

Research on Drilling Technology Methods and Application Effects in Geological Engineering Exploration

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Abstract

Drilling technology is one of the core means of geological engineering exploration. This article systematically reviews the commonly used technical methods in geological engineering exploration, such as rotary drilling, impulse drilling, vibratory drilling, hydraulic rotary drilling, and pneumatic drilling. It focuses on analyzing the principles, characteristics, applicable conditions, and existing problems of each type of drilling technology. On this basis, the application status of drilling technology in geotechnical engineering investigation, hydrogeological investigation, mineral resource exploration and other fields was further explored. The exploration accuracy and quality, efficiency and cost, environmental impact, etc. of drilling technology were systematically evaluated, and corresponding optimization countermeasures and suggestions were put forward, with the aim of providing references for improving the level of drilling technology and better serving the practice of geological engineering exploration.

Keywords

Geological Engineering Exploration; Drilling Technique; Application Effect; Optimizing Strategy.

1. Introduction

Drilling, as a technical means of conducting geological surveys and sampling from the surface to the underground, plays an indispensable role in the field of geological engineering exploration. The scientific and reasonable selection and application of drilling techniques are of great significance for clarifying geological conditions such as lithology, structure and permeability of strata, evaluating the properties of geotechnical engineering, and conducting mineral resource exploration. In recent years, the scale of geological engineering construction in our country has been continuously expanding, which has put forward higher requirements for the quality and efficiency of geological engineering exploration. Drilling technology, as the "main force" of geological engineering exploration, its technical level and application effect to a large extent restrict the development of geological engineering exploration. Therefore, systematically summarizing and analyzing the current application status and existing problems of drilling technology in geological engineering exploration, and exploring the optimization countermeasures of drilling technology, is of great theoretical and practical significance for enhancing the capacity and level of geological engineering exploration.

2. Commonly Used Drilling Techniques and Methods In Geological Engineering Exploration

2.1. Rotary Drilling Technology

Rotary drilling technology is one of the most widely used methods in geological engineering exploration. This technology mainly utilizes rotary drilling RIGS. Through drill bits made of high-hardness materials such as diamond or cone bits, rock layers are cut and broken under the action of drilling pressure and torque, and continuous drilling is carried out to obtain continuous cylindrical core samples, directly revealing information such as stratum lithology, geological structure, and groundwater [1]. Generally speaking, the drilling depth of rotary drilling can reach several hundred to several thousand meters, and the core recovery rate can exceed 90%. Compared with other drilling methods, rotary drilling has a wider range of applications. It can not only drill hard and dense rock layers but also effectively extract loose and broken sedimentary layers. However, the drilling speed of rotary drilling is relatively slow, generally ranging from 20 to 30 meters per day, and the construction efficiency is not high. Moreover, the borehole is prone to collapse, especially when encountering loose strata such as sand layers and pebble layers. The stability of the borehole wall is poor, which can easily lead to accidents such as stuck drill and buried drill, affecting the construction progress and cost. Meanwhile, rotary drilling has high requirements for the performance of drilling rig equipment and drill bits, and the drilling cost is large, generally ranging from 2,000 to 5,000 yuan per meter, which is much higher than other drilling methods.

2.2. Impact Drilling Technology

Impact drilling technology is a drilling method that uses pneumatic or hydraulic hammering devices to break rocks and expel cuttings by the high-frequency and short-stroke impact of the drill bit on the stratum. Compared with rotary drilling, the drilling speed of impact drilling can reach 50 to 100 meters per day, which is 2 to 3 times that of rotary drilling. It is particularly suitable for hard-to-drill strata such as hard rock layers and pebble layers. The commonly used impact drilling equipment at present includes DTH(down-the-hole) impact drilling RIGS and top hammer impact drilling RIGS. Their unit energy consumption can reach 2-3kW·h/m, which is much lower than that of rotary drilling [2]. However, during the process of impact drilling, high-frequency hammering can easily cause the collapse of the borehole wall and diameter reduction, resulting in a 20% to 30% decrease in the borehole diameter and affecting the quality of well completion. Moreover, the core samples obtained by impact drilling are mostly fragmented and have poor integrity. The core recovery rate is generally only 50% to 70%, which is much lower than that of rotary drilling. Meanwhile, impact drilling generates noise levels as high as 110-130dB and vibrations of 5-20 m/s², posing a threat to the health of construction workers and the safety of surrounding buildings and structures. In addition, the gas consumption of impact drilling equipment is large, generally ranging from 15 to 30 cubic meters per minute, which is more than ten times that of rotary drilling, resulting in significant energy costs. Moreover, the drill bit is prone to wear and has a short service life, generally only 30 to 50 hours, which is much lower than that of rotary drilling. This significantly increases the construction cost and restricts its promotion and application.

