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DEVELOPMENT OF A CONCRETE-SPRAYING ROBOT FOR TUNNEL WORK

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Abstract

This paper treats the SL robot, a concrete spraying robot for tunnel construction work in mountains. The SL robot is the core of the SL (Spray Lining) system developed by our company as a very efficient concrete spraying method with low dust generation. The SL robot reduces material loss from rebounding as well as the concentration of the generated dust, while the operation characteristics and the safety are superior in comparison to conventional spraying robots.

1. Introduction

The tunnel construction work in the mountains of Japan has changed from the conventional method with support of the bedrock by steel sheet piles to a method making maximal use of the intrinsic strength of the bedrock itself and holding the tunnel in stable condition by means of the bedrock. On the basis of this way of thinking, the present method depending mainly on rock bolts and concrete spraying as the supporting method has been adopted as the standard work methods for mountain tunnels. The spraying concrete used as support easily closes the tunnel cross section directly after excavation as a ring, it adheres closely to the bedrock to minimize loosening, and it maintains the strength of the bedrock. However, the dust generated at the time of the concrete spraying work causes deterioration of the work environment, there is a large material loss from rebounding, and other problems also have surfaced. In order to respond to these problems, the Ministry of Construction has made "Development of a concrete spraying method with high efficiency and low dust generation" one of the research themes for the year 1984 on the basis of the construction technology evaluation regulations, and it has asked for public participation in the development of a new concrete spraying work method.

In response to this research theme, our company has spent about 1 1/2 years to develop the SL system, a concrete spraying system with further improvement of the conventional concrete spraying work method. New ideas were introduced in the fields of materials and machines, and they were combined in the SL system, which has been recognized as an excellent work method by the Construction Minister and which has received a letter of appreciation in August 1986.

2. Background and Present State of the Introduction of Spraying Robots[1)]

When the concrete spraying method first came into use, human power was used to spray the concrete onto the bedrock, but the problems described below became apparent for human work (refer to photo 1 "Concrete spraying by humans").

(1) Health problems

As large quantities of mineral dust are created, pneumokoniosis is to be feared for the workers.

(2) Safety problems

1) As the work is close to the facing, the workers are exposed to falling rocks, rebounding concrete, and concrete separation during the spraying work.

2) When the hose becomes clogged during pressure feed of the concrete, the hose and the nozzle will oscillate, and it becomes very dangerous to hold the nozzle.

Photo 1 Concrete spraying by humans

3) For tunnels with a large cross section, the spraying work at the ceiling part is hazardous work at height.

(3) Problems of work execution

1) Spraying for a long time is heavy work, so that continuous spraying is difficult and the efficiency is bad.

2) With the spraying work at the ceiling and at arches,

observation of the spraying condition is difficult because of concrete rebound and dust generation.

In order to solve these problems and to be able to execute safe, accurate, and quick concrete spraying, the introduction of spraying robots came into consideration in Japan.

It can be said that the spraying unit used 1965 for the Katsuki tunnel of the Uetsu line of the Japanese Railroads was the precursor of spraying robots in Japan.

This unit had a self-propelled carrier suspended from a profile steel rail installed at the tunnel ceiling, and the body, consisting of boom, nozzle, pneumatic drive parts, etc., was installed on the carrier by means of a pantograph. Operation was executed from the ground by remote control.

Afterwards, improvement and development progressed, and the presently operating spraying robots generally are composed of a nozzle holder part and a base machine. The base machine exists as a crawler type, a track and wheel type, and a rail type, and the construction and mechanisms of the nozzle holder part differ according to the developing company.

The operation method for the spraying robot can be remote control or computer control, and as the condition of the spraying surface differs considerably, remote control presently is being used in most cases, and even the robots with computer control in most cases also are equipped with a mechanism for remote control.

3. Development of the SL Robot

The following items must be observed for the concrete spraying work.[2)] The material loss from rebound and the dust generation amount must be minimized, and it must be possible to spray concrete with the required holding force.

(1) The nozzle always must be held so that it is at a right angle to the spraying surface, and a suitable spraying distance and spraying pressure must be maintained.

(2) Spraying must be executed with a suitable thickness, so that

the sprayed concrete does not drop down, and repeated spraying must be executed until the specified thickness has been obtained.

(3) When spraying is executed at the installation positions of steel timbering, spraying must be executed so that there will be no cavities between the bedrock surface and the steel timbering, and the sprayed concrete and the steel timbering must become a single body.

For the development of the SL robot, functions making these items possible were investigated, and the following important items were specified.

1) The traveling method for the base machine primarily shall be a crawler method under consideration of mobility.
2) The mechanism shall be so that it is easy to maintain an approximately stable distance between the nozzle and the spraying surface.
3) The mechanism shall be so that it is easy to execute repeated spraying.
4) The mechanism shall be so that it is easy to spray concrete between the bedrock and the steel timbering.
5) Operation shall be executed by remote control from a small and light operation panel.

3.1 Development of a Spraying Robot for small Cross Sections

The above 5 items were investigated intensively, and the arch rail spraying robot type SL-2 for side pilot tunnels (cross section: 15 m^2) was developed as the first spraying robot for practical use. As mobility was not a strong requirement, rail travel was used.

