Analysis of stratification in underground space development and utilization: an example from Beisan county of Langfang city

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Abstract. It is important to analyze underground urban spaces for their capacity to meet the needs of urban development without compromising important ecological resources. Through analyzing the soil structure of Beisan County of Langfang City, the cohesive soil has low bearing capacity and easy deformation, which affects the development of underground space; the sand has wide distribution, large thickness and high bearing capacity, which is beneficial to the development of underground space. In 18-22 meters and 50-70 meters underground, there are two cohesive soils with continuous distribution, which are natural protective barriers for groundwater resources. In order to coordinate the development and utilization of underground space with the protection of groundwater resources, a safe method for utilizing space is proposed that protects groundwater resources and avoids breaking continuous aquiclude by stratifying the underground space. The underground space is developed in three sections in the study area: 0–18 meters is the shallow underground space; 22~50 meters is the sub-deep underground space; Below 70 meters is the deep underground space.

1. Introduction

In terms of land resources, underground space has irreversibility compared with the ground engineering. The rational development and utilization of underground space is important in order to effectively guarantee the underground resources. From the perspective of the function of underground buildings, Yashiro Watanabe put forward the concrete idea of layered development of underground space in 1990. Underground space can be divided into four layers: 0–10 meters underground is the shallow underground space, 10~30 meters underground is the sub-shallow underground space, 30~50 meters underground is the sub-deep underground space, and 50~100 meters underground is the deep underground space[1]. This stratification theory has a profound impact on the development of underground space in China. At present, the Japanese method of stratification is adopted in Beijing, Shanghai, Shenzhen and Chongqing, but the underground space is divided into three layers: (0~15m, 15~30m, below 30m) in Guangzhou[2]. According to the condition of natural resources and social development, different cities use stratification depth of underground space. Li et al. proposed a new stratification method: 0~15 meters underground is the shallow underground space; 15~30 meters underground is the sub-shallow underground space; 30~50 meters underground is the sub-deep underground space; 50~100 meters underground is the deep underground space and quantitatively analyzed the potential of underground resources, taking Suzhou as an example[3]. From the perspective of depth division, most cities used 15 meters underground as the shallow space, 15-30
meters as the sub-shallow underground space or the sub-deep underground space, and 30 meters below as the deep underground space. Limited by technical conditions and economic development, few cities develop underground space below 100 meters. However, with the development of science and technology, the stratification of deep space will be gradually perfected and refined.

The conditions of rock and soil and the protection of underground resources should be considered in developing underground space. The difficulty of developing underground space depends on the conditions of rock and soil. Analyzing the structure and type of rock and soil is the foundation of underground space development and utilization. From the perspective of geological safety, developing underground space has interfered with the inherent stress balance condition of rock and soil and led to the occurrence of many engineering geological problems. The site selection of underground space should avoid the serious bad rock and soil conditions[4]. Junlong Shang et al. discussed the issue of the tensile strength of incipient discontinuities in rock and presents preliminary results from a series of laboratory studies. In most rock masses rock discontinuities, as veins or incipient fractures, often retain some tensile strength that may approach that of the parent rock[5]. When developing underground space, it is very important to classify the engineering geological characteristics of different rock and soil. How to protect the underground resources and environment is a problem to be solved in the rational developing underground space. Developing underground space is restricted by the idea of resource and environment protection, so we need to explore the way of both development and protection to achieve the goal of rational developing underground space. In order to achieve the purpose of coordination between development and protection, developing underground space should be carried out moderately on the basis that the resources and environment are not destroyed. Chae et al., (2008) analyzed the chemical composition of infiltration groundwater in Seoul subway. During tunnel construction, the REDOX reaction of manganese containing materials increased the concentration of dissolved manganese in groundwater. Sewage also dissolves iron from the materials which contain Fe, increasing the concentration of iron in groundwater[6]. Li Minmin et al. (2016), based on the water quality change around the borehole before and after the borehole with non-sealing walls being repaired, found that the transfluence occurs between the adjacent aquifers, which have faint hydraulic connection, through the borehole with non-sealing walls. Salt water in the upper aquifer migrates downward along the well tube and enters into the fresh water aquifer causing the salinization[7]. Developing underground space should protect the aquicludes to avoid the " cross strata effect" between different aquifers. Though analyzing the conditions of rock and soil and the distribution of underground resources, the stratified depth of underground space is divided. In this way, the underground space can be developed scientifically in an orderly way by protecting underground resources and reducing the mutual interference of underground projects at different depths. It is very important for the rational and effective developing underground space to find reasonable stratification method and apply it.