2.3. Vibration Drilling Technology

Vibration drilling technology is a drilling method that uses high-frequency vibration devices to achieve rapid cutting of rock layers by the high-speed reciprocating motion of the drill bit combined with rotary motion. The drilling speed of this technology can reach 80 to 120 meters per day, which is 3 to 4 times that of conventional rotary drilling. Meanwhile, the vibration frequency can reach 2,000 to 3,000 times per minute, with an amplitude of 10 to 20mm. Under the high-frequency striking effect between the drill bit and the rock layer, the collapse of the

borehole wall is effectively suppressed, and the change in the borehole diameter is less than 5%, resulting in high hole quality. Moreover, the cuttings produced by vibration drilling have a small particle size, which is conducive to the timely discharge of cuttings, and the core recovery rate can reach over 90%. However, the commonly used vibrating drilling equipment currently has a drilling rig weight of 30 to 40 tons and a price as high as 5 to 8 million yuan, which is 2 to 3 times that of conventional rotary drilling RIGS. Moreover, due to the complex structure of key components such as electromagnetic vibration and hydraulic vibration systems, the maintenance cost is three to five times that of conventional drilling RIGS. Meanwhile, high-frequency vibration is prone to cause fatigue fracture of drill pipes and loosening of joints, resulting in an average service life of the drill tools being less than 500 hours. Moreover, once the vibration direction is not properly controlled, the borehole is prone to deviation, especially in complex strata such as inclined and folded ones, where the deviation slope of the borehole can exceed 5%, seriously affecting the drilling quality. In addition, vibration drilling equipment generates vibration noise as high as 100-120dB. Although the vibration frequency is high, the wavelength is short, and it decays rapidly, it still has a significant impact on the health of workers working at close range.

2.4. Hydraulic Rotary Drilling Technology

Hydraulic rotary drilling technology is a technique that uses high-pressure water as power, utilizes the erosion effect of high-speed water jets, and combines the edge rotation cutting of drill bits made of high-hardness materials such as diamond to rapidly drill into strata. The drilling speed of this technology can reach 50 to 100 meters per hour, which is 10 to 20 times that of conventional rotary drilling. Moreover, the diameter of the boreholes formed by hydraulic rotary drilling is large, generally ranging from 76 to 325mm, with an average of 220mm, which is 2 to 3 times that of rotary drilling. Meanwhile, under the combined effect of high-pressure water jet and drill bit, the integrity of the core is high, and the recovery rate can reach over 95%. However, hydraulic rotary drilling has high requirements for the performance of the drilling rig and needs to be equipped with a high-pressure pump with a power greater than 200kW, with a pressure of 70-300MPa and a flow rate of 200-300L /min. Moreover, the drill bit has a high requirement for wear resistance and needs to use high-hardness materials such as diamond and polycrystalline cubic boron nitride. The manufacturing cost is three to five times that of conventional drill bits. Meanwhile, hydraulic rotary drilling consumes a large amount of water, typically 1 to 2 cubic meters per minute, and most of it is clear water. Water needs to be taken nearby or transported over long distances, making the construction organization difficult and costly. In addition, the amount of mud produced by hydraulic rotary drilling is 5 to 10 times that of conventional drilling, containing a large amount of cuttings and silt. If the cuttings and silt are not separated in time and the drilling fluid is not recycled and reused, it will not only cause waste of water resources, but also the discharged mud will damage the surrounding vegetation, accelerate soil erosion and pollute the environment. Moreover, in weak strata such as sand layers and clay layers, hydraulic rotary drilling is prone to cause hole wall collapse and borehole diameter reduction of more than 20%, which seriously affects the drilling quality.

2.5. Pneumatic Drilling Technology

Pneumatic drilling technology is a drilling method that uses compressed air as power and the reciprocating motion of a pneumatic impact hammer to drive the drill bit to strike and rotate the stratum for cutting. Pneumatic drilling RIGS are generally composed of air compressors, rotating mechanisms, feed mechanisms and impact hammers, etc. Their drilling speed can reach 40 to 60 meters per hour, which is 5 to 10 times that of conventional rotary drilling. Moreover, the equipment is light in weight and small in size, generally weighing 1 to 2 tons, which is convenient for transportation and quick on-site installation. It is widely used in

