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Vibration Reduced Rock Excavation Using Waterjet Technology

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ABSTRACT

Highly developed metropolitan cities need underground space for the effective use of limited land. Ground vibration induced by the blasting process can cause serious problems in the vicinity of the construction site when large underground structures, such as transportation tunnels are constructed in urban areas. Abrasive waterjet technology can be used for hard rock cutting. This type of technology has two principal advantages: high versatility and no mechanical stress generated. This paper introduces an innovative excavation method that combines the conventional blasting process with the precutting of a perimeter of a large tunnel face by cutting performance to minimize ground vibration. In addition, experimental tests were performed to verify the effect of the proposed tunnel excavation method.

1. INTRODUCTION

Rock excavation is necessary to generate underground space. There is always demand for new underground facilities and transportation structures in urban areas whenever a city is rapidly developing. Blasting excavation (i.e., New Austrian Tunneling Method) has been broadly used to excavate rock due to construction cost and time efficiency. However, explosions used to break rocks have induced serious vibration. The blasting vibration damages nearby structures or buildings in the urban area. In addition, the physical, mechanical, and hydraulic properties of this zone are weakened by the blasting impact and stress concentration. This weakening reduces the safety and

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reliability of the large underground structure and leads to poor fragmentation and high support costs (Arora and Dey 2010).

Line-drilling holes along the tunnel's perimeter in the tunneling direction (e.g., smooth blasting method) apply for rock excavation to reduce blasting vibration (Uysal et al. 2008). These line-drilling holes play the role of an artificial screen against the blasting vibration energy (Park et al. 2009). However, in the line-drilling holes method, excavation-near-ground is still connected with the blasting zone. A continuous empty line along the tunnel's perimeter prevents blasting vibration energy (Oh et al. 2012).

In this study, a new vibration-reduced excavation method that uses a continuous empty line generated by an abrasive waterjet is introduced. In order to verify the new method, a field test was performed where the blasting vibration velocities of the developed method were measured and compared with the results of the smooth blasting method.

2. NEW VIBRATION-REDUCED ROCK EXCAVATION METHOD

An abrasive waterjet has been used for precise cutting processes of various engineering materials (Summers 1995). The abrasive waterjet can generate a thin continuous arch void line (i.e., a pre-cutting free surface) with a certain depth along the tunnel's perimeter. A combined method of a pre-cutting free surface and conventional blasting can reduce the blasting vibration because the free surface prevents the propagation of the blasting vibration energy due to reflecting at the pre-cutting free surface. The concept of rock blasting excavation using a waterjet pre-cutting free surface is illustrated in Fig. 1.

3. EXPERIMENTAL PROGRAM

3.1 Field condition

The field tests were performed at a rock mountain that was predominantly composed of phyllite (Fig. 2(a)). The target tunnel was designed with a diameter of 3.56 m and a pre-cutting target length of 5.59 m (Fig. 2(b)).

