New Rock-Fracturing Excavation Method for Hard Rock Tunneling by FON Drill and FASE Method

Tatsuya Noma*, Mitsutaka Hada*, Toshiro Tsuchiya**, Shinji Nakayama***

* FUJITA CORPORATION Technical Institute, 74 Odanacho, Tsuzuki-ku, Yokohama, 224, Japan
** FUJITA CORPORATION Hiroshima Regional Office, 8-6 Nakamachi, Naka-ku, Hiroshima, 730, Japan
*** BRIDGESTONE CORPORATION Products Development Dept., 1, Kashiwaocho, Totsuka-ku, Yokohama, 244, Japan

ABSTRACT

A new rock-fracturing excavation method for hard rock tunneling is developed using a slot made by continuous hole drilling and fracturing toward the slot using a rubber-tube-type fracturing machine. This paper gives an outline of the method of making a slot by continuous hole drilling, the fracturing machine and its system, and the actual tunnel excavating procedure.

1. INTRODUCTION

It is well known that blasting is the most effective and least costly method of fracturing and excavating rock mass. However, this method involves tremendous shock waves and noise, and is not suitable for building tunnels near residential areas. A great deal of the construction now under way in Japan is near residential areas.

The Kaminiko-tunnel, now being excavated at Kure City in Japan, is just such a case.

This tunnel has these restrictions: 1)There is a cluster of houses in the neighborhood of the working site. 2)There are many rocks over the excavation route. Even if protective measures are taken, such rocks may fall because of the vibrations due to blasting.

So, the blasting method cannot be used for all parts of the tunnel excavation. And, the mountainous area of the tunnel route consists of granite rock with compressive strength greater than 200MPa, making simple conventional mechanical excavation such as with a partial face machine impossible. Consequently, after forming a slot (free face) by drilling continuous holes at the tunnel face, excavation of the tunnel is carried out using a rock-fracturing method that fractures rock toward the slot.

While a variety of slot formation methods have been developed [1], problems relating to the need for specialized equipment, formation efficiency, and the continuity of the slot remain. This tunnel uses general purpose equipment in the slot method, and a continuous hole drilling method was developed which was superior to conventional methods in terms of efficiency and accuracy of continuity.

Furthermore, we are also currently working on a new rock-fracturing method. Many static (non-blasting) fracturing methods such as the expansive agent method, hydraulic wedge method, and pressurizing method using gas or water have been developed [2]. However, all of these methods meet with problems of safety and require fracturing machines of too large a scale. In this paper, static fracturing is defined as producing cracks in the rock bed to reduce its strength (primary fracturing) and then completely fracturing it with a breaker or ripper (secondary fracturing) [3].

The authors have been investigating hydraulic-based fracturing methods using high-pressure rubber tubes as a means of primarily fracturing rock bed with ease and efficiency [4]. We tried to expand this method for tunnel excavation, and applied it to this tunnel.

This paper summarizes the methods of the continuous hole fast drilling system and new rock fracturing system.

2. CONTINUOUS HOLES FAST DRILLING SYSTEM —FON DRILL METHOD—

In this slot formation method, single holes are drilled continuously in order to maximize the capacity of the general purpose drill. When drilling the continuous holes, there is a tendency for the hole curves to lean toward the existing hole next to the rod bit. To prevent this, a drilling system was developed whereby a SAB(Spinning Anti-Bend) rod is inserted into the existing hole next to where the hole is to be drilled, and the bit is brought into contact with and knocks this rod.

This prevents gaps from forming between the bit and the SAB rod and the continuity of the slot is maintained. The construction of this SAB-rod allows it to be rotated, and the reduction in friction during drilling brought about by the contact and knocking makes high-speed drilling possible. Figure 1. shows the concept of the SAB rod system, and Figure 2. shows the continuous hole construction procedure. The procedure is as follows: ① Insert the SAB rod into the existing hole. ② Commence drilling. Drill while rotating the bit and knocking it against the SAB rod. The rotation power of the bit will rotate the SAB rod, thereby making high-speed drilling possible. ③ Drilling is carried out to the designated depth. ④ Two continuous holes are formed, the SAB rod is inserted into the second hole, and the procedure is repeated, forming a slot (free face).

