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Study on the Impact of a Metro Depot Cover Structure on the Existing Metro Structure and Additional Settlement of Tracks

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Abstract: The superstructure of the metro depot is not only convenient for traffic but also solves the land-use problem. However, the construction of the superstructure comes after the metro depot has been put into normal operation. The foundation of the depot is bound to produce secondary settlement. Based on the calculation method of the friction-end bearing pile of Mindlin's solution in the specification, the superstructure construction project above the Beijing Guogongzhuang metro depot is taken as the basis. Under certain conditions, the settlement of the pile foundation under the action of secondary load and the influence on the track structure are calculated. Moreover, the finite element analysis software ANSYS 18.0 is used to establish the analysis model of the construction of the superstructure of the applied depot. The results show that the influence of the pile foundation settlement produces a certain additional influence on the surrounding tracks, and the maximum value locates at the center of the bearing platform and gradually decreases outward. Under the conditions of informative construction, uniform loading of the structure and control of the construction process, local bias loads and uneven settlements are avoided. The impact of the construction on the track can be effectively controlled, and the impact on the structure can be kept within the allowable limits. By comparing this instance with a number of similar superstructure projects in Beijing, this study shows that the overall risk of this type of project can be controlled and can provide a technical reference for similar superstructure projects on top of a metro depot construction in the future.

Keywords: metro depot; operation depot; superstructure engineering; pile foundation settlement; Mindlin's solution; settlement; track

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1. Introduction

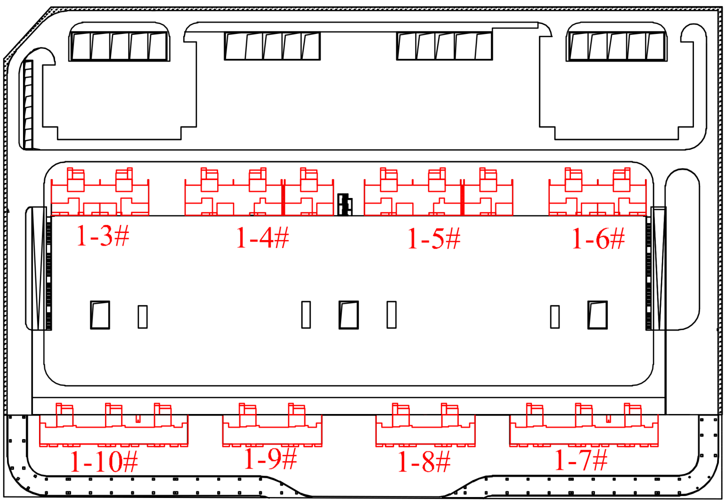
Due to the rapid development of urban rail transit, the number and scale of metro depots are also increasing [1]. With the convenience brought by urban rail transit, the value of land development and utilization around the metro depot is also increased accordingly [2,3], increasing the number of planned construction projects for metro depots [4–6]. However, the utilization intensity of China's existing urban rail transit metro depot itself and the surrounding soil is at a low level [7]. Although the metro depot and the superstructure property development will be unified and integrated, the two are usually tendered for construction in separate phases [8–10]. Usually, the construction process of the superstructure property in the metro depot has been mostly completed and in operation, and the additional settlement of the track caused by the later loading was not fully considered in the previous design. Therefore, it is important to study the influence of the metro superstructure project on the existing structure and track to ensure the safe operation of metro trains in the metro depot.

A great deal of research has been carried out by scholars on the design and construction of urban rail transit superstructure properties [11–15], and it can be seen that, for the research on the superstructure property of metro depot, domestic researchers mainly focus on the construction and design of the urban rail transit superstructure property [16–18], such as the construction position of the pile and column and the layout of station, which will affect the convenient problem of property space utilization [19,20]. Overseas researchers mainly focus on the effects of construction on projects, such as the need for extraordinary means of structural isolation of systems to ensure the proper functioning of properties, etc. [21,22]. However, during the operation of the subway depot, little research has been conducted on the construction of the upper cover project on the settlement of the pile foundation, especially the additional settlement of the track.

This paper takes the superstructure project of Guogongzhuang metro depot in Beijing as the background, and studies the influence of the metro depot structural pile foundation settlement and track deformation in the depot, using theoretical calculations, numerical simulations and actual measurement data for comparison and verification. This study also analyzes the influence of a depot superstructure project on the existing structure and track settlement, summarizes the experience of several similar superstructure projects, shows that the overall risk of this kind of project can be controlled and puts forward relevant requirements and suggestions for the construction of the operational metro depot superstructure project.

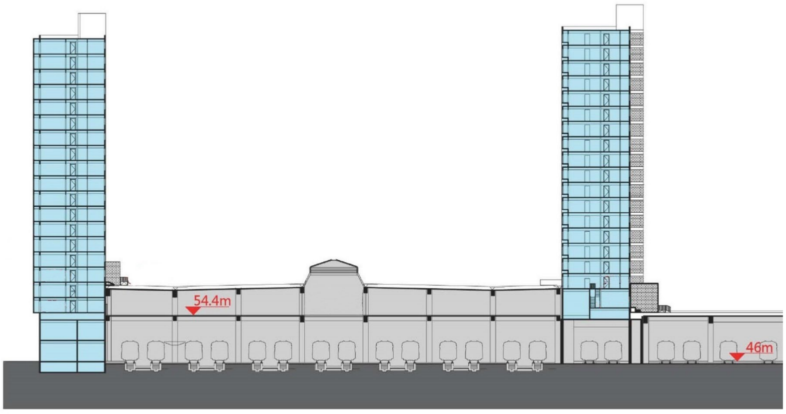
2. Project Overview

The main structure of Guogongzhuang metro depot of Beijing Metro Line 9 has been completed and put into use. According to the original design of the metro depot, by using deformation joints to separate the upper cover area from the non-upper cover area, the interface of the upper cover building is reserved above the structure, and now it is necessary to add a building on the application depot. The superstructure property development project has a construction area of about 100,000 m^2. The commercial residential buildings 1–3# to 1–6# are 18 stories above ground, 1 story of underground structure, 53.1 m high and the commercial residential buildings 1–7# to 1–10# are 21 stories of above ground structure, 60.3 m high, as shown in Figure 1.



