Total Automatic Excavation System for TBMs

Takayoshi Nakayama, Satoshi Inoue, Yasuhide Seno
Kansai Branch, Okumura Corporation

ABSTRACT

A fuzzy logic excavation system for tunnel boring machines, which automates the excavation alignment control and discharging of the excavated materials, has been developed. By constantly monitoring boring machine behavior, geological conditions and roller cutter wear, this system achieves high precision and efficient excavation of both hard rock and soil.

The verification tests using this system have shown that the boring machine can advance stably and efficiently according to the condition of the ground at the tunnel face, and thus confirmed the effectiveness of this system.

1. INTRODUCTION

The demand for tunnel boring machines (TBMs) has increased due to their characteristics of rapid excavation, low noise and low vibration, and their ability to work in a wide range of geological conditions, ranging from hard rock to mixed ground. In recent years, however, the development and deployment of automatic TBMs has become a pressing concern due to rising demand for even faster and safer tunneling with lower casts.

The system we have developed enables high precision and efficient excavation of both hard rock and soft soil by constantly monitoring machine behavior, geological conditions and roller cutter wear, automating excavation alignment control using fuzzy logic control techniques and discharging of excavated materials.

This paper presents an overview of this system, and describes the results of verification tests using this system.

2. SYSTEM OVERVIEW

(1) FEATURES

A summary of this TBM system is shown in Fig. 1. The TBM system comprises a fuzzy logic TBM excavation control system, an alignment control system and an automated excavated materials discharge system. Roller cutter wear is monitored through the wear detectors in real-time to maintain efficient excavation. In response to growing demand, this system is also designed to be quickly adjustable for excavating mixed ground (rock excavation using the TBM method, or clay soil excavation using a shield method).

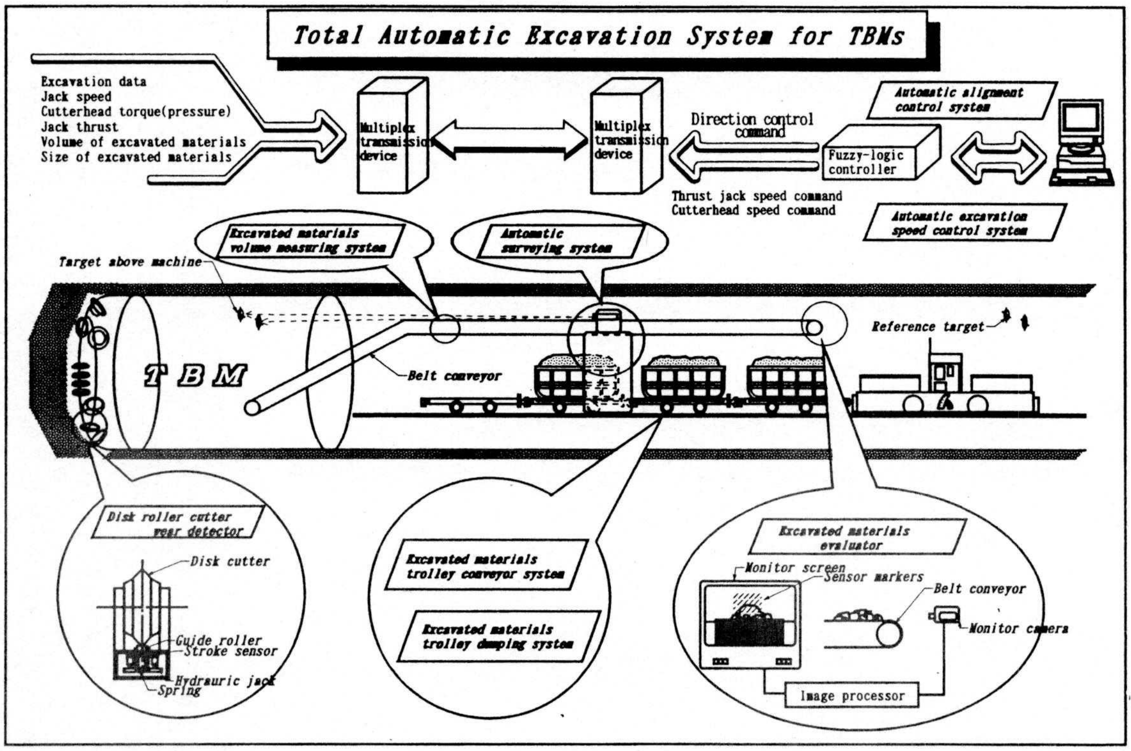

Fig. 1 Functional view of the system (TBM mode)

