Research and analysis of directional drilling technology for long-distance pipeline crossings

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ABSTRACT

This study focuses on the directional drilling technology for long-distance pipeline crossings. Taking a certain long-distance pipeline directional drilling crossing project in China as an example, the construction process of directional drilling crossing is analyzed. Based on this, the key points of directional drilling technology for long-distance pipelines are summarized. Finally, reasonable solutions are proposed for the deviation problem of directional drilling during the crossing process. This lays the foundation for further development in the field of directional drilling for long-distance pipeline crossings. The research indicates that the long-distance pipeline directional drilling crossing project can be divided into three stages: pre-construction preparation, directional drilling operation, and subsequent finishing. Prefabrication technology, pipeline welding, and mud treatment are among the key points of directional drilling crossing. In order to prevent the deviation of directional drilling, various effective measures need to be taken, such as ensuring that the drilling rig is positioned to coincide with the centerline of the designed pipeline, using artificial magnetic fields, and strengthening quality control from multiple perspectives. This ensures the high-quality completion of long-distance pipeline directional drilling crossing operations.

Keywords: Long-distance pipeline, directional drilling crossing, construction process, technical points, deviation of directional drilling

1. INTRODUCTION

With the continuous growth of global energy demand and the deepening of energy resource development, long-distance pipelines play a pivotal role as important channels for energy transportation in the energy supply chain. However, many long-distance pipeline projects face challenges such as complex geology and varied terrain. These projects require the pipeline to be laid through special terrain such as mountains and rivers[1]. In such cases, directional drilling technology has become an important construction method. Compared to traditional surface excavation, directional drilling technology can reduce construction cycles, save manpower and material resources, and improve construction efficiency. Directional drilling technology can minimize surface damage and land occupation, thereby reducing environmental impact and meeting the requirements of sustainable development[2]. Despite the gradual maturity of directional drilling technology, various problems may still arise during directional drilling operations due to factors such as terrain and personnel. This study takes a certain long-distance pipeline project in China as an example to research the key points, problems, and solutions during its directional drilling crossing process, aiming to ensure high-quality directional drilling operations.

2. LONG-DISTANCE PIPELINE DIRECTIONAL DRILLING CROSSING CONSTRUCTION PROCESS

2.1 Project overview

The directional drilling crossing project studied in this research is located in the north-eastern region of China. The entry angle of the directional drilling crossing river is 10 °, while the exit angle is 7 °. The crossing is conducted in a curved manner, with a curvature radius reaching 1500 times the outer diameter of the pipeline. The pipeline used has a size of φ611 mm×11.1 mm. The length of the crossing through the river is 1280 m. The construction process during the crossing

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is illustrated in Table 1.

Table 1. Directional drilling crossing construction process.

Drilling rig construction process	Pipeline construction process
Surveying and Staking	
Site preparation	
Installation of three-way valve and flattening	
Equipment mobilization	
Assembling equipment	Transport and layout of pipes
System debugging	Joint pipe pairing
Drilling pilot hole	Excavating access trench
Pre-reaming Hole	Pipe Pullback
Pipe pullback	Equipment demobilization
Equipment demobilization	Restoring terrain
Restoring terrain	

2.2 Pre-construction preparation stage

During the pre-construction preparation stage, activities primarily include surveying and staking, site leveling, on-site equipment assembly, mud preparation, and drill rig trial drilling. These tasks aim to provide necessary site and material conditions for subsequent construction operations.

(1) Surveying and staking

According to design requirements and terrain conditions, we determine the starting and ending points of the drilling crossing, as well as the path and depth of the borehole. A surveying plan based on the drilling requirements and on-site conditions is developed. The measurement methods and select appropriate instruments and equipment are determined. We conduct on-site surveys along the designated drilling path, including using surveying instruments to measure and record ground terrain and underground pipelines. We set markers at key locations such as the starting point, ending point, and turning points of the drilling path to indicate the position and direction of the borehole[3]. Surveying instruments such as transits and rangefinders are utilized to accurately stake out the drilling positions and directions. Necessary adjustments and corrections are made based on survey results to ensure alignment with design requirements.

