JTE HCMUTE
ISSN: 2615-9740

JOURNAL OF TECHNICAL EDUCATION SCIENCE
Ho Chi Minh City University of Technology and Education
Website: https://jte.hcmute.edu.vn/index.php/jte/index
Email: jte@hcmute.edu.vn

A Numerical Method for Estimating Strut Forces in Multi-Braced Excavation Systems

Tong Nguyen*, **Phuong Le**
[1]*Ho Chi Minh City University of Technology and Education*
* Corresponding author. *Email:* tongn@hcmute.edu.vn

ARTICLE INFO

Received:	18/07/2022
Revised:	05/11/2022
Accepted:	12/12/2022
Published:	28/02/2023

KEYWORDS

Plaxis 2D;
Etabs;
Strut forces;
Multi-braced excavation system;
Numerical method.

ABSTRACT

The paper discusses the development of a numerical method for a multi-braced excavation to estimate strut forces. Two different software were used in the proposed method. Equivalent strut forces were calculated by plane strain analysis on Plaxis 2D. The number of Etabs models built corresponds to the number of strut levels. Loads acting on waler beams in these structural models were derived from the results of equivalent strut forces on the Plaxis 2D model. The results of the proposed method were compared with those of a full 3D analysis. This method ensures the force equilibrium with an error of less than 5% as compared with the total strut forces in the 3D calculation. Due to the corner effect not take into account, the corner strut internal forces in the proposed method are usually larger than those in the 3D analysis, while the internal forces of the middle struts seem to be the opposite. Although the differences have a wide variation, the average error is 35%. However, the results from the proposed method are conservative. The proposed method is useful for practicing engineers, especially in the primary design stage of multi-braced excavation with a complex-shaped plan.

Doi: https://doi.org/10.54644/jte.75A.2023.1249

1. Introduction

When digging, the horizontal stress in the soil changes. The soil will tend to move towards a new equilibrium. Soil movement can cause major damage to the foundation surrounding the excavation and the collapse of adjacent structures. The easiest solution to ensure slip balance is to create a slope for the excavation. The safety of the slope is inversely proportional to the slope angle. Therefore, if the excavation depth is large, creating a slope to ensure safety will require a large excavation space. This is impossible for urban buildings. Therefore, it is necessary to use retaining walls to compensate for the lost horizontal pressure in order to establish a new equilibrium. It is important to note that the retaining wall itself does not create additional horizontal pressure, it only acts as a transfer. As the soil behind the retaining wall tends to move into the excavation, it creates active earth pressure on the back of the retaining wall. When this happens, the retaining wall will tend to move into the excavation and cause overturning. This can only be prevented if the retaining wall is embedded sufficiently deep in the soil to create a passive pressure inside the excavation (the lower part of the wall is embedded in the soil) to rebalance the active force. However, the retaining wall can only transmit if the stiffness of the retaining wall is infinite. Since the actual retaining wall has a finite stiffness, the requirement for a large wall stiffness means that the thinness ratio of the wall is small, or the thickness of the wall is relatively large. With the objectives of economy, the wall thickness will be limited and the thinness ratio of the wall will increase. That makes a reduction in the flexural resistance of the wall, and the retaining wall cannot now be considered as a lever to balance active and passive forces, as the rotation point now depends on the flexibility of the wall. The temporary strut system is a solution to reduce the thinness ratio of the retaining wall. By subdividing the retaining wall at the support points, the temporary strut systems strengthen the wall stiffness, thereby controlling the rotation point of the overturning moment.

Controlling diaphragm wall displacement and strut forces mean control of slip resistance. Therefore, it is very important to accurately predict these strut forces. However, there is very little literature available regarding the temporary strut systems. Terzaghi and Peck (1967) [1] developed an empirical method to estimate strut forces for various soil types in multi-braced excavations, the design strut forces of braced excavations could be calculated using the tributary method applied to the relevant apparent pressure diagrams. Wengang Zhanga, Zhongjie Hou, Anthony T.C. Goh, and Runhong Zhang (2019) [2] carried out to examination of the strut forces for braced excavations in granular soils. Since these forces only reflected one single line of struts in the 2D model, the horizontal tributary area was also factored into the calculations. Therefore, the methods are only suitable for braced excavation with conventional strut systems. But in braced excavation with uneven strut systems, there is a complex force distribution between struts, and it is very difficult to determine exactly which strut has the largest force.

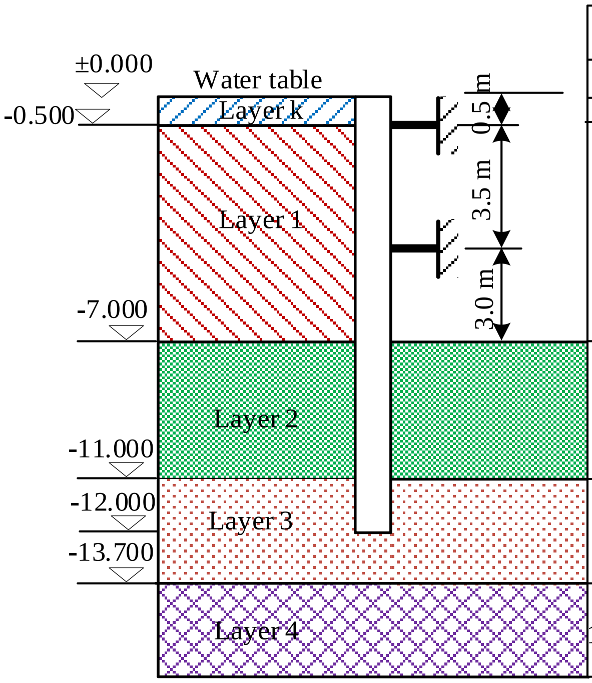
Furthermore, for multi-level strut systems, accidental strut failure is possible, which means if any struts fail, progressive collapse may occur and cause the whole excavation system to fail. A.T.C. Goh, Zhang Fan, Liu Hanlong, Zhang Wengang, and Zhou Dong (2018) [3] investigated the effects of one-strut failure on the adjacent struts by using plane strain and three-dimensional finite element analyses. It is very difficult to really understand the force transfer behavior between struts if only using the 2D model in this case.

