VIET NAM NATIONAL UNIVERSITY
HO CHI MINH CITY

THE STATE COUNCIL FOR PROFESSORSHIP
THE INTERDISCIPLINARY EARTH - MINING SCIENCES COUNCIL
FOR PROFESSORSHIP

VIET NAM METEOROLOGICAL AND
HYDROLOGICAL ADMINISTRATION

Proceedings of the Sixth International Scientific Conference

EARTH AND ENVIRONMENTAL SCIENCES, MINING FOR DIGITAL TRANSFORMATION, GREEN DEVELOPMENT AND RESPONSE TO GLOBAL CHANGE

SCIENCE AND TECHNICS PUBLISHING HOUSE

Table of Contents

RESEARCH ON BEHAVIOR OF ROCK/SOIL MASS DURING UNDERGROUND PARKING EXCAVATION IN MULTI-LAYERED SOILS IN URBAN AREAS

Dang Van Kien[1,*], FORNONI Benjamin[2], Mai Xuan Thanh Tuan[1], Doan Quang Tri[3], Nguyen Khoa Linh[1]

[1] *Faculty of Civil Engineering, Hanoi University of Mining and Geology (HUMG), Hanoi, Vietnam*

[2] *Institut Polytechntqije de Grenoble-Polytech Grenoble, Untversite Grenoble Alpes, Grenoble, France*

[3] *Viet Nam Meteorological and Hydrological Administration*

[*] *Email: dangvankien@humg.edu.vn*

Abstract: Urban underground space is an important part of densely populated urban areas, helping to solve problems of transportation, water supply and drainage infrastructure, electricity, telecommunications, and other public activities. Urban underground space has been built and operated effectively by developed countries for a long time. In Hanoi, Ho Chi Minh city, Vietnam, the lack of parking facilities space is one of the main causes ncreasingly serious traffic congestions. In order to meet the parking demand in the centre, Hanoi has prepared a plan to develop multi-level and underground parking facilities at the Vietnam-Russia Friendship Palace and Tran Hung Dao station, Thu Le Park, Thong Nhat Park… Earlier, Ho Chi Minh City has also prepared a plan to devolop some underground parking lots on Le Lai Street in District 1, in front of Le Van Tam Park on Hai Ba Trung Street in District 1, in the Cho Lon Bus Station in District 5, and on Hai Thuong Lan Ong Street in District 5.... However, they have never moved past the planning stages. The paper study behavior of rock/soil mass during underground parking excavation in multi-layered soils in urban areas by FEM analysis. The pattern of deformation, stress state, and distribution of plastic areas are analyzed by Plaxis 2D software. The study result provides a reliable way to analyze the stability of underground car parking in multi-layered soils in urban areas and also will help to design or optimize the subsequent support.

Keywords: *Underground car parking, FEM, rock/soil mass, Hanoi, Ho Chi Minh, barrette wall*

1. INTRODUCTION

1.1. Current situation of management and development Urban underground construction upace in Vietnam

In fact, in the past urban development, many underground technical infrastructure works have been built such as water supply, drainage, electrical cables, telecommunications, lighting, technical trenches, tunnels ... especially underground urban traffic works such as: urban railway system, tunnels for automobiles, pedestrian tunnels, underground parking lots,... many high-rise buildings in urban development areas with basements, however, most of them are only used for parking, less used for public service purposes; Currently, some areas in major urban areas such as Hanoi, Ho Chi Minh City, Da Nang... (service and commercial centers combined with high-class housing such as Royal City, Times City, Da Nang Plaza, JW Mariot, Vincom Center Dong Khoi...) has built and put into use a relatively synchronous underground space (currently, only Hanoi prepares and approves the general planning of underground construction space of the central urban area - Hanoi city to 2030, with a vision to 2050 (Decision 913/QD-UBND dated March 15, 2022). However, in general, most of the underground works are partial, only exploited for a separate purpose, but there is no overall connection for the whole area or an urban area. This shows that the need to exploit and use underground space in urban areas is becoming increasingly necessary to promote urban development, improve people's quality of life and serve economic development [5-7].

In this paper, the traditional urban core where people reside, commercial and business establishments concentrate, government offices and public services such as hospitals, schools, and museums are located using to study. There are is nearly 600 persons/ha of population density in the Ancient Quarter (AQ) and 214 persons/ha in the FQ (French Quarter). As the center and socio-economic hub, a large number of people flows into the area, thus population density is even higher in the daytime (See Table. 1) [3]. The increasing rapidly of the number of private transport vehicles is at a rate of approximately (10÷15)% per year.

Figure 1. *Situation of common traffic congestion in Hanoi*

Table 1. Socio- Economic Profiles in the traditional urban [3]

		Ancient quarter (AQ)	French quarter (FQ)	Total
Area		80	217	297
Night-Time population (000)		47	46	93
Day- Time (000)	Employment	55	54	109
	Student	11	11	22
	Population	77	76	153
Population Density (n^o/ha)	Night - time	585	214	314
	Day - time	958	351	514
Day - Night Ratio		1.87	1.64	1.64

In 2020, there should be 36 million motorbikes and 3 million cars in Hanoi. Correspondingly, a statistic from the Department of Transportation mentioned that Hanoi has 1,178 parking points (see Table 2). However, this parking points accommodated about 8÷10% of Hanoi's parking demand only. Therefore, Many cars have to park on the sidewalk. It makes the situation of common traffic congestion in Hanoi such as Figure 1 [1].