(2) Site leveling

During the site leveling process, excavation is conducted for mud pits and drill rig anchors. In this project, the dimensions of the mud pits and anchor pits are as shown in Figure 1. Sufficient slope should be left during excavation of anchor pits and mud pits.

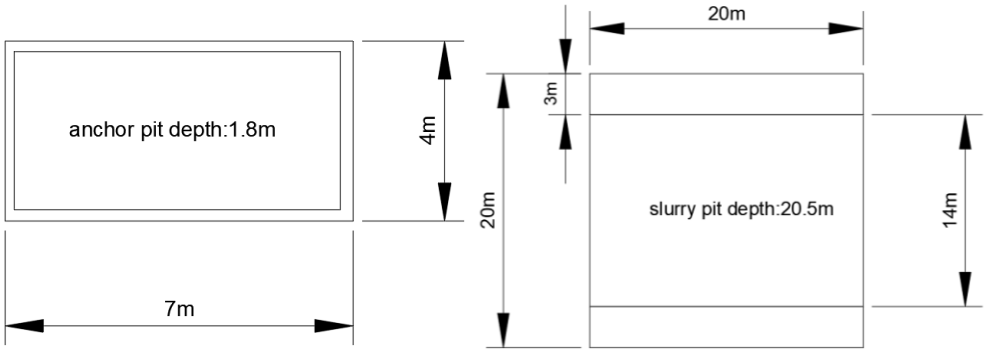

Figure 1. Dimensions of mud pits and anchor pits.

After the excavation of the anchor pit is completed, the anchor box needs to be placed into the anchor pit. Concrete is poured between the anchor box and the anchor pit. Once the concrete has fully cured, the drill rig is anchored to the anchor box. The structure of the drill rig anchor in this project is as shown in Figure 2.

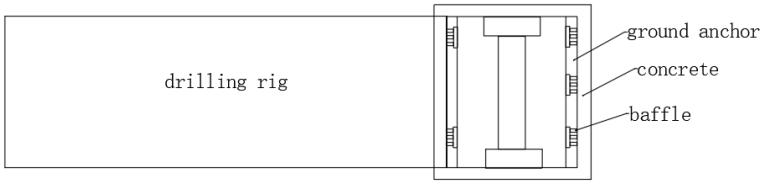

Figure 2. Structure diagram of drill rig anchor.

After anchoring the drill rig, it is necessary to arrange the entry and exit points of the site reasonably. The layout of the entry point and exit point for this project is shown in Figures 3 and 4, respectively.

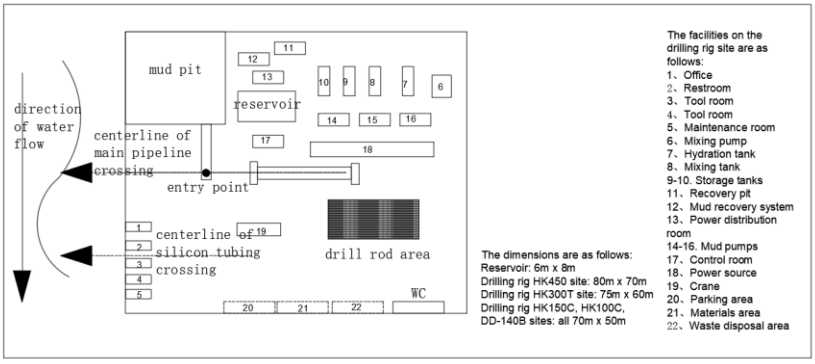

Figure 3. Layout diagram of entry point site.

