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Paper

CREATING FREE SURFACES ON HARD ROCKS

USING ABRASIVE SUSPENSION WATER JET MANIPULATORS

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ABSTRACT

The environmental regulations on noise and vibration are getting more difficult to meet in urban area every year. The cheapest and fastest rock excavating methods, such as Drill & Blast, hydraulic breaker and diamond saw cutting, are losing their ground to alternative methods, such as hydraulic wedging and coring, which are far more expensive and slower. Regardless of methods, the key to the hard rock excavation still lies on the number of free surfaces created on site. A hand-carry type disc cutter and a notch cutter unit using abrasive suspension water jet for pre-drilled holes, have been developed to create extra surfaces around the holes. The free surfaces created perpendicular to and along the drilled holes eased the excavation of the rock and reduced the vibration and noise delivered through the rock.

1. INTRODUCTION

Figure 1-1 Hydraulic Breaker attacking Bottom Corner Rock under Slab Behind column

The rock fragmenting with hydraulic breaker, or drilling & blasting has been forced out of the construction sites in downtown Seoul, due to complaint from neighbors on noise and vibration inherently generated by impacts. On top of the complaint, an unexpected presence of hard rock under ground could force heavy machinery operators struggle with the given job environment (Fig. 1.1).

An alternative method brought in is hydraulic coring and splitting (Fig. 1.2). Rock coring system mount on the crawler replacing the bucket of the excavator can core through even the hardest rock using the hydraulic power of the excavator. A button-type rock splitter with separate hydraulic power system is placed inside the cored hole manually and the buttons are pushed out by the hydraulic pressure to split the rock around the cored hole. The fractures are then developed naturally following the inherent weak plane in the rock mass and the hydraulic breaker is again brought in for the separation of the fractured rock mass. This coring system is, however, short in depth and spacing and burdens among the cored holes be kept narrow, thus resulting in depressing job progress. To enhance the speed of fracturing, abrasive suspension water jet nozzle heads were developed and tested.

a) Hydraulic Coring Machine b) Hydraulic Rock Splitter

Figure 1-2. Hydraulic Rock Coring and Splitting

2. TEST SYSTEM

2.1 Abrasive Suspension System

The abrasive suspension system used for this research comprises of triplex pump and in-line mixer with a flow rate of 14 liter/min at 70 MPa and an abrasive consumption rate of 3kg/min of garnet #80. Disking and notching tests were carried on granite. A dual batch type Diajet mixer for continuous mixing and operation for longer period of time was adapted for the test.

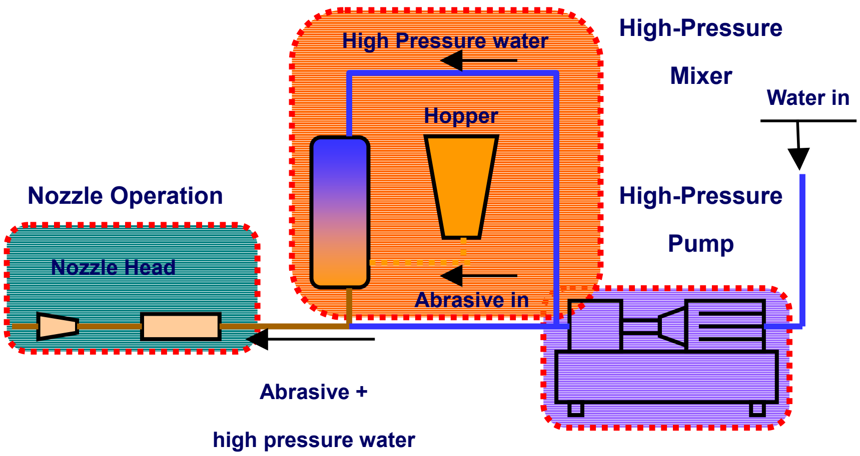


Figure 2.1 Abrasive Suspension System

2.2 Motion System

Preliminary tests carried on the real construction sites were based on the system mount on excavator, tripods or pipes. An excavator with Tiltrotator® (Fig. 2.3) was used to increase the degree of freedom for positioning the disk cutter or notch cutter for pre-drilled holes in hard rock. The tilting and elevating of the forks allowed 2 more DOFs. As the water jetting times increased, however, the excavator arm got lowered due to the leakage of the hydraulic valves and holding its position became a challenging job.

