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Research on Long-Distance Pipe Jacking Construction Technology for Large Pipe Diameter Under Complex Conditions

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Abstract. With the acceleration of urbanization and the improvement of people's demand for high quality life, pipe jacking project shows the development trend of longer and longer single jacking distance and larger and larger pipe diameter. This development trend requires pipe jacking construction technology to be able to adapt to complex geological conditions, including adaptability to different geological conditions, diversification of pipe jacking machines, and research and development of grouting materials. This paper addresses the implementation of pipe-jacking construction techniques for large pipe diameters and long distances in complex environments. It discusses in detail the selection and performance criteria of materials required in pipe jacking construction, including the characteristics of different materials and their performance in construction. The corresponding solutions and methods are proposed by analyzing the grouting and friction reduction control, intermediate relay technology, and jacking attitude correction control and management technology encountered in long-distance pipe jacking construction. By analyzing specific cases and different solutions for different problem factors, the challenges in the construction process are effectively solved, thus improving the construction efficiency and project quality. This research is significant in coping with the complexity of long-distance, large-diameter pipe jacking construction.

Keywords. Complex geological conditions, pipe jacking, large pipe diameter, grouting and friction blocking, inter-relay technology

1. Introduction

With the booming development of underground infrastructure construction [1], especially the promotion of pipe-jacking projects in the past 20 years, pipe-jacking construction technology is developing rapidly and is widely used in the construction of urban pipeline networks. This method applies to various projects, such as heat, natural gas, communication cables, and sewage pipelines. With the accumulation of construction experience, the pipe jacking distance and depth increase with each construction. This trend is to adapt to the limited underground space in the city, which

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allows the construction to be carried out at a longer distance and a more profound level [2]. Due to the diversity and complexity of urban geological conditions, researchers have conducted in-depth studies on the pipe-jacking construction process of urban underground pipe networks, which is an urgent topic. Therefore, this paper provides a detailed summary and in-depth analysis of the critical technologies for long-distance pipe jacking construction of large pipe diameters under complex geological conditions. As shown in figure 1.

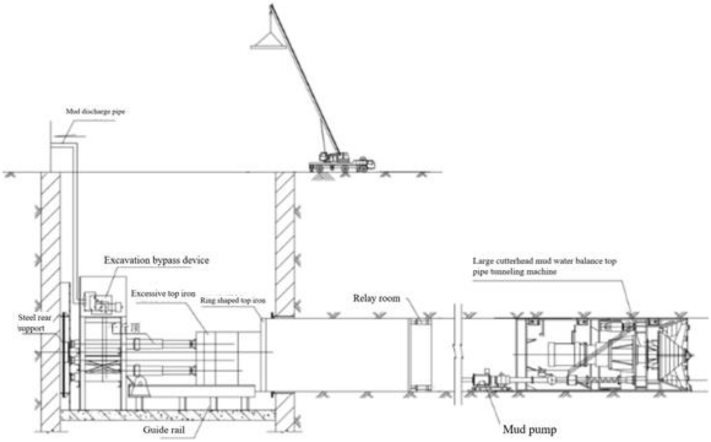

Figure 1. Composition of pipe jacking construction equipment.

2. Grouting Friction Control Technology

When a long-distance large-diameter pipe jacking project is carried out, with the increasing propulsion distance of the jacking pipe, the thrust force on the pipe gradually increases [3], and the frictional resistance between the pipe and the ground layer also gradually rises. In order to effectively mitigate this increase in frictional resistance, the method of bentonite thixotropic mud is usually used. This kind of mud can change the physical properties of the strata and reduce the friction coefficient between the pipe and the strata to reduce the jacking resistance and improve the overall construction efficiency. As shown in figure 2a.

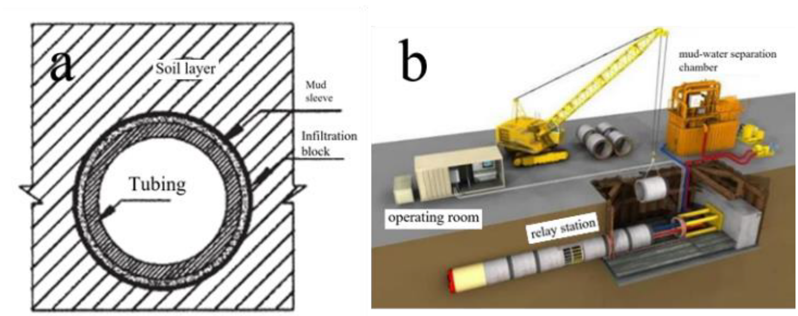

Figure 2. 2a is a schematic cross-section of the pipeline grouting holes, and 2b is a technical diagram of the relay interval.

