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REDUCING THE HORIZONTAL DISPLACEMENT OF THE DIAPHRAGM WALL BY THE ACTIVE SUPPORT SYSTEM IN HANOI

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ABSTRACT: In recent years, Vietnam has had many construction incidents related to deep excavation construction. Notably, the incidents of constructing the underground of a high-rise building such as the excavation collapsing, subsidence of the ground around the deep excavation, diaphragm walls move significantly beyond the allowable value, etc. Construction solutions, which can stabilize the deep excavation and reduce the displacement of diaphragm walls, are very important and extremely necessary. The paper presents the effect of the increasing load from the strut system by hydraulic jack (active support system) to the Barrette wall displacement during the construction of the deep excavation. In this study, a numerical investigation was performed to evaluate the effect of the active support system on the Barrette wall displacement corresponding to each case of 2 to 3 basements for each type of natural ground in Hanoi city. In particular, the Finite Element Model (FEM) simulated the construction sequence of deep excavation with different forces from struts has been compared. The analysis results show that the active support system is an effective solution to stabilize the deep excavation and reduce the horizontal displacement of the Barrette wall, especially the top and the middle of the Barrette wall.

Keywords: Deep Excavation, Horizontal Displacement, Diaphragm Wall, FEM Analysis, Hydraulic Jack

1. INTRODUCTION

Along with the urbanization and modernization in big cities such as Hanoi, Ho Chi Minh, and Da Nang, the demand for accommodation, office, and commercial centers is very high. With a limited area of urban land, many high-rise buildings accompanied by the basements for vehicle parks and trade centers have been constructed to solve that demand. In the process of building and finishing high-rise buildings, the work of constructing foundations and basements is the most complicated works, and construction incidents occur more commonly during this period [1]. It is very important to come up with a reasonable solution to support the excavated hole, which determines the success or failure of the project. In fact, there are many solutions for basement construction such as top-down, bottom-up, and semi top-down methods as shown in Figure 1 to Figure 3 [2-4]. However, which solution to choose depends on many factors such as construction site, progress, cost, the capacity of the contractor. . .etc.

Nowadays, the construction of Barrette walls as an excavation wall in basement construction and then used as a basement wall is increasingly popular. And it is no stranger to Vietnamese construction contractors. However, almost all projects in the period of the excavation construction show that the Barrette walls are relatively large displacement. When the displacement value is higher than the allowed value, it leads to incidents at different levels, such as affecting the structure and architecture of the basement wall, subsidence of the ground around, the excavation collapsed, subsidence, or destruction of surrounding buildings, etc. [5-7].

Currently, in Vietnam, the bottom-up solution is being chosen the most by contractors and investors because it saves costs and is suitable for the capacity of Vietnamese contractors. Especially, the solution of supporting basement walls by strut system combined with hydraulic jacks is being applied by many contractors for buildings from 2 to 3 basements. Figure 4 is the actual construction image of the 108 Military Central Hospital project at No. 1 Tran Hung Dao, Hai Ba Trung, Hanoi, including two basements constructed by a strut system combined with hydraulic jacks. However, there is no research on the effect of the active support system by hydraulic jack combined with the strut system on the Barrette wall displacement during the excavation construction for ground conditions in Hanoi city.

