A Numerical Study on the Influence of Anchored Diaphragm Walls on Adjacent Buildings during Deep Excavation Construction

Van-Hoa Nguyen[1,*], *Nadezhda Sergeevna* Nikiforova[2], *Duy-Duan* Nguyen[1] and *Tien-Hong* Nguyen[1]

[1]Vinh University, Department of Civil Engineering, 182 Le Duan, Vinh, Vietnam
[2]Moscow State University of Civil Engineering, 26, Yaroslavskoye shosse, Moscow, 129337, Russia

Abstract. The aim of this numerical study is to investigate the impact of anchored diaphragm walls on adjacent buildings during deep excavation construction, considering five typical geological conditions in big cities of Vietnam. To achieve this, the behavior of anchored diaphragm walls systems is simulated using the Plaxis 2D program. By conducting these analyses, the study seeks to provide important insights into the behavior of anchored diaphragm walls and their effects on nearby buildings during deep excavation construction.

Keyword: Diaphragm wall, settlement, weak water-saturated soils, PLAXIS, deep excavation.

1 Introduction

Currently, the rapid development of deep foundation pit engineering is driven by the increasing demands and opportunities arising from urbanization and the utilization of urban underground space[1-3].

By employing information construction technology, it becomes possible to compare and analyze construction monitoring data with the original design scheme[4-10]. This allows for the evaluation of the construction's scientificity and the generation of reasonable recommendations to guide subsequent stages of construction and design, aiming for dynamic optimization. Deep foundation pit monitoring entails specific timeliness and accuracy prerequisites [11,12]. Terzaghi's early 20th-century studies focused on the stability of excavated soil and internal support forces, while Peck[13] introduced the research methodology for geotechnical engineering monitoring observations.

The stability and structural integrity of neighboring buildings can be directly and indirectly affected by the presence of anchored diaphragm walls [14, 15]. These effects are contingent upon multiple factors such as the proximity of the buildings to the diaphragm

[*]Corresponding author: vanhoakxd@vinhuni.edu.vn

walls, the depth and scale of excavation for the diaphragm walls, the construction methodology employed, and the properties of the surrounding soil.

2 Analytical model configuration

2.1 Overview of the examined structure

In this study, the analyzed structures are excavations that have a depth of H_k ranged between 8m and 10m (H_k- depth of pit). The chosen structural solution for resisting the deep excavations involved the utilization of diaphragm walls. These diaphragm walls had a thickness of 0.8m and a height of 23m.

2.2 Initial parameters

We determined the parameters for hardening soil models and opted for ground anchors as the construction method for basements. The modeling characteristics of diaphragm walls include the following: EA= 2.304e7 (kN); EI= 1.23e6 (kNm^2/m); w = 19.3 ($kN/m/m$), ν = 0.18.

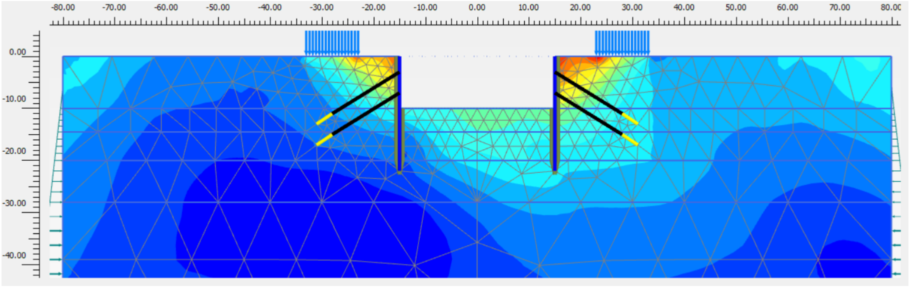


Fig. 1. The method employed for constructing deep excavations with a depth of H_k = 8m involved soil anchoring.

