Performance validation of rock cutting-splitting method by scaled model tests and rock slope excavation

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ABSTRACT: A cutting-splitting method is developed as a mechanized excavation for rock slope and tunnelling. The technique has two procedures. The first step is the rock cutting as designed dimensions (i.e. depth, spacing, width). The second is the rock splitting process by inserting chisel into the cutting slot to split out a rock block. For propagation of tensile crack on the bottom of rock, a sufficient indenting force should be loaded on the cutting slot. An analytic solution was proposed to estimate the indentation force. Numerical analyses were conducted to analyze the tensile fracturing process during the splitting process. A series of scaled model tests were designed and conducted to evaluate the advantageous geometry for the method. Finally, in-situ excavation tests were carried out for a rock slope. The results were compared to the previous method (i.e., drilling-splitting method). It is concluded that the developing method can improve the cutting rate of hard rock.

Keywords: non-vibrating, cutting-splitting, numerical analysis, scaled model test, rock slope excavation.

1 INTRODUCTION

A non-vibration method is being developed because the conventional blasting method causes many complaints from individuals about vibration and noise. Non-vibration methods are frequently used in a various construction site, including underground, pipes, and building, in addition to small sites where it is impossible to access large excavation equipment (Jafri & You 2018). The most popular non-vibration method in South Korea is the drilling-splitting method (Backyang Eng., 2002), which crush the surface to be cut after several holes are drilled (Won et al. 2006). However, the excavation rate of that was recorded 20-25% of the blasting method, which was unsatisfactory level for constructors.

This study tried to develop a new method having rock cutting-splitting mechanism. This consists of two processes of rock cutting and splitting by inserting a chisel into the cutting slots. To increase the cutting efficiency in rock, the optimum dimension of rock block has to be evaluated. A series of scale model tests was performed. From the results, the desirable the optimum cutting spacing (*s*) and depth (*d*) of rock block to cut was evaluated. Then numerical analyses were used to verify the tensile fracturing mechanism and the results of scaled model tests. The numerical results verified the desirable dimension of rock block, and revealed the main mechanism of this method is the tensile fracture formation underneath of cutting lines. The full scale in-situ test was conducted on the rock slope to validate the excavation rate of current method. The detailed procedures are explained in the below chapters.

2 METHODOLOGY AND NUMERICAL ANALYSIS

The rock cutting-splitting processes are composed of cutting a rock to specified cutting depth using a rock saw and then splitting the blocks with a chisel (Figure 1). When the chisel strikes the rock, it makes a tensile stress that causes the rock to fall in the direction of the free surface. The ratio of cut spacing (s) to depth (d) ratio is critical in rock cutting-splitting method. If the ratio is too small, the excavation rate is low. If it is too high, the rock block does not split completely. To define the most efficient dimension of rock block, a series of scale model tests was performed. The results showed that splitting succeeded in the case of spacing depth ratio is 2.0 (s/d= 2) but failed in case of s/d= 3 (Figure 2).

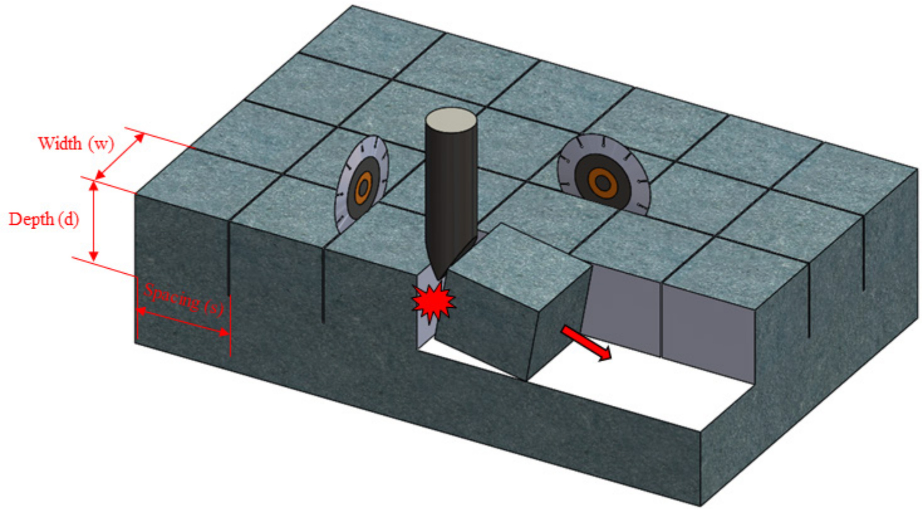
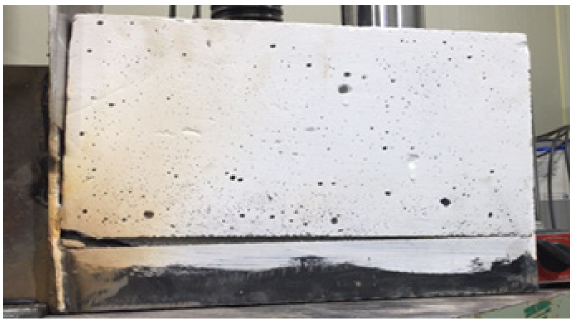


Figure 1. Concept of rock cutting-splitting method.



