TUNNELING BY ROCK FRACTURING METHOD UNDER SMALL CROSS SECTION AREA

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INTRODUCTION

Due to new, stricter fire safety standards, new evacuation tunnels are being added to Japanese highway tunnels constructed in the period 1965-1980.

The new evacuation tunnels connect the up and down lanes of existing twin-bore road tunnels, with at least one lane remaining open during the construction period. Therefore, blasting methods that create large noises and vibrations can't be used and contractors are forced to use mechanical excavation.

Machine excavation of hard rock is classified into two types: single machine excavation and rock fracturing methods. The single machine excavation has some limitations: short-distance excavations are not economical using TBMs, and compressive strength can limit use of a partial face machine. Because these evacuation tunnels are put into the center of existing tunnels, ground conditions of excavation are over 200MPa UCS. With tunnel, cross sections of 10-20 m^2 and lengths of 50-60m, it is impossible to excavate by single machine excavation.

So, the rock fracturing method is considered most suitable for machine excavation of hard rock in these tunnels. For the rock fracturing method, a free face is artificially formed at working face. Then, the free face is used to crush rocks.

In this paper, two cases of evacuation tunnel's excavation are described, one's cross section is $20m^2$, and other's cross section is $10m^2$.

SIGNIFICANCE OF FREE FACE

A free face means a face that does not restrict rupture at the time of crushing. When a tunnel is excavated by blasting, only one free face is formed at the working face. In the case of blasting method, the crushing force is strong and excavation has become possible even with a free face as center cut blasting has been devised.

On the other hand, the crushing capacity of the rock fracturing method is less powerful than blasting, and crushing with one free face is impossible. In the other words, though cracks are caused at the working face by some method, it is difficult to cause large cracks when only one free face is formed. Two or more free faces secure rocks-moving space to make cracks larger. So, it is necessary to artificially form free

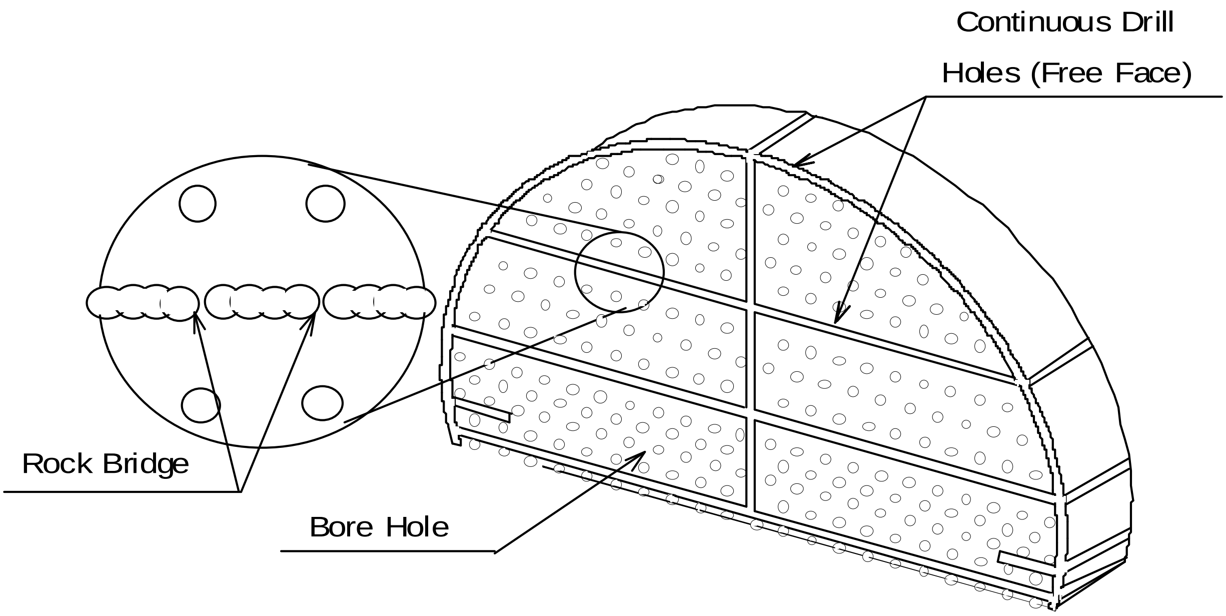

Figure 1 General concept of the free face formation at the tunnel.

faces at the working faces of tunnels.