For the implementation of the anchor method, the anchors are uniformly distributed along the length of the diaphragm wall, with a spacing of 2m. The anchors have a tensile strength *(EA)* of 2.0x10^5 kN and a prestressed force *(p)* of 300 *kN/m*. In the model, the anchor is represented by a 4-meter geotextile element (fixed section) with a stiffness of 1.91x10^6 *kN/m*.

The loadings exerted on the neighboring buildings were evaluated as a surface pressure of q = 20 *kN/m*. These loads were positioned at distances from the excavation (f_L) equal (0.5-1.5)H_k. The groundwater level was measured to be 6 meters below the ground surface. The study focused on examining the typical geological conditions found in Hanoi and Ho Chi Minh City. Further information regarding the soil types can be found in Table 1 [16].

All analyses in this study were conducted using the finite element code Plaxis 2D. The computational procedure involved the following steps, taking the example of H_k=8m with anchors:

Phase 1: Diaphragm walls activation.

Phase 2: Excavation, first step, reaching a depth of -4.0m.
Phase 3: Anchor 1 activation at -3.5m and prestressing application.
Phase 4: Groundwater reduction and excavation, reaching a depth of -8.0 m.
Phase 5: Anchor 2 activation at -7.5m and prestressing application

Table 1. Typical soil types in cities of Vietnam

Soil type	Main characteristics of soils	City
Type I: (0-20м) clays and loams, soft plastic (more 20м) clay with a consistency from semi-solid to refractory	(φ = 4-6^0, c=5-6 kN/m^2, E=1.1 × 10^3 kN/m^2); (φ = 12-16^0, c=24-28 kN/m^2, E=4 × 10^3 kN/m^2 ,SPT =12-30)	Ho Chi Minh city
Type II: (0-20м) clays and loams, soft plastic more 20м sandy loam (sometimes with gravel)	(φ = 4-6^0, c=5-6 kN/m^2, E=1.1 × 10^3 kN/m^2); (φ = 25-26^0, c=5.4-8.0 kN/m^2, E=5× 10^3 kN/m^2)	Ho Chi Minh city
Type III: sandy loam (sometimes with gravel)	(φ = 23-26^0, c=5.4-7.5 kN/m^2, E=(7-9) × 10^3 kN/m^2, SPT =12-30)	Ho Chi Minh city
Type IV: (0-10м) sandy loam plastic and soft plastic loam (10-20м) Sands of medium density, silty and medium size more than 20m soft plastic loam	- (φ = 7-14^0, c=14-21 kN/m^2, E=(7-12) × 10^3 kN/m^2); - (φ = 32-34^0, E=15-28 × 10^3 kN/m^2, SPT =14-22); - (φ = 7-11^0, c=14-18 kN/m^2, E=(15-28) × 10^3 kN/m^2, SPT =7-11)	Ha Noi
Type V : (0-10м) sandy loam plastic and soft plastic loam (10-40м) silty Sands from medium density to dense gravelly	- (φ = 7-14^0, c=14-21 kN/m^2, E=(7-12) × 10^3 kN/m^2); - (φ = 32-34^0, E=(15-50) × 10^3 kN/m^2, SPT =14-50)	Ha Noi

3 Calculated results

After determining the maximum lateral movement of the diaphragm wall and the maximum subsidence of the surrounding soil due to deep excavation, the following coefficients are determined:

$$f_h = \frac{u_h^{max}}{H_k} \tag{1}$$

$$f_v = \frac{u_v^{max}}{H_k} \tag{2}$$

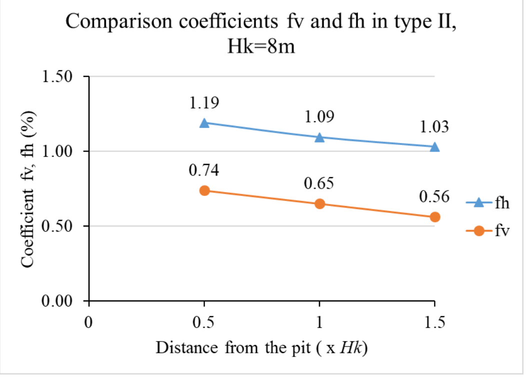
where

- f_h, f_v are the coefficients of the maximum lateral movement of the diaphragm wall and the utmost ground settlement adjacent to the excavation compared to the depth of the excavation;
- u_h^{max} – maximum lateral movement of diaphragm wall
- u_v^{max} – the utmost ground subsidence adjacent to the excavation;
- H_k – depth of the excavation;