Table 2. Current Situation of Parking in Hanoi by District [3]

District	Car		MC		Total	
	Point	Area (m^2)	Point	Area (m^2)	Point	Area (m^2)
Hoan Kiem	144	18,317	177	12,547	321	30,864
Ba Dinh	121	71,320	102	5,417	223	76,737

Hai Ba Trung	106	22,304	137	4,762	243	27,066
Dong Da	77	11,656	82	3,034	159	14,690
Hoang Mai	18	72,572	8	2,700	26	75,272
Long Bien	9	13,353	18	2,095	27	15,448
Cau Giay	32	55,874	22	11,639	54	67,513
Thanh Xuan	15	679	61	8,815	76	9,494
Tay Ho	20	1,551	11	515	31	2,066
Ha Dong	6	378	7	594	13	972
Tu Liem	5	95,147	0	0	5	95,147
Total	553	363,153	625	52,118	1,178	415,271

Note: Data for Parking administrated by DOT, including On-Street and Off - Street Facilities.

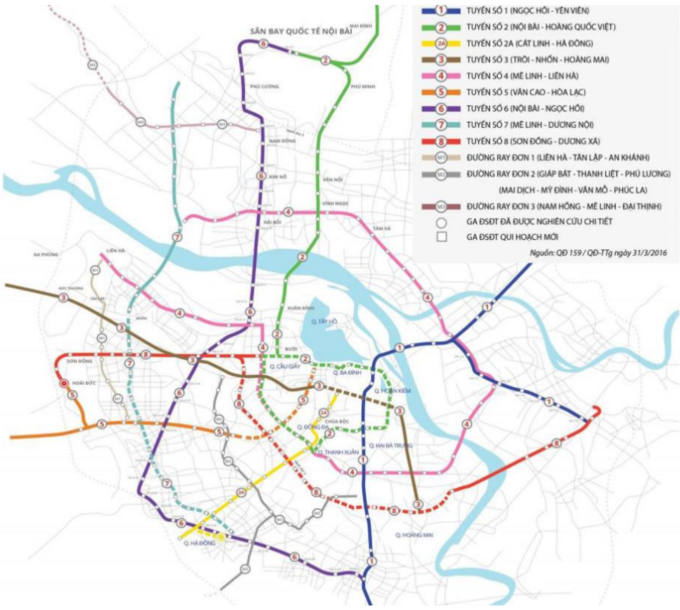

***Figure 2**. Master plan of metro lines in Hanoi [3]*

In fact, in the past urban development, many underground technical infrastructure works have been built such as water supply, drainage, electrical cables, telecommunications, lighting, technical trenches, tunnels ... especially underground urban traffic works such as urban railway system, tunnels for automobiles, pedestrian tunnels, underground parking lots,... many high-rise buildings in urban development areas with basements, however, most of them are only used for parking, less used for public service purposes. Therefore, the planning, design and construction of underground parking lots in big cities like Hanoi and Ho Chi Minh City are very necessary and urgent.

The location of Tran Hung Dao (C10) station is under the intersection of Tran Hung Dao Street and Hue Street in French Quarter area. Hanoi station connected to Tran Hung Dao Street, and Tran Hung Dao Station is a transfer station between Line 3 and Line 2 (Phase -2 section). The station area covers the French Quarter, characterized by its traditional French-style buildings and its wide and grid road network with trees and sidewalks (see Figure 3). An parking area will be constructed underground, above the space where the railway will make a U-turn. This location will devolop the railway terminal after completion of Phase1.

This underground car parking will be contructed by the cut and cover method, hence it is limited additional works to develop an underground parking area [3].

