SEISMIC DISPLACEMENT PREDICTION OF RETAINING WALLS UPON DEEP EXCAVATIONS IN HANOI

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***Abstract**: The high-rise buildings have been more and more built in large urbans in Vietnam, ofespecially Hanoi and Ho Chi Minh City. The basements of these buildings are popularly constructed by using retaining walls associated with the top-down method. Therefore, an estimation of the lateral displacement of the walls is extremely important in the construction process. This paper predicts the displacement of the diaphragm walls in deep excavations of H_k = 12m in Hanoi accounting for seismic loading. The walls are stably sustained using soil nail systems, struts, and top-down method. A finite element analysis software, PLAXIS 2D, is utilized to model the systems. Three soil models including Linear-Elastic, Morh-Coulomb, and Hardening Soil models are considered in the numerical analyses, while the elastic beam element is applied for the retaining walls. A seismic-effected ratio (K_c) is quantified in terms of the maximum lateral displacement induced by the earthquake to the maximum displacement due to the static load. The results show that the seismic-effected ratios are arranged from 1.04 to 1.28, 1.61 to 2.61, and 1.53 to 1.99 for Mohr-Coulomb, Hardening Soil, and Elastic soil models, respectively.*

***Keywords**: diaphragm wall, lateral displacement, soil model, PLAXIS, seismic loading*

***Classification number:** 2.4*

1. Introduction

In recent decades, the pace of economic development and urbanization in large cities in Vietnam such as Hanoi and Ho Chi Minh City has been increased rapidly.Acorrdingly, the need to construct high-rise buildings with underground spaces and buildings next to each others is also getting bigger. There are many high-rise buildings with basements were built using the "walls in soil" method.

In Hanoi, geological conditions in Thanh Xuan districtis primarily are presented by a thick layer of water-saturate clay. The annual average of the surface subsidence due to lowered groundwater levels is ranged from 10 to 20mm/year [1]. Besides, Hanoi is located in a low-to-medium seismicregion. In history, earthquakes with magnitude 7 had ever happened in Hanoi [2]. Therefore, the design of high structures considering seismic loading is extremely necessary. Also, an assessment and prediction of seismic performances of existing structures is indispensable.

Previously, the calculation of influence of the construction phases in deep excavations, underground structures on the existing buildings was implemented by Nikiforova (2008) [3] and Tupikov [4]. However, a study on the effect of earthquake on lateral displacements of retaning walls is not sufficiently performed yet. The purpose of this paper is to predict the displacements of the diaphragm walls during the construction of deep excavations considering earthquake loading. Plaxis 2D, a FEM software, is used formodeling the soil-structure systems. Three soil models are investigated, which are the Mohr-Coulomb, Hardeing Soil, and Linear-Elastic.

2. Analytical model setting

2.1. Description of studied structure

The structures used for analyses in this study are excavations with the depth of H_k varried from 8; 12 to 16m (H_k- depth of pit), with 2-4 basements, which were constructed in Thanh Xuan distric, Hanoi. The selected structural solution is the use of diaphragm walls for resisting the deep exavations.

2.2. Input parameters

We calculated the parameters for all the investgated soil models (i.e. Mohr-Coulomb, Hardeing Soil, Linear-Elastic) and selected the methods for the construction of basements, which are top-down, ground anchors, and using struts.

The properties of diaphragm walls modelling are: EA= $2.304x10^7$ kN; EI= $1.23x10^6$ kNm^2/m; w=19.3 kN/m/m, □= 0.18; d=0,8m. Slab thickness 0.2m, concrete B40 have EA=$6.5x10^6$ kN. For strut modelling, the properties are: EA=$2.51x10^6$ kN; distance resistant L_s=1m.

For the using anchor method, anchors are arranged uniformly along the length of the diaphragm wall with an interval of 2m, the tensile strength EA = $2.0x10^5$ kN. The prestressed force of anchor, p = 300 kN/m. The anchor is modeled by a 4-meter geotextile element with a stiffness of $1.91x10^6$ kN/m.