Table 2. Values of the oefficients f_h, f_v

Soil type	H_k (m)	Distance from the pit (f_L)			Distance from the pit (f_L)		
		0.5	1	1.5	0.5	1	1.5
		f_v			f_h		
I	8	*	*	*	*	*	*
	10	*	*	*	*	*	*
II	8	0.74	0.65	0.56	1.19	1.09	1.03
	10	1.00	1.02	0.84	1.70	1.64	1.52
III	8	0.15	0.14	0.14	0.25	0.24	0.24
	10	0.22	0.22	0.22	0.26	0.26	0.25
IV	8	0.74	0.54	0.55	0.41	0.38	0.36
	10	0.92	0.80	0.79	0.51	0.47	0.45
V	8	0.45	0.44	0.41	0.58	0.56	0.55
	10	0.85	0.86	0.75	0.75	0.72	0.69

*- stability "diaphragm wall" is not ensured



 https://doi.org/10.1051/e3sconf/202345702010

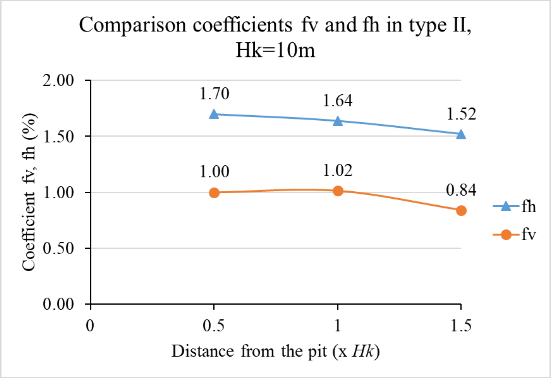


Fig. 2. Comparison coefficients f_v and f_h from L_k, Soil type -II

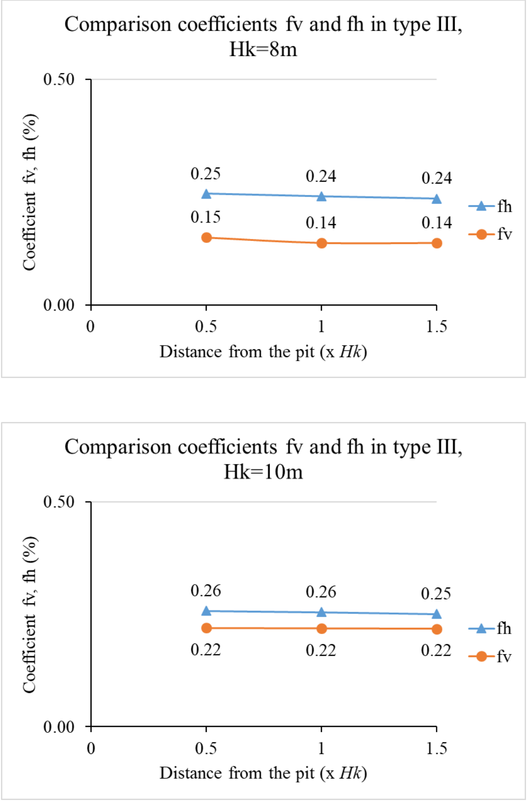


Fig. 3. Comparison coefficients f_v and f_h from L_k, Soil type -III

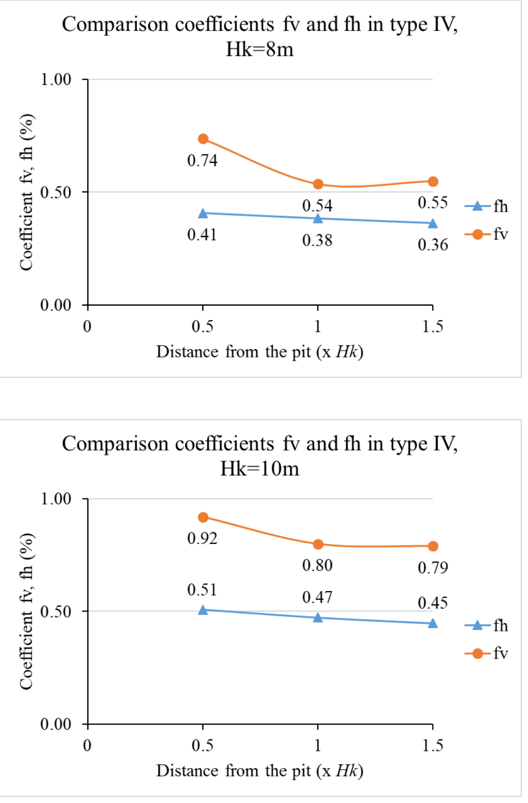
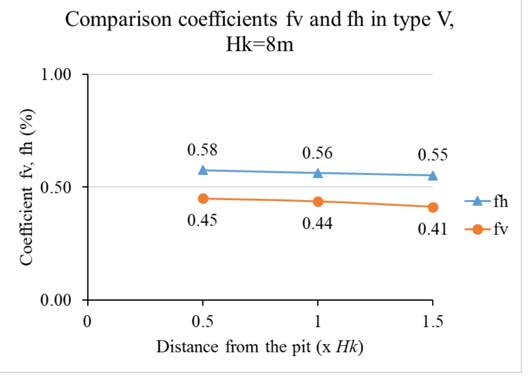


Fig. 4. Comparison coefficients f_v and f_h from L_k, Soil type -IV



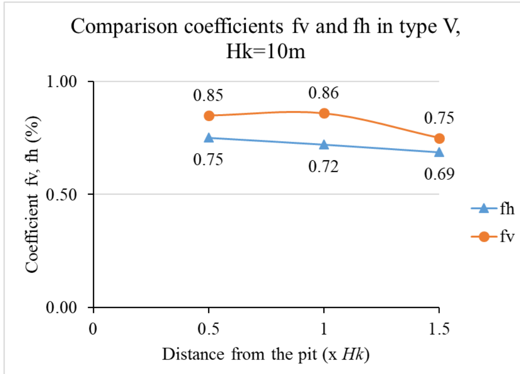


Fig. 5. Comparison coefficients f_v and f_h from L_k, Soil type -V

4 Conclusions

A series of numerical simulations have been conducted to calculate the impact of deep excavation on the subsidence of adjacent structures using soil anchors. Five geological conditions in Vietnamese cities and two depths of diaphragm walls have been analyzed.
As the lateral deflection of the diaphragm wall increases, the subsidence of the surrounding soil also tends to increase. In other words, there is a positive correlation between the two factors. When the diaphragm wall experiences greater lateral displacement, it exerts more pressure on the surrounding soil, causing it to settle or deform.
However, it is important to note that the relationship is not linear or constant. The ratio between the maximum settlement of the surrounding soil and the maximum lateral deflection of the diaphragm wall may vary within a range of 0.6 to 1.8 times, depending on various factors such as soil properties, depth of excavation, and geological conditions. The specific relationship between lateral displacement and settlement will be influenced by these factors and may require further analysis to determine the exact correlation in a given context.

