DEVELOPMENT OF FULLY AUTOMATIC CRAWLER JUMBOS FOR USE IN TUNNEL EXCAVATION

Masaharu Noma, Chief Engineer, Tunneling
Masao Matsuyama, Ass't Chief Engineer, Tunneling
Civil Engineering Technology Division
Kajima Corporation

5-16, Akasaka 6-chome, Minato-ku
Tokyo 107, Japan

ABSTRACT

Because the operation of drilling for tunnel excavation by blasting is performed in a severe work environment and the degree of worker skill shows a declining tendency in recent years, it is becoming difficult to obtain a high degree of precision in drilling and this could become a major problem for the quality of tunnel construction in the future. Kajima Corporation has taken up the development of fully automatic drilling equipment and has achieved good results with this type of equipment in various tunnel construction works. The system adopted, a combination of a memory device and an automatic control mechanism with hydraulic drilling equipment using the newest electronics technology, is a system in which all parts of the drilling operation from determining the drilling position to striking and rotation of the rock drill are fully automated.

1. Introduction

Eighty percent of the land area of Japan is covered by mountains. Because of this fact, tunnel construction is essential in the construction of Shinkansen railway lines, expressways and water conduits. Also, with the present trend toward positive utilization of underground space not only to overcome topographical obstructions but also for the purpose of effective utilization of space such as in the case of underground power generation facilities, the demand for tunneling continues to expand.

2. Development of Fully Automatic Crawler Jumbos

2.1 Sequence of Tunnel Construction

The sequence of tunnel construction by the method which employs rock bolts and shotcrete is shown in Fig. 1. As seen in this figure, tunnel construction involves a great number of operations. Furthermore, each of these operations must be performed directly in contact with natural conditions at the tunnel face. It would be quite difficult to automate these diverse operations uniformly all at one time.

As a start, these operations were separated and analysed, and development was commenced with those operations for which the demand for automation was greatest and which were technically amenable. One of the operations thus chosen for automation was the drilling operation.

2.2 Drilling Operation

At the present time, the majority of tunnels are being excavated by blasting and the holes for blasting are cut by drilling, an operation which is normally performed in accordance with the experience and intuition of the tunnel miner operating the drilling equipment.

2.3 Objectives of Drilling Automation

The drilling operation is performed at the farthest point in the tunnel in a poor environment at all times subject to unknown dangers; rock falls, dust, noise, vibration, the explosion of explosives and, depending on the geological conditions the danger of large quantity water inflows and flammable gases. As a safety measure for a working environment such as this, it is important to "reduce the number of workers by even one person and keep the workers away from the tunnel face as much as possible."

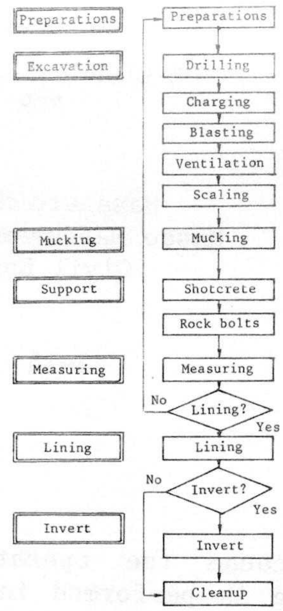


Fig. 1 Sequence of Tunnel of Construction

The labor force engaged in the construction industry in Japan has become generally insufficient asa result of the expansion of domestic demand and business prosperity during the last several years, and in especially short supply are young skilled workers for tunnel construction. The precision of drilling has greatly depended on the degree of skill of the drillers, but by automating this operation as much as possible, it will become possible to perform uniform, high precision drilling, uneffected by the degree of worker skill or the working environment.

A major problem in tunnel construction is to perform excavation close to the design cross section with little overbreak and to secure a smooth cross section with as few irregularities as possible in the excavation surfaces so that stress concentrations will not develop in the ground. Thus, high precision drilling is also required for the improvement of quality.

With automation, when the drilling machine has been set and drilling has been started, the operator can leave this operation and go to some other operation such as equipment maintenance. Also, if the hole positions are memorized by the equipment, the operation of marking the positions of the holes on the face rock becomes unnecessary and drilling operation time can be shortened.

In view of the above described needs, Kajima Corporation introduced fully automatic drilling equipment on an underground power station project in 1980 and, incorporating various improvements, has used such equipment in subsequent general tunnel construction.