Of course, a 3D finite element (FE) analysis [4] is the most ideal for accurately estimating the strut forces. However, for practical purposes, 3D FE is complex, time-consuming, and unnecessary, especially in the primary design stage if equivalent modeling techniques are available. As mentioned above, the strut forces depend on the horizontal pressure of the soil, i.e. the properties of soil around the excavation, the interaction of the retaining wall and the soil, and on the arrangement of the strut systems. The advantage of Plaxis 2D software is to analyze the soil-structure interaction, while the advantage of Etabs software [5] is to analyze the behavior of the structural system. By combining the strengths of these two popular commercial software, the authors propose a numerical method to reliably predict the strut forces. A 3D finite element model was built to verify the proposed method.

2. Methodology and modelling

2.1. *Inputs:*

Soil profiles and strut elevation are shown in Figure 1. The diaphragm wall is a barrette wall, made of reinforced concrete material with a thickness of 600 mm. The size of the excavation boundary is 60 x 65 meters.



γ_{sat}	c’	φ’	E_{oed}	ν	k	R_{inter}
kN/m^3	kPa	(^{o})	kPa	-	m/day	-
20.00	1.00	25.00	5000	0.3	2.0E-4	0.9
21.02	17.94	22.38	4049	0.3	2.0E-4	0.9
20.32	64.17	16.58	15000	0.35	1.4E-5	0.9
21.87	1.50	41.50	45000	0.3	2.0E-4	0.9
19.22	61.69	16.61	37489	0.35	1.1E-6	0.9

Figure 1. Soil profile and strut elevation

The plan of bracing system are shown in Figure 2. The support system is H-shaped steel with cross-sectional dimensions of H 400 x 400 x 13 x 21 millimeters.

A load of adjacent buildings and construction equipment is a uniformly distributed load with a magnitude of $q = 20$ kN/m^2 and 1.0 meter from the edge of the diaphragm wall.

Construction sequences of excavation consist of:

Phase 1: Install the diaphragm wall.

Phase 2: Dewater to -1.5 meters and excavate to -1.0 meters.

Phase 3: Install the support system at -0.5 meters below ground surface.

Phase 4: Dewater to -5.0 meters and excavate to -4.5 meters.

Phase 5: Install the support system at -4.0 meters below ground surface.

Phase 6: Dewater to -7.5 meters and excavate to -7.0 meters.

Phase 7: C/phi reduction soil stability check of phase 2.

Phase 8: C/phi reduction soil stability check of phase 4.

Phase 9: C/phi reduction soil stability check of phase 6.

