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VO NHAT LUAN

STUDY ON GEOTECHNICAL CHARACTERISTICS OF HO CHI MINH CITY FOR THE DEVELOPMENT OF UNDERGROUND TRANSPORTATION

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INTRODUCTION

1. Rationale of the study

Currently, Ho Chi Minh City has been dealing with the consequences of the urbanization process, leading to overload of urban road traffic infrastructure. The inner-city land fund is increasingly depleted. The capacity to simultaneously grow urban height and depth must be the ultimate goal.

In the future, for the underground space in the city center, Ho Chi Minh City will focus on developing 8 radial metro lines, with more than 73km of underground sections and more than 72 underground stations. This proved that the need to build underground space is extremely necessary.

To serve the planning, design, and construction of the underground space in the city, it is necessary to have a database system on geotechnical characteristics. The city already has an urban geological map; a construction geological map and a hydrogeological map with the scale of 1/50,000 and some other related documents.

However, these documents either serve general purposes or mainly serve the treatment of soft ground for a number of different types of construction. Futhermore, there has not been a complete, systematic, and in-depth research on the characteristics of the city's economic conditions serving the construction of underground transportation projects (metro lines, stations, underground tunnels, etc).

Therefore, the study on geotechnical characteristics of Ho Chi Minh City for the development of underground transportation is very urgent and necessary.

2. Research purposes

The purpose of the study is to evaluate the characteristics and subdivision of geotechnical conditions, calculate and predict geotechnical problems that arise when constructing underground traffic works in Ho Chi Minh City.

3. Object and scope of the study

Research object: research the geotechnical environment in Ho Chi Minh City to serve the construction of urban underground traffic works.

Scope of research: evaluate geotechnical characteristics related to the construction of urban underground traffic works (line type) in Ho Chi Minh City, distributed to depth in the interaction area between underground traffic works and the environment geology.

4. Research content

- Overview of geotechnical and underground transportation works; status of geotechnical research for the construction of urban underground traffic works in over the world and Vietnam;
- Evaluate geotechnical characteristics of Ho Chi Minh City: geological environment, technical system and interaction between technical system and elements of the geological environment.
- Geotechnical zoning serving the construction of underground traffic projects in the city;
- Forecast geotechnical issues arising when constructing underground traffic works;
- Propose solutions to ensure stability when constructing underground traffic works.

5. Research methods

The study used a combination of following research methods:

- System analysis: divide the components in the geotechnical environment system, study the interaction between them;
- Inheritance: collect, analyze, synthesize and inherit published documents and research works.
- Theory: add new theoretical bases in Vietnam and the world on geotechnical conditions in the construction of underground traffic works.
- Field work: field trip to metro line No. 1 to supplement data to serve the calculation and prediction of geotechnical issues during construction of urban underground traffic works.
- Use digital modeling and Plasix 2D and 3D softwares.

6. Theses

Thesis 1: Based on geotechnical characteristics from the viewpoint of serving the construction of underground traffic works, the research area is divided into 2 zones, 4 sub-zones and 12 geotechnical plots. Such divisions are the scientific basis for planning, design and construction of linear underground traffic works in Ho Chi Minh City.

Thesis 2: When constructing tunnels with TBM, the allowable settlement limit is not greater than 15mm, in geotechnical conditions such as section II.A.1, the optimal tunneling depth is ≥ 22m with tunnel diameter D ≤ 6m, in geotechnical conditions like plot II.B.1, the optimal tunneling depth is ≥ 15m with tunnel diameter D ≤ 7.0m.

7. New scientific contributions of the dissertation

- The dissertation has contributed to building the theoretical basis and methodology of geotechnical research;
- The dissertation has divided the Ho Chi Minh City area into 02 zones, 4 sub-zones and 12 geotechnical plots to serve the construction of linear underground traffic projects;
- Forecast and analyze changes in ground subsidence during tunnel construction using the TBM method; propose geotechnical solutions to ensure stability when constructing underground traffic works in Ho Chi Minh City area.

8. Scientific and practical significance

Contribute to supplementing the scientific basis for the content and methodology of geotechnical characteristics research serving the construction of urban underground traffic works;

Serve as a reference document to guide planning, surveying, design and construction of underground traffic works in Ho Chi Minh City.

9. Documentation references

The study used documents provided by the Southern Water Resources Planning and Investigation Federation; The Southern Institute of Construction Science and Technology. Other companies and agencies also provided 3,182 images of borehole cylinders and 39,372 experimental soil samples; technical design documents of metro line No. 1, documents collected from field surveys of metro lines and many other related documents.

10. Structure of the dissertation

The dissertation includes 3 chapters and is illustrated by 37 data tables, 56 drawings and graphs, 6 calculation appendices along with 4 published research works and a list of 118 references.

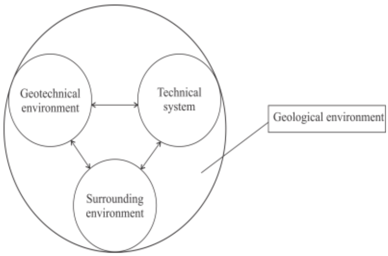
Chapter 1: OVERVIEW OF GEOTECHNICAL RESEARCH FOR CONSTRUCTION OF URBAN UNDERGROUND TRAFFIC WORKS

1.1. Overview of geotechnical and urban underground traffic works

1.1.1. Geotechnical overview

Geotechnical concept: *based on a brief review of geotechnical concepts from domestic and foreign authors, the author proposed that* geotechnical engineering is a scientific branch in the field of construction, using principles and methods of engineering geology, soil mechanics, rock mechanics and other related sciences, specializing in studying the interaction between elements of the geotechnical environment.

In particular, the geotechnical environment is a limited space of geological environment, technical system and surrounding environment, where human economic and construction activities take place along with other processes. Mechanical, physical and chemical processes arise due to the interaction between the geological environment, surrounding environment and construction activities.



⟷ ***Two-way interaction***

Figure 1.1 The relationship of geotechnical environment, geological environment and surrounding environment

In the geotechnical environment, there is always an interaction among the technical system, the geological and surrounding environment. This interactive process will give rise to geotechnical issues - which are adverse problems arising from the interaction between human economic and construction activities, the geological environment and the surrounding environment. Geotechnical problems cause structural instability and degrade the geological environment, negatively affecting human activities.

Research content of geotechnical engineering:

- Geotechnical environmental characteristics related to design, construction and ensuring long-term stability of construction projects;
- Characteristics of construction works in terms of form, scale, and working nature; their interaction with the geological environment, surrounding environment, predicting construction instability, designing foundation solutions to ensure construction stability.