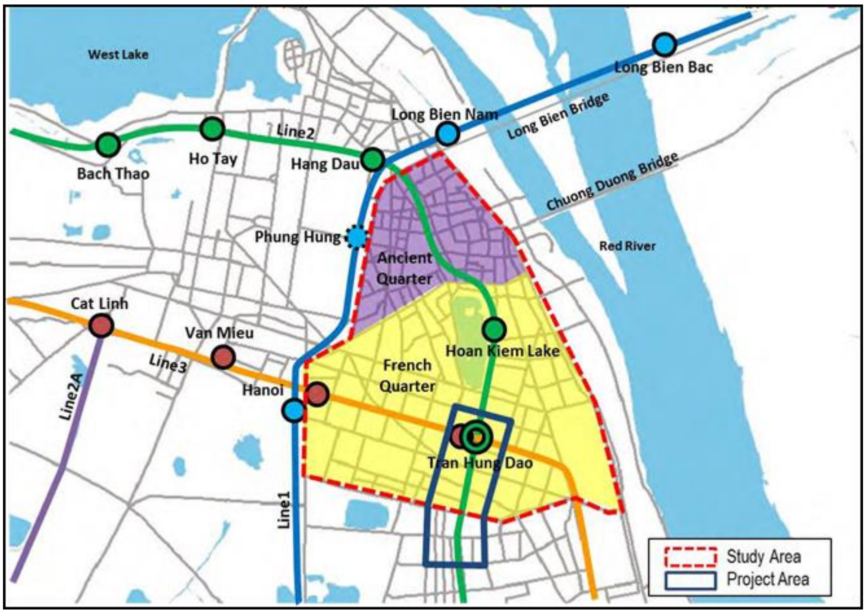

__Figure 3.__ Location of the study area and the project area

1.2. Facility Plan

The dimention of underground parking is 255m in long and 21.4 m in wide (see Figure 4). underground parking will constructed in the underground space, above the space where the railway will make a U-turn i.e. the terminal of the Phase 1 section which will be excavated by the cut and cover method, above Line 2. This underground car parking will be designed a self-propelled 2-floor structure with a capacity of about (i) 200 cars for 2 floors, or (ii) 560 lots for motorbikes on the -1 floor and 100 lots for cars on the -2 floor. It'area is 4,900m^2 each floor including machine rooms, toilets, and others. The underground walkway from the -1 floor will directly connect to the concourse of Tran Hung Dao Station. Two emergency exits to Hue Street will be designed.

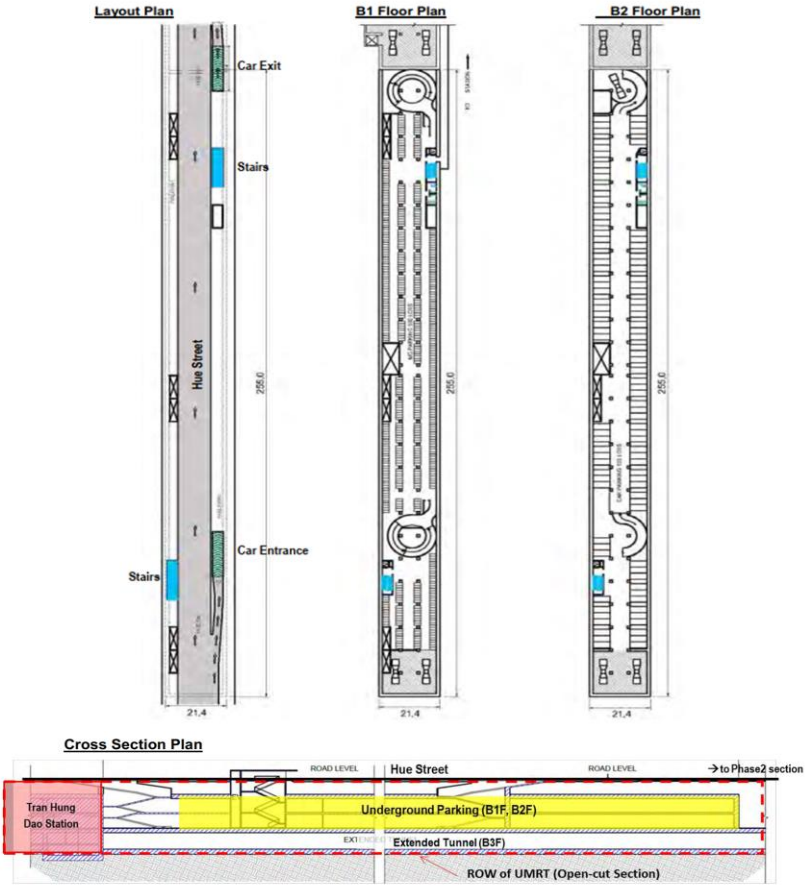

__Figure 4.__ Tran Hung Dao underground car parking' Facility Plan

2. NUMERICAL MODELS

2.1. Description of the model

For the numerical simulation, two-dimensional finite element code PLAXIS is used. The Mohr-Coulomb model is used to model soil. Evaluating the behavior of rock/soil mass during underground parking excavation in multi-layered soils in urban areas performed based on Plaxis 2D software. This software allowed to analyze the sequence of underground parking car excavation and install the wall support. The software is also given maximum stress and strength of barrette wall, the concrete slab and the support column. The study is performed the project according to a plane deformation, with elements at 6 nodes, according to (x,y). *The car park is 255.0 m long,* the model is asymmetrical, since on one side of the car park there is a load which corresponds to the stress caused by the road and traffic. I considered a road 1.50 m from the car park. The road in front of the car park is 317.66 m long and 5 m wide. There will be 5 excavation phases for the construction phase of the project. A soil survey was carried out on site and the lithology is made up of 6 apparent layers. Moreover, a water table was detected 2 metres below ground level.

