

Development of an Unmanned Prelining Machine Using  
the Pre-Arch Shell Support (PASS) Method

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ABSTRACT

Since the NATM method was introduced to Japan some 15 years ago, the technologies and techniques involving tunnelling and the construction of underground caverns have seen some noticeable developments, and their applications have been extended not only to mountain areas, but also, more recently, to urban areas. However, the application of the NATM method for construction in urban areas has experienced various difficulties because it was initially developed for application in the construction of tunnels in mountainous areas. To eliminate this handicap, we have developed the PASS method, which allows for the construction of a concrete arch ahead of the facing, as well as for an unmanned machine to execute that work.

1. INTRODUCTION

The construction of a tunnel using the NATM method allegedly allows for a reasonable, economical design. However, it is disadvantageous in its application in the construction of underground caverns in urban areas with unstable geology, or in an underground area which is directly below buildings or roads. Therefore, preventing the ground from settling, an event which may occur while tunnel excavation is in progress, as well as ensuring the stability of the tunnel facing, form the two serious tasks which must be overcome.

As a solution to these tasks, a method which is capable of reinforcing the natural ground ahead of the facing, and therefore assuming the role of effectively preventing the displacement of the ongoing tunnel route as well as helping form an arch in the natural ground, has been aspired to. Based on this concept, we have developed the PASS method which allows tunneling to continue while an arched shell concrete lining in the natural ground ahead of the facing is being constructed.

As a machine prerequisite for the execution of this type of work, a prelining machine was developed, and research on its unmanned operation was performed. A field application of its abilities then followed before it was put to practical use (Fig. 1. Conceptual illustration of the PASS method).

The proposed system consists of a multi-shaft auger capable of automatically drilling the natural ground ahead of the facing, a boom mechanism to support and set an auger in a predetermined position, a concrete injection pump, a computer capable of performing arithmetic processing as well as automatic control, a caterpillar type base machine on which that computer is mounted, and an automatic measuring device to carry out positional measurement.

This paper will report on an example in which the development of an actual system has been carried out with success; first, the background and basic idea of the system's development will be described; second, the mechanical mechanisms, capacities and control flow will be mentioned, and

then concluded by describing the results of the field application of the proposed machine for the construction of an actual tunnel.

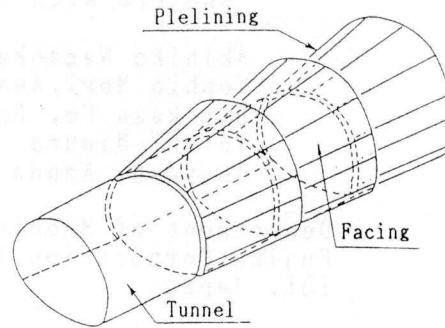


Fig. 1. Conceptual illustration of the PASS method.

## 2. AN OVERVIEW OF THE PASS METHOD

### 2.1 Prelining Construction Process (Fig. 2.)

- (1) Using a 5-shaft auger, excavation is performed in the natural ground ahead of the facing, so as to form a slit 17cm thick, 81cm wide and 4m long.
- (2) In response to the auger gradually being withdrawn, concrete is injected through the end of the auger, to a length of 2.5m and thereby forming a piece of concrete wall. (The length for new concrete to overlap the previously cast concrete is 0.5m, and the effective length of the concrete wall is 2.0m).

Along the tunnel's circumference, work in (1) and (2) above is repeated to construct arched concrete walls, and this is called prelining.

- (3) Excavation of one onward movement (1m) into the arched concrete wall previously constructed, is performed, props are installed, and concrete is sprayed.
- (4) Once again, one onward movement (1m) is excavated, props are installed, and concrete is sprayed.