Research object of construction geotechnics

- Geological environment and technical system in their interaction;
- Methods of calculating and designing foundations, predicting changes in the geological environment during construction and exploitation of works, designing solutions to prevent foundation incidents to ensure long-term stability of works.

Methods used in researching construction geotechnics: Inheritance method; Experiment; Calculation; Numerical methods and modeling; System analysis method.

1.1.2. Overview of urban underground traffic works

Concept of urban underground traffic works*:* is a form of underground works, arranged below the ground surface, performing traffic functions such as: subway lines, subway stations, automobile tunnels, pedestrian tunnels, river crossing tunnels and connecting auxiliary underground works.

Classification of urban underground traffic works*:* Floor plan (works with large and limited length); Cross-section size (underground works with small, medium and large sections); Construction depth (shallow and deep underground structures).

1.1.3. Construction methods for urban underground traffic works

Open excavation method*:* soil is excavated openly, creating space for underground works. After construction, the soil is backfilled, applied to civil works with shallow foundations, short, shallow traffic tunnels.

Closed excavation method*:* includes methods of traditional drilling and blasting, shield excavation, New Austrian Tunnelling Method (NATM), special methods (steam-pressed submerged well, cooling, grouting, forced blasting, submerged tunnel).

1.1.4. Geotechnical problems arise when constructing urban underground traffic works

a. For construction by open excavation method: Stabilize the excavation wall and relocate neighboring structures; Sand flows into the dug hole; Water flows into the dug hole; Stabilize the bottom of the excavation.

b. For construction by underground excavation method

Ground subsidence problem*: is the result of land surface subsidence, which is the deformation of the terrain surface due to urban underground construction activities.*

1.2. Status of geotechnical research for the construction of urban underground traffic works

1.2.1. Research around the world

- Studies on geological environment*:* many authors believed that geological environmental factors play an important role in underground construction such as: Hashash (1992), Hai-Min Lyu et al (2019), Salma Akter et al (2018), Jinchun Chai et al (2020), etc. In which, Estanislao Pujades et al (2015), Xiaokang Zheng (2020) commented that hydrogeological conditions, especially groundwater dynamics, must be carefully predicted because these are the factors that cause the most difficulties during the construction of underground traffic works.

- Studies on the physical and mechanical characteristics of soil and rock*:* Anatoliy Grigoryevich et al (2019), have shown three technical parameters of soil: durability, deformability and permeability. Behavioral characteristics of these factors need to be considered when constructing underground traffic works. Terzaghi (1950) proposed a soil classification system for the construction of underground traffic projects based on soil behavior characteristics. In addition, Terzaghi (1977) evaluated the stability of underground works, for sandy and gravelly soils. Peck (1969), evaluated the stability index of underground works for cohesive soils. For rocks, Terzaghi (1946) classified rock masses based on unfavorable factors when constructing underground works. Don U. Deer (1960), proposed the Rock Quality Designation (RQD) index to evaluate rock quality through the core rate when drilling rock. Bieniawski (1976) proposed a method to evaluate the quality and strength of rock mass according to RMR. In addition, Barton (1974) proposed a method to classify rocks according to Q.

- Studies on calculating and predicting stability of underground traffic works*:* the authors were most interested in the issue of ground subsidence when constructing underground traffic works. Authors Z. H. Xu (2018), Wong, K.S (2009), Xia Bian et al (2016), G.A. Pittaro (2017), E. Karimzade (2017), B. Butchibabua (2019), Takao Kono et al (2020), Baolin Hu et al (2019), Minoru

Kuriki (2020), S. Goodarzi et al (2020), etc. assessed that tunneling will affect adjacent structures; it is necessary to prevent displacement of the earth retaining wall. In weak clay soil, foundation improvement is often applied to reduce the displacement of soil retaining walls.

In general, there have not been any work that systematically and completely studied the contents of geotechnical characteristics from the perspective of serving the construction of urban underground traffic works.

1.2.2. Research in Vietnam

- Studies on geological environment*:* Nguyen The Phung et al (2004), Do Ngoc Anh et al (2018) stated that the stability of stratigraphic blocks is an important condition when constructing underground transportation works. Nguyen Ngoc Dung (2018), Le Dam Ca et al (2020), Nguyen Quang Phich (2020) all stated that the groundwater level has a great influence when digging tunnels.

- Studies on physical and mechanical characteristics of rock and soil*:* Nguyen Sy Ngoc et al (2018) believed that the stress state of rocks surrounding undergroud works must be studied, which depends on the form and cross-section of undergroud works. Nguyen Thi Nu et al (2020), commented that for the construction of the Nhon - Hanoi station metro line, it is necessary to determine the abrasion of sand and gravel because it affects the wear of equipment and excavation performance.

- Studies on calculating and predicting the stability of underground traffic works: Doan The Tuong (2012) recommended that when building subways with TBMs, it is necessary to choose the reasonable parameters of the tunnel (diameter, depth, construction technology, etc.) to minimize adverse changes to the project and the surrounding environment. Nguyen Van Hien (2019), Pham Huy Giao et al (2020), Do Minh Ngoc et al (2020), Do Ngoc Thai (2020) calculated ground subsidence when constructing underground works using TBM. For Ho Chi Minh City area, Vo Minh Quan (2017), Le Bao Quoc (2019), Huynh Quoc Thien (2020), Nguyen Trung Hieu et al (2020), Vo Nhat Luan et al (2021), etc. calculated surface subsidence during subway construction. As a result, surface settlement when constructing tunnels with TBM depends on excavation pressure, tunnel diameter and depth.

Thus, in Vietnam in general and Ho Chi Minh City in particular, there has not been any research project that has completely studied the geotechnical characteristics serving the construction of underground traffic works. Research mainly focused on assessing the impact on surface structures when constructing tunnels. Therefore, the author will delve into geotechnical characteristics, calculate and forecast geotechnical problems that arise when constructing underground transportation projects in Ho Chi Minh City area.

