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# IMPACT OF BARRETTE WALL THICKNESS ON DISPLACEMENT AND FORCE IN DEEP EXCAVATION PROJECT

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**ABSTRACT:** This study investigates the impact of barrette wall thickness on the stability of the deep excavation project, particularly focusing on horizontal and vertical displacements, axial forces, and moments. Using the finite element method (FEM), simulations were conducted on barrette walls with thicknesses of 600 mm, 800 mm, and 1000 mm. The results revealed that while thicker walls marginally reduce both horizontal and vertical displacements, the improvements are not significant enough to warrant the additional costs. Statistical analysis, including ANOVA and the Games-Howell test, confirmed barrette wall thickness on structural stability, with the 600 mm wall demonstrating sufficient strength to maintain the integrity of the excavation. This suggests that a 600 mm wall thickness provides the most cost-effective solution for urban excavation projects without compromising safety. The findings contribute to the existing body of knowledge by offering practical insights into optimizing wall thickness for deep excavation, emphasizing the importance of balancing structural performance with economic considerations.

*Keywords: Barrette wall thickness, Deep excavation stability, Finite element method (FEM), Structural displacement,*

## 1. INTRODUCTION

In the context of rapid urbanization, the demand for developing underground infrastructure and deep excavation projects is becoming increasingly prevalent, especially in large cities [1]. These projects present significant technical challenges to ensure the safety and stability of both the construction itself and the surrounding areas [1-3]. One crucial factor determining the success of deep excavation projects is the load-bearing capacity and deformation control of barrette walls. These walls not only provide stability for excavation pits but also minimize impacts on nearby structures and infrastructure. However, the key question remains: how to optimize the thickness of barrette walls to achieve both safety and cost-efficiency under the complex construction conditions of urban environments?

Previous studies have indicated that optimizing the layout of barrette walls can help reduce deformation and enhance structural stability [4-6]. However, many of these studies have primarily focused on the horizontal load-bearing capacity of the walls without delving deeply into the specific impact of wall thickness on important technical factors, such as deformation and axial force [7, 8]. Moreover, the lack of statistical analysis tools to evaluate the significance of differences between various thickness options has limited the ability of these studies to offer clear, practical recommendations. This gap is what our research aims to address, providing a more detailed understanding of the role of barrette wall thickness in urban deep excavation projects.

Our study distinguishes itself by not only relying on finite element method (FEM) simulations for structural analysis but also applying the statistical ANOVA method to assess the effectiveness and significance of each wall thickness. We conducted experiments with three common thicknesses, 600 mm, 800 mm, and 1000 mm, to evaluate their impact on deformation and axial force. ANOVA allows us to examine the differences between these options and determine whether the variations are statistically significant enough to justify design changes.

The research process is designed to provide practical data for optimizing the design of barrette walls. Simulations are conducted under typical urban conditions, carefully considering factors such as hydrostatic pressure, soil mechanical properties, and specific technical requirements.

This study not only builds upon previous research but also introduces a new approach by integrating statistical methods into the structural design evaluation process. This approach enhances reliability, providing engineers and designers with clear scientific evidence to inform their decisions on barrette wall design. Furthermore, the research lays the groundwork for future applications, where the need for cost optimization and safety assurance will become even more critical. Integrating statistical methods with numerical simulations ensures both objectivity in results and improved practical applicability of research findings in real-world projects.

The structure of the article includes: The research methodology section presents the assumptions and the FEM simulation process along with ANOVA analysis; the results and discussion section evaluates the effectiveness of different wall thicknesses based on deformation and axial force; the final section provides conclusions, recommendations for future projects, and discusses limitations and future research directions.

## 2. RESEARCH SIGNIFICANCE

This study holds significant implications for both the scientific community and practical engineering applications. By examining the impact of barrette wall thickness on the stability of deep excavations, this research provides valuable insights into optimizing structural designs that balance safety and cost-efficiency. The findings challenge the common assumption that thicker walls always offer better stability, instead demonstrating that a 600 mm thickness can be sufficient in maintaining structural integrity while minimizing costs. These results can directly influence the design and execution of future urban excavation projects, contributing to more efficient and economically viable construction practices.

