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Influence of neighboring building on horizontal displacement of deep excavation diaphragm wall

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KEYWORDS
Plaxis
Geotechnical problem
Diaphragm wall
Construction
Neighboring building

ABSTRACT
The Plaxis model is built based on the finite element method, the application of this method to calculate and simulate geotechnical problems is based on the integration in the Morh-Coulomb and Hardening Soil foundation models, and some other models to evaluate the reliability of the problems. This paper has proposed a model area limit when analyzing deep excavations using Plaxis software, the model area limit depends on the excavation width, excavation depth and length of the diaphragm wall. Research on the influence of the model area limit on the results of horizontal displacement analysis of the diaphragm wall shows that once the model area limit has reached a reasonable size, expanding the model area limit has a negligible effect on the results of horizontal displacement analysis of the diaphragm wall in the excavation. With the specific nature of geotechnical works and complex terrain, construction on weak soil and checking the safety of construction methods are really necessary issues and need to be studied. This paper also considers the horizontal displacement of the diaphragm wall at the heights: -1.8m, -5.2m, -8.7m when considering the influence of neighboring structures with the height of the structure being 1-storey, 2-storey, 6-storey and 9-storey for the case with and without consolidation load.

1. Introduction

In construction, excessive vertical displacement or settlement can result in differential settlement or sliding phenomena, which may create instability for neighboring buildings, potentially leading to collapse. Conversely, the load from neighboring buildings during the basement construction exerts pressure that tends to push the deep excavation wall inward. When the displacement becomes significant, it can lead to serious consequences. The consequences of these effects can lead to harm to property and potentially endanger human life.

Numerous incidents have occurred in underground construction, prompting significant interest from various authors. For example, [1] examined the causes of deep excavation incidents and suggested several strategies for managing such incidents during deep excavation projects. The research was carefully analyzed and evaluated, complete with detailed explanations [2]. The system was described, risks were identified, and both qualitative and quantitative analyses were conducted, followed by proposed solutions to minimize those risks [3]. The author proposed risk classification levels based on a matrix, incorporating thresholds for managing sheet pile displacement, ground subsidence, and groundwater levels behind sheet pile walls. [4-5] also outlined the principles of calculation. Recent years have seen similar analyses conducted in various construction projects across Vietnam.

Vinh Long City has multiple basement construction projects, including the Viettel Building, Mobifone Building, Saigon-Vinh Long Hotel, Vincom Plaza Vinh Long Trade Center, Vinh Long Hospital, and additional structures. The geology in Vinh Long City is characterized by a weak composition, featuring a layer of clayey mud interspersed with sand and organic matter, exhibiting shades of gray, blue-gray, and brown-gray. The material flows in a plastic state and reaches a thickness of 28 meters, displaying a low bearing capacity of R = 0.4 kg/cm^2. The soil demonstrates significant compressibility with a value of a = 0.321 kg/cm^2, a high void ratio of e = 1.888, and considerable viscosity at B = 1.15. Additionally, it has a low deformation modulus of E = 3.7 kg/cm^2, minimal shear resistance, limited water permeability, and a high water content, with water saturation at G = 89.01 % (G > 80 %) and a small bulk density. The geology of Vinh Long City indicates the presence of weak soil. The construction of works involving deep excavations in this type of soil presents numerous challenges and considerable impacts, including a heightened risk of subsidence, tilting, and the potential collapse of adjacent houses. Consequently, comprehending the geological features of Vinh Long City and implementing preventive and enhancement strategies is crucial for ensuring the sustainability and safety of construction projects in this area.

Experimental methods are crucial for assisting researchers in determining the connection between real ground movements and construction parameters gathered from numerous comparable structures. This method, while grounded in general assumptions, remains a popular choice in the design field for conducting preliminary calculations. Presented here are several standard experimental methods suggested for forecasting the displacement

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resulting from excavation, featuring the approaches of Peck [6], Lambe [7], O'Rourke [8], and Clough and O'Rourke [9].

The study outlined in research [10] details the findings regarding the stability and displacement of continuous reinforced concrete diaphragm walls, along with the ground displacement surrounding deep excavation activities during construction. The calculation method employs finite elements through Plaxis software, and the prediction results are validated by actual measurements and observational data from a construction site in Ho Chi Minh City. The research highlights both the benefits and drawbacks of employing continuous reinforced concrete diaphragm walls in deep excavation projects involving water-saturated soft clay.

