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Assessment of the Safety Impacts of a Pit Construction on the Neighboring Subway

Song Gao*

China Railway Fifth Survey and Design Institute Group Co., LTD., Beijing 102600, China

Corresponding author: Song Gao, Gaos@hotmail.com

Abstract: In order to study the impact of pit excavation on the adjacent existing subway structure, the safety impact assessment of a project was carried out using project under construction near the subway as the engineering background. The results show that the new pit construction will produce some additional deformation on the existing subway interval structure, the deformation values are within the permissible range for safe operation. Through analysis of the results, the risk point rating of the pit adjacent to the interval is level 2. In general, the impacts of the pit construction on the neighboring subway structure are less than the specification limits.

Keywords: Pit excavation; Safety assessment; Adjacent to existing subway

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1. Introduction

As China's urbanization progresses, the allocation of construction land resources is becoming increasingly tight, which makes the cases of construction of adjacent subway increase. No matter what kind of support method is adopted for the foundation pit construction, the construction process will cause disturbance to the surrounding strata, affecting the stress state of the neighboring subway tunnels, and its displacement, deformation, and local stress concentration. If the impact is large, it will lead to the destruction of the subway tunnel structure, thus affecting the normal operation of the subway. Therefore, it is particularly important to study and evaluate the safety impact of the pit before construction.

Regarding the research on pit construction adjacent to subways, Chinese and foreign scholars generally use theoretical calculations, on-site measurements, model tests, and numerical simulations to carry out research. Among them, Li *et al.* [1] summarized the key points to focus on the pit construction adjacent to the subway by using the method of numerical simulation combined with the actual project. Zeng *et al.* [2] analyzed the impact of different factors on the deformation of the operating station during pit excavation through numerical simulation. In order to solve the impact of pit excavation in loess areas on the operation of the adjacent subway, and to study the mechanism of the interaction between the pit project and the subway tunnel, Wang *et al.* [3] used indoor model test to analyze the force and deformation law of the impact of pit excavation on the existing tunnel. Guo *et al.* [4] combined engineering examples, established elastic-plastic-enclosure finite element calculation model, analyzed the deformation of the tunnel between the neighboring shield interval and the change of tunnel internal force in the two pit schemes, and then came up with the relevant conclusions. It is concluded that the excavation and unloading of the foundation pit will disturb the surrounding geotechnical body, which will adversely affect the adjacent existing subway tunnel. For tunnels located in the outside of the pit and below the two directions, Liu *et al.* [5] carried out the relevant research on the existing tunnel impact mechanism, pit excavation caused by tunnel deformation of the impact zone, tunnel deformation prediction method by pit excavation and pit excavation on the tunnel impact control methods. Liu *et al.* [6] analyzed the relevant data in the construction process through actual engineering cases, and then summarized the disturbing influence characteristics of deep foundation pit construction under pile-anchor support and the deformation characteristics of the tunnel section, which provides guideline for similar projects. In addition to this, the research on the influence of deep foundation pit excavation on the adjacent existing subway tunnels has a certain guiding role in the actual project [7-12].

2. Overview of the project

There are 13 blocks of residential buildings, office buildings, hotels, commercial buildings, and ancillary structures to be constructed, with 2–14 floors above ground, 2 floors of basement, height above ground ranging from 11.4–41.8m, with foundation in the form of independent foundation, pile foundation, and raft slab foundation, and the superstructure in the form of concrete frame structure and shear wall structure. Typical sectional relationship is shown in **Figure 1**.

