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Automatic Shield Tunneling Method with a Small Cross-sectional Area

Shoji Kondo (Senior Manager), Kazuyoshi Matsuzaki (Civil Engineer), Masanobu Kuroiwa (Civil Engineer)
: NTT Tsukuba Field Engineering Development Center

1-7-1 Hanabatake, Tsukuba City, Ibaraki 305 Japan

ABSTRACT

In Japanese urban areas, almost all conduits for telecommunication cables are laid under public roads having heavy traffic. Therefore, we have developed and continued to refine, a new tunneling method (M2) for small cross-sectional area tunnels not requiring personnel in tunnels.

A centralized control system installed in a vertical shaft has made tunnel construction work safe and efficient by automating processes from excavation to lining. All shield machine operations are controlled by a central control system useing digital signals. Automatic transportation of excavated soil and lining material in the tunnel is accomplished by developing an unmanned system for transportation cars which move without rails.

Furthermore, this method employs the cast-in-place lining system, which is controlled by a central control system, using quick-hardening resin mortar as the lining material. This automatic tunnel-lining system permits long distance driving (over 500 m) and a curved driving($R \geqq 100$ m) which are not impossible for the hume-pipe-jacking method.

NTT conducted several field tests and a Practical Application Test (P.A.T.) under a public road and the practicability of this method was demonstrated. In the near future, this method will also be applicable for constructing infrastructures, such as sewage, electricity, water and gas.

1. Introduction

Presently, no-digging methods used for laying undergrounds pipe are important in the urban areas of large cities such as Tokyo and Osaka, where many underground facilities already exist, due to traffic obstruction, underground facility congestion, adverse effects on the environment caused by the construction, etc.

To carry out the conduit installation work in a practical way without digging up the road's surface, NTT has recently developed a pipe-jacking method (ACE MOLE) and a small diameter shield tunneling method (M2) suitable for both driving long distances and high-speed construction. These methods can employ the most of the mechatronic techniques, including the shield tunneling machine mechanism and electronic machine control systems.

An outline of the technical background of the M2 method and the results of the P.A.T. are described in this paper.

2. Outline of the M2 method

2. 1 System configuration

This system uses a shield tunneling machine, consisting of excavation, local electric control, power supply and lining apparatuses.

Photo 1 shows a shield machine and system diagram can be seen in Fig. 1.

2. 2 Features

The M2 method is characterized by the following as well:

(1) An automatic tunnel-lining system, employing a resin mortar possessing rapid hardening and high-strength qualities, allows long-distance driving with a minimum radius curvature of 100 m.

(2) To carry out non-worker tunneling underground, the method is remotely controlled by automatic control system using a computer for a factory automation system (FA system).

(3) To permit excavating of many kinds of soil, such as clay, sand and gravel with small boulders(ϕ200mm), the "Earth Balanced Type Shield Method", which is very popular in Japan, is employed. Therefore, anyone who can operate an Earth Balanced Type shield machine will be able to operate the M2 system after a short training period.

Tables 1 and 2 respectively present the features and main specifications.

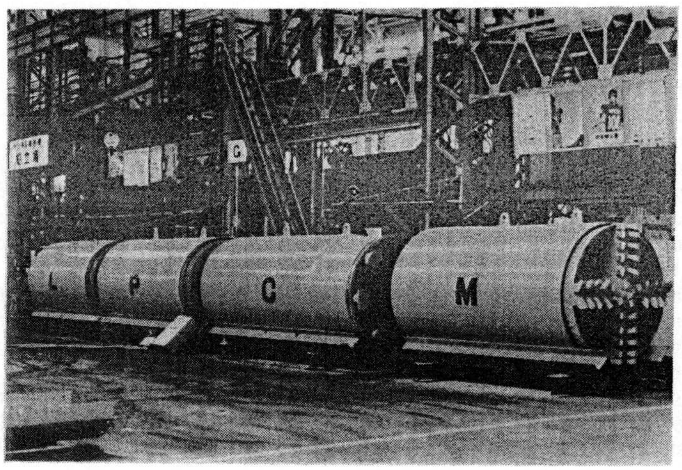

Photo 1. Shield machine.