## 3. MATERIAL AND METHOD

The study site is located in the center of Ho Chi Minh City, Vietnam. The geological structure of the area is characterized by layers of clay and sandy soil, with the clay layer having a thickness of 7.5 meters, while the sandy soil reaches a thickness of 32.5 meters, and the groundwater level is at a depth of -4 meters (Table 1). The parameters of the geological layers were obtained from the geotechnical engineering survey report. During the survey, triaxial compression tests, shear tests, and Standard Penetration Tests (SPT) were conducted to collect input data for the simulations used in this study. The excavation pit measures 11 meters in width and 44 meters in length and extends to a depth of 15 meters (Fig. 1). This setup provides a representative model for urban excavation projects.

To support the excavation (Fig. 2), a shoring system consisting of four layers has been implemented at depths of 1 meter, 4.6 meters, 7.1 meters, and 9.6 meters (Table 2) [9, 10]. The barrette walls, which are critical to the stability of the excavation, were tested with three different thicknesses: 600 mm, 800 mm, and 1000 mm, with a length of 30 m (Table 3). These thicknesses were selected to evaluate the impact on the overall structural integrity and displacement behaviors of the wall and surrounding soil.

The Plaxis 3D software was used to conduct finite element method (FEM) simulations. This software enables detailed analysis of the displacement and forces of barrette walls under various geological conditions. The finite element model was discretized into 15-node triangle elements, including nodes along the edges and inside the element, ensuring high accuracy [11-14]. The simulations were conducted under controlled conditions, keeping other variables constant, including soil type, excavation depth, and groundwater levels [15-17]. The materials were assumed to exhibit elastic behavior. The boundary conditions applied to the shoring system permitted horizontal displacement while constraining vertical movement at the midpoint of each layer. This approach allowed for a focused examination of how changes in wall thickness directly influence the performance of the excavation.

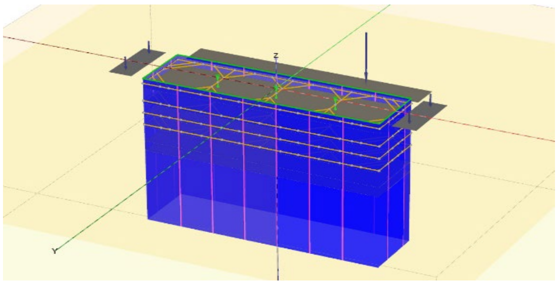

Fig. 1 Overview of deep excavations for wall thicknesses of 600, 800, and 1000 mm

Table 1. Soil description parameters

| Parameter | Soil type | |
|---|---|---|
| | Clay | Sand |
| Soil model | Hardening soil | Hardening soil |
| Drainage | Undrained | Undrained |
| $\gamma_w$ (kN/m$^3$) | 20.25 | 20.12 |
| $\gamma_{sat}$ (kN/m$^3$) | 20.57 | 20.55 |
| $e_{init}$ | 0.5879 | 0.5810 |
| $n_{init}$ | 0.3702 | 0.3675 |
| $E_{50}^{ref}$ (kN/m$^2$) | 6875 | 13.45E3 |
| $E_{oed}^{ref}$ (kN/m$^2$) | 6875 | 13.45E3 |
| $E_{ur}^{ref}$ (kN/m$^2$) | 20.63E3 | 40.35E3 |
| $\upsilon_{ur}$ | 0.2 | 0.2 |
| Power (m) | 0.8 | 0.65 |
| $P^{ref}$ (kN/m$^2$) | 38 | 400 |
| $C'^{ref}$ (kN/m$^2$) | 7.1 | 5.7 |
| φ' (°) | 30.40 | 30 |
| Ψ (°) | 0.4 | 0 |
| $K_z$ (m/day) | 1.43E-05 | 6.91E-6 |
| $K_x = K_y$ (m/day) | 3.59E-05 | 0.138E-3 |

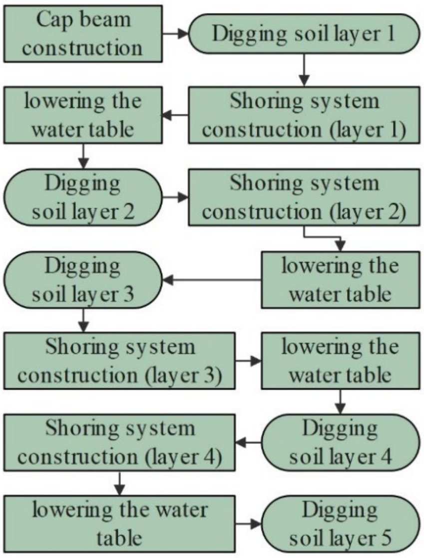

Fig. 2 Excavation process.