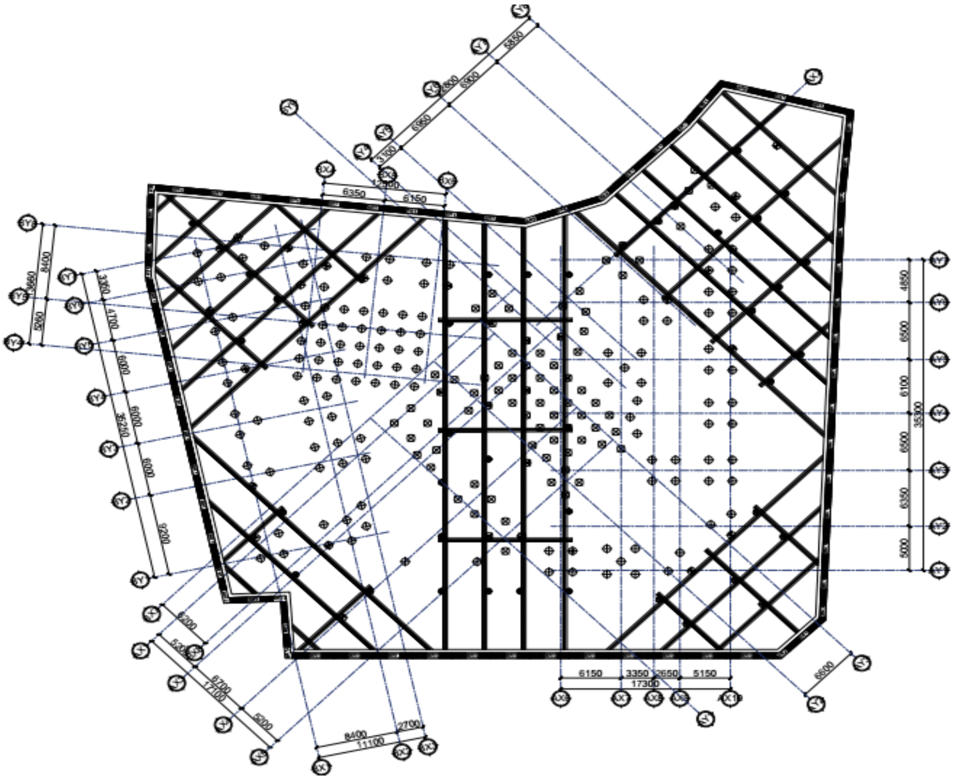


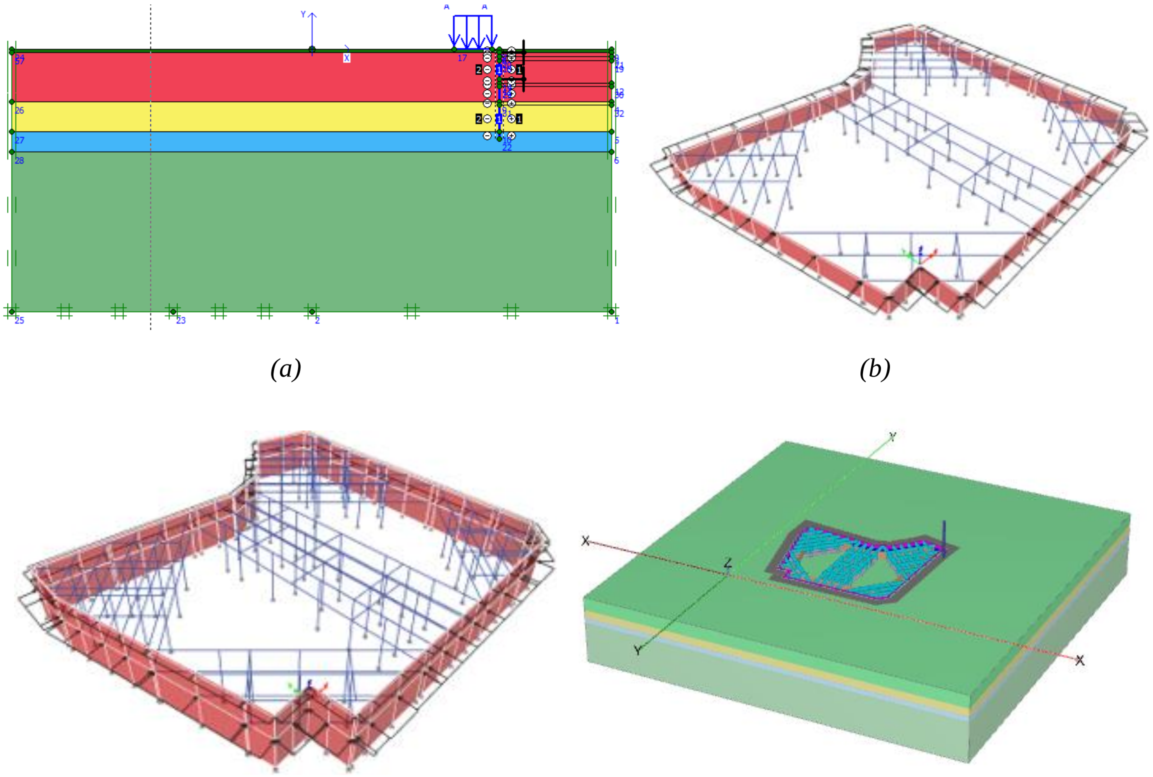
Figure 2. *Plan of strut system*

2.2. Methodology and modelling.

The authors use Plaxis 2D software to analyze the diaphragm wall–soil interaction and Etabs software to analyze the behavior of the support system. The Plaxis 3D model is built to verify the internal forces of the support system. The numerical models of excavation and support systems are shown in Figure 3. Figure 4 describes the steps of strut force estimation by combining Plaxis 2D software and Etabs software.

In Plaxis 2D model, the diaphragm wall is simulated by plate elements, and the steel struts are modelled by node-to-node anchor elements. The linear elastic-perfectly plastic Morh-Coulomb (MC) model is selected as the soil model. Figure 1 summarize the input parameters of the MC model for the soil layers. The outputs of this model are used to check several criteria such as overall soil stability, hydraulic stability, horizontal displacement of the diaphragm wall, and ultimate strength of the diaphragm wall.

JTE HCMUTE
ISSN: 2615-9740
JOURNAL OF TECHNICAL EDUCATION SCIENCE
Ho Chi Minh City University of Technology and Education
Website: https://jte.hcmute.edu.vn/index.php/jte/index
Email: jte@hcmute.edu.vn



(a) *(b)*

(c) *(d)*

Figure 3. *Numerical model of excavation and support systems (a): Plaxis 2D model; (b): Etabs models with one-level strut system; (c): Etabs models with two-level strut system; (d) Plaxis 3D model*

