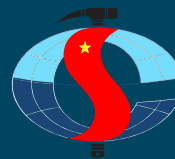




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Volume 2

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Proposing a solution to build pedestrian tunnels combined with commercial spaces in big cities in Viet Nam

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Abstract: In Vietnam, pedestrian tunnels have been built quite extensively in some major cities such as the capital Hanoi and Ho Chi Minh City, Vung Tau... over the past 10 years. However, due to factors such as construction techniques, technology, and the habits of the people, the number of users of pedestrian tunnels is low. This research proposes to enhance the functionality of pedestrian tunnels by constructing commercial spaces such as souvenir and fast food stalls to attract more people to use the tunnels. This paper also develops a calculation model based on adjusting the size of the pedestrian tunnels to increase their functionality. To estimate stress and displacements of surrounding rock/soil and rock support by FEM analysis during build pedestrian tunnels in big cities in Viet Nam combined with commercial spaces. The pattern of deformation, stress state, and distribution of plastic areas are analyzed by Plaxis 2D or 3D software. The project was developed using Plaxis 3D based on detailed geotechnical data. The study includes safety factor analysis and ground displacement monitoring at Thuy Van pedestrian tunnels in Vung Tau city, Viet Nam. An optimized tunnel design was proposed. The study result provides a reliable way to analyze the stability of a pedestrian tunnel combined with commercial spaces and also will help to design or optimize the subsequent support.

Keywords Pedestrian tunnels, commercial spaces, Vung Tau, Hanoi, FEM analysis.

INTRODUCTION

Vietnamese citizens suggest that pedestrian tunnels should offer more functions and services such as better lighting, security, accessibility for disabled people, and even small shops or services to encourage their use. We can add that the locations of the pedestrian tunnels are designed inappropriately and have become a waste. For example, the pedestrian tunnels on Hoang Sa and Truong Sa streets with significant investment, were started in 2005 and inaugurated in 2015, but the current state of these pedestrian tunnels in the area has serious maintenance and cleanliness issues [1-2].

The pedestrian tunnel on Pham Hung Street in Ha Noi is another example, it has deteriorating infrastructure with cracks and damage. The issue of improving sanitation is quite urgent due to waste and stagnant groundwater. The tunnel lacks cameras to ensure the safety of pedestrians. The absence of signage inside the tunnel makes it difficult for residents [1-3].

Even the current situation of the pedestrian tunnel at Nga Tu So, Ha Noi remains quite deserted, with most residents using it for exercise. However, the tunnel is nearly 500 meters long and includes 12 entrances. The tunnel is designed for both pedestrians and cyclists, with lighting available 24/7. The security system includes cameras and patrols, making the tunnel relatively safe.

There are some images illustrating the reasons why pedestrian tunnels and exhibition are as should be combined. The reason is that pedestrian tunnels are built extensively in Hanoi and Ho Chi Minh City, but they are not used by the public. People still cross the busy streets, which is very dangerous (Figure 1)[1-2].



Figure 1. The pedestrian tunnel in Nguyen Xien, Ha noi

The tunnel project in Norway, where the longest cycling and pedestrian tunnel in Europe was opened in Bergen in 2023. This tunnel was not only built for mobility but also designed as a pleasant space to walk through with lights, art, and a safe environment (Figure 2). It became a strong symbol of sustainable mobility and urban innovation (Euronews Green, 2023) [4] .



Figure 2. Artwork and installations line the tunnel in Bergen, taken from the Euronews website [4]

In modern urban areas around the world, the integration of pedestrian tunnels with commercial spaces has become popular. The large number of pedestrians crossing major intersections leads to congestion and accidents at four-way and five-way junctions. It is necessary to incorporate additional commercial and entertainment services to enhance infrastructure and increase public usage. However, the combination of pedestrian tunnels with commercial spaces has never been seen in Vietnam. For example, In South Korea, pedestrian tunnels are designed in conjunction with shopping centers, and these tunnels include business services, shopping stalls, and supermarkets as in the Figure 3.



