Study in engineering geological conditions for underground development in Hanoi

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Abstract: Underground space development is the inevitable trend in modern urban development. Clarification the characteristics of engineering geological conditions to develop underground construction in the Hanoi area is very important and practical. This paper presents the research result of engineering geological properties in the Hanoi area, including the distribution characteristics and the physical-mechanical properties of different soil layers in the research area; the characteristics of hydrogeology. In this paper, we also assess and forecast the engineering geological problems, which may occur during the construction and use of the underground. This result will be used to serve the planning, design and building the different underground constructions in the Hanoi area.

1. Introduction

Underground space is an important part of urban nowadays. It has become a significant trend in the development of modern cities, including the Hanoi city. According to the overall planning for Hanoi up to 2030, approach to 2050, the population of the Hanoi area is forecasted at about 7.5 million people, and that of the central urban is about 5.4 million people, with nearly 2 times the current population size. Therefore, the demand for the use of underground space is very high. For planning and building of this construction efficiency and feasibility, it is very necessary to clarify clearly the engineering geological features, the engineering geological problems which may arise from the construction and use of these works. Up to now, there have had a number of researches on geological conditions in the Hanoi area, but in general these researches are still lack of systematic approach and primarily serve the planning and building the construction on the ground surface. Therefore, the study of geological conditions in a systematic way, oriented to serve the planning, survey, design and construction of all underground types is very urgent and practical.

2. Characteristics of research on geological conditions to serve the construction of underground works

Underground construction is a kind of construction placed deep in the ground, always influenced by soil and groundwater around it during its construction and use. Thus, the underground construction is always influenced by many factors, such as the lithosphere, the transformation of the geological environment during the construction and use of underground works.

According to excavation technology, underground construction can be divided into two types, including open and trenchless technique. Either using open method or trenchless method, the geological problems can be divided into 3 groups, as follows:

+The stability of wall, bottom of excavation, and the deformation of ground around the pit (open excavation) and ground subsidence (trenchless excavation);

+ The issue of soil heaving (boiling), suffosion, suffusion, water flow to the excavation site;

+ The issue of toxic and burnable gas.

The first group mainly relates to the soil strength. For surface constructions, the soil strength is a decisive factor of the ground bearing capacity, but for underground constructions, the soil strength will decide on the wall stability of the excavation, and active, passive earth pressures that act on the wall or retaining structures of the excavation. In which, the friction angles decide to the lateral earth pressure parameter while cohesion forces decide to the cohesion pressure. When these factors do not meet the demand of stability, it will lead to the failure, deformation or subsidence of the ground.

The second group relates to the characteristic of grain composition (loose soils), the soil permeability and the hydrodynamic elements of groundwater.

The third group involves special composition of soil, mostly organic ingredients and the degree of their decomposition.

Therefore, the study of geological conditions for the construction of the underground has its own characteristics and must has its own approach. Accordingly, we must forecast the geological problems that may arise, chose the appropriate models and research methods to predict and identify the geological properties. The prediction is based on an analysis of the characteristics of each type of soil, the characteristics of groundwater around underground works, the features of construction and other local factors. Hence, we need to pay special attention to the following factors: soil compositions (organic matter and grain composition of loose soils); the physical-mechanical properties of soils (wet density, internal friction angle, cohesion force, undrained strength); the distribution characteristics of different soil layers around underground works and their spatial relations; the hydrogeological characteristics (distribution, permeability, hydrodynamic elements of groundwater).

3. The distribution characteristics of different soil layers in the research area

From the results of research on Quaternary geology and engineering geology (Thinh et al, 2004), can be identified 9 common soil types of Quaternary sediments, which are distributed in the Hanoi area, in order from top to bottom, as follows:

-Thai Binh formation (Q_2^3tb)

1. Fluvial sediments (a$Q_2^3tb_3$): clay, sandy clay in brownish grey, yellowish brown, state from stiff to very stiff. (layer 1);

2. Fluvio-lacustrine-swampy sediments (alb$Q_2^3tb_2$): clay, sandy clay in brownish grey, blackish brown, soft state and contain a little organic matter. (layer 2);

3. Fluvial sediments (a$Q_2^3tb_1$): fine sand in blackish grey, brownish grey, state from loose to medium. (layer 3);

-Hai Hung formation ($Q_2^{1-2}hh$)

4. Marine sediments ($mQ_2^{1-2}hh_2$): clay in greenish grey, state from medium to stiff (layer 4).

5. Lacustrine-swampy sediments (lb$Q_2^{1-2}hh_2$): clay, sandy clay in blackish grey and contain organic matter, state from soft to very soft. (layer 5).