2.1. Principles and Requirements of Friction Resistance

In pipe jacking construction, grouting refers to injecting friction-reducing materials into the soil around the pipe through grouting technology to reduce the friction resistance between the soil and the pipe. The main principles of grouting friction resistance include:

The grouting material can change the physical properties of the soil, reduce the friction coefficient between the surface of the pipe and the friction resistance;

In the process of grouting, the material fills up the void of the soil, reduces the deformation capacity of the soil, and reduces the friction resistance due to the deformation of the soil;

The grouting material has a certain degree of lubrication, which can form a lubricating film in the pipeline advancement process and reduce the surface friction between the pipe and the soil.

The grouting material has specific lubricating properties, which can form a lubricating film in the process of pipeline advancement and reduce the surface friction between the pipeline and the soil body. In addition, grouting friction resistance requires choosing suitable grouting materials, controlling grouting pressure and speed, real-time monitoring, and choosing environmentally friendly grouting materials. Reasonable grouting friction control can effectively reduce the friction resistance between soil and pipe in pipe-jacking construction and improve construction efficiency.

2.2. Selection of Grouting Materials

Friction-reducing grouting technology is widely used in long-distance large-diameter mechanical pipe jacking projects. Common friction-reducing materials include bentonite, mud, and new synthetic polymer materials [4].

(1) In the design stage, the situation of the soil layer must be accurately understood.

Moreover, comprehensively understand the type distribution of the soil layer according to the relevant data curves.

(2) Calculate the required soil pressure to determine the pressure to inject the bentonite suspension.

(3) Determine the optimum mixing ratio of the bentonite suspension through detailed soil analysis and conduct periodic tests to ensure that it is adapted to changes in soil properties.

(4) Use accurate mixing ratios and production processes to ensure the prepared bentonite suspension meets standards.

(5) Ensure the bentonite suspension is continuously injected throughout the jacking line and all jacking stages. This is especially true for small soil particles requiring a relatively low bentonite content.

3. Inter-Relay Technology Index

When carrying out pipe jacking construction over longer distances, it is necessary to consider the reasonable setting of relay intervals. In order to cope with the situation, the construction distance should be shorter, which may lead to insufficient jacking force of the main jack. The relay room plays a vital role in this process by advancing the pipe in segments, transferring the jacking force, and spreading the main jacks' burden so that each segment of the pipe is maintained at an acceptable level. This operation ensures smooth construction and effectively solves the difficulty of insufficient jacking force of the main jack that may be faced in long-distance pipe jacking projects [5]. As shown in figure 2b.

3.1. Composition and Setup of Trunks

In tunnel construction, the relay booth is an essential component and consists of three core parts: the front housing, the hydraulic jacks, and the rear housing. The front housing is closely connected to the front receiver to form the first half of the relay booth. Precision machining ensures that no deformation occurs during use. The socket connection method makes the connection, and rubber sealing strips are used to prevent external water, soil, and slurry from flowing into the pipe. As a force transfer device between the relays, the hydraulic jack plays a vital role in transferring force and supporting the advancement of the pipe to ensure the stability of the whole advancement process. The rear housing is connected to the rear receiver to form the rear part of the relay interval. The connection is also socketed with a rubber seal to prevent external water, soil, and mud inflow. The outer diameter of the relay housing is the same as the pipe joints. It is designed to minimize soil disturbance, ground settlement, and forward resistance, thus increasing the stability and efficiency of tunneling. As shown in figure 3a.

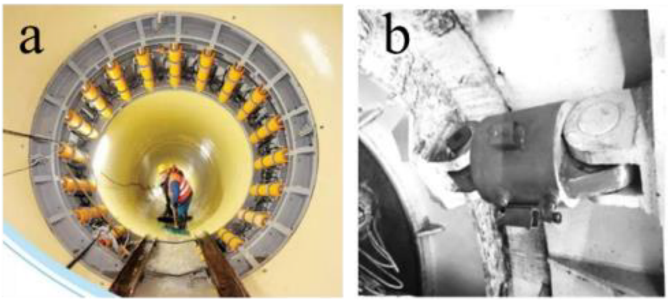

Figure 3. 3a shows the construction of the relay room, 3b shows the corrective cylinder of the pipe jacking machine.

In the actual pipe jacking project construction, due to the influence of construction quality, corrective control, changes in geological conditions, grouting and friction reduction, and other aspects, the theoretical value and the actual value may have a certain degree of error and even an utterly inconsistent situation may occur [6]. Therefore, the setting of the relay interval needs to consider various condition factors comprehensively. This includes the influence of construction quality, the need for corrective control, changes in geological conditions, and the influence of grouting and friction reduction. This comprehensive consideration helps optimize the engineering scheme and improve the overall efficiency of the project:

(1) The maximum allowable jacking force for jacking a concrete pipe shall not be less than the maximum jacking force provided between relays.

(2) When setting up relay intervals, sufficient margin must be allowed to control safety factors and to meet geological conditions. Based on empirical data, the design

position of relay intervals is usually set at 60% of the allowable jacking force provided by the relay intervals. In comparison, the design position of other relay intervals is determined according to 80% of the allowable jacking force the relay intervals provide.