At present, the stratification of underground space development and utilization is not enough, and the environmental geological problems caused by the unreasonable developing underground space occurring from time to time. Taking the three counties in the north of Langfang City (commonly referred to collectively as Beisan county) as an example, this paper discusses the method of dividing the development and utilization depth of underground space by using 135 engineering geological boreholes data in Beisan County and combining with 1:50,000 environmental geological survey results, hoping to provide technical support for the development and utilization of underground space in Beisan County.

2. Regional geological

The plain area of Beisan County is high in the north and low in the south. The above sea level is 5.9 ~ 31.9 meters. The vertical slope of the ground is about 0.66‰[8]. It belongs to alluvial plain geomorphology, which includes flood plain, alluvial plain and lake depression(Figure 1). The lithology of the stratum is mainly silty clay, silt and fine sand in the depth of 50 meters. The bearing capacity of 0-10 m soil is 80 ~ 200 kPa in most areas. The bearing capacity of 10 ~ 30 m soil is 130 ~
The bearing capacity of 30 ~ 50 m soil is 160 ~ 250 kPa. The engineering geological condition is good. In the study area, Shallow groundwater is mainly IV - V type of groundwater and water quality is poorer. In recent years, overexploitation of shallow groundwater caused the continuous drawdown of the groundwater in Gaolou Town, Qixinzhuang Town and Huangzhuang Town.

The main environmental geological problems are active fault, ground subsidence, sand liquefaction and karst collapse in the study area, which affect the engineering construction and the development and utilization of underground space. The Xiadian fault is an active holocene fault in the study area, which has obvious pre-earthquake reflection on earthquakes in surrounding areas, such as the 8-magnitude earthquake in 1679, which caused a 10-kilometer long surface scarp. Land subsidence has influence on the development and safe operation of underground space. Land subsidence rate is between 0 ~ -30 mm/year in most areas. There is a serious subsidence area in Yanjiao Town, whose subsidence rate is -50 ~ -80 mm/year. Sand liquefaction has an impact on developing underground space within 20 meters. When developing the underground space, the liquefied sandy soil may cause quicksand, piping and other engineering geological problems. There is liquefiable sand soil along Chaobai River, Juhe River, northeast of Xianghe County and northwest of Sanhe City. Karst collapse often causes damage to buildings, so it should be paid attention to when developing deep underground space. There is the possibility of karst collapse near Gaolou Town and Qixinzhuang Town, where faults are developed, overburden thickness is thin and relatively broken, and groundwater level varies greatly.

![Figure 1. Beisan county geomorphologic map.](image)

3. Research methods

The research data comes from stratigraphic descriptions of 135 engineering geological boreholes, the test results of more than 3,000 soil and water samples and the physical and mechanical parameters of soil, etc., with a total of more than 20,000 pieces of data. The research method is mainly considered from two aspects of rock and soil condition and protection of groundwater resources: (1) The geotechnical structure in the study area is a multi-layer structure with sand and cohesive soil interbedded and discontinuously distributed. The sand layer is thick and has high bearing capacity,
which is easy to develop underground space. The cohesive soil has poor physical and mechanical properties, low bearing capacity and easy deformation. (2) Shallow groundwater quality is poor and prone to pollution. Cohesive soil has retardation effect on pollutant transport in different depth aquifer. In order to reduce the difficulty of developing underground space and avoid "cross-layer pollution", it is particularly important to protect the continuously distributed aquiclude.