-Vinh Phuc formation (Q_1^3vp)

6. Fluvial sediments (a$Q_1^3vp_2$): sandy clay in yellowish grey, whiteish grey, redish brown, state from stiff to very stiff (layer 6).

7. Fluvial sediments (a$Q_1^3vp_2$): medium sand, fine sand in yellowish grey, state from medium to dense.

-Ha Noi formation (ap, am$Q_1^{2-3}hn$):

8. Pebble, gravel and sand in grey, yellowish grey (layer 8);

-Le Chi formation (ap, am$Q_1^{2-3}hn$):

9. Pebble, gravel, sand and clay in brownish grey, yellowish grey (layer 9).

The distribution characteristics of these layers are shown on table 1 and figure 1. It can be seen that the depth and the thickness of each soil layer in the research area vary significantly. Soils with swampy origins (layer 2, 5) are the most variable; followed by soils with fluvial origins (layer 1, 3, 6, 7); the distribution depth and the thickness of soils with marine origins (layer 4, 8, 9) are relatively stable; especially layer 8 has the biggest thickness (about 34m on average), and the depth distribution is above 35m.

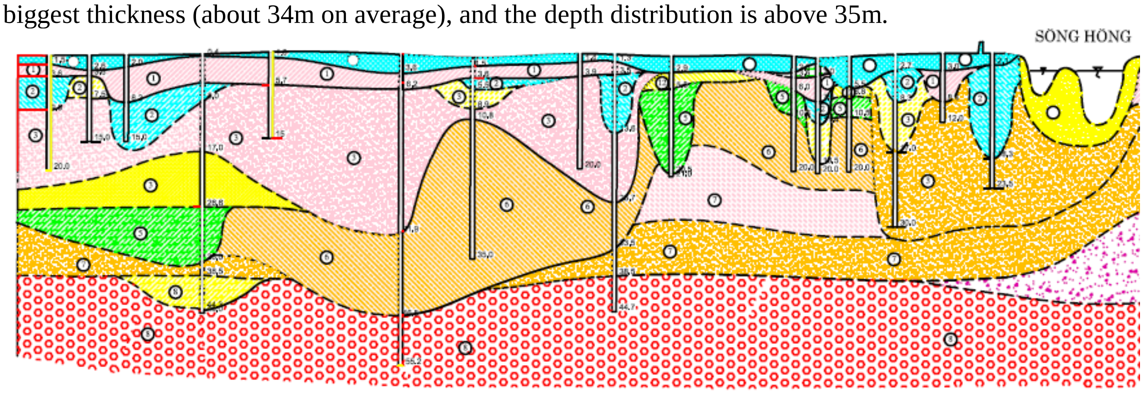

Figure 1: Engineering Geological Section in the research area (from West to East).

Table 1: The distribution characteristics of different soil layers in the Hanoi area

No	**Soil types**	**Main distribution areas**	**Distribution depth/average (m)**	**Thickness/ average (m)**
1	Layer1	Center, the west and the south of Hanoi	(1÷10)/5	(2÷16)/8
2	Layer 2	The south of Hanoi (Hoang Mai, Thanh Tri district) and center (Hoan Kiem, Hai Ba Trung district)	(3 ÷ 20)/10	(1,2÷20)/12
3	Layer 3	The south of Hanoi (Hoang Mai, Thanh Tri district)	(3÷30)/12	(4÷30)/14
4	Layer 4	Scattered distribution in the center and the west of Hanoi (Nam Tu Liem district) and the east (Gia Lam district)	(3÷6)/4	(1÷3)/2
5	Layer 5	Distributes widely from the west to the east, and extends to the south.	(2÷30)/16	(2÷20)/12
6	Layer 6	The north and the east of Hanoi	(1÷17)/10	(5÷10)/7
7	Layer 7	Distributes popularly in almost areas, except for the south of Hanoi.	(10÷35)/18	(6÷16)/10
8	Layer 8	Distributes widely in almost areas	(35÷>50)/40	(20÷37)/34
9	Layer 9	Distributes popularly in almost areas	(45÷70)/55	25÷30