(**a**) Location plan of new buildings.

Figure 1. *Cont.*



(**b**) The location profile of the new buildings.

(**c**) Three-dimensional image of the location of new buildings.

Figure 1. Images of the locations of the new buildings.

The existing Guogongzhuang metro depot is a single-story structure, and the layer height is 7.7 m with pile foundation. The structure of the metro depot is divided into 14 zones, with deformation joints left between the zones. The overall structure in the upper cover areas are areas 4–7 and areas 11–14 for the frame shear wall structure, and non-cover areas for the frame structure are areas 1–3 and areas 8–9, with the use of a library plan and elevation diagram as shown in Figure 2.

Guogongzhuang metro depot uses piles as the foundation design, with pebble ④ layer as the pile's end-bearing soil layer. All piles are reinforced concrete bored piles, and the length of the piles in a non-covered area is 16.5 m; the length of the piles in a covered area is 24 m, and the diameter of the piles is 1 m.

The foundation pile arrangement of the upper cover area is basically the same. Take the foundation for area 1–04 as an example: the bearing platform is 46.9 m long and 7.2 m wide, and there are 46 piles under the bearing platform. The piles all adopt the drilling and grouting process, the pile diameter is 1 m, the pile length is 24.0 m and the pile spacing is 3 m. The foundation pile arrangement of the upper cover area is shown in Figure 3.

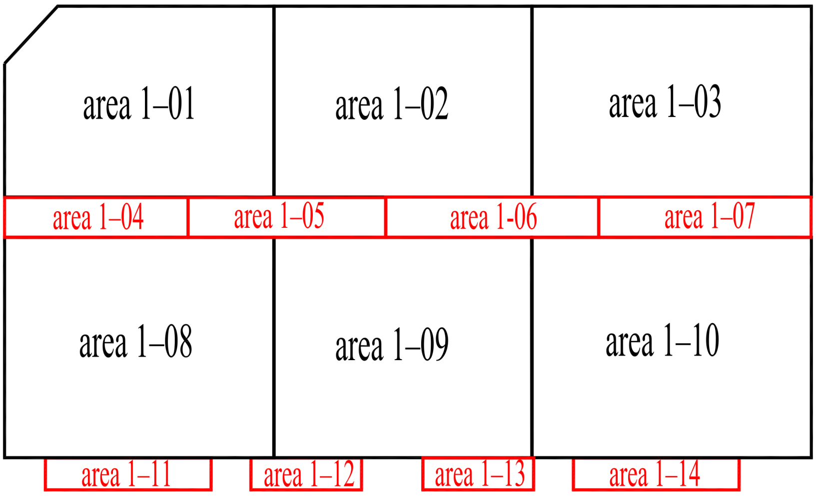


Figure 2. Utilization of depot zoning plan.

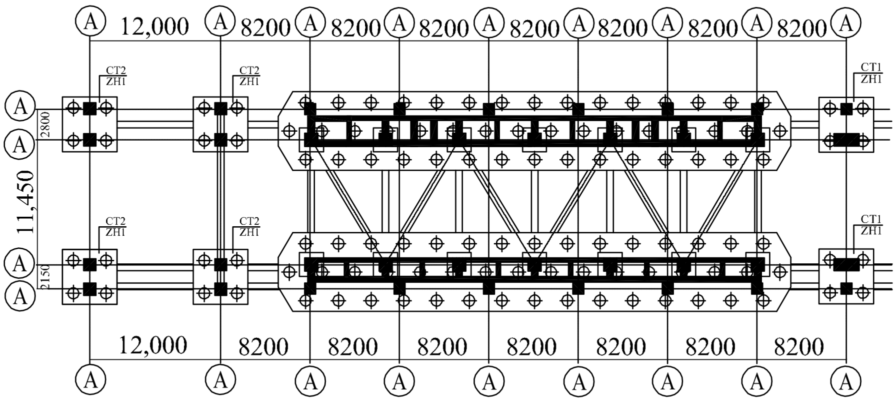


Figure 3. Foundation column arrangement in the upper cover area 1–04.

3. Analysis of the Settlement Mechanism of the Structural Pile's Foundation and Track

Foundation pile settlement calculations generally use the Mindlin solution [23]. In order to analyze the mechanism of the pile foundation and the track settlement in the metro depot using the library superstructure project, the Mindlin solution is introduced. The Mindlin solution is the solution of the stress and displacement induced at any point within the semi-infinite body when a vertical or horizontal concentrated force P is acting within the elastic semi-infinite space.

3.1. Settlement of Pile Foundation Due to Secondary Loading

The design of the metro depot pile foundation has been reserved for the superstructure load; however, the load is applied in two phases, and the time interval is far apart. The second loading is applied under the condition that the first phase's load, such as the self-weight of the metro depot, has settled and stabilized, so the second loading will cause the redistribution of the pile foundation stress and the second settlement of the pile's foundation.

Due to the more uniform distribution of strata, the pile-bearing layer is a pebble layer, and the pile length is 24 m, about 15 m into the pebble layer. According to the Technical Specification for Construction Pile Foundation (JGJ94-2008) [24], the safety factor is taken as 2.0, according to the pile bearing capacity formula:

$$Q_{uk} = Q_{sk} + Q_{pk} = u\sum q_{sik}l_i + q_{pk}A_p \quad (1)$$

where Q_{sk} and Q_{pk} are the standard values of the total ultimate side friction resistance and the standard value of the total ultimate end resistance; q_{sik} is the standard value of the ultimate lateral resistance of the i-th soil layer on the pile side (kPa); q_{pk} is the standard value of the ultimate end resistance (kPa); u is the circumference of the pile; l_i is the thickness of the i-th soil layer around the pile (m); A_p is the area of the pile end.

The calculated pile foundation parameters are given in Table 1, and the loads of phases I and II are the maximum loads for single piles:

Table 1. Pile capacity calculations.