Figures 2.2 & 2.3 Diajet Mixer with Pump used in Field Test with Excavator

Figures 2.4 & 2.5 System mount on tripods and bars-pipes

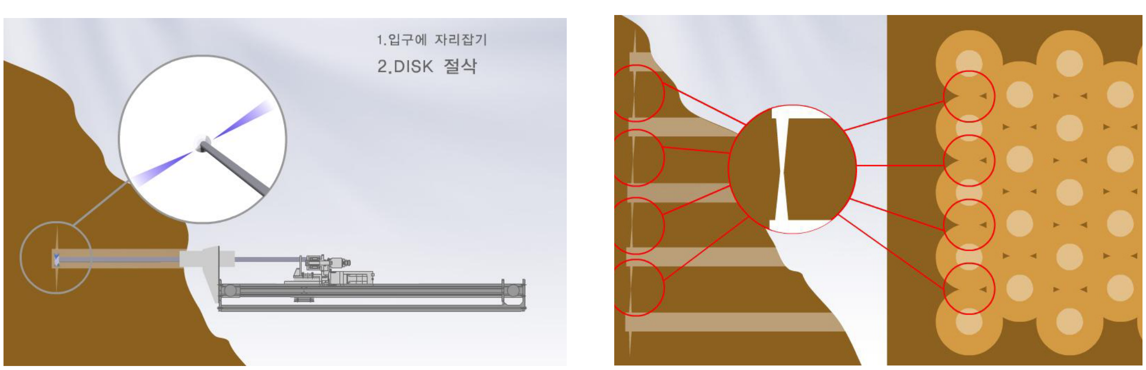
To hold the cutting position for a while, tripods and pipes (Fig. 2.4) were brought in for supporting the system. Both systems held the position successfully but adjusting the cutting system and aligning the system with pre-drilled or cored holes now became the next topic. The orientations of the pre-drilled holes were not parallel, although those holes were drilled with a single machine in a fixed position. Slight error in alignment resulted in the stuck of the nozzle head inside the hole. Short duration of cutting and portable, light, flexible system seemed to be the requirements to practical point of view.

3. DISKING FOR FREE SURFACE

3.1 Free Surface Inside the Rock

More often than not, above mentioned hydraulic breakers failed to be efficient in removing the bottom corner rock due to the lack of free surface ending up chiseling or grinding the hard rock away. To accelerate the excavation, a presence of free surface could extremely helpful and shorten the operation. Disk cutting by water jet nozzle head and connecting the cut spaces could be a solution to the extra free surface needed.

An array of parallel holes are first formed either by drifters or coring machine, maintaining a certain pattern with the distance between the holes kept around the twice the kerfing depth by the given water jet system. The disking nozzle head then inserted and fixed for the disking operation so that the empty disk spaces cut by the nozzle head get connected each



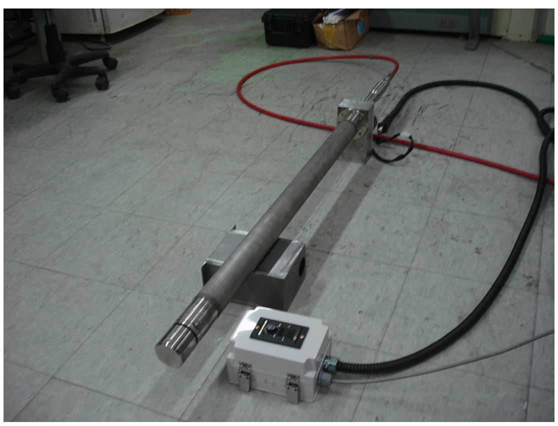
a) A Disking in Pre-Cored Hole b) Connected Disks Forming a Plane

Figure 3-1 Free Surface Inside Rock by Connected Disk Cuttings other to form a plane inside the rock. A free surface inside rock can be, thus, created and subsequent effort to fracture the rock could utilize the free surface for easy fracture and secure the final plane of cutting from outside of the rock.

3.2 Portable System Design

A portable system with similar size of hydraulic rock splitter were designed and built for the test. The test system had a rotation speed controller equipped and nozzle head separated from the pipe body of 1 meter length. The system is light and can be handled by an operator and placed inside the hole and wedged to secure the cutting depth. A visual mark around the system and pipes were used to check the cutting plane of each disk cuttings.