Chapter 2: CHARACTERISTICS OF GEOTECHNICAL ENVIRONMENT IN HO CHI MINH CITY

2.1. Characteristics of Ho Chi Minh City's geological environment

2.1.1. Quaternary stratigraphic and geological characteristics

The main lithological complexes are:

- Marine sediment $\mathbf{mQ_2^{2\text{-}3}}$: fine sand, porous, saturated state;
- Mixed river-sea-swamp sediment $\mathbf{ambQ_2^{2\text{-}3}}$: clay mud, clayey mud, brownish gray, dark gray; clay, clay loam, soft plastic - hard plastic;
- Mixed river-marine sediment $\mathbf{amQ_2^{1\text{-}2}}$: Clay, sub-clay, sometimes mixed with grit; Fine-medium grained sand;
- Mixed river-marine sediment $\mathbf{amQ_1^{3}}$: soft-hard plastic clay; water-saturated sand, plastic state; medium-coarse, medium-dense sand, saturated with water;
- Mixed river-marine sediment $\mathbf{am^{CM}Q_1^{2\text{-}3}}$: clay, sub-clay, semi-hard-hard, sometimes flowing-plastic; ash sand, fine-medium sand, medium-dense sand;
- Mixed fluvial-marine sedimentary lithological complex $\mathbf{am^{CM}Q_1^{1}}$: Clay, sub-clay, soft plastic-hard plastic; semi-sand, loose-medium-dense sand, saturated with water.

2.1.2. Characteristics of construction properties of soil and rock

The dissertation is based on the geological engineering map of Ho Chi Minh City at a scale of 1/50,000, and it is found that the construction properties of soil mainly fall into two types:

- Soil with good construction quality includes hard plastic clay and sub-clay, less commonly soft plastic clay (3/4 of the distribution area of type 1 is the amQ_1^3 lithological complex). The soil is located right on the surface, with an average thickness of 20m. Below it, there are lithological complexes of clay, sub-clay, sub-sand of fluvial-marine origin of middle-upper Pleistocene ($amQ_1^{2\text{-}3}$), poor in underground water.
- Weak soil includes 2 types: clay, sub-clay in fluid and plastic state (accounting for ¾ of the area); Fine-medium-grained sand contains pressurized water, mostly modern Q_2 sediments, of swampy or riverine

origin, found right on the surface, with a thickness of 10-30m, average and common thickness of 18m.

2.1.3. Characteristics of structural geological phenomena

Dynamic geological phenomena affecting the construction of natural structures include ground subsidence and sand flow.

2.1.4. Topographic and geomorphological characteristics

According to morphology and formation origin, the author divided the topography and geomorphology of Ho Chi Minh City into 3 main types: Low eroded hills; Accumulation delta; Low-lying swamps accumulated along rivers and seas.

2.1.5. Hydrological, oceanographic and hydrogeological characteristics

Hydrology*: Ho Chi Minh City has 2 main river systems flowing through it: Dong Nai River, Saigon River and 5 main canal systems with a total length of about 55 km serving drainage.*

Oceanographic characteristics*: Ho Chi Minh City has more than 123km of coastline, with irregular semi-diurnal tides.*

Hydrogeology*: the author is mainly interested in two aquifers:*

- Holocene unconfined aquifer (qh) *in Can Gio, Binh Chanh, lower parts of Cu Chi, Hoc Mon, Thu Duc. This is an underground aquifer, the water level is shallow, from 0.5-2.12m or less.*

- Pleistocene pressurized aquifer (qp) *in fine-medium-grained sand unconsolidated sediment containing pressurized water (qp_3). Water is quite abundant, pressure water levels are found at a depth of 1m to more than 10m above the ground.*

2.1.6. Characteristics of toxic gases

The construction process of the metro line in Ho Chi Minh City is not affected by toxic gases.

2.2. Technical system characteristics of Ho Chi Minh City

2.2.1. Overview of the technical system of Ho Chi Minh City

a. Current land use status:

The total natural area of the entire city is 209,554 hectares, of which: 13 old inner city districts of 14,199.88 hectares, equal to 6.78% of the total area; 6 new districts of 35,182.21 hectares, equal to 16.79% of the total area; Suburban area of 160,172.38 hectares, equal to 76.43% of the total area.Thus, the area of 18 urban districts and Thu Duc city accounts for more than 23%, this is a place with high construction density, many high-rise buildings with large loads, diverse in scale and type of construction works.

The area of suburban districts is agricultural land, accounting for 54.5%.

b. Current status of housing and high-rise building construction

The city currently has 1,458 buildings put into operation, including 276 buildings over 100m high and 1,179 high-rise buildings, proving that the surface area of the inner city has almost been built.

c. Road traffic system

- The total routes managed by the Department of Transport are 844 routes (excluding alley routes under 3.5m) with a total length of about 1,356 km;
- Ho Chi Minh City currently has more than 500 large and small bridges, with more than 61 km of length and 756,560m^2 of bridge surface area;
- Ho Chi Minh City currently has over 2,500m of road tunnel length, with an area of 9,028.96 m^2 such as: An Suong Tunnel; Thu Thiem Tunnel,...
- The land fund for the static transportation system is very large, at 1,032.98 hectares. Currently, the station system is mainly for passenger coaches, buses, freight car stations and bus maintenance technical stations, etc. reaching approximately 228 hectares.

2.2.2. Evaluate the characteristics and hierarchy of Ho Chi Minh City's technical system

Ho Chi Minh City's technical infrastructure has the following characteristics:

- The area with high construction density, the scale of construction items with large loads, many types of underground construction, deep foundations, including metro, is largely located in 13 inner-city districts. These areas are not favorable for planning and construction of underground types;
- 54.5% of the city area is agricultural land, mainly arable land, with the population concentrated in concentrations such as hamlets or small towns. Housing projects are sparse, the houses are often low-rise with shallow foundations, and the technical infrastructure system is not yet developed. These areas are very convenient for planning and executing underground construction;
- The remaining area, about 22% of the city area: is the intermediate area, new locations included in the construction planning. Construction density is sparse, mainly shallow foundations, few or no high-rise buildings, underground construction. These areas are relatively favorable for planning and implementing underground construction.

Technical infrastructure is classified according to **the level of difficulty for underground traffic construction**, *according to 3 criteria: construction density; type of construction work and scale of construction work. In which:*

- ***The technical system that is assessed as "Very difficult for underground traffic construction" - Level 1:*** areas with Level 1 of technical system are the 13 old inner-city districts. These places have very high construction density with many types of construction works (civil works, transportation, technical infrastructure, underground works, etc). In these areas, it is necessary to pay attention to locations with concentrations of construction works on the surface or underground that are highly sensitive to construction and exploitation, such as shallow foundation works, less durable structures, and sensitive structures with uneven subsidence. Here, when planning and constructing underground traffic works, it is necessary to take into account solutions such as: the best way is to avoid designing underground traffic routes passing through these locations. If it is necessary to pass through, we should focus on economic efficiency and solutions to ensure the stability of surface and neighboring works during construction and operation.
- ***Technical infrastructure is assessed as "Difficult for underground traffic construction" - Level 2****:* is an intermediate area, accounting for 22% of the city area, areas with lower construction density compared to areas with level 1 of technical infrastructure. This place does not combine many types of construction works as level 1. The construction works are small-scale, low-level, mainly using shallow foundations or friction pile foundations with small cross-sections and foundation depth. The construction of underground traffic works can still be carried out by moving neighboring works or having reasonable construction solutions to ensure the stability of these neighboring works.
- ***Technical infrastructure is assessed as "Little difficulty for underground traffic construction" - Level 3****:* is the area accounting for 54.5% of the city's agricultural land area, areas with high construction density and type. Construction projects as well as the scale of technical items are low, mainly using strip foundations. Foundation depth is small; there are not many construction projects. So, most of them do not need to calculate or use solutions of special geotechnical techniques when designing and constructing underground traffic works.

