Analysis and Evaluation of the Countermeasures for the Protection Measures of Subway Near-line Pipeline

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Abstract. With the rapid development of urban rail transit, engineering cases such as subway proximity pipelines are not uncommon, and it is increasingly important to take corresponding measures to protect existing pipelines. In this paper, the numerical simulation method is used to study the effect of protective measures on an underground pipeline. It is found that: (1) The maximum tensile and compressive stresses of the underground pipelines when they are not applied as protective structures are 0.719 MPa and 1.319 MPa, respectively. The maximum tensile and compressive stresses are located at the top and both sides of the pipeline; (2) the pipeline is not protected. The maximum vertical displacement of the structure is below the frame bridge, which is 2.42mm, which is less than the displacement control amount of 10mm. (3) The simultaneous protection structure and the sand pebble replacement layer have the largest reduction of stress and deformation, among which the stress The effect of controlling the replacement layer is better than that of the protective structure, and the control effect for the deformation is similar. The research results can provide theoretical support for the selection of underground pipeline protection measures, with technical guidance and reference.

1. Introduction

With the acceleration of the pace of “urbanization”, most cities have opened new types of transportation carriers such as subways and elevated frame bridges. The construction and reconstruction of this traffic are bound to have an impact on the existing pipelines in the city, and research on the protection measures for underground pipelines has gradually gained attention.

In recent years, many scholars have carried out multi-faceted research on the influence of the surrounding structure of the underground pipeline and the surrounding environment on the safety of underground pipelines. Bi Jihong [1] and Zhang Zhiguo [2] studied the effects of tunnel excavation on adjacent underground pipelines; Zhang Chenrong [3], Zhou Xiancheng [4] and other researchers on foundation pit excavation The influence of settlement deformation on adjacent underground pipelines; Wang Weidong [5] dynamically analyzed the influence of excavation unloading on subway tunnels during construction through numerical simulation; Based on the Herschel-Bulkley model, Wang Zhongtao [6] used computational fluid dynamics (CFD) to simulate the impact of submarine landslides on pipelines under different angles. Jia Yuanyuan [7] studied the stress characteristics and displacement variation of existing municipal pipeline tunnels during the construction process of precipitation. Some scholars have used the combination of theory and numerical simulation to study the impact of subway and tunnel proximity [8-10].
This paper comprehensively considers the above research results and takes into account the advantages and disadvantages of the various protective measures not related to the above-mentioned research results on the protective effect of the adjacent pipelines. By means of numerical simulation, the underground pipelines, soils, and above-ground structures are established. The three-dimensional model analyzes the influence of the upper frame reconstruction on the underground pipeline and focuses on the control structure and the control effect of the soil replacement on the pipeline deformation and deformation, thus providing theoretical support for the future urban pipeline protection measures.

2. Project overview

2.1. Introduction of the project
A subway line slab bridge vehicle base is located on the north side of a subway station. This subway train section test line passes through the existing Ring Road under the tunnel and the right turn to the ground ramp. Due to the clearance requirements, it is necessary to renovate the existing tunnels and ground ramps around the Ring Road. Reinforced concrete sewer pipes and water supply pipes are respectively laid under the ramps. In order to ensure the safety of the under-line pipelines after the frame section is reformed and the test driveline is put into operation, the soil layers around the cross-section pipelines are replaced and applied as protection structures.

2.2. Engineering geology
According to the site survey and the horizontal and vertical section of the soil layer, the physical parameters of the formation are determined as shown in Table 1.

| Rock and soil type      | Compression modulus (MPa) | Elastic modulus (MPa) | Poisson's ratio | Cohesion (kPa) | Internal friction angle(°) | Natural severity (kN/m²) |
|-------------------------|----------------------------|-----------------------|-----------------|----------------|---------------------------|-------------------------|
| Artificial fill         | 4.5                        | 0.4                   | 10              | 8              | 1850                      |
| Silty clay              | 5.1                        | 15.3                  | 0.286           | 20             | 14                        | 1950                    |
| Clay soil               | 5.3                        | 15.6                  | 0.30            | 10             | 20                        | 1950                    |
| Silty clay              | 3.4                        | 10.2                  | 0.30            | 15             | 9.3                       | 1900                    |
| Slightly pebbles        | 23                         | 69                    | 0.23            | 0              | 30                        | 2000                    |
| Medium density pebbles  | 32                         | 96                    | 0.20            | 0              | 35                        | 2200                    |

3. Finite difference numerical simulation

3.1. Calculation principle and basic assumptions
According to the engineering properties of underground pipelines crossing the soil layer and some line shapes, the large-scale geotechnical limited-difference software Flac3D is used to analyze the deformation of the pipeline, including the geotechnical, underground pipelines and their protective structures, frame sections, track plates, U-shaped trough, ramp, simply supported beam cap and bridge pile model.

