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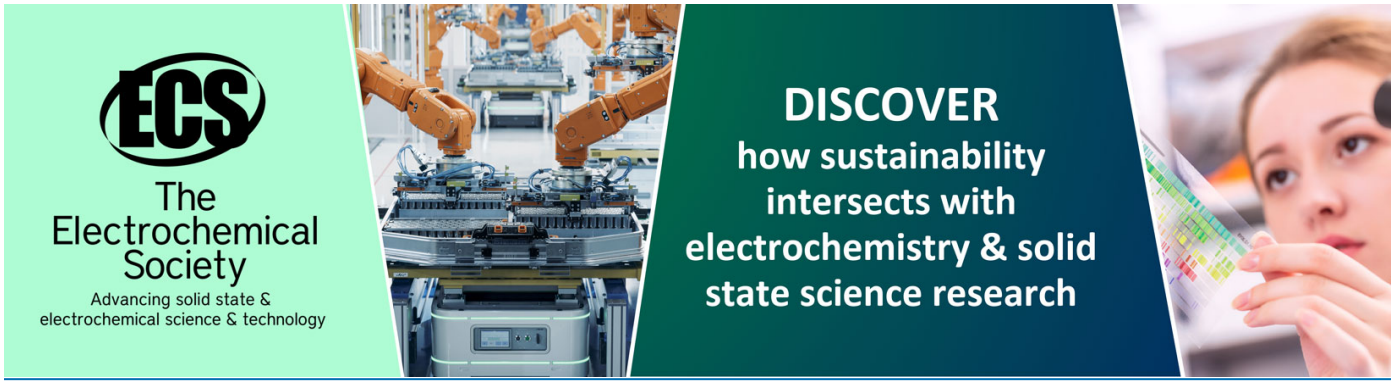

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Research on key technology of jacking cable tunnel construction in mudstone and gravel composite stratum

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Abstract. In this paper, the key technology of jacking cable tunnel construction in mudstone and gravel composite stratum is studied. According to the conditions of the jacking cable tunnel crossing the mudstone gravel composite stratum, the selection of the jacking method, the design of the relay and the construction technology of the mud jacket were analyzed. This has important practical significance for promoting the construction of ecological underground engineering and reducing the impact of underground crossing construction on the ground environment and underground environment. It also has great social and economic benefits.

1. Introduction

With the rapid development of the national economy, in order to solve the contradiction between power grid construction and land supply and demand, and meet the requirements of environmental landscape, high-voltage cable lines have been widely used in urban power grid construction. Commonly used laying methods for high-voltage cables include direct burial laying, protective pipe laying, cable trench laying, tunnel laying, and bridge laying and shaft laying under special engineering conditions. Among them, the tunnel laying method has the following advantages: (1) The number of cables to be accommodated is large, (2) the scalability is good, (3) the reliability is high, and (4) the operation and maintenance are convenient. With the vigorous development of the national grid, the construction of cable tunnels in special composite formations will become more and more common, and related engineering problems must be paid enough attention and attention.

According to the construction method, tunnels can be divided into open tunnels and undercut tunnels. Pipe jacking technology is one of the methods of underground excavation. Its development has been more than 100 years old. Compared with the open-buried pipelines constructed by open excavation and tunneling, the pipe jacking construction has the advantages of uninterrupted traffic and no danger to the foundation of the houses on both sides of the street. Therefore, the application of pipe jacking technology at home and abroad is increasing year by year.

Mudstone is a complex formation between soft soil and rock, belonging to soft rock. Soft rock is widely distributed in China, and its engineering properties are obviously different from hard rock and soft soil. Many scholars at home and abroad have carried out experimental research on local soft rock [1-5], and obtained the physical and mechanical properties of soft rock. Soft rock has obvious elastoplastic deformation characteristics, and as the strain increases, strain softening and dilatancy appear. Soft rock also has strong creep, which is an important cause of instability and deformation of surrounding rock [6]. However, the compactness of the round gravel is not uniform and the pebble is partially clamped. In this stratum, the implementation of the jacking pipe has high permeability coefficient, large top force, difficulty in axis control, and less redundancy of correction, and less

domestic related applications and research. The related technical problems need to be solved urgently. In the project, the pipe diameter is large, the pipeline is long, and the pipe cost is high. It is necessary to carry out research on key technologies of pipe jacking cable tunnel construction to bring better economic and social benefits.