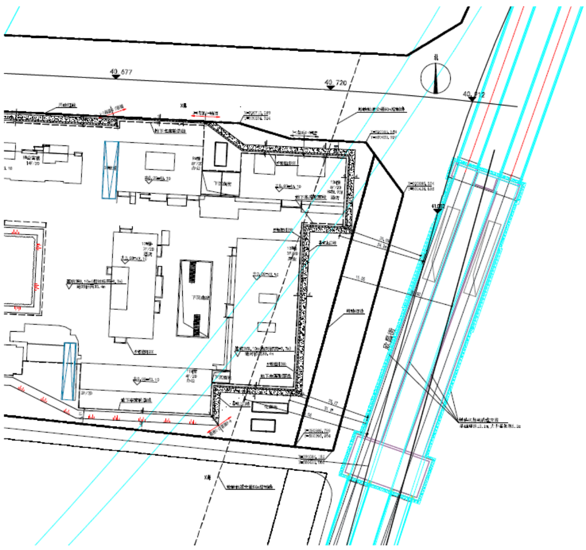


Figure 1. Typical sectional relationship diagram

The proposed pit depth is 8.75m, the pit support near the subway side uses the pile-anchor support, the nearest distance of pit enclosure piles from the subway structure is 29m. The distance of anchor cable from the nearest subway is 16.1m, which is smaller than the subway protection zone, thus the building pit design and construction need to solve the problem of reducing the impact on the subway.

3. Engineering geology

According to the geotechnical investigation report, the project site is top to bottom:

(1) Artificial fill:

Layer 1: Plain silty fill, mainly clayey silt, partly containing a small amount of brick slag and gravel, the top plate elevation is 38.83–42.06m, the depth of the bottom of the layer is 1.00–4.10m, the thickness of the layer is 0.40–3.40m, and the average thickness of the layer is 1.74m. Most of the sites are distributed.

Layer 2: miscellaneous fill, mainly construction waste, and composed of brick slag, crushed stone, and a small amount of concrete block, with a small amount of pulverized soil, the elevation of the top plate is 39.36–42.33m, the depth of the bottom of the layer is 0.50–4.00m, the thickness of the layer is 0.50–4.00m, and the average thickness of the layer is 1.55m. It is partly missing.

(2) Recently deposited soil (Q4al+pl):

Layer 3: clayey silt, locally silty clay and sandy silt thin interlayer, the top plate elevation is 32.85–40.56m, the bottom depth of the layer is 3.00–12.10m, the thickness of the layer is 0.50–8.60m, and the average thickness of the layer is 3.03m. Most of the site is distributed.

(3) General Quaternary alluvial-diluvial layers (Q4al+pl):

Layer 4: fine sand, top plate elevation is 30.53–35.95m, layer bottom depth is 8.60–13.70m, layer thickness is 0.40–7.60m, average layer thickness is 3.18m. It is distributed in the whole site, and there are chalk and medium sand in some sections.

Layer 5: silty clay containing ginger stone, ginger stone content accounts for about 10%, ginger stone grain size is 1–3mm, mainly calcium, partly containing clayey powdery clay thin interlayer, the top plate elevation is 28.46–33.28m, the bottom depth of the layer is 11.70–14.90m, the thickness of the layer is 0.80–5.90m, the average thickness of the layer is 2.25m. It is distributed throughout the whole site.

Layer 6: rounded gravel, gravel content of about 60%, particle size is 5–20mm, maximum particle size is 50mm, subrounded, parent rock composition is mainly sandstone, medium and coarse sand filling, top plate elevation is 22.16–29.78m, layer depth is 16.00–23.80m, layer thickness is 1.70–10.00m, average layer thickness is 6.99m. Most of the site is distributed.

Layer 7: pebbles, pebble content of about 60%, grain size is 30–60mm, maximum grain size is 100mm, subrounded, parent rock composition is mainly sandstone, medium and coarse sand filling, the top plate elevation is 17.38–27.16m, the layer has not been uncovered, uncovered layer thickness of 0.70–10.20m, the average thickness of the layer is 4.66m. Most of the site is distributed.

4. Content and methodology of the security assessment

The assessment was carried out using finite element numerical simulation to analyze the impact of different excavation conditions on the existing subway by modeling the actual project, and then carry out the safety assessment of the project.