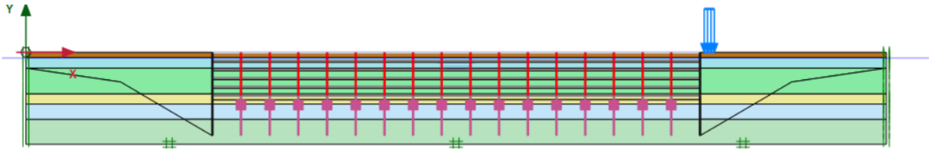

Figure 5. *Numerical model*

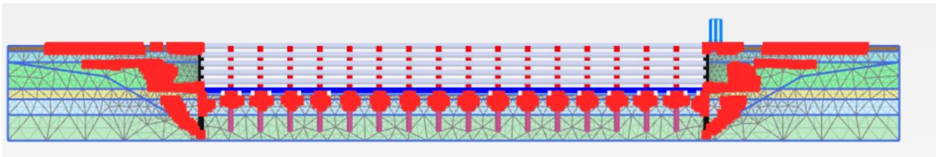

Figure 6. *Meshing of the study area*

Concerning the boundary conditions on the edges, on the vertical edges. The model is blocked vertical movements so that the model doesn't leave the defined zone and this causes problems in the convergence of the calculations. On the bottom horizontal edge. The model is also blocked vertical and horizontal movement. For the top horizontal edge, all movements are free. In addition, in order to understand the behavior of the soil on the structure. All the elements of the structure deformable are left. The model is calculated through 10 phases, in order to have a good understanding of how the soil would behave during the construction of the car park. The phases are as follows:

- Initial phase: Construction of the bar wall, bored piles, steel columns encased in concrete and the first concrete slab.

- Phase 1: Lowering of the water table to -4.0 m from the ground surface then excavation to -3.5 m from the ground surface

- Phase 2 : Construction of the second slab.

- Phase 3: Lowering of the water table to -7.0 m from the ground surface then excavation to -6.5 m from the ground surface.

- Phase 4: Construction of the third slab.

- Phase 5: Lowering of the water table to -10 m from the ground surface then excavation to -9.5 m from the ground surface.

- Phase 6 : Construction of the fourth slab.
- Phase 7: Lowering of the water table to -13 m from the ground surface then excavation to -12.5 m from the ground surface.
- Phase 8: Construction of the fifth slab.
- Phase 9 : Lowering of the water table to -17 m from the ground surface then excavation to -16.5 m from the ground surface.
- Phase 10 : Construction of the sixth slab.

As far as lowering the water table is concerned, the underground ware is located 1.0 m below the future excavation to facilitate working conditions and the installation of the slab. Similarly, the excavation is carried out 0.5 m below the height of the concrete slab, enabling it to be built in good conditions.

2.2. Material Parameter Setting

Various reconnaissance tests have revealed the following lithological parameters. The soil model used for this project and its study is the Mohr-Coulomb model. Given the lithology of the soil, the different soil layers exhibit different behaviours, so it's more appropriate to use the Mohr-Coulomb model. In addition, the soil is predominantly sandy. The parameters of this model are the angle of friction (φ), cohesion (c), angle of expansion (Ψ), Poisson's ratio (ν) and Young's modulus (E). In this project, the Mohr-Coulomb model will be used to assess the forces and stresses exerted on the structure and also to evaluate the stability of the soil-wall model. Soil lithology and its parameters is presented on Table 3. The properties of the embedded beam row are Table 3 as follows:

Table 3. Physical and mechanical parameters of the simplified stratum

Layers	γ (kN/m^3)	γ' (kN/m^3)	C (kN/m^2)	φ (°)	ν	E (MN/m^2)	Thickness (m)
Backfill	18	8	0	30	0.2	22.74	1.8
Sandy Clay	19.4	9.4	60	2	0.3	13.32	3.7
Fine Sand	18	8	0	24	0.2	17.726	9
Sandy Clay	20.1	10.1	60	3	0.3	13.9	3.5
Clayey Sand	19.7	9.7	14	21	0.2	17.614	5.3
Fine to coarse Sand	18	8	0	30	0.2	28.658	8.7

In the case of the barrette wall, the concrete slab and the support column, we resonate at a depth of 1 metre. For each element we consider its weight in the analysis of the results such as Table 4, the properties of the embedded beam row is presented on Table 5.

Table 4. The properties of the plates

Plate	Road	Last concrete slab	Concrete support column	Barrette wall	Concrete slab
Material type	Elastic	Elastic	Elastic	Elastic	Elastic
Thickness (m)	0.2	0.8	0.4	1	0.3
Young's Modulus (MN/m^2)	30000	30000	30000	50000	30000
Poisson's ratio	0.2	0.2	0.2	0.2	0.2

EA (Elastic stiffness) ($kN.m^2/ml$)	6000000	24000000	12000000	50000000	9000000
EI (Bending stiffness) ($kN.m^2/ml$)	70 000	1 280 000	160 000	4167000	67500

Table 5. The properties of the embedded beam row

Identification	Bored piles
Material type	Elastic
Young's Modulus (kN/m^2)	30 000 000
Volume weight (kN/m^3)	25.0
Diameter (m)	1.0
A (m^2)	0.7854
I (m^4)	0.04909
$L_{spacing}$ (m)	1.5
$T_{skin, start, max}$ (kN/m)	188.5
$T_{skin, end, max}$ (kN/m)	188.5