It is becoming more and more common to construct cable tunnels in special composite formations. Many scholars have conducted research on related methods and techniques for the construction of a specific cable tunnel. In [7], the authors introduce the design and construction method of the 400kV cable system for the Severn Tunnel. In [8], Anchor spacing design of pre-stressed tunnel concrete lining with un-bonded annular anchors for Songhua River water supply project is studied. In [9], the soil pressure balance shield tunneling parameters of the water-rich gravel stratum and the gravel mudstone composite stratum are compared and analyzed, and the calculation method of the bucket soil pressure value range is discussed. In the literature [10], the author takes a certain gravel and mudstone composite stratum in Nanning as an example to study the construction technology of the mud tunnel shield of the subway tunnel under such stratum conditions. Although there have been many studies on the construction of cable tunnels in special composite strata, from the current research status analysis, there are few comprehensive studies on theoretical analysis, experimental techniques, design methods, construction techniques, etc. for the construction of composite strata such as mudstone gravel. There are many imperfections in theory and practice. The application of domestic engineering practice has just begun. With the current design and construction technology level, there is still a large technical difficulty in the underground crossing and micro-disturbing construction without stopping.

Therefore, in combination with the underground underground crossing project that is constantly emerging in the construction of underground cable tunnels in China, it is very necessary and urgent to study the construction technology of reasonable composite structures such as mudstone and gravel. The research results are to promote the construction of ecological underground engineering and reduce underground crossing. The impact of engineering construction on the ground environment and the underground environment has important practical significance, and it also has great social and economic benefits.

This paper focuses on the conditions of pipe jacking cable tunnel crossing mudstone gravel composite stratum, and analyzes the choice of pipe jacking method, the design of relay room and the construction technology of mud bushing.

2. Research on Design Method of Pipe Jacking Cable Tunnel

This section studies the design method of cable tunnels and lays the foundation for the subsequent construction techniques. The design of the cable tunnel includes the design of the main line, the design of the pipe joint, and the structural design of the tunnel.

2.1. Total line plane and profile design

The line inside the tunnel should be designed as a straight line. When a curve is required, the curve radius is generally not less than 400m. The maximum slope of the cable tunnel constructed by the pipe jacking method should not exceed 30‰. In the section of the cable tunnel located in the high drop section, the passage should not be stepped, and the longitudinal slope should not be greater than 15°. The minimum slope in the cable tunnel should not be less than 5‰. In the difficult area, under the condition of ensuring drainage, the slope of less than 5‰ can be used, but should not be less than 3‰. The buried depth of the cable tunnel structure should reduce the adverse impact on the environment during and after construction. Consider the effect of the surrounding environment on the structure caused by urban planning. The roof of the tunnel under the main road of the city should not be less than 3m, and the top cover soil under the urban secondary road should not be less than 2m. For special locations, the thickness of the covering soil should be adjusted accordingly according to the opinions of the planning department.

2.2. Tube design

The most important two points in the design of the pipe jacking section are the calculation of the load and top thrust of the vertical segment. For the theoretical analysis of the pipe jacking load model and its pipe jacking force calculation, please refer to the literature [11,12].

Through the analysis of the load bearing capacity of the vertical pipe jacking, the precautions for the calculation of the force of the jacking pipe and the selection principle of the pipe wall thickness are as follows:

(i) The calculation of earth pressure should adopt the principle of water and soil division, and the water and soil calculation should not be used. The main reason is that the effect of water pressure on the pipeline is uniform, and the vertical and horizontal effects of earth pressure are different, so the water and soil is not applicable. Calculated for such pipelines.

(ii) When calculating the strength of the steel pipe, if the expansion joint is provided, it is not necessary to consider the influence of the temperature difference on the longitudinal stress.

(iii) When calculating the steel pipe, if it is the working condition, the corrosion margin of the wall thickness should be deducted, generally 2mm, but when the construction stage is jacked, the allowance can be deducted.

2.3. Structural design of the tunnel

According to different functional requirements and construction methods, general cable tunnels are divided into two types: circular tunnels and rectangular tunnels. The circular tunnel section has a diameter of 3m. Mainly set up lamps, cables, drains and corresponding fire-fighting facilities, the cable tunnel channel is about 1m wide. In this paper, a circular tunnel is adopted for the jacking tunnel of the mudstone gravel composite stratum. The circular tunnel has strong adaptability to the stratum, and the construction of a tunnel with a large depth in the area with high groundwater level has high technical and economic superiority. However, when encountering soft and hard stratum, high-strength rock stratum, pebble layer, lone stone, knife-cutting mud cake, etc., it will affect the tunneling speed. Therefore, the selection of the shield machine and the configuration of the cutterhead are relatively high.