4. The physical-mechanical properties of different soil layers in the Hanoi area

The results of some main physical –mechanical properties of different soil types are shown on table 2 and 3. Accordingly, the layer 2 and 3 have the low strength with the small friction angle which will cause the high lateral earth pressure; layer 1 and 6 have the small internal friction angle varying from 13^0 to 14^0 but high cohesion force (28 to 29 kPa), so it is a favorable condition for stability of underground work; sand layers (3, 7), gravel layers (8, 9) have the high internal friction angles, so it also makes favorable conditions for stability of underground works.

Table 2: Synthesis of some main properties of cohesive soils

Soil layers	Number of samples	Water content	Wet density	Specific density	Settlement parameters	Cohesion force	Internal friction angle	Lateral earth pressure parameters
		W (%)	γ (g/cm^3)	γ_s (g/cm^3)	a_{1-2} (cm^2/kG)	C (kPa)	φ (degree)	–
Layer 1		32,3	1,90	2,70	0,042	28	13°15’	0,633
Layer 2*		52,7	1,67	2,61	0,088	19	2°20’	**0,923**
Layer 4		32,8	1,89	2,69	0,076	22	8°38’	0,742
Layer 5*		49,3	1,69	2,65	0,085	17	1°10’	**0,962**
Layer 6		29,3	1,91	2,70	0,036	29	14°23’	0,603

** Strength properties of soft soils (layer 2 and 5) were derived from UU triaxial test.*

Table 3. Grain composition characteristics and mechanical properties of cohesiveless soils

Sand layers	Number of samples	Grain composition (%)				SPT (blow)	Internal friction angle ** (degree)	Lateral earth pressure parameters
		Pebble	Gravel	Sand	Silt			
Lớp 3	685	0	0,3	89,7	10	12	27	0,376
Lớp 7	476	0	3,7	92,0	4,3	29	32,3	0,303
Lớp 8	115	45,7	31	23,3	0	>50	45	0,172
Lớp 9	0	-	-	-	-	>50	45	0,172

*** The internal friction angle of cohesiveless soils was calculated from SPT values*

Comments:

Based on the distribution characteristics and the physical-mechanical properties of different soil layers, we can see that: soils in layer 2 and 5 are soft soils with low strength (lateral earth pressure parameters above 0,9), and distribute in the shallow depth, so it is disadvantages for underground works; layer 1, 4 and 6 have the relatively high strength (high cohesion force), so it is an advantageous condition for underground construction, especially layer 1 and 6, which distribute near the surface with big thickness; layer 4 has small thickness, so its role is insignificant; sand layers (3, 7) have the high strength with relatively big thickness and distribute in median depth; gravel layers (8, 9) have the very high strength with big thickness, but they distribute in big depth (figure 2).