The study examines the deformation and stability of the surrounding ground during the construction of deep excavations in District 5, Ho Chi Minh City. The study outlines the construction of basement diaphragm walls, detailing the construction methods as well as the research and calculation techniques employed. This study compares the calculation results obtained from Plaxis software with actual monitoring results and analytical calculation results. The author provides conclusions and recommendations regarding the use of calculation methods and software to guarantee accuracy and practical application [11].

The study examines the risks associated with deep excavation construction, particularly in the context of high-rise building projects within urban environments. Deep excavation construction frequently faces intricate challenges, including subsidence, deformation of adjacent structures, instability of excavation support systems, and various other unfavorable external factors. The authors outline the principles of risk analysis in deep excavation construction and strategies to mitigate risks. This study additionally provides an illustrative application example for deep excavation in Dong Hoi [3].

A study [12] examined the factors influencing the displacement of the diaphragm wall in deep excavations built using the Bottom-up method in Ho Chi Minh City. This study employed the finite element method alongside the Plaxis 2D program to assess how factors such as depth, diaphragm wall thickness, horizontal strut spacing, and pre-jacking force in support systems affect the displacement of the diaphragm wall during deep excavation. The research findings indicated that enhancing the depth of the diaphragm wall will considerably influence the stability of the wall tip and decrease the horizontal displacement of the wall. The thickness of the diaphragm wall influences horizontal displacement, and the spacing of horizontal struts along with the pre-jacking force in the support systems significantly contribute to managing the displacement of the diaphragm wall.

A study [13] assessed the potential for instability at the base of a deep excavation pit resulting from alterations in the initial stress state and damaging water pressure. The outcomes of calculations employing mechanical methods alongside simulations with Plaxis 2D software were utilized to analyze, compare, and determine the suitable depth of the excavation pit in the context of a pressurized aquifer to guarantee stability. The calculations and comparative analysis revealed that the maximum excavation depth of the bottom of the excavation pit in this specific case was 5.4 m, aligning with the simulation results obtained from Plaxis 2D software, which did not take into account the tensile strength of the soil. The maximum calculated excavation depth of 7.1 m is deemed unsafe when evaluating the shear strength of the ground, as it fails to take into account the actual behavior of the ground.

Incidents occurring during the construction of high-rise building basements can impact adjacent structures, such as instances of muddy water flowing into the foundation pit's base (Figure 1). Water transports sand and soil, flowing into the basement (Figure 2):

Figure 1. Occurrence of muddy water entering the base of the foundation pit.

Figure 2. Water carries soil and sand into the basement.

This study simulated 11 cases of horizontal displacement of the deep excavation wall at heights of -1.8 m, -5.2 m, and -8.7 m. The analysis took into account the influence of neighboring buildings, considering heights of 1-storey, 2-storey, 6-storey, and 9-storey, both with and without consolidation load.

2. Materials and Methods

2.1. Problem model

The simulation problem diagram is shown in Figure 3:

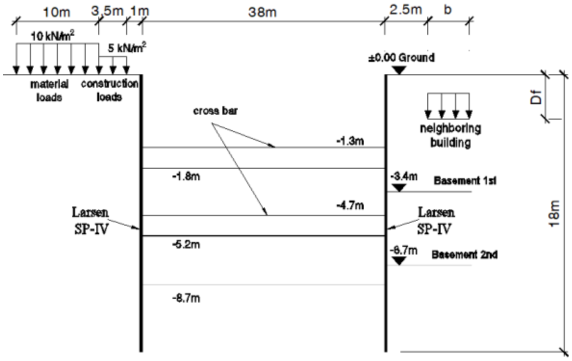

Figure 3. Problem diagram in this study.

2.2. Description of construction stages

- Step 1: Activate load and foundation of neighboring buildings

- Step 2: Consolidate neighboring buildings

- Step 3: Construct Larsen SP-IV piles

- Step 4: Consider temporary construction loads and construction loads

- Step 5: Excavate soil from elevation ±0.0 m to elevation -1.8 m, lower groundwater level.

- Step 6: Construct H350 shoring system at elevation -1.3 m.