2.3. Ho Chi Minh City geotechnical zoning to serve the construction of underground traffic works

2.3.1. Purpose and meaning of geotechnical zoning

- Serve the calculations and quantitative forecasts of geotechnical issues when constructing linear underground traffic works. Design and construction of geotechnical solutions to ensure sustainable stability for linear underground traffic works.

2.3.2. Principles of geotechnical zoning

Zoning units from high to low: zones, sub-zones and geotechnical plots

2.3.3. Geotechnical zoning criteria

- Geotechnical zones are based on the characteristics and construction features of soil and rock;
- Geotechnical sub-zones are based on groundwater characteristics and characteristics of geotechnical problems;
- Geotechnical plots are based on the characteristics of construction conditions of linear underground traffic works.

2.3.4. Method of establishing geotechnical zoning diagram

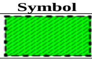
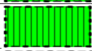
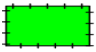
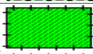
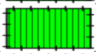
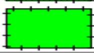
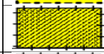
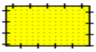
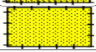
1) Method of editing collected data

Refer to TCVN 9153:2012 Irrigation works - Method for adjusting soil sample test results.

2) Techniques for establishing geotechnical zoning diagrams

The geotechnical zoning diagram is built on the basis of a Quaternary geological map of the same scale, fully showing the location and distribution of zones, sub-zones and geotechnical plots. Geotechnical subdivision symbols are illustrated in table 2.11

Table 2.11. Symbols of geotechnical zoning

No.	Zone		Sub-zone		Plot	
	Symbol	Description	Symbol	Description	Symbol	Description
1		Zone I: convenient for underground traffic construction		Sub-zone I.A: good soil is sticky soil in a soft to hard plastic state		Plot I.A.1
						Plot I.A.2
						Plot I.A.3
				Sub-zone I.B: the foundation is bedrock exposed right on the surface		Plot I.B.1
						Plot I.B.2
						Plot I.B.3
2		Zone II: not favorable for underground traffic construction		Sub-zone II.A: soft soil is cohesive soil in a plastic and flowing state		Plot II.A.1
						Plot II.A.2
						Plot II.A.3
						Plot II.B.1
				Sub-zone II.B: soft soil is sand meeting underground water		Plot II.B.2
						Plot II.B.3

Results of geotechnical zoning

Table 2.13: Geotechnical characteristics of zones, sub-zones and plots serving the underground traffic

Zone	Sub-zone	Plot	Distribution range	Soil and rocks that the underground roads pass through	Groundwater characteristics	Level of difficulty when constructing underground traffic
Shallow underground						
I	I.A	I.A.1	Scattered in Cu Chi, Hoc Mon, Binh Chanh, Tan Binh, Binh Thanh, Districts 6, 9.	Clay, sub-clay, soft to hard plastic state	Water poverty	Convenience. There are some geotechnical problems: sliding of the foundation pit, instability of the foundation, etc. but not serious.
		I.A.2	Mostly in Cu Chi, scattered in Hoc Mon, Go Vap, Thu Duc			Convenience. There are some geotechnical problems: Sliding of the foundation pit, instability of the foundation, etc. Note that projects using pile foundations go deeper than 12-15m.
		I.A.3	In Cu Chi district, Binh Chanh, scattered in District 9			Convenience. There are some geotechnical problems: foundation pit wall sliding, foundation instability, etc. Construction conditions are relatively favorable
	I.B		Northeast of District 9	The rock has an age of J_3-K_1	No water	No geotechnical problems arose during construction, but excavation work was difficult.
II	II.A	II.A.1	Scattered in Hoc Mon, Binh Chanh, Districts 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, Binh Thanh, Go Vap, Nha Be, Thu Duc	Clay mud, sub-clay mud, sub-sand mud, clay, sub-clay state flows to plastic flow	The underground water level is shallow, from 2-8m	Difficult. There are some geotechnical problems: instability of the foundation pit, water flowing into the foundation pit, instability of the foundation, etc. difficult construction conditions.
		II.A.2	Scattered in Cu Chi, Binh Chanh, Go Vap, Tan Binh, Nha Be, District 9.			Difficult. There are some geotechnical problems: instability of the foundation pit wall, water flowing into the foundation pit, instability of the foundation, etc.
		II.A.3	Mostly in Can Gio, south of Cu Chi, Hoc Mon, District 12, Binh Chanh, District 9, Nha Be			Difficult. There are some geotechnical problems: instability of the foundation pit wall, water flowing into the foundation pit, instability of the foundation, etc. favorable construction conditions.
	II.B	II.B.1	Districts 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, Thu Duc city, a small area in the south of Can Gio, Hoc Mon, Cu Chi	Fine-grained sand - coarse, spongy to medium dense	The underground water level is shallow, from 2-8m	Difficult. There are some geotechnical problems: instability of the foundation pit, water flowing into the foundation pit, instability of the foundation, etc. difficult construction conditions
		II.B.2	A small part in Cu Chi, Hoc Mon			Difficult. There are some geotechnical problems: instability of the foundation pit wall, water flowing into the foundation pit, instability of the foundation, etc.
		II.B.3	In the Northeast of Cu Chi, a small part in Hoc Mon, the South, Southeast of Can Gio			Difficult. There are some geotechnical problems: instability of the foundation pit wall, water flowing into the foundation pit, instability of the foundation, etc. favorable construction conditions.