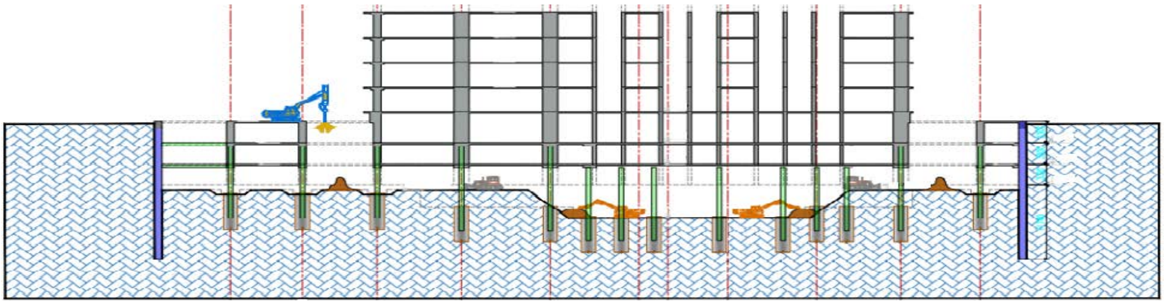


Fig. 1 Top-down method

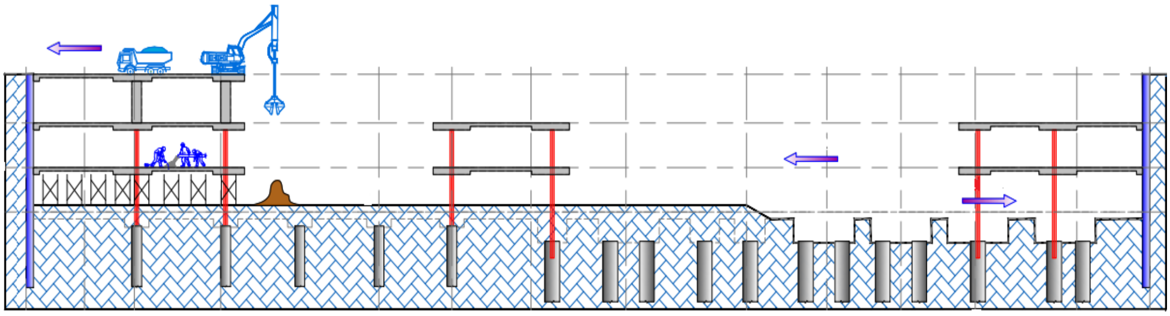


Fig. 2 Semi Top-down method

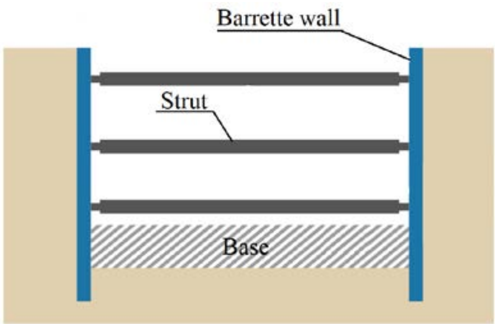


Fig. 3 Bottom-up method

Fig.4 108 Military Central Hospital project constructed the basements by the strut system combined with hydraulic jacks

2. RESEARCH SIGNIFICANCE

In this study, the paper investigates the effect of the active support system by hydraulic jack combination with the strut system on the Barrette wall displacement during the excavation construction for each type of ground in Hanoi city. From the analysis result, it is the scientific foundation for practical application to reduce the movement of the basement wall and reduce incidents occurring during the construction of the deep excavation.

3. GROUND CONDITION IN HANOI AND THE ACTIVE SUPPORT SYSTEM

3.1 Ground condition in Hanoi

Hanoi is the capital of Vietnam, located near the center of the Northern Delta of Vietnam. Hanoi's topography is classified into three types: mountains, hills, and plains. High mountains from 400 to 1200 meters are distributed in the West. Along the foot of the mountain are bowl-shaped hills 20 to 350 meters high, and the plains accumulate with the remnant, relatively flat hills 3 to 15 meters tall. According to Doan The Tuong's research [8], based on the characteristics of distribution according to the area and depth of the types of soil in the Hanoi area, their physical and mechanical properties can distinguish three main types of natural ground. It is a homogeneous natural ground, a two-layer heterogeneous ground, and a multi-layer ground with soft soil. The homogeneous ground is made by only one soil of the same name, the same origin, and of course, has the same physical and mechanical properties. The two-layer heterogeneous ground is made by two different soil types and diverse in composition and properties. The multi-layer land

Table 1 Structure and distribution area of the ground in Hanoi city

Type of ground	Name	The basic characteristics	Area of distribution
A Single-layer ground and homogeneous	A1	Clay type, Vinh Phuc layer, the origin of river-sea, age of Pleistocene, uniform in composition and properties.	Southwest of Tu Liem district to Dong Anh district
	A2	Clay type, Thai Binh layer, the origin of the river, age of Holocene, less uniform in composition and properties.	Inner-city of Hanoi city
B Two-layer ground and heterogeneous	B1	Layer 1: Clay type, Vinh Phuc layer, 10m of thickness. Layer 2: Sand, Vinh Phuc layer, medium density, up to 20m of thickness.	North of Dong Anh district
	B2	Layer 1: Clay type, Thai Binh layer, from 5 to10m of thickness. Layer 2: Sand, Thai Binh layer, medium density, up to 20m of thickness.	Thanh Tri, Gia Lam district and South of Dong Anh district
C Multi-layer ground with soft soil	C1	Layer 1: Clay type, Vinh Phuc layer, 10m of thickness. Layer 2: Organic soil, Vinh Phuc layer, up to 10m of thickness. Layer 3: Sand, Vinh Phuc layer.	North of Dong Anh district
	C2	Layer 1: Clay type, Thai Binh layer, from 5 to 10m of thickness. Layer 2: Organic soil, Hung Hai layer, up to 10m of thickness. Layer 3: Sand (clay), Vinh Phuc layer.	Dong Anh district, Gia Lam district (small area)
	C3	Layer 1: Clay type, Thai Binh layer, from 5 to 10m of thickness. Layer 2: Organic mud soil, Hai Hung layer, from 5 to 30m of thickness. Layer 3: Sand (clay), Vinh Phuc layer.	Thanh Tri district and the South of Tu Liem district