Bearing Capacity of Pile Foundation	Phase I Load (kN)	Phase II Load (kN)	Single Pile Bearing Capacity Characteristic Value (kN)
Upper cover area	490	3447	5208

The pile foundation is firstly subjected to elastic compression settlement under the first phase of loading; the resistance is the pile end resistance and part of the pile side friction resistance, and the pile foundation is in equilibrium. When the load above exceeds the load bearing capacity of the pile foundation itself, the structure will experience a certain degree of settlement and additional pile compression. At this point, the frictional resistance of the pile side comes into play further, allowing the pile to move and reach a new state of equilibrium.

For pile foundations whose pile center distance is not greater than six times the pile diameter, the final settlement can be calculated using the equivalent action stratified sum method. The equivalent action surface is located in the pile end plane, and the equivalent action area is the projected area of the pile bearing. The equivalent action additional pressure is divided into two parts including part of the pile end resistance, and the action surface is the projected size of the bearing. The second part is the additional stress generated in the soil layer by the pile lateral frictional resistance. Settlement from additional stresses can be calculated according to the Mindlin's solution [25–28] in the Technical Specification for Construction Pile Foundations (JGJ94-2008) [24] considering the effect of pile diameter:

$$s = \psi \sum_{i=1}^{n} \frac{\sigma_{zi}}{E_{si}} \Delta z_i + S_e \quad (2)$$

where n is the calculated number of stratifications of the soil layers within the depth of settlement calculation, and the number of layers should be combined with the nature of the soil layer, and the thickness of the layers should not exceed 0.3 times the calculated depth; σ_{zi} is the sum of the additional vertical stresses generated by individual foundation piles within the influence of the horizontal plane to the thickness of i-th soil layer below the plane of the pile's end at the point of stress calculation, and the stress calculation point should be taken as the nearest pile center point to the settlement calculation point; Δz_i is the thickness of the i-th calculated soil layer (m); E_{si} is the compressive modulus of the calculated soil layer (MPa); s_e for calculating the pile compression; ψ is the empirical coefficient of settlement calculation, and when there is no local experience, it can be taken as 1.0.

When considering the pile foundation force as shown in Figure 4, α is the pile's end resistance ratio, β is the uniformly distributed side resistance ratio and Q is the vertical load of the monopile. Because the pile foundation is located in a more uniform layer, the pile's side wear resistance that mainly bears the soil layer is the 4 m thick sand layer and 15 m pebble layer, so the assumption of the friction resistance along the pile's side uniform distribution is made in order to simplify the calculation, i.e., $\alpha + \beta = 1$, where $\alpha Q = 1080$ kN and $\beta Q = 2367$ kN.

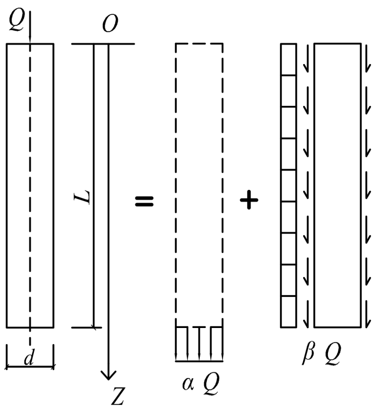
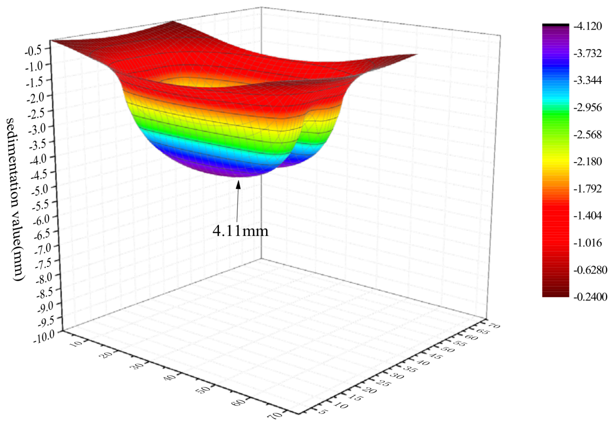


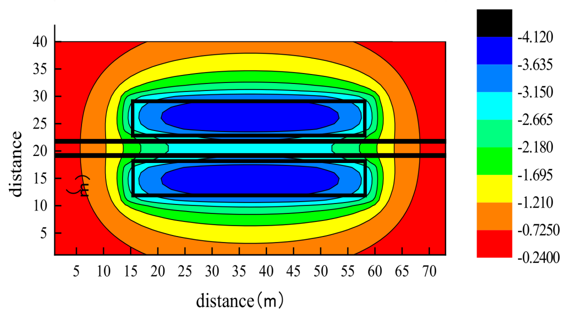
Figure 4. Schematic diagram of single pile load in Mindlin's solution.

Based on the above calculation method, the focus is on area 1–04 as an example to calculate the settlement of the pile foundation at each location within the influence area after the second loading of the upper cover area.

The influence of the force on the foundation settlement on the single bearing platform is calculated by using the layered sum method, and then the results of the two bearing platform calculations are superimposed. The maximum settlement of the foundation pile foundation in the upper cover area is 4.11 mm, the pile end settlement was 2.61 mm and the pile compression was 1.50 mm. Since the load shared by the pile foundation at the edge of the building is relatively small compared with that at the center, the maximum settlement location occurs at the center of the building, and the settlement values within the bearing platform range between 1.29 mm and 4.11 mm. The settlement diagram within the calculation range of the upper cover area is shown in Figure 5.



(**a**) Three-dimensional sedimentation diagram.



(**b**) Settlement diagram.

Figure 5. Settlement diagrams within the calculation range of the upper cover area.

3.2. The Effect of Pile Settlement on Track Structure

Because the track structure is located in the ground near the pile bearing, the pile foundation settlement will cause the surface of the pile's side to settle together at the same time, and the soil settlement above the pile's bearing is equal to the pile's settlement. Considering the common influence of multiple pile foundations below the building, the track settlement between the bearing platforms is equivalent to the surface settlement between the bearing platforms, and the closer the distance between the bearing platforms, the closer the surface track settlement is to the bearing platform settlement.