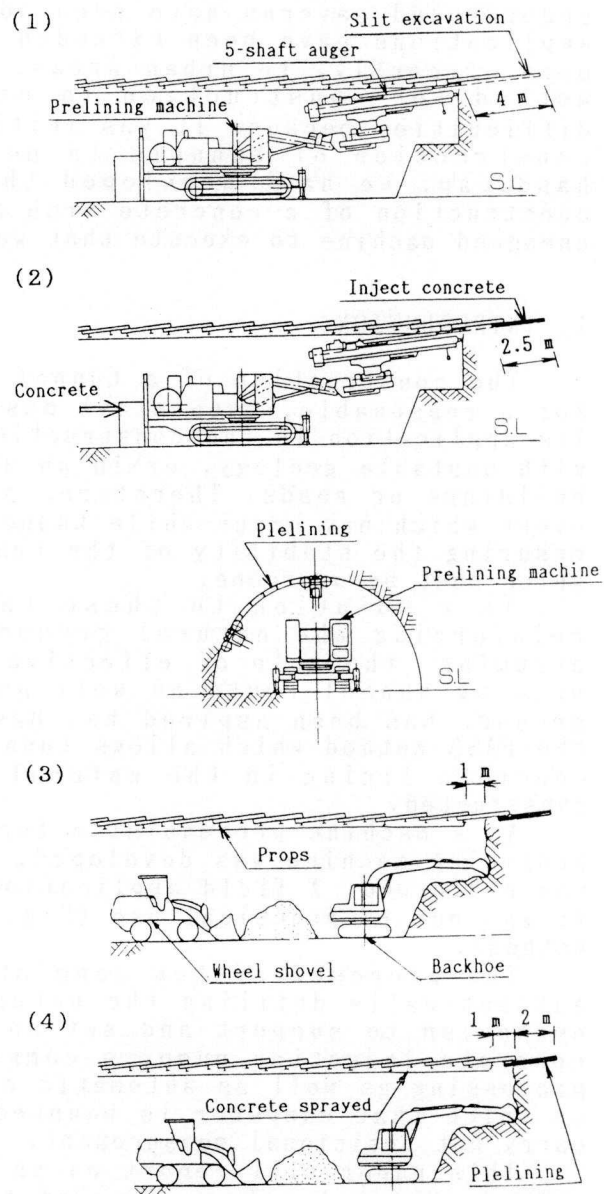


Fig. 2. Prelining construction process.

At the point when the excavation of 2 meters in (3) and (4) above has been finished, the prelining previously constructed in (1) and (2) above, which covers one span length (2m), has been constructed in the natural ground ahead of the facing.

The tunnel will be constructed through a repetition of the work mentioned in (1) through (4).

## 2.2 Features of the PASS method

- (1) Can effectively prevent the occurrence of antecedent displacement as well as help to form arches in the natural ground, thereby preventing the ground surface from settling and ensuring an improved, stable facing.
- (2) Through the abovementioned effects, short-benching becomes feasible, thereby ensuring the ease of construction.
- (3) Most excavation is mechanically performed, therefore is proceeded underneath the prelining constructed in advance, and the safety of construction executed in the facing can be greatly improved.
- (4) As a prelining becomes a support after excavation, the amount of concrete spraying work can be reduced, and this can ensure the ease of construction and an improved environment in the tunnel.
- (5) Can quickly cope with the situation in which the facing is becoming unstable, by constructing a prelining against the face of the facing.

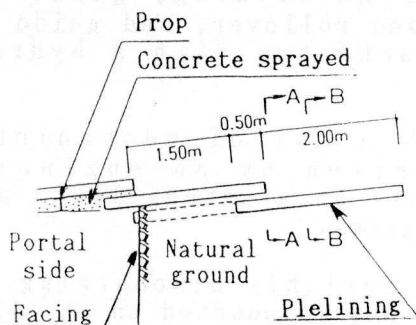


Fig. 3. Side view of a prelining.