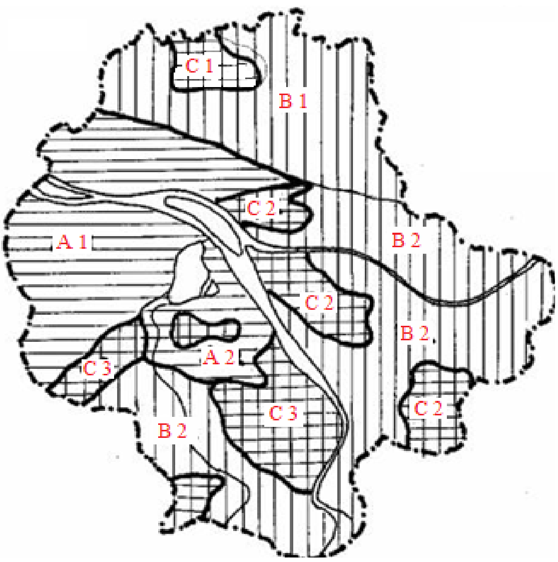


Fig. 5 Distribution of natural ground types in Hanoi city (A: single-layer; B: double layer; C: multi-layer)

with soft soil is composed of many different soil types, but there is a soil layer with special structure and properties. The structure and distribution area of the ground in Hanoi were shown in Table 1 and Fig.5 [8]. Table 2 listed the soil parameters used in this study.

3.2 The active support system

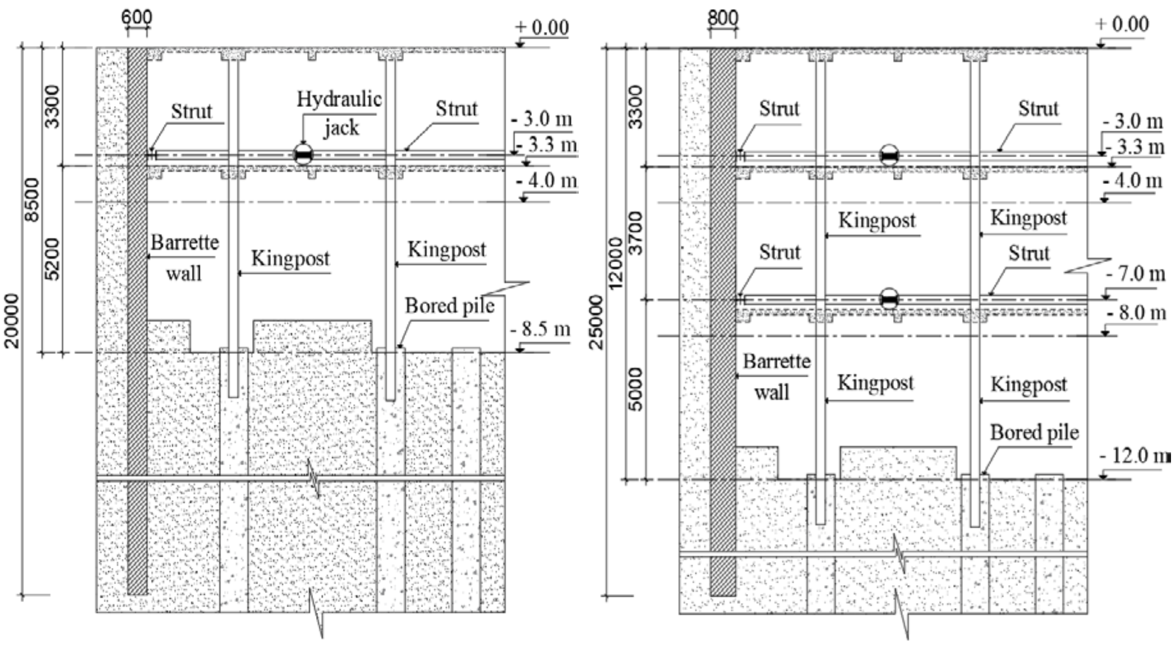
An active support system to reduce the horizontal displacement of the Barete wall during the construction of the basement is the steel H-beam system combined with hydraulic jacks. The construction and dismantling of the active support system has been published [9].