To calculate $T_{skin, start, max}$ and $T_{skin, end, max}$, the following formula (1) is used:

$$T_{skin, start, max} = T_{skin, end, max} = Q_s * 2 * \pi * R \text{ (radius)} \qquad (1)$$

Where: the maximum axial skin resistance $T_{skin,max}$. With regard to road and traffic loading, the article by, entitled design and construction experience, predicts a load of 40 kN/m^2 in a traffic jam in front of the car park. This loading is considered in model because it's the most unfavourable for the structure and involves more instability and therefore displacements. In this section, the study is performed to look at the influence of soil behaviour on the structure in terms of the displacements and stresses that this implies for the structure. It's interesting to analyse the stability and safety of the structure with the safety measures that apply in Vietnam in order to find solutions to optimise the project.

2.3. Safety standards

As far as the maximum displacement is concerned, in Vietnam the maximum tolerable displacement $u_{x, max}$ must be less than where H is the height H of the moulded wall.

3. RESULTS AND DISCUSSION

The part of the structure subject to the most displacement is the moulded wall. It's therefore necessary to study the stresses and displacements caused by the ground on the wall. The two moulded walls in the study of displacements is distinguish. Table 6 shows the maximum deformation of the structure caused by the ground:

Table 6. The maximum deformation of the structure

Phase	Maximum displacement of the moulded wall on the park side (cm)	Maximum displacement of the moulded wall on the roadside (cm)
1	1.54	1.85
2	1.58	1.90

3	2.74	3.04
4	2.75	3.06
5	3.92	4.23
6	3.93	4.25
7	4.96	5.25
8	4.96	5.26
9	6.38	6.68
10	6.40	6.72

In fact, the moulded walls are subject to the most stress due to the earth pressure and the hydraulic pressure of the ground. The bending moment in the two moulded walls during the phase 10, as it's during this phase that it's most significant is presented Figure 7. The maximum absolute bending moment is 2578 kN.m/m.

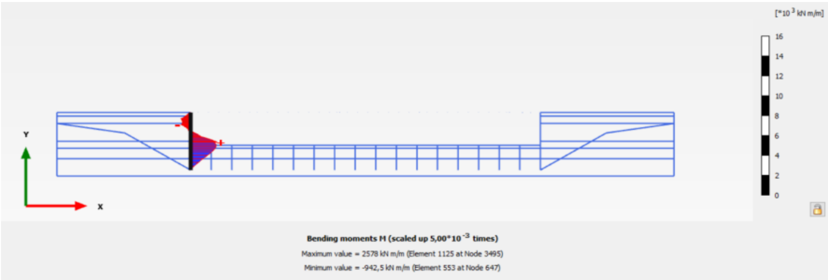

Figure 7. *Bending moment during phase 10 on the park side*

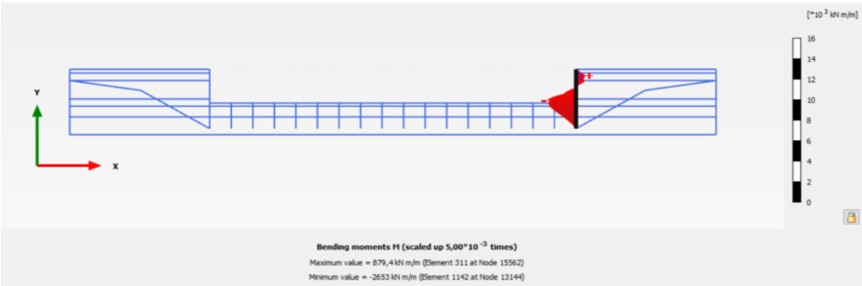

Figure 8. *Bending moment during phase 10 on the roadside*

The maximum absolute bending moment is 2653 kN.m/m. These bending moments are quite significant. When it comes to the water status of the project, there are several things to check, such as flow rate, pore pressure and degree of saturation:

- Interstitial pressure increases with depth;
- In absolute terms, the highest value of interstitial pressure is 320 kN/m^2;
- The flow is zero everywhere in this project.