Zone	Sub-zone	Plot	Distribution range	Soil and rocks that the underground roads pass through	Groundwater characteristics	Level of difficulty when constructing underground traffic
Deep underground						
I	I.A	I.A.1	In the center and south of Cu Chi, Binh Chanh, Hoc Mon, Tan Binh, Thu Duc city, Districts 9, 2, 3, Binh Thanh	Clay, sub-clay, soft to hard plastic state	Water poverty	Convenience. There are some geotechnical problems related to ground instability, etc. but not serious.
		I.A.2	Mainly in Cu Chi district, part of Thu Duc city, District 2			Convenience. There are some geotechnical problems: foundation instability,... note that the project uses pile foundations deeper than 25-30m.
		I.A.3	In Cu Chi, Binh Chanh, part of Thu Duc city			Convenience. There are some geotechnical problems related to ground instability, construction conditions are relatively favorable
	I.B		In the Northeast of District 9	The rock has an age of J_3-K_1	No water	No geotechnical problems arose, excavation work is difficult.
II	II.A	II.A.1	In Districts 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, Nha Be	Clay mud, sub-clay mud, sub-sand mud, clay, sub-clay state flows to plastic flow	The underground water level is shallow, from 2-8m	Difficult. There are some geotechnical problems: water flows into the foundation pit, destabilizing the foundation, etc., difficult construction conditions.
		II.A.2	Some places in Nha Be, Binh Chanh, Cu Chi districts			Difficult. There are some geotechnical problems: instability of the foundation pit wall, water flowing into the foundation pit, instability of the foundation, etc.
		II.A.3	In Cu Chi, Binh Chanh, Nha Be, Can Gio districts, distribution is not wide.			Difficult. There are some geotechnical problems: instability of the foundation pit wall, water flowing into the foundation pit, instability of the foundation, etc., favorable construction conditions.
	II.B	II.B.1	Southwest, South of Cu Chi, North of Hoc Mon.	Fine-grained sand - coarse, spongy to medium dense	The underground water level is shallow, from 2-8m	Difficult. There are some geotechnical problems: water flowing into the foundation pit, destabilizing the foundation, etc., difficult construction conditions
		II.B.2	North of Can Gio, South of Binh Chanh, scattered in Districts 9, 3, Hoc Mon, Cu Chi			Difficult. There are some geotechnical problems: water flowing into the foundation pit, destabilizing the foundation, etc.
		II.B.3	Distributed in all districts in Ho Chi Minh City			Difficult. There are some geotechnical problems: water flowing into the foundation pit, destabilizing the foundation, etc., favorable construction conditions.

Chapter 3: FORECASTING GEOTECHNICAL PROBLEMS AND PROPOSING SOLUTIONS FOR STABILITY DURING CONSTRUCTION OF UNDERGROUND TRAFFIC WORKS

3.1. Characteristics of scale and construction technology of underground traffic works in Ho Chi Minh City

3.1.1. Regarding the scale characteristics of underground traffic works

According to the plan, Ho Chi Minh City urban railway system includes 8 metro lines. However, only line No. 1 Ben Thanh - Suoi Tien has been basically completed. Line 1 has a 2.6 km long underground section through 3 stations and a 17.1 km elevated section through 11 stations, a total length of 19.7 km. The average depth of the tunnel is about 15-25m. The route includes 2 parallel tunnels with the outer diameter of each tunnel being 6.65m.

3.1.2. Regarding the technological characteristics of underground traffic works

In Ho Chi Minh City, there have been two construction methods: open excavation and closed excavation. The closed excavation method is applying TBM excavation shields to construct underground sections of metro line No. 1.

3.2. Forecasting geotechnical problems when constructing underground traffic works

3.2.1. Calculation method and selection of calculation software

- Calculation method: *finite element method;*
- Calculation software: *Plaxis 2D software;*
- Select soil model: *Hardening Soil model.*

3.2.2. Analyze and select geotechnical cross sections for calculations

According to the geotechnical zoning results, II.A.1 and II.B.1 are plots with typical geotechnical characteristics and are likely to easily generate geotechnical problems during construction; so, they will be selected for examination.

3.2.3. Forecasting geotechnical problems during open excavation construction

a. Open excavation in geotechnical conditions of plot II.A.1

In the geotechnical conditions at plot II.A.1, the study *investigated the stability of the excavation, using Plaxis 2D software, in 2 cases:*

- Open excavation with sloping roof (1:1; 1:1,5; 1:2)

Table 3.4. Geological parameters input to the Plaxis model

	Layer 0 - Soil layer	Layer 1 - Clay mud layer	Layer 2 - Clay, clay loam, plastic flow	Layer 3 - Clay, clay loam, soft plastic - hard plastic
Model	Hardening soil	Hardening soil	Hardening soil	Hardening soil
Thickness (m)	2.0	4.0	6.1	6.5
Drainage type	Drainage	No drainage Class A	No drainage Class A	No drainage Class A
ϒ (kN/m^3)	18.5	15.0	17.5	19.3
e	0.5	2.2	1.152	0.895
E_{50}^{ref} (kPa)	10,000	2,000	3,000	8,000
E_{oed}^{ref} (kPa)	10,000	2,000	3,000	8,000
E_{ur}^{ref} (kPa)	30,000	6,000	9,000	24,000
m	0.5	1	1	1
c' (kPa)	1	16	20	25
φ' (độ)	30	19	22	28
ν (-)	0.3	0.3	0.3	0.3

- *The result indicated that open excavation with slopes in soft soil conditions (mud, flowing plastic clay) is very difficult, with a high risk of causing slope instability. Construction sites in urban environments are limited, so digging holes with large slopes (1:2; 1:3) is impossible.*

- Open excavation with earth retaining wall with 3 options:

+ Option 1: 16m larsen pile + 2 floors of support

+ Option 2: 16m larsen pile + 2 floors of ground anchors

+ Option 3: 18m larsen pile + 2 floors of support

Table 3.6. Comparison of open tunnel excavation options at plot II.A.1

Comparison criteria	Option 1: Larsen pile + support	Option 2: Larsen pile + ground anchors	Option 3: Lengthen the Larsen pile
Ground displacement	U_{max}=24.8cm	Huge displacement due to anchor loss	U_{max}=20.95cm
Retaining wall displacement	U_{max}=17.9cm	Huge displacement due to anchor loss	U_{max}=15.48cm
Bending moment of pile wall	M_{max}=432.1 kN/m	The anchor is pulled down before digging to the final step	M_{max}=402.2 kN/m
Stability coefficient	FOS = 1.9	The anchor is pulled down before digging to the final step	FOS=2.27

- It is necessary to apply the soil retaining wall method with a retaining system using shoring or soil anchors when excavating at plot II.A.1.
- Larsen piles + support and larsen piles embedded deep into the good soil layer; this is the optimal reinforcement plan. Stability coefficient > 1.5
- Ground anchors are not suitable for excavations in areas of flexible clay, because the resistance of anchors in this area is small, causing instability of the excavation.

b. Open excavation in geotechnical conditions of plot II.B.1

Similar to section II.A.1, the study *investigated the stability of the excavated hole, under the geotechnical conditions at plot II.B.1.*