Figure 3. Example of one pedestrian tunnels in South Korea

All around the world, pedestrian tunnels are developing, we can mention Canada with the Underground City in Montreal. A 32 km long network of tunnels with ceilings adorned with colorful LED lights, granite floors, and modern shopping centers. It is particularly connected to 10 subway stations, 2,000 shops, and office buildings (Figure 3). There is also the Inato Mirai Tunnel in Yokohama in Japan. It is a clean tunnel with shiny stone floors, featuring signage in both Japanese and English. It notably connects the port area to the train station, equipped with elevators and escalators (Figure 4).

Pedestrian tunnels around the world are not only a transportation solution but also a symbol of urban creativity, combining functionality and aesthetics. Major cities worldwide are heavily investing in this type of

infrastructure to move towards an environmentally friendly "walkable city" model.



Figure 4. A pedestrian tunnel in Canada [4]



Figure 5. A pedestrian tunnel in Japan [2]

All of this gave the idea to design a new type of pedestrian tunnel in the Vietnamese context, one that is larger, more welcoming, and includes small commercial spaces (like cafés, shops, or services). These additions could transform the tunnel into a useful and attractive urban space, not just a crossing point. The goal is to encourage real use by making the tunnel part of city life, rather than just an underground passage.

Case Study in Pedestrian Tunnel in Vung Tau

The study carried out on a real project site located in Vung Tau, a coastal city in southern Vietnam. It is situated near the Back Beach (Bãi Sau), which is a very popular area for both tourists and residents. As shown in the Figure 6, the proposed tunnel is designed to pass under Thùy Vân Street, a very wide and busy road. It has six traffic lanes, and it separates the beach from hotels, restaurants, and residential areas. Because of the heavy traffic, it is difficult and sometimes dangerous for pedestrians to cross the road, especially during weekends or holidays.



Figure 6. Location map of the tunnel [9]

The idea of building a pedestrian tunnel here is to improve safety and comfort for people going from the hotel zone to the beach. To make it more attractive and used by the public, the tunnel could include small commercial spaces, such as kiosks selling drinks, snacks, beach gear, or local products. This real location and its urban context were used as the base for my modelling work with Plaxis 3D in the following sections.

For the analysis of the tunnel stability, The study used the Strength Reduction Method in Plaxis 3D, which is based on calculating safety factors (F_s). This method is commonly used in geotechnical engineering and follows the principles of the Eurocode 7, which is the European standard for geotechnical design. Although The study used other tools and approaches during the project, this report focuses only on the Strength Reduction Method to give a clear overview of the overall study [10-11].

Plaxis calculates the safety factor by gradually reducing the soil strength parameters, cohesion (c) and friction angle (φ), until the model becomes unstable. This process simulates what happens if the soil is weaker than expected.

The software applies a reduction factor (strength reduction factor, SRF) to these parameters [5]:

$$C_{reduced} = \frac{c}{SRF}; \tan(\varphi_{reduced}) = \frac{\tan(\varphi)}{SRF};$$

It increases the SRF step by step until the model no longer reaches equilibrium. The last stable SRF value before failure is the global safety factor. According to Eurocode 7, two main safety factors are typically used [5]:

- 1.5 for long-term (permanent) conditions, which ensures long-term stability (e.g., when the tunnel is completed and in service),

- 1.3 for short-term conditions, such as during construction stages, when soil has not yet fully consolidated or drained.

These values mean that in the long term, the soil should be 50% stronger than the minimum required to resist failure. In the short term, a 30% margin is considered acceptable.

This method is useful because it does not require manually applying partial factors to each load or material, it gives a clear and global measure of stability, which is easy to compare across designs. Also, it can be used in complex 3D models where many interacting elements exist. In this case, this method helped me assess the tunnel's stability at different phases and identify potential weaknesses in the design.

Numerical modelling by Plaxis 3D Software and the Strength Reduction Method

The geometry of the tunnel was designed to meet both functional and safety requirements for pedestrian use in an urban environment. As shown in the Figure 8, the structure consists of a central underground passage going beneath the road, and four entrance and exit ramps connecting the tunnel to the surface.

This configuration allows easy access from both sides of the road and supports a good flow of pedestrians. The surface connections are placed strategically to reach sidewalks and nearby points of interest such as the beach and surrounding hotels.