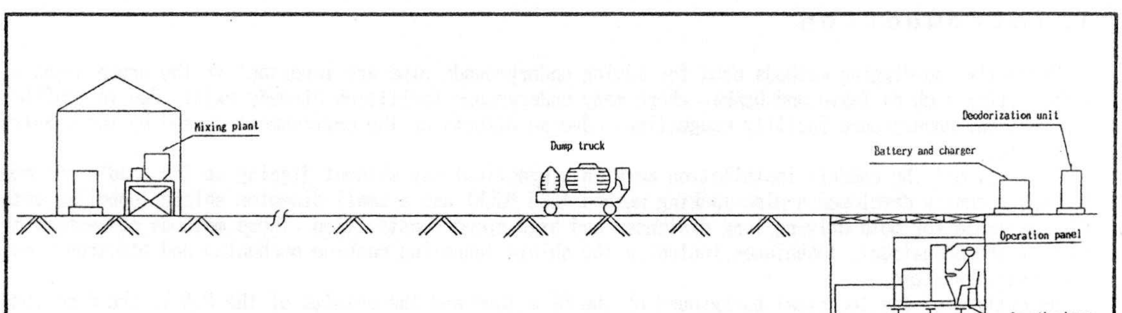

Fig. 1 M2 system diagram.

Table 1. Tunnel and Soil Features

Item	Feature
Inner Diameter	φ1,200 mm
Driving Distance	500 m
Soil Suitability	Clay,Sand,Gravel(φ200mm)
Water Pressure	1.0 kgf/ cm²
Driving Alignment	Straight,Curve(R ≧100 m)
Departure Shaft	10 ×4.5 m

Table 2. M2 Specifications

Eqeipment	Item	Specification	
Shield	Diameter(mm)		1,480
	Length(mm)	Excavation apparatus	3,520
		Local electrical control apparatus	2,500
		Power supply apparatus	2,520
		Lining apparatus	2,655
		Total length	11,195
	Jack Power(ton)	Shield jack	180(30×6)
		Thrust jack	180(30×6)
	Cutter Torque (ton・m,r.p.m)	—	5.9,2.7
	Screw Conveyer (kg ・m,r.p.m)	—	288,0 18.6
	Power-unit(kw)	—	11×4p
Transport Vehicle	Length(mm)	Battery Locomotive	3,210
	Velocity(km/h)		0.5 :4
	Length(mm)	Material wagon	5,160
	Capacity(ℓ)		420
	Length(mm)	Muck wagon	5,710
	Capacity(m³)		1.6

2. 3 The cycle of work execution

The construction process in this method is as follows:

(1) After the muck wagon moves into the tunnel, the excavation apparatus moves 70 cm forward while excavating earth by rotating the cutter wing and extending the shield face-jacks forward. The excavated soil is hauled out of the tunnel using the muck wagon.

(2) The local electric control, power supply and lining apparatuses move 70 cm forward by contracting the shield-jacks and extending the thrust-jacks, which push the resin mortar lining cast previously in the form.

(3) The material wagon, loaded with resin mortar, moves into the tunnel and is connected to the lining apparatus using coupling device.

(4) High-early-strength resin mortar mixed with hardner by the mixing unit is put into the form which molds a ring-shaped tunnel lining in the lining apparatus. The resin mortar put in the form finishes hardening within 30 minutes after casting, so that a 70 cm length tunnel lining section can be constructed.

(5) The void between tunnel lining and natural ground is filled up with void filling material through the grouting pipe.

Figure 2 shows the work cycle in the tunnerl and Photo 2 gives a view of the muck wagon entering tunnel.

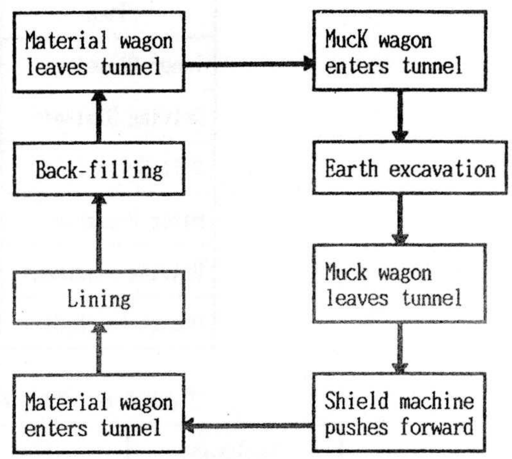

Fig. 2. Work cycle.