3.2.1 Diaphragm wall

Today in Vietnam, Barrette walls are trendy for high-rise buildings with many basements when built in the inner city. It acts as a diaphragm wall for the underground construction process, an integral part of the underground construction method. In the finishing work, the barrette walls are plastered with a thin layer and used as basement walls. The excavation cross-section of the actual construction is shown in Fig.6. Fig.6 shows that in the case of 2 basements, the width, and depth of the barrette walls

Table 2 Soil parameters used in FEM analyses

	Material	h (m)	γ_{unsat} kN/m^3	γ kN/m^3	e	γ_{sat} kN/m^3	k_x m/day	k_y m/day	E_{1-2} kN/m^2	ν	E_{ref} kN/m^2	c_{ref} kN/m^2	φ(o)
A1	Soft plastic clay	50	19.5	27.2	0.725	19.97	0.003	0.001	10000	0.32	7685	19	11.4
A2	Sandy-clay	50	18.7	27.1	0.881	19.09	0.001	0.001	11200	0.3	8909	28.7	11.7
B1	Gray sandy-clay	10	19	27.2	0.838	19.33	0.001	0.001	14900	0.3	11852	30.5	13.14
	Medium-grained sand	30	20	26.6	0.766	19.40	1	1	24550	0.3	19528	0.1	25
B2	Sandy-clay	10	18.75	26.75	0.881	18.90	0.001	0.001	11250	0.3	8949	28.7	11.6
	Fine to small-grained sand	30	20	26.6	0.766	19.40	1	1	10800	0.3	8591	0.1	24
C1	Soft plastic clay	10	19.5	27.2	0.725	19.97	0.003	0.001	10000	0.32	7685	19	11.4
	Sandy-clay contains peat	10	17.7	26.8	1.037	18.25	0.001	0.001	4200	0.3	3341	21	2.7
	Medium–coarse sand	30	20	26.6	0.766	19.04	1	1	10800	0.3	8591	1	24
C2	Sandy-clay	10	17.7	26.8	1.037	18.25	0.001	0.001	4200	0.3	3341	21	2.7
	Soft clay contains peat	10	16.2	25.9	1.483	16.40	0.001	0.001	1500	0.35	1089.4	8.7	5.5
	Medium–coarse sand	30	20	26.6	0.766	19.40	1	1	24550	0.3	19528	0.1	25



(a) (b)

Fig.6 Typical section of underground basement in each case; (a): two basements, (b): three basements.

are 0.6m and 20m, respectively. For the case of 3 basements are 0.8m and 25m respectively. Parameters of the wall in each case were shown in Table 3.

3.2.2 The steel H-beam system

The support system is the steel H-beam system (H350x350x12x19), which is sold or leased on the Vietnamese market. The specifications of steel H-

Table 3 Parameters of Barrette wall

Dimensions/Properties	Symbol	Units	Case with two basements	Case with 3 basements
Modulus of elasticity	E	kN/m^2	31000000	31000000
The thickness of Barrete wall	h	m	0.6	0.8
Calculated width	b	m	1	1
Area of X-section	A	m^2	0.6	0.8
Second moment of inertia	I	m^4	0.018	0.0426
Axial stiffness	EA	kN	18600000	24800000
Bending stiffness	EI	$kN.m^2$	558000	1320600

Table 4 Parameters of steel H-beam

Dimentions/ Properties	Symbol	Units	Value
Height	d	mm	350
Flange width	b	mm	350
Flange thickness	t_s	mm	19
Web thickness	t_w	mm	12
Cross-sectional area	A	cm^2	171.9
Unit mass	m	kg/m	135
Second moment of area	I_x	cm^4	39800
	I_y	cm^4	13600
Radius of gyration of area	i_x	cm	15.2
	i_y	cm	8.89
Section modulus	W_x	cm^3	2280
	W_y	cm^3	776

beam are indicated in Table 4. The steel H-beams will be supported from one end to the other of the Barrette wall, as shown in Fig.6. The distance between the struts is usually equal to the width of one segment of the Barrette wall from 1.2 to 6 m [10,11]. To accurately assess the effect of the hydraulic jack load, we will take the distance between the largest struts is 6 m to increase mechanization in construction. The link between hydraulic jack and steel H-beam was shown in Fig.7. The active support system will be kept stable by Kingpost (H400x400x13x21).