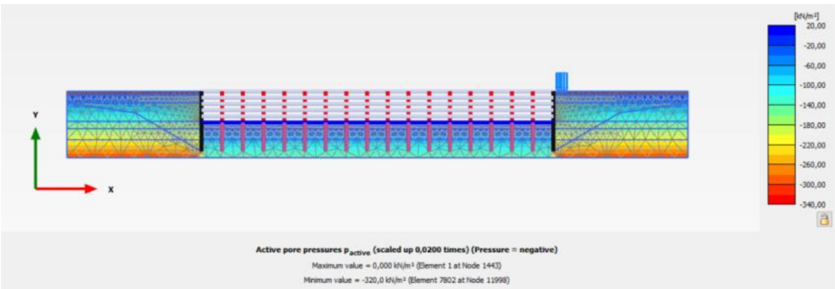

Figure 9. *Interstitial pressure in this project*

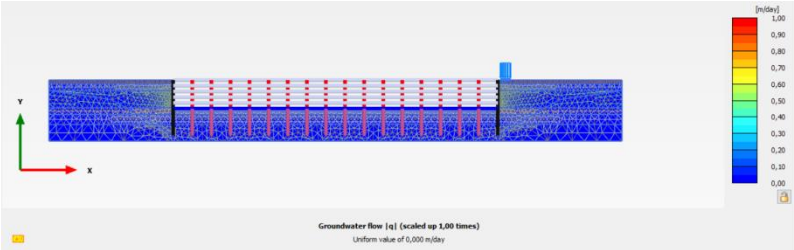

Figure 10. *Water flow in the car park*

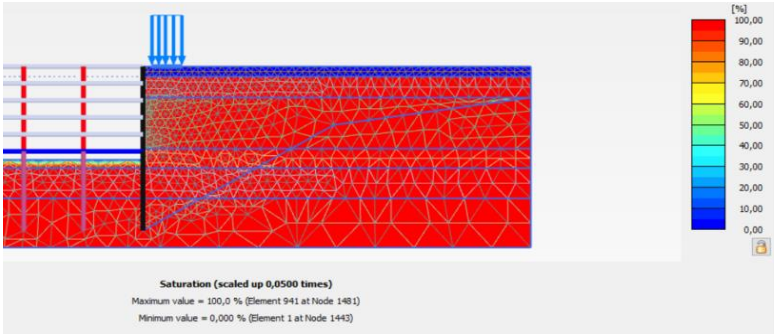

Figure 11. *Representation of soil saturation on the distributed load side*

In fact, the initial state means that the water level is high, which implies that the flow is zero. Soil saturation is as follows. The soil is 100% saturated below the water table on the land side. Similarly, on the excavation side, the soil is 100% saturated below the water table. Suction is the capacity of a soil to retain water inside its pores due to capillary forces. The higher the suction, the more water the soil retains and the more difficult it's for water to move. Suction measures the capillary tension in the soil, which is created by the forces of interaction between the water molecules in the soil. In the suction is very weak or almost non-existent.

3.1. Exploitation of results

Firstly, in terms of displacements in the structure linked to the ground during excavation, the element that moves the most is the moulded wall on the uniformly distributed load side, that is the roadside. The greatest displacement of the moulded wall occurred during the penultimate phase, with a displacement of 6.72 cm. According to the standards in force in Vietnam, this displacement is tolerated. Indeed, the height H of the moulded wall is 19 m, so the maximum permissible displacement is 9.5 cm indeed $\frac{H}{200}$ is equal to 9.5 cm.

These displacements can be explained on the one hand by the presence in the soil of powdery layers, that is granular materials such as sand which, under the application of a load, sees the angle formed by the particles exceed the friction angle, thus causing slippage between the particles and thus causing displacements in the structure. In addition, granular materials are permeable, which means that water can pass through them, altering the mechanical properties of the soil and causing displacement or settlement of the structure. The presence of clay in the sandy soil makes it somewhat coherent but can concentrate hydrostatic pressure on certain points of the structure, destabilising it due to its impermeability. Figure 7 shows that the ground is saturated when the water table falls to 100%, which means that there is no suction, as confirmed by Figure 8. This is because the water fills all the empty spaces between the soil particles, so there is no capillary force to hold it back. The problem with zero suction in the ground is that it can lead to excessive drainage, allowing a large quantity of water to pass through and thus causing high hydrostatic pressures on the structure. For example, many companies around the world choose to continue pumping groundwater even after the site has been completed. In the case of the Tran Hung Dao underground car park, a large concrete slab is poured at the bottom of the excavation to make it impermeable, and this slab is supported on piles spaced 1.5 m apart to prevent the slab from lifting as a result of the hydrostatic pressures beneath it. So, once the car park is built, they can stop pumping groundwater. However, during the construction phase, a great deal of pumping will be necessary as the soil remains very permeable. In terms of the forces that pass through the moulded walls, it's consistent to find a higher bending moment for the wall on the roadside, as the load linked to the road and traffic increases the vertical and horizontal stress values in the ground. The values obtained for the bending moment were used to design the walls, taking into account the forces due to the different layers of soil, the hydrostatic thrust due to the water table and the distributed load due to road traffic. Having studied the behaviour of the ground on the structure during excavation of the car park, it's worth optimising the project by finding solutions that will reduce displacements in the structure, particularly at the level of the moulded wall, and by reducing the stresses in order to optimise the design.