Different RPMs and cutting times were tried, but due to the nature of abrasive suspension system of complicated start-and-stop procedure, no extensive effort was made to verify the disk cutting effect on different rock types and cut orientation. Each cutting was made for 1~2 minutes of jetting and no great change was observed among the circular kerfing depth. 50~100 RPM seemed to be a good range of rotation to start and the kerf depth seemed to be converging to a certain value depending on the rock regardless of cutting time.




Figures 3-2 & 3-3 Portable Disking Nozzle Head and A View Placed inside a Cored Hole

3.3 Disking Test

The kerf depth were found to be between 80~110mm and considering the hole diameter of 75mm, the connecting disk holes, then, were cored 250mm apart from each other. Dual orifice type of nozzle head was used as a single orifice type of nozzle head resulted in excessive eccentric force inside the hole and resulted in widening the kerf width and shortening the depth. All the tests were carried out on granite. 7-holes rock block was tested and the plane was formed inside the rock block and the connection of the disks could be easily identified by the draining of the water and sound.

Figures 3-4 & 3.5 View from the Inside the hole and From Outside the Block after cuttings

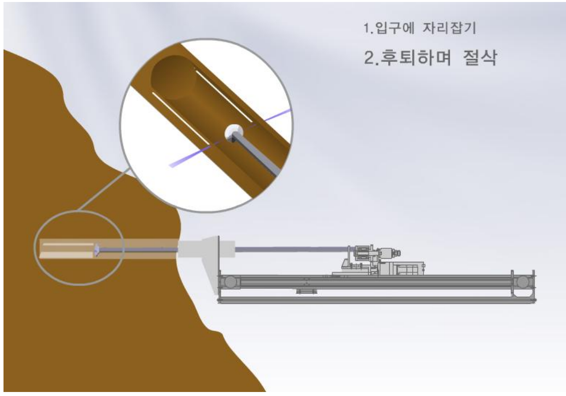
Figure 3-6, 3-7 Disked Rock : Individual Disk Cross Section & Split Apart Rock Block

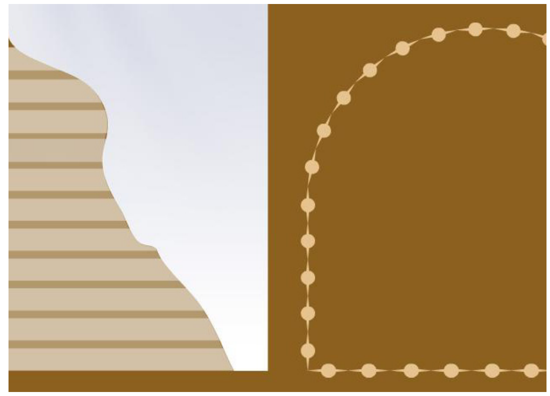
4. NOTCHING TO CONNECT DRILLED HOLES

4.1 Final Surface Cut First

Including tunnels and shafts, the rock excavating operation in urban area near existing structures or residential area, faces complex problems such as vibration, noise, structural damage, subsidence and just the fear that construction site is undergoing around the area. Rock removing experts quickly run out of the solutions as the complaint varies from door to door. Any mechanical excavation method such as T.B.M.(Tunnel Boring Machine) can not be justified due to the length of tunnel and the spectrum of rock types in urban area.

As in the case for the Disk Cutters developed for under-digging operation, the drilled or bored holes with hydraulic rock splitter are gaining the ground more and more as the excavation site approaches the downtown. This methods is by far the most expensive and slow excavating method and, as they do not exploit the existence of free surface as in blasting, the most energy consuming procedure.