The loadings of surrounding buildings are calculated as a pressure q=20 kN/m on the ground surface. This load is located at distances to the excavation from $0.5H_k$, $1.0H_k$,and $1.5H_k$. The ground-water level at a depth of -6m from the ground surface. The parameters of the soil models are presented in table 1 and table 2.

Table 1. *Material parameters for Morh - Coulomb model.*

Mohr-Coulomb		**Loams**	**Loamy sands**	**Silty Sands**	**Medium-sized Sands**	**Loams**	**Sands gravelly**
Depth of layer (m)		**5.0 м**	**4.0 м**	**5.0 м**	**7.0 м**	**9.0 м**	**11.0 м**
γ_{unsat}	kN/m^3	14	15	16	17	14	-
γ_{sat}	kN/m^3	19	19	20	20	18	-
κ	m/day	-	-	-	-	-	-
C’	kPa	35	16	1	1	31	1
φ		13	15	25	23	12	24
E_{ref}	kPa	16000	11900	15000	28000	15900	50000
υ		0.3	0.25	0.25	0.25	0.3	0.2
R_{inter}		0.7	0.9	0.7	0.9	0.7	0.7
		Drained	Drained	Undrained	Undrained	Undrained	Undrained

Table 2. *Material parameters for Hardeing Soil model.*

Hardening Soil		**Loams**	**Loamy sands**	**Silty Sands**	**Medium-sized Sands**	**Loams**	**Sands gravelly**
Depth of layer (m)		**5.0 м**	**4.0 м**	**5.0 м**	**7.0 м**	**9.0 м**	**11.0 м**
γ_{unsat}	kN/m^3	14	15	16	17	14	-
γ_{sat}	kN/m^3	19	19	20	20	18	-
κ	m/day	-	-	-	-	-	-
C’	kPa	35	16	1	1	31	1
φ		13	15	25	23	12	-
E_{50}^{ref}	kPa	13867	9917	12500	23300	13780	40000
E_{oed}^{ref}	kPa	13867	9917	12500	23300	13780	40000
E_{ur}^{ref}	kPa	41600	29750	37500	69900	41340	12000
υ		0.3	0.25	0.25	0.25	0.3	0.2
K_0^{nc}		-	-	-	-	-	-
R_{inter}		0.7	0.9	0.7	0.9	0.7	0.7
		Drained	Drained	Undrained	Undrained	Undrained	Undrained