Furthermore, as the SAB rod can be rotated, wear on the rod and bit are reduced, and the SAB rod itself wears more evenly, leading to a longer service life. This method involves attaching the SAB rod to a bracket on the tip of the feed. Insertion and withdrawal are carried out using the slide on the feed. The continuous hole drilling capacity in hard granite (such as was encountered in this tunnel) using a 102 mm diameter bit, was approximately 3.5～4.0 ㎡/h with a hole depth of 1.1 m. Figure 3. shows the relationship between continuous hole drilling ability and rock strength.

The features of this method are not limited to high operation capacity. Ease of attachment/removal of the SAB rod and reduced congestion of the workspace can be expected

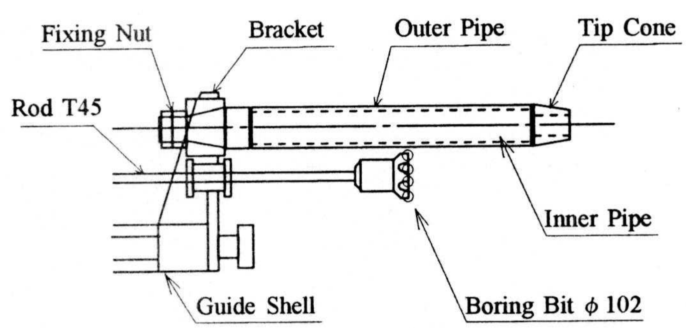

Figure 1. Concept of SAB rod

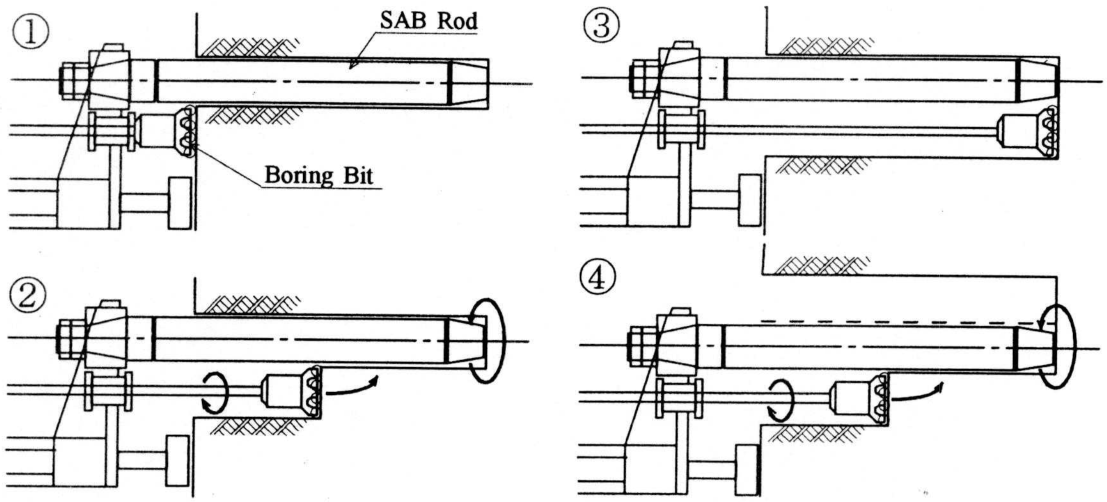

Figure 2. Procedure of continuous hole drilling

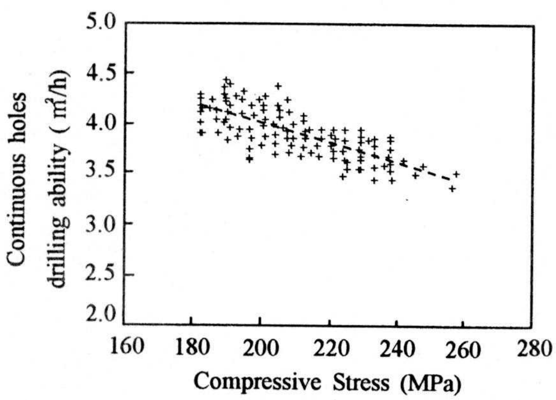

Figure 3. Relationship between continuous hole drilling ability and rock strength

Figure 4. Continuous hole drilling

because drilling of rock-fracturing holes and rock bolting can be carried out by the same machine. Furthermore, the only consumable part of the SAB rod is the thick pipe, making it very economical in terms of parts replacement.

This method was named "FON (Fast, Onside and Nonpareil) Drill Method" because its high operation capacity and accuracy of continuity.

Figure 4. shows the state of continuous hole drilling.