3.2. Installation of inter-relay attachments

Repeaters between the ancillary equipment, including the hydraulic pumping station, and repeaters between the ring arrangement of cylinders, tubing, telescopic guide, and other elements.

(1) Selection of pumping stations and cylinders between relays:

In order to guarantee the high efficiency of the project, it is necessary to ensure that the operating efficiency of the pumping station is adapted to the pipe jacking machine and the central jacking pumping station. This requires moderate expansion and contraction speeds of the inter-relay cylinders to avoid possible delays in the project caused by the stagnation of the pipe jacking machine and the central roof pumping station.

(2) Telescopic guide device

During the jacking process, the front end of the inter-relay guide rail starts under the guidance of the front guide rail and gradually pulls the subsequent segmental guide rails. Each small section of the segmental guideway pushes the next section forward after stretching to 40mm. This unique segmental guideway mechanism realizes the flexible expansion and contraction of the inter-relay while ensuring the unimpeded and smooth passage of the rail battery car.

4. Attitude Control during Jacking

In long-distance large-diameter mechanical pipe jacking construction, ensuring that the pipe jacking machine can effectively control the initial attitude throughout the construction process is crucial. Therefore, detailed preparations must be carried out before the pipe jacking machine starts jacking.

4.1. Ejector Attitude Control

There are two main aspects of control:

(1) Adjusting the tunnel entry attitude of the jacking machine

In the process of the pipe jacking machine entering the tunnel, when the position of 2.3 meters (center of gravity) from the cutter plate is close to the end of the extension guide rail, the operator needs to cautiously and slowly extend the bottom two sets of deflection correction cylinders to ensure that the angle of the front inclinometer is kept below 1°. When the whole pipe jacking machine crosses the extension guide rail, the deflection correction cylinders are adjusted in time according to the measurement results to improve the accuracy and safety of the work and reduce the frequency of similar operations. This operation helps prevent the pipe jacking machine from becoming unstable while moving and reduces the likelihood of needing repeated adjustments during the project. Maintaining the machine's stability through timely adjustments ensures the accuracy and safety of the work. It should be noted that the throw height reserved in advance was about 34.9 mm to accommodate possible positional changes. The careful operation of this process guarantees smooth construction and control of the machine during excavation. (Reserve throw height: 2000 x sin1° = 34.9mm)

(2) Installation of the "header pipe."

Usually, the construction process is triggered when the pipe jacking machine reaches 75% of its length (approximately 3.9 meters). The overall jacking work is suspended at this point, stopping the jacking machine from advancing. Next, pre-fabricated "header pipe" was prepared, including welding six 32mm diameter steel bars to ensure compliance with the design requirements. The "header pipe" is then arranged at an angle of 60° to the pipe jacking machine and is usually screwed to the front end of the pipe jacking machine and the first two sections of the "header pipe." This connection aims to ensure that the "header pipe" and the pipe jacking machine are tightly integrated to strengthen the guiding role of the jacking and to effectively prevent the pipe jacking machine from drifting during the advancement process. Once the "header pipe" installation is completed, the overall jacking construction can be resumed to ensure that the pipe jacking machine is guided by the "header pipe" and pushed forward accurately per the designed axis. Through this "header pipe" installation operation, the jacking direction of the pipe jacking machine was successfully controlled to minimize the deviation and improve the accuracy of pipe jacking construction.

4.2. Correction of Pipe Jacking

In the process of jacking, if it is found that the front-end pipe section deviates from the initially designed axis direction or elevation, various methods must be taken quickly to adjust the attitude of the pipe section to ensure that it returns to the original design position. Then, the jacking can be continued. Returning the pipe section to the design position forcedly is called deflection correction. In order to ensure that the pipe section is jacked accurately according to the design direction, the key lies in timely measurement, detection of errors, making correct judgments, and adopting the necessary correction methods. Although the causes of deviation are complicated, there are some rules and operational steps to follow in the process of deviation correction, which help to effectively adjust the position and direction of the pipe section to maintain the accuracy and stability of the jacking process. 3b shows the corrective cylinder of the pipe jacking machine.

5. Conclusion

This paper provides a comprehensive synthesis in optimizing the soil-pressure-balanced pipe jacking construction process and, at the same time, thoroughly researches the grouting and friction-reducing construction control technology, the intermediate relay technology, the jacking attitude control technology, and the corrective control and management technology. Our research is essential in adapting to long-distance pipe jacking under complex geological conditions in urban pipeline construction. With the continuous emergence of various innovative technologies, new materials, and cutting-edge techniques, pipe-jacking construction control technology will usher in a brand new stage of development. This series of optimization measures aims to improve construction efficiency, reduce project risks, and lead the pipe-jacking construction field in a more advanced and sustainable direction. These innovative measures provide a feasible and sustainable path for future pipe jacking construction and contribute to more far-reaching creativity and progress in urban infrastructure construction.

Acknowledgments

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