Study on the engineering geological problems of Nantong Metro and the construction countermeasure

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Abstract. The special geological structure formed by the interactive sedimentation of the Yangtze river brings many potential engineering problems during the subway construction. It is particularly important to carry out the identification of the key layer of geological structure that affects the subway construction to ensure the safety of the project. Based on the geological data of Nantong Metro Line 1, two-dimensional geological model is established to carry out the geological suitability zoning of the project along the subway line, and the key geological formations in different regions are systematically identified. The results show that the key layer group is the thick water-rich sand layer, weak silt soil layer and the newly deposited soil layer in the area, which mainly faces the engineering water hazard problems such as substrate subsidence deformation, permeation deformation and saltwater corrosion. This study provides a reference for subway construction under similar geological conditions.

1. Introduction
With the rapid development of social economy, urban diseases such as traffic congestion have brought a lot of inconvenience to people's lives [1]. The construction of subways can effectively alleviate traffic congestion and facilitate travel [1-2]. China has a vast territory and engineering geological risk factors are different under different geological conditions [3]. For example, Shanghai located at the estuary of the Yangtze River, which faces the huge challenge of settlement and deformation caused by deep soft soil [4]. Once these risk factors are out of control, it will bring unpredictable disasters and losses to subway construction and operation. Therefore, based on the engineering geological data, the systematic identification of the key layers affecting the construction of the project has a decisive impact on ensuring the safe construction of the subway.

In the early stage of subway construction, it mainly involves surveying and sampling, conducting geotechnical tests, and generating section diagrams based on the test results. However, the subway project is located underground, with long crossing distances and complex strata changes. When a large number of soils are exposed in the survey, a wide range of soil types will cause problems for the designers. Establishing a reasonable division of engineering geological strata and generalized geological models can help designers understanding the geological conditions and improving work efficiency [5]. Based on the characteristics of different geological conditions, domestic and foreign scholars have divided the engineering geological layers according to local conditions and analyzed the possible engineering geological problems in a targeted manner. Gou Fugang et al. [6] divided the engineering geological strata within 100m of the Nantong area on the north bank of the Yangtze River Delta based on a large amount of drilling data, and found the dominant and weak sensitive layers, which provided references for engineering construction in Nantong from a macro perspective. However, no specific
problems were pointed out for specific projects. This paper establishes a two-dimensional geological model for Nantong Metro Line 1 on the basis of the previous research on the division of engineering geological strata groups. Accordingly, the key layers are identified, and the construction countermeasures and suggestions are proposed.

2. Project background
Nantong City is located in the southeast corner of Jiangsu Province, on the front edge of the Yangtze River Delta. Nantong Metro is planned to be constructed into 4 urban lines and 4 municipal lines. The first phase of line 1 and 2 approved for construction have 2 backbone lines with a total length of 59.55 km and a total of 41 stations [6].

The terrain of Nantong area is higher in the west and lower in the east. It can be divided into two sedimentary structure areas: Tectonic denudation remnant hill (I) and plain area (P). The plain area (P) can be subdivided into Tonglu water ridge area. (II), Guhe branch area (III), New delta alluvial-marine plain area (IV), Riverside (marine) low plain area (V) 4 forms. The geomorphic units of Line 1 passing through are the Tonglu water ridge area (II) and the New delta alluvial plain area (IV). The huge thick sand layer and the soft soil layer of the ancient river channel that Nantong Metro Line 1 tunnels mainly pass through are the 3rd and 4th main layers [11], as shown in Table 1. The water table is about 1.0-3.0m. The key aquifer groups that have the greatest impact on Nantong Metro are the porous phreatic aquifer group and the first confined aquifer group. Among them, the porous phreatic aquifer group may directly affect the subway tunnel construction.