Figure1 shows a conceptual diagram of free face formation in a tunnel. When a continuous hole is drilled like a groove as shown in the Figurer the working face is divided into blocks. This brings about multiple free faces and makes crushing rocks easy. When natural ground becomes hard, it is difficult to crack it and many grooves should be formed. Continuity and widths of grooves formed influence rock fracturing efficiency. If there remain rock bridges (as shown in the Figure) that interrupt continuity of grooves, a large compressive force is necessary for cracking. Also, the wider the grooves that are formed, the larger the moving spaces created and the easier rocks come to be cut.

However, it takes considerable labor and time to form grooves on hard rocks. So, it is very important for excavating tunnels by the rock fracturing method to form continuous free faces efficiently and economically. The usual method requires a special forming device and has some problems with forming efficiency and accuracy of continuity[1)]. To solve these problems, they have developed the method to drill single holes more efficiently and continuously than by the conventional method[2)].

After the continuous hole drilling, a large-scale hydraulic wedge was used for rock fracturing (primary fracturing). This hydraulic wedge is mounted on a 0.4m3 backhoe, and can fracture a depth of 1m, and needs bore hole as 100mm diameter and 1.6m depth. The hydraulic wedge has the following features (1) high crushing capacity, (2) creates wide cracks and (3) control of crack causing direction. Also, there is a small handheld type hydraulic wedge, so-called “DARDA”, but its fracturing capacity is inferior.

After these processes, a breaker was used for the secondary crushing to complete the rock fracturing.

FREE FACE FORMING METHOD

As mentioned above, they paid special attention to the following points in developing the new free face forming method: (1) High free face forming efficiency, (2) Sufficient maintenance of continuity accuracy and (3) Applicability to general purpose drill jumbo. The following section outlines this method and examines the efficiency of this method. For the free face forming method, they adopted a general-purpose drill jumbo and the continuous drilling method of single hole that can display this ability to the maximum.

In the case of continuous drilling of a single hole, the rod bit is apt to drill a hole that tends towards to a neighboring existing hole. They developed the method to drill a continuous hole by inserting an SAB (Spinning anti-bend) rod (φ89mm) in a neighboring existing hole and by making a bit touch and strike against an SAB rod by using this property.

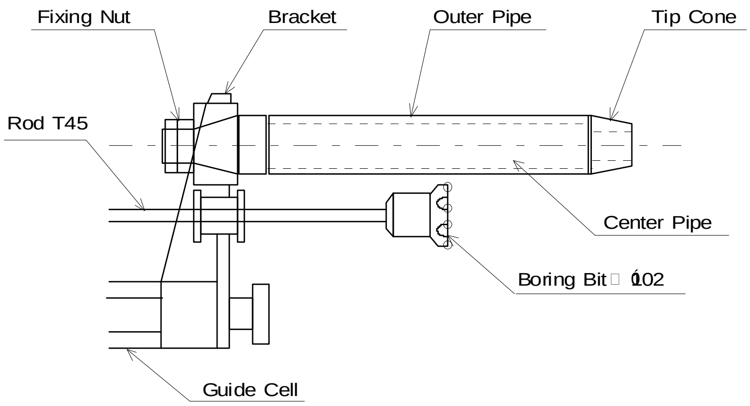

Figure 2 Concept of SAB rod.

Figure 2 shows the schematic diagram of the SAB rod. Contacting the bit to and striking it against the SAB rod at the time of drilling a hole do not cause any clearance between the bit and the rod and secured continuity of a free face. This SAB rod is structured to rotate and enables drilling a hole at high speed when the resistance by contacting and striking at the time of drilling a hole is reduced. The SAB rod is designed to be fitted to the bracket on the tip of the guide cell of a general-purpose rock drill and is inserted and pulled out when the guide cell is moved.

Figure 3 shows the drilling procedures. The drilling procedures are as follows:

(1) Insert the SAB rod in an existing hole.
(2) Start drilling a hole. The bit drills a hole while it touches and strikes against the SAB rod. The SAB rod rotates as the bit rotates, and this makes a high speed drilling possible.
(3) Keep drilling to the specified depth.
(4) Keep inserting the SAB rods one after another and drilling to form a continuous hole (free face). It makes high continuity free face forming possible that the bit touches the SAB rods.

