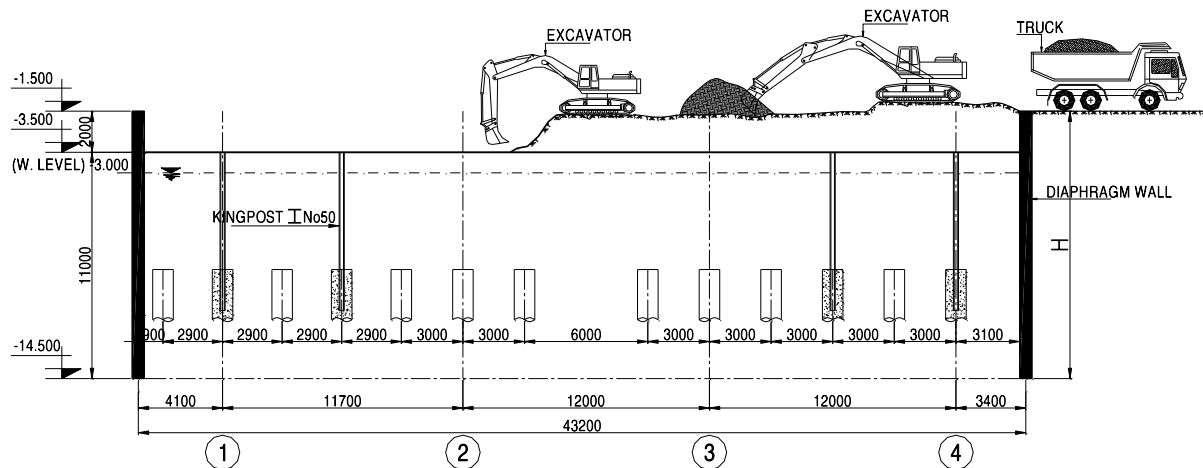


Figure 16. Stage 1: The soil is excavated to first basement slab's bottom

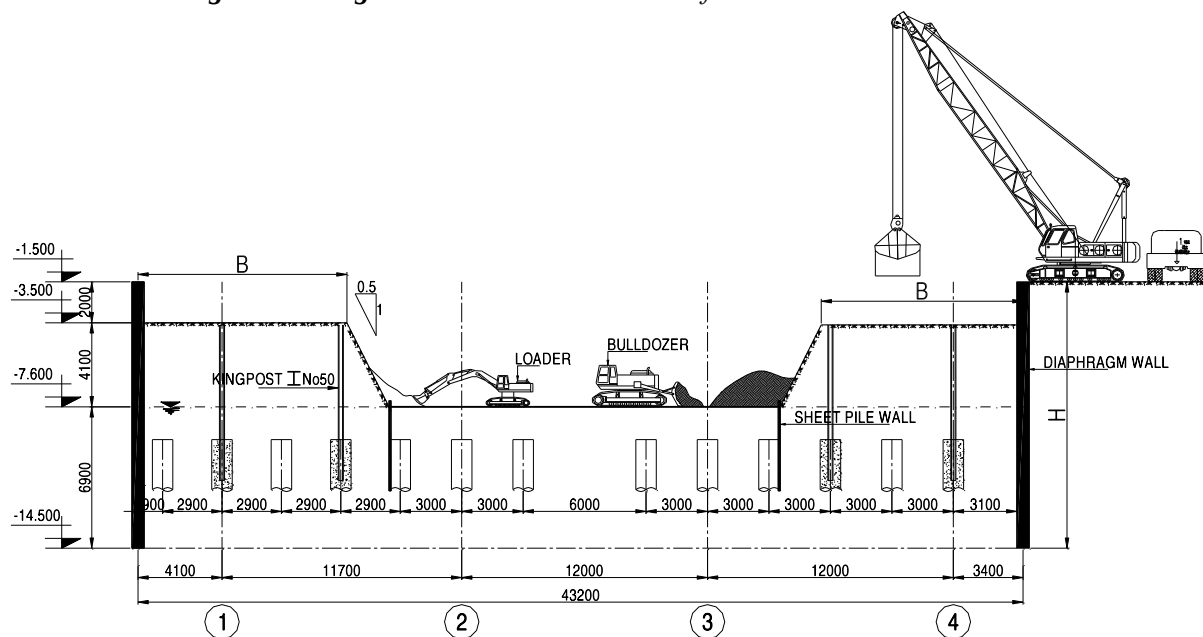


Figure 17. Stage 2: Partially excavating and simultaneously lowering the water level to -7.600m. Stabilize the earth-bank and foundation pit using earth-bank and steel sheet wall (instead of bracing struts).