(2) SYSTEM CONFIGURATION

a. Automatic alignment control system

The machine is steered automatically to maintain correct alignment by means of fuzzy logic control based on data on the machine position and orientation angle detected by an automatic surveying device.

b. Automatic excavation control system

[1] Automatic excavation speed control

The cutterhead torque, thrust, size and volume of the excavated materials are detected to optimally control the excavation speed. An optimum load on the roller cutter is maintained as the TBM advances by controlling the excavation speed according to the geological condition of the tunnel face. Efficient excavation is thus possible, abnormal wear of the cutter ring can be prevented, and the cutters last longer as a result.

[2] Automatic cutter head speed control

The geological condition (fissure density, collapsibility) of the tunnel face is estimated from the size and volume of the excavated materials in order to control the cutterhead speed accordingly. As a result, when the amount of excavated material increases while boring through collapsible rock, for example, the cutterhead speed can be decreased to reduce the amount of excavated materials taken from the bucket, and thus reduce the chances of collapse while continuing excavation. The cutterhead speed can also be increased when boring through hard rock to maintain the excavation speed.

[3] Automatic excavation system for mixed grounds

The excavation system has two modes: TBM mode and shield mode. Changing from excavating hard rock to softer soil can be achieved by changing the fuzzy logic controller from the TBM mode to automatic advancement control. When shield mode is selected, the earth pressure in the chamber and the amount of excavated materials are detected and used to adjust the excavation speed and screw conveyor speed using fuzzy logic control.

c. Automatic excavated materials trolley conveyor and dumping system

This system uses air-bag type muck cars to automatically load and transport the excavated materials through the tunnel, and dump them into the pit.

d. Roller cutter wear detection system

Determining the appropriate cutter replacement time is made easier by detecting cutter ring rotation, evidence of uneven wear and ring wear in real-time using a stroke sensor installed on the back of the roller cutter.

(3) SYSTEM EFFECTS

a. The TBM system enables significant labor savings while also improving worker safety by reducing manual labor requirements.
b. Rock collapse and cutter life are extended by controlling excavation according to the rock conditions. Adjustment for mixed ground is also quick.
c. Quantitative determination of rock and tunneling conditions replaces conventional dependence on operator experience and intuition while fuzzy logic control eliminates human error to maximize boring machine efficiency and thus reduce overall tunneling time.
d. Surveying tasks are reduced, and tunneling precision is improved by steering the machine correctly based on accurate measurement data.
e. Cutter replacement after appropriate intervals improves tunneling efficiency and reduces cutter costs.

3. TEST OPERATION

(1) WORK SUMMARY

A plan view and cross section of the test excavation site are shown in Fig. 2. This job was to build a sewer main tunnel with outer diameter 2.13 m and length 873 m using the full shield TBM shown in Photo 1. Granodiorite (qu = 500 - 1700 kgf/cm^2) is distributed throughout the first 670 m from the tunnel entrance, and a sandy layer (N = 10 - 20, water permeability k = 2.5 x 10-2 cm/sec) covers the remaining 200 m. The first 670 m section was therefore excavated in TBM mode, shield mode was used for the 200 m section, and the cutter face was changed where the soil changed.