To ensure the statistical validity of the findings, an ANOVA (Analysis of Variance) test was conducted. This statistical method was used to determine the significance of differences in the displacement and stress results across the different wall thicknesses. The ANOVA test provided a robust framework for validating the simulation results, confirming whether the observed variations were statistically significant (Fig. 3).

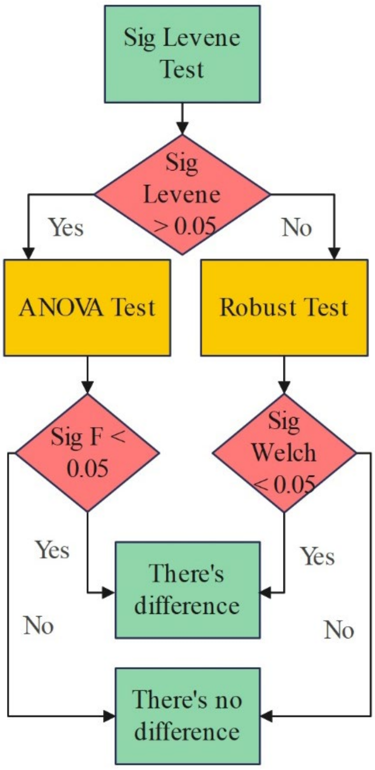

Fig. 3 The ANOVA Testing Process

Table 2. Parameters describing shoring system materials

| Parameter | Value |
|---|---|
| Material type | Elastic |
| Y (kN/m$^3$) | 78.5 |
| A (m$^2$) | 0.02187 |
| I2 (m$^4$) | 0.666E-3 |
| I3 (m$^4$) | 0.224E-3 |
| E (kN/m$^2$) | 210.0E6 |

In this study, the Games-Howell post hoc test was utilized to analyze the differences between group means after conducting an ANOVA [18]. The Games-Howell test is particularly useful in situations where the assumption of equal variances is violated, as it does not require homogeneity of variances and adjusts for unequal sample sizes. The analysis was performed using data from different wall thicknesses (600 mm, 800 mm, and 1000 mm), which were compared across various structural parameters such as displacements, axial forces, and moments. The test provided pairwise comparisons between the groups, highlighting statistically significant differences with adjusted confidence intervals to ensure robustness in the presence of unequal variances.

Table 3. Description parameters of barrette wall material

| Parameter | Value |
|---|---|
| Material type | Elastic |
| Y (kN/m$^3$) | 8 |
| E1 (kN/m$^2$) | 32.50E6 |
| E2 (kN/m$^2$) | 32.50E6 |
| D (m) | 0.6; 0.8; 1.0 |
| G12 (kN/m$^2$) | 16.25E6 |
| G13 (kN/m$^2$) | 16.25E6 |
| G23 (kN/m$^2$) | 16.25E6 |

*Note: D = 0.6, 0.8, and 1.0 correspond to barrette wall thicknesses of 0.6, 0.8, and 1.0, respectively.*

## 4. RESULTS

### 4.1 Displacements and Forces Through Descriptive Statistics

Initially, cap beams were constructed to connect and stabilize the barrette walls (Table 4). Following this, the soil excavation began, proceeding in phases to minimize the impact on the surrounding environment. Concurrently, a shoring system was installed, with layers placed at depths of -1 meter, -4.6 meters, -7.1 meters, and -9.6 meters to further stabilize the excavation site. Groundwater with water levels strategically lowered at various depths (-6 m, -9 m, -13 m, and -16 m).

