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Analysis of Influence of Pipe-Jacking Construction on Railway Settlement Based on Particle Swarm Optimization Algorithm

Zhichao ZHANG[a1] and Hua LIU[b]
[a] *Hubei Three Gorges Polytechnic, China.*
[b] *Central and Southern China Municipal Design & Research Institude Co.,Ltd., China*

Abstract. In order to study the risk of pipe jacking construction in the sensitive soft soil area to the railway safety in the surrounding city, particle swarm optimization algorithm based on the application of the influence analysis of municipal pipe jacking soft soil area side through the city railway as an example. Firstly, the design scheme and pipe jacking implementation scheme of the urban railway are analyzed, and the influence of pipe jacking construction on the urban railway design scheme is controllable. Secondly, the numerical influence of adjacent railway sections on the railway in the process of road construction is collected to obtain monitoring data, and the particle swarm optimization algorithm is used for back analysis to obtain soft soil "correction parameters". Finally, the influence of setting reasonable driving parameters and "modified parameters" on pipe jacking is analyzed and evaluated. The research shows that, through the analysis of the influence of road construction on the municipal railway by particle swarm optimization, the influence degree of construction in soft soil area on the municipal railway can be judged, and the reasonable adjustment parameters of soft soil can be obtained. And determine whether the impact of the pipe jacking construction on the railway in the city is controllable. The calculation results show that the method is rigorous and feasible by introducing an intelligent optimization algorithm to correct rock and soil parameters.

Keywords. Tunnel engineering, the soft soil layer, pipe jacking, urban railway, correction parameters

1. Introduction

When the project is in the soft soil layer, its construction will cause unfavorable influence on the surrounding existing structures[1]. For example, when the excavation of the foundation pit causes excessive soil and water loss, or brings great loss to the stress of the surrounding soil layer, the surrounding structures may suffer great damage[2]. Therefore, how to use effective methods to analyze the risk of sensitive soft soil layer has become an effective means.

As a scientific and reliable method, intelligent geotechnical research and application can obtain accurate mechanical parameters of rock and soil mass through back analysis of surrounding deformation and displacement information[3].

[1] Corresponding Author: Zhichao ZHANG, Hubei Three Gorges Polytechnic;
e-mail: 992704656@qq.com

For example, Huang Kan [4] et al., based on the learning samples and test samples established by orthogonal experimental design and FLAC3D, established the potential mapping relationship between the parameters to be inverted and the surrounding rock displacement with the neural network through the surrounding rock displacement information obtained from the engineering site. Tala et al. [5] aim at the current problem that mechanical parameters of materials determined through indoor or in-situ tests are significantly different from actual parameters in geotechnical engineering.

As early as 2004, Liu Yongjian [6] et al. introduced the principle and characteristics of intelligent inversion method of displacement back analysis and the research progress in this field in recent years on the basis of analyzing the research status of rock and soil mechanics displacement back analysis.

In order to effectively analyze the soil layer stress in the soft soil area and the surrounding deformation settlement, particle swarm optimization algorithm is intended to be used to reverse analyze the displacement information of the surrounding engineering and obtain the soil layer parameters in the field. And this parameter is used to simulate the finite element calculation during the excavation of pipe jacking tunnel in order to calculate the influence of the project on the surrounding railway.

2. Project Overview

An urban railway is located directly below the urban trunk road in an alluvial marine plain, with flat and open terrain, less important buildings around, mostly farmland, villages, towns, and roads [7].

The municipal pipe network water supply and drainage project are planned to be implemented around the urban railway, within the control line of the urban railway, which has a relatively adverse impact on the urban railway.

The red line of the municipal road project is 40 m wide, with a total length of about 3009.7 m. There are many pipelines along the red line, of which the municipal pipelines are mainly used in rainwater, sewage, water supply, gas, and power. The rainwater, sewage, and gas pipes are buried deeply and carried out by shallow burial and partial open excavation [8]. The minimum clear distance from the designed ground level to the top vertical direction of the roof of the urban railway structure is about 6.9 m. The municipal sewage pipe is buried deeply, constructed by open caisson and pipe jacking.

The impact of the municipal pipeline on the urban railway is mainly the impact of open caisson construction and pipe jacking construction. The specific positional relationship between open caisson, pipe jacking, and urban railway [9] is as Table 1.

Table 1. Working Well Parameters

Well No.	Structure size (mm)	Pipe bottom elevation (m)	Clear distance from railway	Railway top elevation
W1	6500×3000	-0.936	2	-1.335
W2	4000×2200	-1.003	4.9	-0.8
W3	6500×3000	-1.461	4.3	-0.5
D1	4000×2200	-2.4	8.4	-1.76
D2	Φ7000	-2.4	4	-1.74

Soft soil easily affected in the Wenzhou stratum leads to mud water balance construction adopted for this jacking. First, mud water is prepared with certain concentrations and specific gravity through a similar stratum jacking test section. During the mud water construction, the pressure value needs to be adjusted in real-time to reduce the impact on the urban railway. The mud water system sends the mud water to the tunnel face, forming a stable layer for balancing the water and soil pressure in the stratum and excavation [10]. In pipe jacking, the soil is continuously cut into the slag and sludge discharge system to continuously transport them to the ground mud water treatment system, by which the residue separates. The mud water can be recycled and residue discarded.

