The impact of pipe jacking method entrance and exit construction on the surrounding environment

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Abstract: This paper analyzes the effect mechanism of pipe jacking on the surrounding soil disturbance during the construction of subway station pipe jacking, and uses MIDAS GTS/NX to numerically simulate the impact of pipe jacking on the surface and internal forces of the building. During the construction, the influence of the surrounding soil disturbance and the existing railway track was studied, and the law of the influence on the surrounding buildings and the ground surface during the pipe jacking construction process was analyzed and studied.

1. Introduction
With the increasing progress of social economy and the gradual development of subway projects, under the conditions of densely populated cities in China, how to effectively and reasonably alleviate the conflict between subway entrance and exit construction and urban traffic pressure is a problem faced by every city. Most of the entrances and exits are constructed by open-cut method. However, the construction process of open-cut method will inevitably cause a series of problems such as urban traffic congestion and main road changes. Therefore, the rectangular pipe jacking method is safe, efficient and has little impact on the environment. New technologies are also increasingly used in subway entrances and exits, street crossings, and other linear projects. Therefore, among the densely populated cities, the impact of the pipe jacking method on the surrounding environment during the construction of the entrance and exit will be a concern.

The pipe jacking method was first applied to engineering in 1896, which originated in the United States[1] and attracted much attention. In 1982, a concrete pipe with a diameter of 1524 mm was pushed into 49 m in the UK, and it took 9.5 hours. This record broke the world record at that time[2].

After the technology has been widely used, many countries have begun to focus on theoretical research. Among them, Japan mainly focuses on small pipe diameter technology[3]. After substantial progress has been made, it has begun to study long-distance pipe jacking construction.

Domestic research on pipe jacking technology lags behind foreign countries. The technology was first adopted in Beijing in 1953, and then in 1956, Shanghai began to conduct experimental research using hand-dug pipe jacking machines[4]. In 1967, a company in Shanghai developed a small-diameter remote-controlled earth pressure mechanical pipe jacking machine that can be used for construction.
without people entering the pipeline\cite{5}. After production, the machine was used in tunnels, highways and underpass railways. Its cumulative jacking length has exceeded 400 m in 1969\cite{6}. In 1978, a kind of squeeze type pipe jacking was developed to be applied to unfavorable geological conditions such as silt and soil. With the continuous update and advancement of pipe jacking technology, from the initial application to water supply and drainage engineering to the construction of power cables, the method has been vigorously promoted and used.

2. Project Overview
The project is based on the entrance and exit of a subway in Jinan. The shape of the pipe jacking starting well is rectangular. The length of the foundation pit is about 14.5m from north to south, and the width is about 14m from east to west. The construction length of the pipe jacking method is 33m, the depth of the foundation pit is 12m, and the total length of the adjacent subway station is 275.1m. The standard total width is 20.35m. There is a six-story brick-concrete brick-concrete structure in the nearest 4m from the west side of the pipe jacking entrance. It has a rubble foundation, a two-story basement, and the pipe jacking channel structure all adopts prefabricated rectangular reinforced concrete pipe joints. The overall size of the pipe joints is 4.2m×9m, the wall thickness is 0.45m, the pipe section length is 1.5m, the engineering safety level is level 1, and the importance factor is 1.1. Figure 1 shows the mutual position of the surrounding environment of the pipe jacking method. According to the detailed survey report, the physical and mechanical parameters of the rock and soil mass are shown in Table 1.

| Serial number | Project                  | Bulk density $\gamma$ (kN/m$^3$) | Elastic Modulus E (MPa) | Cohesion $c$ (kPa) | Internal friction angle $\phi$ (°) |
|---------------|--------------------------|-----------------------------------|------------------------|-------------------|-----------------------------------|
| 1             | Miscellaneous fill       | 16                                | 56.5                   | 7.8               | 20                                |
| 2             | Silty clay               | 16.1                              | 65.15                  | 5.5               | 2.6                               |
| 3             | Fully weathered diorite  | 19.5                              | 156                    | 36.25             | 20.28                             |
| 4             | Strongly weathered diorite | 23                            | 153                    | 300               | 30                                |
| 5             | Moderately Weathered Diorite | 25.5                        | 13E4                   | 800               | 35                                |

3. Model calculation

3.1 Establishment of calculation model
In this paper, the finite element software Midas GTS/NX is used for numerical simulation analysis. The model size is 165m×165m×55m, and the excavation depth is 3–5 times as the distance from the boundary of the 3D calculation model to the foundation pit enclosure. Define the surrounding rock and soil material as an isotropic continuous medium, assume it is an ideal elastoplastic material, select Mohr-Coulomb elastoplastic model, use 3D solid elements to simulate soil and building basements; use 2D plate elements to simulate pipe jacking tunnels Segments, each floor of the building and the main station floor; the soil grid is divided into quadrilateral grids, the calculation model is shown in Figure 2.
3.2 Simulation calculation
This article mainly focuses on the impact of the pipe jacking process at the entrance and exit of the pipe jacking tunnel on the building, the surrounding surface environment and the main station that has been built. After the displacement is cleared, the jacking of the pipe jacking tunnel is simulated. The construction conditions are: 1) calculation of the initial stress field; 2) driving the entrance and exit fence; 3) excavating the entrance and exit soil; 4) using the two-ring pipe jacking segment as a unit, gradually excavating and supporting the segment, this process is simulated in eleven steps until the excavation reaches the main station.