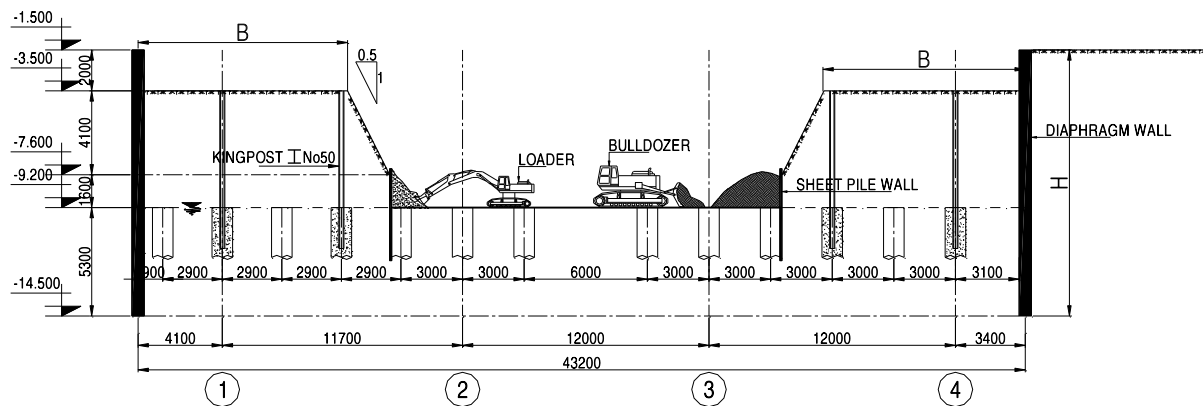


Figure 18. Stage 3: Excavated and groundwater level was lowered to formation level at -9.200m.

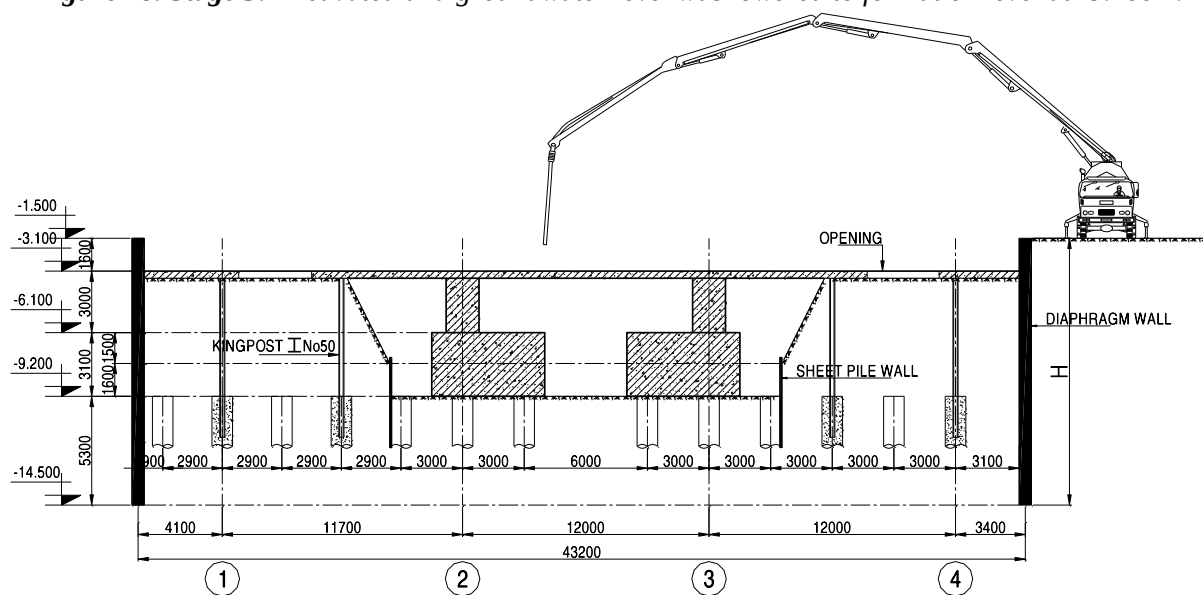


Figure 19. Stage 4: Constructing foundation and 1st basement floor slabs.

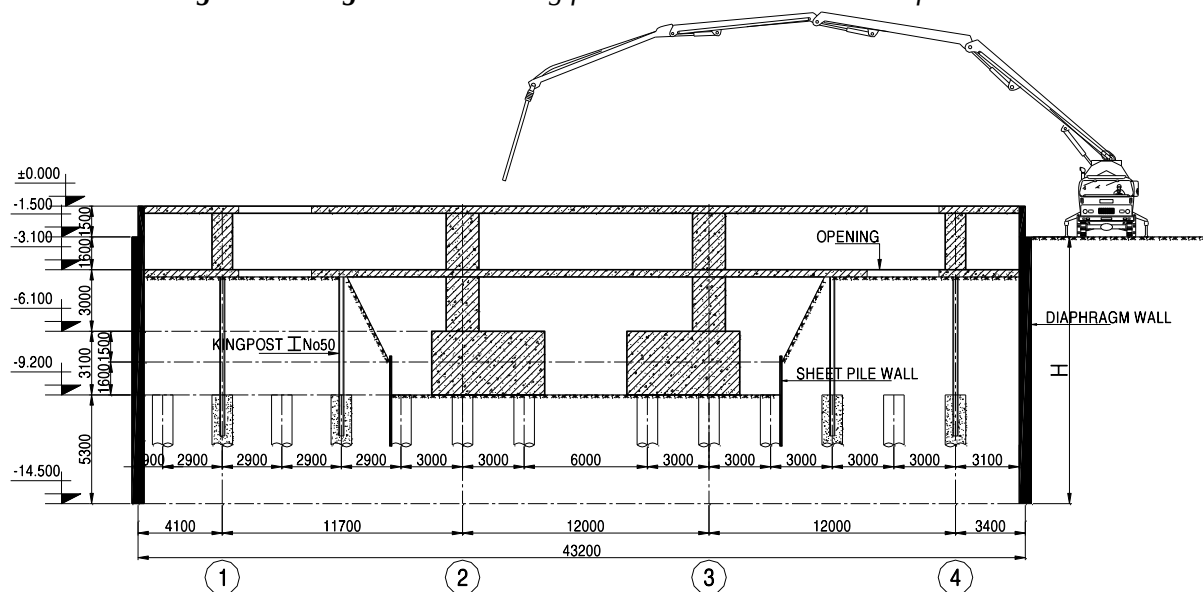


Figure 20. Stage 5: Constructing ground floor slabs.