This structure not only makes it safer to cross a wide avenue, but also offers space for small shops, making the tunnel more attractive

and useful for daily use. Figure 7 shows a cross-sectional plan of the base tunnel [7].

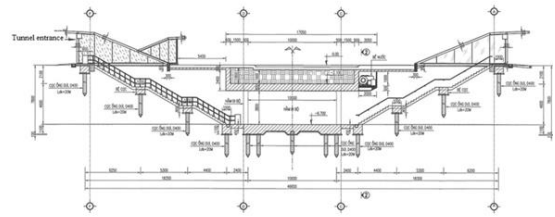


Figure 7: The cross-sectional plan of the base tunnel [7]

The pedestrian tunnel has a total width of 10 meters and a uniform height of 3 meters. It consists of a central walkway that is 6 meters wide, and a 4-meter-wide area on one side designed for kiosks. The total length of the tunnel body is 53.4 meters. Inside, the kiosks are separated by brick walls, which can either be decorated or left open, depending on how the space is intended to be used.

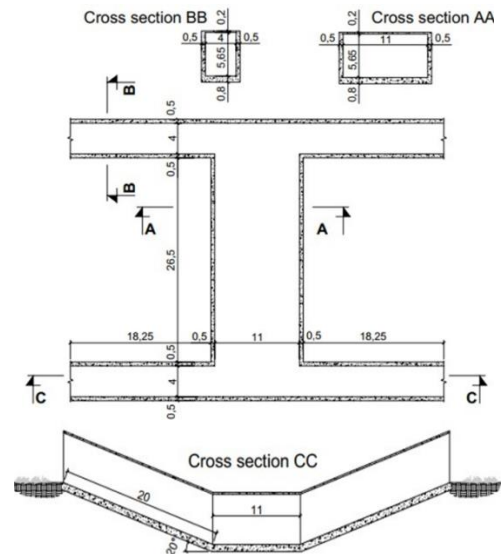


Figure 8: Plan and cross-sections of the pedestrian tunnel [7]

Figure 9 and Figure 10 illustrate the tunnel's cross-section dimensions and a general plan of the pedestrian tunnel. These drawings clearly show the areas dedicated to kiosks and small shops along the tunnel. These commercial spaces are designed to make the tunnel more attractive and inviting for pedestrians. The idea

is to encourage people to use this underground passage not only as a transit route, but also as a place for daily stops, promoting a livelier and more functional urban space.

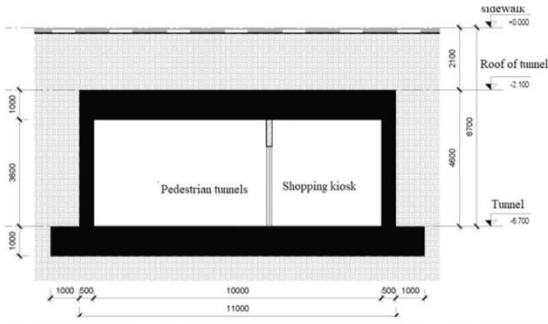


Figure 9. Tunnel's cross-section dimensions

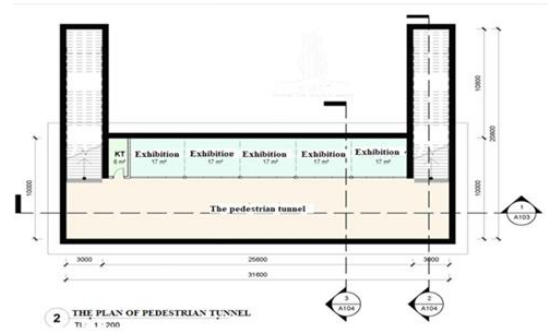


Figure 10: The general plan of the pedestrian tunnel

Approximately 40% of the tunnel's width is allocated to kiosks, while the remaining 60% is reserved for pedestrian circulation. This layout ensures that pedestrians can move freely in both directions without feeling confined or crowded. As shown in the plan, five individual commercial spaces of around 17 m² each can be created along the tunnel. These small shops will bring activity and life to the space, encouraging people to use the underpass and transforming it into a dynamic, multifunctional urban corridor.