Table 3.7. Geological parameters input to the Plaxis model

	Layer 0 - Soil layer	Layer 2 - Clay, clay loam, soft plastic, hard plastic	Layer 3 - Sand, loose to compact state
Average thickness of soil layer (m)	2	6	
Model	Hardening soil	Hardening soil	Hardening soil
Drainage type	Drainage	No drainage Class A	Drainage
ϒ (kN/m^3)	18.5	19.5	19.6
e	0.5	0.895	0.62
E_{50}^{ref} (kPa)	10,000	7,500	14,000
E_{oed}^{ref} (kPa)	10,000	7,500	14,000
E_{ur}^{ref} (kPa)	30,000	22,500	42,000
m	0.5	1	0.5
c’ (kPa)	1	25	1
φ’ (độ)	30	28	29
ν (-)	0.3	0.3	0.3

Table 3.8. Summary and comparison of shallow tunneling options at plot II.B.1

Comparison criteria	Option 1: Larsen pile + support	Option 2: Lengthen the Larsen pile	Option 3: Larsen piles + ground anchors
Ground displacement	U_{max}=7,5cm	U_{max}=7.2cm	U_{max}=3,7cm
Retaining wall displacement	U_{max}=2.5cm	U_{max}=2.4cm	U_{max}=2.6cm
Bending moment of pile wall	M_{max}=107.4 kN/m	M_{max}=103.7 kN/m	M_{max}=98 kN/m
Overall stability coefficient	FOS = 1.5	FOS = 1.7	FOS=1.59

From the results of table 3.8, we can see the following conclusions:

- Soil retaining wall displacements in sand will be smaller than in soft plastic-flow-plastic clay conditions;
- Ground anchoring in the geotechnical conditions of plot II.B.1 can be applied;
- Increasing the length of the pile wall will increase the length of the seepage flow, thereby reducing the seepage pressure and increasing the safety factor of the excavation.

3.2.4. Method for predicting surface settlement during construction using TBM

The author selected a cross-section of metro line No. 1 and used monitoring data to calculate and compare data. The calculated cross section has two parallel tunnels. The first tunnel is deeper, at a depth of 16.8m (from the center of the tunnel) in a layer of medium-dense sand. The second tunnel is shallower, at a depth of 11.5m (from the center of the tunnel).

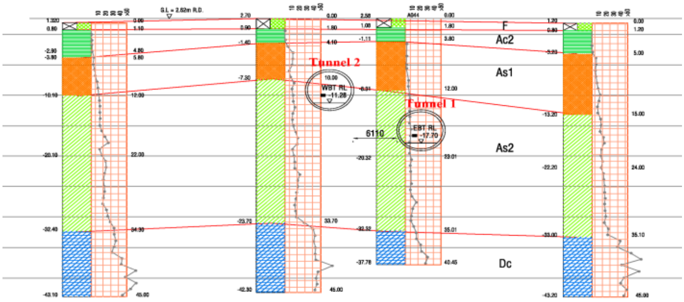


Figure 3.16. Geological section of metro line No. 1 at Km 1+440

Table 3.9. Soil parameters in the model

Soil layer/parameter	Embankment (F)	Clay layer (AC2)	Sand layer (AS1)	Sand layer (AS2)
Model	HS	HS	HS	HS
Drainage type	Drainage	No drainage class B	Drainage	Drainage
γ(kN/m^3)	19	16,5	20,5	20,5
c' (kPa)	0,1	-	0,1	0,1
φ' (degree)	25	-	30	33
Cu (kPa)	-	10	-	-
ν (-)	0,3	0,3	0,3	0,3
E_{50}^{ref} (kPa)	10.000	3.000	12.500	37.500
E_{oed}^{ref} (kPa)	10.000	3.000	12.500	37.500
E_{ur}^{ref} (kPa)	30.000	90.000	37.500	112.500
m	0,5	1,0	0,5	0,5
Permeability coefficient, k(m/s)	1.00E-06	1.00E-09	2.00E-05	2.00E-05

Results:

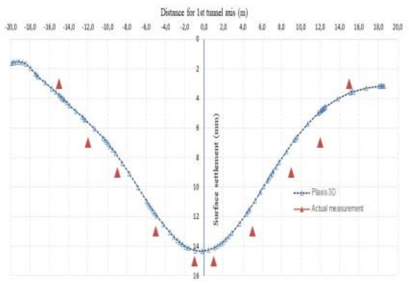


Figure 3.21. Surface displacement when digging the first tunnel (deeper tunnel)

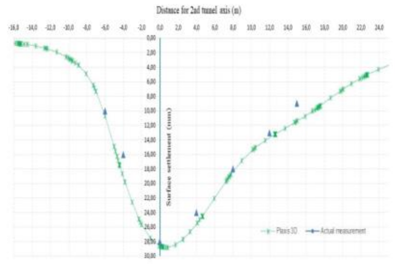


Figure 3.22. Surface displacement when digging the second tunnel (shallower tunnel)

3.3. Research on factors affecting surface settlement when constructing tunnels using TBM technology

3.3.1. Effect of shield pressure

The ground settlement along the tunnel shield during the process of digging the first tunnel (deeper tunnel) is shown in Figure 3.25 when using the shield pressure values (at the tunnel roof position) from 100kPa to 280kPa, respectively.

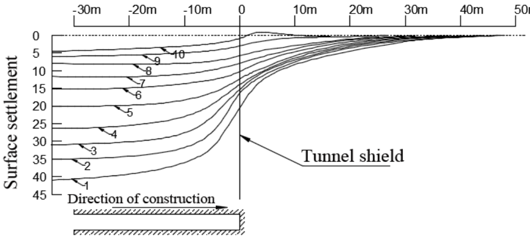


Figure 3.25. Dependence of surface settlement on shield pressure value

1-q=100 kPa; 2-q=120 kPa; 3-q=140 kPa; 4-q=160 kPa; 5-q=180 kPa; 6-q=200 kPa; 7-q=220 kPa; 8-q=240 kPa; 9-q=260 kPa; 10-q=280 kPa.

The larger the shield pressure generated by the TBM, the smaller the surface settlement. Too large shield pressure will cause the ground to rise (case 10-q=280kPa). It is necessary to calculate the appropriate shield pressure value before construction.

3.3.2. Influence of building foundation structure on surface settlement

The dissertation selected 3 types of projects with typical foundation structures:

- Type 1: Foundation on bored pile foundation with a depth of 40-50m, usually applied to high-rise buildings with large loads.
- Type 2: Foundation on square piles or PHC piles with a depth of about 25m, applied to projects with medium to large loads.
- Type 3: Shallow foundations or foundations reinforced with bamboo piles.