Table 5. Descriptive Statistics results

| Thickness | Var | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| 600 | Ux (mm) | -16.6 | 16.6 | 0.0 | 2.9 |
| | Uy (mm) | -43.5 | 39.2 | -1.5 | 19.8 |
| | Uz (mm) | 17.2 | 19.4 | 18.2 | 0.7 |
| | N1 (kN/m) | -2264.4 | 2293.1 | -122.4 | 244.5 |
| | N2 (kN/m) | -1417.7 | 572.0 | -434.4 | 252.7 |
| | Q12 (kN/m) | -754.8 | 761.1 | 0.4 | 66.1 |
| | Q23 (kN/m) | -1498.8 | 1479.9 | -0.1 | 142.3 |
| | Q13 (kN/m) | -2033.2 | 3033.9 | 19.8 | 199.5 |
| | M11 (kN m/m) | -874.6 | 653.1 | 28.3 | 177.7 |
| | M22 (kN m/m) | -1252.6 | 332.0 | 30.1 | 173.4 |
| | M12 (kN m/m) | -285.2 | 285.2 | 0.5 | 68.1 |
| 800 | Ux (mm) | -14.6 | 14.6 | 0.0 | 2.6 |
| | Uy (mm) | -38.9 | 35.7 | -1.3 | 18.1 |
| | Uz (mm) | 17.1 | 19.0 | 18.0 | 0.6 |
| | N1 (kN/m) | -2678.6 | 2730.6 | -129.0 | 265.8 |
| | N2 (kN/m) | -1409.3 | 723.6 | -459.1 | 277.4 |
| | Q12 (kN/m) | -874.5 | 879.7 | 0.4 | 70.2 |
| | Q23 (kN/m) | -1634.5 | 1635.1 | -0.2 | 160.3 |
| | Q13 (kN/m) | -2443.5 | 3438.5 | 25.2 | 241.6 |
| | M11 (kN m/m) | -1113.7 | 959.3 | 79.1 | 280.2 |
| | M22 (kN m/m) | -1606.0 | 481.0 | 44.9 | 277.4 |
| | M12 (kN m/m) | -443.7 | 443.8 | 0.9 | 110.6 |
| 1000 | Ux (mm) | -13.3 | 13.2 | 0.0 | 2.4 |
| | Uy (mm) | -35.6 | 32.9 | -1.1 | 16.9 |
| | Uz (mm) | 17.0 | 18.7 | 17.9 | 0.5 |
| | N1 (kN/m) | -3029.2 | 3100.1 | -136.5 | 283.8 |
| | N2 (kN/m) | -1448.4 | 867.4 | -480.1 | 300.3 |
| | Q12 (kN/m) | -1001.6 | 1007.9 | 0.4 | 73.8 |
| | Q23 (kN/m) | -1982.5 | 1982.9 | -0.3 | 180.1 |
| | Q13 (kN/m) | -2747.3 | 3780.3 | 30.7 | 280.5 |
| | M11 (kN m/m) | -1241.3 | 1308.0 | 160.6 | 397.6 |
| | M22 (kN m/m) | -1929.3 | 664.1 | 61.4 | 408.8 |
| | M12 (kN m/m) | -608.6 | 608.6 | 1.1 | 152.3 |

Table 4. Cap beam material description parameters

| Parameter | Value |
|---|---|
| Material type | Elastic |
| Y (kN/m$^3$) | 25 |
| Height (m) | 0.8; 1.0 |
| Width (m) | 0.8; 1.0 |
| A (m$^2$) | 0.02187 |
| I2 (m$^4$) | 0.666E-3 |
| I3 (m$^4$) | 0.224E-3 |
| E (kN/m$^2$) | 210.0E6 |

*Note: Height (m) = 0.8 and Width (m) = 0.8 for barrette wall thicknesses of 0.6 and 0.8. Height (m) = 1.0 and Width (m) = 1.0 for a barrette wall thickness of 1.0.*

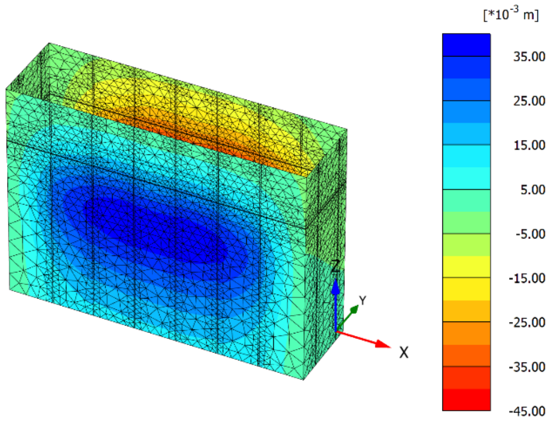

Fig. 4 Displacements in the Uy direction (600 mm)

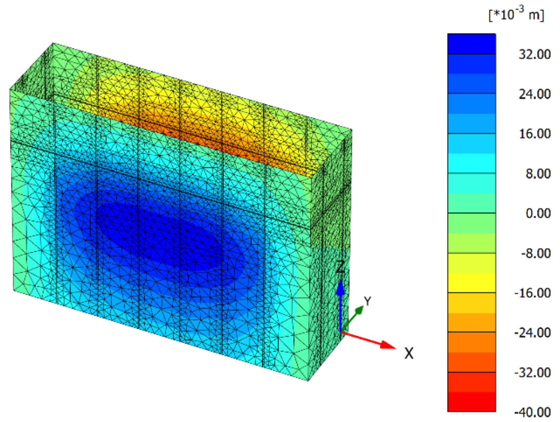

Fig. 5 Displacements in the Uy direction (800 mm)