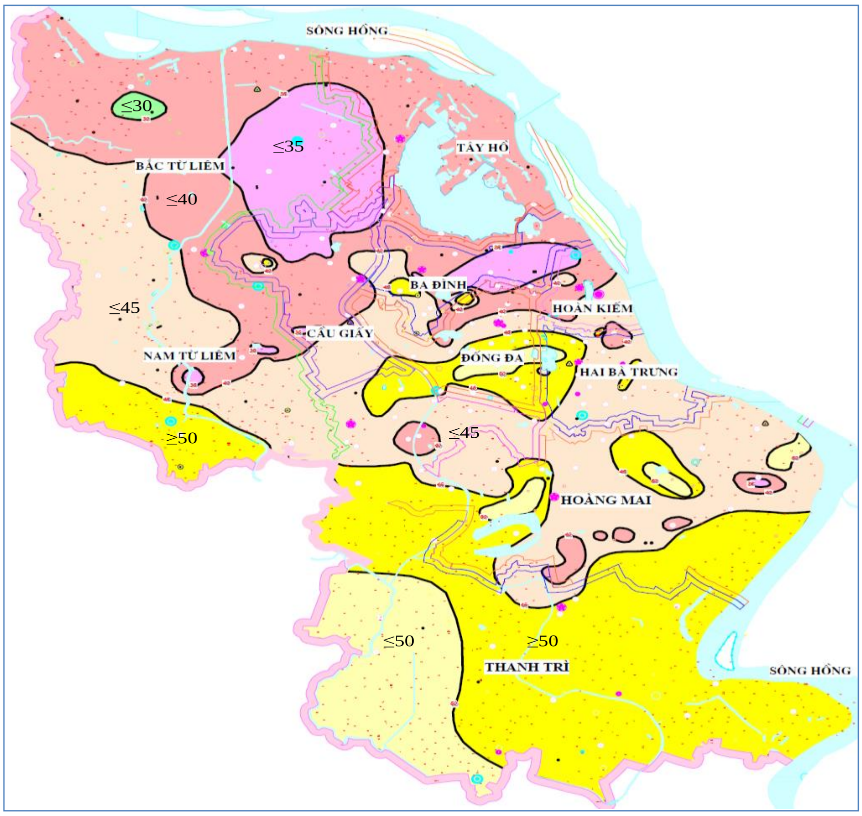

Figure 2. Map distribution of layer 8 (Phuong et al, 2004)

5. Characteristics of hydrogeology in the Hanoi area

Hydrogeology in the research area includes two main aquifers: Holocence aquifer (unconfined aquifer) (qh) and Pleistocence aquifer (confined aquifer) (qp)

The Holocence aquifer distributes widely in the study area, except for some areas like Co Nhue, Thuy Phuong. The distribution characteristics of this aquifer are shown in the figure 4. The soil composition of this aquifer is mainly in Thai Binh formation (layer 3) with the permeability parameter, k= (1,4÷5,26) x 10^{-3} cm/s; the flow rate, q= (3,3 ÷ >10) l/s.m. The water table of this aquifer varies strongly with the season. It often fluctuates and depends on rainfall and the water surface. In riparian zones, the water level of wells in this aquifer often fluctuates with the water level of the Red river.

The Pleistocence aquifer also distributes widely in the research area. The depth distribution and the thickness of this aquifer vary relatively strongly. The distribution characteristics of this aquifer are shown on figure 5. The flow rate (q) of the aquifer qp_2 (in layer 7) is about 0,18÷2,41l/s.m while that of qp_1 (layer 8) is about 6,96 ÷ 32,19l/s.m. This aquifer is in relation to rainfall and hydraulic relation to the Red river. In addition, this aquifer is also influenced strongly by the regime of groundwater exploitation in this area.

Thus, the qh aquifer exists in layer 3, the qp aquifer exists in layer 7 and 8. Therefore, the construction of underground works in these layers should pay attention to some problems such as water flow to the excavation sites, suffosion, suffusion and soil heaving (for confined aquifer, qp).