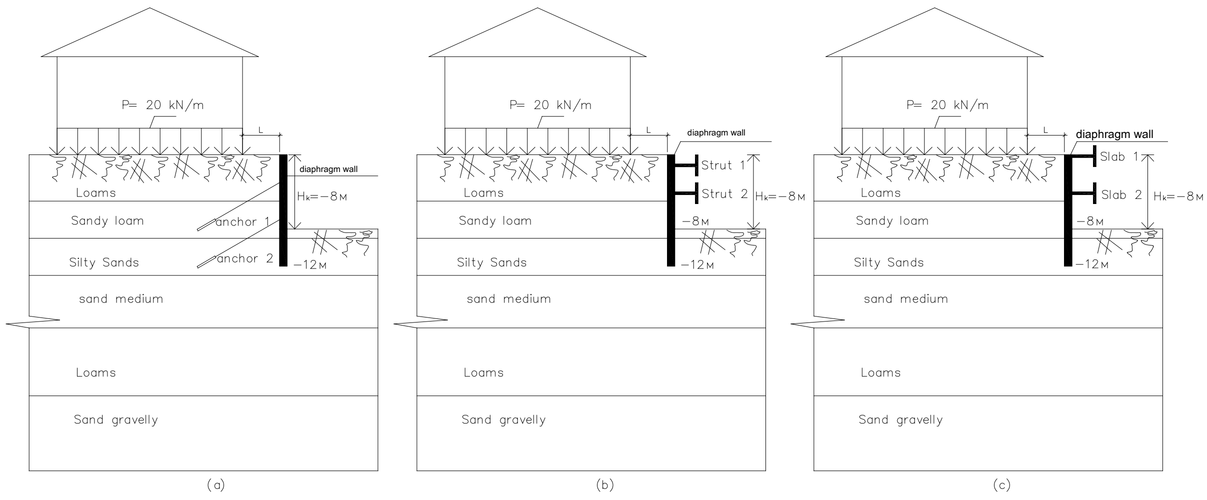

Figure 1: *Construction of deep excavations H_k = 8m by the method of anchoring in soil (a); use strut (b); Top-down construction (c).*

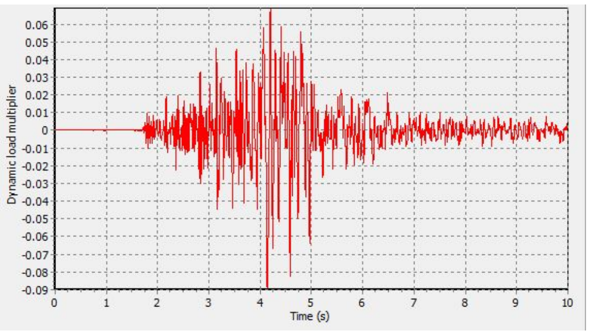

Figure 2: *The trace of the 2001 Dien Bien earthquake.*

The finite element code Plaxis 2D is used for all analyses. The following computational steps have been performed, example for the H_k=8m, anchors:

- Stage 1: activation of diaphragm walls

- Stage 2: excavation step 1 (to level -4.0m)

- Stage 3: activation of anchor 1 at level -3.5m and prestressing

- Stage 4: groundwater lowering and excavation step 2 (to level -8.0m)

- Stage 5: activation of anchor 2 at level -7.5m and prestressing

- Stage 6: caculated earthquake.

The time-history acceleration of the 2001 Dien Bien earthquake (Fig. 2) is utilized in this study.

3. Calculated results

After determining the maximum horizontal displacement u_r of the diaphragm walls in two cases: with and without earthquakes ($f\frac{u_r}{H_K}$ (%)). Then determine the seismic effect coefficient, K_c:

$$K_c = \frac{f^{seismic}}{f^{no\ seismic}} \qquad (1)$$

Where:

$f^{seismic} = \frac{u_r}{H_k} * 100\%$ - earthquakes

$f^{no\ seismic} = \frac{u_r}{H_k} * 100\%$ - no earthquakes

Table 3. *Maximum horizontal displacement of the diaphragm wall Hк=-8м (no earthquakes).*

L (m)	4M			8M			12M		
	Ux (MC)	Ux (HS)	Ux (LE)	Ux (MC)	Ux (HS)	Ux (LE)	Ux (MC)	Ux (HS)	Ux (LE)
Anchor (mm)	31.64	28.87	1.40	26.69	24.82	1.39	29.53	22.20	1.39
Ur/Hк (%)	*0.40*	*0.36*	*0.02*	*0.33*	*0.31*	*0.02*	*0.37*	*0.28*	*0.02*
Struts(mm)	24.61	14.24	2.01	24.45	13.47	2.00	24.40	12.84	2.00
Ur/Hк (%)	*0.31*	*0.18*	*0.03*	*0.31*	*0.17*	*0.03*	*0.30*	*0.16*	*0.02*
Top-down (mm)	22.86	12.67	1.78	22.76	12.03	1.78	22.73	11.54	1.77

Uг/Нк (%)	*0.29*	*0.16*	*0.02*	*0.28*	*0.15*	*0.02*	*0.28*	*0.14*	*0.02*

Table 4. *Maximum horizontal displacement of the diaphragm wall Нк=-8м (earthquakes).*