With the type SL-2, a boom with a nozzle travelled freely on an arch rail shaped along the spraying surface (arch travel), so that the distance fluctuations between the spraying surface and the nozzle were small and repeated spraying could be executed easily. For spraying of concrete between bedrock and timbering, the nozzle had four degrees of freedom for horizontal and vertical oscillation (elliptical movement), inclination, and extension and retraction, while the boom, on which the nozzle was installed, had one degree of freedom for sliding. The type SL-2 used a hydraulic jack to raise and lower the body, and including the rail travel of the body and the arch travel of the boom, it had a total of 8 degrees of freedom. The operation method was wired remote control.

The overall view of the type SL-2 is shown in photo 2, the operation outline is shown in Fig. 1, and the specifications are shown in table 1.

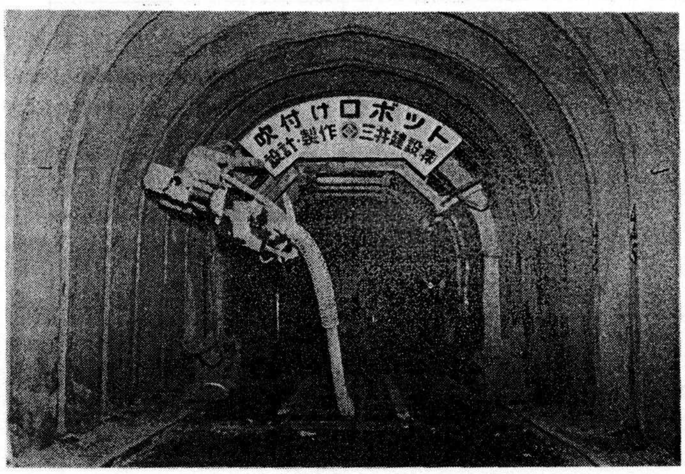

Photo 2 Spraying robot type SL-2 for small cross sections[3)]
(Used for the work on the western side of the Kagosaka tunnel on the East Fuji route of the Japan Highway Public Corporation)

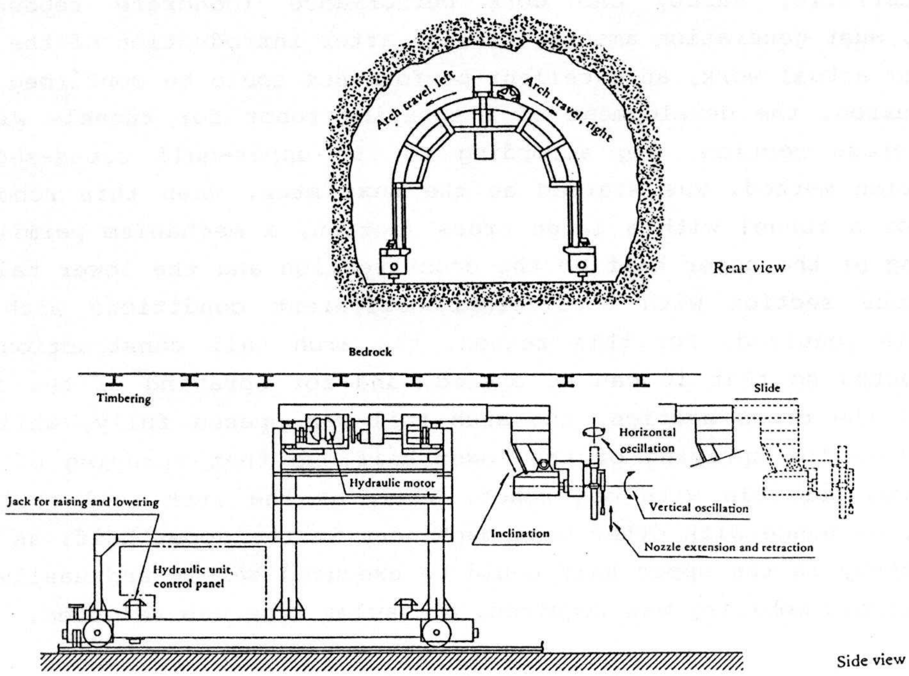

Fig. 1 Operation outline for the type SL-2[4)]

Table 1 Specifications of the type SL-2[5)]

Item		Specifications
Boom	Arch travel speed	8.00 m/min
	Slide travel length	1.25 m
Spray nozzle	Inclination angle	Total angle: 60°
	Horizontal angle	Total angle: 60°
	Oscillation range (elliptical movement)	0.11 x 0.24 m
	Extension length	0.20 m
Truck	Travel speed	10.00 m/min
	Raise/lowering height	0.50 m
Operation method		Remote control

3.2 Development of a Spraying Robot for Large Cross Sections

As the result of follow-up investigations in regard to operation characteristic, safety and work performance (concrete rebounding amount, dust generation amount, finish) after introduction of the type SL-2 for actual work, an excellent performance could be confirmed. For this reason, the development of a spraying robot for tunnels with a large cross section, dug according to the upper-half cross-section excavation method, was started as the next step. When this robot is used for a tunnel with a large cross section, a mechanism permitting spraying of the upper half of the cross section and the lower half of the cross section with considerably different conditions with one robot is required. For this reason, the arch rail construction was constructed so that it can be opened, and for spraying of the upper half of the cross section, the arch rail was opened fully, while it was folded for spraying of the lower half, so that spraying of both parts was possible with one robot. Also, as the arch rail could be folded, exchange with other work machinery in the upper half, as well as stand-by in the upper half could be executed safely and easily. As considerable mobility was required, a crawler type was selected.