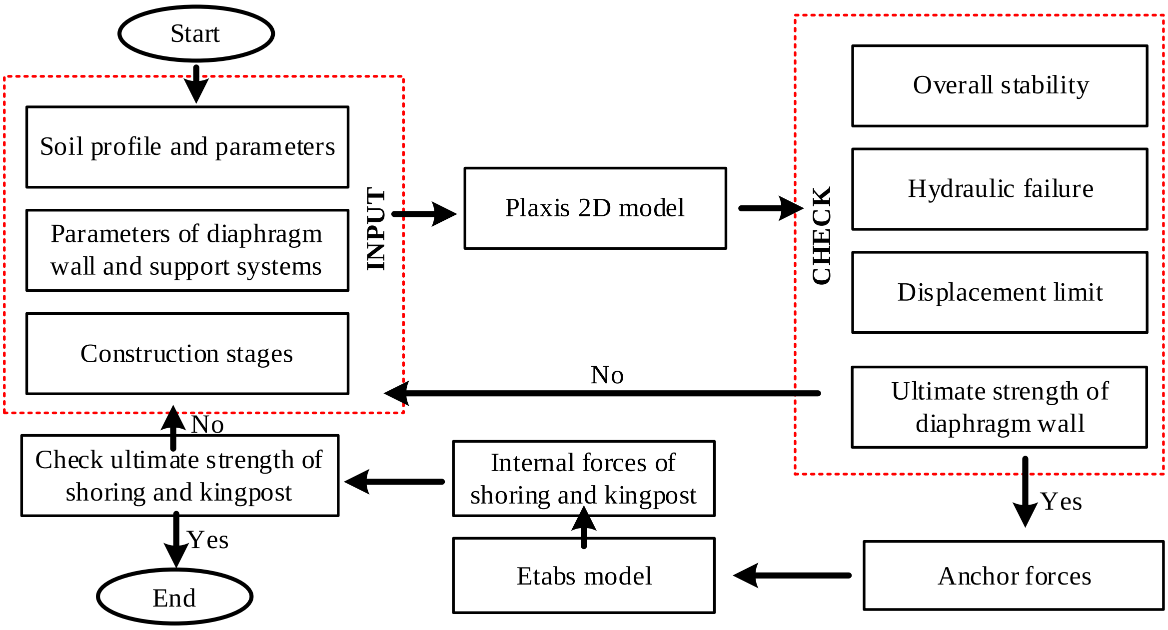


Figure 4. *Steps of strut force estimation by combining Plaxis 2D software and Etabs software*

In the Etabs model, the diaphragm wall is simulated by plate elements, and the shorings and kingpost are modeled by beam and column elements respectively. The frame is loaded by its own weight and by horizontal force taken from Plaxis 2D software. This force is the force created in struts during the phases of construction according to Plaxis and its values are shown in Table 1. The horizontal pressures of soil and water acting on the diaphragm wall are transferred partly to the struts through the waler beams and partly to the soil support below the excavation level. In this mechanism, the waler beam acts as a load distributing element, and the strut acts as a compression element to balance the soil and water pressures on both sides of the diaphragm wall. Strut reaction forces taken from the Plaxis 2D model represent this force equilibrium. Thus loads acting on waler beams in the structural model is the simplest way to estimate strut forces.

It notes that with multi-braced excavation, the number of Etabs models built corresponds to the number of strut levels. In this study, the braced wall system is supported by two levels of struts, which means there are two Etabs models as shown in Figure 3. According to the construction sequence, the corresponding strut level is always installed after the previous excavation step is finished. Therefore, these struts are not subjected to any load from wall displacement before the next step is taken. So Etabs models are built in this next excavation step. In the first Etabs model, the depth of the diaphragm wall and kingposts is taken to be -4.5 meters below the ground surface, while in the second Etabs model it is taken to be -7.0 meters below the ground surface. The diaphragm wall and the kingpost are restrained by pinned support.

In the Plaxis 3D model, the diaphragm wall and soil model are simulated similarly to the Plaxis 2D model, while the shorings and kingposts are simulated with beam and column elements respectively.

Table 1. *Strut forces of the Plaxis 2D model at various excavation stages*

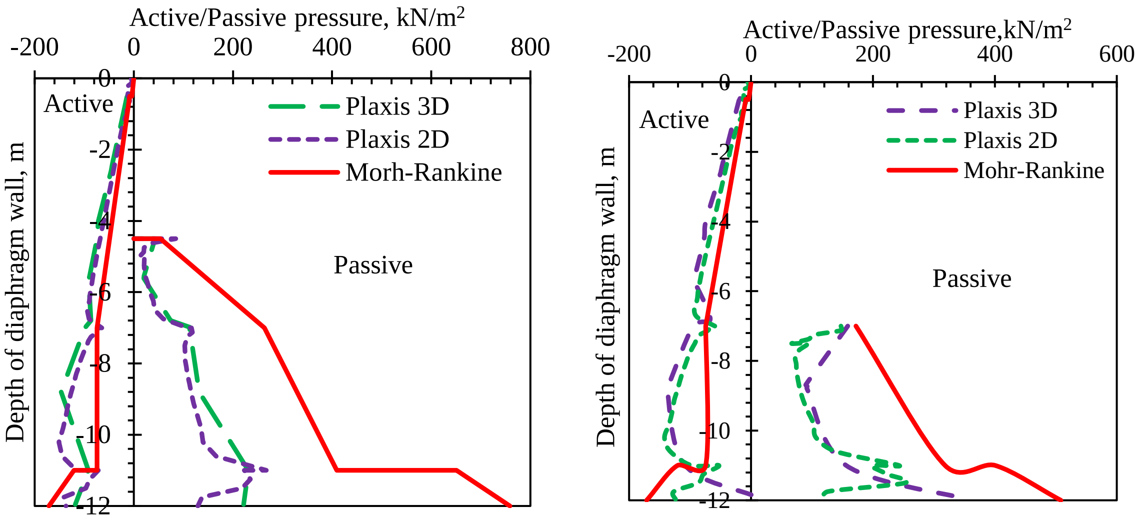
Phase	1st strut (kN/m)	2nd strut (kN/m)
4	-170.4	-
6	-116.1	-175.4

3. Results and Discussion

3.1. Evaluate the reliability of Plaxis 2D and Plaxis 3D models

Usually, it is best to verify numerical models based on field observations of diaphragm wall displacement. However, at an early stage of the design process, monitoring data is not available. Therefore, other methods are needed to verify the reliability of the numerical models. The main objective of the paper is to predict the internal force of the struts. The design of a safe support system is to determine the appropriate earth pressure diagram. That means that instead of verifying the reliability of numerical models based on observational data, a method of checking the accuracy of earth pressure on a diaphragm wall is a possible method. There are many different theories to determine horizontal earth pressure. With simplicity but with certain reliability, Mohr-Rankine theory will be used in this paper to verify numerical models.