	4M			**8M**			**12M**		
	Ux (MC)	**Ux (HS)**	**Ux (LE)**	**Ux (MC)**	**Ux (HS)**	**Ux (LE)**	**Ux (MC)**	**Ux (HS)**	**Ux (LE)**
Anchor	42.69	72.04	4.36	35.59	66.10	4.34	40.06	61.25	4.34
Uг/Нк (%)	0.53	0.90	0.05	0.44	0.83	0.05	0.50	0.77	0.05
Struts	29.28	25.00	4.19	28.78	23.51	4.18	28.57	22.35	4.18
Uг/Нк (%)	0.37	0.31	0.05	0.36	0.29	0.05	0.36	0.28	0.05
Top-down	25.86	19.08	3.25	25.57	18.07	3.24	25.43	17.29	3.24
Uг/Нк (%)	0.32	0.24	0.04	0.32	0.23	0.04	0.32	0.22	0.04

Tables 5*. Coefficient Kc, when the distance from the adjacent works to the deep excavation is f=L/H$_k$= 0.5.*

	f=0.5, MC		**К**	**f=0.5, HS**		**К**	**f=0.5, LE**		**К**
	без см	**см**	**(см/ без см)**	**без см**	**см**	**(см/ без см)**	**без см**	**см**	**(см/ без см)**
А - $f\frac{u_г}{H_к}$ (%)	0.395	0.534	**1.35**	0.361	0.900	**2.50**	0.0175	0.0544	**3.10**
Р- $f\frac{u_г}{H_к}$ (%)	0.308	0.366	**1.19**	0.178	0.313	**1.76**	0.0252	0.0524	**2.08**
П- $f\frac{u_г}{H_к}$ (%)	0.286	0.323	**1.13**	0.158	0.239	**1.51**	0.0223	0.0406	**1.82**

Tables 6. Coefficient Kc, when the distance from the adjacent works to the deep excavation is f = L/H$_k$ =1.0.

	f=1 , MC		**К**	**f=1 , HS**		**К**	**f= 1, LE**		**К**
	без см	**см**	**(см/ без см)**	**без см**	**см**	**(см/ без см)**	**без см**	**см**	**(см/ без см)**
А- $f\frac{u_г}{H_к}$ (%)	0.334	0.445	**1.33**	0.310	0.826	**2.66**	0.017	0.054	**3.12**
Р- $f\frac{u_г}{H_к}$ (%)	0.306	0.360	**1.18**	0.168	0.294	**1.75**	0.025	0.052	**2.09**
П- $f\frac{u_г}{H_к}$ (%)	0.285	0.320	**1.12**	0.150	0.226	**1.50**	0.022	0.041	**1.83**

Tables 7. Coefficient Kc, when the distance from the adjacent works to the deep excavation is f = L/Hk =1.5.

	f=1.5 , MC		**К**	**f=1.5 , HS**		**К**	**f= 1.5, LE**		**К**
	без см	**см**	**(см/ без см)**	**без см**	**см**	**(см/ без см)**	**без см**	**см**	**(см/ без см)**
А- $f\frac{u_г}{H_к}$ (%)	0.369	0.501	**1.36**	0.277	0.766	**2.76**	0.017	0.054	**3.13**
Р- $f\frac{u_г}{H_к}$ (%)	0.305	0.357	**1.17**	0.161	0.279	**1.74**	0.025	0.052	**2.09**
П- $f\frac{u_г}{H_к}$ (%)	0.284	0.318	**1.12**	0.144	0.216	**1.50**	0.022	0.040	**1.83**

Similar calculations for the case of the deep excavation H$_k$= 12m and 16m.