4.1. Assessment contents

The assessment contents are as follows.

(1) Establishing a two-dimensional cross-section calculation model to simulate the construction process of the new project and provide the deformation analysis results of the existing subway interval structure.

(2) According to the calculation results, analyzing the impact of the construction of the new project on the

safety of the existing subway interval structure and track structure.

(3) Suggesting the construction sequence, technology, and protection measures of the new project, and providing the control indexes of the deformation of the existing subway interval structure and track structure during the construction stage.

4.2. Assessment concept

The focus of this project is the assessment of the impact on the safety of the interval structure and track structure of the existing Metro New Airport Line during the construction of the new project. Mainly through the collection, collation, and analysis of various geological, design, and status quo investigation and testing data, and the use of numerical analysis, engineering analogy, and expert review and other methods, the deformation caused by the construction of the existing Metro New Airport Line interval structure and track structure is predicted, and on the basis of which it is evaluated whether the interval structure of the existing Metro New Airport Line is safe, and whether the track meets the operational requirements.

4.3. Assessment methods

Mechanical models used for theoretical calculation of underground structures can be summarized into two kinds. The first is continuous medium model, i.e. stratum-structure model, and the second is action-reaction model, i.e. load-structure model. These two mechanical models have their own characteristics, the stratum-structure model is mostly used for structural deformation analysis due to the consideration of the joint action of the stratum and the structure, while the load-structure model only takes the structure as the object of computation, and is mostly used for the analysis of the internal force and deformation of the structure. Specifically for this project, considering that the structural settlement of the subway line caused by construction is closely related to the stratum, the stratum-structure model is used for deformation analysis. At present, the large-scale calculation software that can be used for stratum-structure model analysis include ANSYS, Midas, Flac, and so on. Midas GTS-NX software is used in this calculation to simulate the impact of the construction process of the new project on the safety of the interval structure and track of the existing Metro New Airport Line, to provide the results of the deformation analysis of the existing structure, to assess the safety of the interval structure and the track structure of the existing Metro New Airport Line, and to propose the deformation control of the interval structure and the track structure of the existing Metro New Airport Line during the construction of the new project by synthesizing the various influencing factors in accordance with the requirements of traffic safety. The deformation control standards and protection measures for the existing Metro New Airport Line interval structure and track structure during the construction of new projects are proposed according to the requirements of traffic safety by combining various influencing factors.

4.4. Calculation assumptions

The assumptions are as follows.

(1) The existing subway structure during the construction of the new project only considers the normal use of the working conditions, it does not consider the earthquake, human defense conditions.

(2) It is assumed that the material of the existing project is linear elastic material.

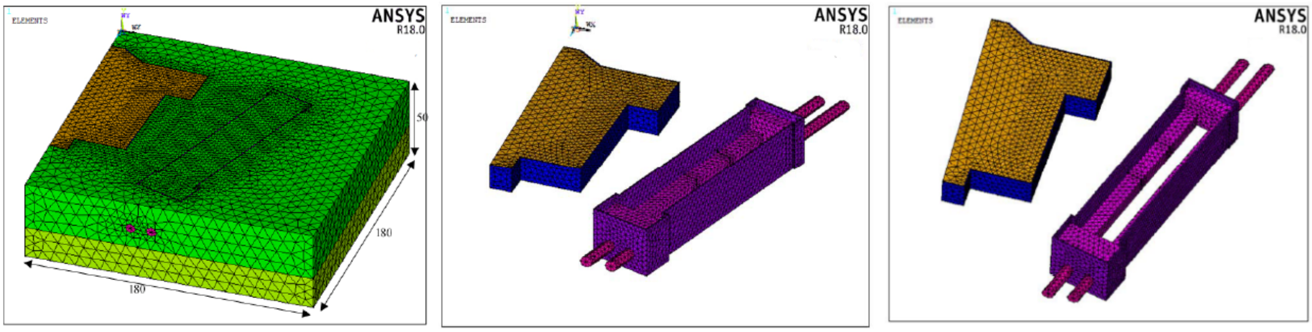
(3) It is assumed that the deformation coordination principle is met between the new construction, the structure of the interval of the existing subway New Airport Line, and the soil body.