2.4 Outline of Fully Automatic Drilling Machine

The fully automatic drilling machine shown in Fig. 2 (hereinafter called AD) operates by the teaching-playback system. By setting the machine in the basic position for the face to be drilled and starting the automatic drilling device, the machine automatically drills the face down to completion of the last hole in accordance with a previously memorized drilling pattern.

(1) Teaching method: Teaching is performed by marking the drilling pattern on a mock face the same size as the real face and moving the AD booms by manual operation in the order of the hole numbers. (Fig. 3) The memory capacity is 4 patterns with 100 points per pattern.

(2) Alignment mechanism: The AD is set in the prescribed position for the face to be drilled by raising AD on its outriggers and moving it up and down and sideways. (Fig. 4)

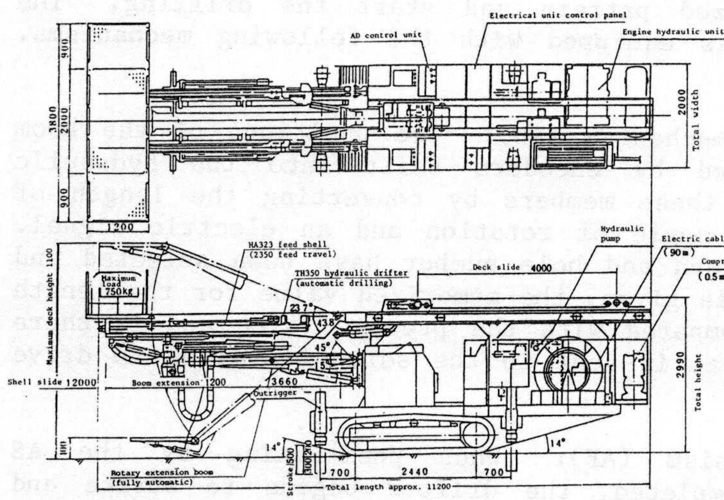


Fig. 2 Fully Automatic Hydraulic Crawler Jumbo

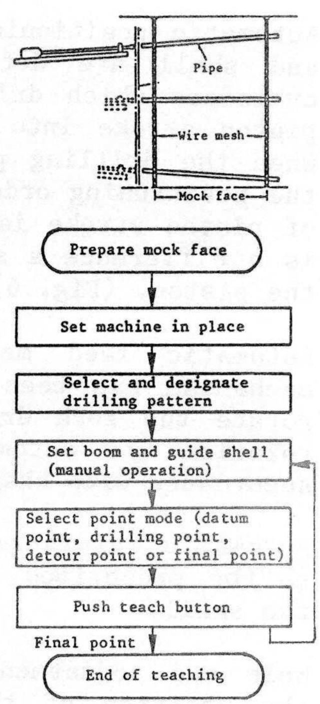


Fig. 3 Procedure for Teaching Drilling Pattern

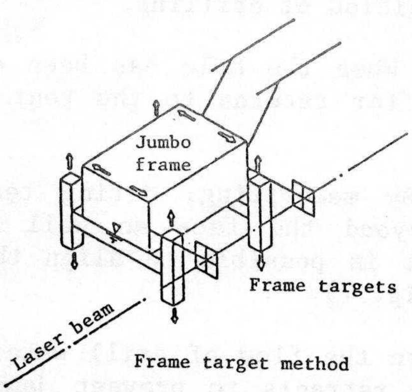


Fig. 4 Method of Setting Jumbo to Line

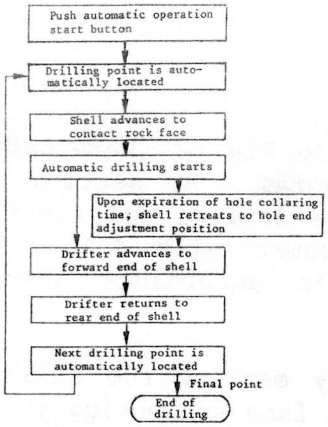


Fig. 5 Flow Fully Automatic Drilling

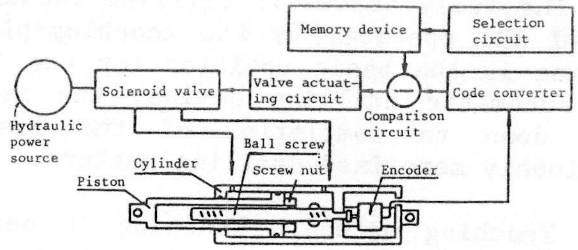


Fig. 6 Automatic Positioning Mechanism

(3) Automatic drilling device: When AD is set at the face to be drilled and the automatic drilling device is started, the automatic positioning mechanism (AS) and other control functions go into action to move the booms and guide shells to the hole positions in accordance with the previously memorized pattern and start the drilling. The automatic drilling device is equipped with the following mechanisms. (Fig. 5)