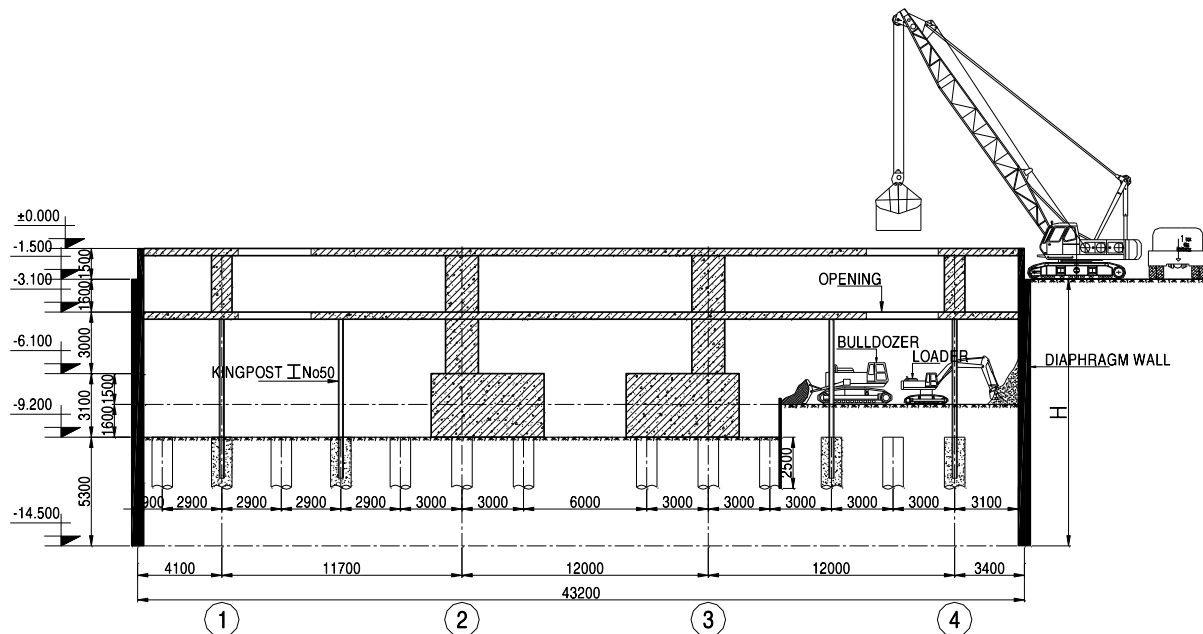


Figure 21. Stage 6: Excavating the rest of soil to formation level.

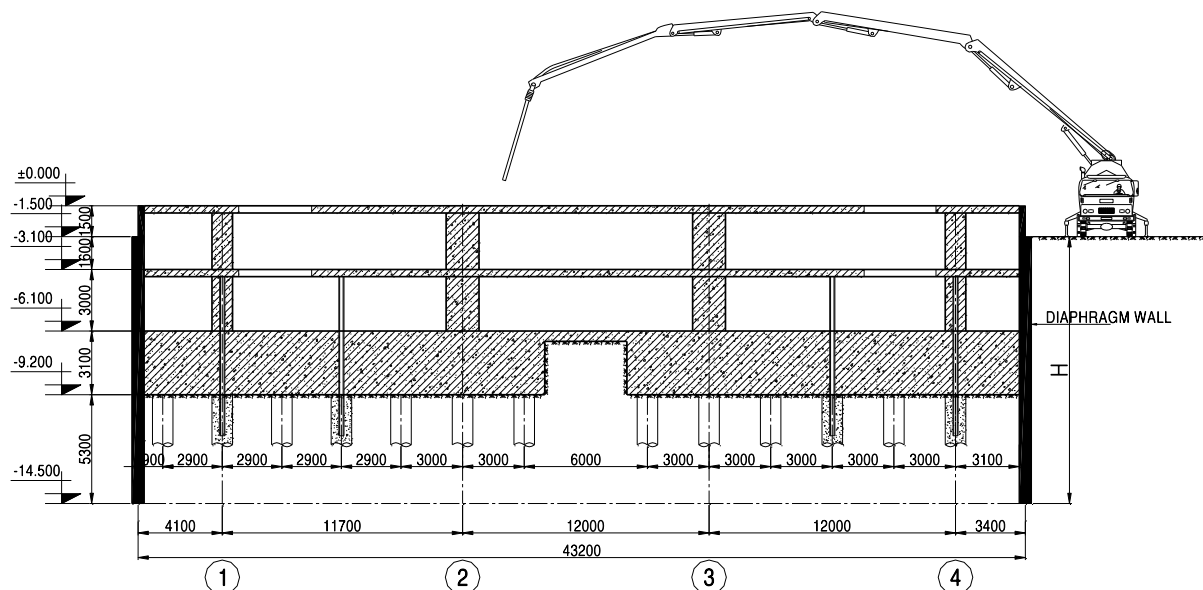


Figure 22. Stage 7: Constructing foundation beams, the rest of foundation and 2nd basement floor slabs

3.2 Observations:

Through construction process, the authors realized that the stability of adjacent soil depends on the stability of side walls (or how deep that side walls were embedded). Along with that, earth-bank also helps to resist horizontal displacement of side walls and behaves as a gravity wall, so its stability depends on its own width (or B: earth-bank top width 0.5:1). Besides, steel sheet piles encompassed foundation pits will keep the earth-bank from bulging while the foundation is constructed.