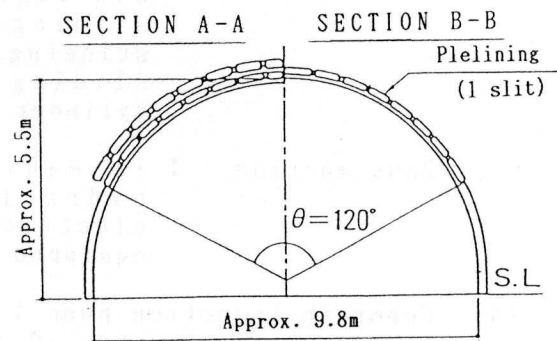


Fig. 4. Cross section of a prelining.

## 3. PRELINING MACHINE

### 3.1 Development Conditions

We have developed the proposed prelining machine in consideration of the following points:

- (1) The prelining of a tunnel having a cross section equal to a double-track tunnel ( $R \cong 5.5m$ ) is constructed without moving the base machine.
- (2) Any cross section can be dealt with.

- (3) The prelining machine is able to be coupled to, and separated from, other facing construction machines in the upper half of the facing.
- (4) High construction accuracy is assured.
- (5) An improved and uniform construction speed is ensured.
- (6) Simplified operation is ensured.

### 3.2 Constitution of the Prelining Machine

The prelining machine is composed of the following components.

- (1) Auger : A hydraulic type capable of drilling the natural ground ahead of the facing.

Table 1. Specifications of the auger.

Diameter of auger screw	φ 170mm	Drilling speed	200cm/min
Length of auger screw	5,600mm	Drilling torque	200kg·m/shaft
Number of auger shafts	5	Drilling revolutions	50rpm
Thrust	15tons	Drilling stroke	4,800mm

- (2) Boom mechanism : The auger is supported with articulations with six degrees of freedom: boom lifting, boom sliding, guide frame tilting, guide frame swinging, guide frame rollover, and guide frame sliding, and is actuated with a hydraulic cylinder etc.
- (3) Base machine : Is equipped with a swivel mechanism, is hydraulically driven by an engine-cum-electricity, travels on a caterpillar, and is equipped with outriggers.
- (4) Concrete injection pump : Is of the variably discharging swing type (0 ~ 10m<sup>3</sup>/h), and is mounted on the lift-up device located in the rear portion of the base machine.

Also, for the purpose of measuring the positions of the base machine and the auger, an automatic surveying system was installed in the rear portion of the base machine.

### 3.3 Specifications

Table 2 shows the specifications of the prelining machine.

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Overall length	15.5m	Overall width	3.0m	Overall height	3.6m
Weight	54.6t	Electric capacity	120kw		