3. FRACTURING MACHINE AND SYSTEM -FASE METHOD-

We sought to develop a fracturing system that could break down masses of rock quietly, easily, efficiently, safely and economically. In this paper, we give an outline of a rubber-tube-type fracturing machine (hereinafter called the Aqua-Splitter) and its system.

3.1 Rubber-tube-type Fracturing Machine

Figure 5. illustrates the concept of the rubber-tube-type fracturing machine. The Aqua-Splitter consists of a high-pressure rubber tube, a rubber protector, and a steel loading plate. Rubber is the principal material of the Aqua-Splitter because it is lightweight (80N), yet has high crushing force (maximum working pressure: 50 MPa). Due to the device's configuration, it can be used repeatedly and the direction of cracking can be controlled. Also, many Aqua-Splitters can be used at the same time (10 Aqua-Splitters can be used for 1 unit), thereby improving the efficiency of fracturing work.

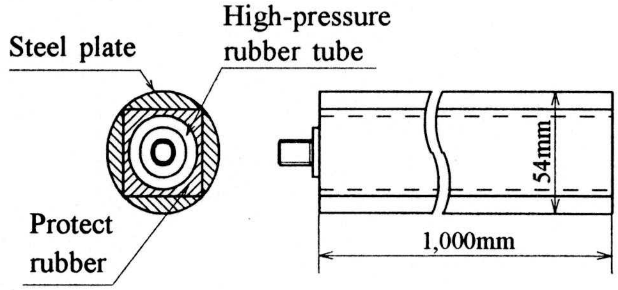

Figure 5. Concept of Aqua-Splitter

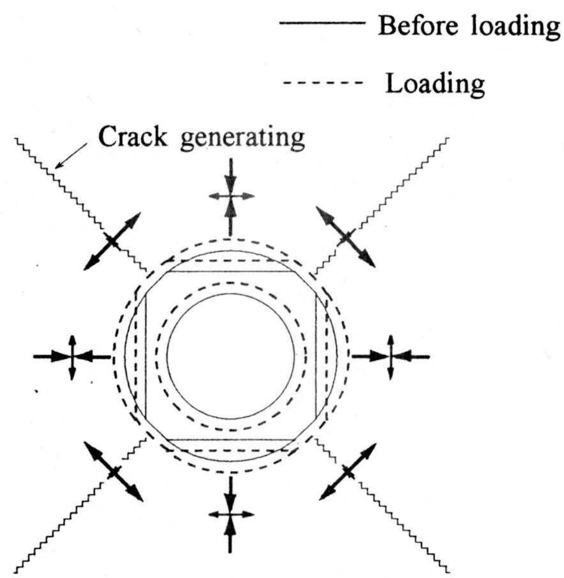

Figure 6. Mechanism of fracturing

The mechanism of the Aqua-Splitter is as follows: First, the Aqua-Splitter is inserted into a bore hole. Next, by providing high liquid pressure to the high pressure tube, the high pressure tube and the rubber protector are expanded and transmit the pressure to the loading plate. Figure 6. shows a typical model of the motion of the high-pressure rubber tube, the rubber protector, and the loading plates and also shows the generated principle stresses in the rock mass caused by high liquid pressure as analyzed by the finite element method. According to this figure, the compressing force at the top of the loading plates which are arranged at right angles to each other results in tension at the point between them. This tension fractures the rock mass. The 90-degree angle between the loading plates allows tension to be exerted in four directions, enabling the direction of fracturing to be controlled, and rock mass fracturing to be effectively performed. In addition, the rubber protector protecting the high pressure tube prevents the tube from being damaged upon abrupt pressure release during rock mass fracturing so that it can be used repeatedly.

3.2 Fracturing System

Figure 7. outlines the fracturing system. The system consists of a hydraulic unit, a control microcomputer, and the Aqua-Splitter mentioned previously. The hydraulic unit converts oil pressure, which is generated by a hydraulic pump, into water pressure, and at the same time,