These components formed a simultaneously operative system. It's very hard to explain exactly the behavior this structural system using explanation and theory for simplifying and fragmenting it. So in order to have the precise results in each construction period, the writer proposes using Finite Element Method (FEM) in Plaxis 7.2 to simulate the simultaneous operation of this structural system.

4. Calculation for construction method:

4.1 Material properties of soil model and components:

a. Properties of subgrade soil in Hardening-soil model:

Hardening-soil model is selected because it has the ability to distinguish between compression rigidity and dilatancy of soil. So it is compatible for simulating the process of excavation.

Table 1. Properties of subgrade soil in Hardening-soil model.

Parameter	Name	Layer 1 (SC)	Layer 2 (CH)	Layer 3a (SM/SW)	Layer 3b (SM/SW)	Layer 4 (CH)	Unit
Material model	<i>Model</i>	HS	HS	HS	HS	HS	-
Type of material behaviour	<i>Type</i>	<i>UnDr.</i>	<i>UnDr.</i>	<i>Drained</i>	<i>Drained</i>	<i>UnDr.</i>	-
Dry soil weight	γ_{dry}	22.80	22.70	20.90	20.50	20.70	kN/m ³
Wet soil weight	γ_{wet}	22.85	22.75	20.98	21.34	20.76	kN/m ³
E_{50}^{ref} (for $p_{ref} = 100$ kPa)	E_{50}^{ref}	4950	7600	5075	6125	10050	kN/m ²
E_{ur}^{ref} (for $p_{ref} = 100$ kPa)	E_{ur}^{ref}	14850	22800	14625	18375	30150	kN/m ²
E_{oed}^{ref} (for $p_{ref} = 100$ kPa)	E_{oed}^{ref}	4950	7600	6650	6125	10825	kN/m ²
Cohesion	c'	28.3	50	1.4	0.5	80.5	kN/m ²
Friction angle	ϕ'	18	20	34.53	33.58	18.75	°
Dilatancy angle	ψ	0	0	4.53	3.58	0	°
Lateral stress coefficient	K_0^{nc}	0.69	0.71	0.43	0.45	0.68	-
Poisson's ratio	ν_{ur}	0.2	0.2	0.2	0.2	0.2	-
Interface reduction factor	R_{inter}	0.7	0.7	0.7	0.7	0.7	-

Table 2. Properties of Diaphragm wall.

Structural element	Paramater	Name	Value	Unit
Diaphragm wall (plate)	Type of behaviour	<i>Material type</i>	Elastic	-
	Normal stiffness	<i>EA</i>	$1.86 \cdot 10^7$	kN/m
	Flexural rigidity	<i>EI</i>	$5.58 \cdot 10^5$	kNm ² /m
	Equivalent thickness	<i>d</i>	0.6	m
	Weight	<i>w</i>	8	kN/m/m
	Poisson's ratio	<i>v</i>	0.2	-

Table 3. Properties of steel sheet pile walls around foundation pits.

Structural element	Paramater	Name	Value	Unit
Sheet pile wall	Type of behaviour	<i>Material type</i>	Elastic	-
	Normal stiffness	<i>EA</i>	$1.97 \cdot 10^6$	kN/m
	Flexural rigidity	<i>EI</i>	$1.15 \cdot 10^5$	kNm ² /m
	Poisson's ratio	<i>v</i>	0.3	-

Table 4. Properties of basement slabs.

Structural element	Paramater	Name	Value	Unit
Basement slabs	Type of behaviour	<i>Material type</i>	Elastic	-
	Normal stiffness	<i>EA</i>	$1.09 \cdot 10^7$	kN/m
	Flexural rigidity	<i>EI</i>	$1.11 \cdot 10^5$	kNm ² /m
	Equivalent thickness	<i>d</i>	0.35	m
	Weight	<i>w</i>	8.75	kN/m/m
	Poisson's ratio	<i>v</i>	0.2	-

Table 5. Properties of concrete columns.

Structural element	Paramater	Name	Value	Unit
Concrete columns	Type of behaviour	<i>Material type</i>	Elastic	-
	Normal stiffness	<i>EA</i>	$6.98 \cdot 10^7$	kN
	Spacing out of plane	<i>L_s</i>	8	m
	Maximum force	<i>F_{max}</i>	$3.49 \cdot 10^4$	kN

Table 6. Properties of King post.

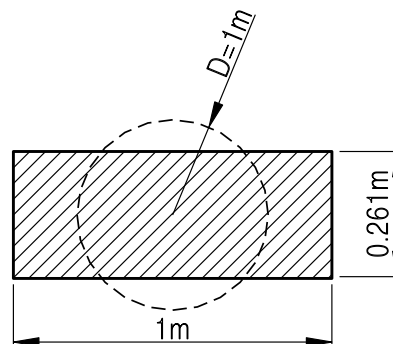
Structural element	Paramater	Name	Value	Unit
King post (Decking)	Type of behaviour	<i>Material type</i>	Elastic	-
	Normal stiffness	<i>EA</i>	$2.1 \cdot 10^8$	kN
	Spacing out of plane	<i>L_s</i>	8	m
	Maximum force	<i>F_{max}</i>	$2.3 \cdot 10^5$	kN

Table 7. Properties of foundation footings.