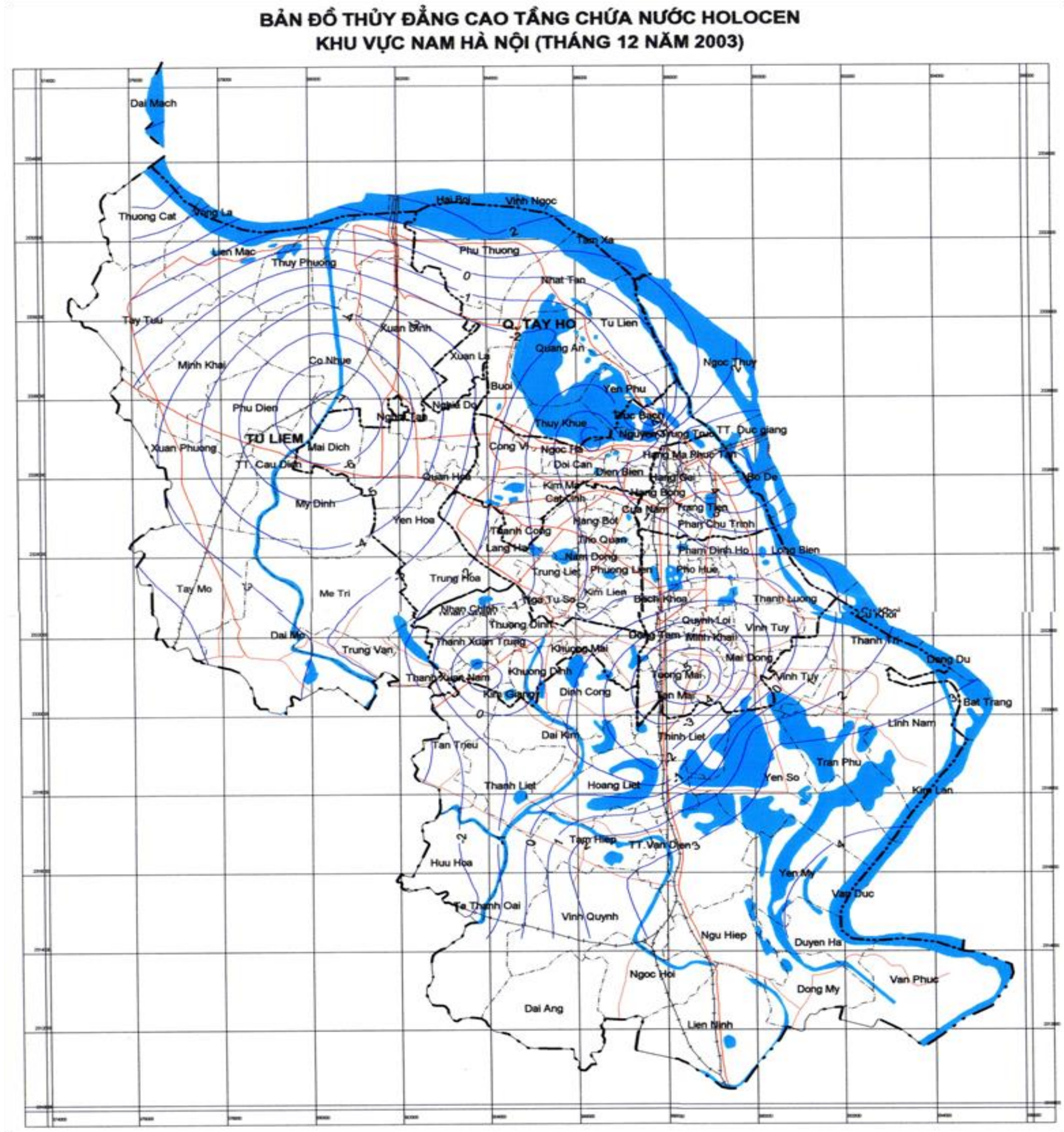

Figure 3. The depth distribution of Holocence aquifer

Figure 4. The depth distribution of Pleistocence aquifer

6. Some engineering geological problems may arise during construction and utilization process

6.1. Suffosion phenomenon

Suffosion is a phenomenon whereby fine particles are transported through the voids between larger particles by seepage flow, results in an increase of the void ratio (Fannin, 2014). This phenomenon can cause some problems such as instability of soil around the underground works, and ground subsidence.

Suffosion can occur in certain conditions of grain composition and pressure gradient of seepage flow. According V.X. Istomina (1957), to evaluate the possibility of suffosion, can rely on the hydraulic gradient (I) and coefficient of uniformity (η) which are shown in Figure 6

Where: $\eta = \dfrac{d_{60}}{d_{10}}$

d60: particle size at 60% passing by mass;

d10: particle size at 10% passing by mass.