3.2. Solutions for optimising the structure

The search for solutions to optimise the project will focus primarily on the interaction between the ground and the moulded wall, with the aim of finding various effective ways of reducing displacements and the bending moment in the walls. Various solutions can be implemented, such as changing the dimensions of the wall, external reinforcement, the use of nails…

3.3. Variations in moulded wall dimensions

Increasing the wall thickness increases rigidity and therefore resistance to deformation. In fact, this increases the quadratic moment, allowing the loads to be distributed more evenly over a larger surface area and therefore reducing the stresses applied to the wall. The following Table 7 shows the influence of wall thickness on displacements and bending moment:

Table 7. The influence of wall thickness on displacements and bending moment

/	e = 1 m				e = 2 m			
/	|u|(cm)		M (kN.m/m)		|u|(cm)		M (kN.m/m)	
Phase	Park wall	Roadside wall	Park wall	Roadside wall	Park wall	Roadside wall	Park wall	Roadside wall
1	1.54	1.85	547.9	635.8	1.18	1.50	1344	1457
2	1.58	1.90	536.6	623.4	1.25	1.57	1318	1429
3	2.74	3.04	1161	1262	1.88	2.14	2898	2936
4	2.75	3.06	1155	1254	1.91	2.18	2878	2915
5	3.92	4.23	1734	1827	2.93	3.14	3861	3899
6	3.93	4.25	1725	1815	2.95	3.17	3847	3883
7	4.96	5.25	2145	2237	4.23	4.38	4240	4295

8	4.96	5.26	2129	2221	4.24	4.40	4228	4281
9	6.38	6.68	2565	2600	6.19	6.34	3946	3995
10	6.40	6.72	2579	2657	6.23	6.40	3876	3945

In this section, in the roadside wall is interested. It shows that increasing the thickness of the wall reduces the displacement by around 3 mm in the final phase.

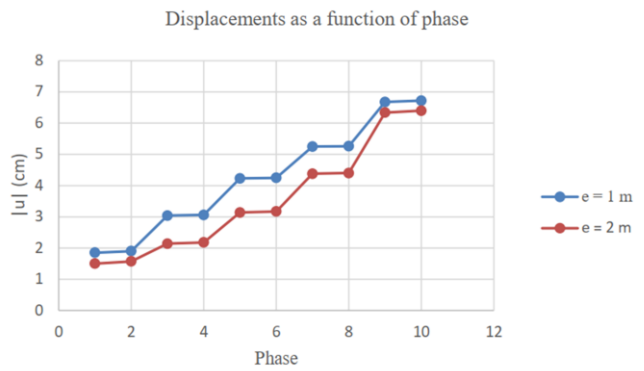

Figure 12. *Graph showing the evolution of displacement as a function of phase with variation in thickness*

Reducing displacements reduces deformation, cracks and therefore damage to materials. However, we can see that on the other hand there is a significant increase in the bending moment. In fact, if we increase the quadratic moment, the bending strength of the cross-section will increase, which means that the structure will have a greater capacity to resist bending moments. This means that the structure will be able to withstand greater bending moments, hence the increase in bending moment. Yet, we can also play with the depth of the wall, and after several simulations with the Plaxis software, It can be found interesting to reduce the moulded walls by 6 m. The wall is now 23 m deep. It's interesting to see how this can affect displacements and efforts. The following Table 8 shows the displacements of the walls on the park and road sides for each phase:

Table 8. The displacements of the walls on the park and road sides for each phase

Phase	Maximum displacement of the moulded wall on the park side (cm)	Maximum displacement of the moulded wall on the roadside (cm)
1	1.88	2.44
2	1.99	2.57
3	2.94	3.46
4	3.00	3.54
5	4.35	4.82
6	4.39	4.89
7	6.19	6.62
8	6.22	6.69
9	8.84	9.62
10	8.99	9.90

It can be seen that the displacements are greater when the depth of the wall is reduced. This is because reducing the depth of the wall results in a reduction in the cross-section, so the wall is less resistant to bending movements and deformations. Displacements are still permissible, they are less than $\frac{H}{200}$ [4÷7], [12], in this case, H equal to 23m. However, reducing the height of the retaining wall can reduce the bending moment applied to the wall.

This is because it reduces the distance between the line of action of the loads and the axis of rotation of the wall. Yet, reducing the height of the wall may reduce its stability to withstand loads and therefore encourage it to topple over. The bending moment in the two moulded walls during the phase 10 is presented on Figure 10, as it's during this phase that it's most significant. The maximum absolute bending moment is 1382 kN.m/m.