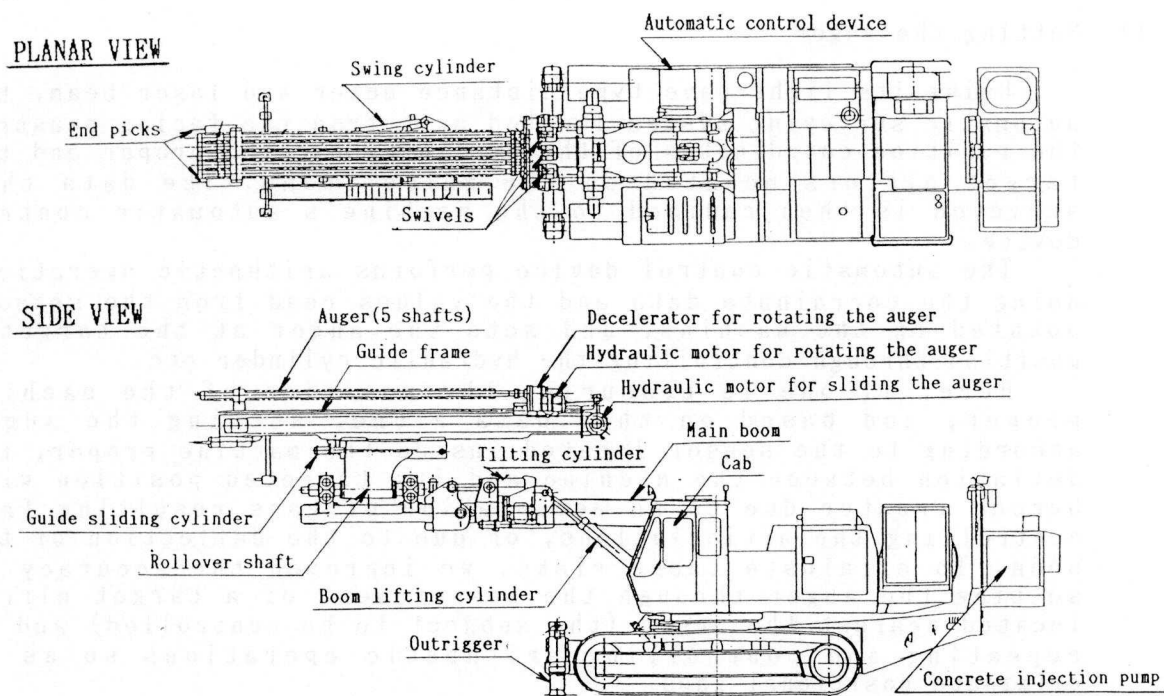


Fig. 5. Prelining machine

### 3.4 Automatic Control

In order to construct arched shells as one continuous diaphragm, manual operation as performed by machine operator is not able to achieve satisfactory results regarding accuracy, quality, or construction speed. As a solution to these problems, we addressed the realization of automatic auger setting, drilling and concrete injection.

The mechanical control device is composed of an automatic control device, sensors, target mirrors, hydraulic proportional valves, and hydraulic cylinders. The operator's cab is equipped with a monitor display to observe the state of automatic operation going on, and to instruct the operator to operate the machine. With an automatic operation panel, etc. the operator can, as per the instruction appearing on the monitor display, easily handle the keyboard in order to input the slit numbers, or start setting the auger, thus allowing it to drill, and injecting concrete through it. Fig. 6 shows the flow of work, in which each item enclosed with a rectangle falls into the category of automation. Fig. 7 illustrates the state in which the construction of prelinings is performed.

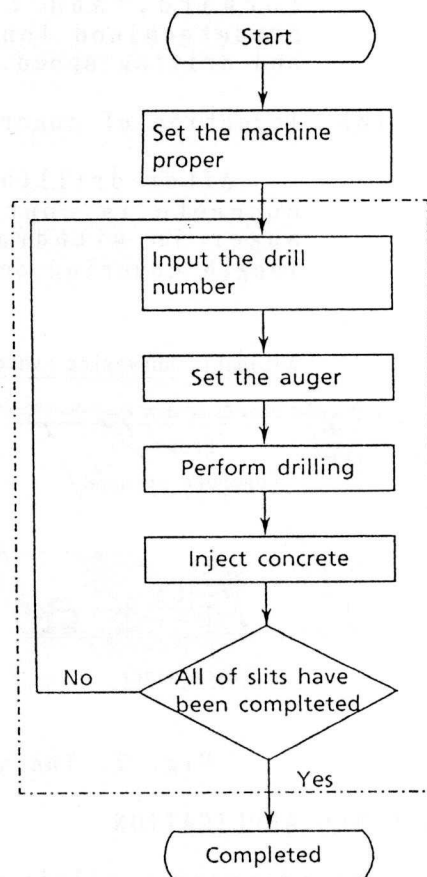


Fig. 6. Flow of work.

(1) Setting the auger

Using its light-wave type distance meter and laser beam, the automatic surveying system located away from the facing measures the position coordinates of the prelining machine proper and the target mirrors mounted on the guide frame. The data thus achieved is then radioed to the machine's automatic control device.

The automatic control device performs arithmetic operations using the coordinate data and the values read from the sensors mounted on the machine, and sets the auger at the targeted position through controlling the hydraulic cylinder etc.