According to the previous engineering experience, considering the feasibility of construction and the cost of engineering measures, when the tunnel adopts a small diameter (3m~4m diameter) circular section, when the section length is greater than 1.2km, the shield method is more economical and the interval length is smaller than The jacking method is more economical at 1.2km.

3. Research on Key Technology of Pipe Jacking Construction

In order to adapt to the complex geological environment, it is necessary to study a set of efficient and reliable cable tunnel construction methods. This section is mainly for the conditions of the jacking cable tunnel crossing the mudstone gravel composite stratum, and the selection of the jacking method, the design of the relay and the construction technology of the mud jacket are analyzed. The key technologies for the construction of jacking cable tunnels under the combined geological conditions of mudstone and gravel are given below.

3.1. Selection of pipe jacking method

According to the different methods of unearthing, the pipe jacking construction methods are mainly divided into two categories: muddy water balance pipe jacking method and earth pressure balance pipe jacking method. The muddy water balance pipe jacking machine and the earth pressure balance pipe jacking machine have different applicable conditions respectively. If the pipe jacking construction method and the pipe jacking machine suitable for the site conditions are not selected, it will not only be difficult to jack up, but also cause the jacking of the pipe piece to be damaged.

At the same time, the cutterhead setting is also a very important aspect. The choice of the cutter head should not only consider the compressive strength of the rock formation, but also the rock quality and composition of the rock formation. In general, the choice of commonly used cutter heads is divided into the following cases: 1) soft rock selection cutters with a compression strength of 20MN/m^2 or less, 2) soft rock or medium hard rock selection hobs with a compression strength

exceeding 20MN/m^2, 3) A complex type of cutterhead is selected for complex rock formations containing the above two rock formations.

For the mudstone and gravel composite stratum, the stratum strength is relatively large, and the gravel is from fine gravel with a diameter of 2mm to coarse gravel, and even contains boulders with a particle size of 30cm or more. Therefore, it is suitable to select a soil pressure balance pipe jacking machine with a large opening. Figure 1 below is a schematic diagram of the earth pressure balance top pipe method. The earth sand cut by the cutter head is filled in the soil bin at the front end of the tunnel, and has a certain fluidity, which balances the water and earth pressure at the front end of the top pipe, and discharges the spoil through the earthmoving machine connected thereto. The earth pressure type can effectively control the cost because it does not require mud water treatment equipment.

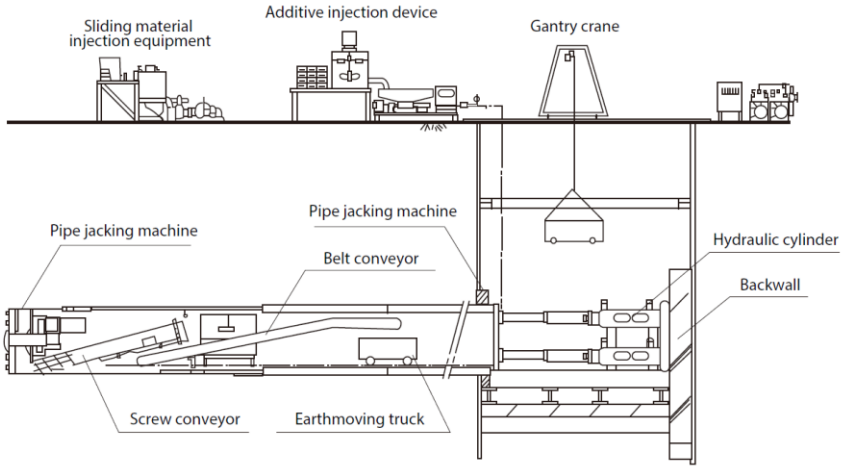

Figure 1. Earth pressure balance top pipe method.

3.2. Design of cutter opening rate

The cutterhead opening rate is an important parameter to characterize the geological adaptability of the shield machine. The cutterhead opening rate has a significant influence on the silo pressure and the cutterhead torque. If the opening position is not set properly, the bauxite cannot enter the earthen space, which will accelerate the wear of the cutter tool. The shield machine tool is installed on the shield machine cutter disc. The cutter disc form can be divided into panel type and spoke type according to engineering geological conditions and construction control requirements. Generally, the panel type cutterhead has an opening rate of about 30%. The spoke type cutterhead has a large opening rate of about 60% to 95%.