(a) Automatic positioning mechanism (AD): The positions of the boom and shell are detected by encoders built into the hydraulic cylinders which drive these members by converting the length of piston stroke into an angle of rotation and an electric signal. When the drilling pattern and hole number have been selected and the positioning order is given, the memorized value for the length of piston stroke is compared with the present value and if there is a difference a signal is sent to the solenoid valves to drive the piston. (Fig. 6)

(b) Automatic feed mechanism (AF): When positioning by the AS mechanism has been completed, the drifter begins to strike and rotate the rock drill and feed it into the hole. Striking and rotation are automatically regulated by hydraulic mechanism in accordance with changes in the condition of drilling.

(c) Automatic return mechanism (AR): When the hole has been drilled to the prescribed length, the drifter returns to the rear end of the shell.

(d) Hole end adjustment mechanism: By memorizing, during teaching, the position of the hole end beyond the face as well as the position and angle of drilling, it is possible to align the ends of all holes in the same plane. (Fig. 7)

(e) Jamming prevention mechanism: When the flow of drill water falls below a certain rate, the drifter retracts to prevent jamming of the drill in the hole.

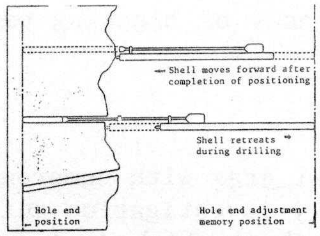


Fig. 7 Hole End Adjustment Mechanism

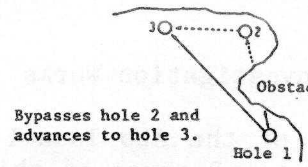


Fig. 8 Bad Hole Detour Mechanism

(f) Bad hole detour mechanism: When the drill can not be moved to the memorized position because of an obstacle such as a rock projection, the drill is moved to the next drilling position. The total number of undrilled holes is indicated on the control panel. (Fig. 8)

3. Achievements in Actual Construction

3.1 Imaichi Underground Power Station

This was a project to construct the main structures of a 1,050 megawatt capacity underground power station of the pumped storage type and involved the excavation of a large cavity of egg shaped cross section (33.5 m wide, 48.5 m high and 160 m long) as shown in Fig. 9. Because this cavity of large cross section was designed with a permanent lining of shotcrete, it was necessary to secure smooth finished excavation surfaces with as little irregularity as possible to prevent the development of stress concentrations in the ground and for the sake of good appearance too. AD was used in the excavation of the arch of the power house and main transformer house with good results achieved.

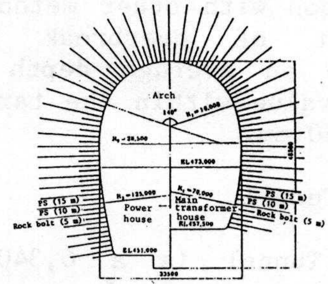


Fig. 9 Cross Section of Imaichi Power Station

(a) The results of overbreak measurements at 12 cross sections selected at random are shown in Fig. 10. It had been assumed that the average depth of overbreak from the design line would be 15 cm, but the result was only 8 cm, indicating that drilling of high precision was achieved.

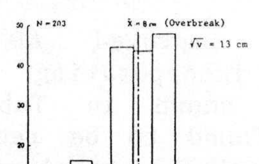


Fig. 10 Histogram of Overbreak Depth at Imaichi Power Station

(b) There was no irregularity in drilling time and working efficiency was improved by approximately 30%. (The average speed of drilling was 1.5 m/min and the average time for boom movement was 20 sec.)

(c) Because one operator can control two booms, a 50% labor saving is possible compared to conventional machines.

(d) Becaus? the hole ends are aligned, the efficiency of blasting was improved.