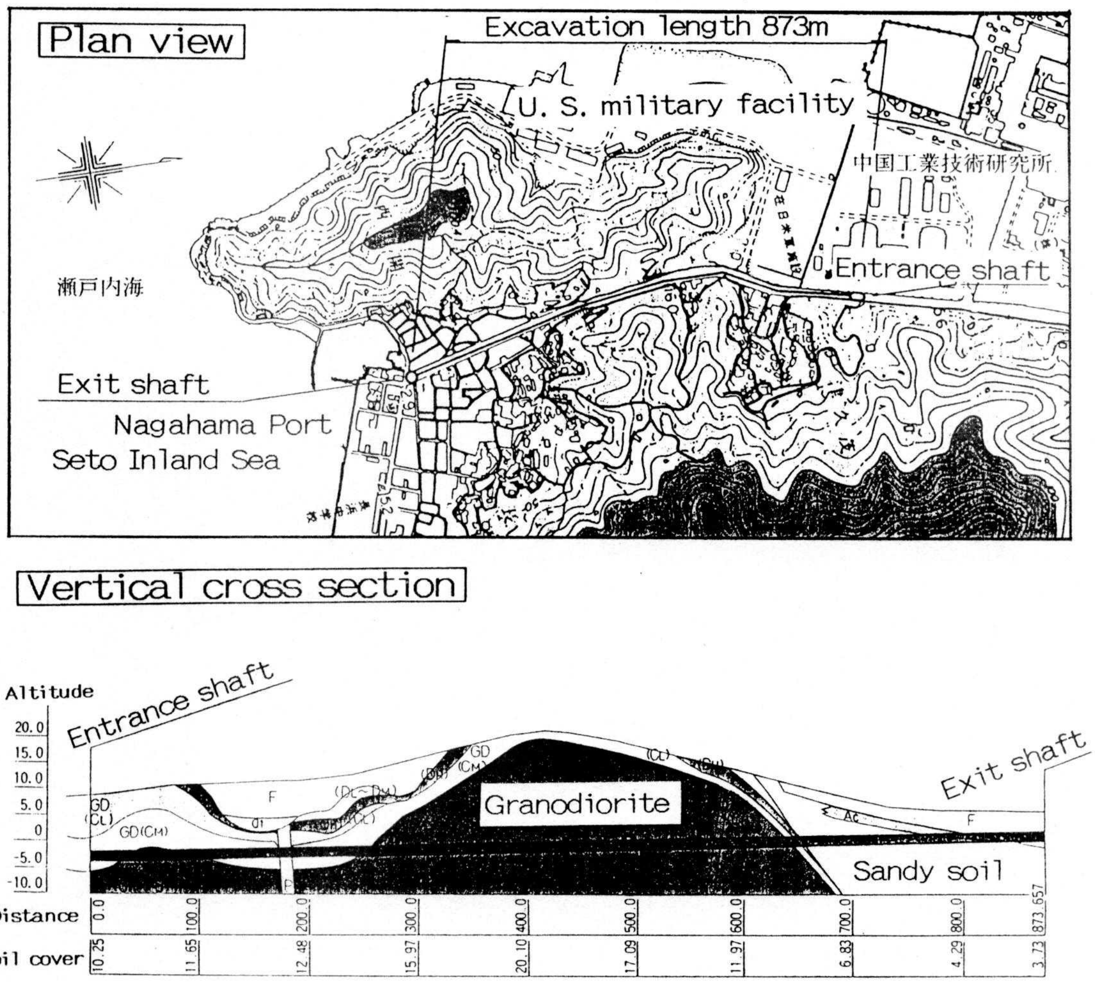

Fig. 2 Plan and vertical cross section

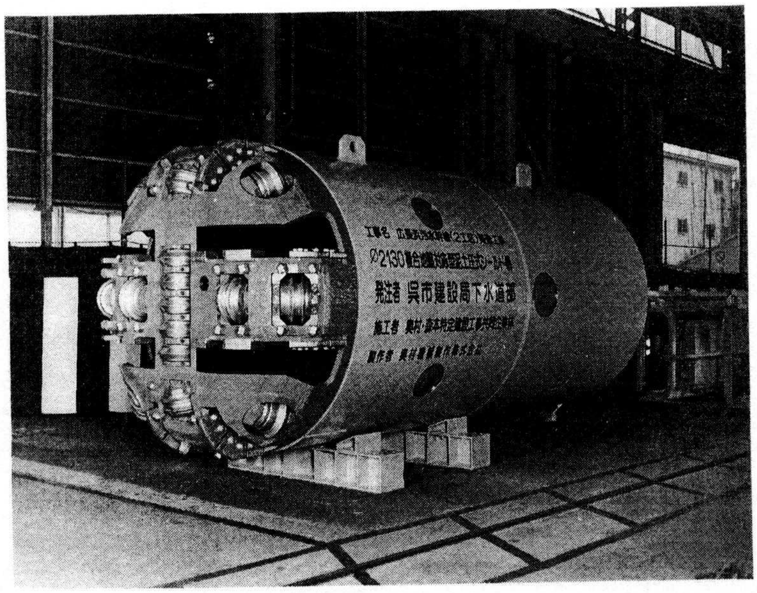

Photo 1 Full shield TBM

(2) FUZZY LOGIC AUTOMATIC ADVANCING SYSTEM

a. System overview

The system installation is shown in Photo 2. This system comprises a personal computer containing the fuzzy logic controller, and a communications control panel for transmitting data between the personal computer and the TBM system.