4. ANALYSIS PROCEDURES

In this study, the behavior of the diaphragm wall during excavation for the construction of the underground was emulated by the Plaxis V8.6 finite element software [12]. The characteristic of the underground pit is quite symmetrical, so the calculation model was selected as one side of the diaphragm wall, the calculation steps were utterly consistent with the construction process and construction schedule. The uniformly distributed load value around the pit was 10kN/m, with the start point has the distance from the mouth of the hole is 2 meters, and the length of the distribution area is 18 meters. A series of 2D analyses were performed, and their results were compared.

4.1 Construction process and calculation for the case of 2 basements

For the case of 2 basements, the sequence of excavation construction in Plaxis 2D consists of 5 steps as follows:

Step 1: Constructing the diaphragm wall and the load value around the pit 10 (kN/m).

Step 2: Excavating to -4.0 m. deep.

Step 3: Constructing the strut system and hydraulic jack at -3.0 m.

Step 4: Increasing the hydraulic jack force value P (kN)

Step 5: Excavating to -8.50 m. deep.

The detail of the excavation construction sequence is presented in Fig.8.

Fig.7 The link between hydraulic jack and steel H-beam

4.2 Construction process and calculation for the case of 3 basements

For the case of 3 basements, the sequence of excavation construction in Plaxis 2D consists of 8 steps as follows:

Step 1: Constructing the diaphragm wall and the load value around the pit 10 (kN/m).

Step 2: Excavating to -4.0 m deep.

Step 3: Constructing the first strut system and a hydraulic jack at -3.0 m.

Step 4: Increasing the hydraulic jack force of the first strut system with P1 value.

Step 5: Excavating to -8.0 m deep.

Step 6: Constructing the second strut system and

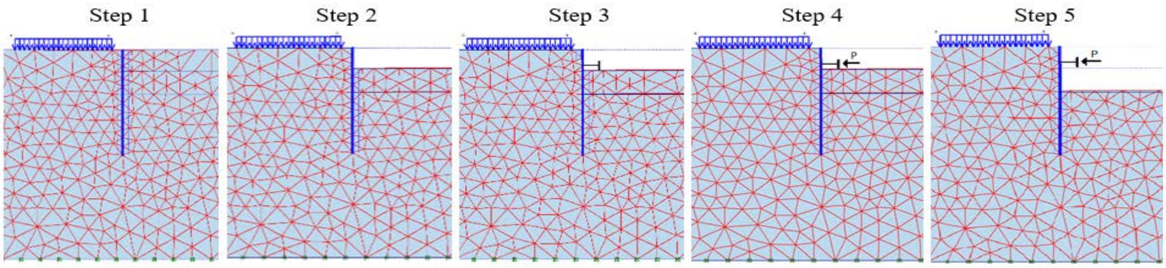


Fig.8 Excavation construction sequence for two basements in 2D Plaxis software

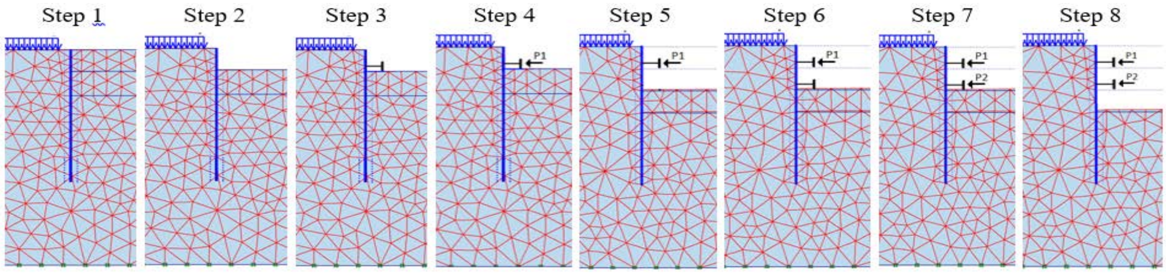


Fig.9 Excavation construction sequence for three basements in 2D Plaxis software

a hydraulic jack at -7.0 m.

Step 7: Increasing the hydraulic jack force of the second strut system with P2 value.

Step 8: Excavating to -12.0 m deep.

The detail of the excavation construction sequence is presented in Fig.9.

5. RESULT AND DISCUSSION

5.1 Effect of active support system to the diaphragm wall displacement in the case of 2 basements

Currently, in Vietnam, there is no standard on controlling the horizontal displacement of the diaphragm wall, so the study only focuses on the influence of the hydraulic jack forces from the strut system to the displacement value of the retaining wall.