Table 1  Nantong Subway Tunnel Mainly Through the Formation

| Layer number | Layer name                  | Layer thickness/m | Soil layer characteristics                                                                 |
|--------------|-----------------------------|-------------------|--------------------------------------------------------------------------------------------|
| 3-1          | Silt with silt              | 2.5–23.1          | Mainly silt, local silt, slightly dense to medium dense, engineering geological conditions are general. |
| 3-2          | Silt with silt              | 2.1–28.5          | Mainly silt, local silt, medium density, general to good engineering properties.             |
| 3-3          | Silt with silt              | 3.2–15.5          | Mainly silt, local silt, medium-density mainly, and general engineering geological conditions. |
| 4-1          | Mucky silty clay with silt  | 4.0–24.2          | Soft plastic ~ flow plastic, bad soft soil layer, poor engineering properties.               |
| 4-2          | Silt with silt              | 3.0–14.0          | Mainly silt, local silt, medium density mainly, local slightly dense, engineering geological conditions are general. |
| 4-3          | Silty clay, Silt interbedded with silt | 3.0–31.7 | Soft plastic, partially silty clay is flow-plastic, with poor engineering properties. |

3. Geological model of Nantong Metro Line 1 and the engineering geological problems

3.1. Construction of 2-D geological model and identification of key strata
Metro Line 1 is the first subway in Nantong. It is divided into two phases. The first phase is currently under construction, with a total length of 39.4km. There are 28 stations on the whole line, all of which are underground. Combining engineering geology and hydrogeology data to construct a two-dimensional model on the basis of the geological profile of Line 1, as following principles:

(1) according to construction method, dividing into underground and elevated section; (2) according to topography, dividing into plain area and Tectonic denudation remnant hill area; (3) substratum dividing into sand and soft substratum; (4) according to the hydrogeological condition, dividing into poor water-rich zone, general water-rich region and good water-rich zone; (5) the same type with similar
3.2. Identification and suggestions for engineering geological problems

3.2.1. Analysis and Suggestions on the Influence of Soft Soil.
The characteristic engineering index data of Nantong soft soil are shown in Table 3.

### Table 3: Characteristic Engineering Index Data of Nantong Soft Soil

| No | Geomorphological Unit | Substratum Type | Water-rich Conditions (Single Well Discharge) | Key Engineering Geology Strata Group | Major Engineering Geological Problems |
|----|-----------------------|----------------|---------------------------------------------|-------------------------------------|--------------------------------------|
| I  | Delta Plain           | Substratum of soft soil | 100~300m³/d (General water richness) | 4-1 Mucky silty clay (High compressibility) | Settlement deformation of basement Flow soil |
|    |                       | Sand Substratum    | >300m³/d (Good water richness)             | 3-2 Silt with silt (Slight liquefaction) | Settlement deformation of basement Flow soil |
| II | Delta Plain           | Substratum of soft soil | <100m³/d (Poor water richness)            | 4-1 Muddy silty clay (High compressibility) | Settlement deformation of basement Flow soil |
| III| Delta Plain           | Sand Substratum    | 100~300m³/d (General water richness)      | 3-2 Silt with silt (Slight liquefaction) | Settlement deformation of basement Flow soil |

Figure 1: Geological model of Nantong Metro Line 1

Figure 2: Particle size distribution

Table 2: Nantong Metro Line 1 Engineering Geology Comprehensive Evaluation Table
### Table 3  Representative soft soil test data in Nantong area

| Layer number | Statistical indicator | Moisture content (w/%) | Void ratio (e) | Liquid limit (wL, %) | Liquidity Index (IL) | Coefficient of compressibility |
|--------------|-----------------------|------------------------|----------------|---------------------|---------------------|------------------------------|
| 4-1          | Max                   | 44.2                   | 1.287          | 39.5                | 1.82                | 0.96                         |
|              | Min                   | 28.0                   | 0.717          | 27.4                | 0.52                | 0.38                         |
|              | Average               | 34.9                   | 1.009          | 33.4                | 1.07                | 0.52                         |
| 4-3          | Max                   | 40.6                   | 1.195          | 38.3                | 1.52                | 0.66                         |
|              | Min                   | 22.2                   | 0.685          | 29.0                | 0.43                | 0.17                         |
|              | Average               | 31.7                   | 0.951          | 32.1                | 0.96                | 0.35                         |

