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Analysis of Rock Drilling Performance by Dual-Nozzle Waterjet: Experimental Study with Field Application

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ABSTRACT

This study evaluates the rock drilling performance of a dual-nozzle waterjet system through experimental tests and field application. The dual-nozzle design was developed to improve drilling efficiency. In-lab tests were conducted to investigate the influence of key parameters such as water pressure, standoff distance, and exposure time on rock drilling efficiency. The field test confirmed that the system maintains stable drilling with low noise and vibration under real-site conditions. While efficiency decreased slightly in the field, overall trends remained consistent with laboratory results. Consistent drilling geometry and minimal surface damage were observed in both conditions. These findings demonstrate the potential of the dual-nozzle waterjet system for precise, low-impact rock drilling in environments sensitive to disturbance.

1. INTRODUCTION

Urban areas increasingly require safe and precise rock excavation methods. Traditional methods such as blasting and mechanical excavation cause high noise, strong vibration, and excessive overbreak (Kong et al., 2023; Yoo and Lee, 2025). These issues limit their application in dense cities and raise concerns about structural safety and public complaints.

Waterjet drilling offers a promising alternative to overcome these challenges. The method uses high-pressure water mixed with abrasive particles to remove rock through erosion, not impact. Because the jet does not physically strike the surface, it generates significantly less noise and vibration. This advantage makes waterjet drilling well-suited for excavation in sensitive urban environments.

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Previous studies have primarily evaluated waterjet drilling under laboratory conditions. These studies have demonstrated its effectiveness in cutting hard rock. However, limited research has assessed its performance under real field conditions. In practice, factors such as heterogeneous rock properties, groundwater inflow, and restricted working space may affect the drilling outcome. Field-based experiments are needed to evaluate the practical feasibility and limitations of waterjet drilling under such conditions.

This study examines the drilling performance of a dual-nozzle waterjet system through full-scale field tests on granite. The objective is to assess removal depth, cutting efficiency, and the applicability of this method to underground construction in urban environments.

2. TEST SETUP

To evaluate the effectiveness of AWJ drilling, a series of field tests were conducted using a custom-designed waterjet drilling unit. Vertical drilling experiments were performed on two rock conditions with different strengths, and the results were analyzed.

The field tests were carried out at a nearby quarry site in the southern region of Korea (Fig. 1). Two rock types with distinct strength characteristics were selected within the exposed rock face. The first condition was a weathered rock with an uniaxial compressive strength (UCS) of approximately 30 MPa, as measured by a Schmidt hammer. The second condition was a hard rock with a UCS of about 170 MPa. According to Oh and Cho (2014), the weathered rock was expected to exhibit faster drilling performance due to its low strength and high degree of weathering, whereas the hard rock condition was anticipated to show relatively slower penetration.

To simulate a conventional drilling setup, vertical waterjet drilling was performed using a nozzle-fixing frame, as presented in Fig. 2.

Fig. 1 Photograph of field site

Fig. 2 Photograph of the AWJ drilling unit

The AWJ drilling system used in the field tests consists of several key components: a high-pressure waterjet pump, a waterjet nozzle, a water supply tank, and an abrasive feeder, which are directly involved in jet generation; and auxiliary devices such as a nozzle-fixing frame and a nozzle rotation and feed control system to enhance drilling performance.

The cutting process of the AWJ system proceeds as follows. Water from the supply tank is pressurized by the pump and delivered to the nozzle. Simultaneously, abrasives are fed pneumatically into the nozzle. The high-pressure water passes through a small-diameter, ultra-hard orifice within the nozzle, converting it into a high-speed jet stream. This stream enters the mixing chamber, where it is combined with the abrasive particles. The abrasive-laden jet is then focused and discharged through a focusing tube, forming a concentrated waterjet stream that cuts into the rock surface. This process is continuously repeated during drilling.

The auxiliary components play critical roles in ensuring stable and effective drilling. The nozzle-fixing frame secures the nozzle at a desired position during jetting and controls reaction forces to maintain operational stability. Park et al. (2021) proposed a method using dual nozzles to increase cutting width by splitting the flow, and this concept was applied in the system design, enabling two nozzles to be stably mounted for enhanced performance in hard rock conditions.