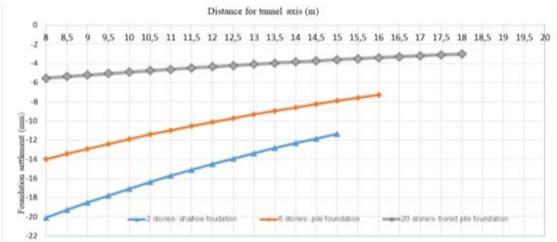


Figure 3.28. Forecasting settlement of structures with different types of foundations in the tunnel's influence area

3.3.3. Influence of tunnel diameter

The author performed the calculation with the following parameters: geological according to section 3.2.3 (table 3.4 and table 3.7); tunnel depth is 20m (at the tunnel center); shield pressure; load on surface of 20 kPa. Tunnel diameter varies according to the following values: 5m; 5.5m; 6.0m; 6.5m; 7.0m; 7.5m; 8.0m.

At plot II.A.1

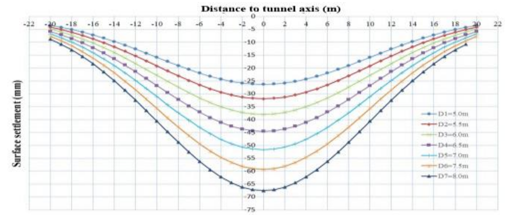


Figure 3.31. Dependence of settlement according to tunnel diameter at plot II.A.1

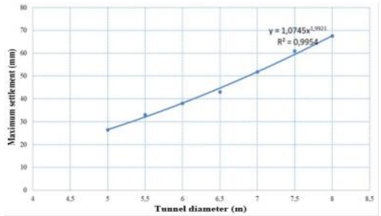


Figure 3.32. Dependence of maximum settlement according to tunnel diameter

At plot II.B.1

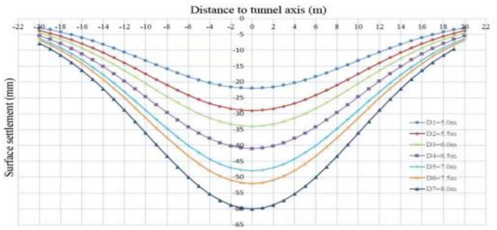


Figure 3.34. Dependence of settlement according to tunnel diameter at plot II.B.1

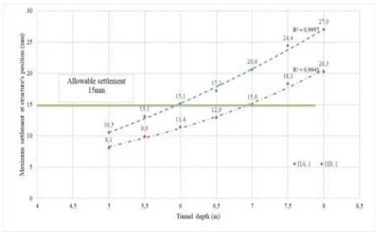


Figure 3.35. Construction settlement with different tunnel diameters

Taking the construction's settlement limit of 15mm as current projects, for plot II.A.1, the optimal tunnel diameter is ≤ 6.0m, for plot II.B.1, the optimal tunnel diameter is ≤ 7.0m.

3.3.4 Effect of tunnel depth on surface settlement

The author kept the geological parameters fixed in section 3.2.3 (tables 3.4 and 3.7), tunnel diameter 6.6m, live load condition above 20 kPa, only changed the tunnel depth from 10-31m (This depth is common with the operating conditions of the subway lines of Ho Chi Minh City and Hanoi) and the corresponding shield pressure to ensure tunnel shield stability.

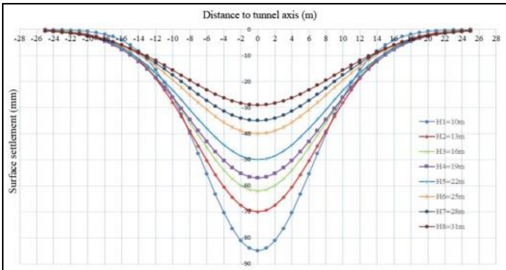


Figure 3.37. Dependence of settlement according to tunnel depth at plot II.A.1

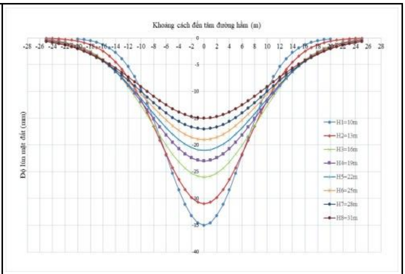


Figure 3.38. Dependence of settlement according to tunnel depth at plot II.B.1

Analysis of the tunneling depth to ensure the construction settlement is within the allowable limit is shown in Figure 3.39.

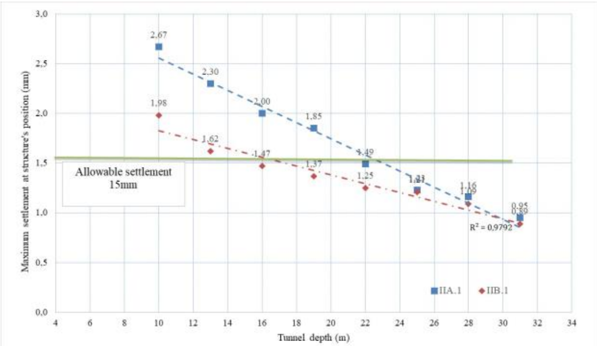


Figure 3.39. Construction settlement with different tunnel depths

With plot II.A.1, the optimal tunneling depth is ≥ 22m, with plot II.B.1, the optimal tunneling depth is ≤ 16m.

3.4. Proposing solutions for stability when constructing underground traffic works

3.4.1. For underground traffic works construction using the open excavation method

The dissertation investigated the same problem of geological conditions and excavation depth as in section 3.2.1 to see the effectiveness of the foundation reinforcement method using soil-cement piles (CDM). CDM is designed based on experience with projects with similar geological conditions: lateral compressive strength (qu) of 800 kPa, replacement rate at 30%.

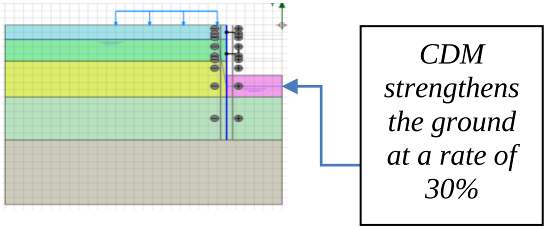


Figure 3.40. Excavated pit model with CDM reinforced foundation

The dissertation synthesized recommendations for shallow tunneling at plots II.A.1 and II.B.1.