The horizontal displacements of retaining wall in each case of hydraulic jack force and ground type corresponding to the case of 2 basements are illustrated in Fig.10. Fig.10 shows that as the hydraulic jack force increases, the displacement of the retaining wall decreases significantly compared to the case of no hydraulic jack (P=0). In addition, when the value of hydraulic jack increases, the upper part of the retaining wall tends to move outside the excavation hole. From Figures 10(a), 10(b), 10(c), and 10(d), it is shown that for the good ground types as A1, A2, B1, and B2, the active support system only reduces the horizontal displacement of the top and middle of the diaphragm wall, the movement of footwall is no change. The reasonable hydraulic jack force value for the four ground types is P $\leq$ 500 kN.

Fig.10(e) shows that for C1 ground as a multi-layer ground with a soft soil layer, the largest displacement of the wall is the wall-body corresponding to the position of the excavation bottom. Besides, when the value of the hydraulic jack force increases, the displacement of the abdomen and the top of the wall decreases relatively large compared to the case of P = 0. The reasonable jacking force value for C1 ground type is P from 1000 kN to 2000 kN.

From Fig.10(f), it is shown that for a multi-layer ground with an organic soil layer of the Hung Hai layer, the displacements of the wall are enormous in all cases of hydraulic jack force. It is explained by the very weak organic soil layer and broad depth distribution. For this ground type, it is recommended to consolidate the excavation bottom by deep mixing method [13,14] before applying the open-pit method with the active support system.

5.2 Effect of active support system to the diaphragm wall displacement in the case of 3 basements

The horizontal displacements of the diaphragm wall in each case of the hydraulic jack force and the ground type corresponding to the case of 3 basements are shown in Fig.11. Fig.11 indicates that when the hydraulic jack force increases, the horizontal displacement of the retaining wall is significantly reduced compared to in the case of no-hydraulic jack (P1=0; P2=0). Besides, when the P1 value increases, the wall top displacement tends to decrease and move outside the excavation pit. When the amount of P2 increases, the wall-body movement tends to decrease. Fig.11(a), 11(b), 11(c),