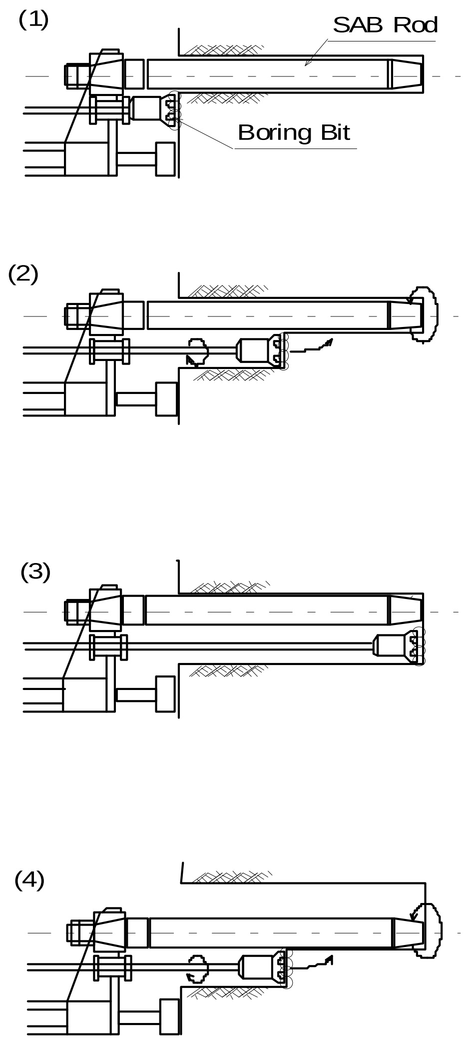

Figure 3 Procedure of continuous hole drilling.

In addition, it reduces wear of rod and bit and makes even the SAB rod itself wear evenly so that the SAB rod can rotate. So, the SAB rod can be used for hours. Also, the consumable part of the SAB rod is the thick pipe only, and the SAB rod is very economical.

As mentioned above, the general-purpose rock drill is generally used for fixing rock bolts and drilling fracturing (or loading) holes, but mounting a SAB rod on a general-purpose rock drill makes it possible to drill continuous holes. So, no dedicated machine is necessary.

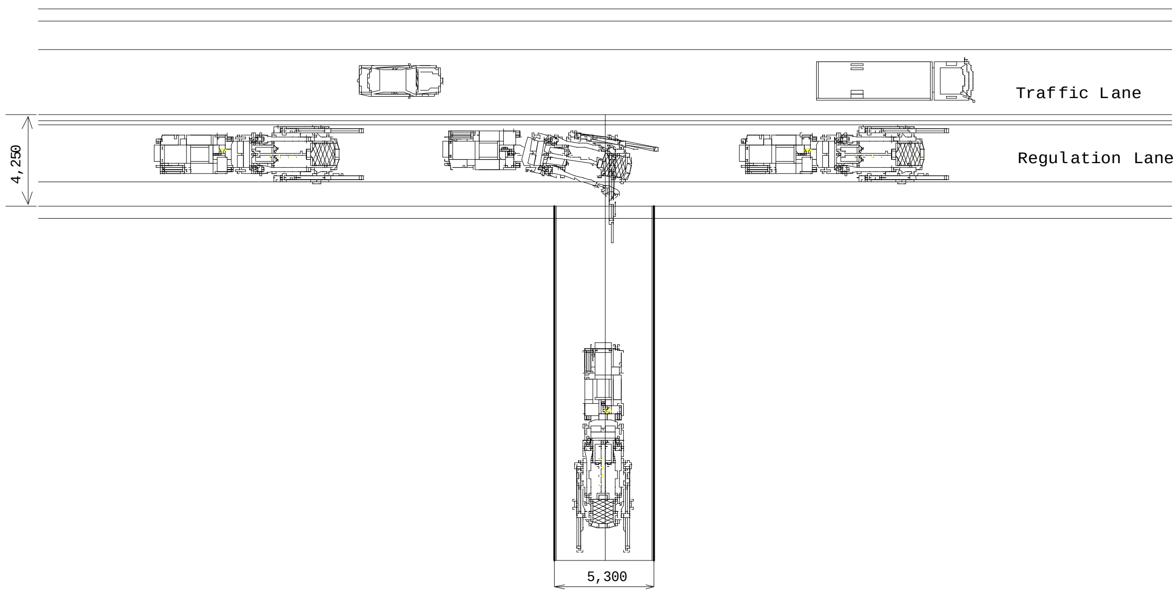

Figure 4 The arrangement of the machine for drilling rock in A tunnel.