As shown in Table 3, the natural porosity ratio is greater than 1 for layer 4-1 and 4-3, classifying as silty soft soil. When the soft soil layer is located on the sidewall of the underground structure, it may induce sidewall shear failure (collapse and instability of the foundation pit). When the soft soil layer is located at the base of the tunnel, it may induce settlement deformation. All stations in Zones I, III and V, shield tunnels between Yongxing Avenue Station in Zone II and Shennan Road Station, and Intermediate Court Station in Zone IV to Hongqiao Road Station, a total of 18 stations was required attention to structural deformation resistance design.

#### 3.2.2. Settlement caused by newly deposited soil.

The low plain area along the Yangtze River crossed by Nantong Metro Line 1 formed a new age. The vertical distribution of Rudong formation is shown in Table 4.

| Series            | Formation | Member                  | age            | thickness/m |
|-------------------|-----------|-------------------------|----------------|-------------|
| Holocene series   | Qhr       | Upper member            | 0~2500yera(s)  | 2~15        |
|                   |           | Middle member           | 2500~7500years | 13~44       |

The depth of the subway is about 20m. It belongs to the upper member of Rudong Formation. Test results show that its over-consolidation ratio is less than 1, which is under-consolidated soil and will still be consolidated under its own weight. The area where the three stations of Nengda Business District Station, Zhenxing Road Station and Hexing Road Station pass through this highest degree of underconsolidation area, may possess the largest settlement. In future subway operation and maintenance, monitoring of soil settlement and preventive measures should be taken.

#### 3.2.3. Research on seepage deformation and construction suggestions

Using the discrimination method recommended by the Engineering Geological Survey Code, the proportion of fine materials less than 2mm is determined on the particle curve. Piping occurs when 0%<P<25%, and while 35%<P<100% flow soil occurs. The layer 3-2 of sand is sampled for particle analysis test. Figure 2 shows the representative soil particle distribution of this layer.

According to the statistical analysis of the test data, the average proportion of fine materials less than 2mm is 89%, far more than 40%. Hence, the subway line 1 site is prone to flow soil. The water-stop curtain should be installed when the subway foundation pit is excavated. From the analysis of the model, it can be seen that there are a total of 15 stations in District II and District IV with sand substratum, and the excavation of the stations required special attention.
In summary, the main influence of groundwater in the site on subway construction is as follows.

1) Due to the high groundwater level, the anti-floating design should be done in the design stage to prevent the floor cracking and other problems. During the construction period, it is recommended to take drainage measures to lower the water level until the upper structure completed.

2) The degree of groundwater corrosion in Nantong City is high. Under long-term flooding conditions, this may cause micro-corrosion to the concrete structure, and local moderate corrosion.

   It is necessary to pay attention to corrosion protection for the 8 stations of Nantong Metro Line 1 from Huancheng East road station to Zhenxing road station. It is suggested that the thickness of concrete cover should be increased, and resin or polymer coating should be used in corrosive areas.

4. Conclusion

1) The geological conditions of Nantong Metro Line 1 are complex and special. The engineering geological problems during construction are representative and can provide references for subway construction under similar conditions.

2) The soft soil is widely distributed along the subway, which may cause uneven settlement in the subway section. It is recommended that settlement joints be set up in the 18 stations of the line.

3) When subway passes through the newly deposited soil along the Yangtze River, large settlement may occur due to the high self-consolidation. It is suggested that settlement monitoring should be done in the crossing area of 3 stations of this line.

4) The water-rich sand layer is deep and the groundwater is shallow. It is recommended that the 15 stations of the line should take measures to prevent seepage deformation caused by high hydraulic head difference.

5) The groundwater in Nantong area is salty and has certain corrosiveness. It is suggested that the density of concrete and coating the surface with polymer resin of 8 stations should be increased.

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