Yap, S. P, Salman, F. A and Shirazi, S. M (2012) [6] conduct a comparison of the active earth pressure on retaining walls between different theories and the results from Plaxis 2D software. They found that the results from Mohr-Rankine's theory are highly compatible with Plaxis analysis for magnitude and distribution of active earth pressure. As shown in Figure 5, the active earth pressure from the two Plaxis models is quite similar in both magnitude and distribution to Mohr-Rankine's result. However, passive earth pressure from the Mohr-Rankine result is larger in magnitude than the Plaxis result, despite having the same distribution pattern. According to the assumption of the Mohr-Rankine theory, the soil reaches a plastic equilibrium under the conditions of active and passive earth pressure. Therefore, the diaphragm wall must be allowed to move to a certain extent in order for the soil to reach plastic equilibrium. This means that the active and passive earth pressures are a function of the diaphragm wall displacement. Clough and Duncan (1991) [7] showed that significantly large displacements are required to mobilize fully passive earth pressures, while active states are mobilized at smaller wall displacements. Sadrekarimi A and Damavandinejad Monfared S (2013) [8] reconfirmed wall displacement required for active state mobilization. In Figure 6, the ratio between the maximum displacement of the diaphragm wall and the wall height ranges from 0.0035 (phase 4) to 0.0042 (phase 6). According to Clough and Duncan (1991) [7], this ratio is in the range of 0.001 to 0.01, depending on the soil type, the soil reaches active condition, while to reach a passive state, this ratio must be from 0.01 to 0.05. Apparently, most of the soil behind the diaphragm wall has reached an active state, while the soil below the diaphragm wall has not yet reached this state. This explains the high similarity of the results of the Rankine theory with the results from the Plaxis models, while there is a large difference in the results of the passive earth pressure. It can be concluded that the Plaxis models have certain reliability so that the next steps can be analyzed.



(a) *(b)*

Figure 5. *Active/Passive soil pressure on diaphragm wall (a) Phase 4; (b): Phase 6*

3.2. Check several aspects of design considerations for the excavation

The results derived from the Plaxis 2D model must ensure several aspects of design considerations such as overall stability, displacement limit, and hydraulic failure.

Factors of safety (FOS) from phase 7 to phase 9 in the Plaxis 2D model are 6.1, 6.0, and 6.4 respectively, where critical slip surfaces of phase 7 and phase 8 do not cut through the diaphragm wall. These results are a clear indicator to reduce any uncertainty about the shear strength of soil below the excavation because all of the values are greater than 1.5 [9] [10].

Very few building codes provide explicit limits for allowable displacement and these limits are not quantitative. Most of the codes that address this issue put the responsibility on the Constructors to avoid damaging all neighboring structures. Measured wall displacements from various published histories of deep excavations show that wall displacements range from 0.05% times to more than 2% times the excavation depth [11]. The top displacements of the diaphragm wall in phase 4 and phase 6 are expressed in Table 2, and all of the values are less than the value of allowable displacement (35 mm). Meanwhile, the maximum displacement values of the diaphragm wall are also less than the values of the displacement limit (140 mm).

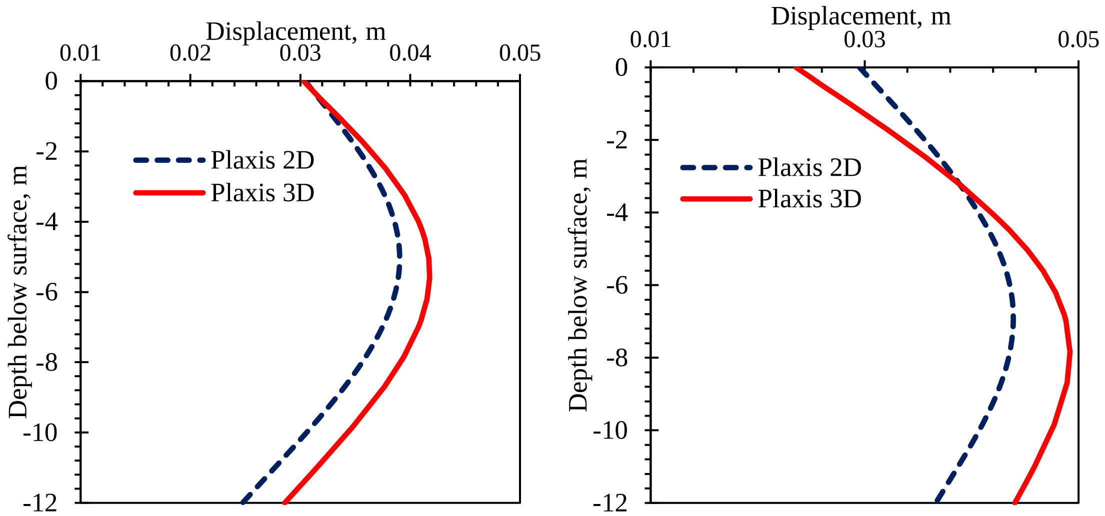
Hydraulic ground failure occurs because the water flows into the excavation through an underlying soil layer. To avoid hydraulic ground failure the pressure gradient should be less than the critical value. The values of the pressure gradient in phase 2, phase 4, and phase 6 are 0.012, 0.04, and 0.46. The critical values of the pressure gradient in phase 2, phase 4, and phase 6 are 1.10, 1.10, and 1.03. It is noted that the pressure gradients presented above are calculated by the critical hydraulic gradient method. According to Kohsaka and Ishizuka (1995) [9], the FOS of the hydraulic ground failure for the critical hydraulic gradient method is taken to be equal to and greater than 2.0. All the values of pressure gradients are less than the critical value with a safety factor of 2.0.