The total length of the model is 60m, the total width is 300m, and the depth is 55m, which is divided into 350,000 units. The sewage pipe has a diameter of 1.6m and a wall thickness of 0.16m. The water supply pipe has a diameter of 1.2m and a wall thickness of 0.1m. The top of the pipe is 0.6m away from the bottom of the ramp. The protective structure is made of concrete, and the replacement soil layer is sand and gravel. The Mohr-Coulomb constitutive model is used in the calculation of the soil, and the elastic constitutive model is adopted for the pipeline and frame bridge. In this paper, the frame bridge train load is calculated to take a uniform load of 3.7m wide and 48.11kPa. The numerical simulation model is shown in Figure 1.
a. Spatial location of the main structure.

b. Details of pipelines and protective measures.

Figure 1. Numerical model diagram.

3.2. Calculation condition

In order to protect the pipeline, two measures are proposed: apply protection structure and replacing the sand and gravel layer. In order to compare and analyze the effect of the two measures on the pipeline protection, the two measures are arranged in the following four conditions for analysis and calculation, which is divided as shown in Table 2.

| Conditions | Measures                                           |
|------------|----------------------------------------------------|
| Condition 1| No protective structure, no replacement            |
| Condition 2| Apply protective structure, no replacement         |
| Condition 3| No protective structure, replacing sand and gravel layer |
| Condition 4| Apply protective structure, replacing sand and gravel layer |

4. Analysis of calculation results

4.1. Stress analysis
a. Main tensile stress cloud diagram of pipeline section (Pa).

b. Main compressive stress cloud diagram of pipeline section (Pa).

Figure 2. Tensile and compressive stress cloud map of the underground pipe.

Table 3. Maximum main stress table of two pipelines under various working conditions.

| Conditions | Sewage pipe | Water pipe |
|------------|-------------|------------|
|            | Maximum principal tensile stress | Maximum principal compressive stress | Maximum principal tensile stress | Maximum principal compressive stress |
| Condition 1| 0.719MPa    | 1.319MPa   | 0.601MPa   | 1.053MPa   |
| Condition 2| 0.560MPa    | 1.269MPa   | 0.217MPa   | 0.825MPa   |
| Condition 3| 0.447MPa    | 1.222MPa   | 0.190MPa   | 0.760MPa   |
| Condition 4| 0.336MPa    | 1.173MPa   | 0.172MPa   | 0.664MPa   |
This paper mainly selected the maximum compressive stress force reference, as figure 2 is the selection of underground pipeline stress program of tension and compression (4 kinds of force characteristic in the cases of the same, so only show a kind of operating mode), can be seen from the chart to the top, the maximum tensile stress in the sewer pipe, the maximum compressive stress located in both sideline, the law conforms to the rules of stress. Coupled with table 3 and figure 3 shows under various operating conditions of stress, stress attenuation effect can be seen that the protection structure for the worst, the best is applied at the same time for protective structure and sandy pebble infill layer, its for two lines of maximum tensile stress attenuation degree reached 54% and 72%, for the tensile performance of concrete structure is not strong, have very good protection effect.

4.2. Pipeline settlement

a. Longitudinal sedimentation of sewage pipeline. b. Longitudinal settlement of water supply pipeline.

Figure 4 shows the vertical deformation curve of the sewage and water supply pipelines along the longitudinal direction. It can be seen that when the pipeline is under the frame bridge, its displacement is the largest. When any protective measures are applied to the pipeline, the maximum vertical settlement of the sewage and water supply pipeline is 1.95mm and 2.42mm respectively, which is less than the displacement control standard of 10mm stipulated in the technical specification for monitoring of urban
rail transit engineering (GB 5091-2013). It can be seen from the settlement curves of the two displacement charts of working conditions 2 and 3 that the application of protective structure and the application of sand and pebble replacement have inhibitory effects on the deformation of the structure, and the reduction degree of the vertical displacement of the two is similar. However, when the two protective measures are taken at the same time, the vertical deformation of the structure has a greater inhibitory effect than that of the single protective measure.

5. Conclusion
(1) Four protection measures were proposed and their effects were analyzed. A three-dimensional model was built with the help of finite-difference software to simulate the calculation conditions of four protection measures with or without protection structure and without sand and pebble replacement, and the corresponding analysis method system was formed, which could provide a reference for subsequent projects.

(2) The maximum tensile stress of the underground pipeline under load without protective measures is 0.719MPa, which occurs at the top of the sewage pipe, and the maximum compressive stress is 1.319MPa, which occurs at the two sides of the sewage pipeline. The maximum vertical deformation of the pipeline is under the frame bridge, in which the sewage pipe is 1.95mm and the feed pipe is 2.42mm.

(3) Simultaneous application of sand pebble replacement layer for protective structure and sand pebble replacement layer has the greatest attenuation range for pipe stress, among which single application of sand pebble replacement layer is superior to a single application of protective structure. The attenuation degree of the two measures for pollution and maximum tensile stress of water supply pipe is 54% and 72%, respectively, and the weakening effect of the two measures on the tensile stress is obvious.

(4) Can be applied at the same time for protective structure and sand gravel layer in filling for piping vertical deformation effect is most obvious, separate sand and gravel layer in filling or protective structure for displacement control function were similar, it can be applied at the same time for two kinds of protective measures, fouling, give water two lines maximum vertical deformation is 1.5 mm and 1.75 mm respectively, than those not modifies protective measures deformation has obvious decrease.

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