Soil Characteristics

To run the 3D numerical simulation in Plaxis, the study used a detailed geotechnical soil model provided by my local supervisor. The data comes from a site in Thù y Vân, in Vung Tau, Viet Nam. Even though this is not the exact location of the tunnel, the geological conditions in the region are similar and the model is very complete. It provides values for 10 soil layers, including both sand and clay, with different mechanical behaviours. The Table 1 below shows the main geotechnical parameters used in the simulation.

Table 1. Presentation of the soil layer characteristics [7]

Soil layer	SL - Backfill	Layer 1.1 - Sand	Layer 1.2 - Clay	Layer 2.1 - Clay	Layer 2.2 - Clay	Layer 3 - Sand mix	Layer 4 - Fine sand	Layer 5 - Clay	Layer 6 - Clay loam	Layer 7 - Sand mix
Method	HS - DR	HS - UDR	HS - UDR	HS - UDR	HS - UDR	HS - DR	HS - DR	HS - UDR	HS - UDR	HS - UDR
γ_{unsat} (KN/m ³)	18	14,7	14,7	18,7	18,7	20	0,7	20,5	20	20,5
γ_{sat} (KN/m ³)	18,5	15,3	15,3	18,9	18,9	20,5	21,1	20,9	20,4	20,9
E_{50}^{ref} (KN/m ³)	10000	5243	5797	12319	8847	36555	28606	20373	16028	36941
E_{eo}^{ref} (KN/m ³)	10000	3985	4406	11211	8051	36555	28606	20373	16028	36941
E_{ur}^{ref} (KN/m ³)	30000	27265	30144	64061	46004	1E+05	85817	61119	48084	110823
m	0,5	0,9	0,9	0,85	0,85	0,5	0,5	0,8	0,8	0,5
v	0,25	0,35	0,35	0,3	0,3	0,3	0,3	0,3	0,3	0,3
c (KN/m ²)	5	11,7	13,8	35,2	27,9	8,2	0	68,4	46,6	14,2
ϕ (°)	25	12	13	15,1	13,2	28,5	33,5	19,5	25,6	27,9

R_{inter}	0,5	0,55	0,55	0,7	0,7	0,75	0,8	0,8	0,8	0,8
Base elevation of layer	-2,3	-11	-17,3	-26	-35,9	-39,2	-44,7	-54,8	-58,7	-65,1

Each soil layer is defined by several physical and mechanical parameters:

Soil layer: Name and number of the layer, ordered from top to bottom.

- Method: The soil behaviour model used in Plaxis. In this case, all layers use the Hardening Soil model (HS), which is more advanced than the Mohr-Coulomb model. It allows better simulation of real soil behaviour under loading.

The addition of DR (Drained) or UDR (Undrained) indicates whether the simulation allows water to flow through the soil.

- Drained conditions (DR) are used for coarse soils like sand, where water can move easily.

- Undrained conditions (UDR) are used for fine soils like clay, where water cannot escape quickly during construction phases.

- $\gamma_{unsat}/\gamma_{sat}$: Unsaturated and saturated unit weights of the soil. These represent the weight of the soil when it is dry (unsaturated) and when it is fully filled with water (saturated).

- $E_{50}^{ref}/E_{eod}^{ref}/E_{ur}^{ref}$: These are the main stiffness parameters used in the Hardening Soil model;

- E_{50}^{ref} : Secant stiffness in a standard drained triaxial test;

- E_{eod}^{ref} : Tangent stiffness for primary oedometer loading (used in 1 D compression);

- E_{ur}^{ref} : Unloading and reloading stiffness (elastic behavior);

- m: Power for stress dependency of stiffness moduli. A higher value means that stiffness changes more with pressure.

- ν : Poisson's ratio, which describes how the soil deforms laterally when compressed;

- c: Cohesion of the soil, which is the shear strength without friction;

- ϕ : Internal friction angle. It defines how well the soil particles resist sliding over each other;

- R_{inter} : Interface strength reduction factor between soil and structure (important for soil-structure interaction);

- Base elevation of layer: The depth at the bottom of each soil layer, used to define the vertical position in the model.