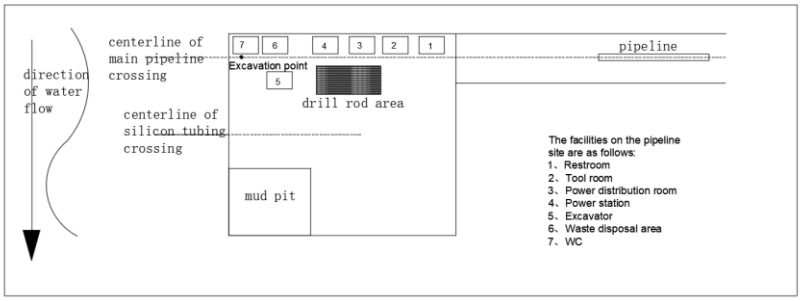

Figure 4. Layout diagram of entry and exit point site.

(3) Assembling Equipment

After arranging the site properly and cleaning the construction foundation to ensure it is flat and sturdy, providing a solid foundation for the installation of the drill rig. Following the assembly instructions and construction drawings of the drill rig, assemble the drill rig, including installing drill bits, drill columns, hydraulic systems, control systems, and other components. Weconnect supporting pipelines such as water inlet and drainage pipes according to construction needs to ensure the water source and drainage required for the drill rig's normal operation.

(4) System Debugging

We determine the starting point, ending point, and path of the borehole according to design requirements and terrain conditions. We select a certain number of control points along the drilling path for measurement and control of the borehole direction. The materials and equipment required for the coils are prepared, including wires, insulation materials, brackets, etc., according to measurement requirements. Suitable positions and directions are selected for laying coils based on the drilling path and control point locations to ensure effective measurement and control. The laid coils are checked to ensure their connection and fixing are in good condition without any looseness or breakage[4]. We debug and test the measurement instruments to ensure their normal operation and accurate measurement. Conditions for real-time monitoring and control of the borehole direction are prepared.

(5) Mud preparation

We determine a suitable mud formula based on geological conditions, drilling purposes, pipeline requirements, and other factors. Mud formulas typically include base liquids, suspending agents, thickeners, pH regulators, etc. The required raw materials and chemicals are prepared according to the mud formula to ensure the quality of raw materials meets the requirements and ensure the stability and effectiveness of the mud during construction. We add various raw materials to the mixing tank according to the formula ratio and mix the mud thoroughly using mixing equipment to ensure uniform distribution of all components and achieve the required concentration and performance requirements.

(6) Drill rig trial drilling

The borehole position and direction and select appropriate trial drilling points are comfired according to design requirements and geological conditions.We inspect and prepare the drilling tools, drill bits, mud, auxiliary equipment, etc., required for trial drilling. The required drilling tools on the drill rig are installed, including drill bits, drill columns, drill rods, etc., ensuring a firm connection to prevent breakage or detachment during trial drilling. Drilling parameters are adjusted according to geological conditions and design requirements, including rotation speed, feed speed, mud flow rate, mud density, etc., to ensure smooth trial drilling and protection of the stratum. We start the drill rig and begin trial drilling, gradually adjusting drilling parameters according to design requirements and geological conditions to ensure smooth trial drilling[5]. We monitor the operation status of the drill rig and the progress of drilling in real-time, promptly identifying and resolving any potential problems.

2.3 Directional drilling operations stage

(1) Drilling pilot hole

Adjust drilling parameters, including rotation speed, feed rate, mud density, etc., according to the directional objectives and geological conditions to ensure the stability and accuracy of the borehole. Start the drill rig and begin drilling the pilot hole, gradually adjusting the angle and position of the directional tools according to design requirements to control the direction and deviation of the borehole. Use directional tools such as inclinometers to monitor the direction and angle of the borehole in real-time, making timely adjustments to the position and angle of the directional tools to ensure that the borehole conforms to the design requirements.