References

1. Deyun Ding, et al., Research on seismic performance of large underground structures of urban rail transit. Proceedings of 19th International Conference on Soil Mechanics and Geotechnical Engineerin (Sep. 17-22, COEX, Seul, Korea), 2017: p. 1671-1674.
2. Fabiano Bertoldo, Luigi Callisto, and Jian-Gu Qian, An interpretation of the behaviour of a deep excavation in Shanghai based on numerical analysis. Proceedings of 19th International Conference on Soil Mechanics and Geotechnical Engineering (Sep. 17-22, COEX, Seul, Korea), 2017: p. 699-702.
3. Ilyichev V.A., Nikiforova N.S., and Konnov A.V. A settlement calculation for neighbouring buildings with mitigation measures upon underground construction. in Proceedings of 19th International Conference on Soil, Mechanics and Geotechnical Engineering (Sep. 17-22, COEX, Seoul, Korea). 2017.
4. Shi, L., et al. Monitoring and Analysis of Deep Foundation Pit Construction of Structural Loess in Northwest China. in IOP Conference Series: Earth and Environmental Science. 2021. IOP Publishing, DOI 10.1088/1755-1315/719/3/032001.

5. XU Si-fa, ZHOU Qi-hui, ZHENG Wen-hao, ZHU Yong-qiang, WANG Zhe. Influences of construction of foundation pits on deformation of adjacent operating tunnels in whole process based on monitoring data[J]. Chinese Journal of Geotechnical Engineering, 2021, 43(5): 804-812. doi: 10.11779/CJGE202105003.
6. Nguyen Viet Tuan, Stress-strain state of soils of the foundation and sides of the pit, tak-ing into account the spatial factor. 2006: M. p. 197.
7. Nguyen Xuan Bac, Forecast of displacements and deformations of the rock mass and the earth's surface during the construction of tunnels in Ho Chi Minh City. 2012, Na-tional Mineral and Raw Materials University "Gorny": St. Petersburg. p. 21.
8. Nikiforova N.S. and Konnov A.V., Prediction of building settlement with protective measures in the zone of influence of underground construction. Bulletin of civil engineers, 2016(2): p. 94-100.
9. Nguyen Van Hoa, Nikiforova N.S, and Nguyen Duy Duan, Semic displacement prediction of retaining walls upon deep exavations in Ha Noi. Journal of Transportation Science and Technology (in Vietnamese), 2018. 27+28: p. 192-197.
10. Nguyen Van Hoa, Nikiforova N.S., and Nguyen Duy Duan. Prediction of soil displacement surrounding deep excavations in Ha Noi. in Proceeding of the international conference on the 55th anniversary of establishment of Viet Nam institute for building science and technology. 2018.
11. Nikiforova N.S. 2008 Deformation of the buildings near deep excavations and under-ground construction and protection measures (Moscow: Doctor Diss) 324 p
12. Nikiforova N.S., Nguyen Van Hoa, and Alekseev G.V. Measured and forecast settlements of buildings near deep pits in Vietnam. in Journal of Physics: Conference Series. 2019. IOP Publishing, DOI 10.1088/1742-6596/1425/1/012059.
13. Peck R B. Deep excavation and tunnelling in soft ground. State of the art report. in Proc 7th Int Conf SMFE. 1969. Mexico City, pp 147-150.
14. Huynh, Q.T., Lai, V.Q., Boonyatee, T. et al. Behavior of a Deep Excavation and Damages on Adjacent Buildings: a Case Study in Vietnam. Transp. Infrastruct. Geotech. 8, 361–389 (2021). https://doi.org/10.1007/s40515-020-00142-7.
15. Nguyen, V.G., T.H. Nguyen, and T.D. Nguyen. Stabilize the Diaphragm Wall by the Method of Anchoring in the Ground in the I-Tower Project in Quy Nhon City, Binh Dinh Province. in CIGOS 2021, Emerging Technologies and Applications for Green Infrastructure: Proceedings of the 6th International Conference on Geotechnics, Civil Engineering and Structures. 2022. Springer.
16. Nguyen Van-Hoa and Nikiforova N S, 2017. Consideration of the features geological conditions when developing the underground space of Vietnam. Saint Pt, p277-281, Conferences Geotechnical engineering surveys, design and construction of foundations and underground structures.