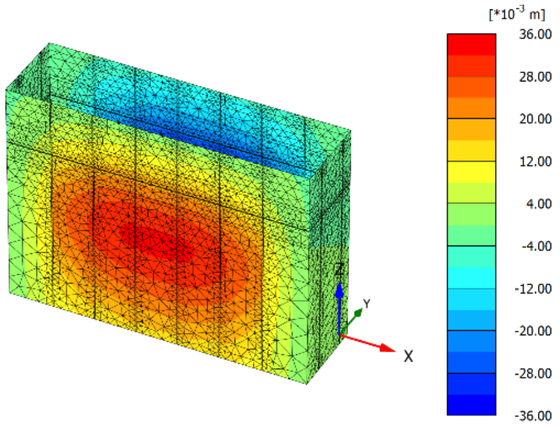

Fig. 6 Displacements in the Uy direction (1000 mm)

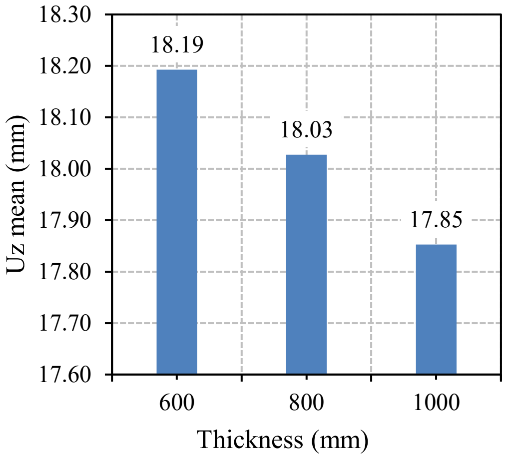

Fig. 7 Vertical displacement

The simulation results for wall thicknesses 600 mm (DW600) (Fig. 4), 800 mm (DW800) (Fig. 5), and 1000 mm (DW1000) (Fig. 6) provide detailed insights into the behavior of these structures under simulated conditions. The displacement values (Ux, Uy, Uz), axial forces (N1, N2), shear forces (Q12, Q23, Q13), and moments (M11, M22) were thoroughly analyzed for each scenario (Table 5).

The results indicate that increasing wall thickness does not significantly improve performance in terms of vertical displacement (Uz). Specifically, the average vertical displacement values decreased only slightly with increased wall thickness, with values of 18.19285 mm, 18.027485 mm, and 17.852472 mm for walls of 600 mm, 800 mm, and 1000 mm thickness, respectively (Fig. 7). This minor reduction suggests that increasing wall thickness does not correspondingly decrease the rate of vertical displacement.

Furthermore, the horizontal displacements (Ux and Uy) and moments (M11, M22) also show only minor variations among different wall thicknesses. These slight differences further emphasize that increasing wall thickness does not significantly improve the stability of the structure or reduce horizontal displacement. The analysis also reveals that axial forces (N1, N2) and shear forces (Q12, Q23, Q13) vary with changes in wall thickness. However, these variations do not follow a clear trend that suggests a significant advantage of one wall thickness over another in terms of overall stability. The statistical dispersion (as indicated by the standard deviation) is fairly uniform across different wall thicknesses, indicating the limited impact of wall thickness on these parameters.

### 4.2 ANOVA and Games-Howell Tests

The homogeneity of variance test table, utilizing Levene's statistic (Table 6), indicates that the variance among the different wall thickness groups is significantly different for all measured variables (e.g., Ux, Uy, Uz, N1, etc.). This is demonstrated by the p-values (Sig.) being 0.000 in all tests, meaning the assumption of variance homogeneity has been violated. This explains why using the Robust test method and the Games-Howell post-hoc test is appropriate.

Table 7 presents the results of the Welch test, which is used when the assumption of equal variances is violated. The results indicate that for most variables (e.g., Uy, Uz, N1, N2, Q13, M11, M22), the mean differences between groups are statistically significant, as demonstrated by p-values (Sig.) less than 0.05. However, for variables Ux, Q12, Q23, and M12, the p-values are greater than 0.05, suggesting no significant mean differences between groups for these variables.