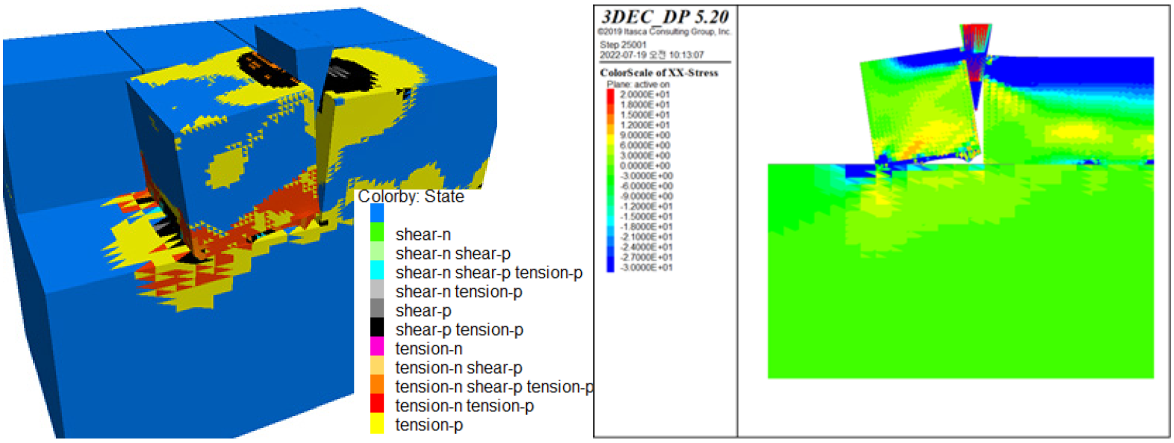
(a) s/d = 2

(b) s/d = 3

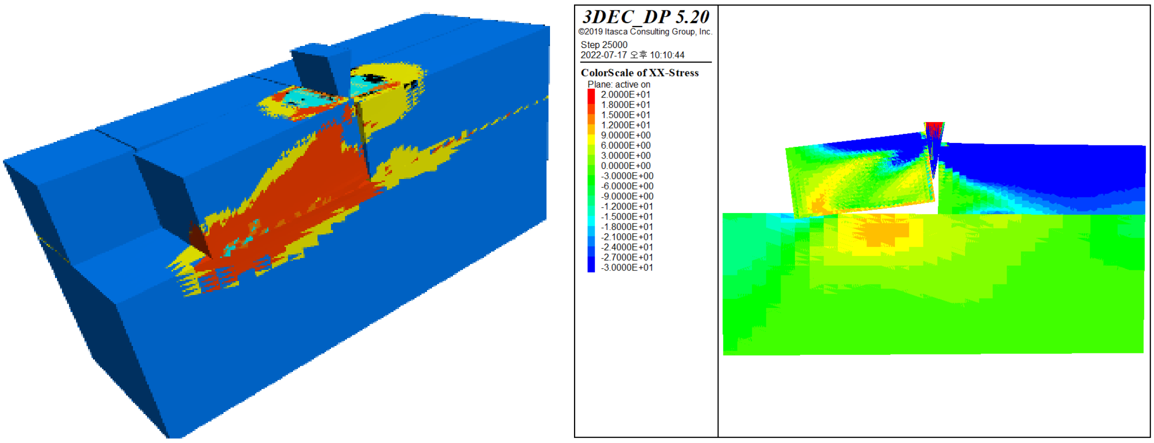
Figure 2. Results of scaled model tests.

A series of numerical analysis was used to verify the scale model testing results. The distinct element method of 3DEC (Itasca Consulting Group Inc., 2013) was adopted to simulate the fracturing mechanism when the rock block was split by chisel insertion. The rock was cut by pre-designed dimensions and the chisel model was vertically penetrated into the cutting slot.