3.3. Verification for the proposed method using the Plaxis 3D model

Table 2. *Comparison of diaphragm wall displacement between Plaxis 2D model and Plaxis 3D model*

Phase	**Phase 4**			**Phase 6**		
Location	**Top**	**Max**	**Base**	**Top**	**Max**	**Base**
Plaxis 2D (mm)	30.50	39.00	24.75	29.52	43.90	36.66
Plaxis 3D (mm)	30.30	42.23	28.59	24.08	49.42	44.30
Error (%)	0.66	-7.25	-13.43	22.59	-11.17	-17.25

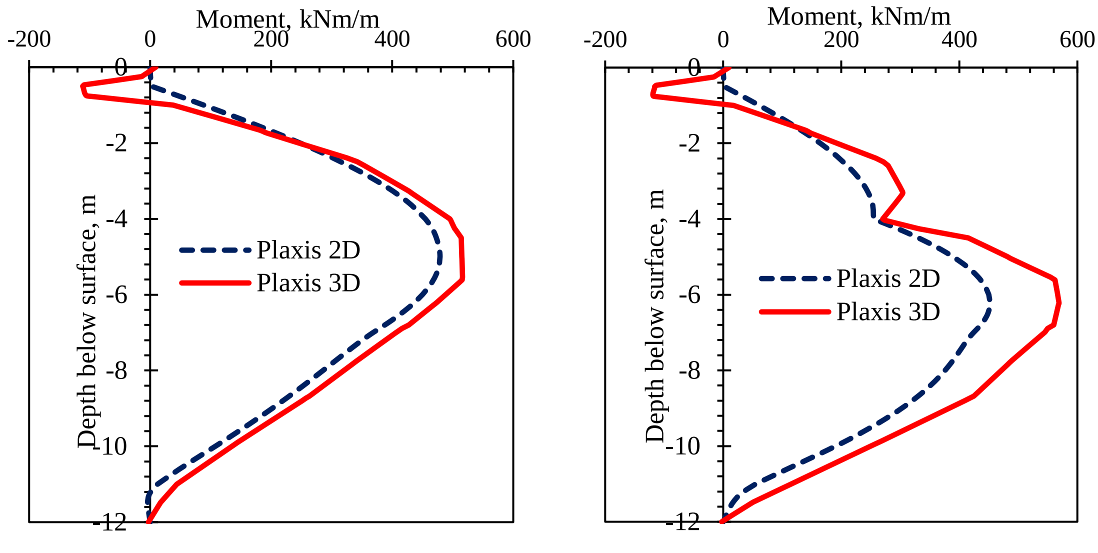
Since the strut forces predicted from the finite element analysis are a function of the strut deformation, which is related to the wall displacement, the good agreement of the wall displacements between 2D analysis and 3D analysis may ensure good results in predicting the strut forces. Figure 6 shows the diaphragm wall displacement results from two Plaxis models. As shown in Figure 6, the results of diaphragm wall displacement from analyses of Plaxis 2D and Plaxis 3D are similar in displacement shape but different in magnitude. Table 2 presents the results of the magnitude comparison between the two models. This difference in magnitude may be related to the assumed boundary condition of the diaphragm wall. In the 2D analysis, the diaphragm wall is assumed to be an infinite plate. L. W. Wong, I. T. Pratama and C. R. Chou (2020) [12] showed that the existence of 3D corner effects has a significant influence on the diaphragm wall displacement in the 3D analysis of deep excavation. There are no significant differences in values of maximum diaphragm wall displacement between the two models (see table 2). However, the locations of the maximum diaphragm wall displacement in the Plaxis 3D model are lower than in the Plaxis 2D model. Even so how these differences affect the strut force distribution will be analyzed in detail in the following section.



(a) *(b)*

Figure 6. *Comparison of Plaxis 2D model and Plaxis 3D model wall displacement at various excavation stages (a) Phase 4; (b): Phase 6*

As can be observed from Figure 7, there is no significant difference between 2D and 3D analysis on the bending moment diagrams. It should be noted that the bending moment diagrams in the 3D analysis are taken at the center of the primary diaphragm wall, implying the moments in the center of a stretch of the diaphragm wall are appropriate to the plane strain condition. The error of the maximum bending moment values of the 2D Plaxis model compared to the 3D Plaxis model is 7.20% in phase 4 and 20.55% in phase 6. This shows that the assumption of equivalent strut stiffness in the Plaxis 2D model is a reasonably simplified assumption and is compatible with the results from the 3D analysis. However, there is still part of difference in the bending moment of phase 6 of 3D analysis at the lower part of the diaphragm wall versus 2D analysis. This can also be evidence of the difference in strut force distribution between the proposed method and the 3D Plaxis model.