The Games-Howell analysis reveals statistically significant differences between wall thicknesses (600 mm, 800 mm, and 1000 mm) for many study variables. Specifically, vertical displacement (Uz) shows a slight difference with increasing wall thickness, with mean changes of 0.165361 mm between 600 mm and 800 mm and 0.340374 mm between 600 mm and 1000 mm, with a significance p-value of 0.000. Similarly, axial forces (N1 and N2) also show significant differences, with N1 increasing by 14.112323 kN/m and N2 by 45.651767 kN/m as wall thickness increases from 600 mm to 1000 mm, suggesting that thicker walls have better load-bearing capacity during excavation. For moments (M11 and M22), results also show significant differences between wall thicknesses, especially with a marked increase in the moment when wall thickness increases from 600 mm to 1000 mm. Horizontal displacement (Uy) shows significant differences between 600 mm and 1000 mm walls but not significantly between 800 mm and 1000 mm. In summary, the Games-Howell analysis affirms that wall thickness has a substantial impact on structural parameters in excavation projects, particularly regarding vertical displacement, axial forces, and moments, underscoring the importance of optimizing wall thickness to ensure the safety and stability of the structure.

Table 6. Test of Homogeneity of Variances

| Var | Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|---|
| Ux | 89.719 | 2 | 158721 | 0.000 |
| Uy | 554.383 | 2 | 158721 | 0.000 |
| Uz | 5251.452 | 2 | 158721 | 0.000 |
| N1 | 178.672 | 2 | 158721 | 0.000 |
| N2 | 331.775 | 2 | 158721 | 0.000 |
| Q12 | 63.113 | 2 | 158721 | 0.000 |
| Q23 | 483.292 | 2 | 158721 | 0.000 |
| Q13 | 1308.510 | 2 | 158721 | 0.000 |
| M11 | 11598.659 | 2 | 158721 | 0.000 |
| M22 | 16631.541 | 2 | 158721 | 0.000 |
| M12 | 4809.127 | 2 | 158721 | 0.000 |

Table 7. Robust Tests of Equality of Means

| Var | Statistica | df1 | df2 | Sig. |
|---|---|---|---|---|
| Ux | 0.024 | 2 | 105278.725 | 0.976 |
| Uy | 6.874 | 2 | 105378.567 | 0.001 |
| Uz | 4430.350 | 2 | 104225.894 | 0.000 |
| N1 | 37.630 | 2 | 105416.747 | 0.000 |
| N2 | 365.554 | 2 | 105285.934 | 0.000 |
| Q12 | 0.006 | 2 | 105600.116 | 0.994 |
| Q23 | 0.019 | 2 | 104854.286 | 0.981 |
| Q13 | 27.534 | 2 | 103773.715 | 0.000 |
| M11 | 2649.022 | 2 | 96093.699 | 0.000 |
| M22 | 157.483 | 2 | 95304.235 | 0.000 |
| M12 | 0.472 | 2 | 95676.012 | 0.624 |

## 5. DISCUSSION

In comparison with prior research, where the horizontal displacement limit was established at 1/200 for cases involving "expected superficial damage," this translates to a maximum allowable displacement of 75 mm for a 15-meter deep excavation. Our study evaluated wall thicknesses of 600 mm, 800 mm, and 1000 mm, and the results indicate that all these thicknesses produced horizontal displacements well below the 75 mm threshold. Specifically, the horizontal displacement for the 600 mm wall was significantly lower than this limit (Table 8), ensuring that the structural integrity remains uncompromised and the risk of superficial damage to buildings and rigid pipelines is mitigated.

The significance of our findings lies in the fact that the 600 mm wall thickness proves to be the most economical and technically viable option. Although increasing the wall thickness to 800 mm or 1000 mm slightly reduces vertical displacement (Uz) and horizontal displacement (Uy), the improvements are marginal. For instance, the vertical displacement decreased from 18.192 mm for the 600 mm wall to 17.852 mm for the 1000 mm wall, and similar trends were observed for horizontal displacement. These minimal gains do not justify the additional costs associated with thicker walls, making the 600 mm thickness the most cost-effective solution.