Here, if one is measuring the position of the machine proper, and based on that data alone, setting the auger according to the sensor located inside the machine proper, the deviation between the machine and its targeted position will become greater due to an accumulation of gaps resulting from controlling the articulations, or due to the deflection of the boom. To eliminate these risks, we improved the accuracy of setting the auger through the measurement of a target mirror located nearest the auger (the subject to be controlled) and by repeating and controlling arithmetic operations so as to eliminate positional gaps.

(2) Drilling

After the auger has been set, it rotates to begin moving forward, and continues to drill until it reaches the predetermined length while it also controls the rotating torque and driving speed.

(3) Injection of concrete

After drilling has been completed, the injection amount of concrete is controlled in response to the speed at which the auger is withdrawn, and a concrete wall with the specified length covering one slit is then constructed.

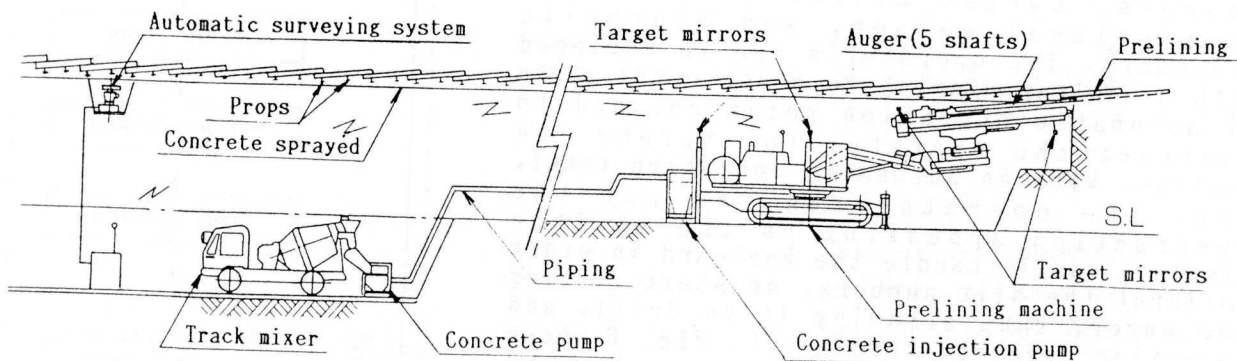


Fig. 7. The view of prelining work being performed.

4. FIELD APPLICATION

The proposed prelining machine was applied in the construction of the following tunneling project, thereby confirming the operability and compatibility of the machine under an actual construction environment.

#### 4.1 An Overview of the Tunnel Construction Project

Project title : The Toyo Express Line Katsutadai Tunnel (at Ikegami)  
Construction Project

Location : Yachiyo city, Chiba prefecture, Japan

Total length : 153m

Geology : The tunnel's overburden consists of Kanto loam formation and the cross-sectional portion to be excavated consists of Narita sand formation and diluvial clay formation, both of which are unconsolidated.

Constructional characteristics: There are quiet living quarters adjacent to the projected route. The overburden is very shallow at 4 ~ 7 meters.

Geological age	Geological name	Geological symbol
	Top soil	Ts
Diluvial epoch	Loam	Lm
	Tuffaceous clay	Tc
	Slit	Dc
	Clayey slit	
	Sandy slit	
	Sand	Ds