EVACUATION TUNNELS EXCAVATION

In this paper, the evacuation tunnel with a cross sectional area is 20m^2 is called A tunnel, and another tunnel (cross section of 10m^2) is called B tunnel.

Because both tunnels' cross sectional area is very small, machine sizes are limited. Figure 4 shows the arrangement of the machine for drilling rock in A tunnel. In order to keep one lane in service, the machine must come in a right angle using only one regulated lane.

Table 1 shows a comparison of construction machines for tunnels of normal cross-sectional area (more than 50m^2), A tunnel, and B tunnel.

This table shows as below.

With a normal size tunnel excavation a drifter of over 170kg can be used (so-called "Rocket Boomer). However, for evacuation tunnels a 140kg or 150kg drifter has to be used. This means that many times are required for drilling (both continuous holes drilling and rock fracturing holes drilling).

Also, for a normal size tunnel excavation a 2000kg breaker can be used, whereas for evacuation tunnels a less efficient 400kg or 800kg breaker has to be used.

Therefore, (1) keeping high free face forming efficiency, (2) being exploited hydraulic wedge's abilities to the full, and (3) crushing almost bedrock by primary fracturing are very important.

Table 1 Comparing main using construction machines.

	Normal tunnnel (Cross section area over 50m^2)	A evacuation tunnnel (Cross section area 20m^2)	B evacuation tunnnel (Cross section area 10m^2)
Rock Drill	Three-boom rigs Rock drill's weight: over 170kg	Two-boom rigs Rock drill's weight: 150kg	One-boom rigs Rock drill's weight: 140kg
Fracturing machine	Two hyadraulic wedges with 0.4m^3 backhoe	One hyadraulic wedge with 0.4m^3 backhoe	One hyadraulic wedge with 0.4m^3 backhoe
Weight of breaker	2000kg	800kg	400kg

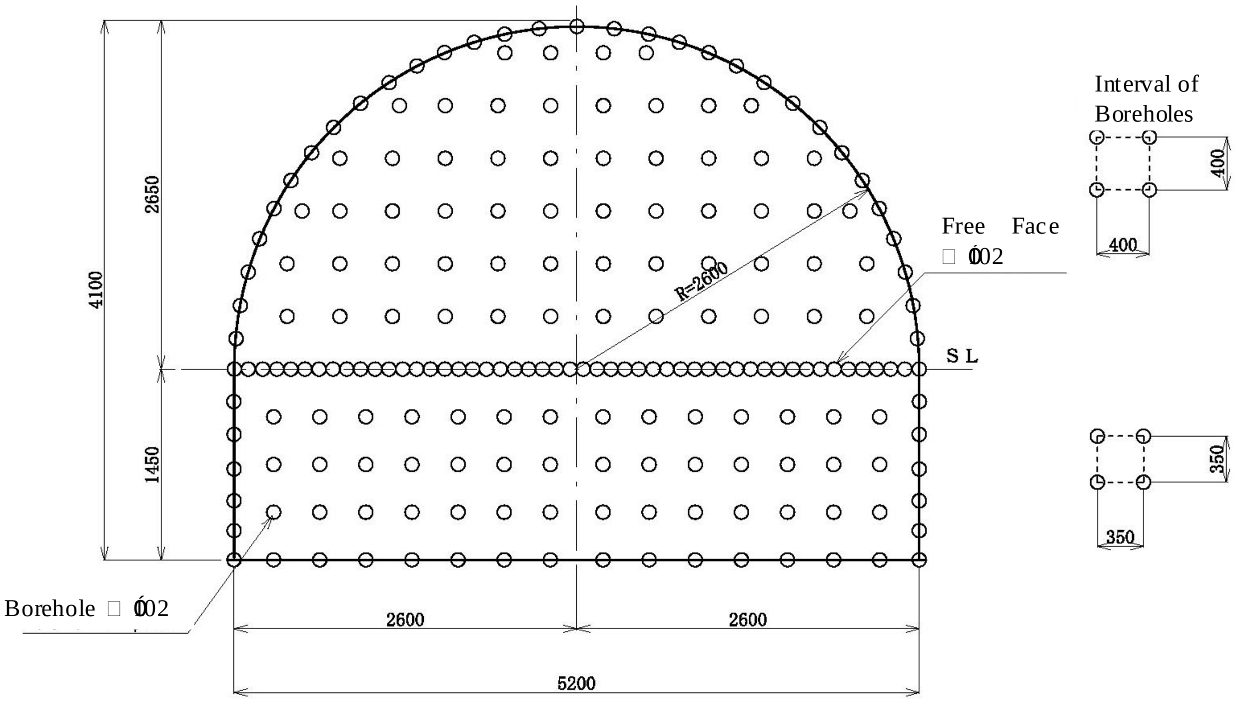

Figure 5 The drilling pattern in the A tunnel.

