The 2021 World Congress on
Advances in Structural Engineering and Mechanics (ASEM21)
GECE, Seoul, Korea, August 23-26, 2021

Feasibility analysis of rock cutting-splitting method by scaled model tests

Chang-Heon Song[1)], Dae-ji Kim[2)], Dae-Ji Kim[3)], Joo-Young Oh[4)], Jung-Woo Cho[5)*], Mun-Gyu Kim[6)] and Sang-Hwa Yu[7)]

[1-5)] *Construction Equipment Technology Center, Korea Institute of Industrial Technology, Gyeongsan-si, 38408, Korea*
[6)] *Hochang Engineering Co., Chuncheon-si, 24233, Korea*

[5*)] *chojw1665@kitech.re.kr*

ABSTRACT

A rock cutting and splitting method is under developing to improve the rock excavation performance. The key mechanism of the method is fracturing on the base plane of rock blocks by indenting a chisel into the cutting lines. This method can improve the rock penetration rate during mechanized excavation process. A series of tests were designed and conducted to evaluate the advantageous geometry for the rock splitting process. The results showed that the maximum splitting spacing of rock blocks was 2 times of cutting depth. According the results, the excavation performance of current method was compared with the previous drilling and splitting method.

1. INTRODUCTION

Recently, drilling and blasting method are not permitted in the urban area, many mechanized tunneling methods (e.g. hydraulic breakers, drilling-splitting method, and roadheaders, TBMs) are adopted in the tunneling sites in South Korea. Hydraulic breakers also incur noise and vibrations, and drilling-splitting method and roadheaders showed slow tunneling performance when encountering hard rocks. TBMs can show the high performance but the economic feasibility is satisfactory for the long tunneling site. Thus, previous methods has some limitations to alternate the drilling-blasting method.

A new tunneling method having cutting-splitting procedure is under developing to improve the rock excavation performance. The key mechanism is tensile fracturing on the base plane of rock blocks by indenting a chisel into the cutting lines (Kim et al., 2019). The method can improve the excavation rate of rock excavation project. Because a large rock chips (i.e., split rock blocks) can be produced from the rock mass, this save the energy and time to break rocks into small particles. If the rock blocks are larger, the excavation rate is higher.

[1-5)] Principal researcher
[6)] Professional engineer

To guarantee the tensile fracturing of rock blocks, scaled model tests of cutting-splitting process were designed. Four kinds of strength model was selected for the tests. A series of tests were conducted to evaluate the advantageous geometry of rock splitting process. The excavation performance of current method was quantitatively compared with the previous drilling and splitting method. This method can show a high excavation rate for hard rocks because a large rock blocks can be extracted. Also, it is expected to significantly reduce the vibration comparing the blasting method.

2. METHODOLOGY

2.1 Proposed method

The proposed method is cutting-splitting method which is consisted of two processes: cutting and splitting. First step is rock cutting by a rock saw according to the predesigned dimensions (regular spacing, width and depth). Then, a sharp chisel is percussed into the cutting slot to propagate the tensile crack on the bottom surface of rock mass (Fig. 1).