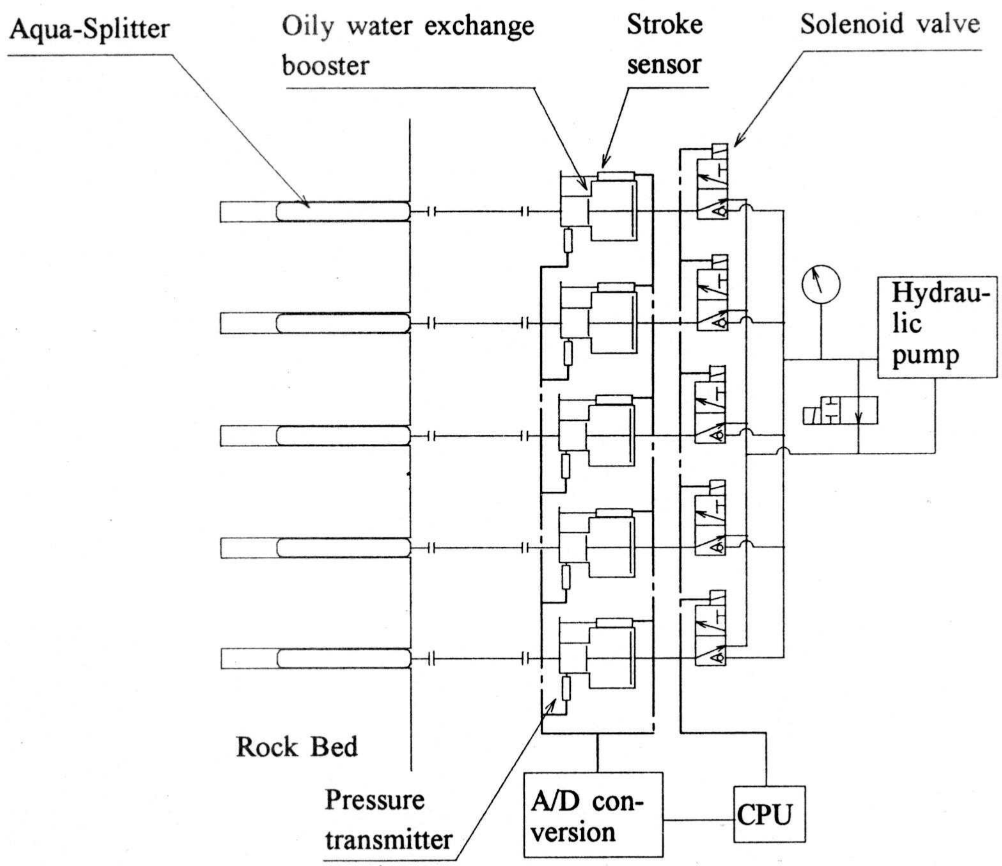

Figure 7. Fracturing system

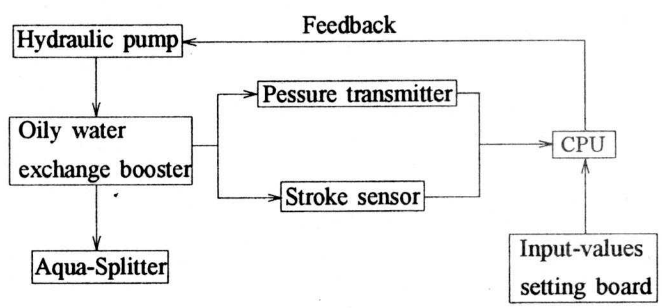

Figure 8. Control flow of pressure

amplifies the water pressure using an oily water exchange booster. The purpose of exchanging oily water is to protect the rubber against oil-induced deterioration.

A control microcomputer is introduced to control the pressure and water-supply rate. Figure 8. shows the control flow of pressure. The system applies pressure to the Aqua-Splitter through the oily water exchange booster , which consists of a piston and primary and secondary cylinders. By installing a pressure transmitter in the cylinder of the oily water exchange booster, it is possible to monitor and control the amount of pressurized water to be supplied to the Aquq-Splitter, based on pressure readings and the piston ejection volume, which is measured with a stroke sensor.

To be more specific, loading stops when a large crack is produced in the rock bed, at which time the pressure drops sharply. Loading also stops automatically when the stroke reaches a preset level even if the pressure does not drop. This control method prevents the fracturing machine from expanding excessively, thereby markedly reducing the likelihood of damage to the machine.

This method was named FASE (Fujita Aqua-Splitting Excavation) Method.

4. TUNNEL EXCAVATING PROCEDURE

In this tunnel, the excavating procedure includes the following tasks: marking the tunnel face, drilling fracturing holes, drilling continuous holes, primary fracturing by Aqua-Splitters, secondary fracturing by braker, mucking, shotcreting, and rock bolting.