Before starting the numerical modelling in Plaxis 3D, it is essential to follow a clear sequence of steps to ensure a consistent and reliable simulation. The Figure 11 presents a flow chart outlining the main steps followed when using Plaxis 3D to simulate the excavation process and analyse the structural behaviour of the tunnel. It summarizes the different phases of modelling, including geometry definition, soil layering, boundary conditions, construction stages, and safety analysis. The diagram Figure 11 provides a clear overview of the overall methodology used throughout the project.

The numerical modelling of the pedestrian tunnel is presented based on a realistic construction sequence. Each step of the project is simulated in Plaxis 3D, considering soil-structure interaction and the local geotechnical conditions. At every stage, a stability analysis is performed using the Strength Reduction Method to ensure the safety and consistency of the design.

The modelling begins with the excavation of the central area of the tunnel, which runs under the main road. Once the excavation is complete, the central tunnel section is installed. The next steps involve the excavation of the four lateral ramps, which will provide pedestrian access from the surface. After this,

the temporary walls separating the central zone from the side ramps are removed, allowing full connection throughout the tunnel. The side sections of the tunnel are then installed. Finally, the entire structure is backfilled, completing the construction process.

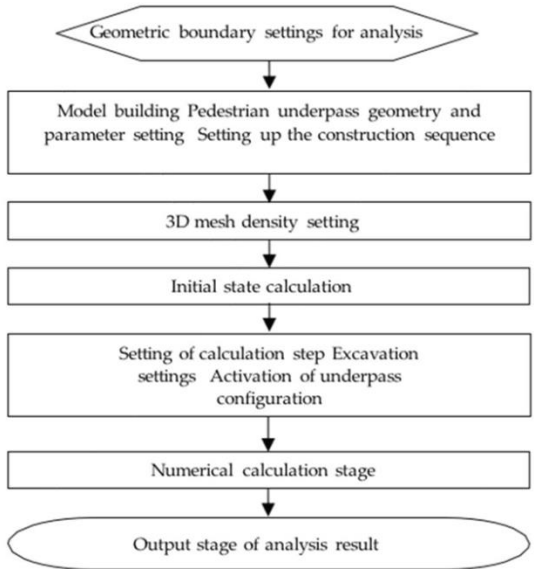


Figure 11. The flow chart outlining the main steps followed when using Plaxis 3D [3]

This progressive phasing helps to evaluate soil deformation and the global stability of the structure during each critical stage of the construction.

Regarding the mesh and computation settings, it could not refine the mesh too much because it made the calculations too heavy and very long on my computer. Despite this limitation, the study managed to reach around 100,000 nodes, which is already quite detailed for a student project and allows for good quality results. The study tried to keep a balance between accuracy and reasonable computation time.

RESULTS OF NUMERIAL MODEL

Excavation of the central area of the tunnel

The first phase of the project focuses on the excavation of the central underground zone, which corresponds to the main part of the tunnel that passes beneath the road. To

support the soil during the excavation, diaphragm walls were installed on both sides. These walls are 9 meters deep and 1 meter thick. The Figure 12, Figure 13 show the before and after of this step.

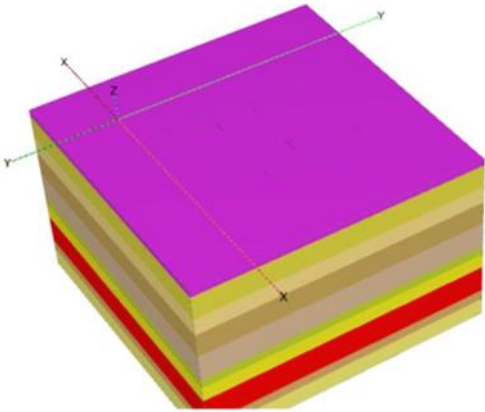


Figure 12. Plaxis 3D model before excavation

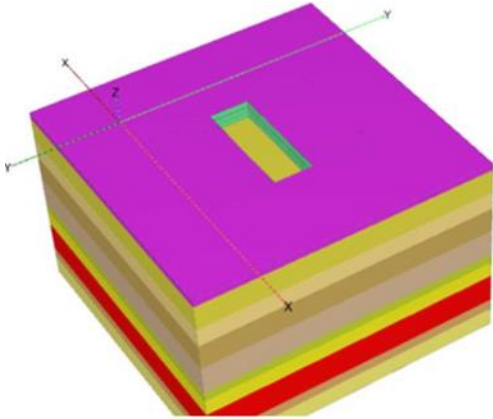


Figure 13: Plaxis 3D model after central excavation

The excavation was then carried out in six successive stages, allowing for gradual digging and better control of deformations. The model has analysed using the Strength Reduction Method to check the safety factors at the final stage (the most critical one). The horizontal displacement results obtained during the six excavation stages. The displacement results are presented in the Table 2.