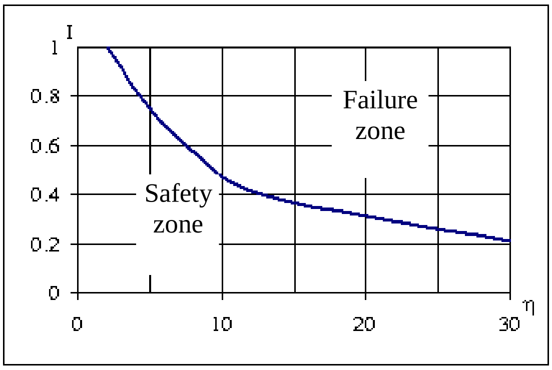

Figure 5. Relationship between η and I

The figure 6 shows that suffusion mainly occurs in cohesionless soils with the coefficient of uniformity η >10 (while I ≤0.5). The higher coefficient of uniformity is, the easier suffusion occurs, especially in soils with η>20 (Suffosion can occur in soils with η>20 even when I ≤0.3)

Result analysis of particles in sand layers is shown in table 3. It can be seen that the sand in layer 7 (Vinh Phuc formation) has a high risk of suffosion.

Table 4. Result analysis of particles in sand layers

Soil layers	d_{60}	d_{10}	η	Limited hydraulic gradient (I_{gh})	Assessment
Layer 3	0,20÷0,25	0,05÷0,06	3÷5	> 0,75÷0,80	Low risk of suffosion
Layer 7	0,45÷0,55	0,05÷0,08	8÷11	> 0,45÷0,50	High risk of suffosion

6.2. Sand suffusion phenomenon

Suffusion is a phenomenon whereby sand moves away from its natural state due to the seepage flow or due to its own weight when exposed. This phenomenon may be quantified by a mass loss, no change in volume and an increase in hydraulic conductivity (Fannin, 2014). Suffusion often occurs in fine-grained sand, silt with high flexibility, low density and full saturation. This sand is prone to liquefy under the effect of dynamic loads.

Suffusion can cause instability of the wall of the excavation, make difficulties in the construction process, and may cause subsidence and deformation of the ground. When liquefaction occurs, the strength will reduce to zero and lateral earth pressure parameters equal 1 and then it will make an increase in pressure on underground works.

Based on an analysis of grain composition and relative density of sands in the research area, we can realize that the sand in Thai Binh formation (layer 3) has a high risk of suffusion and liquefaction, so it should be taken into the calculation, design and building.

6.3 Soil heaving and ground subsidence

When the underground is built through soft soils, the bottom of the excavation can be heaved due to water pressure or earth pressure. The former occurs when the bottom is composed of cohesive soils and under this layer is confined aquifer. The latter occurs when the bottom is formed by soft soils with low strength. In this case, lateral earth pressure can heave the bottom. In fact, the issues of suffusion, suffosion, and soil heaving are not treated completely can lead to ground subsidence.

Based on the characteristics of the ground structure, the physical-mechanical properties of different soil layers and hydrogeological characteristics in the research area, we can see that soil heaving phenomenon occurs due to water pressure when the confined aquifer (qp) lies below the bottom of the pit (layer 7 or 8), and due to earth pressure when the underground is constructed through the soft soils (layer 2 and 5).

6.4. The issue of toxic and combustible gas

This issue often occurs when underground work is constructed in the layer with high organic content. The analysis result of organic content shows that soils in $albQ_2^3tb_1$ sediments (layer 2) contain a few percent of organic matter, about 4,7% on average; soils in $lbQ_2^{1-2}hh_1$ sediments (layer 5) often contain a high content of organic matter, about 20 to over 50% with the decomposition level of 45 to 78%. Therefore, the layer 5 has a high risk of toxic and combustible gas.

7. Assess the level of convenience for the construction of the underground in the Hanoi area based on different ground structures

Based on the distribution characteristics, the physical-mechanical properties, hydrogeological characteristics and the ability to generate geological problems during the construction and use of underground, we can assess the level of favorable, unfavorable conditions for the construction of the underground in the Hanoi area. The result is shown on table 5.