(a) *(b)*

Figure 7. *Bending moment of diaphragm wall (a) Phase 4; (b): Phase 6*

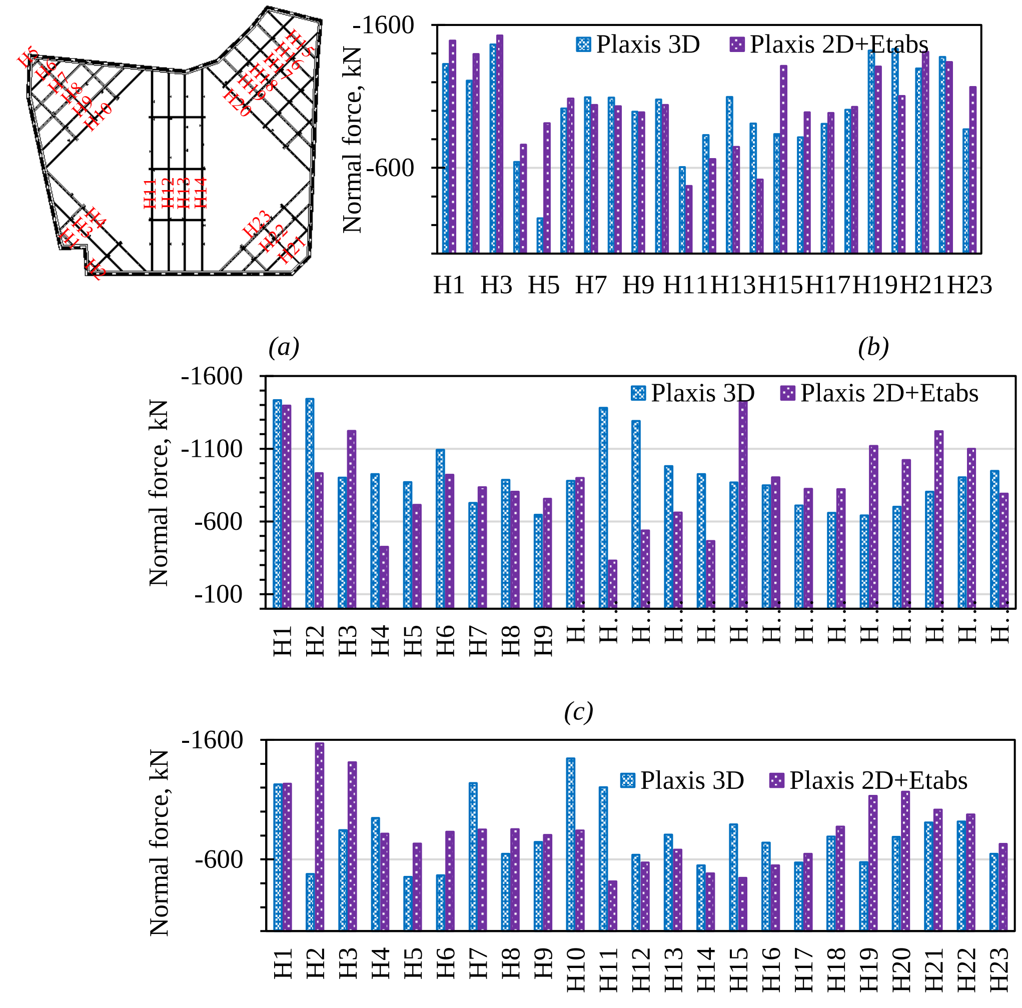
The total internal forces of the 1st level struts in the Etabs 1 model are 24314 kN and in the 3D Plaxis model at phase 4 is 23554 kN. The relative difference between these two models is 4%. The total internal forces of 1st level struts and 2nd level struts in the Etabs 2 model are 20130 kN and 19629 kN, while in phase 6 in the 3D Plaxis model are 21159 kN and 18519 kN, respectively. The relative difference between the 2 models in 1st level struts is 5.0 %, and in 2nd level struts is 6.0 %. If considering the total forces of the two strut levels, the relative difference between the two models is 4%, consistent with the difference between the Etabs 1 model and the 3D Plaxis model at phase 4. The proposed method ensures that the load acts on the strut system with an error of 4%. This means that assumption of equivalent strut stiffness in the Plaxis 2D model is compatible with the stiffness of strut systems in the Plaxis 3D model.

Figure 8 shows a comparison of the internal forces within the struts. In phase 4, a high level of compliance in the distribution and magnitude of the strut forces is obtained from the Etabs model compared with the 3D Plaxis model. The difference in the distribution of internal forces in each strut has a wide variation (see table 3), but the average error is 35%. Under plane strain conditions, the displacement pattern of the diaphragm wall is the same along the wall length. However, in the three-dimensional condition, the above assumption is incorrect. As pointed out above, the corner effect is part of this difference. That can affect the internal force distribution at each strut. It may be the reason for the difference in the internal force of each strut between the two models. This can be clearly seen in Figure 8 and Table 9. The internal force of the corner struts in the proposed method is usually much larger than the internal force from the 3D analysis, while the internal force of the middle struts is approximately the same, sometimes the results from the 3D Plaxis model are larger. However, the trend is quite conservative with the results from the proposed method.

Table 3. *Errors of strut forces between Plaxis 2D model versus Plaxis 3D model*

Name	**Error (%)**			**Name**	**Error (%)**		
	Phase 4	**Phase 6**			**Phase 4**	**Phase 6**	
	1st strut level	**1st strut level**	**2nd strut level**		**1st strut level**	**1st strut level**	**2nd strut level**
H1	12.28	-2.59	0.48	H13	-31.87	-32.49	-15.42
H2	15.36	-35.35	229.46	H14	-43.08	-49.75	-12.07
H3	4.37	103.65	67.00	H15	56.87	64.51	-50.19
H4	19.22	-53.98	-13.93	H16	21.38	6.54	-25.58
H5	271.14	-18.10	61.59	H17	8.26	16.33	12.74
H6	6.79	-15.87	77.66	H18	1.99	24.58	10.68
H7	-4.94	14.95	-31.34	H19	-7.95	74.19	96.62

H8	-5.41	-9.00	31.86	H20	-22.92	45.66	47.58
H9	-0.30	16.97	7.93	H21	9.03	51.79	11.72
H10	-3.52	2.50	-41.69	H22	-2.47	21.76	6.48
H11	-21.78	-76.03	-65.45	H23	34.06	-16.61	12.96
H12	-20.27	-58.22	-9.85		-	-	-



(a) *(b)*

(c)

(d)

Figure 8. *Strut forces at various stages of construction (a): Names of shoring system(b): 1st level strut forces in Phase 4; (c): 1st level strut forces 1 in Phase 6 ; (d) 2nd strut level forces in Phase 6*