The study carried out a small parametric study to optimize the thickness of the diaphragm walls. Several values tested: 1.0 m, 0.8 m, 0.7 m, 0.6 m, and 0.5 m, and observed the variations

in safety factors during the final excavation stage. The results are presented in the Table 3:

Table 2. Displacement results with a 1 meter thick diaphragm wall

Phase number	Excavation depth [m]	Horizontal displacement U_x [mm]	Horizontal displacement U_y [mm]
Phase 1	0	-	-
Phase 2	2	2.287	6.196
Phase 3	2.3	2.402	7.579
Phase 4	4	3.470	16.080
Phase 5	6	5.865	32.950
Phase 6	7.75	11.070	54.150

Table 3. Results of safety factors for different diaphragm wall thicknesses

Wall Thickness [m]	Safety Factor
1	4.370
0.8	3.835
0.7	3.857
0.6	3.816
0.5	3.625

However, the safety factor alone is not sufficient to determine the optimal wall thickness. The study therefore decided to analyse the horizontal ground displacements during each excavation phase for each tested thickness. The graph below shows the horizontal displacement U_x for each wall thickness (Figure 14).

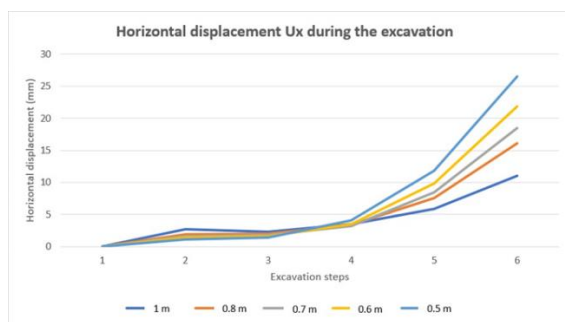


Figure 14. Graph showing horizontal displacement (U_x) for different wall thicknesses during excavation

The graph below shows the horizontal displacement U_y for each wall thickness (Figure 15).

The analysis of horizontal displacements revealed that for diaphragm wall thicknesses

down to 0.7 m, lateral movements remain below 20 mm along the x-axis and under 100 mm along the y-axis, even during the most critical excavation stages. Compared to thinner wall configurations, the 0.7 m thickness shows significantly better control of ground displacements, both along the x- and y-axes. This suggests improved performance in limiting deformations, which is essential in urban tunnelling projects.

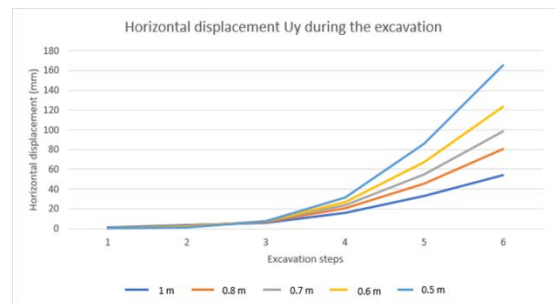


Figure 15: Graph showing horizontal displacement (U_y) for different wall thicknesses during excavation

Based on these findings, a wall thickness of 0.7 m appears to be a well-balanced solution, offering improved material efficiency and reduced construction costs compared to the initial 1.0 m design, while still maintaining satisfactory safety margins and deformation control.

Installation of the central part of the tunnel

To make the model as realistic as possible, the central part of the tunnel using three adjacent tunnel elements is represented. The main section is located in the center, while two smaller side sections were added in the opposite direction to align the tunnel openings with the future access ramps. This configuration was chosen to best match the real geometry of the tunnel entrances.