3. Engineering Geological Conditions

Dependent upon the survey, the rock-soil layers in the proposed project area, according to their causes, are classified from top to bottom, mainly including silt, silty sand, silt, clay, gravelly sand, and clay. Their physical performance indexes are shown in Table 2.

Table 2. Physical and mechanical Property Indexes of Each Soil Layer

Rock-soil Name	Weight	Cohesion	Internal Friction Angle (°)	Compressive Modulus	Secant Modulus	Tangent modulus
	kN/m^3	kPa	°	MPa	MPa	MPa
Plain Fill	17	5	10	1.57	1.34	1.57
Silt	16.6	22	17.9	1.6	1.36	1.6
Silt	16.5	10	14.1	1.8	1.53	1.8
Clay	18.4	21	17.5	5.5	4.68	5.5
Clay	18.6	32	17.9	6.0	5.1	6.0

4. Back Analysis of Displacement Monitoring Based on Particle Swarm Optimization

4.1. Impact of Municipal Road Construction on Urban Railway Monitoring

Municipal roads are currently in the construction stage, which has a certain impact on the urban railway. The municipal road, 3 km long with five bridges and culverts [11], is treated with mixing piles. The buried depth in the open excavation and concealed burying section of the urban railway is 5~8 m. The municipal road reconstruction is bound to have an adverse impact on the urban railway. Moreover, the tunnel's maximum horizontal displacement is -2.2 mm, the maximum settlement deformation is 1.45 mm, and the maximum horizontal displacement of the track bed is -2.85 mm. The specific construction progress and current situation are shown in Figure 1.

Figure 1. Scene Photograph

The foundation of the urban railway tunnel project adopts a pile foundation for settlement protection, and the pile bottom is in a hard geotechnical structure. According to the deformation results, the horizontal displacement of the tunnel changes greatly, and the settlement deformation is small, which is mainly due to the construction of the lot mainly for the soft soil reinforcement construction on both sides. According to the protection standard of urban railway is 5 mm, the road construction in this area greatly impacts the urban railway. An intelligent algorithm is necessary for optimizing and calculating the geotechnical parameters after silt correction [12].

From the existing monitoring data, reclamation road construction has a certain impact on the urban railway. In the construction process, it is necessary to strengthen the monitoring and analysis of the health status [13]. If there are any adverse conditions, the emergency rescue plan and reinforcement protection shall be given in time [14].

4.2. Particle Swarm Optimization

Particle swarm optimization (PSO) is used to simulate the foraging behavior of birds. The solution of each optimization is expressed as a bird in a search space, abstracted as particles without mass and volume, and extended to N-dimensional space. The position and velocity of particle i in N-dimensional space are expressed as vectors. PSO first initializes particle swarm randomly in feasible solution space and velocity space to determine particles' initial position and velocity.

For example, the position and velocity of the i-th particle in the d-dimensional target search space are expressed as $X_i=[x_{i,1},x_{i,2}...,x_{i,\mathrm{d}}]$ and $V_i=[v_{i,1},v_{i,2}...,v_{i,\mathrm{d}}]$, respectively. In each iteration, the objective function of each particle shall be evaluated to determine the best position P_{best} passed by each particle at time t and the best position g_{best} found by the swarm. By tracking these two best positions, the speed and position of each particle are updated by Equations (1) and (2).

$$v_{id}(k+1) = wv_{id}(k) + c_1 r_1 (p_{id} - x_{id}(k)) + c_2 r_2 (p_{gd} - x_{id}(k)) \tag{1}$$

$$x_{id}(k+1) = x_{id}(k) + v_{id}(k+1) \tag{2}$$

where, c_1 and c_2 are positive learning factors, or acceleration constants $c_1=c_2=1.8\sim2.0$, usually; r_1 and r_2 are random numbers evenly distributed between 0 and 1. w is the inertia weight, which should decrease with the iteration of the algorithm, avoiding difficulty in converging near the global optimal solution for the later stage of the algorithm. The decreasing formula is as follows (3):

$$w = w_{max} - \frac{w_{max} - w_{min}}{t_{max}} t \tag{3}$$

where W_{max} and W_{min} are the maximum and minimum inertia weights, respectively; t is the current iteration times, t_{max} is the maximum iteration times, generally W_{max}=0.9, and W_{min}=0.4.

4.3. Back Analysis of Parameters in Soft Soil Area

This excavation simulation selects the river section with silt, where the maximum horizontal displacement of the urban railway tunnel is -2.2 mm, and the maximum settlement deformation is 1.45 mm.