After completion of the construction work for the road tunnels of the East Fuji route, the type SL-3 presently is being used for the arch rail in folded condition, is shown in photo 4.

After development of the type SL-3, the spraying robot type SL-4 for large cross sections was developed by making the entire robot body lighter and smaller. While the type SL-3 used an arch rail which could be opened and closed, this type SL-4 uses a fixed arch rail. This permits a simpler overall construction, and the work and operation characteristics of the mechanism have been improved notably. Photo 5 shows the outline of the type SL-4.

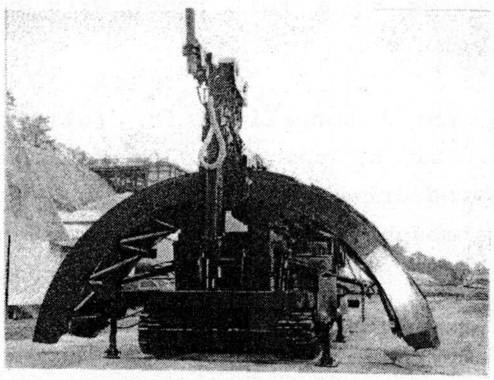

Photo 3 Spraying robot type SL-3 for large cross sections[6)]
(arch rail fully open)

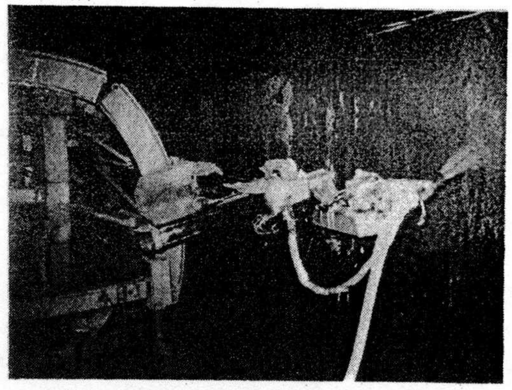

Photo 4 Type SL-3 spraying the side wall of the lower half of the cross sections

(Introduced for the Kagosaka tunnel of the East Fuji route of the Japan Highway Public Corporation)
(Presently used at the Takayama site of the Kyushu route of the Japan Highway Public Corporation)

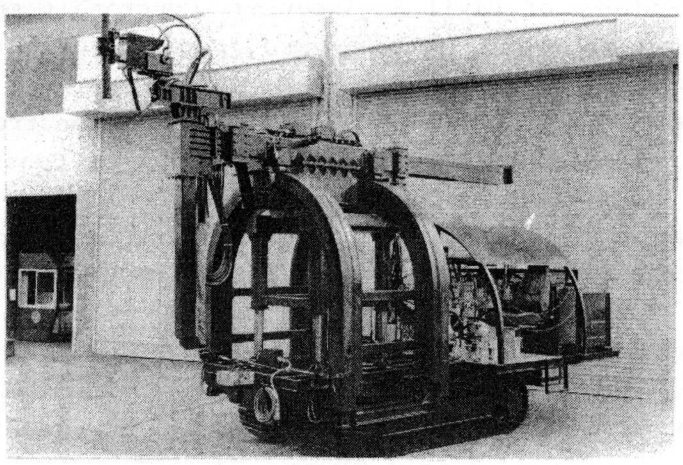

Photo 5 Spraying robot type SL-4 for large cross sections
(Presently used for the work for the temporary water discharge tunnel of the Gassan dam of the Tohoku office of the Ministry of Construction)

4. Conclusion

Including the type SL-mini for extremely small cross sections, which has not been treated in this paper, there are four types of SL robots, and for each robot, remote control is used for movement in the tunnel, positioning of the robot, and nozzle operation. However, in regard to the nozzle operation typical for a spraying robot, the mechanism is so that a combination of simple operations is selected by the operator. The ideal is change to a full robot with completely automatic operation in the future.

It is believed that there are 2 conditions for fully automatic operation to become possible. One of them is the necessity for a detector permitting continuous measuring of the shape and condition of the sprayed surface in an atmosphere of rebounding concrete and mineral dust. The other one is the development of a spraying machine which constantly can supply a fixed amount of concrete even when the conditions of the mixed concrete varies to some degree. It is believed that these two conditions are not impossible to fulfill.

Reference literature

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5), 6) Teruhiko Umezono, Toshio Tanaka: Present state of construction robots and future problems, Robot, Japan Industrial Robot Industry Association (1987.6, No. 58), p. 102