A evacuation tunnel

A evacuation tunnel is 58.2m long and connects the up and down lanes of existing twin-bore road tunnels.

The geology along the route is rhyolite. Around the portal the bedrock is cracky with a uniaxial strength of up to 100MPa, but the bedrock becomes hard with excavation of tunnel, and the uniaxial strength at center of tunnel is about 230MPa.

Within 8m of the portal, the large-scale hydraulic wedges can't fit in the tunnel, "DARDA" is used for fracturing. Between 8m to 18m, the bed rock is cracky and uniaxial strength is up to 150MPa. In this region an artificial free face is not necessary, only a large-scale hydraulic wedge and 800kg breaker are needed for excavation. But after 18m, where the bedrock is intact and the uniaxial strength is over 150MPa, artificial free face forming is necessary. Figure 5 shows the drilling pattern in this case. Forming free face is one line about spring line, less than normal size tunnel's free face as forming periphery in Figure 1. The main reason for this is that the cross sectional area is small, and, when drilling on the periphery, holes can't be bored square to the tunnel face, and some angle be remains. This angle becomes overbreak, and overbreak should be preventable.

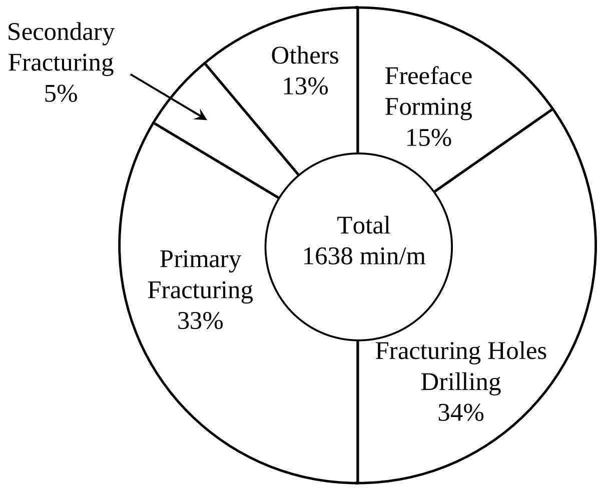

Figure 6 An example of the cycle time in the A tunnel.

Figure 6 shows an example of the cycle time. In the figure, about half time is spent by boring, and third part of time is rock fracturing.

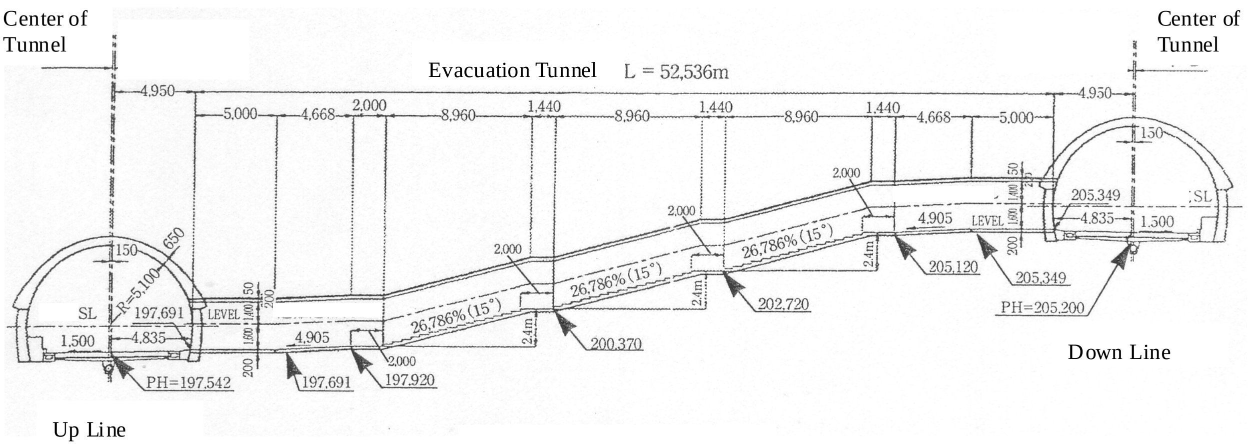

Figure 7 The longitudinal profile of the B tunnel.