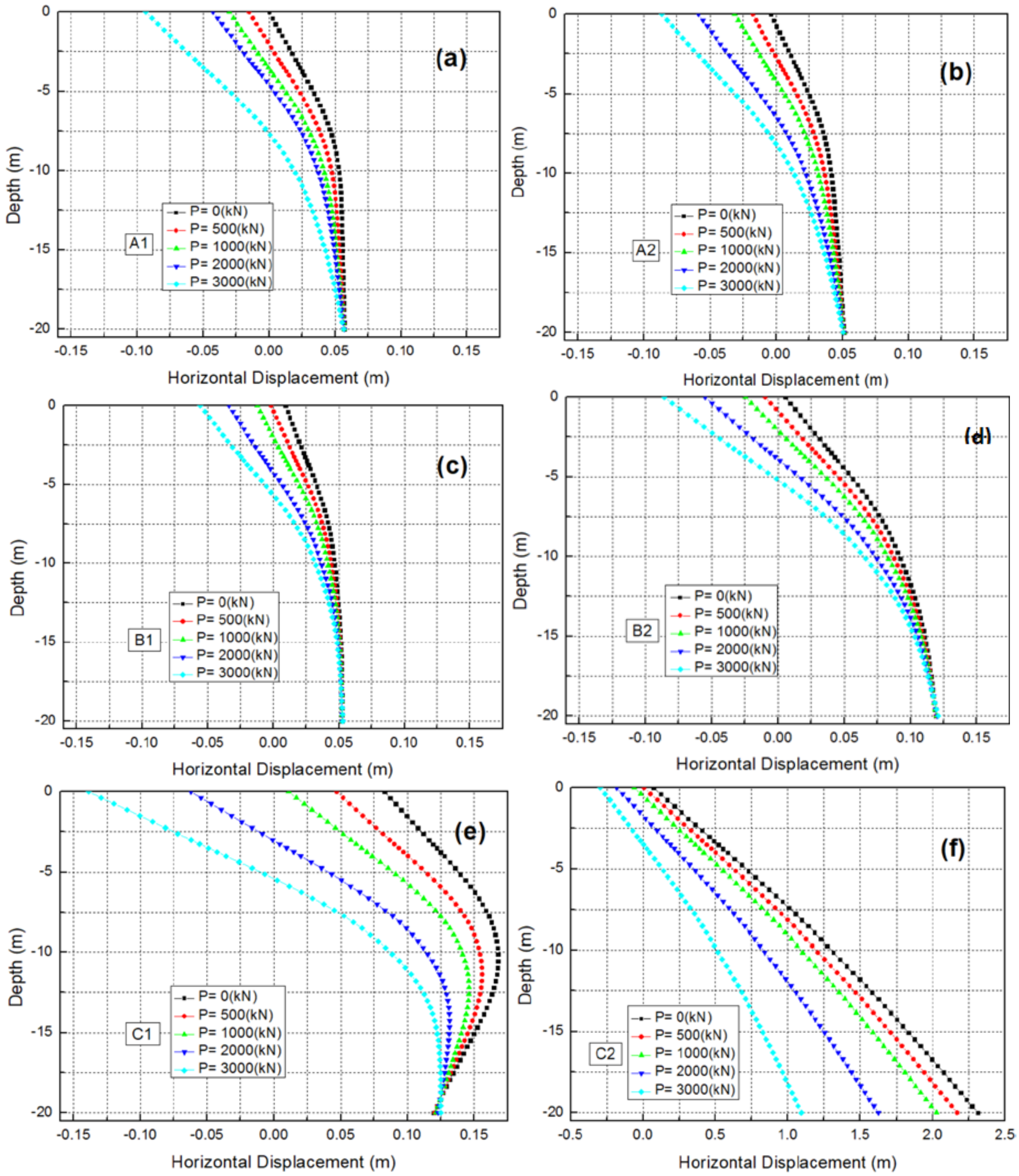


Fig.10 The horizontal displacement of the diaphragm wall in case two basements; (a), (b), (c), (d), (e) and (f) corresponding A1, A2, B1, B2, C1 and C2 ground type.

and 11(d) show that for good ground types such as A1, A2, B1, and B2, the active support system only reduces the displacement of the top, and the middle of the wall, the movement of footwall is no change. Reasonable hydraulic jack force values for the four ground types are P1 < 1000kN, and P2 < 2000kN.

Fig.11 (e) and 11 (f) show that for the multi-layer ground with a soft soil layer when the thickness of the soft soil layer is larger, the wall displacement tends to increase significantly. For the C1 ground type, the movement of the diaphragm wall decreases significantly after increasing the hydraulic jack force. The reasonable hydraulic jack force value of the C1 type is P1 < 2000kN, P2 < 2000kN. In the case of C2 ground type, the wall displacement value is huge in all cases. For this ground type, it is recommended to consolidate the excavation bottom by the deep mixing method [13,14] before applying the open-pit method with the active system.

Based on the analysis results of the horizontal displacement of the basement wall corresponding to each case of the hydraulic jack force, the author proposes a reasonably distributed load for each type