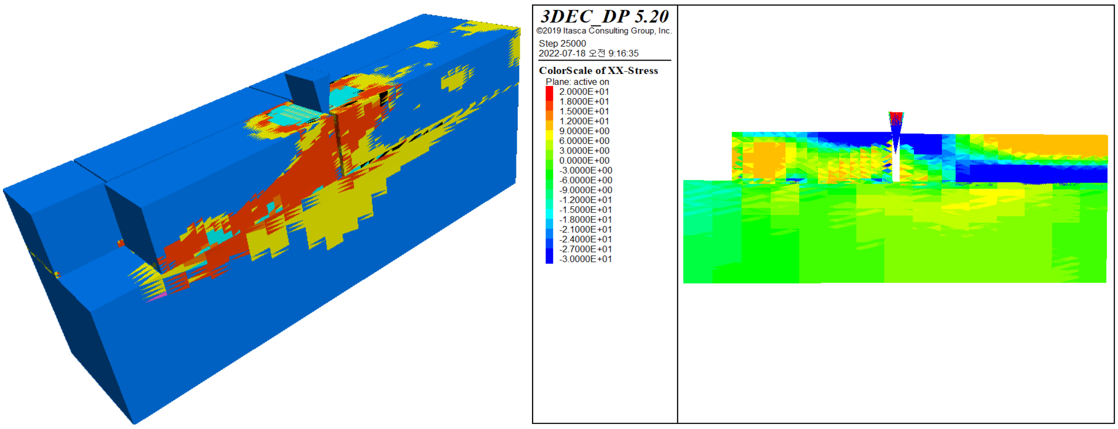
Figure 3 shows the three models of s/d=1, 2, and 3 respectively. The result in Figure 3(a) indicates that the tensile stress was concentrated at the bottom point of cutting slot. The shear failure only occurred on the contact area between chisel and upper rock surface. As the indenter are inserted, the plastic regions (yellow color) of tensile stress were created first. Then the tensile fractures (red color) on the baseline were propagated toward the free face. Figure 3(b) shows the result of s/d=2, in which the tensile fractures are developed and the block split well from the baseline. Figure 3(c), s/d=3, shows the tensile fracture zone were widely occurred, but the rock block was not fully split out. This means the normal force of chisel was used not only to induce tensile fracture but to create large shear stress zone. Thus, the undesirable fracture by shear stress was formed as shown in the scaled model test (Figure 2(b)). The simulation verified the basic mechanism of cutting-splitting method is tensile failure. It was confirmed that the maximum ratio of spacing to depth in hard rock is 2.



(a) Stress distribution of spacing (*s*): depth(*d*)=1:1



(b) Stress distribution of *s:d* =2:1



(c) Stress distribution of *s:d* =3:1

Figure 3. Numerical simulation results by 3DEC.

3 IN-SITU TEST

A newly developed rocksaw prototype model was attached on a 50-ton excavator to cut the rock slope. Then, in-situ rock cutting tests were conducted on hard rock slope (Figure 4(a)). The desirable cutting/depth ratio 2 from the scaled model test was applied to the in-situ test. To follow the ratio, the cutting spacing of vertical line and cutting depth were set to 1 and 0.5 m, respectively. Figure 4(c) shows the cutting lines on the rock slope, the spacing of adjacent line is 1.0 m. After 6 lines having 6.5 meters in length, were cut in 87 minutes, rock splitting was carried out by inserting a chisel into the cut position.

Including equipment movement time and muck hauling time, the total working time was 155.5 minutes. The excavated volume was measured by photogrammetric method. The total volume was 23.16 m^3 was excavated. The net cutting rate and actual cutting rate was 11.6 and 8.94 m^3/h, respectively. This represents an improvement of over 80% in net cutting rate compared to split drilling method (Backyang Eng., 2002) in Korea. The resulting data shows a competent level to apply to real construction sites (e.g. rock slope and tunnel excavation).

(a) Rock cutting by rocksaw prototype (b) Cut lines on rock slope

(c) Splitting processes

Figure 4. In-situ test of rock cutting-splitting method.

4 CONCLUSIONS

A cutting-splitting method is newly developed to enhance the cutting rate of mechanized excavation method. In this study, scaled model tests were adopted to determine the proper ratio of cut spacing to depth, and numerical simulations were conducted to verify the testing results. Rock slope excavation test was carried out as an in-situ test to validate the cutting performance.
The results of this study are summarized as follows.

1. From the scaled model tests, the desirable spacing to depth ratio (s/d) was 2.
2. Numerical analysis revealed that hard rocks can be split using a cut spacing to depth ratio of 2/1, and the basic mechanism was tensile failure of basement of rock block.
3. Finally, an in-situ test was conducted on a hard rock slope, and the net cutting rate was found to be 11.6 m^3/hr.

Therefore, it appears that the rock cutting-splitting method can significantly improve cutting speed on hard rock compared to previous drilling-splitting methods.

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