The maximum settlement at the track location within the impact area is 3.87 mm, and the pile's top burial depth is about 4 m. The settlements of the pile foundation and bearing platform caused by the surrounding surface settlement are most obvious in the region about 10 m away from the center on both sides, and the settlement decreases abruptly outside 10 m. The settlement curve is shown in Figure 6. Since the analysis ignores the stiffness of the track structure, the track is considered to be deformed in concert with the soil. Therefore, the calculation result is larger than the actual one, and the analysis's conclusion is safe.

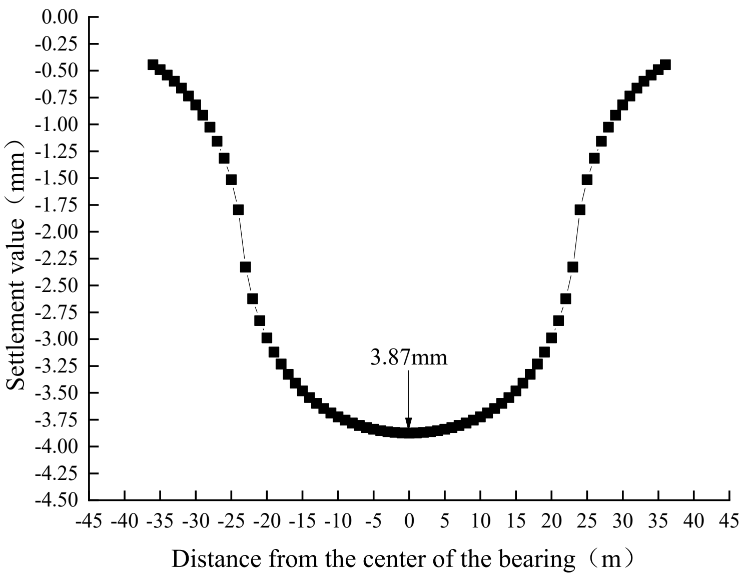


Figure 6. Settlement curve of the rail track.

4. Numerical Simulation Analysis

According to the characteristics of this project, the finite element calculation software ANSYS was applied to model and analyze the foundation and its structure of the application depot based on the geotechnical investigation report. After the completion of the construction of the application depot, the load of the property residence on the upper cover was applied. The additional deformation of the foundation of the application depot caused by the additional load was analyzed.

4.1. Soil Material Parameters

Considering that the construction-induced settlement of the foundation of the applied depot structure is closely related to the layer, the layer-structure model is selected for deformation analysis. The parameters of the soil's intrinsic model are listed in Table 2.

Table 2. Soil unit parameters.

Name	Thickness (m)	Density (g/cm^3)	Poisson's Ratio	Cohesion (kPa)	Internal Friction Angle (°)	Elastic Modulus (MPa)
Clayey powdered soil plain fill	0.9	1.85	0.3	--	--	19.3
Powdery clay	6.4	1.92	0.2	26.0	19.1	18.0
Nakasand	4.8	2.00	0.2	0	32	80.0
Pebbles	30	2.20	0.3	0	40	200.0

4.2. Model Loads

The model calculations consider the following loads (Table 3):

1. Roof load

Table 3. Roof load value.

Serial No.	Name	Maximum Structural Design Live Load kN/m^2
1	Fire Lane	35
2	Upholstered roofs (metro depot roof)	3.0
3	Upholstered roofs (parking garage roofs)	4.0
4	No upper roof	0.5

2. New building loads:

The buildings in the superstructure area 4–7 have a total of 19 floors which give a load of 418 kPa on the basement.

4.3. Model Building

According to the foundation soil conditions revealed by the geotechnical investigation report and the current design conditions, multiple high-rise and low-rise buildings are built on the same overall large-area foundation, and deformation calculations are required according to the joint actions of the foundation, the foundation itself and the superstructure.

The settlement of the upper cover area is concentrated in the position near the pile's bearing. Considering the boundary effect of finite element calculations, the model ranges are 170 m along the long side direction of the bearing and 120 m along the short side direction of the bearing; the model takes the soil thickness of 70 m, and the soil's thickness under the pile's end is greater than the calculated depth in the specification method. The model includes the use of the depot pile foundation, bearing platform and rail slab structure, simplifying the upper building to convert them into building load evenly distributed on the corresponding bearing platform. Among them, the piles, bearing, track slab and soil are simulated with the Solid45 unit, and the pile–soil contact is simulated with contact units TARGE170 and CONTAC174. In the calculation process, the ground adopts a free boundary, and other boundary surfaces are normally constrained. The finite element models using library 3D analysis are shown in Figures 7 and 8.

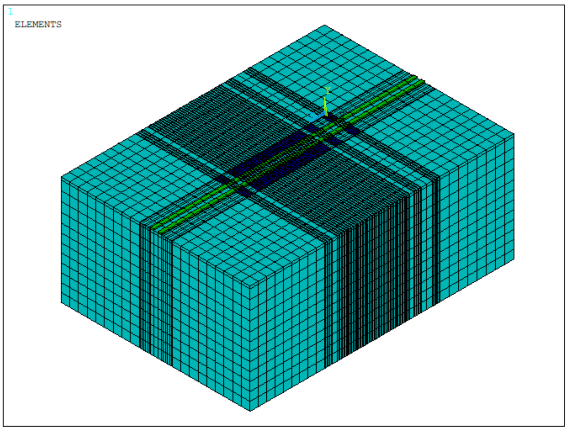


Figure 7. Existing finite element calculation models.

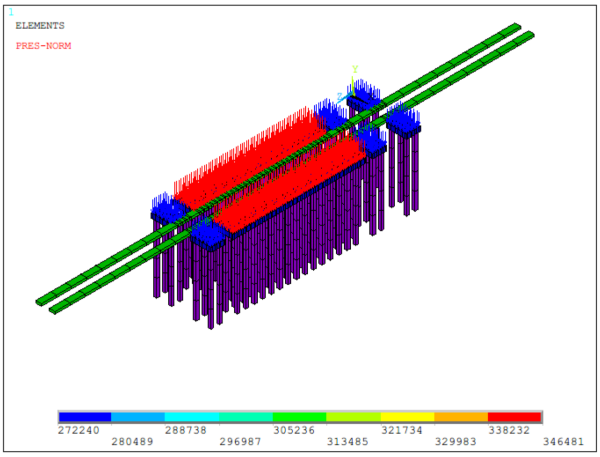


Figure 8. Foundation and load application (m).