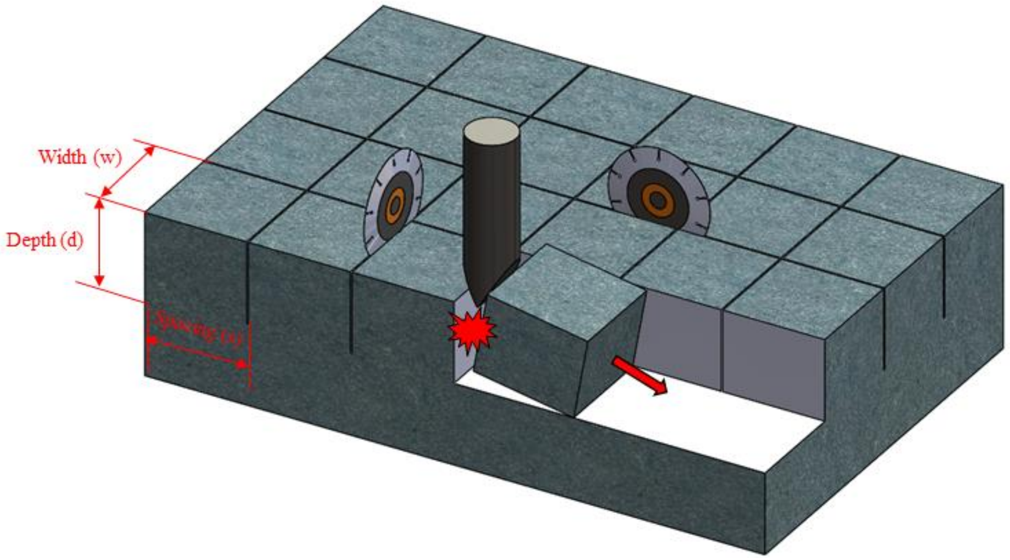


Fig. 1 Conceptual diagram of rock cutting-splitting method

2.2 Dimension analysis for scaled model

Scaled model tests are planned to evaluate the advantageous conditions of the method. The method has no previous data or references, the optimum cutting geometry, chisel angle for each rock strength should be defined. The real scale tests are expensive and time consuming works, so the scale model test are performed to reduce the costs.

The ratio of scaled model to real rock was determined as 0.2. The density ratio of cement mortar of scaled model to real rock was 0.923. Based on this two ratio values, the strength ratio for scaled model was calculated as 0.185 by the dimension analysis (Table 1). The target strength values of four rocks were calculated and listed in Table 2.

The cement mortar samples were cured and tested according the four strength levels (i.e., 2.8-31.4 MPa).

Table 1 Dimension analysis of scaled model

Scaled dimension				Dimension analysis		
Variable	Parameter	Real model	Scaled model	Ratios	Dimension	value
Material	-	Rock	Cement mortar	Ratio of length	-	0.2
Density	ρ	2.6	2.4	Ratio of density	M/L^3	0.923
Total height	H	1500	300	Ratio of gravitational acceleration	L/T^2	1
Cut depth	D	800	160	Ratio of time	T	0.447
Cut spacing	S	1600	160	Ratio of mass	M	0.007
Cut width	W	1600	160	Ratio of strength	$M*L^{-1}*T^{-2}$	0.185

Table 2 Target strength of scaled model

Level	Minimum	Maximum	Mean	Target strength of scaled model
Extremely High strength	240	300	270	49.8
High strength	100	240	170	31.4
Medium strength	50	100	75	13.8
Moderate strength	25	50	38	6.9

2.3 Design of experiment

The three main design factors are selected as strength, cut spacing, and chisel angle. The method is planned to produce a cubic rock blocks, so only spacing dimension is only geometry factor. The cut depth was fixed to 160 and the cut spacing/depth was in the range of 1.0~4.0. Four levels for each factor are determined in Table 3. The total design of 16 experiments are listed in Table 4.

Table 3 Design factor for scaled model tests

Design factor		Level			
No.	Factor	Lv.1	Lv.2	Lv.3	Lv.4
A	Rock strength	Moderate strength	Medium strength	High strength	Extremely High strength
B	Cut spacing	160	320	480	800
C	Chisel angle	2	3.5	7	10