B evacuation tunnel

B evacuation tunnel is 52.5m long and connects the up and down lanes of existing twin-bore road tunnels.

The geology of this route was expected to be sandstone and slate with a strength of about 100 MPa, but in practice was hard sandstone with a strength of 170-230MPa..

Figure 7 shows the longitudinal profile of the tunnel. This tunnel's cross section area is 10m2 for man traffic, because there is an 8m difference in elevation between up line and down tunnels. A large quantity of water is necessary for drilling, excavation is started from up line for drainage by gravity.

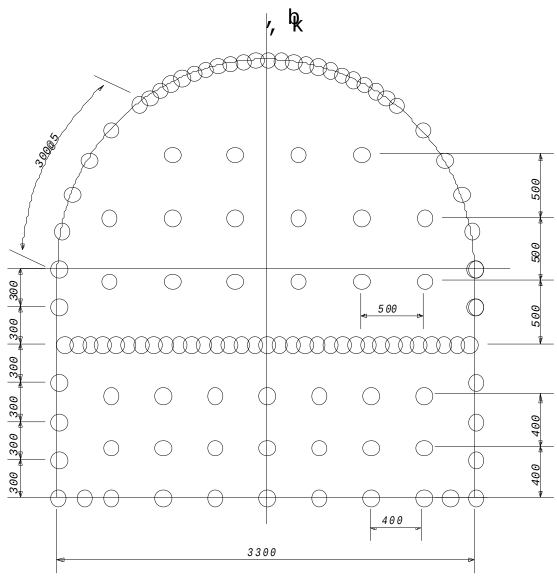

Figure 8 The drilling pattern in the B tunnel.

As for the A tunnel, within 8m from the portal, the large-scale hydraulic wedge can't fit into the tunnel, "DARDA" is used for fracturing. At 8m from the portal, the entrance is enlarged for the large-scale hydraulic wedge entering.

Figure 8 shows the drilling pattern in this case. Forming free face is one line about spring line same as A tunnel, but at most hard rock case, free face is forming at crown about 2m because the route is upgrade.

Figure 9 shows an example of the cycle time. In the figure, about 60% is spent boring, but less than 20% is rock fracturing. This result is different from A tunnel. This occurs for two reasons. One reason is number of booms on the rig, A tunnel uses a two boom rig, but B

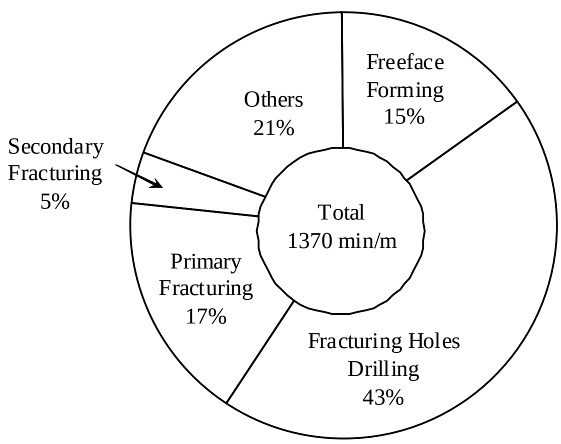

Figure9 An example of the cycle time in the B tunnel.

tunnel uses a one boom rig. The second reason is the difference of drifter's capacity. The 150kg drifter has about 1.5 times ability in comparison with the 140kg drifter.

Thus, when making an execution plan by the rock fracturing tunneling, it is necessary to take ability and the boom number of rock drills into account.

In tunneling such small size by rock fracturing, it is possible to excavate that making continuous free face. Figure 10 shows the state of rock fracturing by the large-scale hydraulic wedge in the A tunnel, and figure 11 shows the state of making free face in the B tunnel.

Figure 10 The state of rock fracturing by the large-scale hydraulic wedge in the A tunnel.

Figure 11 The state of making free face in the B tunnel.

CONCLUSION

In this paper, two cases of small size tunneling by the rock fracturing method are shown. Conclusions are described as below.

- In tunneling such small size by rock fracturing, it is possible to excavate that making continuous free face.
- The efficiency of excavating is depending on the ability of the rock drill.

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