4.4. Analysis of the Model Calculation Results

After the finite element calculation, the settlement of the upper cover area after the second loading was obtained.

From the Figures 9 and 10, it can be seen that the group's pile foundation effectively transfers the load to the pile end, and the settlement in the pile end plane is approximate to the surface settlement. The maximum settlement of the model is 4.74 mm, which occurs at the upper part of the bearing platform position offset to the track side.

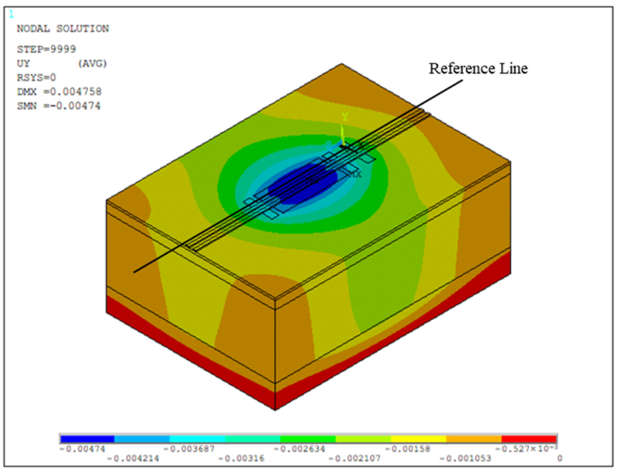


Figure 9. Calculation results of the additional settlement of upper load (m).

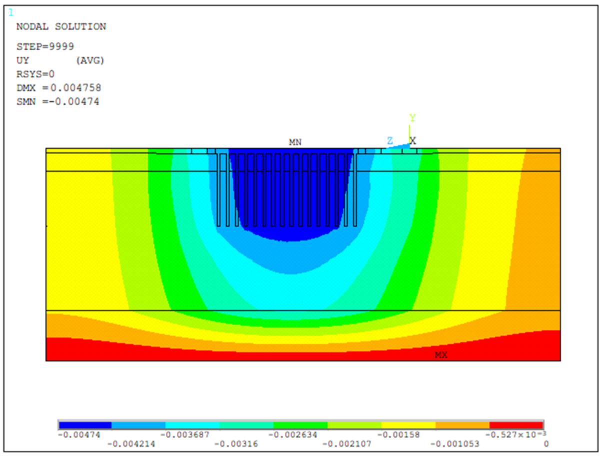


Figure 10. Settlement contour of the maximum settlement section along the line road direction (m).

From Figure 11, it can be seen that the settlement curve of the reference line position is "W"-shaped, and the maximum settlement point occurs at the inner side of the bearing platform, with the maximum settlement of 4.74 mm. Because of the large stiffness of the bearing platform, the settlement curve of the bearing platform position tends to be straight. The farther away from the center, the smaller the settlement amount.

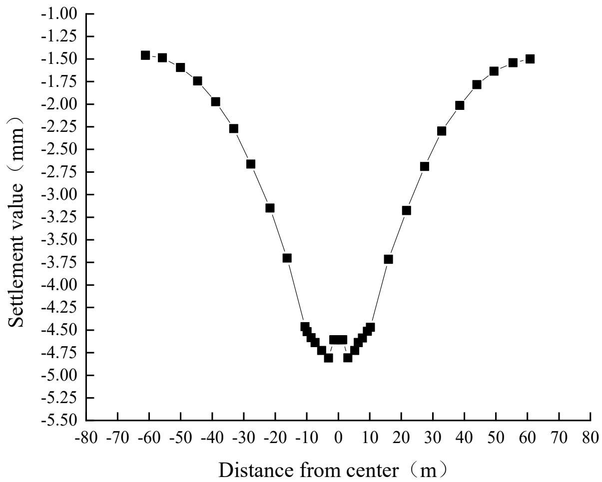


Figure 11. Settlement curve of the reference line position.

From Figure 12, it can be seen that the maximum settlement at the track position is 4.63 mm, and the whole settlement curve is "U"-shaped. The maximum settlement point occurs in the middle of the group's pile bearing platform; the settlement of the pile foundation outside the group pile bearing platform is smaller than the group pile foundation, and the maximum is 3.88 mm. The farther away from the central position, the smaller the settlement amount. The settlement affects the range of about 160 m.

The maximum settlement of the pile foundation is 4.74 mm, and the maximum settlement of the track structure is 4.63 mm using the finite element method, while the maximum settlement of the pile foundation is 4.12 mm and the maximum settlement of the track is 3.87 mm using theoretical empirical calculations. The settlement calculated by the finite element method is greater than that calculated by the theoretical and empirical method, and for this project, the calculation results of the finite element analysis are on the safe side.

When calculating foundation settlement, because the finite element method considers the influence of the bearing platform stiffness, the settlement above the bearing platform position is approximately a straight line. The theoretical empirical method only considers the settlement of the pile's top and does not consider the influence of the overall stiffness of the bearing platform, so the deformation at the bearing platform position deviates from the calculation results of the finite element numerical simulations. In the track settlement calculation, the theoretical empirical method does not consider the superimposed influence of the settlement of the pile foundation at the outer non-superior position of the group pile bearing platform, and the finite element calculations consider the influence of the pile foundation at the outer side of the group's pile bearing platform on the track. Therefore, the method is not as reliable as the finite element numerical simulation method in responding to the deformation of the track structure. In summary, the finite element method calculation and the theoretical empirical method come to basically the same conclusion.