This data provides solid basic data for rational stratified developing underground space. This paper systematically studies the core data of 135 engineering geological boreholes and the results of physical and mechanical tests of rock and soil, establishes the rock and soil structure for the development and utilization of underground space. According to the physical and mechanical properties of different rock and soil, the degree of difficulty in developing underground space is determined. The buried depth and thickness of the top and bottom of the sand layer are counted, and the buried depth range of the aquifer and the aquiclude that need to be protected is delineated. Considering the difficulty of developing underground space and the protection of groundwater resources, the stratified depth of underground space development is divided.

Table 1. Underground space development and utilization of stratified data sources.

| Number | technological means       | Workloads      | Results achieved          |
|--------|---------------------------|----------------|---------------------------|
| 1      | Engineering geological drilling | Holes 50 meters deep | 6500 m                     | Structure of rock and soil |
|        |                            | Holes 80 meters deep | 400 m                     |
| 2      | In-situ test              | Standard Penetration Test | 3375times               | Physical and mechanical property |
|        |                            | Shear velocity     | 400 m                     | Bearing capacity |
| 3      | Sample testing            | Soil test         | 2450 piece                | Groundwater quality |
|        |                            | Water quality analysis | 120 piece               |

4. Geotechnical conditions
The stratigraphic sedimentary facies within 50 meters of the study area are mainly flood plains, rivers, lakes and underwater deltas. Considering the formation age and the physical and mechanical properties of rock and soil, there are 14 types of rock and soil in the 0-50m depth stratum (see Table 2). As can be seen from Table 2, the strata are divided into Holocene and late Pleistocene strata from top to bottom. Holocene rock and soil structure mainly includes: artificial fill, brownish yellow silty clay, grayish yellow silt, grey silty clay, light grey fine sand and yellowish grey silty clay. The artificial fill is mostly plain fill and mixed fill, which is widely distributed with loose structure and poor engineering properties. Brownish yellow silty clay is soft plastic-plastic soil and there is soft soil in some areas. Grayish yellow silt is loose - slightly dense and there is liquefiable soils in some areas. Gray silty clay is widely distributed and is a soft plastic soil. Light gray fine sand is loose - slightly dense and prone to liquefaction. Yellowish gray silty clay is a soft plastic -plastic soil, widely distributed, with calcareous nodules at the bottom. The late Pleistocene rock and soil strata mainly include: brownish yellow silty clay, yellowish grey silty sand and fine sand, grey silty clay, light grey silty sand and fine sand, greyish yellow silty clay, yellowish grey silty sand and fine sand, grey silty clay, light grey silty sand and fine sand. Brownish yellow silty clay is continuously distributed, plastic, with calcium nuclei at the top. In the late Pleistocene rock and soil, the sandy soil is middle-dense and widely distributed. The cohesive soil is plastic - stiff with continuous distribution and unequal thickness.

The stratigraphic lithology in the study area is mainly cohesive soil and sandy soil. Dense sandy soil and strong cohesive soil can be used for underground space construction. Because loose sand and deformable cohesive soil tend to collapse during excavation and construction, more effort is needed to solve this complex soil. The physical and mechanical properties of rock and soil change with the increase of depth, especially the compressibility of cohesive soil decreases with the increase of depth, and the cohesiveness and bearing capacity increase with the increase of depth. These changes follow the regular that cohesive soil gradually compacts and consolidates under dead weight. Holocene
cohesive soil has a low bearing capacity and compressive deformation can occur when the load exceeds 130 kPa. Silty clay has high compressibility and low bearing capacity. Under the action of high water pressure, the silty soil is easy to produce seepage deformation such as loose leaching and pipe gushing. Silty sand and fine sand are easy to produce quicksand and sand liquefaction. From the perspective of rock and soil structure (As shown in Figure 2), the top of the late Pleistocene was "stiff clay", whose roof was buried 14~19 m deep and 2~5 m thick. Stiff clay is widely distributed with medium compressibility and calcareous nodules, but its thickness is small, which is not conducive to the development of underground space. “Stiff clay” is a continuous aquifuge and a natural protection barrier to avoid "cross-layer pollution" of groundwater. On the whole, the condition of rock and soil in Beisan County is conducive to the development of underground space. However, the development of underground space should be coordinated with the protection of underground resources.