Table 8. Comparison of horizontal displacement results

| Var | FEM | | | Rankin (1988) |
|---|---|---|---|---|
| | 600 | 800 | 1000 | Limit |
| Uy (mm) | 43.472 | 38.937 | 35.6 | 75 |

Further examination of other observed variables, such as axial forces and moments, supports the conclusion that increasing wall thickness does not significantly improve performance. The axial force N1 increased by 14.112 kN/m and N2 by 45.652 kN/m as wall thickness increased from 600 mm to 1000 mm, indicating that while thicker walls do enhance load-bearing capacity, the impact is not substantial enough to outweigh the costs. Similarly, moments (M11 and M22) showed significant changes with increasing wall thickness, but these benefits are not uniformly observed across all structural parameters.

Our research on the impact of barrette wall thickness on the stability of deep excavation projects offers different and complementary perspectives compared to previous studies. The prior research focused on analyzing the stability mechanisms of backfill materials after mining using FLAC3D simulations, with the primary failure mechanisms being sliding or crushing, depending on the mine depth and the rock-wall closure. Meanwhile, our study extends beyond material stability to analyze the role of wall thickness in reducing deformation and axial forces in urban conditions, emphasizing that a 600 mm wall thickness is sufficient to meet safety requirements without the need for increased thickness. Similarly, previous research indicated that well-arranged groups of barrette walls can reduce horizontal deformation through numerical models based on p-y curve analysis but did not emphasize the effect of wall thickness. Our research fills this gap by demonstrating that a 600 mm thickness is adequate to ensure stability for deep excavation projects. This distinction shows that while previous studies focused heavily on horizontal resistance and soil-wall interaction, our research broadens the perspective by highlighting the impact of wall thickness on cost efficiency and practical applicability in urban projects with budget constraints.

Although the FEM simulations provide valuable insights into the effects of wall thickness on displacement and structural performance, it is important to consider the limitations of the model. For example, factors such as soil heterogeneity, variations in groundwater levels, and the influence of external loads, such as traffic or nearby construction activities, were not explicitly included in the simulations. Future studies could expand on these findings by incorporating these variables into the model to better understand their combined effects on deep excavation stability. For future research, it is essential to explore the effects of other factors, such as material properties and environmental conditions, on the stability of deep excavation projects. Understanding these influences could lead to more comprehensive design guidelines that ensure both safety and efficiency in similar future projects.

## 6. CONCLUSION

This study employed finite element method (FEM) simulations to analyze the impact of barrette wall thickness (600 mm, 800 mm, 1000 mm) on displacement and force in deep excavation projects. The key research questions focused on determining the optimal wall thickness that balances structural performance with cost efficiency and understanding how wall thickness affects displacements. The analysis included statistical methods such as ANOVA and the Games-Howell test to validate the findings. The key findings indicate that a wall thickness of 600 mm is sufficient to maintain structural integrity, as it results in horizontal and vertical displacements well below critical thresholds, such as the 75 mm limit established by Rankin. Specifically, the horizontal displacement for the 600 mm wall was significantly lower than this threshold, which indicates its ability to prevent superficial damage to adjacent structures. Although increasing the wall thickness to 800 mm or 1000 mm marginally reduces vertical displacement from 18.192 mm to 17.852 mm, the improvement is not substantial enough to justify the additional costs. This suggests that the 600 mm wall thickness is the most cost-effective and technically viable option.

By providing a comprehensive analysis of various structural parameters, such as axial forces and moments, this study underscores the limited benefits of increasing wall thickness in terms of overall structural performance. The findings emphasize that while thicker walls do offer slight improvements in load-bearing capacity, these are outweighed by the increased costs and the minimal gains in displacement reduction. As a result, the study provides clear guidance for the design of deep excavation projects, suggesting that a 600 mm wall thickness is sufficient for most applications without compromising safety.

The limitation of this study lies in its reliance on finite element method (FEM) simulations without field validation. The simulations were conducted under the specific geological conditions of the central area of Ho Chi Minh City, where layers of clay and sand exist, along with groundwater at a depth of -4 meters. Therefore, the results of the study may not be fully applicable to areas with different geological conditions and groundwater levels.

In terms of practical application, the results of this research can be directly used in the planning and execution of urban excavation projects. Engineers can utilize the insights from this study to optimize the design of retaining walls, ensuring both cost efficiency and structural stability. Moreover, the research highlights the importance of considering economic factors alongside technical specifications when selecting wall thickness, which is crucial for the successful completion of construction projects. Future studies should build on this foundation by exploring the impact of material properties and environmental conditions on wall performance, thereby enhancing the robustness and applicability of these findings.

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