3.2 Abo Tunnel Investigation Works

The vicinity of the Abo Tunnel is a geothermal area with numerous natural hot springs. Because of this, a preliminary investigation adit was excavated to investigate the geological conditions which included high temperatures and volcanic gases (hydrogen sulfide gas) characteristic of volcanic areas. The temperature within the adit was over 30°C and there was high humidity also. In order to protect the health of tunnel workers in this hot and humid tunnel environment and secure excavation precision, a fully automatic drilling machine with an enclosed operators cabin (Photo 1) was employed as one step in advancing automation and labor saving in excavation operations at the face.

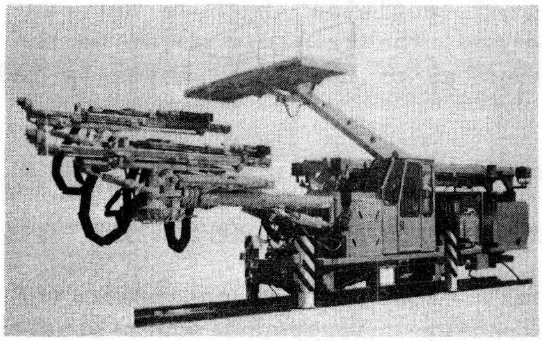


Photo 1 AD Jumbo for High Temperature Tunnel

Good blasting effect was obtained because the drill pattern could be drilled accurately and the hole ends could be aligned. Histograms of overbreak are shown in Fig. 11. In comparison with other methods, the amount of overbreak was reduced to an average depth of 243 mm, a value within the target depth of 250 mm.

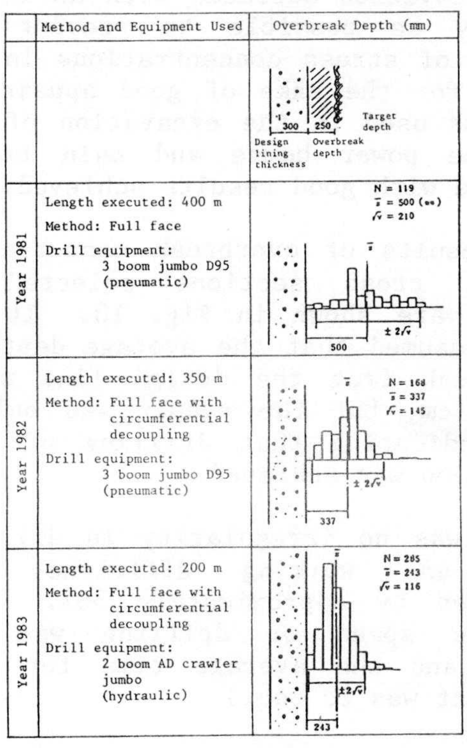


Fig. 11 Reduction in Overbreak at Abo Tunnel

3.3 Higo Tunnel

Higo Tunnel is a 6,340 m long expressway tunnel on the island of Kyushu. Kajima undertook the southern construction section which was 3,340 m long.

A new improved AD was developed incorporating the improvements shown in Table 1 which were found to be required from the previous experience in using AD. This new machine was introduced in May 1984.

However, because the teaching-playback system was employed in controlling the boom movement, the teaching operation was time consuming and it was difficult to teach the machine the numerous drilling patterns required to meet the ground conditions.

To solve this problem a numerical input function was added giving this machine a dual system by which boom movements are controlled by computer using numerical input data for the hole locations and errors which develop in the machine and its members can be adjusted by teaching. Because this adjustment of error can be performed all by teaching, it can be performed simply, even over a wide range.

Table 1 Improved AD Functions

Problems	Improved Functions
Hole depth is short.	The length of feed was extended to make possible the drilling of horizontal holes 3.0 m in depth.
Boom movement takes time.	Various functions were added, including a function to avoid mutual interference between booms and a function for 2 stage control of boom operating speed.
Hole location error is large.	Boom rigidity was increased and hinge pin play was reduced. A circular boom was adopted.
Deck boom is hard to use.	Ease of use was improved by increasing the length of slide by 2 m to 6.0 m and widening the deck by about 1 m.
Encoder inspection takes time.	Up to now, the encoder was built into the boom cylinder. On this machine, a mechanism was adopted to detect the rotation angle at the hinge pin.