4. Analysis of numerical simulation results

4.1 The impact of pipe jacking tunnel excavation on ground surface deformation
In the mutual confirmation of the results of the three-dimensional simulation calculation and the field measurement, Figures 3 and 4 are the Z-direction displacement cloud map of the surface environment around the pipe-jacking tunnel when the pipe-jacking starts to excavate and the displacements of various surface points under the actual measured conditions. When the pipe-jacking machine enters the entrance and starts to advance, the changes of the DBCF4 points near the top of the foundation pit are large. In the case of timely grouting, the pipe jacking will lift the soil. The surface changes greatly, increasing to a positive value, and the maximum lifting amount is 4.55mm; Figures 5 and 6 are the Z-direction displacement cloud map of the surface environment around the pipe-jacking tunnel and the displacements of various surface points under the actual measured conditions when the pipe jacking is in the tenth ring road. When the pipe jacking is in the tenth ring road, the pipe jacking advances halfway and the DBCF2 above the position the amount of change at each point gradually increased, and the surface was uplifted greatly due to the cumulative effect. The maximum amount of uplift was 18.57mm. Due to the vehicles on the surface and the underground construction, the surface changes caused by the jacking tunnel were relatively large; Figures 7 and 8 are the Z-direction displacement cloud map of the surface environment around the pipe-jacking tunnel at the end of the pipe-jacking tunnel and the displacement of the surface points under the actual measured conditions. When the pipe-jacking is completed, the amount of change in DBCF1 at the end of the tunnel is large, as -3.20mm, after the pipe jacking is completed, the ground settlement is relatively large due to the destruction of the main pile of the station, while other points have hardly changed.

It can be seen from the figure that during the tunneling process of the pipe jacking tunnel, the surface settlement is in the shape of a groove near the center of the pipe jacking tunnel. The settlement value varies according to the excavation position. The closer the excavation distance is, the maximum settlement is often directly above the excavation position. After the tunneling, the grouting pressure will make the surface subsidence uplift and rebound, so that the surface subsidence will rise slightly. When the grouting pressure is stable, the surface will hardly change.
4.2 The impact of pipe jacking tunnel excavation on ground surface deformation

Through simulation and on-site actual measurement, we can clearly see the changes in surrounding buildings during the excavation of the pipe jacking tunnel. Figure 9, Figure 10, Figure 11 are the vertical displacement cloud diagrams of the building when the pipe jacking is pushed into the first ring, the pipe jacking is pushed into the tenth ring, and the pipe jacking is finished; field measurement data of neighboring buildings under various working conditions during the construction process.

It can be seen from the figures that when the entrance and exit of the foundation pit is excavated, when the pipe jacking is advanced to the tenth ring and the pipe jacking tunnel is advanced to the middle position, the building is lifted due to the grouting pressure and the principle of stratum loss, and the maximum lift height is 1.32mm; when the pipe jacking method is completed, the settlement of the building is small because the position affected by pipe jacking is relatively far away from the building.
5. Conclusion
In this paper, taking a pipe jacking tunnel project at the entrance and exit of a subway in Jinan as an example, the following conclusions are drawn from the three-dimensional numerical simulation:

(1) The impact of the pipe jacking tunnel on the surrounding ground environment is directly related to the distance. The settlement value of the surface point above the center line of the pipe jacking tunnel is the largest, and the settlement value decreases successively to the outside, forming a groove as a whole; for surface points, under different construction conditions, the settlement law is that the soil is slightly lifted due to the extrusion of the pipe jacking, and then it is lowered due to excavation, and then lifted due to the grouting pressure, gradually tending to stabilize.

(2) There is a great relationship between the surrounding buildings and the location of the monitoring point when the pipe jacking tunnel is driving. The maximum settlement point of the building is close to the corner point of the tunnel, and there is a tendency to shift toward the entrance and exit foundation pit in the horizontal direction.

To sum up, in this type of project, the most important thing to pay attention to is the settlement of the surrounding environment during the tunneling process. The tunnel entrance and exit foundation pit is strictly in accordance with the "support first, then dig, and distribute the The principle of “digging and timely monitoring”. In this project, the phenomenon of exceeding the control value at a certain point is accidental, and the construction risk is safe and controllable, providing a reference for similar projects.

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