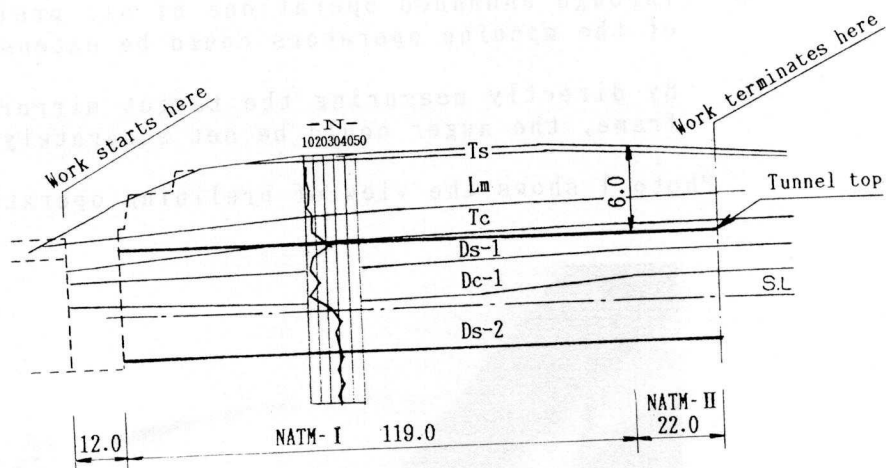


Fig. 8. Geological profile.

#### 4.2 Application Results

Of the total construction length of 153 meters, a section approximately 110 meters long was constructed on schedule without trouble or interruption by using the proposed prelining machine. Through this application, we were able to obtain various data on cycle time etc.

##### (1) Measurement of displacements

Ground surface settlement was able to be convergently limited to approximately 30mm when excavating the upper half of the facing, and to approximately 40mm in the lower half of the facing. Antecedent settlement resulted in approximately one-third of the final convergent value ensued from the excavation of the upper half of the facing. These settlements and displacements are far less than those generally encountered during the construction of any tunnel using the urban type NATM method. Thus, the prelinings constructed by the proposed machine were proven to be highly effective.

(2) Construction cycle

The tunnel's length excavated per day by the proposed machine was 1.6 meters on average, thereby greatly surpassing the approximately 1 meter achieved by the urban NATM method.

(3) Coping with cross-sectional excavation

The proposed prelining machine was able to easily cope with excavation at transient portions having different cross sections.

(4) Results of mechanical control

- ① Highly accurate prelinings could be automatically constructed.
- ② Drilling compatible with geological changes could be automatically performed.
- ③ Through unmanned operations of all prelining work, the burden of the machine operators could be extensively reduced.
- ④ By directly measuring the target mirrors mounted on the guide frame, the auger could be set accurately in a very short time.

Photo 1 shows the view of prelining operations being performed.

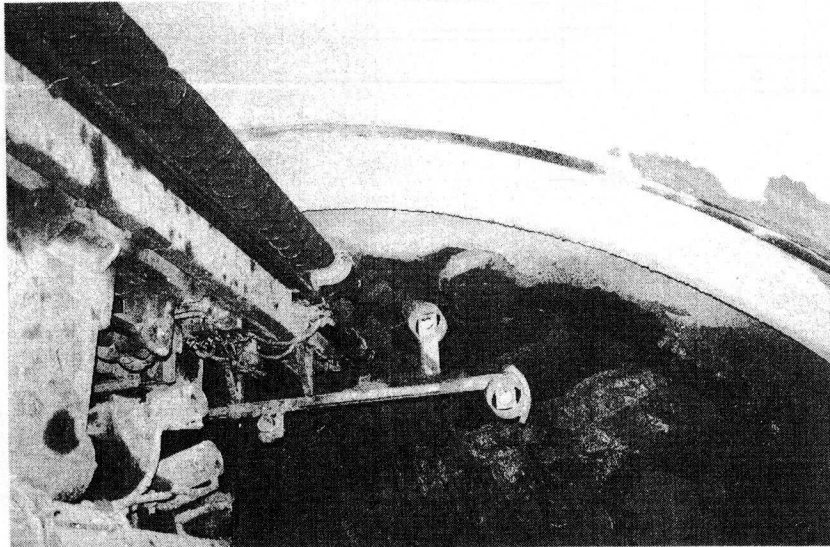


Photo 1. The view of prelining operations being performed.

## 5. CONCLUSION

Through its application for the construction of an actual tunnel construction project, the proposed prelining machine has been proven to be highly operable and adaptive, as well as extremely practical.

From this time onward, we will continue to further improve the prelining machine so that it can be applied for the construction of as many tunnels with a complex geology, as is possible.