A drilling data control system was incorporated by which operating data can be obtained by collecting and storing in a cassette data on the condition of each hole drilled including the drilling pattern, drilling time, drilling speed and actual hole position. (Fig. 12)

Further, a cross section measurement system was incorporated by which cross sectional data can be collected and stored in a cassette by touching the point of the boom to points along the perimeter of the excavated face. Using print out plots of the excavated cross section and the design cross section based on this data, it is now possible to make improvements in the drilling pattern to obtain good blasting efficiency and small overbreak. (Fig. 13)

3.4 Five Boom Crawler Jumbo

Separately from the AD's described above, Kajima has developed a 5 boom crawler jumbo for use with the mini-hench method of excavation and employed it in the construction of an expressway tunnel (Myojin Tunnel).

When constructing a tunnel in medium to hard rock of not very good quality, it is normal to employ the short bench method. However,

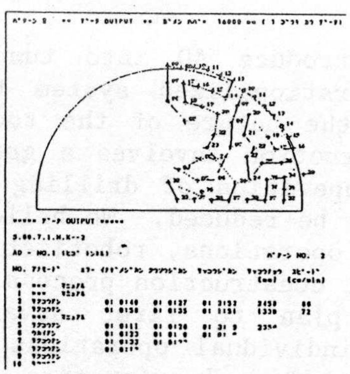


Fig. 12 Hole Drilling Data Output

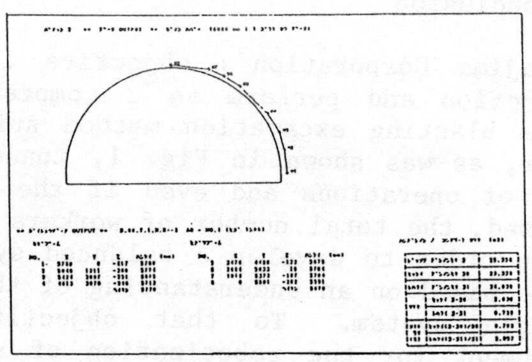


Fig. 13 Cross Section Measurement Output

because the upper half and lower half excavations are performed at forward and following positions, operations become congested within the narrow confines of the tunnel, presenting a problem in the aspect of safety. A method which can be used to resolve this problem is the minibench method (Fig. 14), but this method has a drawback in the fact that the equipment becomes excessive when the excavation cross section is large.

The newly developed jumbo (Photo 2) has 5 booms and a pantograph type elevating mechanism so that it can drill both the upper and lower half faces simultaneously and also can climb up on the bench and drill the upper face in the upper half drift method. This jumbo was not completely automated, but numerous attempts were made in the direction of robotization including the adoption of a system which enables full operation by remote control.

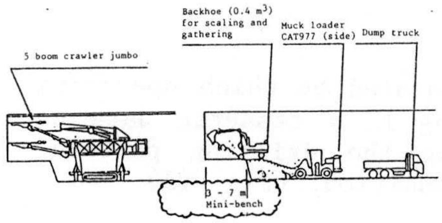
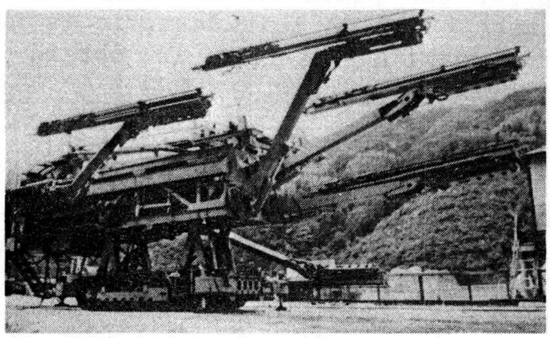


Fig. 14 Mini-bench Method

Table 2 Tunnel Robot System Project

Drilling	AD
Charging	Automatic charging device
Mucking	Single trip hauling by large container car
Shotcrete	Placing by slip form
Rock bolts	Equip AD with rock bolt autosetter

Photo 2 Five Boom Crawler Jumbo



4. Conclusion

Kajima Corporation's objective is to introduce AD into tunnel construction and perform as a comprehensive rationalized system the optimum blasting excavation method suited to the nature of the rock. However, as was shown in Fig. 1, tunnel construction involves a great number of operations and even if the single operation of drilling is robotized, the total number of workers will not be reduced. We believe that in order to develop a balanced system of operations, robotization must be based on an understanding of the tunnel construction process as a single system. To that objective, we p]an to first advance development for the robotization of several individual operations as shown in Table 2 and gradually work toward a balanced automation and robotization of the tunnel construction process as a whole.