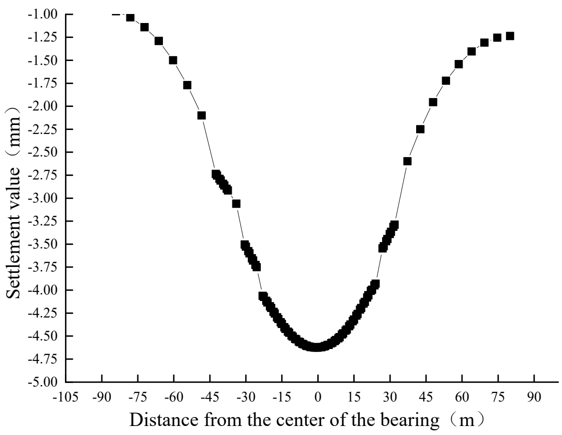


Figure 12. Track position settlement curve.

5. Comparative Analysis of the Monitoring Data

Third-party-monitoring measures are applied in the project, and the monitoring ranges are superstructure area 4–7, parking line strand 15, strand 16, part of the transition track below area 4–7, and the shear wall and track within the single line length of about 286 m.

The monitoring points of the foundation settlement are placed at the corner and middle positions of each span of shear wall, and a total of 24 monitoring points of vertical deformation of the shear wall structure are placed. The vertical deformation monitoring points of the track structure are set up along the line road direction for each road with monitoring points at a spacing of 20 m. A total of 64 monitoring points of vertical deformation of the track structure are set up for the position of the different deformation measurement points in and out of the depot. The layouts of the measurement points are shown in Figures 13 and 14.

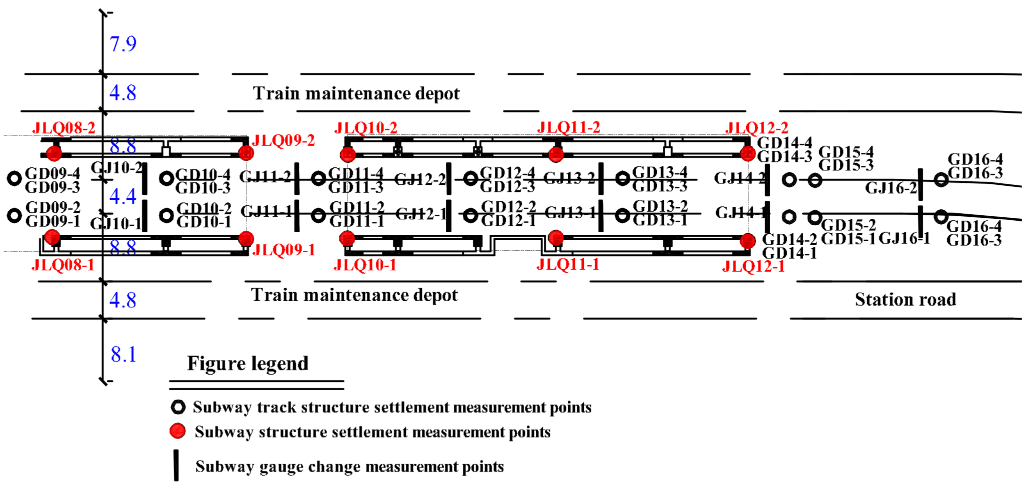


Figure 13. Measurement point layout plan (I).

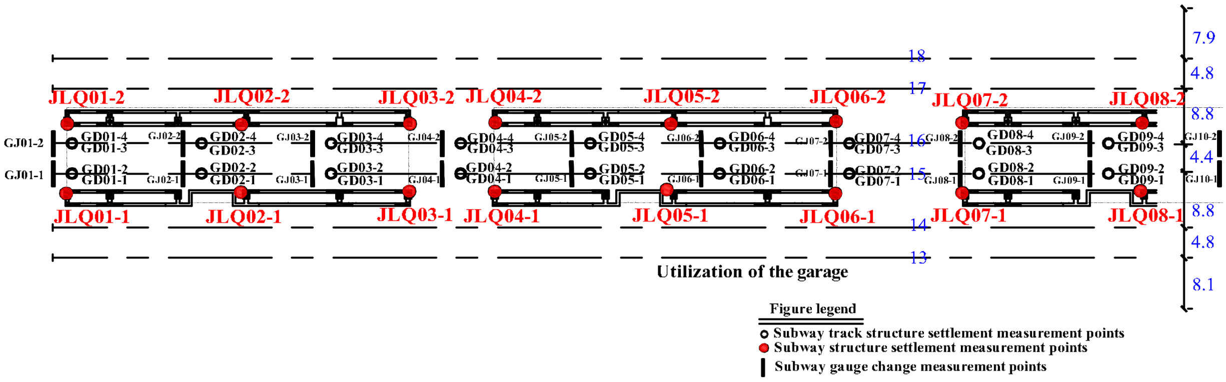


Figure 14. Measurement point layout plan (II).

5.1. Foundation Settlement Analysis

The construction of the upper building was completed on the 209th day after the construction started. From the monitoring data, it is clear that the foundation settlement developed and tended to stabilize during and after the completion of the construction of the upper building. To further derive the trend of foundation settlement, the observed settlement curves were fitted using the hyperbolic method.

According to the analysis of many subsidence observation data, the subsidence time course curve can be approximated with a hyperbolic simulation. When using a hyperbolic simulation of subsidence, it is first assumed that the mathematical expression of the subsidence time course curve is as follows:

$$S_t = S_0 + \frac{t - t_0}{a + b(t - t_0)} \tag{3}$$

when $t \to \infty$, the corresponding final settling volume is the following:

$$S_\infty = S_0 + \frac{1}{b} \tag{4}$$

where S_t is the settlement at time t; S_∞ is the settlement at the final time; S_0 is the settlement at the start time of calculation; a and b are the regression coefficient, calculated from the settlement observation data.

Equation (3) can be rearranged to yield the following:

$$\frac{t - t_0}{S - S_0} = a + b(t - t_0) \tag{5}$$

that is, by plotting $(t - t_0)/(S - S_0)$ versus $(t - t_0)$ and then using the least squares method to fit the curve to obtain the regression coefficients a and b; finally the settlement curve is found with the final settlement amount. Take t_0 when the building construction is completed, which is 209 days after the start of construction, corresponding to $S_0 = 2.0$ mm. Calculate $(t - t_0)/(S - S_0)$ and $(t - t_0)$, respectively, and plot the relationship to derive the least squares-fitted straight line. The settlement-versus-time curve at the test measurement point is shown in Figure 15.

