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ANALYSIS, COMPARISON AND APPLICATION OF DRY AND WET DRILLING METHODS FOR ANTI-BUOYANCY ANCHOR BOLTS

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Abstract: With urbanization and the continuous expansion of building scale, the load-bearing capacity of underground structures is becoming increasingly prominent. Anti-buoyancy anchors, as a practical foundation method, have been widely used in various building projects, such as basements, underground garages, and bridge foundations. This study aims to systematically explain the processes of two technologies and compare and analyze them from the perspectives of construction methods, construction quality, and cost. It provides a scientific theoretical basis and technical guidance for engineering practice, helping engineers make more rational technical choices in actual construction, improving project quality, reducing project costs, and achieving safe, efficient, and sustainable construction.
Keywords: Anti-buoyancy anchor; Construction technology; Construction quality

1 INTRODUCTION

Anti-buoyancy anchors are tension members embedded in the soil below the foundation to resist the upward movement of underground structures due to groundwater pressure. When the structural load and overburden cannot resist the buoyancy of groundwater, the presence of groundwater buoyancy will cause the basement floor to bulge to varying degrees, causing certain damage. In severe cases, it can even cause uneven buoyancy of the entire building, or even tilting[1-3]. Anti-buoyancy anchors balance the buoyancy generated by groundwater through the friction between themselves and the surrounding soil layers, reducing the impact of groundwater. Due to their strong adaptability to site soil layers, low cost, and convenient construction, anti-buoyancy anchors have been widely promoted and applied in the anti-buoyancy design of basements in coastal areas[4-7].

2 DRY DRILLING TECHNOLOGY

2.1 Applicable Conditions

Mainly used for strata with good stability and low risk of borehole collapse, such as stiff to hard cohesive soils, completely weathered rock formations, strongly weathered rock formations, and some poorly loose gravelly soils. Suitable for water-scarce areas or sites with strict restrictions on mud pollution (such as urban areas and water source protection areas).

2.2 Construction Process

Construction Preparation: Clear the construction site, mark the anchor bolt hole positions, and measure and lay out the lines to ensure that the hole position, depth, and inclination angle meet the design requirements; simultaneously check the condition of the anchor bolt drilling rig, drill rod, auger bit, and other equipment, and prepare the anchor bolt body, anchoring agent, and other materials.
Layout and Positioning: Based on the building's survey control network and the anti-buoyancy anchor bolt layout diagram, use professional surveying instruments to accurately determine the center position of the anti-buoyancy anchor bolt. Insert short reinforcing bars into the ground for clear marking.
Drilling Rig Positioning: Move the anchor bolt drilling rig to the hole position, adjust the rig body so that the drill rod axis is consistent with the inclination and azimuth angle of the designed hole position, and fix the drilling rig to prevent displacement during construction.
Dry Drilling: Start the drilling rig, and use the auger bit to rotate and break up the strata. The broken soil is discharged upwards through the auger blades as the drill rod rotates, falling directly around the hole opening (it needs to be cleaned up promptly to prevent soil from falling back into the hole); monitor the hole depth in real time during drilling, and stop drilling and withdraw the drill rod once the designed depth is reached.
Hole Cleaning and Inspection: Due to the thorough removal of slag during dry drilling, the drill rod is repeatedly raised and lowered 2-3 times to remove residual slag from the bottom of the hole using high-pressure air. Afterwards, a measuring rope is used to check the hole depth and diameter to ensure the borehole meets requirements.
Anchor Bolt Installation: The pre-fabricated anchor bolt (with positioning bracket) is slowly inserted into the hole,

ensuring the bolt is centered and the exposed length of the top meets design requirements (for subsequent tensioning and locking).

Grouting and Secondary Grouting: Grouting is performed using bottom-to-bottom reverse grouting. The grouting pipe is inserted into the bottom of the hole, and cement grout is injected into the hole using a grouting pump. As the cement grout is injected, the grouting pipe is gradually withdrawn, allowing the cement grout to fill the hole from the bottom upwards, ensuring full grouting. After the first grouting is completed, secondary grouting is performed at certain time intervals according to design requirements.

Curing and tensioning: Wait for the anchoring agent or cement grout to reach the design strength (usually 7-14 days), then install the anchors and jacks, tension the anchors in stages according to the design requirements, and lock the anchors after the specified tension is reached to complete the construction.