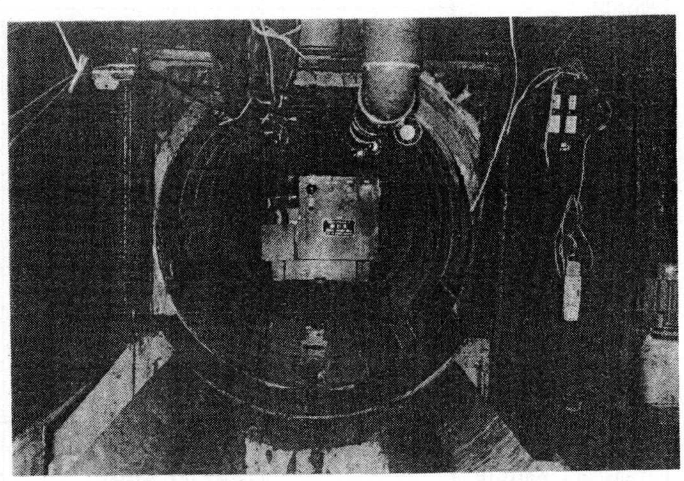

Photo 2. Muck wagon entering resin tunnel.

3. Technical Background

3.1 Control system

The control system permits supervision of the shield machine and transport vehicle from the control panel installed in the departure shaft. All operations are carried out automatically by each sequence controller under the control of a FA controller.

Since work control employs the distributed processing system using a FA controller, system extension and maintenance are easy.

The control system diagram is shown in Fig. 3.