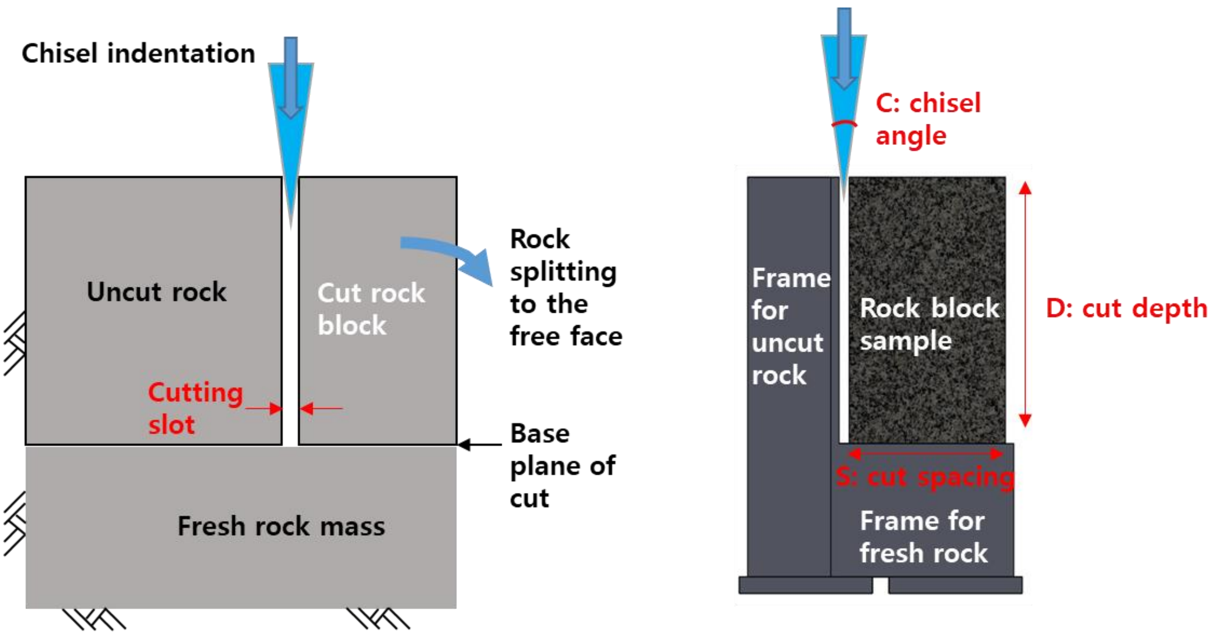
3. Scaled model tests

3.1 Testing jig

The main purpose of the test is evaluation of optimum cutting condition for the cutting-splitting method. Thus, the cutting slots for each block were pre-cut before the scaled splitting experiments. The testing concept and testing jig designed for the testing are shown in Fig. 2.

Table 4 List of designed 16 experiments

Exp. No.	A	B	C
1	Moderate strength	160	2
2	Moderate strength	320	3.5
3	Moderate strength	480	7
4	Moderate strength	800	10
5	Medium strength	160	3.5
6	Medium strength	320	2
7	Medium strength	480	10
8	Medium strength	800	7
9	High strength	160	7
10	High strength	320	10
11	High strength	480	2
12	High strength	800	3.5
13	Extremely High strength	160	10
14	Extremely High strength	320	7
15	Extremely High strength	480	3.5
16	Extremely High strength	800	2