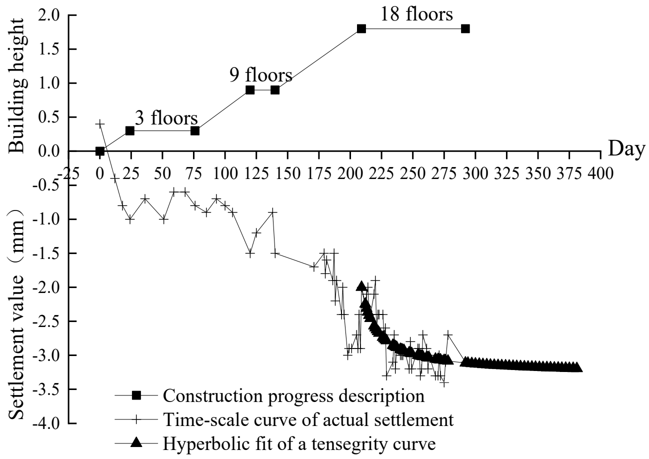


Figure 15. Foundation settlement versus time curve.

As can be seen from the above figure, the main structure was topped out 209 days after the construction started. During the construction of the main structure, the foundation settlement increased continuously, and there was still a small amount of settlement after the topping out, but a stable trend has been shown now. The settlement-versus-time curve can be approximated by fitting a hyperbolic curve after the construction of the project is completed. As can be seen from the curve, the final settlement value is 3.3 mm, which is comparable to the monitoring value at this stage. The maximum monitored settlement in the monitoring data is 3.4 mm, and it can be assumed that the foundation will not settle more after that and that the monitored settlement value at this stage can be regarded as the final settlement value of the foundation approximately.

5.2. Analysis of Vertical Deformation of the Track Structure

From the monitoring data, the maximum vertical settlement of the track structure is 3.4 mm, and the analysis in the previous section shows that the foundation settlement tends to be stable at this stage, so the settlement at this stage can be approximated as the final settlement. After the construction is completed, the settlement curve can be approximated with hyperbolic fitting. The track settlement time curve is shown in Figure 16, and the final fitted settlement value is 3.1 mm, which is comparable to the settlement detection value at the present stage. Therefore, it can be considered that the maximum settlement of the new superstructure project on the track structure is the maximum value of settlement monitoring at the present stage, and its value is 3.4 mm.

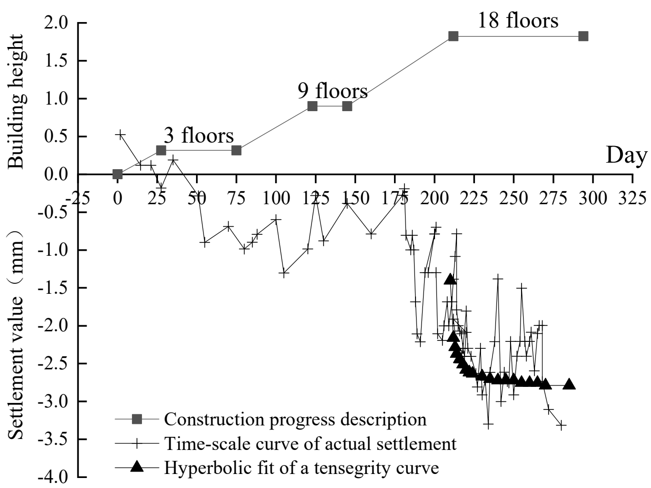


Figure 16. Track settlement-versus-time curve.

5.3. Comparison Analysis of the Monitoring Data and the Calculation Results

The actual measured data and results of the foundation and track settlements within the area 1–04 are compared. The foundation settlement extraction consists of a siding of monitoring points, and the location of the comparison siding is shown in Figure 17.

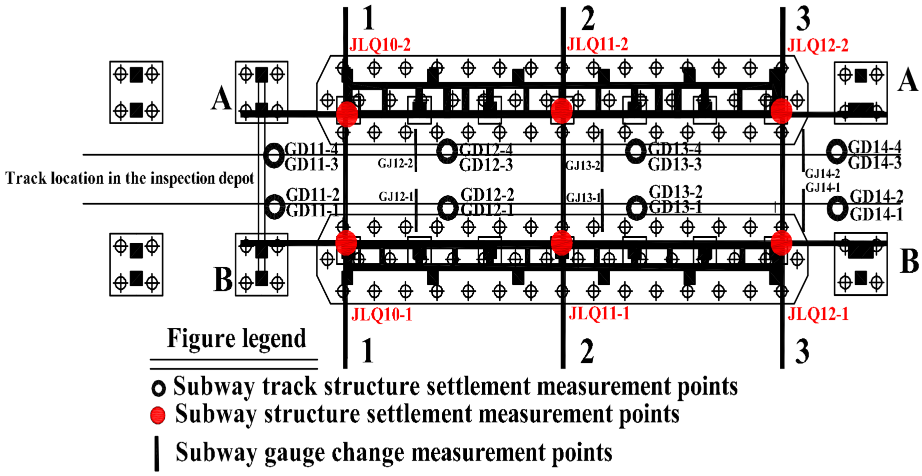


Figure 17. Contrast measurement line positions.

The measured data, finite element calculation results and theoretical calculations of line 2–2 and the track settlement trends and observations are depicted in Figures 18 and 19. The maximum measured values of the base structure settlement and the track settlement are 3.4 mm and 3.3 mm, respectively. The settlements obtained with theoretical calculations at the corresponding measurement point locations are 3.9 mm and 3.7 mm, respectively, and the settlements obtained with the finite element calculations are 4.6 mm and 4.5 mm, respectively.