The reasonable opening rate of the cutterhead is closely related to the geological conditions of the passage of the tunnel. The sensitivity of the different strata to the cutter disc structure is quite different. The clay and fine sand stratum have low sensitivity to the cutter disc structure, and almost all kinds of cutterheads can be used. The structural form, while the gravel-pebble formation is highly sensitive to the structure of the cutterhead, and the poor design of the cutterhead structure will have a serious impact on the excavation and even cause engineering accidents. Table 1 summarizes the cutterhead opening rate and geological comparison of the construction of the nose at home and abroad.

Considering the fact that the actual project is in the composite stratum of gravel and mudstone, and referring to the existing engineering cases at home and abroad, the spoke-type cutterhead with moderate opening ratio is adopted, and the cutterhead is used as an auxiliary measure for the stability of the excavation face. The cutterhead opening rate is set in the range of 25%~35%.

Table 1. Comparison of cutterhead opening rate and geological conditions.

Soil layer	Geological condition	Opening rate(%)
Flood rock	Clay soil	25~30
	Sandy soil	15~20
	Gravel soil	20~25
	Soft and hard interlayer	30~35
Impact rock	Clay soil	20~25
	Sandy soil	10~15
	Gravel soil	15~20
	Soft and hard interlayer	20~25

3.3. Design of relay

For the special formation of mudstone gravel, special processing is used for the relay between the steel relay rooms. The relay top adopts a two-segment and one-shoulder retractable sleeve socket structure, and the deflection angle α=20^o . The end structure is the same as the selected pipe joint, and the outer shape is basically the same as the pipe joint. Two sealing devices for radially adjusting the sealing gap are arranged at the hinge to ensure no leakage when jacking, and a nozzle capable of injecting lithium grease No.1 at the socket is provided to reduce the sealing ring when jacking abrasion. Four grouting holes are provided at the hinge of the relay top, and simultaneous grouting can be performed when jacking, reducing the jacking resistance.

In normal jacking, only the first seal is used and the second is used as a reserve. When the first seal ring is worn, it is found that there is a slurry leakage point, and the radial adjustment device can be used to adjust the seal gap so that the slurry leakage phenomenon can be stopped in time. When the first seal fails, the second seal can be activated to ensure continuous advancement. Due to the long penetration distance, the sealing ring wears quite badly. To prevent the first sealing device, the first sealing device is designed to be detachable, and it is easy to replace the sealing ring, thus achieving foolproof. The schematic diagram (unit: mm) of the relay is shown in the figure 2.

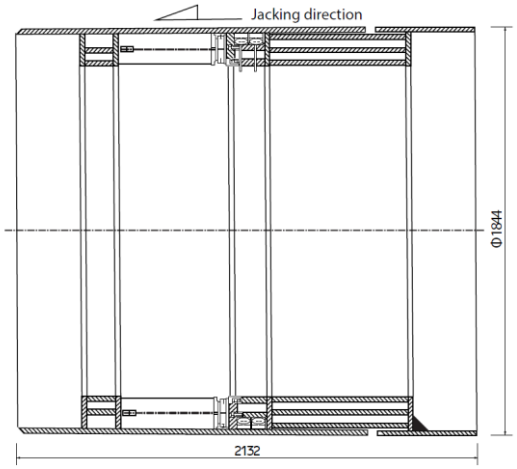

Figure 2. Relay diagram with double-layer inflatable seal expansion ring structure.

According to the "Technical Regulations for Water Supply and Drainage Pipe Jacking Engineering CECS246:2008" and the literature [13,14] for the number of calculation formula for relays:

$$n = \frac{\pi D f_k (L+50)}{0.7 f_0} - 1,$$

where D indicates the outer diameter of the pipe (m); L indicates the jacking length (m); f_k indicates the average frictional resistance between the outer wall of the pipe and the soil (KN/m^2); f_0 indicates the allowing force between relays (KN).

3.4. Design of grouting system

The earthwork cut by the pipe jacking machine is conveyed into the dumping tank through the screw machine. After being stirred, it is transported to the ground sedimenting tank through the conveying pipeline by muddy water. The muddy water is discharged after sedimentation, and the clean water is transported to the dumping tank through the returning pipeline for reuse. The principle of jacking system is shown in the figure 3.