(4) The premise of this assessment and analysis is that the construction is under normal and well-controlled conditions.

5. Security assessment

5.1. Calculation model and parameters

The calculated parameters are shown in **Table 1**. Considering the spatial effect in the construction process, the calculation model takes the effective influence range of new construction and existing construction, and in this assessment, the scope of investigation includes the range of 180m longitudinally along the existing subway line, 180m horizontally, and 50m soil thickness. The focus is on the deformation and force generated by the existing structure due to the construction. The calculation model is shown in **Figure 2**.



(a) (b) (c)

Figure 2. Computational model: (a) Assessment overall model diagram (b) Assessment location relationship diagram (c) Assessment location relationship diagram

Table 1. Calculated parameter list

No.	Name	Density (kN/m^3)	Angle of internal friction (°)	Cohesion (kPa)	Poisson's ratio (v)	Modulus of elasticity (MPa)
1	Miscellaneous fill	18.0	15	10	0.3	12.0
2	Powdery clay	19.3	20	20	0.3	15.0
3	Clayey silt	19.2	20	20	0.3	30.0
4	Fine sand	19.5	25	-	0.3	50.0
5	Powdery clay	19.3	15	25	0.3	40.0
6	Gravel	20.0	30	-	0.3	150.0
7	Cut-and-cover interval (C40)	2.5	-	-	0.2	3.25e4
8	Shield interval (C50)	2.5	-	-	0.2	3.45e4

5.2. Simulation process

The new construction is open-digging foundation pit, according to the construction process of the new construction, the main stages of construction simulation are as follows.

(1) The first stage: completing the new perimeter piles, and carrying out the construction of the first anchor cable

(2) The second stage: excavating the first layer of soil, and carrying out the construction of the second anchor cable

(3) The third stage: excavating to the bottom slab

(4) The fourth stage: applying construction loads

5.3. Deformation prediction

The construction process of the new foundation pit produces a certain degree of additional deformation on the interval structure and ground surface of the existing Metro New Airport Line, in order to effectively understand this additional deformation, the lateral deformation and vertical deformation of the interval structure will be analyzed under each process. In order to reflect the deformation and the law of the existing structure, the deformation cloud map of the existing structure at each stage will be extracted after the construction is completed, and the deformation results and the law of the existing structure will be analyzed. It is known from the model calculation results that the vertical deformation of subway interval structure is uplift deformation, and the deformation part is in the neighboring subway side wall. The lateral deformation is biased to the excavation side of the foundation pit, and the deformation part is in the neighboring subway side top plate.

Evaluation of track safety of five existing subway new airport line is as follows. According to the three-dimensional finite element analysis calculation, the following track structure deformation conclusions are drawn. The impact of the new construction on the track structure of the interval of the existing Metro New Airport Line is relatively small, and the maximum lateral deformation of the track structure of the interval of the existing Metro New Airport Line is about 0.24mm, and the maximum vertical deformation of the track structure of the interval is about 0.41mm.

Evaluation conclusion is as follows:

(1) Through the establishment of a three-dimensional stratum-structure model and the deformation calculation, and analysis of the existing new airport interval structure and track structure, it can be seen that due to the construction of the new project, a certain degree of vertical deformation and lateral deformation has been generated in the existing structure.

(2) Based on the analysis of numerical simulation results, the new pit construction will produce certain additional deformation of the subway interval, and the deformation value is within the permissible range of operational safety.

(3) The impact of this project on the track is small, the deformation value is within the permissible range, and the status quo track condition meets the requirements of relevant standards.

Disclosure statement

The author declares no conflict of interest.

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