The nozzle rotation and feed control system enables adjustment of the nozzle movement. The rotation device allows the nozzle to form a wider circular bore by spinning, with the rotation speed adjustable depending on site conditions. The feed control device gradually advances the nozzle along the drilling axis, maintaining a consistent standoff distance between the focusing tube tip and the rock surface. This ensures steady energy delivery to the target area, which is critical for maintaining drilling efficiency in deep boreholes.

3. RESULTS

Drilling performance was evaluated based on the depth of boreholes formed after jetting. Fig. 3 presents a normalized comparison of the drilling results obtained from each rock condition. The hard rock condition exhibited approximately 40% lower drilling rate compared to the soft rock, which can be attributed to the difference in rock strength.

A common observation across both test sites was a significant decrease in drilling efficiency as the operation progressed. This trend was visualized by dividing the drilling process into two stages: the initial stage and the later stage. The decline in performance is believed to be caused by residual water accumulating inside the borehole during drilling or groundwater inflow, which creates a submerged environment similar to underwater AWJ conditions. According to Haghbin et al. (2015), submerged environments are known to reduce the drilling rate compared to operation in air.

In both rock conditions, the drilling rate during the later stage decreased by approximately 85% compared to the initial Stage. Therefore, when applying AWJ techniques in field conditions, proper drainage planning to remove residual jetting water and prevent groundwater accumulation is critical to maintain optimal drilling efficiency and avoid submerged jetting conditions.

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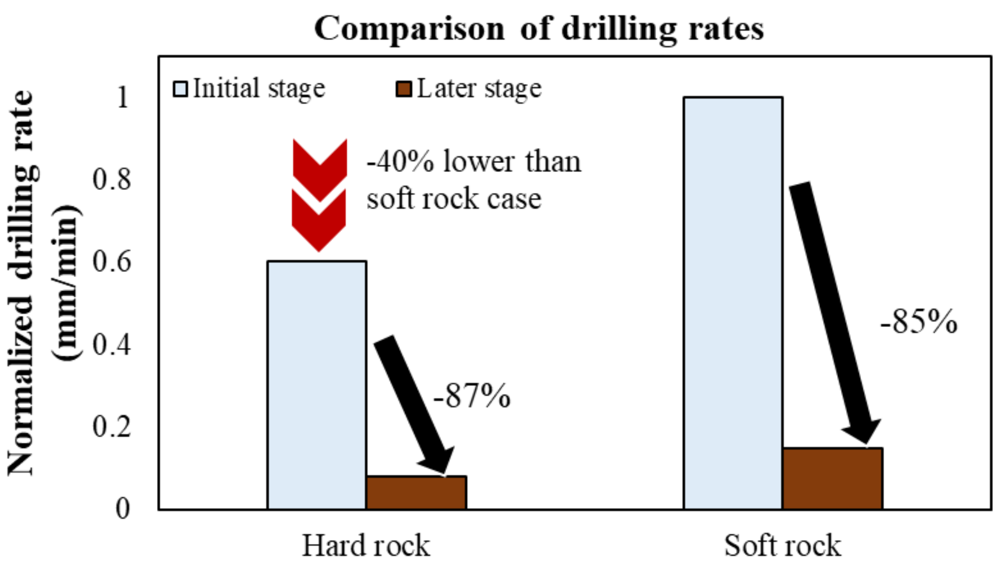

Fig. 3 Normalized drilling rate comparison between initial and later stages

4. CONCLUSIONS

This study validated the field applicability of a custom-designed dual-nozzle AWJ drilling system through full-scale tests on rocks of varying strength. The system achieved effective drilling with minimal noise and vibration, highlighting its potential as an alternative to conventional excavation methods in sensitive environments.

Drilling rates were found to decrease with increasing rock strength, and efficiency dropped by up to 85% during the later stage of operation. This decline was attributed to residual water and groundwater inflow, which created submerged-like conditions. To maintain optimal performance, site-specific drainage strategies should be implemented to avoid water accumulation and preserve air-based jetting conditions.

These results emphasize the importance of environmental management in field applications and contribute to the practical understanding of AWJ drilling for underground construction.

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