Figure 9. shows the pattern of fracturing holes and continuous holes of this tunnel. Where compressive strength was greater than 150 MPa along the tunnel route, slots were drilled along the periphery and at the center of the tunnel, one line was in a vertical direction, two lines were in a horizontal direction, to form 6 divided blocks, then each block was fractured by the Aqua-Splitter.

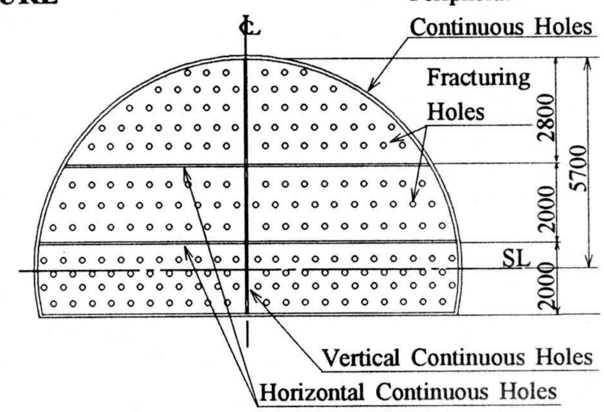

Figure 9. Continuous and fracturing hole pattern

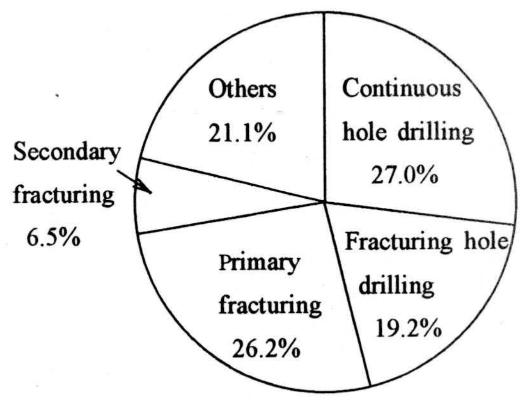

Figure 10. Cycle time

The total drilling line was 62m, and a 102 mm diameter bit was used for drilling. The total number of drilling holes was about 700 because of the lapping zone for continuous holes. Although many drilling holes are needed for slot formation, the continuous hole drilling capacity of the new method is as high as 3.5 to 4.0 m^2 /h as mentioned previously, and a 3-boom jumbo was used for this tunnel, so the rate of continuous hole drilling is 27% for the cycle time as shown in Figure 10. Because a 102 mm diameter bit was used, the width of the free face was broader than in the conventional method (which uses a 65 mm diameter) and the slot continuity was very accurate. The total cycle time could therefore be reduced.

After continuous hole drilling, the tunnel face was fractured by the Aqua-Splitter as shown in Figure 11. The Aqua-Splitter's rock fracturing ability is 5MN. This is less than that of the conventional method (the hydraulic wedge has a rock fracturing ability of 10MN). For this reason, 17 to 20 fracturing holes were drilled horizontally in a straight line for each block. Then 17 to 20 Aqua-Splitters were inserted into the fracturing holes, and 2 hydraulic units were used to create pressure, thereby generating a long and massive crack in one operation.

Primary fracturing was therefore effective, since a long and massive crack could be

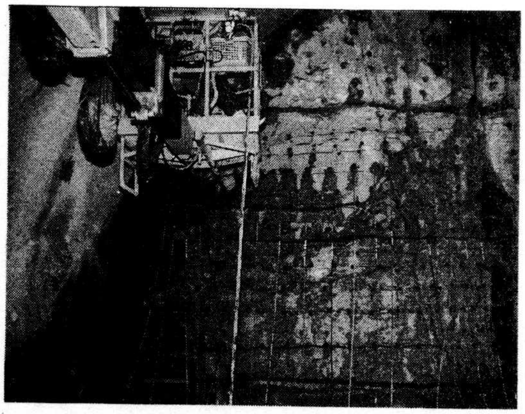

Figure 11. Primary fracturing by Aqua-Splitter

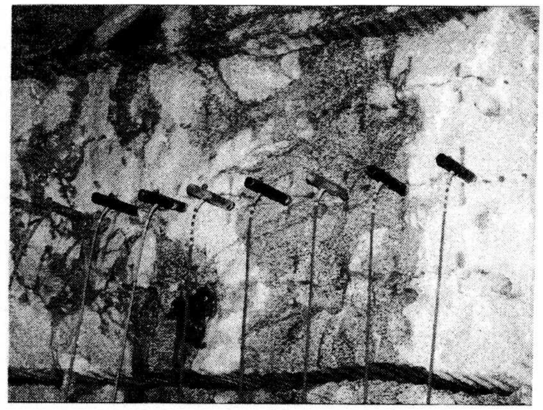

Fig 12. Crack generating

generated in one operation.