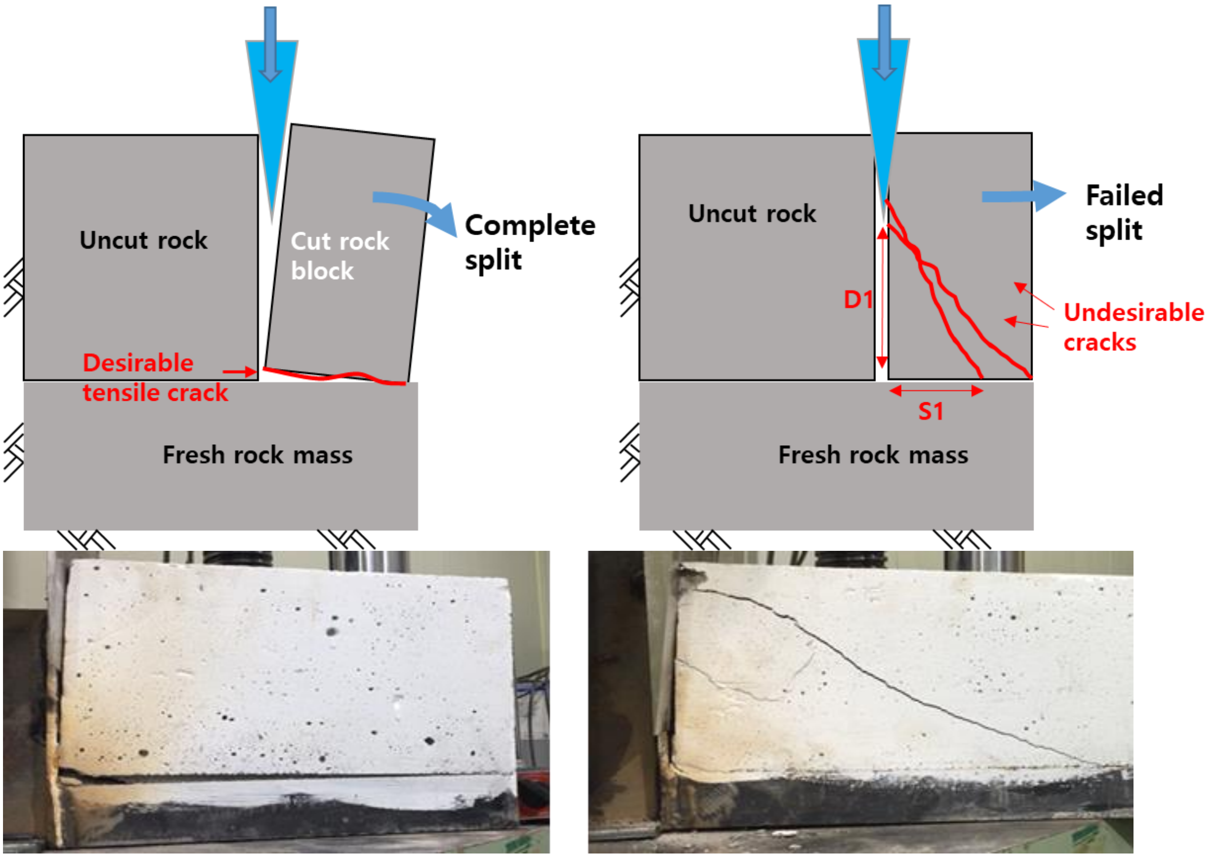


(a) (b)

Fig. 2 Scale model test: (a) Concept diagram of cutting-splitting method, (b) designed testing jig.

3.2 Decision of testing results

The success of scaled model testing was categorized into two groups: complete and failed split as shown in Fig. 3. The success case was defined when the tensile crack propagates according to the base plane of cut (Fig. 3(a)). Other cases with undesirable crack was decided as failed split (Fig. 3(b)). The uncut depth and spacing were recorded as D1 and S1 respectively. This incomplete split blocks need additional rock splitting or breaking procedures, the cutting-splitting method is no longer efficient or economical for rock excavation.



(a) (b)

Fig. 3 Decision of scaled testing results: (a) complete, (b) failed split.

3.3 Testing results

The testing results were summarized in Table 5. All the cases of ratio cut spacing (S) to depth (D) =1.0 were completed and one case of S/D=2/1 at medium strength was failed. All the cases of S/D=3.0-4.0 were failed. The output means the case of S/D=1.0 can be successfully cut and split by the method.

Based on the results, the variance analysis was conducted. The contribution rate was calculated in Table 6. The cut spacing was a significant factor for the completion of method, because the contribution rate of this for the complete decision was 81%. This means that the cutting geometry (i.e., cut spacing and depth) is the most important factor to design the rock excavation work. The scaled model ratio to real scale was 1/5, so the desirable geometry is 800 mm of cut spacing when the cut depth is 800 as well. In other words, the real dimension of 800*800*800 mm rock block is suitable for the cutting-splitting method

Table 5 Results of scaled model splitting tests.

Rock class	Case No.	S_{scaled}	D_{scaled}	W_{scaled}	Chisel angle	Max. force	Max. displaceme	S1	D1	Decision
		(mm)	(mm)	(mm)	(deg)	(kN)	(mm)	(mm)	(mm)	
Moderate strength	1	160	160	160	2	4.05	47.43	-	-	Complete
	2	320	160	160	3.5	4.90	85.82	-	-	Complete
	3	480	160	160	7	31.7	158.9	401	115	Failed
	4	800	160	160	10	42.45	82.74	716	40	Failed
Medium strength	1	160	160	160	3.5	6.10	43.19	-	-	Complete
	2	320	160	160	2	22.85	155.78	255	0	Failed
	3	480	160	160	10	57.05	91.92	390	60	Failed
	4	800	160	160	7	55.20	113.96	570	10	Failed
High strength	1	160	160	160	7	3.45	20.11	-	-	Complete
	2	320	160	160	10	7.94	106.98	-	-	Complete
	3	480	160	160	2	15.44	153.62	380	0	Failed
	4	800	160	160	3.5	36.00	152.46	735	0	Failed
Extremely High strength	1	160	160	160	10	12.95	22.21	-	-	Complete
	2	320	160	160	7	44.90	162.78	-	-	Complete
	3	480	160	160	3.5	18.39	138.32	405	0	Failed
	4	800	160	160	2	110.55	165.32	621	0	Failed