Photo 2 System installation

b. Automatic TBM excavation control system

The TBM fuzzy logic control system is illustrated in Fig. 3. The relationships between input and output data are described by the fuzzy logic control rules. The basic operation is described below.

[1] The excavation speed is adjusted to approximately the prescribed value so that the cutter pressure approaches the target value.
[2] If the cutter pressure permits, the excavation speed setting is raised.
[3] If the total thrust approaches and seems likely to exceed the setting, it is lowered.
Tests were also conducted for the system measuring the size and volume of excavated materials, showing that this system can adjust both cutter speed and TBM system excavation speed by applying fuzzy logic control based on the size and quantity of the excavated materials.

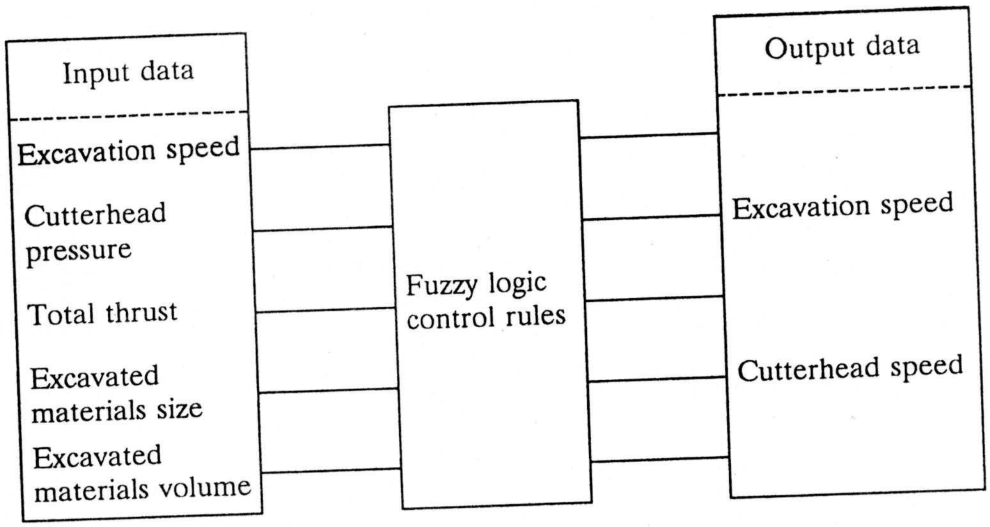

Fig. 3 Fuzzy logic control in TBM mode

c. Earth pressure balanced shield automatic **excavation control system**

The earth pressure balanced shield fuzzy logic control system is illustrated in Fig. 4. The following operation is accomplished by the control rules of this system.

[1] The screw conveyor speed is adjusted so that the earth pressure at the tunnel face approaches the target value.

[2] If the earth pressure varies or tends to vary greatly from the target value, the **excavation speed** is adjusted so that the earth pressure approaches the target value.