Structural element	Paramater	Name	Value	Unit
Foundation footing	Type of behaviour	<i>Material type</i>	Elastic	-
	Type of material behaviour	<i>Type</i>	Non-porous	-
	Unit weight	γ	25	kN/m ³
	Young's Modulus	<i>E</i>	$3.1 \cdot 10^7$	kN/m ²
	Poisson's ratio	ν	0.2	-

Table 8. Properties of bored pile.

Structural element	Paramater	Name	Value	Unit
Bored pile	Type of behaviour	<i>Material type</i>	Elastic	-
	Type of material behaviour	<i>Type</i>	Drained	-
	Unit weight	γ	25	kN/m ³
	Permeability	$k_x=k_y$	0.05	m/day
	Young's Modulus	<i>E</i>	$3.1 \cdot 10^7$	kN/m ²
	Poisson's ratio	ν	0.2	-

**Figure 23.** Equivalent sections in 2-D of bored pile.

Construction plants load is converted to equivalent load $q=10\text{KN/m}^2$.

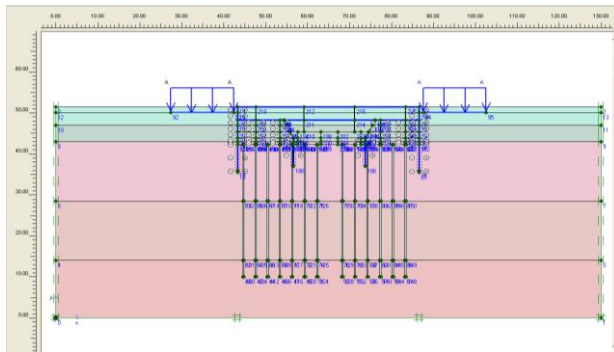


Figure 24. Calculation model in Plaxis.

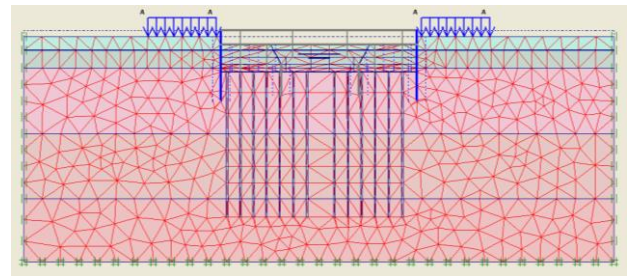


Figure 25. Stage 1: The soil is excavated to first basement slab's bottom

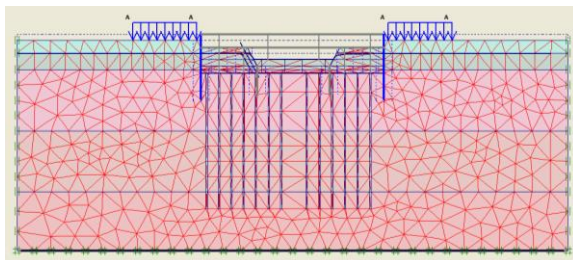


Figure 26. Stage 2: Partially excavating and simultaneously lowering the water level to -7.600m. Stabilize the earth-bank and foundation pit using earth-bank and steel sheet wall

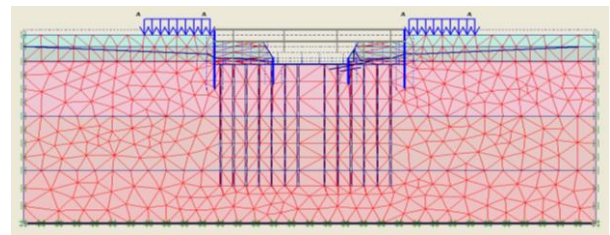


Figure 27. Stage 3: The soil was excavated and groundwater level was lowered to formation level at -9.200m.

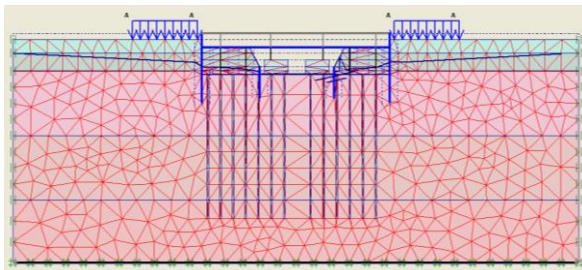


Figure 28. Stage 4: Constructing foundation and 1st basement floor slabs

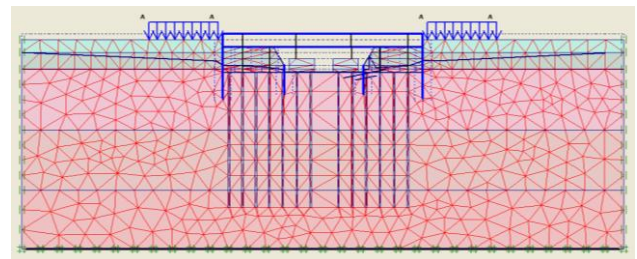


Figure 29. Stage 5: Constructing ground floor slabs

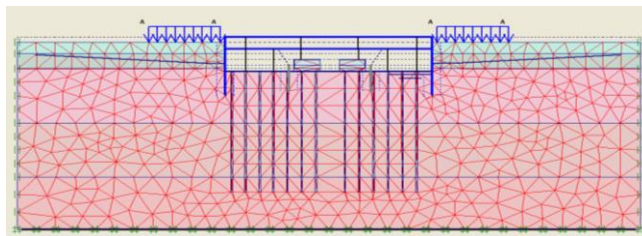


Figure 30. Stage 6: Excavating the rest of soil to formation level

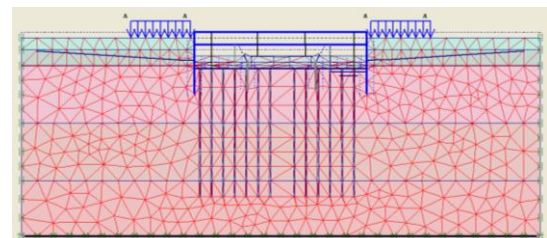


Figure 31. Stage 7: Constructing foundation beams, the rest of foundation and 2nd basement floor slabs