(2) Hole enlargement and hole cleaning

Hole enlargement or hole cleaning tools are installed onto the drill column, selecting appropriate tools according to design requirements and ensuring secure installation. We start the drill rig and begin hole enlargement operations, gradually increasing the diameter of the borehole according to design requirements. The parameters of the hole enlargement tools are adjusted according to geological conditions and actual situations to ensure smooth hole enlargement. During the hole enlargement process, we use hole cleaning tools to clean the bottom of the hole, removing impurities such as rock debris and residual mud to keep the hole bottom clean. Hole cleaning also helps reduce drill bit wear and drilling resistance, improving drilling efficiency. The steps for hole enlargement and hole cleaning in this project are as follows: 24'' barrel

reamer-30’’ barrel reamer-36’’ barrel reamer-36’’ barrel reamer for hole cleaning.

(3) Pipe pullback

A pullback head or pullback device is installed onto the pipeline or steel pipe to be pulled back, typically installed at the rear end of the pipeline for connection to the pulling device. A tractor, pulling ropes, or other pulling devices is used to connect the pulling device to the pipeline or steel pipe to be pulled back, ensuring a secure connection capable of withstanding the pulling force and stress during the pullback process[6]. We start the pulling device and begin pipe pullback operations, gradually pulling the pipeline or steel pipe along the borehole to the target position, controlling the pulling speed and force to avoid damage or deformation to the pipeline or steel pipe. The drilling tools used for fiber optic cable pullback in this project are: 100T pullback universal joint+5-1/2" drill rod+silicon core steel pipe casing. The main pipeline pullback uses the following drilling tools: 36’’ barrel reamer+250T pullback universal joint+5-1/2’’ drill rod + crossing main pipeline.

(4) Pipe cleaning and diameter measurement

Pipe cleaning tools are used to remove impurities such as mud, rock debris, and gravel from the borehole, ensuring unobstructed drilling. Pipe cleaning work typically involves high-pressure water flushing, rotary brushing, etc., to thoroughly remove impurities from inside the pipeline. After pipe cleaning, diameter measurement tools are used to measure the diameter of the pipeline accurately. Diameter measurement operations usually use laser rangefinders, diameter measurement pipes, etc., to accurately measure the diameter of the pipeline. Data is recorded such as pipe cleaning conditions and diameter measurement results during the cleaning and diameter measurement process to ensure accurate and complete data recording, serving as a reference for subsequent pipeline laying and construction.

2.4 Final closure stage

The equipment, machinery, and tools used for drilling operations are evacuated from the construction site. Cranes, trailers, or other transportation tools are used to transport the equipment away from the construction site, ensuring safety during transportation. The construction site is cleaned, including removing debris, waste, and residues from the site. Temporary facilities, fences, and signs around the construction site are dismantled and cleaned[7]. The surface of the construction site is repaired and restored by filling and leveling the soil to its original condition. Grass, trees, and other vegetation are planted to restore the original landscape. Soil protection and fixation measures are strengthened to prevent soil erosion and loss of soil and water.

3. KEY POINTS ANALYSIS OF DIRECTIONAL DRILLING FOR LONG-DISTANCE PIPELINES

3.1 Prefabrication technology

Outside the construction site, prefabricate the pipeline, including determining the length, diameter, and material of the pipeline, and manufacturing and assembling the pipeline in a factory or other location. The length of the prefabricated pipeline is usually customized according to actual needs to fit specific drilling projects. Appropriate joint systems are designed to facilitate easy connection of prefabricated pipelines during drilling. These joints should be quickly installable and removable while ensuring the sealing and structural integrity of the pipeline. Suitable transportation plans are arranged to transport prefabricated pipelines to the drilling construction site, considering the dimensions, weight, and transportation routes of the pipelines to ensure a safe and efficient transportation process[8]. On the drilling construction site, prefabricated pipelines segment by segment is installed into the borehole, requiring precise operation and docking to ensure smooth installation and proper positioning and orientation of prefabricated pipelines. After the installation of prefabricated pipelines, we carry out the connection work between the pipelines, including the joint systems between pipeline sections, to ensure firm and sealed connections. After completing the installation and connection of prefabricated pipelines, we conduct testing and acceptance of the pipelines, including checking and testing the sealing, strength, and stability of the pipelines to ensure compliance with design and construction requirements.