hydrogeological and engineering geological exploration, especially suitable for field operations in mountainous areas, plateaus, deserts and other places with inconvenient transportation. However, the average air consumption of pneumatic drilling equipment is as high as 10 to 20 cubic meters per minute, which is three to five times that of rotary drilling. It is characterized by high energy consumption and high costs. Meanwhile, the exhaust noise of pneumatic drilling RIGS is generally between 110 and 130 decibels, approaching the noise level of aircraft engines, which seriously affects the health of construction workers. Moreover, during the drilling process, a large amount of dust-containing aerosols will be produced, with dust concentrations reaching 20 to 200mg/m³. In severe cases, it can cause occupational diseases such as pneumoconiosis, posing a threat to the health of drilling workers. In addition, under the influence of impact and rotation, pneumatic drilling is prone to cause the hole wall to collapse, reducing the hole diameter by 10% to 20% and resulting in poor hole quality, which is particularly evident in sand layers and pebble layers. Moreover, the rock cores are mostly in fragmented form with poor integrity, and the recovery rate is only 40% to 60%, which greatly reduces the geological logging quality of pneumatic drilling.

3. The Application of Drilling Technology in Geological Engineering Exploration

3.1. Geotechnical Engineering Investigation

Drilling technology plays a crucial role in geotechnical engineering investigation. Through core sampling by drilling, unprocessed soil samples and rock cores of different depths and lithologies can be obtained, which directly reflect the lithology, structure, color, weathering degree and other characteristics of the strata, providing a reliable basis for identifying the burial depth of the bearing stratum of the foundation, the properties of rock and soil, the type and water-richness of groundwater. Meanwhile, in-situ tests such as standard penetration tests, cross plate shear tests, and water pressure tests can be conducted through boreholes to obtain the physical and mechanical property parameters of rock and soil layers, providing important parameters for geotechnical engineering design and construction. In addition, drilling also creates conditions for sampling and on-site testing, and is an important means to determine a reasonable foundation form and dewatering plan.

3.2. Hydrogeological Investigation

Drilling technology is one of the main means of hydrogeological exploration. Through drilling, hydrogeological parameters such as the lithology, thickness, burial depth and water richness of aquifers can be obtained, and the occurrence state and recharge, runoff and discharge conditions of groundwater can be clarified, providing an important basis for the evaluation and development and utilization of groundwater resources. Meanwhile, by conducting pumping tests, water injection tests, water pressure tests, etc. through boreholes, hydrodynamic parameters such as the permeability coefficient, water conductivity coefficient, and water storage coefficient of the aquifer can be obtained, providing necessary parameters for the numerical simulation and optimized exploitation of groundwater [3]. In karst areas, through drilling, the development characteristics and patterns of rock liquid can also be discovered, providing important information for determining the water-richness of karst water and predicting karst disasters.

3.3. Mineral Resource Exploration

Drilling technology is the core means of mineral resource exploration. Through drilling engineering, geological information such as the spatial distribution, continuity, thickness and grade of concealed ore bodies can be systematically obtained, and the characteristics of ore-controlling structures and surrounding rock alteration can be identified, providing an

important basis for deep mineral exploration. Rope core drilling can obtain complete rock cores at depths ranging from 100 meters to 1,000 meters. It can analyze the lithology, structure, and mineral composition of ores and surrounding rocks, conduct comprehensive studies such as isotope dating and fluid inclusions, and clarify the age, environment, and mechanism of mineralization, providing key evidence for the study of ore deposit genesis and deep exploration [4]. Conducting underground geophysical exploration measurements in boreholes can achieve three-dimensional depth extension positioning of ore bodies, delineate deep mineral exploration target areas, and significantly improve the efficiency of mineral exploration.

4. Analysis of the Application Effect of Drilling Technology Methods

4.1. Exploration Accuracy and Quality

The exploration accuracy and quality of drilling technology directly affect the reliability and applicability of geological engineering investigation. On the one hand, the rational selection of drilling methods and process parameters, as well as the optimization of drilling equipment and tools, can effectively increase the drilling speed, core recovery rate and hole formation quality, obtain complete and continuous formation cores, and provide reliable geological basis for accurately identifying the lithology, structure, permeability and other aspects of the formation. On the other hand, strictly implementing drilling operation procedures and quality control measures, strengthening the management of the entire drilling process, enhancing the technical proficiency of drilling workers, and optimizing on-site logging and indoor testing procedures can maximize the representativeness and completeness of drilling data and core samples, providing high-quality geological data for engineering design and construction decisions. However, constrained by factors such as drilling techniques and complex geological conditions, on the one hand, the stratum information revealed by the boreholes has varying degrees of limitations and uncertainties, making it difficult to fully reflect the continuous variation law of the strata. On the other hand, core disturbance deformation and cuttings contamination also affect the reliability of in-situ test data, bringing certain uncertainty risks to engineering investigation and design. Therefore, it is necessary to integrate geophysical exploration, logging and other means to improve the accuracy and quality of geological engineering investigation [5].