- Step 7: Excavate soil from elevation -1.8 m to elevation -5.2 m, lower groundwater level.

- Step 8: Construct H400 shoring system at elevation -4.8 m.

- Step 9: Excavate soil from elevation -5.2 m to foundation bottom elevation -8.7 m.

In all simulation cases, the load of the neighboring building is considered in both the newly constructed case and the case that has been constructed for a long time (considered to have reached stable settlement). The displacement of the pile wall is only considered from the beginning of the excavation stage.

Simulation cases to survey the horizontal displacement of the diaphragm wall during excavation construction:

- Case 1: Do not consider the load of the neighboring building.

- Case 2: Consider the load of the neighboring buildings as 1-storey (load 105 kN/m). Melaleuca pile foundation, foundation depth D_f = -1.2 m. Pile tip depth -5.2 m.

- Case 3: Consider the load of the neighboring building as 2-storey (load 173 kN/m). Melaleuca pile foundation, foundation depth D_f = -1.2 m. Pile tip depth -5.2 m.

- Case 4: Consider the load of the neighboring building as 6-storey (load of 835 kN/m). The foundation consists of 6 prestressed centrifugal concrete piles with a diameter of D = 300 mm. Pile tip depth -31.2 m.

- Case 5: Consider the load of the neighboring building as 9-storey (load level of 1800 kN/m). The pile foundation consists of 6 prestressed centrifugal concrete piles with a diameter of D = 450 mm. Pile tip depth -41.2 m.

- Case 6: Consider the load of the neighboring building as 9-storey (load level of 2400 kN/m). The pile foundation consists of 6 prestressed centrifugal concrete piles with a diameter of D = 500 mm. Pile tip depth -41.2 m.

- Cases 7, 8, 9, 10 and 11: similar to Cases 2, 3, 4, 5 and 6 but taking into account the consolidation of adjacent building loads.

3. Results and discussions

The typical presentation for case 7 is as follows: Consider the consolidation of the load from the adjacent building as equivalent to 1-storey, with a load of 105 kN/m. Figure 4 illustrates the Melaleuca pile foundation, with a foundation depth D_f of -1.2 m and a pile tip depth of -5.2 m:

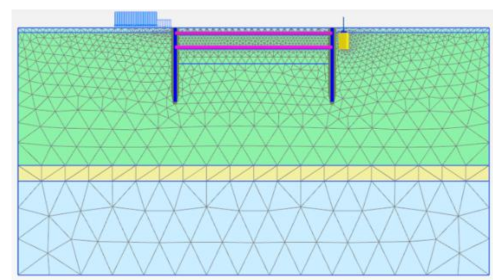

Figure 4. Problem diagram in simulation.

3.1. Horizontal displacement of diaphragm wall at excavation depths in simulation for typical case 7

The calculation results for Case 7 indicate that the neighboring building consists of 1-storey with a load of 105 kN/m. The Melaleuca pile foundation has a foundation depth of D_f = -1.2 m, with a pile tip depth of -5.2 m. The horizontal displacement of the wall at excavation depths of -1.8 m, -5.2 m, and -8.7 m is recorded as 0.086 m, 0.247 m, and 0.312 m, respectively.

Simultaneous simulation is conducted for all cases, and the results of horizontal displacement of the pile wall at excavation depths are shown in Figures 5, 6, 7, and in Table 1:

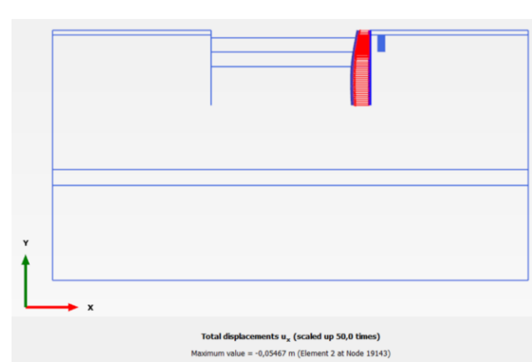

Fig.5. Horizontal displacement of the diaphragm wall (a depth of -1.8 m).