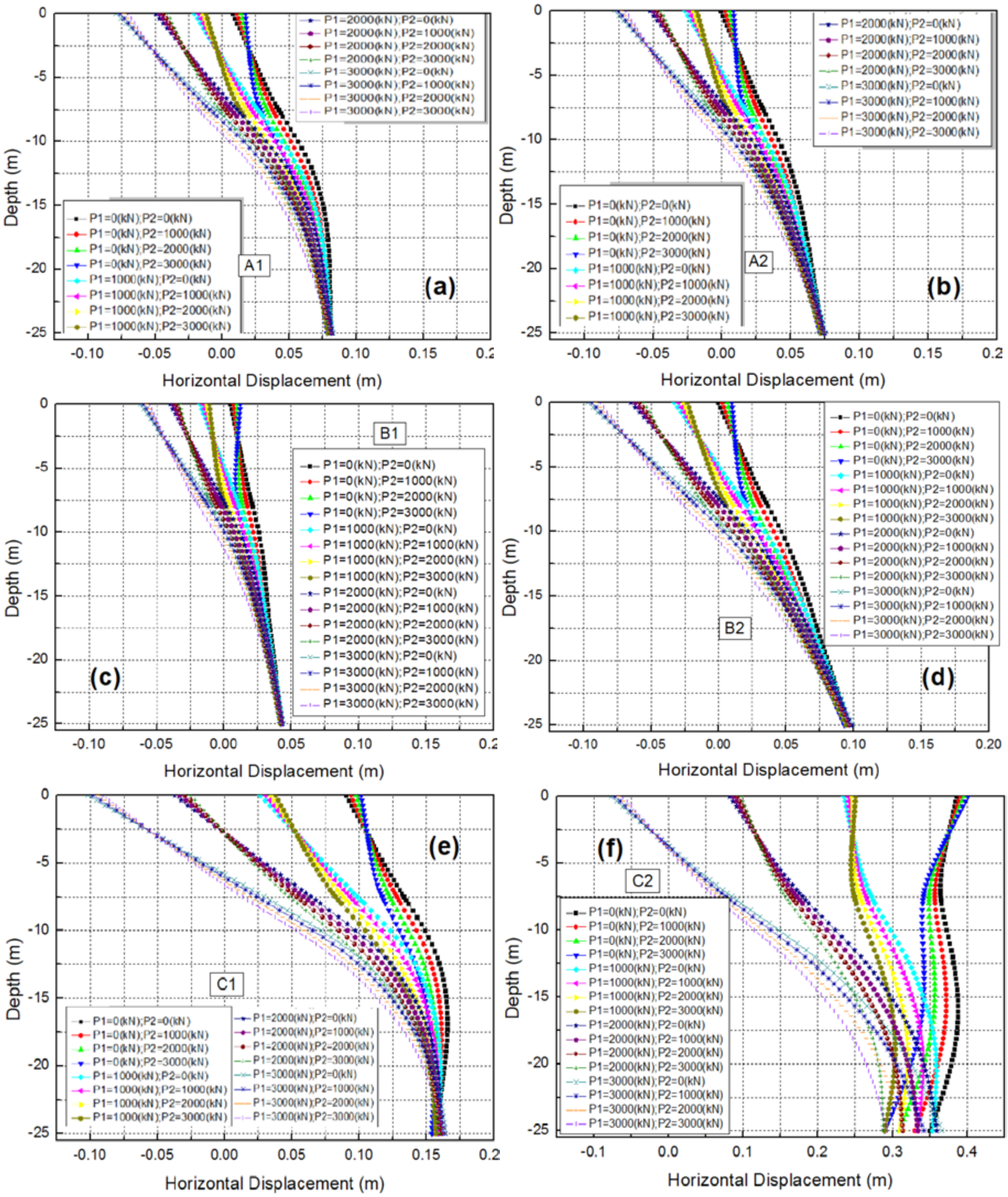


Fig.11 The horizontal displacement of the diaphragm wall in case three basements; (a), (b), (c), (d), (e), and (f) corresponding A1, A2, B1, B2, C1, and C2 ground type.

of ground. The uniformly distributed load will be equal to the hydraulic jack force value divided by the strut distance as follows.

$q = P/L$ [kN/m] (1)

$q_1 = P1/L$ [kN/m] (2)

$q_2 = P2/L$ [kN/m] (3)

Where:

q, q_1, q_2: The uniform distributed load along the perimeter of the diaphragm wall.

P, P1, P2: The hydraulic jack force

L = 6(m): The distance between struts

Table 5 The uniform distributed load

Ground types	Two basements	Three basements	
	q(kN/m)	q_1(kN/m)	q_2(kN/m)
A1	$q \leq 83$	$q_1 \leq 166$	$q_2 \leq 333$
A2	$q \leq 83$	$q_1 \leq 166$	$q_2 \leq 333$
B1	$q \leq 83$	$q_1 \leq 166$	$q_2 \leq 333$
B2	$q \leq 83$	$q_1 \leq 166$	$q_2 \leq 333$
C1	$166 \leq q \leq 333$	$q_1 \leq 333$	$q_2 \leq 333$

6. CONCLUSION

This study focused on the effect of the hydraulic jack forces from the strut system to the horizontal displacement of the Barrette wall during the construction of the deep excavation. The sequence of excavation construction corresponding to each case of 2 to 3 basements for each type of natural ground in Hanoi city was simulated by the Finite Element Model. A series of 2D analyses were performed. Based on the analysis results, the conclusions were obtained as follows:

1) The active support system is an effective solution to limit the horizontal displacement of the diaphragm wall during the construction of deep excavation with the open-pit method. The movement of the retaining wall depends on the hydraulic jack force value, the procedure of increasing the hydraulic jack force, and the type of ground. The active support system can only reduce the horizontal displacement of the top and middle of the retaining wall, not reduce the movement of the footwall.

2) When using the active support system, it is easy to adjust the stress in the struts by increasing or decreasing the hydraulic jack force value in case of abnormal movement of the diaphragm wall. The large distance between the struts helps to increase mechanization and speed up the construction progress in underground construction.

3) Based on the analysis results, the author proposes a reasonable hydraulic jack force for each natural ground type in Hanoi city, which is presented in Table 5. Particularly for the C2 ground type, which is very weak ground, it is recommended to consolidate the excavation bottom by deep mixing method before applying the open-pit method with the active support system.

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