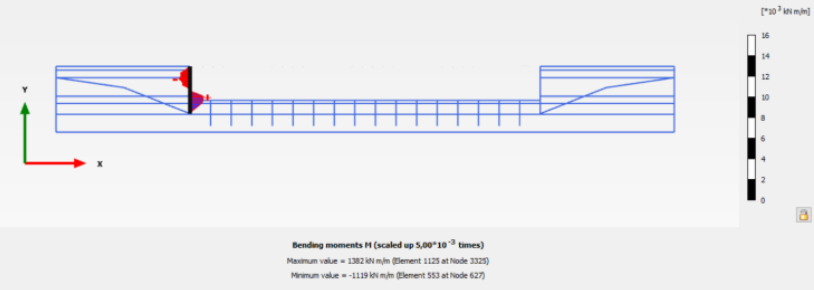

Figure 13. *Bending moment during phase 10 on the park side*

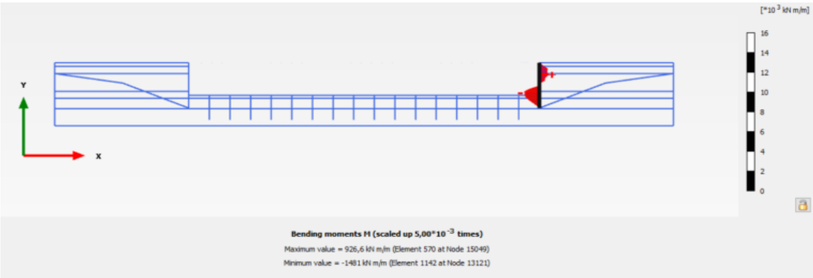

Figure 14. *Bending moment during phase 10 on the roadside*

The maximum absolute bending moment is 1481 kN.m/m (Figure 10). It can be seen that in both cases the maximum bending moment has been reduced, or better distributed in the wall. The retaining wall is keeped this configuration of, that is 23 m deep and 1 m thick.

4. CONCLUSION

1. This paper describes the behavior of rock/soil mass during underground parking excavation in multi-layered soils in urban areas. Based on results of numerical simulation, it is reasonable to conclude that:

2. The pattern of deformation, stress state, and distribution of plastic areas of rock/soil mass during underground parking excavation in multi-layered soils in urban areas can be analyzed by Plaxis 2D software with phases.

3. The maximum vertical displacement and maximum horizontal displacement of the supporting structure are positively correlated with the excavation depth. The the maximum vertical displacement and the maximum horizontal displacement of the support structure are smaller than the allowable limit. The research results summarized in this paper can be used as a means to assess the control risk of foundation pit excavation.

4. The evolution of displacement as a function of phase with variation in thickness. A better understanding of the ground helps to ensure the stability and safety of the structure. Understanding the behaviour of multi-layered soils in urban areas is also very important because it has an environmental impact. The understanding of the soil on which a structure is being built makes adapt the structure to the soil and not the soil to the structure. Improving soil management by optimizing the quantity of soil excavated to limit soil pollution by reducing the number of injections, particularly those used to stabilize, solidify, and consolidate the soil.

REFERENCES

[1] Doc. No.81/KH-UBND “Plan for developing transportation infrastructure of Hanoi, period 2011-2015".

[2] Luong Tu Quyen, Head of Scientific Research task- City level: Research designing system of underground public car park in the city of Hanoi. Code 01C- 04 / 06-2008-2.

[3] JICA Project Team. Project for Studying the Implementation of Integrated UMRT and Urban Development for Hanoi in Vietnam. Final report – main text II. Hanoi. 2008.

[4] Lam Quang Cuong (2006): *Exploitation and developmental management of underground space in Hanoi. Symposium Presentation: Exploiting the advantages of Natural Resources and Socio-economic conditions in the process of urbanization and sustainable development of the capital Hanoi*. Hanoi in 10/2006.

[5] Doan The Tuong (2008): The urban form of background in Hanoi, Ho Chi Minh City and assess them for the construction of underground works. APAVE. Articles Underground.

[6] Doan The Tuong (2000) - Head of research The technical problem of construction of urban underground. The report summarizes the Scientific researches task- State level. Institute of Science and Technology Construction, the Ministry of Construction. Hanoi.

[7] Doan The Tuong (2004)- Head of research: Mastering the technology of construction of underground works in urban soft soil of Vietnam. Final report of Scientific researches task- Ministry level. Institute of Science and Technology Construction, the Ministry of Construction. Hanoi.

[8] ChetanVaidya, KeerthiGowda B.S (2014). Analysis of Underground Parking Structure. International Journal of Emerging Trends in Engineering and Development. Issue 4, Vol.3 (May 2014). ISSN 2249-6149.

[9] http://hanoimetro.net.vn/en/ban-do-8-tuyen/

[10] Midhula Jayanandan (2015). Numerical Simulation of Soil Nailed Structures. nternational Journal of Engineering Research & Technology (IJERT. Vol. 4 Issue 08, August-2015.

[11] Babu G, Singh VP, Simulation of soil nail structures using PLAXIS 2D. Plaxis Bulletin. Spring issue; 2009. p. 16–21.

[12] Luu Nguyen Vu, Pham Quoc Dung. Double diaphragm wall – Design and construction experience. Infrastructure Development, Lecture Notes in Civil Engineering 62. https://doi.org/10.1007/978-981-15-2184-3_57.

[13] Oliaei, M., Norouzi, B., & Binesh, S. M. (2019). Evaluation of soil-nail pullout resistance using mesh-free method. Computers and Geotechnics, 116, 103179. https://doi.org/10.1016/j.compgeo.2019.103179 .

[14] Babu G, Singh VP, Simulation of soil nail structures using PLAXIS 2D. Plaxis Bulletin. Spring issue; 2009. p. 16–21.

[15] Tobias, P., Hugo, C., Eduardo, G., & Alejandro, P. (2012). Imposed Deformations in Concrete: Case Study of an Underground Car Park. Journal of Materials in Civil Engineering, 24(12), 1513–1519. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000542