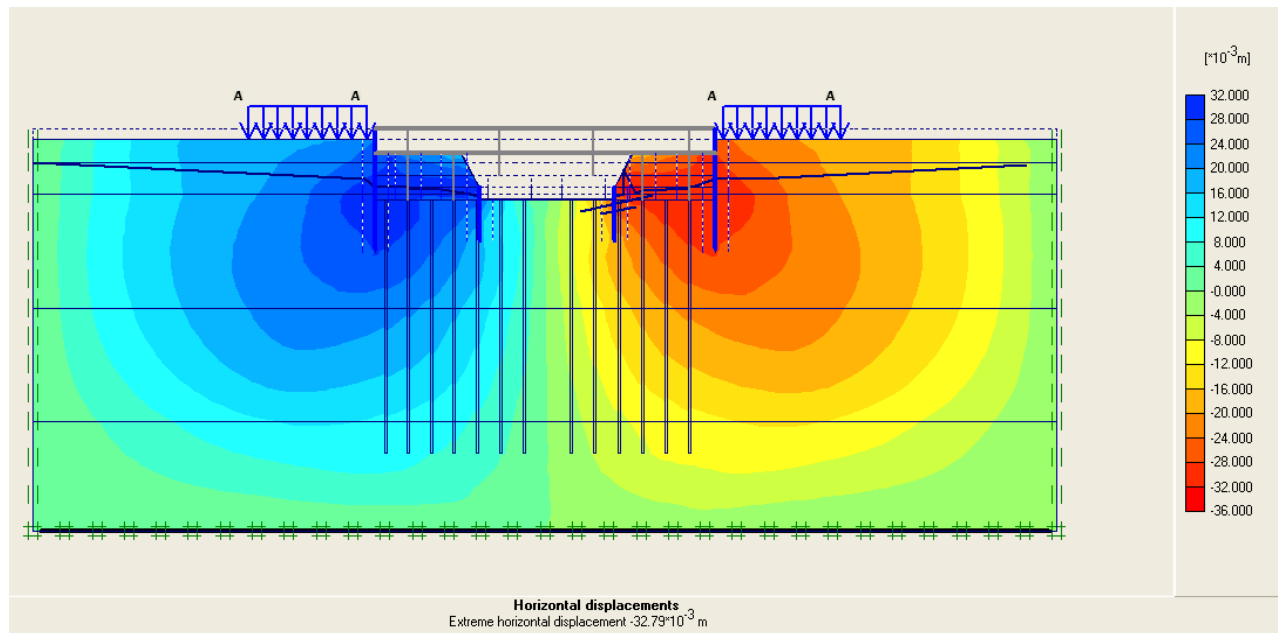


Figure 32. Horizontal displacement.

b. Observations:

Simulation of construction process shows that the horizontal displacement of side walls mostly occurred in stage 1,2,3 and 6. In which:

- Horizontal displacements in Stages 1, 2, 3 depend on H: wall depth and B: Earth-bank top width (0.5:1).
- In stage 6, horizontal displacement depends on H: wall depth and EI: flexural rigidity of the wall. Because wall thickness was restrained by construction plants, so horizontal displacement in this stage mostly depends on wall depth.

4.2 Analysing and selecting compatible side wall depth $H(m)$ and optimal earth bank width $B(m)$ for stabilizing excavation as well as restraining wall's movement.

a. Analysing and selecting optimal value for B and H in stages 1, 2, and 3:

- Horizontal displacement $S_h(mm)$ of the left basement wall:

Table 9. Horizontal displacement $S_h(mm)$ of the left basement wall in relation to B and H .

Wall depth	Horizontal displacement $S_h(mm)$ in relation to $B(m)$						
$H(m)$	$B=0$	$B=7$	$B=8$	$B=9$	$B=10$	$B=11$	$B=12$
$H=12$	121.05	34.43	33.82	32.58	31.54	30.66	29.38
$H=13$	115.20	34.37	33.76	32.46	31.36	30.63	29.32
$H=14$	109.37	34.69	34.02	32.43	31.12	30.42	29.14
$H=15$	108.30	35.44	34.63	32.97	31.60	30.80	29.60
$H=16$	105.90	36.39	35.53	33.77	32.31	31.47	30.25
$H=17$	104.83	37.17	36.30	34.52	33.05	32.17	30.92
$H=20$	104.83	39.65	38.77	36.95	35.30	34.42	33.10