**Table 2.** Rock and soil structure and physical and mechanical properties table.

| Geologic Age | Number | Lithology       | Colour          | Void Ratio | Compression Coefficient | Standard Penetration Test | Cohesive Force | Internal Friction Angle |
|--------------|--------|----------------|----------------|------------|-------------------------|--------------------------|----------------|------------------------|
| Qh<sub>1</sub> | 1      | Artificial fills |                |            |                         |                          |                |                        |
|              | 2      | Silty clay      | Brownish yellow| 0.54~1.22  | 0.15~0.86               | 8~80                     | 3.0~29.1       |                        |
|              | 3      | Silt            | Grayish yellow | 0.59~1.09  | 0.15~0.55               | 11~72                    | 9.6~37.2       |                        |
|              | 4      | Silty clay      | Grey           | 0.42~1.15  | 0.16~0.71               | 1~67                     | 2.4~31.9       |                        |
|              | 5      | Fine sand       | Light grey     |            |                         | 9~25                     |                |                        |
|              | 6      | Silty clay      | Yellowish grey | 0.50~1.01  | 0.16~0.65               | 3~78                     | 1.1~32         |                        |
|              | 7      | Silty clay      | Brownish yellow| 0.43~1.07  | 0.1~0.66                | 5~78                     | 2.3~43.4       |                        |
|              | 8      | Silty sand, Fine sand | Yellowish grey |            |                         | 21~41                    |                |                        |
|              | 9      | Silty clay      | Grey           | 0.5~1.06   | 0.15~0.52               | 2~90                     | 1~31.5         |                        |
|              | 10     | Silty sand, Fine sand | Light grey   |            |                         | 19~45                    |                |                        |
|              | 11     | Silty clay      | Greyish yellow | 0.45~1.13  | 0.12~0.43               | 5~178                    | 1~31.1         |                        |
|              | 12     | Silty sand, Fine sand | Yellowish grey |            |                         | 25~53                    |                |                        |
|              | 13     | Silty clay      | Grey           | 0.40~1.07  | 0.11~0.53               | 3~104                    | 1.5~38.8       |                        |
|              | 14     | Silty sand, Fine sand | Light grey   |            |                         | 28~50                    |                |                        |

**Figure 2.** Section diagram of stratigraphic structure in Beishan county.
5. Discussion on the stratification of underground space development

5.1. Divide the development and utilization depth

The sand in the study area is widely distributed with relatively large thickness and high bearing capacity, which is conducive to the development of underground space. In this paper, the bottom buried depth and thickness of sand in 135 boreholes are counted (130 boreholes are 50 meters deep, 5 boreholes are 80 meters deep). As can be seen from Figure 3, sand layers of 0~50 meters are mainly concentrated in a range of 0-18m and 22-50m, and the thickness of sand layer below 70 meters is greater than that between 50 and 70 meters. Considering the exploitation depth of agricultural irrigation Wells in the study area (70~100m), this study believes that there is an aquifer within the range of 70~100m. According to the analysis of the bottom buried depth and thickness of the sand layer, there are two stable and continuously distributed cohesive soil layers at 18~22 meters and 50~70 meters, which are important protective barriers for groundwater. When developing underground space, we should avoid destroying these two aquicludes (Figure 2).