3.2 Pipeline welding and mud treatment

In directional drilling for long-distance pipelines, pipeline welding and mud treatment are crucial. For pipeline welding, high-quality welding materials and equipment are needed to ensure the quality and strength of welded joints. Appropriate welding processes are adopted, including gas shielded welding, arc welding, etc., to ensure stable and reliable welding processes. We strict quality control and testing of welded joints, including weld seam inspection, ultrasonic testing, etc.,

to ensure welding quality meets standards and requirements. For mud treatment, we select suitable mud formulas and adjust mud parameters such as density and viscosity according to geological conditions and pipeline requirements. Efficient mud treatment equipment is used, including agitators, centrifuges, filters, etc., to ensure mud stability and cleanliness. We regularly monitor and adjust the mud, promptly handling impurities and pollutants in the mud to maintain its performance and effectiveness. Measures are taken to reduce pollutant emissions during mud treatment, including recycling mud and treating wastewater, to protect the construction site and surrounding environment and prevent mud from polluting soil and water sources, reducing environmental impact.

4. ANALYSIS OF COUNTERMEASURES FOR MITIGATING DEVIATION DURING DIRECTIONAL DRILLING OF LONG-DISTANCE PIPELINE GUIDING HOLES

Ensuring the alignment of the drill rig position with the centerline of the designed pipeline, using artificial magnetic fields, and enhancing quality control are crucial measures to prevent deviation during directional drilling of guiding holes.

Firstly, before drilling, precise measurement and positioning are conducted to determine the position and orientation of the drill rig. Advanced measurement devices such as total stations, GPS, etc., are utilized to ensure the accuracy of measurement results. High-precision positioning systems like inertial navigation systems, differential GPS, etc., are employed for real-time monitoring and adjustment of the drill rig's position and orientation to ensure alignment with the centerline of the designed pipeline. Real-time positioning and correction technologies are utilized to monitor and adjust the position and orientation of the drill rig in real-time, comparing it with the centerline of the designed pipeline to promptly detect and correct deviations, ensuring alignment with design requirements.

Secondly, directional tools equipped with magnetic field sensors such as magnetic compasses, magnetic ranging systems, etc., are utilized to detect the direction and intensity of magnetic fields and guide the direction of the drill bit. Based on magnetic field information, the drilling direction is adjusted promptly to align with the centerline of the designed pipeline. Pre-measured and established magnetic field models are used to calibrate and correct actual magnetic field data. Adjustments are made based on corrected magnetic field data to ensure alignment with the centerline of the designed pipeline. Advanced magnetic field guidance algorithms calculate the direction and angle adjustments of the drill bit based on real-time measured magnetic field data, aligning it with the centerline of the designed pipeline under the influence of the magnetic field.

Finally, an integrated quality monitoring system is established to monitor the position, direction, and deviation of guiding holes in real-time using sensors and monitoring equipment. Deviations are promptly detected, and strict quality inspection standards and requirements are formulated, clarifying acceptable deviation ranges and corrective measures. Corresponding inspection plans and indicators are developed based on design requirements to ensure drilling quality meets specifications. Professional technical guidance and training are provided to cultivate operators' awareness and sensitivity to drilling quality, enhancing their understanding and skill level in drilling quality control through strengthened training efforts.

4. CONCLUSION

Directional drilling, as a mature and advanced technology, is essential for long-distance pipelines traversing complex terrain. However, various types of issues may arise during directional drilling operations. Therefore, comprehensive control of its technical aspects is necessary. Multiple measures should be implemented to prevent deviation of guiding holes, ensuring the quality of directional drilling operations. Through meticulous attention to technical details and the implementation of appropriate measures, the successful execution of directional drilling operations can be assured, thereby facilitating the seamless installation of pipelines through challenging terrain.

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