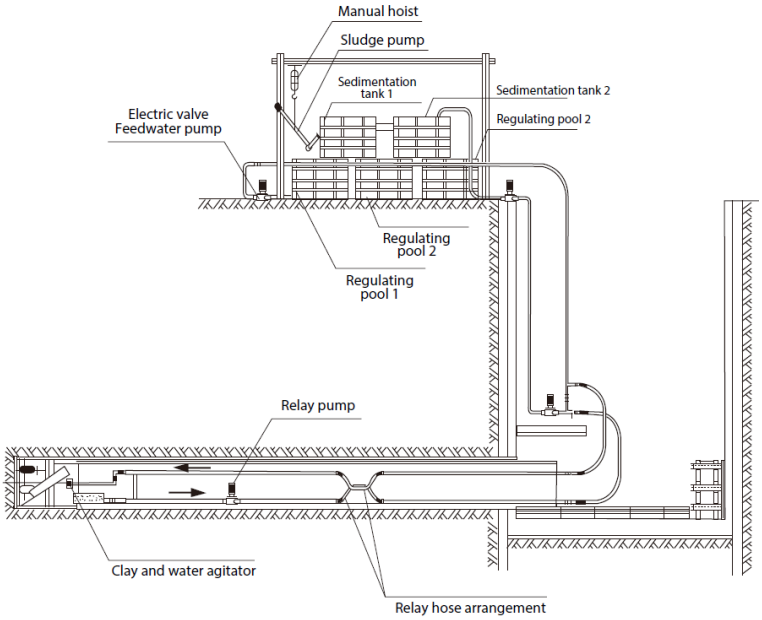

Figure 3. Schematic diagram of the jacking system.

In jacking construction, the use of drag reduction mud is the main measure to reduce the jacking resistance. When jacking, through the grouting hole on the pipe joint, a quantitative drag reduction mud is injected into the outer wall of the pipe to form a mud ring around the pipe. Reduce the friction between the outer wall of the pipe joint and the soil layer, thereby reducing the top force when jacking. The effect of thixotropic mud drag reduction is related to the quality of the mud itself (the amount of mud blending and the thickness of the mud jacket), as well as the grouting pressure, grouting procedure, grouting amount, and placement of grouting holes.

To determine the grouting pressure, you must first know the water and earth pressure at the top of the pipe, that is, the water pressure at the top of the mud jacket:

$$P_A = \gamma_w H_1 + \gamma H \tan^2(45^\circ - \frac{\phi}{2}) \cdot$$

When there is an unloading arch,

$$P_A = \gamma_w H_1 + \gamma h_0 ,$$

where

$$h_0 = \frac{D[1+\tan(45^\circ - \frac{\phi}{2})]}{2\tan\phi} .$$

In the above equations, P_A indicates the water pressure and main power (kPa) at the top of the mud jacket; γ_w indicates the gravity density of water (kN/m^3); H_1 indicates the height of the water column above the earth surface or the unloading arch; H indicates that the top of the pipe covers the soil height; h_0 indicates the height of the unloading arch; D indicates the outer diameter of the pipe; γ indicates the gravity of the soil; ϕ indicates the internal friction angle of the soil.

If the pressure of the mud sleeve $P < P_A$, the soil will collapse to the mud, so it is required that $P \geq P_A$. But it can't be too big, too much mud loss is increased. In case of thin cover layer, it is also possible to arch the soil surface, and at the same time, the mud sleeve is enlarged, and the amount of pulp is greatly increased. Therefore, the grouting pressure P is required to remain in the following ranges:

$$P_A \leq P \leq P_A + 30(kPa).$$

4. Conclusions

In this paper, we studied the key technology of jacking cable tunnel construction in mudstone and gravel composite stratum. The following aspects were analyzed for the conditions of the pipe jacking cable tunnel crossing the mudstone gravel composite stratum.

(1) Selection of pipe jacking method. For mudstone gravel composite stratum, the stratum strength is relatively large. It is suitable for selecting earth pressure balance pipe jacking machine with large opening.

(2) Design of the inter-relay. For the special formation of mudstone gravel, the special processing of the relay room uses steel relay room. The relay top adopts a two-stage one-hinge retractable sleeve socket structure. Two sealing devices for radially adjusting the sealing gap are arranged at the hinge to ensure no leakage when jacking, and a nozzle capable of injecting lithium grease No. 1 at the socket is provided to reduce the sealing ring when jacking abrasion. Four grouting holes are provided at the hinge of the relay top, and simultaneous grouting can be performed when jacking, reducing the jacking resistance.

(3) Design of the grouting process. When the jacking is passed through the grouting hole on the pipe joint, a quantitative drag reducing mud is injected into the outer wall of the pipe, and a mud ring sleeve is formed on the outer periphery of the pipe to reduce the gap between the outer wall of the pipe joint and the soil layer. Friction, thereby reducing the top force when jacking. The grouting pressure is required to remain in the following ranges: $P_A \leq P \leq P_A + 30(kPa)$.

Acknowledgments

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