![Figure 3. Distribution of bottom buried depth and thickness of the sand.](image)

![Figure 4. Proposed stratification map of underground space in Beisan county.](image)

Referring to the characteristics of stratigraphic structure and the angle of water resources protection in the study area, this paper considers that the development and utilization of underground space can be divided into three layers (Figure 4): The stratum of 0~18 meters is shallow underground space, which can be used as the construction space of comprehensive pipe gallery, storage and shopping, life
and entertainment, parking lot and other facilities. The stratum of 22~50 meters is subdeep underground space, which can be used as the construction space of underground transportation corridor and logistics channel. The stratum below 70 meters is deep underground space, which can be used as the construction space of strategic infrastructure such as water storage pipe gallery.

5.2. Compare the stratification of underground space in Xiongan New Area

As an important non-capital functional evacuation area, the development and utilization of underground space in Xiongan New Area has attracted extensive attention. According to previous research results on the development and utilization of underground space in the Demonstration Area of Xiongan New Area (Hao Aibing et al.), the stratum of 0~70 meters in the demonstration area can meet the needs of long-term development and utilization of underground space. There are two relatively continuous water-bearing sands in the stratum of 0~70m. In order to protect groundwater resources, we should avoid destroying these two aquifers when developing underground space. In this way, the stratification results of the underground space are as follows: The stratum of 0~30 meters is used as shallow underground space, the stratum of 30~50 meters is used as subdeep underground space, and the stratum of 50~70 meters is used as deep underground space (Figure 5).

![Figure 5. Sectional diagram of engineering construction layers of underground space.](image)

The commonalities of underground space stratification between Beisan County and Xiongan New Area is that they divided the depth of underground space development and utilization from the perspective of water resources protection[10] and combining with the local stratigraphic characteristics. The difference lies in the difference of stratum structure, which leads to different protection objects in underground space development. The sand in Beisan County is widely distributed and thick, and the cohesive soil has a retardation effect on the pollutant migration in different depth aquifers. In order to avoid contamination of aquifers, it is very important to protect continuously distributed aquiclude. The cohesive soil in Xiongan New Area is widely distributed with a large thickness and the sand is distributed in the form of lens. During the development of underground space, the aquifer may be destroyed and the groundwater flow field will change, which will lead to the shortage of groundwater resources and other environmental geological problems. Therefore, attention should be paid to the protection of aquifers in the development of underground space in Xiongan New Area, and the thickness and distribution of sand should be considered as one of the factors influencing the development and utilization of underground space.

6. Conclusion

The development and utilization of underground space should be coordinated with economic development and resource protection. Based on a large number of borehole data and from the perspective of rock and soil structure and protection of groundwater resources, this paper explores the method of dividing the development and utilization depth of underground space, so draw the following conclusion:
(1) Stratified development of underground space is determined by the conditions of rock and soil, and structure and type of rock and soil determine the difficulty of underground space development. The stratum of 0~80 meters in the study area is a multi-layer structure with sand and clay interbedded layers. The cohesive soil has low bearing capacity and large deformation, which affects the development of underground space. The sand layer has wide distribution, large thickness and high bearing capacity, which is beneficial to the development of underground space, but the sand layer needs waterproof treatment.

(2) Underground space development should avoid damaging groundwater resources. There are two continuous aquicludes in the underground 18-22 meters and 50-70 meters, which are the natural protection barriers for groundwater resources. When developing underground space, we should avoid destroying these two aquicludes.

(3) The development and utilization of underground space can be divided into three layers in the study area: The stratum of 0~18 meters is shallow underground space. The stratum of 22~50 meters is subdeep underground space. The stratum below 70 meters is deep underground space.

(4) The stratified development of underground space should be based on the stratum structure and geological environment elements, and avoid destroying the underground resources at the same time.

Acknowledgments
This work was financially supported by the China Geological Survey Program (DD20190820 DD20190251).

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