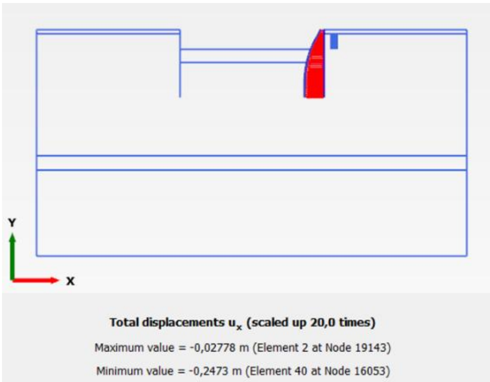

Fig.6. Horizontal displacement of the diaphragm wall (a depth of -5.2 m).

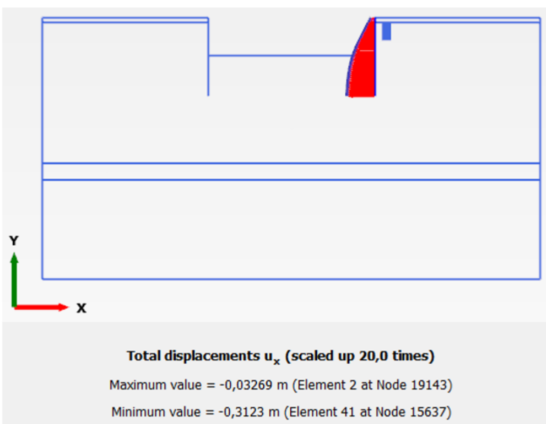

Fig.7. Horizontal displacement of the diaphragm wall (a depth of -8.7 m).

3.2. Horizontal displacement Ux excavation depth -1.8m

*1-storey neighboring building:

Horizontal displacement Ux case 1, case 2 and case 7 are shown in Figure 8:

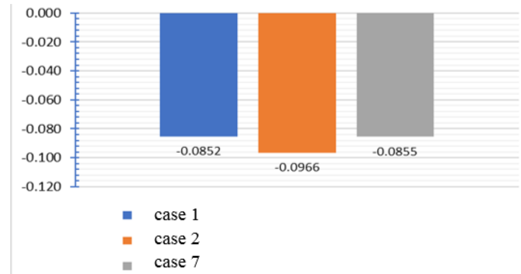

Figure 8. Horizontal displacement Ux Case 1, Case 2 and Case 7.

At a depth of -1.8 m (Figure 8), it is observed that Case 1 and Case 7 exhibit identical horizontal displacement values. In Case 2, the horizontal displacement Ux reaches its maximum value, exceeding the case without house load by 12 %. If consolidation is not taken into account for the same 1-storey house, the horizontal displacement is 11 % greater than when the load of the neighboring building is considered for consolidation. Consequently, even though the adjacent building consists of just 1-storey, if it has been reinforced, the horizontal displacement of the diaphragm wall will decrease by over 11 %, indicating that the building will be more secure throughout the construction process.

*2-storey neighboring building:

Horizontal displacement Ux case 3 and case 8 are shown in Figure 9:

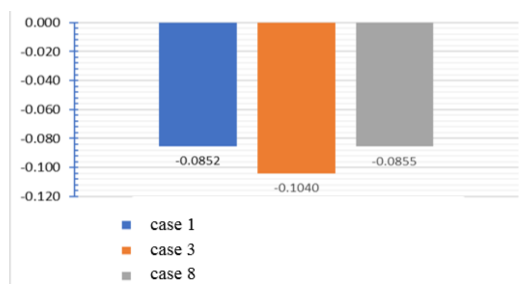

Figure 9. Horizontal displacement Ux case 3 and case 8.

Table 1. Results of horizontal displacement (HD) of diaphragm wall at different excavation depths.

No.	Cases	Load of neighboring building (kN/m)	Foundation depth	HD Ux at excavation depth -1,8m (m)	HD Ux at excavation depth -5,2m (m)	HD Ux at excavation depth -8,7m (m)
1	Case 1: No load on neighboring building	-	-	-0,0852	-0,2472	-0,3128
2	Case 2: 1-storey neighboring building	105	Pile foundation depth -5,2m	-0,0966	-0,2563	-0,3204
3	Case 7: 1-storey adjacent building (consolidation considered)	105	Pile foundation depth -5,2m	-0,0855	-0,2473	-0,3123
4	Case 3: 2-storey neighboring building	173	Pile foundation depth -5,2m	-0,1040	-0,2606	-0,3248