Although this is not a perfect solution, since it introduces two internal walls at the center of the tunnel that should not exist, it remains the closest approach I could implement within the limits of the software. A visual of the tunnel model is presented in the Figure 16.

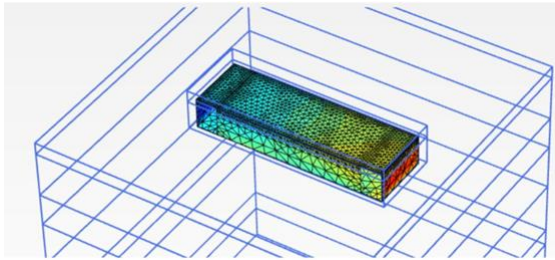


Figure 16. Plaxis 3D modelling of the central tunnel

Regarding results, the maximum horizontal displacement observed after this stage is 22.78 mm, as shown in the image below. The safety factor computed using the Strength Reduction Method is 1.869, indicating a stable configuration at this point of the construction (Figure 17).

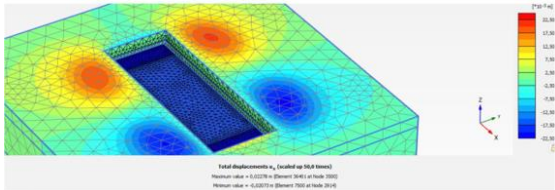


Figure 17: Displacement results of the installation of the central part of the tunnel

These results indicate a very stable structural behaviour at this stage of construction. The safety factor of 1.869 is well above the commonly accepted threshold of 1.5 for long-term conditions, suggesting that the system has a good margin of safety. Additionally, the maximum horizontal displacement of 22.78 mm remains relatively low, which is a positive outcome. Overall, this confirms that the design of the central tunnel section is both safe and effective.

Excavation of the four side sections

At this stage of the project, the excavation of the four side sections of the tunnel was carried out. These areas correspond to the future access ramps that will connect pedestrians from street level to the underground passage.

Before proceeding with the excavation, new diaphragm walls were installed around

each of these zones. These walls were modelled with the same optimized thickness of 0.7 meters as those used in the central section. Their role is to ensure soil retention and stability during the excavation phases of the access ramps.

The analysis focused on horizontal displacements (along the x and y axes) during three key stages of excavation: an initial phase, an intermediate phase, and a final phase. Figure 19 shows these three excavation stages in Plaxis 3D (Figure 18).

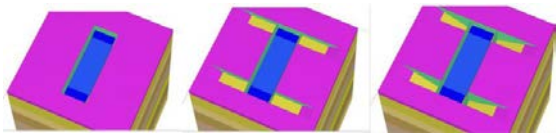


Figure 18. Plaxis 3D modelling of the three excavation stages

The Table 4 shows that the maximum displacements remain quite stable and low throughout the process, which confirms the good performance of the structure. These values are consistent with those observed during the previous stages. In parallel, the safety factors were recalculated after this excavation step. A slight decrease is observed, from 1.869 to 1.835. However, this variation is minimal and remains well above the critical thresholds, indicating that the overall stability of the model is not affected by this additional phase of excavation.

Table 4. Results of the three excavation stages

Stage 0		Stage 1		Stage 2		
Ux [mm]	Uy [mm]	Ux [mm]	Uy [mm]	Ux [mm]	Uy [mm]	
22.89	113.4	22.89	112	22.88	110.4	
1.869		1.861		1.835		Safety factors

CONCLUSION

In this study, a numerical analysis using finite element software has been conducted to investigate on the build pedestrian tunnels combined with commercial spaces in big cities in Viet Nam. Some interesting conclusions arising from numerical simulations are given: Throughout the different modelling phases,

excavation, structure installation, the results demonstrate a globally stable behaviour of the tunnel, with moderate displacements and satisfactory safety factors. The optimizations made, especially regarding the diaphragm wall thickness, helped achieve a good balance between structural stability and material efficiency. The final model meets safety requirements while displaying consistent and effective mechanical performance. A technically and economically viable solution, checked its compatibility with the ground conditions by analysing displacements, global stability, and structural deformability. Safety was also a major consideration, particularly through the calculation of safety factors at critical construction stages.

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