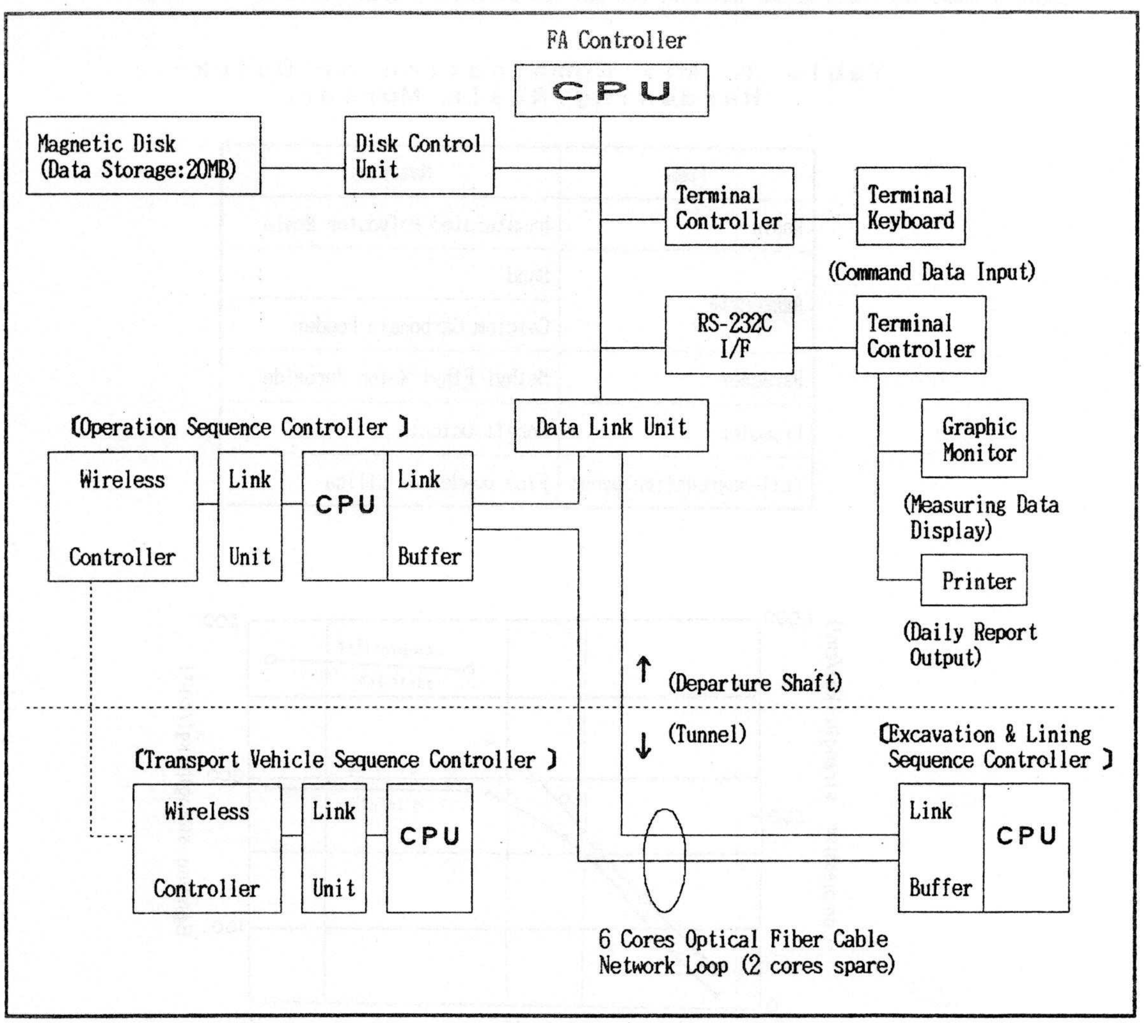

Fig. 3. Control system.

3. 2 Transportation in the tunnel

Automation of the excavated soil and lining material in the tunnel was accomplished by developing an unmanned system for the transportation vehicles. The method is remotely controlled by radio, a stopping apparatus using a position sensor and an anti-rolling mechanism with an automatic steering apparatus.

3. 3 Lining

The lining material must satisfy certain requirements, including quick-hardening, excellent molding features and long-range high reliability. An automatic tunnel lining construction technique using high-early-strength resin mortar is one of the features of the method. Since no conventional material can satisfy these requirements, NTT has developed a quick-hardening resin mortar with low shrinkage during curing.

Table 3 shows the resin mortar material content and strength properties is shown in Fig. 4.

Table 3. Mix Combination of Quick-Hardening Resin Mortar.

Item	Material
Resin	Unsaturated Polyester Resin
Aggregate	Sand
	Calcium Carbonate Powder
Hardener	Methyl Ethyl Keton Peroxide
Promoter	Cobalt Octoate
Anti-segregating agent	Fine powder of silica

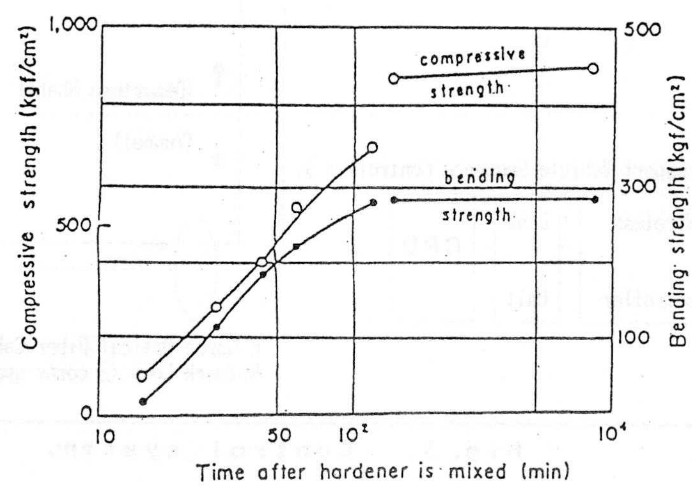

Fig. 4. Resin mortar strength properties[2]

4. Construction Example using the M2 System

This system was utilized in Oyama City, Tochigi Prefecture to the north of Tokyo. The Practical Application Test (P.A.T.) conditions are shown in Table 4. The upper part of soil conditions in this test is Kanto loam and this loam consists of volcanic ash with numerous small holes. Given these conditions, ground subsidence was a main factor requiring special attention.