No.	Cases	Load of neighboring building (kN/m)	Foundation depth	HD Ux at excavation depth -1,8m (m)	HD Ux at excavation depth -5,2m (m)	HD Ux at excavation depth -8,7m (m)
5	Case 8: 2-storey adjacent building (consolidation considered)	173	Pile foundation depth -5,2m	-0,0855	-0,2468	-0,3107
6	Case 4: 6-storey neighboring building	835	D300 pile foundation depth -31,2m	-0,0991	-0,2550	-0,3127
7	Case 9: 6-storey adjacent building (consolidation considered)	835	D300 pile foundation depth -31,2m	-0,0813	-0,2355	-0,2921
8	Case 5: 9-storey neighboring building	1800	D500 pile foundation depth -41,2m	-0,1025	-0,2489	-0,3016
9	Case 10: 9-storey adjacent building (consolidation considered)	1800	D500 pile foundation depth -41,2m	-0,0791	-0,2234	-0,2749
10	Case 6: 9-storey neighboring building	2400	D500 pile foundation depth -41,2m	-0,1115	-0,2584	-0,3106
11	Case 11: 9-storey adjacent building (consolidation considered)	2400	D500 pile foundation depth -41,2m	-0,0790	-0,2228	-0,2732

At a depth of -1.8 m (Figure 9), akin to the 1-storey adjacent building, the 2-storey neighboring building, disregarding the consolidation of building loads, exhibits the highest horizontal displacement value Ux. The difference in performance between the 2-storey building, both with and without building load consolidation, is 21 %. Additionally, when the neighboring building transitions from 1-storey to 2-storey, the horizontal displacement doubles in the absence of consolidation. Furthermore, when comparing the horizontal displacement of case 3 to case 2 during the shift from 1-storey to 2-storey, there is an increase of 7 %.

*6-storey neighboring building:

Horizontal displacement Ux case 4 and case 9 are shown in Figure 10:

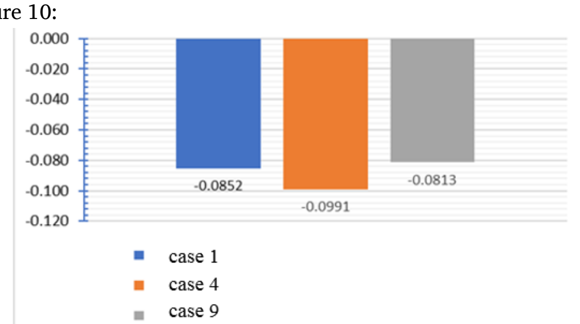

Figure 10. Horizontal displacement Ux case 4 and case 9.

At the excavation depth of -1.8 m (Figure 10), the horizontal displacement from 2-storey to 6-storey increased by 5 %. This value decreased from 1-storey to 2-storey, where the difference was 7 %. The value does not distinctly illustrate the impact of the horizontal displacement of the diaphragm wall when transitioning from 2-storey to 6-storey.

*9-storey neighboring building (load 1800 kN/m):

Horizontal displacement Ux for case 5 and case 10 is shown in Figure 11:

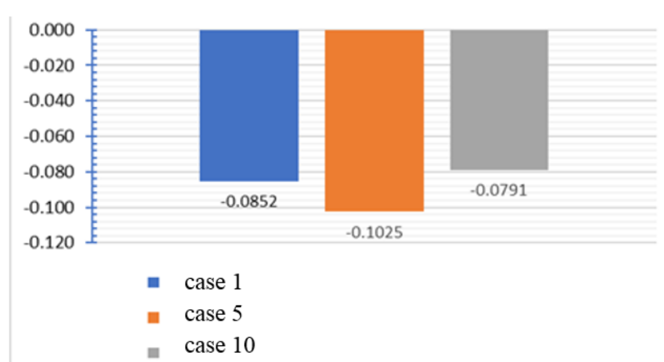

Figure 11. Horizontal displacement Ux case 5 and case 10.

At the excavation depth of -1.8 m (Figure 11), adjacent to a 9-storey building, the horizontal displacement of the diaphragm wall, when the load of the neighboring building is not applied, shows an increase of 8 % compared to a scenario where the load of the neighboring building is taken into account during consolidation. The fifth case of the 9-storey building, which involves horizontal displacement, is comparable to the third case.