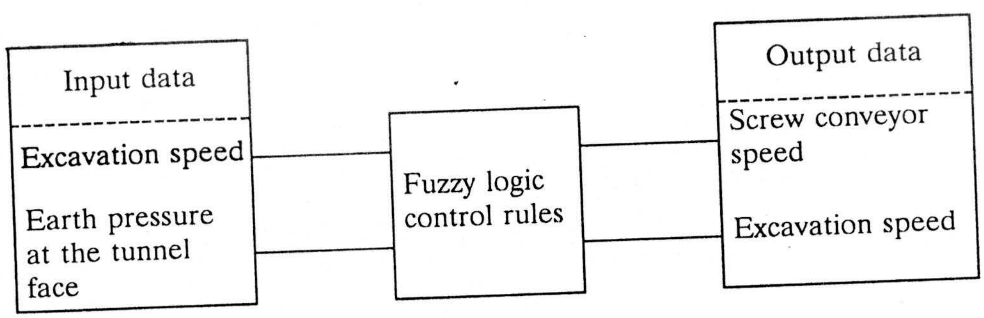

Fig. 4 Fuzzy logic control in shield mode

(3) RESULTS

The results of excavation test described above are reported below. Fig. 5 shows the advancing results from rings 558 - 561, and Figs. 6 and 7 show the advancing data at rings 558 and 559, respectively. The results shown in these figures were obtained while tunneling through essentially the same rock conditions. Automatic control maintains fairly constant cutterhead pressure, as is obvious from comparing the results of manual and automatic advancing control in Figs. 6 and 7. As shown by the detailed advancing results shown in Figs. 6 and 7, automatic control (Fig. 7) maintains a virtually constant excavation speed and stable overall operation, and reduces the advancing time per ring.