Table 8. *Averaged coefficient K$_c$.*

Model	**Metod construction**	**coefficient Kc**								
		Hk =-8м			**Hk =-12м**			**Hk =-16м**		
	A1 = L/Hk	0.5	1	1.5	0.5	1	1.5	0.5	1	1.5
MC	A	1.35	1.33	1.36	1.26	1.28	1.28	-	-	-
	P	1.19	1.18	1.17	1.07	1.07	1.06	1.07	1.06	1.06
	П	1.13	1.12	1.12	1.04	1.04	1.04	1.03	1.03	1.03
HS	A	2.5	2.66	2.76	2.03	2.21	2.61	-	-	-
	P	1.76	1.75	1.74	1.78	1.78	1.78	1.55	1.56	1.59
	П	1.51	1.5	1.5	1.62	1.61	1.61	1.43	1.44	1.45
LE	A	3.1	3.12	3.13	1.98	1.99	1.99	-	-	-

	P	2.08	2.09	2.09	1.66	1.66	1.66	1.14	1.14	1.14
	Π	1.82	1.83	1.83	1.53	1.53	1.53	1.07	1.07	1.07

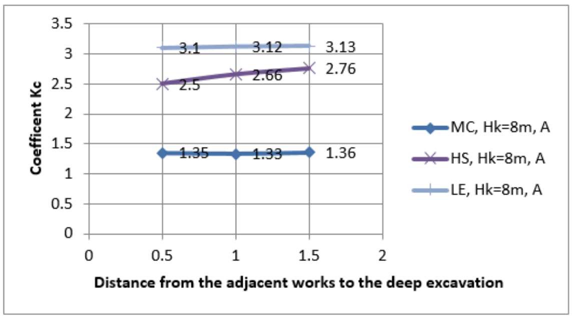

Figure 3: *The dependences between the coefficient K_c, and the ratio of L/Hk when construction use the method anchor.*

Figures 3 - 8 show the calculated coefficient K_c by applying various construction methods and soil models in numerical analyses. We can see that in the method using anchors, the displacement of the bottom of the walls is slight. The K_c is varried from 1.33 to 1.35 for Mohr-Coulomb, from 2.50 to 2.76 for Hardening Soil, and from 3.11 to 3.13 for Linear - Elastic models.

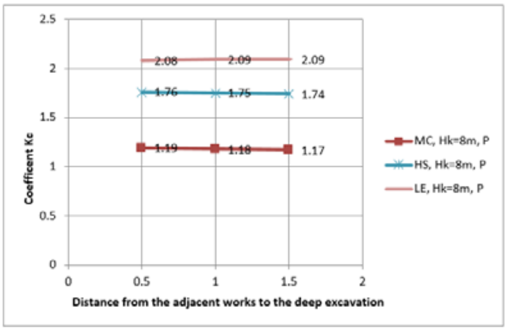

Figure 4: *The dependences between the coefficient K_c, and the ratio of L/Hk when construction use struts.*

In the method using struts, the displacement of the bottom of the excavation is also slight. K_c is arranged from 1.17 to 1.19 for Mohr Coulomb, from 1.74 to 1.76 for Hardening Soil, and from 2.08 to 2.09 for Linear - Elastic model.

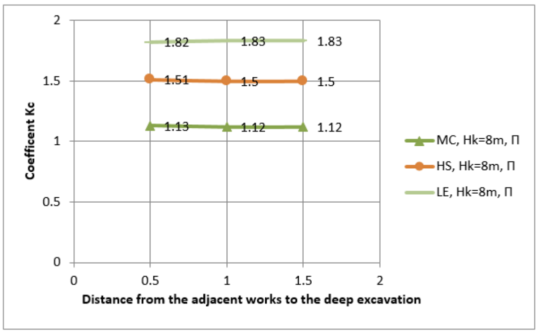

Figure 5. *The dependences between the coefficient K_c, and the ratio of L/Hk when construction use the method top-down.*

Similarly, in the top-down method, the displacement of the bottom of the wall is also slight , K_c ranged from 1.12-1.13 for Mohr Coulomb, from 1.50-1.51 for Hardening Soil, and from 1.82-1.83 for Linear-Elastic model.