*9-storey neighboring building (load 2400 kN/m):

Horizontal displacement Ux case 6 and case 11 are shown in Figure 12:

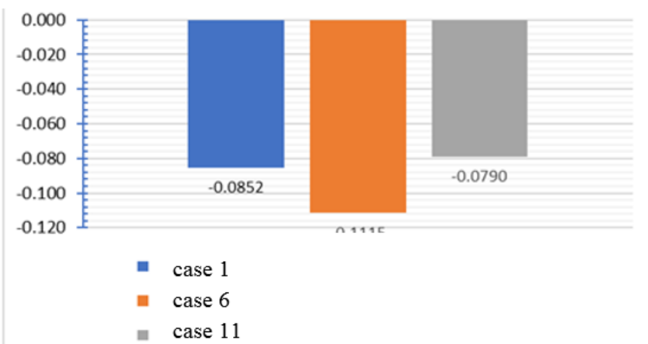

Figure 12. Horizontal displacement Ux case 6 and case 11.

At a depth of -1.8 m (Figure 12), the horizontal displacement of the 9-storey neighboring building (with an adjacent building load of 1800 kN/m) rose to 8 % of the 9-storey neighboring building (with an adjacent building load of 2400 kN/m).

3.3. Horizontal displacement Ux excavation depth -5.2m

*1-storey neighboring building:

Horizontal displacement Ux case 2 and case 7 are shown in Figure 13:

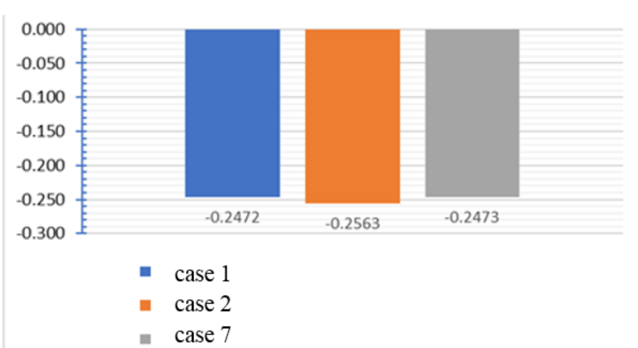

Figure 13. Horizontal displacement Ux case 2 and case 7.

At the excavation depth of -5.2 m (Figure 13), the differences among case 1, case 2, and case 7 are minimal. Increasing the excavation depth to -5.2 m for a 1-storey building, whether considering building load consolidation or not, yields the same result.

*2-storey neighboring building:

Horizontal displacement Ux case 3 and case 8 are shown in Figure 14:

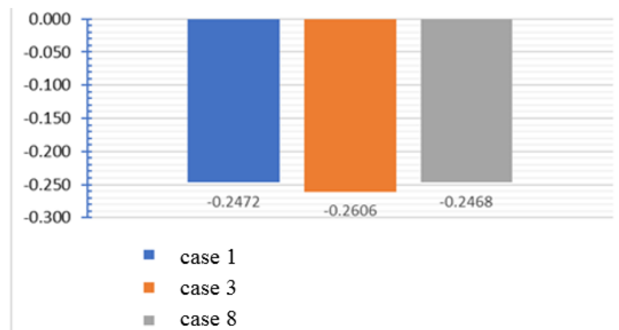

Figure 14. Horizontal displacement Ux case 3 and case 8.

At the excavation depth of -5.2 m (Figure 13) and (Figure 14), the difference in horizontal displacement is minimal, measuring at 1.6 %. At this depth, the transition from 1-storey to 2-storey remains consistent.

*6-storey neighboring building:

Horizontal displacement Ux case 4 and case 9 is shown in Figure 15:

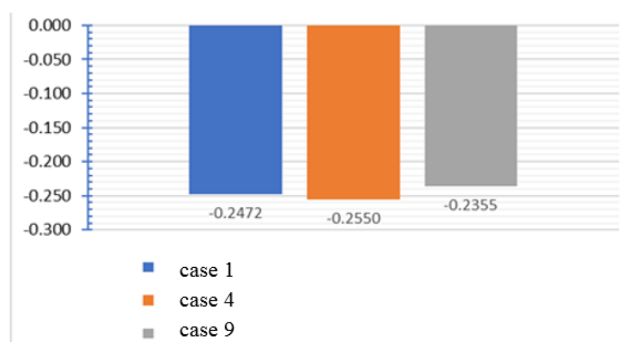

Figure 15. Horizontal displacement Ux case 4 and case 9.