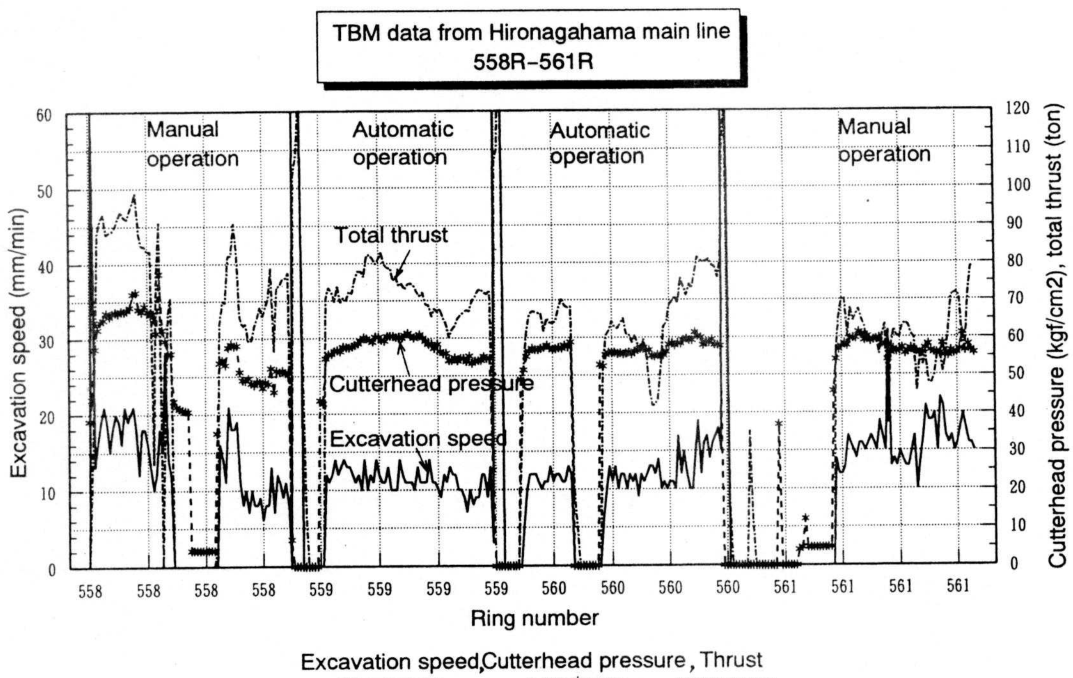

Fig. 5 TBM advancing results

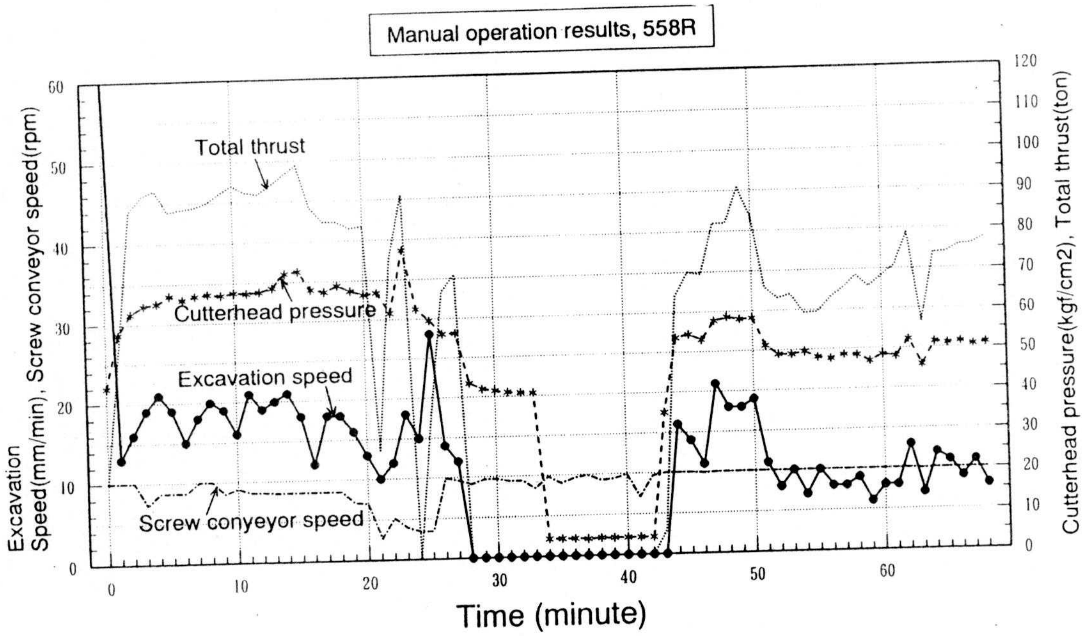

Fig. 6 Manual TBM operation results

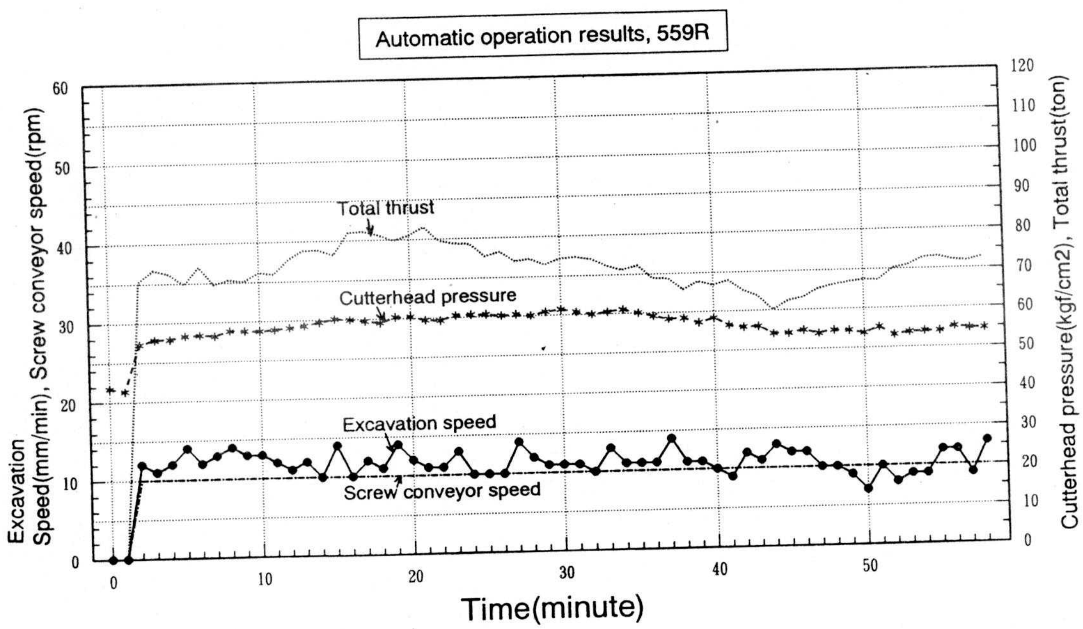

Fig. 7 Automatic TBM operation results

4. CONCLUSION

The superiority of this system in TBM excavation was confirmed by the test results described above. Automatic excavation control in both TBM and shield modes was also shown to be feasible.

This system can be adapted for all types of TBM, including the soil type (rock, soft soil), tunnel conditions (inclined, horizontal), and excavators (shield types, open-face types). The automatic surveying system, automatic excavation control system, automatic excavated materials trolley conveyor and dumping system, and other component systems can also be adapted for shield excavators.

We hope this report will contribute to the continued development of TBM construction in the future.