4. Conclusions

The proposed method is a practical approach for practicing engineers. The comparisons of results between this method and the 3D analysis get quite good results, sufficient for design purposes. Some conclusions are drawn as follows:

- The approach of using equivalent strut stiffness is appropriate and can be used to take reaction forces. Those are loads acting on waler beams in the Etabs models. This method ensures the force balance condition of the whole system. The difference between this method and the 3D analysis is 5 %.
- The distribution of internal forces within the strut depends on the correctness in predicting the displacement shape of the diaphragm wall. Diaphragm wall displacement depends on the selection of equivalent strut stiffness and excavation shape (relative to corner effect). The selection of the cross-sectional location of the excavation to build the 2D problem is very important. The selected location should be in the middle of the long edge of the excavation. At the same time, the arrangement of struts

should be simple enough to accommodate the simplification of equivalent strut stiffness in the 2D problem.

- The corner strut internal forces in the proposed method are usually larger than those in the 3D analysis, while the internal forces of the middle struts seem to be the opposite. The average error when comparing the internal force of each strut between the two methods is 35%. However, the results from the proposed method are conservative.

The calculation procedure presented above, which is used in the design, includes two separate problems: behavior analysis of the diaphragm wall and behavior analysis of the strut system. In 3D analysis, this distinction is not necessary because they are considered in a single model. However, in the preliminary design stage, the input data is not clear, and the use of 3D modeling is not effective in a trail design to find the optimal solution. By using Plaxis 2D software to calculate equivalent strut forces, then using them as output data to establish a static scheme in Etabs models, the proposed method is a simple way to estimate strut forces quite accurately. Some advantages of the proposed method are as follows:

- With simple manipulation in modeling and easy correction when there are some mistakes, the proposed method helps the designer quickly find a suitable strut system to ensure the safety of the excavation before verifying it by a 3D analysis.
- Using the proposed method, the designer is allowed to estimate strut forces based on the information provided for the site-specific situation by using soil models on Plaxis 2D software. Besides that, the influence of the change of the stress state in the soil stratum as construction sequence on strut forces is described like a 3D model.

REFERENCES

[1] K. Terzaghi and R. B. Peck, *Soil Mechanics in Engineering Practice,* 2nd ed. New York, USA: John Wiley Sons Inc, 1967.
[2] W. Zhanga *et al*., "Estimation of strut forces for braced excavation in granular soils from numerical analysis and case histories," *Computers and Geotechnics*, vol. 106, pp. 286-295, 2019.
[3] A. T. C. Goh, Z. Fan, L. Hanlong, Z. Wengang, and Z. Dong, "Numerical Analysis on Strut Responses Due to One-Strut Failure for Braced Excavation in Clays," in *Proceedings of the 2nd International Symposium on Asia Urban GeoEngineering*, 2018, doi: 10.1007/978-981-10-6632-0_43
[4] *PLAXIS 3D tutorial Manual CONNECT,* V20 ed., Bentley Systems Inc., USA, 2019.
[5] *CSI analysis reference manual*, Computer and Structures Inc., Berkeley, California, USA, 2020.
[6] S. P. Yap, F. A. Salman, and S. M. Shirazi, "Comparative study of different theories on active earth pressure," *Journal of Central South University of Technology*, vol. 19, no. 10, pp. 2933-2939, 2012.
[7] W. G. Clough and J. M. Duncan, "Earth pressures," in *Foundation Engineering Handbook*, HY. Fang, Eds., Boston, MA, USA: Springer, 1991, ch. 6, pp. 223-235.
[8] S. D. Monfared and A. Sadrekarimi, "Numerical Investigation of The Mobilization of Active Earth Pressure on Retaining Walls," in *18th International Conference on Soil Mechanics and Geotechnical Engineering*, Paris, France, 2013, pp. 793-796.
[9] N. Kohsaka and K. Ishikuza, "Stability of bottom during deep excavations - A survey on Japanese codes," in *Underground Construction in Soft Ground,* Balkema, Rotterdam, 1995, pp. 323-328.
[10] N. M. Tam and T. V. Thai, "Analysis of diaphragm wall's available displacement according to safety factor," *Vietnam Journal of Construction - Copyright Vietnam Ministry of Construction*, pp. 141-147, 2017.
[11] P. Fok *et al*., "Limiting values of retaining wall displacements and impact to the adjacent structures," *The IES Journal Part A: Civil & Structural Engineering*, vol. 5, no. 3, pp. 134-139, 2012.
[12] L. W. Wong, I. T. Pratama and C. R. Chou, "Corner Effects on Wall Deflections in Deep Excavations," in *The HKIE Geotechnical Division 40th Annual Seminar* 2020, Hongkong, 2020.

Tong Nguyen received the B.S. degree in civil engineering from Ho Chi Minh City University of Technology and Education, Ho Chi Minh City, Vietnam, in 2012 and the M.S. degree in geotechnical engineering from Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam, in 2015.
From 2012 to now, he has been a lecturer with Ho Chi Minh City University of Technology and Education, Ho Chi Minh City, Vietnam. His research interest includes soil mechanics and foundation engineering.

Phuong Le received the B.S. degree in civil engineering from Ho Chi Minh City University of Technology and Education, Ho Chi Minh City, Vietnam, in 2012 and the M.S. degree in geotechnical engineering from Ho Chi Minh City University of Technology, Ho Chi Minh city, Vietnam, in 2014.
From 2012 to now, he has been a lecturer with Ho Chi Minh city University of Technology and Education, Ho Chi Minh city, Vietnam. His research interest includes soil mechanics and foundation engineering.