At the excavation depth of -5.2 m (Figure 15), the horizontal displacement gradually increases from the 1-storey to the 2-storey and then begins to decrease for case 4, which involves a 6-storey building that does not take into account the consolidation of building loads. The horizontal displacement reduces by 2 % when comparing a 6-storey building to a 2-storey building.

*9-storey neighboring building (load 1800 kN/m):

Horizontal displacement Ux case 5 and case 10 are shown in Figure 16.

At the excavation depth of -5.2 m (Figure 16), the horizontal displacement continues to decrease and is 3 % smaller than that of the 1-storey building, indicating that as the excavation depth increases from -1.8 m to -5.2 m, the horizontal displacement gradually diminishes.

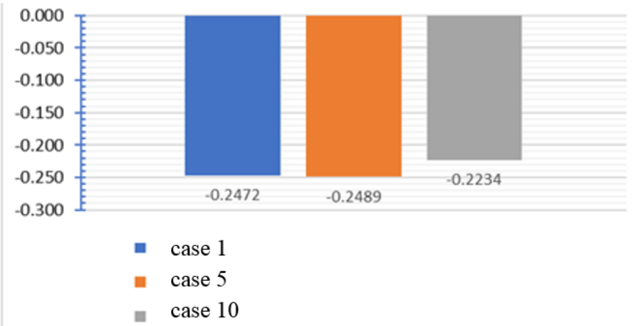

Figure 16. Horizontal displacement Ux case 5 and case 10.

*9-storey neighboring building (load 2400 kN/m):

Horizontal displacement Ux case 6 and case 11 are shown in Figure 17:

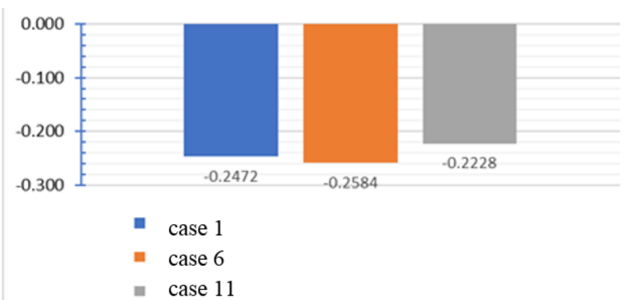

Figure 17. Horizontal displacement Ux case 6 and case 11.

At a depth of -5.2 m (Figure 17), the 9-storey building with a building load of 2400 kN/m experiences a 4 % increase in horizontal displacement compared to the 9-storey building with a load of 1800 kN/m. The distinction between case 6 and case 11 is 16 %, both when factoring in and excluding building load consolidation.

3.4. Horizontal displacement Ux excavation depth -8.7m

*1-storey neighboring building:

Horizontal displacement Ux case 2 and case 7 are shown in Figure 18:

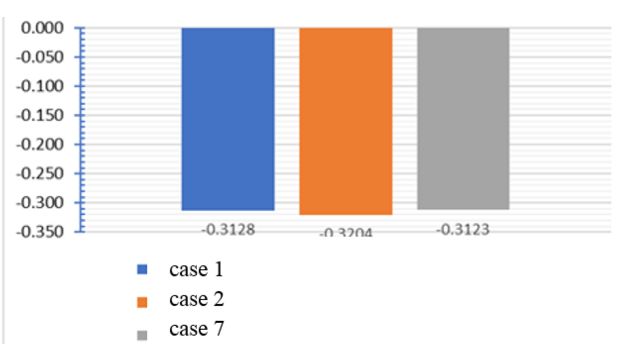

Figure 18. Horizontal displacement Ux case 2 and case 7.

At the excavation depth of -8.7 m (Figure 18), in comparison to the 1-storey building at the same depth, the increase from the excavation depth of -5.2 m is noted as shifting from -0.2563 m to -0.3204 m. In contrast, when looking at case 2 of the 1-storey building at the excavation depth of -1.8 m, it decreases to 0.0966.