4.2. Exploration Efficiency and Cost

The exploration efficiency and cost of drilling technology are important considerations in geological engineering investigation. On the one hand, adopting appropriate drilling methods and equipment, optimizing drilling process parameters, and strengthening the organization and management of drilling construction can help increase the drilling speed, shorten the construction period, and reduce drilling costs. Meanwhile, through the monitoring of the drilling process and data analysis, the drilling layout and footage can be dynamically optimized to reduce ineffective drilling and effectively control drilling costs. On the other hand, the rational selection and maintenance of drilling equipment and tools, increasing their service life and matching rate, reducing the frequency of equipment maintenance and replacement, and strengthening the centralized procurement and refined management of drilling consumables can also effectively lower drilling costs. In addition, the adoption of new drilling techniques, such as directional drilling and large-diameter drilling, can significantly increase the amount of engineering information per unit footage, reduce the number of boreholes, and enhance drilling efficiency. However, the unit cost of drilling is relatively high, accounting for more than 50% of the total cost of geological engineering exploration. Moreover, the drilling progress and construction period are prone to be affected by unforeseeable geological factors, resulting in drilling overruns and idling, which in turn affects the project progress and benefits [6]. Therefore, how to further enhance drilling efficiency and reduce drilling costs while ensuring

the quality of exploration is an urgent issue that needs to be addressed in geological engineering exploration.

4.3. Environmental Impact Assessment

The impact of drilling operations on the environment cannot be ignored, so it is necessary to carry out an environmental impact assessment of drilling. On the one hand, the noise, dust, wastewater, mud and other substances generated during the drilling process, if not properly disposed of, can easily cause pollution to the surrounding environment. Especially in environmentally sensitive areas, the high noise generated by large drilling rig operations and the eutrophication of water bodies caused by mud leakage can easily lead to environmental disputes and affect the normal implementation of geological engineering exploration. On the other hand, the land occupation of drilling projects and the construction of construction roads will cause certain disturbances and damages to the regional land use pattern and ecosystem. If the site selection and construction layout are unreasonable, it is easy to aggravate soil erosion and induce geological disasters. At the same time, the improper discharge of drilling waste mud will also have an adverse impact on the quality of the soil environment. In addition, the leakage of drilling fluid and the collusion of boreholes with aquifers can easily cause groundwater pollution and loss, affecting the regional groundwater environment and water resources. Therefore, strengthening the environmental impact assessment of drilling, adopting environmental protection measures such as noise control, dust treatment, mud recycling and ecological restoration in accordance with local conditions, and enhancing environmental management throughout the drilling process to minimize the adverse impact of drilling on the environment are the objective requirements for the high-quality development of geological engineering exploration in the new era [7].

5. Summary

In conclusion, drilling technology, as a key technical means in geological engineering exploration, plays a significant role in clarifying geological conditions, obtaining in-situ samples, and evaluating engineering properties. However, due to the constraints of factors such as technical level, geological conditions, and cost-effectiveness, the current drilling technology still has many problems that need to be urgently solved in terms of exploration accuracy and quality, efficiency and cost, and environmental impact. In the new era, the objects of geological engineering exploration are becoming increasingly complex, and the scale of construction is constantly expanding. It is urgent to further optimize drilling technology, promote the intelligence of drilling equipment, the specialization of drilling processes, and the digitalization of quality supervision, and continuously improve the engineering, industrialization, and standardization levels of drilling to ensure the construction of major projects and the development and utilization of resources.

References

- [1] Lin Hao. Research on the Methods and Applications of Drilling Technology in Mine Geological Engineering Exploration [J]. World Nonferrous Metals,2024(09):187-189.
- [2] Deng Junjun. Research on the Methods and Applications of Drilling Technology in Geological Engineering Exploration [J]. Engineering Technology Research,2020,5(06):122-123.
- [3] Wang Jun. Analysis of Drilling Techniques in Geological Engineering Exploration and Their Application Effects [J]. World Nonferrous Metals,2018(08):190-191.
- [4] Chang Xin. Methods and Application Analysis of Drilling Technology in Geological Engineering Exploration [J]. Heilongjiang Science and Technology Information,2017(08):104.

- [5] Su Ruidong. On the Application and Development of Geological Exploration Drilling Technology [J]. World Nonferrous Metals, 2022, (21): 118-120.
- [6] Liu Senfeng. Analysis of the Application Effect of Medium and Large Diameter Drilling Technology in Geological Exploration of Goaf Areas in Mines [J]. China Metal Bulletin, 2021, (12): 80-82.
- [7] Liu Shihai, Wang Zhaohui, Ding Leiming. Methods and Specific Functions of Drilling Technology in geological Engineering Exploration [J]. China Metal Bulletin, 2020, (01): 271-272.