Table 5. The level of favorable, unfavorable conditions for the construction of the underground in the Hanoi area

Soil types	Hydrogeological features	Geological problems	Assessment
Layer 1	Waterproof layer	-	Favorable
Layer 2	Waterproof layer	Soil heaving, ground subsidence	Unfavorable
Layer 3	Unconfined aquifer, qh	Suffusion, water flow to excavation site	Unfavorable
Layer 4	Waterproof layer	Soil heaving	Less favorable
Layer 5	Waterproof layer	Soil heaving, ground subsidence, toxic and combustible gas	Very unfavorable
Layer 6	Waterproof layer	-	Favorable
Layer 7	Confined aquifer qp_2	Suffosion, water flow to excavation site	Unfavorable
Layer 8	Confined aquifer qp_1	Water flow to the excavation site	
Lớp 9			

However, the assessment and forecast results in table 5 only indicate how favorable and the possibility of geological problems may arise when underground works are built in a simple condition (the ground has only one type of soil). In fact, the soil around underground work is often composed of many types of soil with different compositions and properties. Therefore, the assessment and forecast of geological problems to guide the planning, survey, design and construction of underground works must be based on each type of ground structure.

According to the research results of the key project of Hanoi in 2004 (Phuong et al, 2004), the ground structure of the research area (the right bank of the Red river) was divided into four types (figure 6). Accordingly, type I distributed mainly in Bac Tu Liem and Tay Ho district with typical structure including layer 6 and 7 (Vinh Phuc formation); type II has a large distribution with many types of soil in Thai Binh and Vinh Phuc formation (exclude Hai Hung formation); type III distributed mainly in the center with soils in Hai Hung and Vinh Phuc formation (exclude Thai Binh formation); type IV distributed in large areas in the west and the south of Hanoi with soils in the three formations (Thai Binh, Hai Hung, Vinh Phuc).

Based on the presence of soils in each type of ground structure and the results of assessment in table 5, we can assess how favorable and forecast the geological problems arising when the underground is built in each type of ground structure. (table 6)