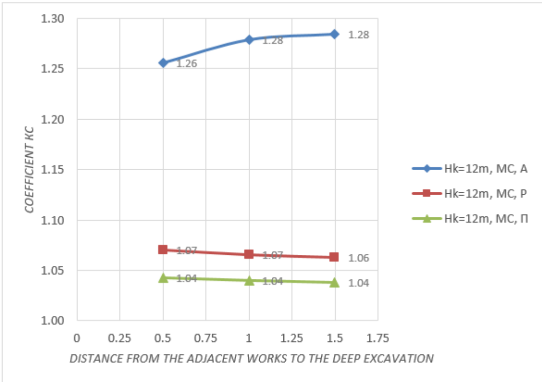

Figure 6: *The dependences between the coefficient K_c, and the ratio of L/Hk when calculated according to the model Morh – Coulomb.*

We can observe that in the case of the excavation depth of 12 m with Mohr - Coulomb soil, the impact of the earthquake on diaphragm wall displacement is the smallest (K_c= 1.04) for using top-down method and the largest (K_c=1.26-1.28) for using anchors method.

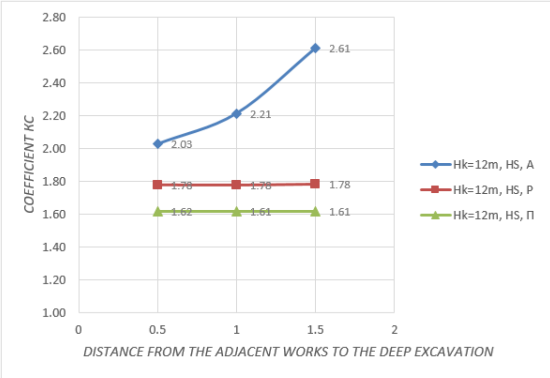

Figure 7. *The dependences between the coefficient Kc, and the ratio of L/Hk when calculated according to the model Hardeing Soil.*

In the case of the excavation depth of 12 m with Hardening soil, the impact of the earthquake on diaphragm wall displacement is the smallest (K_c= 1.61-1.62) for using top-down method and the largest (K_c=2.03-2.61) for using anchors mothod.

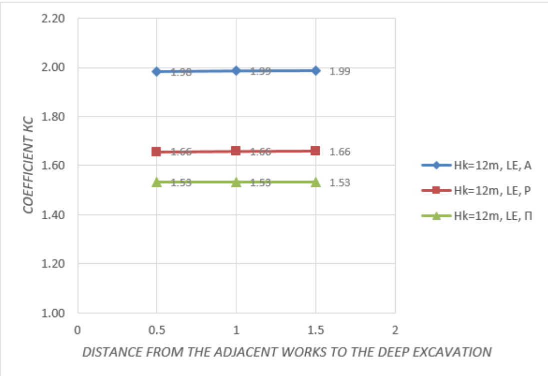

Figure 8: *The dependences between the coefficient Kc, and the ratio of L/Hk when calculated according to the model Linear Elastic.*

In the case of the excavation depth of 12 m with Linear - Elastic soil, the coefficient of the effect of earthquake on diaphragm wall, K_c is 1.99, 1.53, and 1.66, for using anchors, top - down, and struts, respectively.

4. Conclusions

The following conclutions are drawn based on numerical analysis results:

- A set of K_c values of diaphragm walls in deep excavations was achieved taking into account the seismic effects;

-With increasing depth of the pit decreases the impact of seismic effects on the movement of the diaphragm wall;

- The horizontal displacements of the diaphragm walls when applying the top - down method is the smallest in comparison with the anchoring and the strutting methods;

- Based on comparison of results, we recommend using Hardening soil model for calculating displacements of diaphragm walls in case of with and without seismic loadings❑

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