*2-storey neighboring building:

Horizontal displacement Ux case 3 and case 8 are shown in Figure 19:

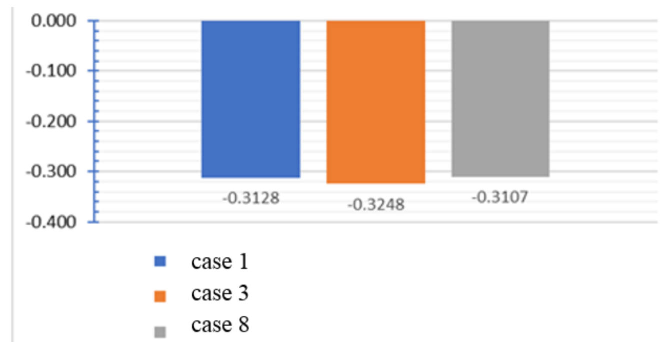

Figure 19. Horizontal displacement Ux case 3 and case 8.

At the excavation depth of -8.7 m (Figure 19) equivalent to the horizontal displacement of a 1-storey building with a displacement of -0.3248 m.

*6-storey neighboring building:

Horizontal displacement Ux case 4 and case 9 is shown in Figure 20:

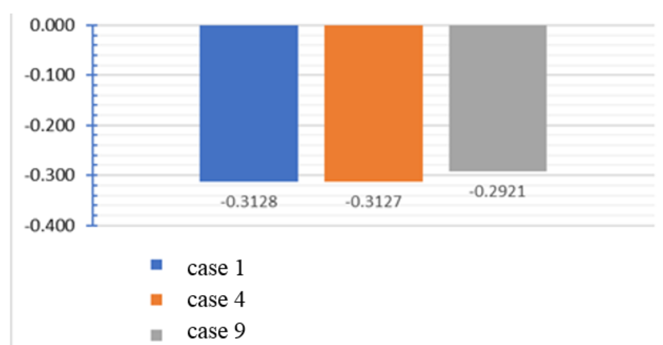

Figure 20. Horizontal displacement Ux case 4 and case 9.

At the excavation depth of -8.7 m (Figure 20) and also equivalent to case 3 and case 8 2-storey building with the same excavation depth of -8.7 m.

*9-storey neighboring building (load 1800 kN/m):

Horizontal displacement Ux case 5 and case 10 are shown in Figure 21.

At excavation depth -8.7 m (Figure 21): case 5 is reduced by 4 % compared to case 4 (Figure 20).

Figure 21. Horizontal displacement Ux case 5 and case 10.

*9-storey neighboring building (load 2400 kN/m):

Horizontal displacement Ux case 6 and case 11 are shown in Figure 22:

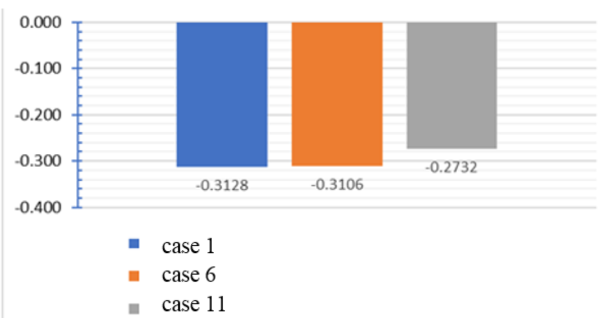

Figure 22. Horizontal displacement Ux case 6 and case 11.

At excavation depth -8.7 m (Figure 22): horizontal displacement increased by 3 % compared to case 5 (Figure 21).

4. Conclusions

In 1- to 2-storey buildings utilizing shallow foundations on Melaleuca piles, the horizontal displacement of the diaphragm wall remains nearly constant as the load level rises. This indicates that, in these circumstances, the load level does not play a crucial role in the wall's displacement.

In high-rise buildings that utilize reinforced concrete pile foundations, it is observed that the horizontal displacement of the wall tends to diminish slightly as the load level rises. Nonetheless, this reduction is minimal, suggesting that the wall's horizontal displacement is independent of the building's load level.

The depth of the foundation significantly influences the horizontal displacement of the diaphragm wall. The greater the depth of the foundation, the lesser the horizontal movement of the wall. The majority of the significant displacements are observed at the base of the wall, where the foot is situated in a clay layer that exhibits weak displacement, while the wall itself is embedded in the ground without any anchoring.

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