3 WET HOLE FORMATION TECHNOLOGY

3.1 Applicable Conditions

Suitable for various complex strata, especially loose, easily collapsible soil layers (such as sand, silt, and backfill) and fractured rock layers. The water's wall-protecting effect effectively prevents borehole collapse.

Sufficient water supply is required, and the discharged drilling mud must be treated.

3.2 Construction Process

Construction Preparation: Basically the same as dry hole formation. In addition to material and equipment preparation, mud pits, sedimentation tanks, water supply equipment, and mud treatment equipment are also required to ensure the recycling of circulating water.

Layout and Positioning: Same as dry hole formation.

Drill Rig Positioning and Drill Mud Preparation: The drilling rig is aligned with and fixed in place. Simultaneously, drilling mud (water + bentonite + additives) is prepared according to the designed ratio. The mud must have a certain viscosity and specific gravity for wall protection, cuttings carrying, and drill bit cooling.

Wet drilling and cuttings removal: The drilling rig is started, and the drill rod drives the drill bit to rotate and break up the formation. Simultaneously, drilling mud is injected into the hole through the central channel of the drill rod. The mud forms a protective layer within the hole, preventing collapse. It also mixes the broken soil and debris into a mud slurry, which returns to the surface through the annular space between the drill rod and the hole wall, flowing into a mud pit. After sedimentation in a settling tank, the cleaned mud slurry is pumped back into the hole for reuse. Waste cuttings are periodically removed.

Hole cleaning and mud replacement: After drilling to the designed depth, drilling is stopped, and cleaned mud slurry is continuously injected and circulated to replace the thick mud slurry carrying a large amount of soil and debris in the hole until the sand content and viscosity of the mud returning from the holehead meet the design requirements, ensuring that the thickness of the sediment at the bottom of the hole does not exceed the standard.

Anchor bolt installation: After hole cleaning, the anchor bolt (which must be wrapped with an anti-corrosion layer to prevent mud corrosion) is immediately and slowly inserted into the hole. The positioning bracket on the bolt must avoid the grouting pipe.

Grouting and anchoring: Two-stage grouting is typically used. Primary atmospheric pressure grouting involves injecting cement grout through grouting pipes until grout of the same concentration as the injected material returns from the borehole. This forms the basic protective layer and anchor body of the anchor bolt. Secondary high-pressure fracturing grouting, performed after the primary grout reaches a strength of 5 MPa, involves injecting grout under high pressure (typically >2.5 MPa) through pre-embedded secondary grouting pipes. This fracturing process splits the primary grout and allows it to penetrate the surrounding soil, forming an enlarged head-shaped anchor body, significantly increasing the anchoring force.

Curing and tensioning/locking: Following the same dry drilling process, tensioning and locking are performed after the grout reaches its design strength.

4 COMPARATIVE ANALYSIS OF DIFFERENCES

4.1 Comparison of Construction Methods

Dry and wet construction methods are similar in their construction processes, both involving initial positioning and layout, preparation of the drilling rig, drilling, grouting, and curing. However, their construction methods differ significantly (Table 1). Dry construction requires a dry, water-free site, while wet construction requires mud circulation and a moist site. Consequently, there are substantial differences in the construction details, primarily in the methods of drilling and cleaning (Figures 1-2).

Table 1 Comparison of Dry and Wet Construction Methods

	Dry method	Wet method

Applicable Conditions	Stable strata that are not prone to collapse	loose, complex strata that are prone to collapse, including various rock formations.
Drilling Method	Hole formation requires a dry, water-free site, where drilling is performed directly by a drilling rig.	Hole formation also requires simultaneous drilling and mud slurry application to the borehole walls, as the site may be damp.
Drilling Cleaning Method	Sludge is removed using a spiral drill pipe and high-pressure air.	Sludge is also removed through a mud circulation system.
Environmental Impact	Smaller, no mud pollution, but higher noise and dust.	Larger, generating a large amount of waste slurry and drilling cuttings, requiring off-site disposal.
Water Demand	It's rarely used.	It requires a large water supply.
Construction Machinery	The core equipment is the auger drilling rig, along with air compressors, grouting pumps, etc.	The core machinery consists of a drilling circulation system composed of roller cone or triplane drill bits, central control drill rods, and mud pumps, as well as mud mixers, sedimentation tanks, etc.
Construction Rate (General)	One machine per shift can support approximately 16-18 anchor bolts with a diameter of 200mm and a depth of 10m.	Another machine per shift can support approximately 11-13 anchor bolts with a diameter of 200mm and a depth of 10m.