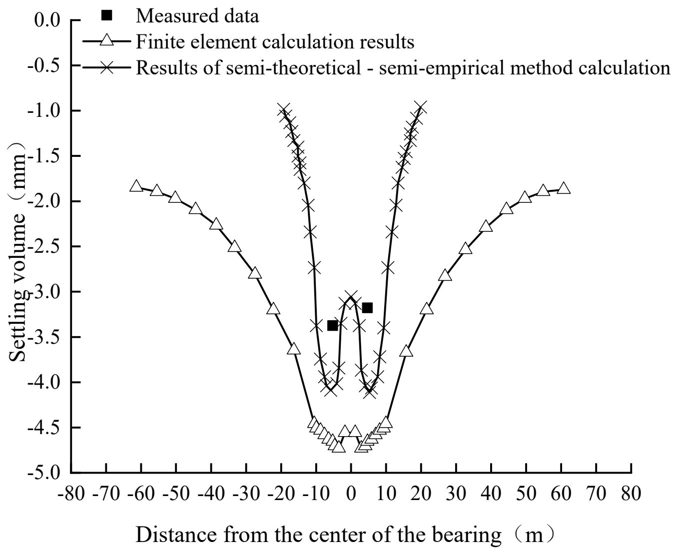


Figure 18. Measured line 2–2 settlement trend and observed values.

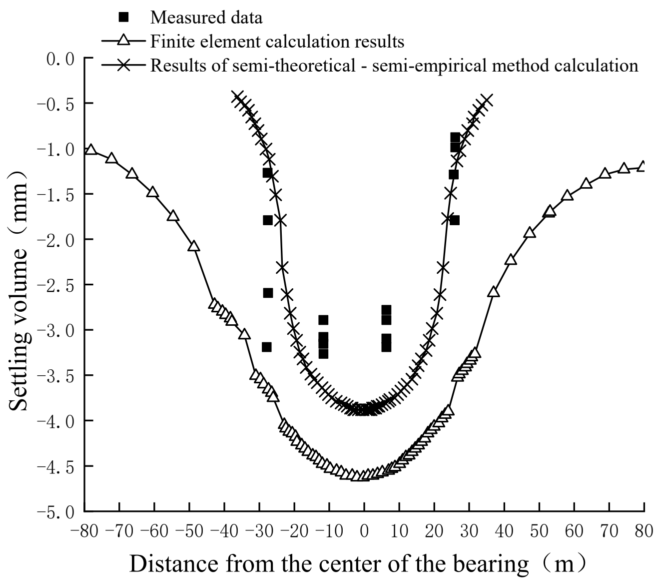


Figure 19. Track settlement trend and observed values.

The theoretical calculations and finite element simulations of the foundation and track settlements are basically consistent with the measured values. The overall settlement is large near the center of the bearing and small at distances far from the center of the bearing.

6. Case Studies of Similar Projects

After the completion of the construction of the Guogongzhuang metro depot superstructure project in Beijing, which was the first metro depot superstructure project in the Beijing area, a number of metro depot superstructure projects were subsequently carried out, all of which have now been completed. The Beijing Metro Line 6 Wuluju metro depot superstructure project has similar stratigraphic conditions to this research project, the Beijing Metro Line 6 Pingxifu metro depot superstructure project has similar superstructure building conditions to this thesis research project, and the Beijing Metro Line 16 Beianhe metro depot superstructure project has similar foundation reservation conditions to this research project; therefore, it has some reference significance. Therefore, the information data of these projects are collected and put in the following table (Table 4).

Table 4. Summary of similar works on the superstructure of metro depots.

Project Title	Conditions of the Superstructure	Stratigraphy and Foundation Preliminaries	Final Settlement (mm)
Beijing Metro Line 6 Wuluju metro depot superstructure	9 buildings above, 6 and 10 stories	Pebble strata, end bearing piles, and pile length of 13.5 m	3.2 mm
Beijing Metro Line 6 Pingxifu vehicle superstructure	9 buildings above, 22 and 11 stories	Clay strata, friction pile, and pile length of 60 m	6.5 mm
Beijing Metro Line 16 Beianhe metro depot superstructure	23 buildings above, 6 and 9 stories	Clay, rounded gravel stratum, friction pile, and pile length of 34 m	3.4 mm

According to the successful cases of similar superstructure projects, as the structure of this type of superstructure project has been reserved—under the conditions of informative construction, uniform loading of the structure and control of the construction process—the settlement of the metro depot structure shows an overall settlement trend, and the settlement distribution is relatively uniform. The impact on the structure can be controlled within the permissible range, and the overall risk of the superstructure project can be controlled.

7. Conclusions and Recommendations

1. This paper is based on the calculation method of the friction end bearing pile Mindlin solution and the pile foundation force assumptions to calculate the use of the library pile foundation in the secondary load loading under the action of settlement and to calculate the impact on the track structure. The finite element analysis software is used to establish the model method for the superstructure construction for comparison and verification, and the influence of the loading of the upper construction on the settlement of the use depot is investigated. The theoretical calculations show the maximum track settlement of 3.87 mm, and the numerical calculation results show a maximum settlement of 4.63 mm.
2. The comparison with the monitoring data shows that the method is feasible for the settlement analysis of friction end-bearing piles with secondary loading. In the single pebble ground conditions of this project, the calculation assumptions are more consistent with the actual pile stresses. In the area with more complex ground conditions, the unevenness of the distribution and the lateral wear resistance will be greater.
3. Within the influence of the pile foundation settlement, there will be some additional influence on the surrounding rail tracks, with the maximum settlement occurring at the center of the bearing platform and gradually decreasing outward. According to the calculation analysis, the settlement change rate is the largest at 2.5 times the burial depth of the pile foundation from the center of the bearing, and the surface settlement decreases abruptly beyond 2.5 times the burial depth.
4. The construction of the superstructure area should adopt the principle of laying in layers within the whole floor at the same time to avoid local bias load and uneven settlement to the detriment of the structure, which can effectively control the impact to the track.
5. Through comparison with similar superstructure projects in Beijing, the superstructure project is able to control the impact on the structure within the required range under the conditions of information-based construction, uniform loading of the structure and control of the construction process. The overall risk of this type of project is manageable.

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