Figures 4-1 & 4-2 Notching Along Pre-drilled Hole & Connecting for Profile

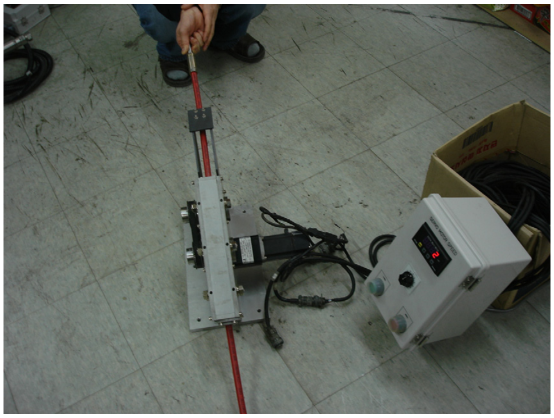
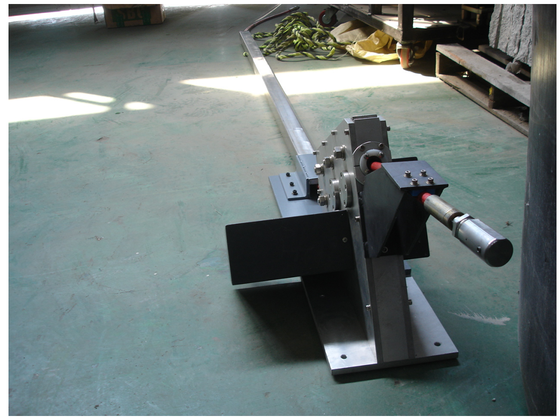
As an effort to revive the drill and (controlled) blast for cautious excavation, the abrasive-water-jet-notched drill holes replacing the line drilling was suggested and developed for field trial. The possible benefit from notched and connected profile are : 1) Controlled overbreak for less shotcrete, 2) Decreasing vibration for less complaint and damage to nearby structures, 3) Pre-defined final surface eliminating the need for secondary work.

Similar nozzle head as disk cutter could be utilized for notching along the drilled holes. When the hole depth increases up to 4m, above mentioned hydraulic excavator-mounted drilling system or notching system faces the position holding problem in field due to the weight and the hydraulic system leakage as the cutting or kerfing time increases. A system was needed to adapt to the condition that the constantly varying starting position and non-straight hole with unknown hole orientation and the depth.

4.2 Flexible System Design

A flexible pressure hose based nozzle head was then designed and built for its adaptability to adjust to the curvature and act flexibly and still maintain its radial orientation. Based on the water jet system cutting ability, the notching speed of up to 10mm/sec and maximum depth of 4.5m were chosen for the design of the nozzle system.

The axial stiffness which works against the friction along the hole wall, was found to be enough for most of the high pressure hoses as the high pressure hoses were built with steel strands twisted in 2~3 layers in the working pressure range ratings. Even the hoses could be bent with relatively short bending radius, they still resisted to the torque and, thus could easily maintained its radial orientation even with twisting and bending forces applied at the same time.

Figures 4-8 & 4-9 Flexible Notching Nozzle Head Top and Front Views

4.3 Notching Test

Based on the kerfing test result on the given water jet system, 90~120mm(Fig 4-10), a series of holes were drilled parallel and notch cutting directions were marked so that the neighboring notches connect each other(Fig. 4-11). The holes were intentionally drilled not in the straight line and the notching orientation varied by each hole as same orientation could result in non-connecting notches as the hold the same direction and run parallel. Furthermore, the starting position inside the pre-drilled hole also affected the connecting point as the nozzle head could move inside the hole as the bouncing water jet stream collided with nozzle head and hose shaking the notching position.

Figure 4-10 & 4-11 Notching Test & Notching Direction Marking

The notches were connected successfully when the neighboring notch angles differed by more than about 10º and had a difficulty in connection running almost parallel when they were laid with less than 10º in angle. The Figures 12 & 13 shows the connections and the step shown in between second and third left holes represent non-connected notches running parallel.


Figures 4-12 & 4-13 Notch Cuts Connected & Split View

5. CONCLUSIONS

An analysis based on first field trial showed a few parameters to be considered for the improved design with higher applicability. The improved systems were built and tested for the urban area applications for free surface and final profile achievement before excavation.

A portable disking system was operated for less than 2 minutes in each disk cutting operation in a position at less than 100 rpm. Holes were drilled 250mm apart, and the connected disks resulted in a free surface inside the rock mass.

A flexible hose based nozzle head was built and tested for notching along the pre-drilled holes. Most of the high pressure hose had enough strength to resist the friction and torque created in between holes wall and nozzle head. A series of notched holes were connected together forming a pre-designed final profile. A careful design of notch directions was required to ensure the connection of the notches.

6. REFERENCE

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