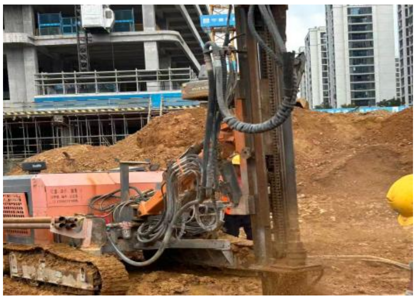

Figure 1 Dry Processing Machinery

Figure 2 Wet Processing Machinery

4.2 Comparison of Construction Quality

The dry method, due to the absence of mud slurry for borehole wall protection and its relatively dry and smooth borehole walls, reduces the impact of mud slurry on the borehole walls and avoids problems such as excessive mud cake, thus ensuring the bonding effect between the anchor and the borehole wall. However, it is dependent on site soil conditions. In loose and fractured soil layers, the quality of borehole formation cannot be guaranteed due to greater soil disturbance. However, the quality of borehole formation is acceptable when soil conditions are good.

Dry borehole formation, because there is no water inside the borehole, allows for a smoother anchor lowering process, reducing the likelihood of the anchor being covered or stuck by mud slurry. This better ensures the installation depth and verticality of the anchor. Due to the dryness of the borehole and the absence of mud slurry interference, the grout can better fill the borehole space, bonding tightly with the anchor and the borehole wall, resulting in relatively high grout density.

The wet method has an absolute advantage in maintaining borehole wall stability. It is superior in borehole wall stability and adaptability to complex strata, making it the preferred process for complex strata such as soft soil, sand, and gravel layers. Using the positive and negative circulation system of mud wall protection technology, the broken small particles of sand and gravel are carried out of the bottom of the hole. Practice shows that high-quality mud can effectively stabilize the hole wall of the sand and gravel layer, so that the hole wall does not collapse for a considerable period of time, and the hole formation quality is relatively stable [8].

However, since the hole is filled with mud, the anchor rod may be affected by the buoyancy and resistance of the mud during the lowering process, which makes the anchor rod installation difficult and makes it difficult to ensure the verticality and installation depth of the anchor rod. If the performance of the mud is not properly controlled, such as the specific gravity and viscosity of the mud being unsuitable, it may lead to an excessively thick mud cake on the hole wall, affecting the bonding strength between the anchor rod and the hole wall, and thus reducing the pull-out resistance of the anchor rod. During grouting, the mud may mix into the grouting fluid, causing the grouting fluid mix ratio to change, affecting the performance and density of the grouting fluid. (Table 2)

	Dry hole forming	Wet hole forming
Poor borehole wall stability	No wall protection; relies entirely on formation self-stabilization. Prone to borehole collapse in loose, fractured formations.	Excellent: Protected by mud slurry; hydraulic pressure supports the borehole wall, preventing collapse, especially suitable for unstable formations.
Bottom cleanliness	Sedimentation may occur. Airflow may not be able to remove all fine powder, leaving loose sediment at the bottom of the borehole, significantly weakening the anchoring force.	Accumulation may also occur. Rock cuttings will settle after pump shutdown, but this can be effectively controlled through secondary cleaning (slurry replacement, air-lift reverse circulation).
Hole diameter uniformity	oderate. High impact vibration; prone to "plum blossom" holes and over-diameter holes in uneven formations.	Good. Smooth rotary cutting; smooth and regular hole walls; minimal hole diameter variation.
strata disturbance	The impact is significant. High-pressure airflow may penetrate the fissures, disturbing and loosening the surrounding rock and soil.	Smaller. The mud seeps in and forms a mud cake, causing minimal disturbance to the original soil.
Anchor Bolt Body Installation	It is relatively simple. Because the hole wall is dry and smooth, the rod body can be easily sent to the bottom of the hole, and it is also easier for the rod body to form a reliable bond with the hole wall.	It's quite difficult. The hole being filled with mud makes it difficult to lower the anchor rod, and the mud may also cause poor adhesion between the rod and the hole wall.
Grouting density	Good. Due to the dryness inside the borehole and the absence of mud interference, the grout can better fill the space inside the borehole and bond tightly with the anchor bolt and borehole wall, resulting in a relatively high grout density.	Poor. Mud may mix into the grouting fluid, causing changes in the grouting fluid's mix ratio and affecting its performance and density.