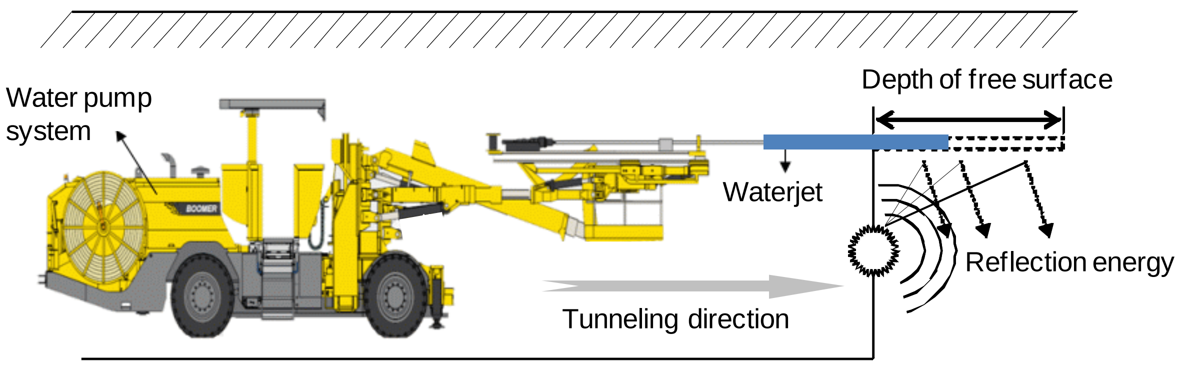

Fig. 1. Concept of rock excavation method using abrasive waterjet system

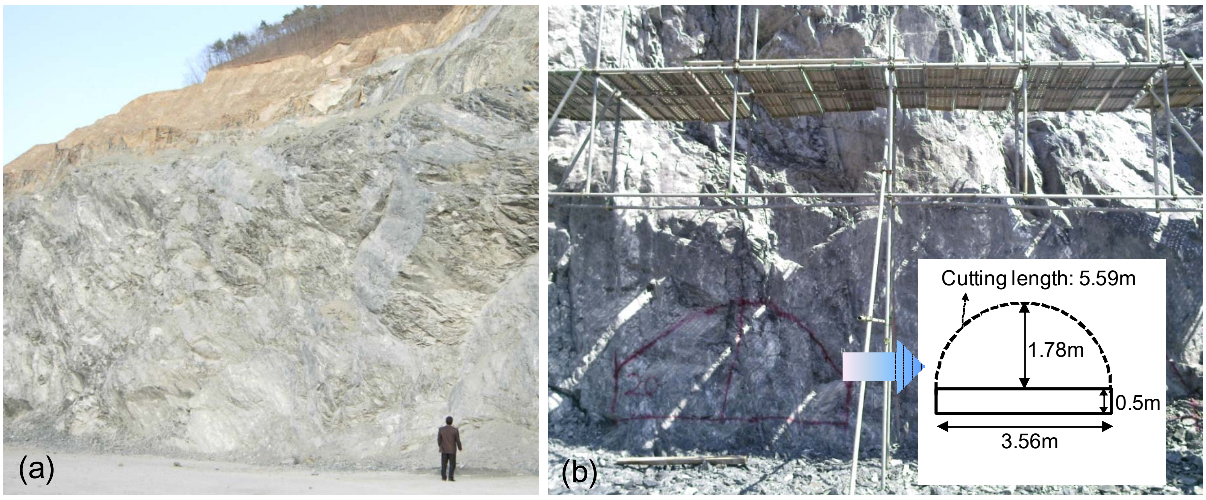

Fig. 2. Field test site: (a) front view and (b) target tunneling dimension

Fig. 3. A plunger type pump

3.2 Abrasive waterjet system setup

A water pump, an abrasive feed tank, and a nozzle movement system were prepared to perform the waterjet pre-cutting operation. A plunger type pump was used for the high-pressure water pump (Fig. 3). The nozzle was installed on the equipment, which was moved along the rail after being attached to an arch (tunnel-like) shaped frame (Fig. 4).

3.3 Explosive Preparation

Blasting tests for both the waterjet pre-cutting method and the smooth blasting method were performed under the same conditions, except the suggested method has a pre-cutting zone instead of roof and wall holes. Thus, the waterjet pre-cutting method requires the drilling of only 17 holes, while the smooth blasting method demands the drilling of 26 holes. With a reduced number of holes, the weight of the necessary explosive charges decreases in this method (9.5 kg) compared to that of the smooth blasting method (12.65 kg). The hole depth needs to drill and install the explosives is 1.3 m for both methods.

3.4 Monitoring sensor installation

Three vibration sensors (geophones) were installed on the ground surface along the tunnel center (approximately 9 m above the tunnel crown). The location of the sensors is shown in Fig. 5.