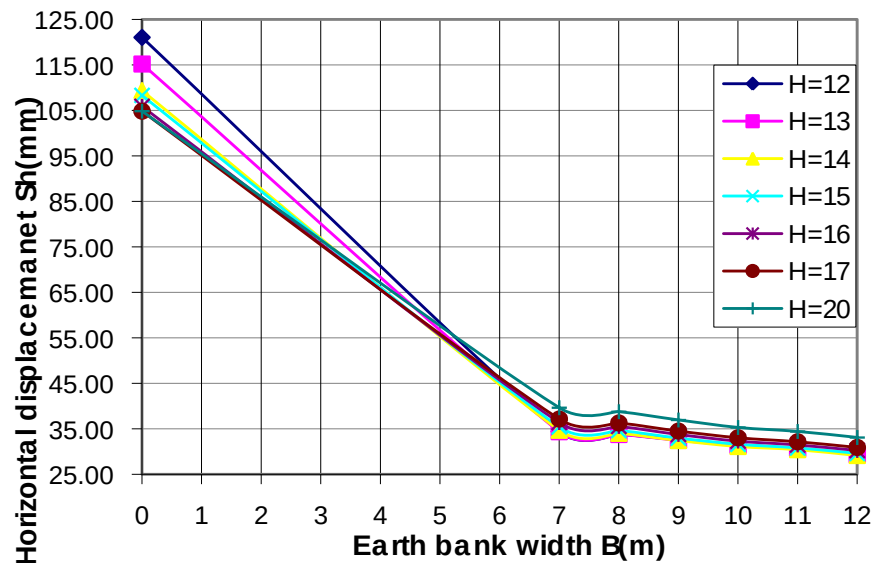


Figure 33. Horizontal displacement S_h (mm) of the left basement wall in relation to B .

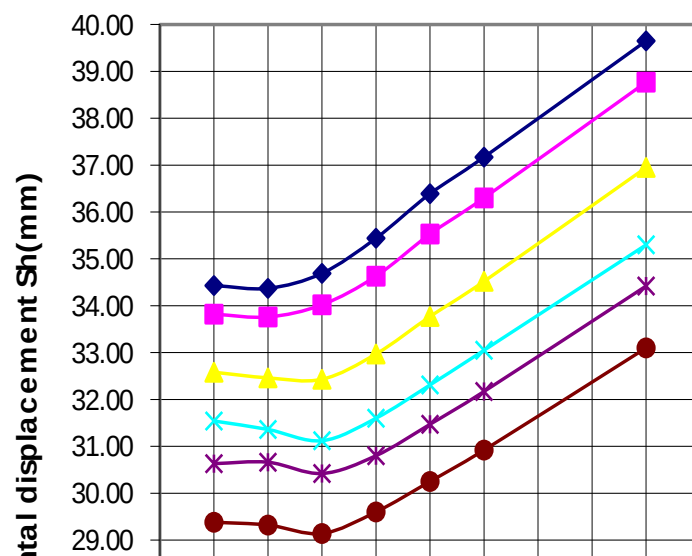


Figure 34. Horizontal displacement S_h (mm) of the left basement wall in relation to H .

- Horizontal displacement S_h (mm) of the right basement wall:

Table 10. Horizontal displacement S_h (mm) of the right basement wall in relation to B and H .

Wall depth H (m)	Horizontal displacement S_h (mm) in relation to B (m)						
	$B=0$	$B=6.5$	$B=7.5$	$B=8.5$	$B=9.5$	$B=10.5$	$B=11.5$
$H=12$	127.83	35.40	34.73	33.45	32.30	31.46	30.08
$H=13$	119.15	35.13	34.55	33.13	31.97	31.27	29.87
$H=14$	110.25	35.60	35.05	33.16	31.79	31.25	29.77
$H=15$	107.26	36.42	35.77	33.76	32.23	31.70	30.19
$H=16$	105.94	37.33	36.64	34.52	32.96	32.39	30.85
$H=17$	109.69	38.14	37.44	35.22	33.65	33.03	31.48
$H=20$	105.87	40.72	39.94	37.92	36.13	35.53	33.87

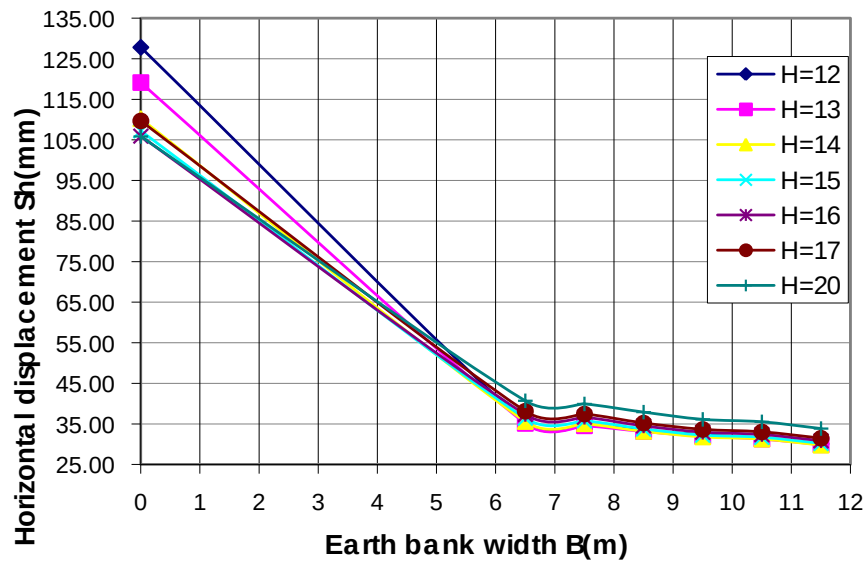


Figure 35. Horizontal displacement S_h (mm) of the right basement wall in relation to B .