Table 2 Summary of the Comparison between Dry and Wet Construction Quality

4.3 Cost Comparison

4.3.1 Material Costs

The requirements for the main materials, anchor bars and concrete, are basically the same for both drilling techniques.

Dry drilling does not require the use of mud materials, reducing the procurement costs of mud additives such as bentonite and polyacrylamide. Its material costs are concentrated on the main materials such as anchor bars and cement. Wet drilling, due to the use of large amounts of mud, water, and other mud additives, is more expensive than dry drilling.

Dry drilling uses compressed air during the hole cleaning process. Compared to the mud circulation system of wet drilling, it does not require additional water resources and related treatment agents, further reducing material costs.

4.3.2 Equipment Costs

Dry drilling uses relatively lightweight drilling rigs, such as auger drills, resulting in lower equipment purchase or rental costs. Wet drilling uses larger and more complex machinery, such as rotary drills. Furthermore, wet drilling requires mud preparation equipment, mud circulation systems, and mud treatment equipment, increasing equipment investment costs. The resulting equipment installation and maintenance costs are also considerable, further increasing the equipment cost of wet drilling. (3) Labor Costs: Dry drilling has a relatively simple construction process and requires fewer operators. Wet drilling, however, involves multiple stages such as mud preparation, slag removal, and treatment, requiring more manpower for operation and management, resulting in higher labor costs.

4.3.3 Additional Costs

The main additional cost of dry drilling is the environmental impact and associated costs. This primarily includes dust and noise generated during drilling. Effective dust control measures, such as setting up dust nets and water spraying, can keep dust pollution at a low level, resulting in lower treatment costs.

In contrast, mud treatment is a significant cost in wet drilling. Mud requires transportation, dewatering, and solidification to meet environmental protection requirements. Mud transportation costs vary depending on the distance and volume, generally around 50-100 yuan per cubic meter. Mud dewatering and solidification require specialized equipment and chemicals, leading to higher treatment costs, approximately 100-200 yuan per cubic meter. For a large-scale anti-buoyancy anchor bolt project, the cost of mud treatment can reach hundreds of thousands of yuan or even higher. However, dry drilling does not produce mud, so there is no mud treatment cost.

5 CONCLUSION

In terms of construction technology, dry drilling utilizes drill rod rotation and impact combined with compressed air for hole cleaning, resulting in a simple process and convenient operation. Wet drilling relies on mud wall protection and positive circulation for slag removal, making the process more complex and mud management more difficult.

Regarding geological adaptability, dry drilling is suitable for soil layers with low water content and hard rock layers, but is limited in pebble strata. Wet drilling is suitable for various soil layers and some soft rock strata, but its applicability is poor in hard rock and high pebble content strata.

In terms of construction efficiency, dry drilling machinery is lightweight and flexible, eliminating mud-related processes and resulting in high drilling efficiency. Wet drilling is constrained by mud preparation and treatment processes, leading to lower construction efficiency.

In terms of engineering quality, dry drilling produces dry and smooth borehole walls, resulting in better anchor installation and grout compaction. While mud wall protection in wet drilling can maintain borehole stability, the mud may affect the bonding between the anchor and the borehole wall and the grouting quality.

In a cost comparison, dry drilling has advantages in material, equipment, and labor costs, and eliminates the need for mud treatment. Wet drilling, on the other hand, incurs high costs for mud materials, equipment, and treatment, resulting in a higher overall cost.

In summary, dry drilling technology offers significant advantages in construction efficiency, cost control, and environmental protection, but it has stringent requirements regarding geological conditions. Wet drilling technology, however, performs excellently under complex geological conditions and with better management. Both methods have their own advantages. In hard, intact rock formations, the high efficiency and low cost of dry drilling make it a more desirable choice. In complex formations, mud wall protection and borehole cleaning techniques can ensure high-quality boreholes in various complex formations, with relatively controllable environmental impact.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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