Table 6 Contribution rate of design factors on testing results

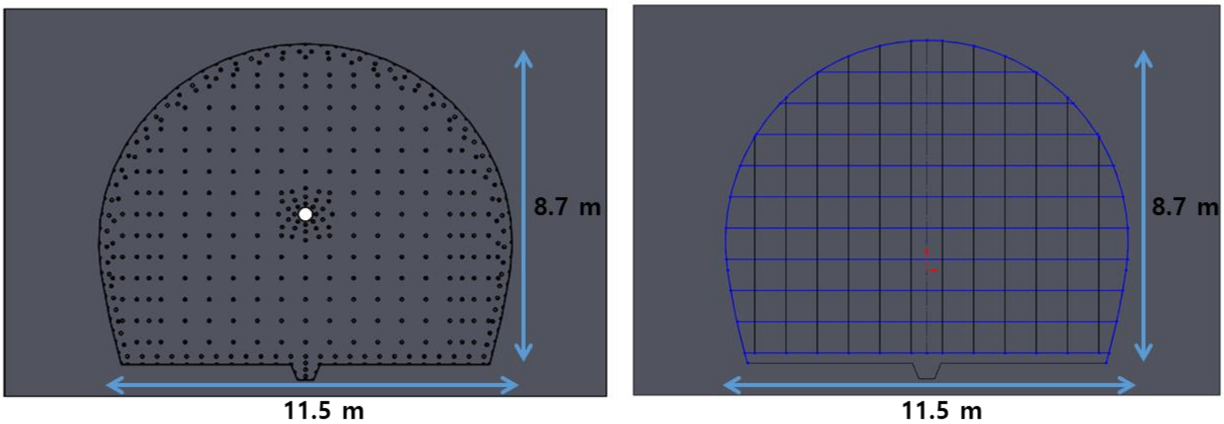
Design factor		Contribution rate		
No.	Name	Max. Force	Max. Displacement	Complete/Fail
A	Rock strength	19.8%	4.3%	4.8%
B	Cut spacing	53.5%	70.8%	81.0%
C	Chisel angle	8.9%	15.5%	4.8%
-	Error	17.8%	9.4%	9.5%

4. DISCUSSIONS

The cutting geometry of the new method was determined in the paper. The consuming time for tunnel excavation was compared to the previous drilling-splitting method (Won et al., 2006). The 8.7*11.5 m dimension of tunnel was selected for the comparison (Fig. 4). The tunnel face, drilled space, cut length and volume was precisely drawn by CAD (computer-aided design) program. Fig 4(a) shows the drilled tunnel face of the previous

Super wedge method (2002), in which the core part has more drill holes located closely. Whereas, the cutting lines of new method are arranged with a regular spacing (i.e., 800 mm).

The drilling and cutting rate was input and the working time and total consuming time was calculated. The results were listed in Table 7. The new developing method of the study showed 141% reduction time than the previous one. This means that the cutting-splitting method can enhance the tunneling rate up to 41%.



(a) super wedge method (b) new cutting-splitting method

Fig. 4. Works of previous drilling and new cutting methods for tunnel excavation.

Table 7. Excavation time of previous and new methods

Index	Abbr.	Unit	Previous	New
Drilled/cut volume	Vd	m^3	3.16	1.18
Excavated rock volume	Ve	m^3	58.2	58.2
Drilled to excavated volume ratio	Vd/Ve	-	0.05	0.02
Drilling/cutting time	Td	hr	11.8	5.1
Splitting time	Ts	hr	11.3	11.3
Total time	Tt	hr	23.05	16.40
Time reduction ratio	Rr	%	100%	141%

5. CONCLUSIONS

The paper introduced a new method with cutting and splitting process as anti-vibration method for tunnel excavation. The mechanism was briefly explained and the feasibility was evaluated by the scaled model tests. The testing results conclude as follows.

1) The cutting geometry (i.e., cut spacing and depth) is the most important factors to design the rock excavation work.
2) The desirable ratio of cut spacing to depth was 1/1 for excavation the moderate and intermediate rocks, that ratio was possible up to 2/1 for the hard and extremely hard rocks.

3) According the 1/1 ratio value, working time for a specific tunnel face was calculated and the new method proposed in the study can increase the excavating rate up to 41% compared to the previous method.

The conclusions were derived based on the scaled model testing results, so that is current limitation of the paper. For the exact validation, a series of real scale model tests should be carried out in the future.

Acknowledgement: This research was supported by a grant (21TBIP-C160989-01) from Technology Business Innovation Program (TBIP) funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCES

Kim D.J., Song C.H., Oh J.Y., Lee S.M., Cho J.W., (2019), Optimization of HJC material model for Mode I fracturing simulation of rock, Spring symposium of Korea Society for rock mechanics (2019. Mar. 28).

Li HY, and Shi GY. (2016), A dynamic material model for rock materials under conditions of high confining pressures and high strain rates, International Journal of Impact Engineering, 89, pp. 38-48.

Won Y.-H., Kang C.-W. Ryu C.-H., (2006),The Study of noise and vibration on application of the method breaking & excavating rock (Super wedge), 2006 fall symposium of Korea society for explosices and blasting engineering (2006 Oct. 19).

Super wedge method (2002), New Excellent Technology (NET) No.336. Ministry of Land, Infrastructure and Transport of Korean government.