Table 3.13. Summary of recommendations for shallow tunnels at plots II.A.1 and II.B.1

Tunnel depth	Type of traffic tunnel project	Construction method	Type of earth retaining wall	Type of support structure	Plot II.A.1			Plot II.B.I		
					Geology where the tunnel passes through	Potential geotechnical issues	Recommendations	Geology where the tunnel passes through	Potential geotechnical issues	Recommendations
< 10 m	- Tunnel - Transition from the elevated section to the underground section (subway ramp)	Cut and cover	- Steel piles (Larsen IV); - Adjacent piles	- Support made of shaped steel; steel pipes (for plots II.A.1 and II.B.1). - Ground anchor for plot II.B.1	Flowing plastic clay	- Excessive movement of earth retaining walls due to weak geology; - Ground breaking phenomenon due to pressured water column.	- Reinforce the foundation with CDM at the foot of the excavation	The sand is from porous to dense	Sand flows into the dug hole through the gap in the earth retaining wall (Larsen piles); - Sand flows into the foundation pit due to hydraulic seepage (boiling)	- Extend the soil retaining wall to increase the length of seepage flow - Construction solution: avoid the phenomenon of exposed piles during pile construction; If there is an opening in the pile, it is necessary to drill and inject mortar at the opening to avoid sand flow
10-15 m	Subway station	Open construction	Reinforced concrete wall parked on site (in-ground wall)	Use basement floors as support during excavation	Flexible and soft clay	- Excessive movement of earth retaining walls due to weak geology; - Ground breaking phenomenon due to pressured water column.	- Reinforce the foundation with CDM at the foot of the excavation; - Calculate the retaining wall structure to withstand the load.	The sand is porous to dense	- Sand flows into the dug hole through the gap created by the wall; - Sand flows into the foundation pit due to hydraulic seepage (boiling)	- Extend the soil retaining wall to increase the length of the seepage flow; - Construction solution: avoid the phenomenon of exposed piles during pile construction; If there is an opening in the pile, it is necessary to drill and inject mortar at the opening to avoid sand flow

3.4.2. For construction of underground traffic works using the closed excavation method

The dissertation synthesized recommendations and proposed prevention solutions during the process of digging deep tunnels at plots II.A.1 and II.B.1.

Table 3.14. Summary of recommendations for deep tunnels in sections II.A.1 and

Type of traffic tunnel project	Construction method	Type of support structure	Khoảnh II.A.1			Khoảnh II.B.I		
			Type of support structure	Potential geotechnical issues	Recom-mendations	Type of support structure	Potential geotechnical issues	Recom-mendations
Urban railway tunnels	TBM tunnel drilling complex	The tunnel shell is made of precast reinforced concrete	Mainly in soft plastic clay	- Surface movement during tunneling. - Water broke in front of the tunnel shield	Choose the type of integrated TBM: EPB earth pressure type suitable for Ho Chi Minh City's geological conditions - Choose the appropriate tunnel diameter and depth	The sand is from porous to dense	- Surface movement during tunneling. - Water broke in front of the tunnel shield. - Sand flows into the excavation shield	- Choose an integrated TBM machine: EPB earth pressure type suitable for Ho Chi Minh City's geological conditions. - Good control of digging shield pressure. - Design the appropriate composition of the spray solution in front of the tunnel shield, helping to stabilize the tunnel shield.

CONCLUSION

There are conclusions made from this dissertation:

1. Ho Chi Minh City is mostly made of soft soil, including 2 groups: cohesive soil (clay, sub-clay) in flowing, plastic state (accounting for ¾ of the area) and loose soil (fine-medium grained sand) containing underground water, distributed mainly on the surface, with a thickness of 10-30m but the average and common thickness is 18m. The underground water level is shallow. These characteristics have a great influence on the planning, design and construction of underground traffic works.

2. Ho Chi Minh City has a high population density and very complex technical infrastructure, according to the characteristics of the existing technical infrastructure. From the point of view of assessing the level of difficulty for the construction of linear urban underground traffic works, Ho Chi Minh City's technical infrastructure can be divided into 3 levels: level 1 - very difficult for building underground traffic works; level 2 - difficult to build underground traffic works; level 3 - less difficult for underground traffic construction.

3. Based on geotechnical characteristics, from the perspective of serving the construction of underground traffic works, the Ho Chi Minh City area is divided into 02 geotechnical zones (zone I and zone II are favorable and unfavorable, respectively, for the construction of underground traffic projects), 04 sub-zones and 12 geotechnical plots.

4. To ensure surface settlement when constructed using TBM, within the allowable limit (≤15mm), at plot II.A.1, the optimal tunnel depth is ≥ 22m with tunnel diameter ≤ 6.0m; At plot II.B.1, the optimal tunnel depth is ≥ 16m with tunnel diameter ≤ 7.0m.

5. Solutions to ensure stability during construction:

- For holes dug in geological conditions of soft soil, the method of reinforcing the foundation with CDM will be the optimal solution.
- For deep-seated underground traffic works constructed using TBM technology, we should design appropriate shield pressure to ensure allowable surface settlement.

LIST OF PUBLISHED SCIENTIFIC WORKS RELATED TO THE DISSERTATION

Vietnamese

1. *Vo Nhat Luan, Nguyen Thi Nu, Do Minh Toan (2020),* Current status, development orientation of Ho Chi Minh City underground transportation system and tasks of geotechnical research*, National Conference on Earth Sciences and Resources for sustainable development (ERSD2020), p. 50-56, ISBN 978-604762277-1.*

2. *Nguyen Van Hung, Vo Nhat Luan, Bui Van Binh, Phung Huu Hai, Nguyen Tan Son (2022),* Research on geotechnical characteristics of the sand lithological complex of Pleistocene river-sea origin ($am^{S}Q_1^{3}$) in District 1, Ho Chi Minh City serving the construction of urban centers, *National Scientific Conference on Geotechnical and Construction for Development sustainability (Vietgeo 2021), Phu Yen, May 2022, pp100-109, ISBN code: 978-604-67-2296-0.*

Tiếng Anh

3. *Vo Nhat Luan, Nguyen Thi Nu, Do Minh Toan (2021),* Consolidation Properties of Ho Chi Minh City Soil, Vietnam, *Iraqi Geological Journal, Pages 1-10, Vol.54, No.1A, ISSN: 2663-8754.*

4. *Vo Nhat Luan, Nguyen Thi Nu, Do Minh Toan (2021),* Prediction of Ground Subsidence During Underground Construction of Metro line 2, Section 1, Ben Thanh - Tham Luong*, Journal of the Polish Mineral Engineering Society, pages 543-553, Vol.1, No.2, 2021, ISSN: 1640-4920.*