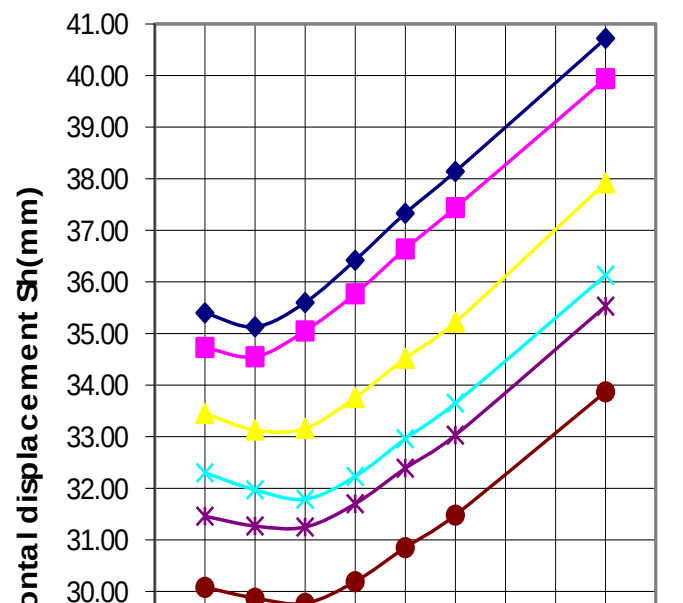


Figure 36. Horizontal displacement S_h (mm) of the right basement wall in relation to H .

Observations:

According to Charts 1 to 4, we can see the important role of earth-bank and basement walls in stabilizing as well as restraining horizontal displacement S_h of side walls.

Horizontal displacement of side walls increases very slowly when reducing B : the top width of earth-bank. But if the value of B decreases below 6 meters then horizontal displacement raises up very quickly. So earth-bank works as a bearer which also has displacement, and its displacement is totally subordinated to its own rigidity (or B : earth-bank top width).

- When remove the earth-bank ($B=0$), basement walls work as cantilever retaining walls and horizontal displacement depends on wall depth (H). Horizontal displacement decreases when increasing H and stops decreasing when H reaches a compatible value, then its value just depends only on flexural rigidity (EI) of the wall.

- In the opposite way, when earth-bank is included, basement walls work as buttress walls. Horizontal displacement will only decrease in a class interval of wall depth value (H). Outside that class interval, horizontal displacement (S_h) will increase when increasing or reducing H.

b. Analysing and selecting optimal value for H in stage 6:

According to constructive condition at site, and best horizontal displacement resistance conditions can be obtained, the writer proposes selecting excavation method in which top earth-bank width is 11 meters (0.5:1), and wall depth is 14 meters for stages 1, 2, 3.

After checking the options for stage 6, the writer realized that at stage 6, basement walls was supported by ground floor slab and 1st basement floor slab to resist horizontal displacement. According to table 11, horizontal displacement (S_h) just decreases in a class interval of wall depth value, outside of that interval, horizontal displacement will raise when increasing or reducing wall depth value (H). So it is logical to maintain wall depth value (H) by 14 meters for this construction stage.

Table 11. Horizontal displacement S_h (mm) of retaining walls at stage 6 with $B=11m$ and various values of H.

Horizontal displacement S_h (mm)	Various values of H(m)						
	H=11	H=13	H=14	H=15	H=16	H=17	H=20
	34.79	33.90	33.72	34.59	35.53	36.26	38.85

c. Assessment of safety factor (FS) of stability during construction phases:

Table 12. Safety factor (FS) stability during construction phases

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
FS	9.911	2.054	4.247	3.662	3.839	10.991	7.437

According to table 12, the safety factor of stability in the construction stages of excavation pit combined with earth-bank (stage 2) is smaller than the other construction stages. Hence, the overall stability of the pit depends mainly on the stability of the earth-bank. When applying this method, attention should be paid to measures to improve the stability of the earth-bank

5. Conclusion:

In using “Semi Top-down combined with Earth-bank” construction method to resist horizontal displacement of retaining walls, the stability of the earth-bank is the most important element that determine whether this method can be effective or not. Earth-bank works as bearer equivalent to a buttress in buttress wall. If this bearer is rigid enough (compatible earth-bank width), horizontal displacement value will change trivially when increasing or reducing earth bank width. But if earth-bank width is decreased too much (not rigid enough), then horizontal displacement will rise very quickly. Then, basement wall will work as cantilever wall, and horizontal displacement totally depends on flexural rigidity and the wall depth.

When there is requirement for horizontal displacement resistance, we shouldn't increase wall depth (H) of basement wall, just reinforce the lateral bracing at positions which has high horizontal displacement value before proceed further for the next stages.

This is an economically and technically effective construction method.

References:

- [1] Dung Tien Construction Company Ltd 2005 *Analysing and selecting construction method for Sacombank Buiding's basement report*.
- [2] Bui Q T 2007 *Graduate thesis “Analyze the behavior of diaphragm wall during excavation and construction of the basement floor”* HoChiMinh city University of Technology. p71-108
- [3] Ke Ng B 2002 *Design And Construction Of Deep Foundation Pit* Construction Publisher.

- [4] Lan Transport & Authority 2005 *Bottom-Up & Top-Down Construction Method*.
- [5] <http://dungtien.com/en/project/done-project>
- [6] Brinkgreve R B J, Vermeer P A 1998 *PLAXIS 2D Foundation Version 7 Manual* Balkema A A Rotterdam Brookfield Netherlands