The horizontal interval along the line of fracturing holes was about 40 to 50 cm. This interval allowed easy secondary fracturing.

The pressure applied by the Aqua-Splitter for fracturing the rock was about 20 to 30 MPa and pressure was applied for about 2 minutes. The process of applying pressure using the Aqua-Splitter was repeated more than 30 times. Figure 12. shows crack generating.

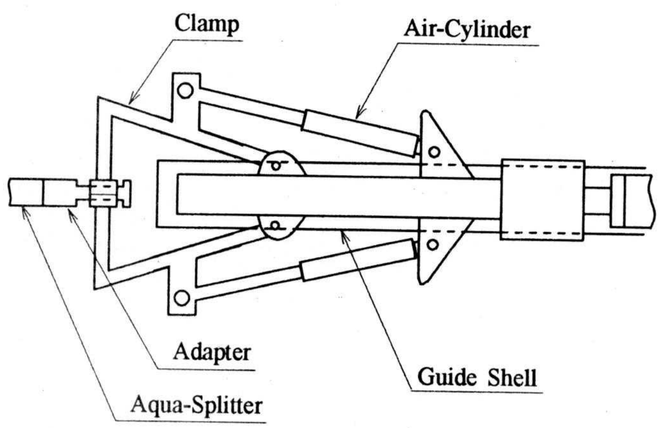

Figure 13. Inserting and removing machine

Comparing this method to the hydraulic wedge, a conventional engineering method, it has the following advantages: a long and massive crack is opened in one operation; the rock-fracturing holes are small in diameter; and there is no need for excess length of rock-fracturing holes.

However, there was danger of the tunnel face collapsing because of generating a long and massive crack, so it was necessary to keep away from the tunnel face. Consequently, the work of inserting the Aqua-Splitter into the fracturing hole and removing it from the hole was carried out not by manpower but by machinery. For this reason, the inserting and removing machine shown in Figure 13., was mounted on the guide shell of the jumbo. By using this machine, the task of inserting and removing the Aqua-Splitter could be performed from the driver's seat of the jumbo. The mechanism of this machine is as follows: Grip the adapter, which is connected to the bottom of the Aqua-Splitter by the clamp, then slide the guide shell to insert or remove the Aqua-Splitter. By adopting this machine, primary fracturing could be carried out safety.

After these processes have been repeated, secondary fragmentation is carried out using a breaker, which completes the excavation procedure. Figure 14. shows secondary fracturing.

Figure 14. Secondary fracturing

5. CONCLUSION

We have outlined the new rock-fracturing excavation method for hard rock tunneling. This method has two key points. One point is the method of continuous hole drilling with a SAB rod. The advantages of this method are not only efficiency and accuracy of continuity, but the option of using a general purpose jumbo. Another point is the primary fracturing using the Aqua-Splitter. The advantages of this method are that it generated a long and massive crack in one operation, and rock fracturing holes are small in diameter and there is no need for excess length.

Because this method hardly damages the rock around the tunnel being excavated, it seems that this method is suitable for tunnel excavating for various waste.

REFERENCES

1. Hagimori, K., Furukawa, K., Nakagawa, K., Yokozeki, Y. 1991: Study of non-blasting tunneling by slot drilling method, Proc. 7th ISRM Int. Congr. on Rock Mechanics, 1991, Aachen, pp. 1001-1004.
2. Nakagawa, K. 1987.: Recent method of excavating of rock mass by non-blasting, "Kyoryo", No. 2, pp. 42-46. (in Japanese)
3. Hagimori, K. 1990.: Study on tunneling into hard rock using a slot drill, Doctoral Thesis of Nagoya University. (in Japanese)
4. Noma, T., Hada, M., Kadota, S., Murayama, H., Ueda, S., 1995. : Development and practical application of the static rock-mass fracturing method using hydraulic pressure, Proc. 8th ISRM Int. Congr. on Rock Mechanics, 1995, Tokyo, pp. 653-656