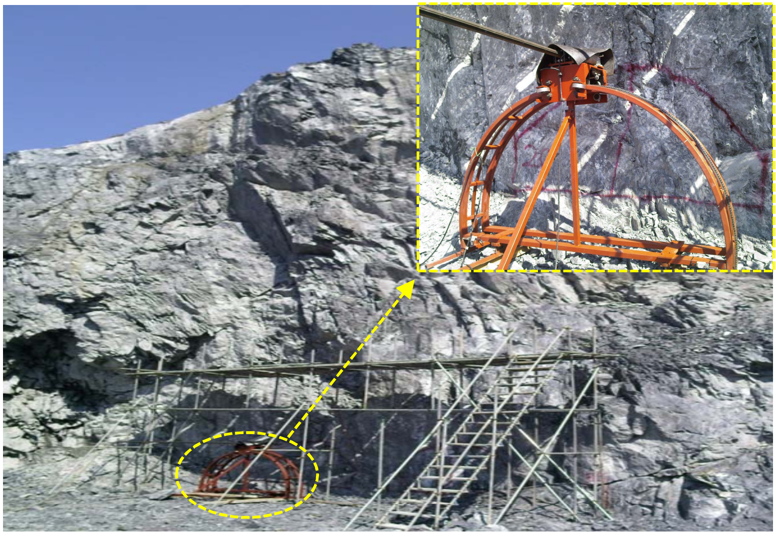
Fig. 4. Abrasive waterjet system setup

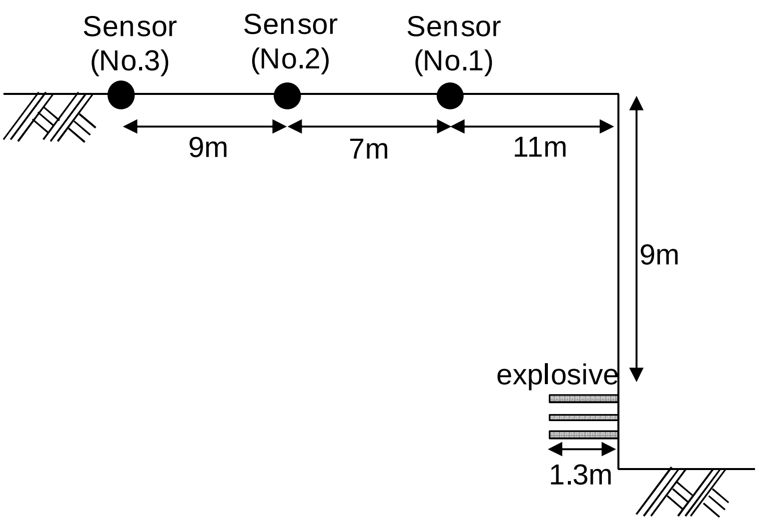

Fig. 5. Locations of vibration sensor installation (side view)

4. RESULTS AND DISCUSSION

4.1 Pre-cutting performance

The dual nozzle abrasive waterjet operates well in the pre-cutting process on the tunnel face. It is observed that a clean pre-cutting line is formed. The average cutting width generated is approximately 10 cm, obtained on tunnel face, and decreases with an increase in depth. The generated average cutting depth is 1.3 m. In particular, abrasive waterjet cutting process is focused on the top part of the target tunnel in order to maximize the vibration reduced effect on the pre-cutting free surface.

4.2 Blasting Vibration

The vibration velocities (i.e., peak vector sum, PVS) are measured by geophones. The vibration velocity decreases with an increase in the distance from the explosive location due to material damping of the ground. In vibration comparison, the vibration velocities from the waterjet pre-cutting method are reduced to 40.1-55.0% at sensors No.1, No.2, and No.3, compared to the vibration velocity from the smooth blasting method.

CONCLUSION

In the study presented here, an innovative tunnel blasting system that installs a continuous arch void (i.e., a precutting free surface) along the tunnel's perimeter is proposed in order to minimize the blasting-induced vibration and overbreak. To verify the proposed tunnel blasting technique, an experimental test is performed. It is found that the vibration velocity is reduced by up to 55% compared to the vibration velocity found when the smooth blasting method is used.

The waterjet pre-cutting method has additional benefits: the construction cost will decrease due to decreases in 1) the number of drilling holes, 2) the weight of the explosive charges, 3) the overbreak space, and 4) the excavation-damaged zone. The loosening earth pressure acting on the tunnel's structure (such as shotcrete and concrete lining) can be reduced. In particular, the reduction of the overbreak space and excavation-damaged zone enhances the safety of tunnel construction.

ACKNOWLEDGEMENTS

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