The results are described in detail by the following as well:

(1) An inner diameter of 1,200 mm was obtained within a tolerance of 10 mm and the inner tunnel surface was very good.

(2) The result of the lining strength test conducted on the test pieces sampled from the cast-in-place lining was satisfied. The average bending-tensile strength was 290 kgf/cm² which means twice required strength of 150 kgf/cm².

(3) The ground subsidence was 3 to 5 mm which was measured at a diatance of 20 meters from the departure shaft.
However, the ground subsidence was not observed at any other point.
The results of this was also very good.

(4) The work cycle was conducted according to the original plan. In particular, the success of the automatic tansportation vehicle and automatic lining cast-in-situ under the water level demonstrate the feasibility of long driving tunneling system (over 500 m), which is one of the original objectives of P.A.T..

The P.A.T. results summary is shown in Table 5 and Photo 3 is a photograph of interior view of resin tunnel.

Table 4. P. A. T. Conditions

Item		Description
Construction Site		Oyama City, Tochigi Prefecture
Driving Period		1985.9.27 ~1986.1.30
Driving Alignment	Planimetric	Straight and curved, with minimum radius of curveture R=200 meters
	Longitudinal	Up-grade 1.0%
Soil Conditions		Silty clay and Sandy silt
Grand-water level		-3.6~6.9 meters
Earth covering		3.8 meters at departure shaft 2.5 meters at arrival shaft
Driving Length		170 meters

Table 5. P. A. T. Results'

Item		Results
Lining	Shaping	1,200 ±10mm (inner diameter) Good inner tunnel surface
	Strength	qu=950kgf/cm² average compressive strength t=290kgf/cm² average bending-tensile strength
	Injection Rate	92% average
Transport Vehicle Automatic Control		5 km/h (R=200 meters) maximum velocity

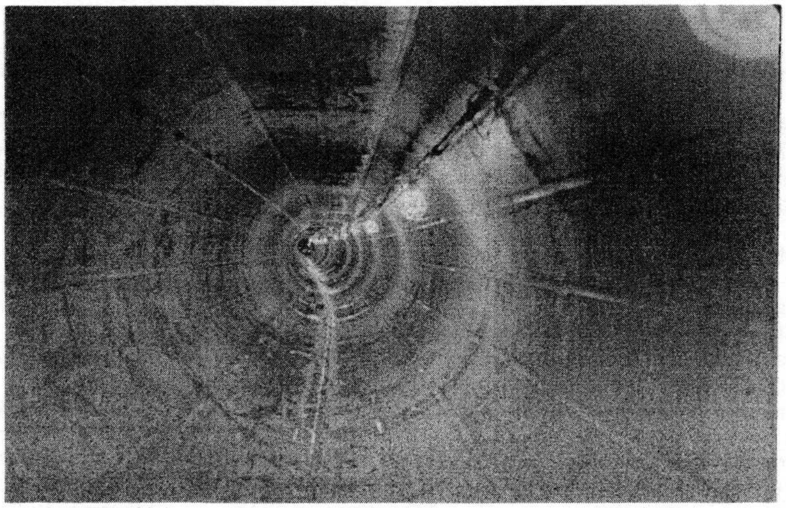

Photo 3. Interior of resin tunnel.

5. Conclusion

NTT has succeeded in constructing a 170-m resin tunnel under a public road using an unmanned method in a tunnel for the first time, a world first. The M2 method might be described as making a great stride toward the new robot-age in small-diameter tunnel construction.

Telecommunications and information systems are currently viewed as essential infrastructures for industry and society of all nations. This autumn, another resin tunnel for a part of the Integrated Services Digital Network (ISDN) will be constructed by the M2 method in Tokyo.

Further development of the M2 system, to permit applications to various soil conditions and to improve the efficiency and economy of cable tunnel construction is presently underway.

This method will contribute to the construction of the ISDN and other infrastructures, such as sewage, electricity, water and gas now and into the 21st century.

REFERENCES

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2. Tetsushi Sakane, "AUTOMATIC TUNNELING METHOD USING QUICK-HARDENING RESIN MORTAR", VI Australian Tunnelling Conference, Melbourne, March 1987.