For the feasibility of the method, it can be assumed that the silt of the soil layer is unknown, requiring parameter back analysis. The parameter value range is c=(5~20KPa), Φ=(10°～30°).

The modified Mohr-Coulomb model is used to simulate the deformation of urban railway structures. It is assumed that the displacement of each measuring point calculated is the monitoring displacement (x_{i0},y_{i0}); the algorithm generates the silt parameter, and the calculated displacement (x_i, y_j) is generated by the finite element, comparing with the monitoring displacement to obtain the objective function value. Formula (4) are the details. Finally, the optimal solution satisfying the objective conditional convergence criteria is obtained by continuous iteration.

$$f(x, y) = \sum \left[(x_i - x_{i0})^2 + (y_i - y_{i0})^2 \right] \tag{4}$$

According to the back analysis results, the modified silt parameter is c=11kpa, Φ=7°.

5. Impact Analysis of Immersed Tunnel on Urban Railway

Since Wenzhou urban railway has been put into operation, it is assumed that the settlement of the tunnel structure of line S1 is entirely caused by the disturbance of open caisson and pipe jacking construction. Also, the most unfavorable excavation of the foundation pit is selected for analysis. The simulation calculation is performed combining with the modified silt correction parameters.

- In this simulation, the two working wells (W1 and W3) and two receiving wells (W2 and W4) closest to line S1 and the relevant terrain and structures within the pipeline range are selected for establishing the finite element analysis model.
- The model is a simplified model. The soil layer adopts a uniformly distributed material structure. The modified Mohr-Coulomb elastic-plastic constitutive model is proposed in this calculation model.
- Normal constraints are adopted around the model's boundary, with fixed constraints at the bottom of the model and no constraints on the top surface.

Dependent upon engineering experience and theoretical analysis, the model range is 400 m by 250 m by 60 m (long by wide by high). The model is modeled and simulated by Midas. The whole calculation model has 465040 units and 259035 structural nodes, as shown in Figure 2. The sewage pipe is close to the structure of line S1, with a local minimum of only 2m.

In the construction of open caisson and pipe jacking, the structural stress and deformation of the tunnel of S1 in urban railway gradually changed. First, the excavation settlement and then the pipe jacking structure is adopted in the excavation. Through the simulation and analysis of the excavation process, the most unfavorable deformation is shown in the figure below.

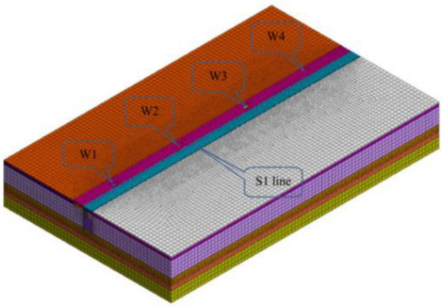

Figure 2. Finite Element Calculation Model

Figure 3. Horizontal Displacement

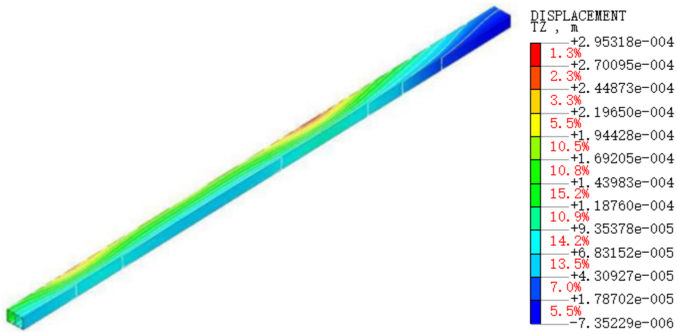

Figure 4. Vertical Displacement

In Figure 3 and Figure 4, after completing the sewage pipe construction, the maximum horizontal displacement of the urban railway is 0.165 mm. The maximum vertical displacement of the urban railway is 0.295 m.

5. Conclusion

According to the impact analysis of municipal road reconstruction on urban railways, with significant impact on the surrounding existing buildings, the construction of underground works with high risk is not suitable for soft soil areas. For the influence of foundation pit construction on the urban railway in soft soil area, the back analysis based on particle swarm optimization is adopted to solve the geotechnical parameters of silt, through which the influence of pipe jacking side crossing urban railway is analyzed.

By the back analysis of geotechnical parameters in soft soil area, the parameters of silt are modified and obtained based on particle swarm optimization. The parameters are smaller than the ones provided by geological exploration.

It is necessary to adopt excavation parameters with less impact when studying the impact of pipe jacking construction on urban railway projects. Also, it is necessary to strengthen the monitoring and measurement of the urban railway to control its construction impact in real time. If necessary, corrective measures to protect the urban railway are required. The numerical calculation of pipe jacking construction is performed by combining the known silt correction parameters. The final results show that the impact of pipe jacking construction on the urban railway is controllable, and the scheme is feasible.

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