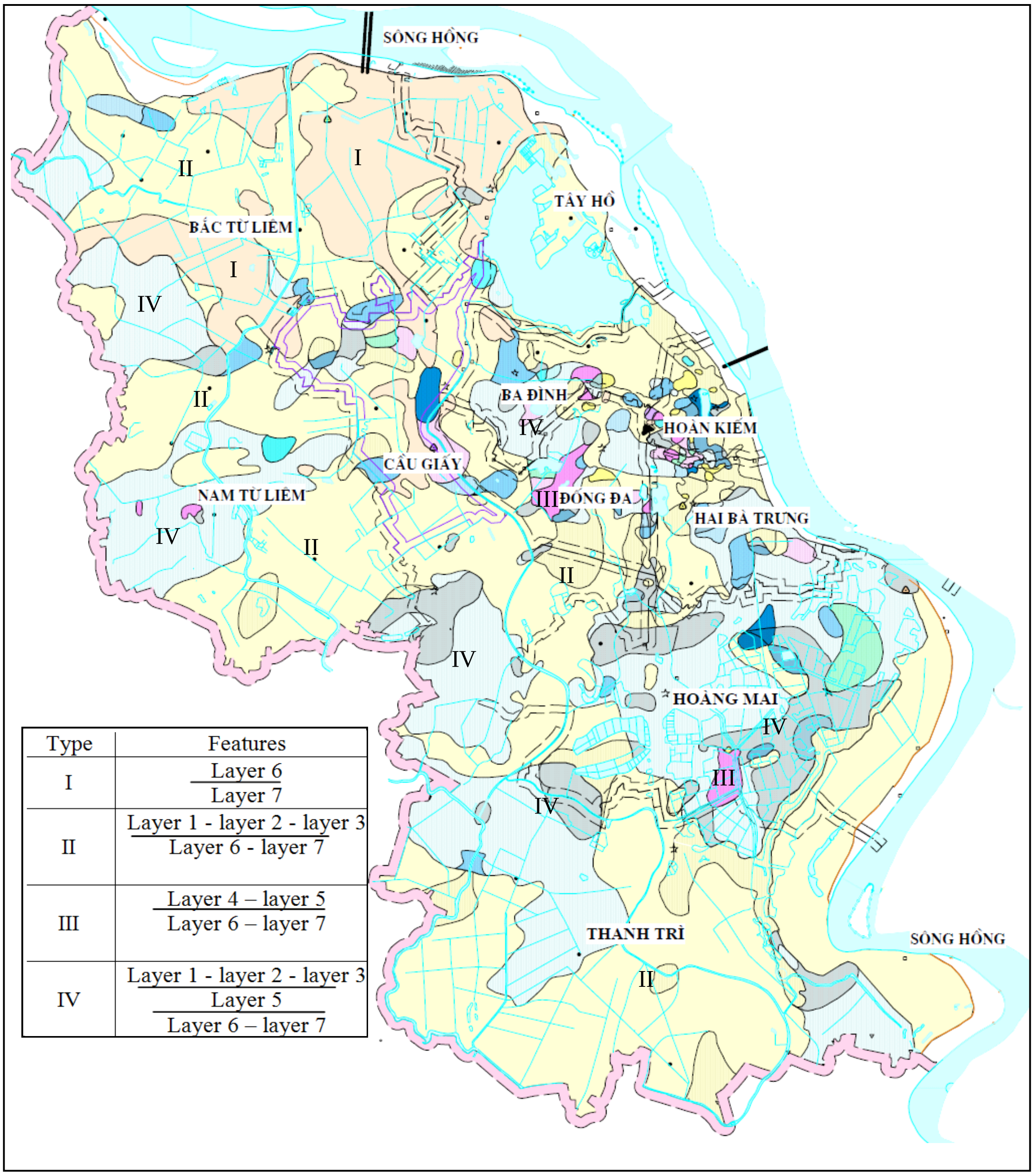

Figure 6. The map of ground structure in the Hanoi area (Phuong et al, 2004)

Table 6. The level of favorable, unfavorable conditions for the construction of the underground in the Hanoi area (According to each type of ground structure)

Type	Features	Geological problems	Assessment
I	Layer 6 / Layer 7	Water flow to the excavation site	Favorable
II	Layer 1 - layer 2 - layer 3 / Layer 6 - layer 7	Suffusion, soil heaving, ground subsidence, water flow to the excavation site	Unfavorable
III	Layer 4 – layer 5 / Layer 6 – layer 7	Soil heaving, ground subsidence, toxic and combustible gas, water flow to the excavation site	Very unfavorable
IV	Layer 1 - layer 2 - layer 3 / Layer 5 / Layer 6 – layer 7	Include all problems	Very unfavorable

7. Conclusions and proposals

7.1. Conclusions

-Distribution characteristics, compositions and physical-mechanical properties of soils, hydrogeological characteristics will decide on the geological problems which may arise during construction and use of the underground. The problems are the stability of the wall and bottom of the excavation, deformation of soil around the excavation, ground subsidence, suffusion, suffosion, soil heaving, water flow to the excavation site, toxic and combustible gas.

- The Quaternary sediments of the Hanoi area include 9 types of soil (9 layers), distributes widely in the research area with different thickness and depth distribution. In particular, layer 1 and 6 make favorable conditions while layer 2, 3, 4, 7, 8, 9 make unfavorable conditions; and layer 5 is very unfavorable for the building of the underground.

- The ground structure of the research area is classified into 4 types, of which type I is favorable; type II is unfavorable; type III and IV are very unfavorable for the construction of the underground.

7.2. Proposals

-In the coming years, along with the economic development and expansion in area and population size, the demand for underground space development in the Hanoi area is very high. Therefore, the planning and construction of urban works need to be linked closely with the development of the underground space.

-Research on engineering geological characteristics to serve the planning, building all kinds of underground work in the Hanoi area should pay attention to the complexity and the specific characteristics of the underground that is located completely in the ground (surrounded by soil and water), and influenced by diverse factors of lithosphere.

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